Government of Jammu and Kashmir
**Public Works(R&B) Department**
Civil Secretariat, J&K Jammu/Srinagar

**Subject**: **Adoption of J&K Public Work Department 'Building Manual' 2023.**

Reference: Administrative Council Decision No.62/5/2023 dated 21.06.2023

**Government Order No 283-PW(R&B) of 2023**
**Dated: 06-07-2023**

Sanction is hereby accorded to the adoption of **"J&K Public Works Department Building Manual-2023"** appended as "**Annexure**" to this Government order. Manual provides procedures, upgraded standards to bring transparency in engineering practices in building construction in the Union Territory of Jammu and Kashmir.

**By order of the Government of Jammu & Kashmir**

**Sd/-**
**(Shailendra Kumar) IAS**
**Principal Secretary to Government,**
**PW (R&B) Department**

No:- PWD-ADM/123/2022-14 Dated:06-07-2023

**Copy to the:-**

1. All Administrative Secretaries
2. Divisional Commissioner, Kashmir/Jammu
3. Engineer-in-Chief [Development Commissioner (Works)]
4. All District Development Commissioners
5. All Chief Engineers, Civil/Mechanical.
6. OSD to Advisor (B).
7. Pvt. Secretary to Chief Secretary, J&K.
8. Private Secretary to Principal Secretary to Govt. PW (R&B) Department.
9. Govt. order file (w.2.s.c)

**Copy also to**

Joint Secretary (J&K), Ministry of Home Affairs, Govt. of India

6/7/2023

**Director Finance**
PW(R&B) Department

# GOVERNMENT OF JAMMU AND KASHMIR

सत्यमेव जयते

# BUILDING MANUAL

# PUBLIC WORKS (R&B) DEPARTMENT, J&K

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# BUILDING MANUAL


PUBLISHED BY

**PUBLIC WORKS (R&B) DEPARTMENT**

**JAMMU & KASHMIR**

# TABLE OF CONTENTS

# 1. GENERAL INTRODUCTION

This Building Manual has been drafted by the Public Works (R&B) Department to provide procedures, upgrade standards and bring perfection in engineering practices in the Union Territory of Jammu and Kashmir. The Manual shall serve as a concise document ensuring proper planning in works and bringing further accountability and transparency in the department. The Manual has been derived from latest building codes and IS specifications and strives to ensure construction of quality structures that are safe, durable, economical, aesthetically pleasing and environmentally sound.

The Manual provides sound perspective on various aspects of the building construction and shall be of immense utility in all such projects under execution in the union territory of Jammu and Kashmir. The Manual shall serve department in achieving desired work objectives by fostering better understanding among engineers and enhancing their skills.

The Manual provides opportunity to the engineering professionals with information on building materials and construction practices with lucid explanation of the underlying principles and concepts. Various subjects ranging from planning and project preparation, site reconnaissance and survey including land title verification, geotechnical investigations, structural designs, statutory permissions, building materials and procurement, building construction, project scheduling and monitoring of works have been incorporated with due consideration to various techniques entailed in the conservation of heritage buildings.

# 2. BUILDING PLANNING & PROJECT PREPARATION

Preparation of a detailed project report is a pre-requisite for proper evaluation of the project, its approval by competent authority and finally its execution. Properly prepared project report is very helpful in ensuring timely completion of the project thereby ensuring fullest advantage of the project avoiding time and cost overruns. Project preparation activity can be divided into the following three broad stages:-

(1) Feasibility Study
(2) Preliminary Project Report
(3) Detailed Project Report

## 2.1 Feasibility Study

All projects simply begin as an idea. An “idea” is a rough notion in our head about something we like or want to do. As an idea is developed, it goes through a fine-tuning process which results in a final form known as a “concept”. Many concepts will never be developed, while some will. A feasibility study is an important technique which helps to decide which concepts should be developed as a project.

Feasibility studies in the construction sector are preliminary studies undertaken at the very early stage of a project. They tend to be carried out when a project is large or complex. Construction projects require huge investment, in both time and money, and for this reason it is important to establish if the project will be feasible at a very early stage. The purpose of a feasibility study is to;

- ❖ Establish if the project is viable.
- ❖ Identify numerous feasible options.
- ❖ Assist in the development of business cases and project execution plans.

A detailed feasibility study can take time in accordance with the size of the project. It will let the client know if the project is viable, needs to be adjusted or is unlikely to succeed. The project feasibility is assessed in five specific areas:

### 2.1.1 Technical Feasibility

In this area, the whole project is studied in a technical aspect by the concerned project team. The team will use engineering knowledge to decide if the proposed project is technically possible. This will involve considering the size of the site, access, land topography, geotechnical information, existing buildings on the site, flooding risks and other environmental factors associated with the site.

### 2.1.2 Economic Feasibility

This is where a cost benefit analysis is carried out. In this step, we to determine if the project is economically viable. Based on experience and current market trends, we have to analyse various options and advise on what type of project or scheme is best suited to the site.

### 2.1.3 Legal Feasibility

To establish the legal feasibility of a project a due diligence process is undertaken. It ensures that the project can be performed in accordance with current legal requirements and that key aspects of the project have been analysed from a legal perspective. In this stage, issues like planning permission, land ownership/easements and taxation are all considered by the project team.

### 2.1.4 Operational Feasibility

This stage assesses how well the proposed project solves problems and meets goals. Whether it is a new school, hospital or housing development; every construction project is and should be an answer to a problem. The operational feasibility takes a bigger picture view of the outcomes of the project to ensure that when completed as planned and budgeted, that the identified problems and goals are achievable.

**2.1.5 Scheduling Feasibility**

This assessment is arguably the most important for project success. A project will fail if not completed on time. In scheduling feasibility, the project team estimates how much time the project will take to complete. It is beneficial to analyse the design, materials, budgets, environmental impacts, regulations, and risk areas. It is also important to assess the ability of the team to succeed in completing the construction project on-time and on-budget.

If the consensus is that the project is feasible based on these five assessments, it will be time to move on to the next step in the planning phase of the project.

## 2.2 Planning

Planning is the process of devising of a scheme for doing, making or arranging a project or programme before the commencement of a work. Thus, construction planning is a process requiring the use of intellectual faculties, imagination, foresight and sound judgement to decide in advance as to what is to be done, how and where it is to be done, who will do it and how the results are to be evaluated.

In any project the sequence through which the project is to develop should be decided. The requirement is met in a systematic manner by scheduling or programming. Scheduling considers the main construction activity and also supporting elements such as labour, material, equipment and expenditure. All the activities consume resources of three kinds,viz., time, labour and material.

Here, the construction project may be housing-complex project, multi-storeyed buildingprojects, factory-building projects, which involves in land acquisition, planning of theproject, method of construction, material procurement, construction stages, etc.

## 2.3 Objectives of Planning

The main objective of any planning, particularly construction planning, is to execute theproject most economically both in terms of money and time. Effective planning includesthe following factors:

- Design of each element of the project.
- Selection of equipment and machinery depending on the magnitude of the project.
- Arrangement of repair of equipment and machinery near the site of project to keepthem ready to work at all times.
- Procurement of material well in advance.
- Employment of trained and experienced staff on the project.
- Arrangement of welfare schemes for the staff members and workers such as medicaland recreational facilities.
- Arranging constant flow of funds for the completion of the project.
- Providing safety measures such as ventilation, arrangement of light, water and firstaid.
- Arrangements or means of communication and feedback, etc.

## 2.4 Stages of Planning

During the planning of a construction project, the entire project is phased out identifyingthe sequence of construction. Secondly each phase is divided for operation into a numberof jobs or units of construction. Different stages of planning are as follows:

- Job planning
- Technical planning

- ❖ Contract planning

**2.4.1 Job Planning**

Each job or unit of construction has to be further planned with respect to the following:

❖ **Manner of Execution of the Job:**The jobs may be executed departmentally or through contractor. In case the work is done through the contractor, type of contract is to be finalised.

❖ **Duration of the Job:** The factors which contribute for the duration of job or the proposed period of its completion are:

- ❖ Urgency of the work
- ❖ Availability of resources
- ❖ Position of the construction with reference to network

❖ **Planning of Resources:** Resources of a construction project comprises of the following:

- ❖ Plant, equipment and machinery
- ❖ Construction stores
- ❖ Both technical and non-technical staff and skilled and unskilled labour
- ❖ Construction Material

**2.4.2 Technical Planning**

Technical planning is done by engineer or concerned authority for economical execution ofthe construction project. It starts after the administrative approval of the work is obtainedfor technical sanction. Technical planning is carried out in order to satisfy the followingobjects:

- ❖ Finalisation of design, provide detailed drawing and specification to be adopted.
- ❖ Preparation of a detailed estimate and modification of estimate if necessary.
- ❖ Deciding the executive authority, like departmentally or though contract.
- ❖ Planning resources and initiating procurement action.
- ❖ Foresee the obstacles in the completion of the project and take necessary steps forfruitful completion.

**2.4.2.1 Contract Planning**

Contract planning is divided into the following two categories:

❖ **Pre-tender Planning**

Planning required for the time of inviting of tenders up to the receipt of the same is termedas pre-tender planning. It consists of the following works:

❖ **Finalisation and Acquisition of Site:** Before issue of order to contractors the acquisition of the project site has to be finalised and legal issues if any should be finalised.

❖ **Planning of Resources:** Resource planning includes the following:

- ❖ Availability of site,
- ❖ Availability of stores,
- ❖ Availability of labour and
- ❖ Availability of equipment and plants.

❖ **Planning Time Limit:** The requirement of resources and time limit are inter-related and both these aspects are to be taken together. In some cases the time needed for completion is decided based on the available resources. Such is the case when the work has to be completed departmentally. Even when the work has to be executed by the contractor, circumstances of the project has to be decided and modified before inviting tenders. As a matter of fact the contractor submits tender considering the following aspects:

- ❖ Site survey,
- ❖ Availability of materials,
- ❖ Equipment and plants to be hired and purchased,
- ❖ Fuel,
- ❖ Labour,
- ❖ Facilities for camp and
- ❖ Study of drawing/design/specifications.

❖ **Post-tender Planning**

In post-tender planning the following aspects are considered irrespective of the work done by contractor or departmentally:

- ❖ Setting camp site office,
- ❖ Welfare of staff/labour amenities,
- ❖ Materials required,
- ❖ Labour required,
- ❖ Equipment,
- ❖ Safety measures to avoid accidents and theft,
- ❖ Fllow-up of drawing/specifications and
- ❖ Billing, to record progress, to calculate materials, labour, etc.

In the works executed by contractors, responsibility is fixed for recording the work indiary the day-to-day details of work done. The planned progress in the form of bar chartsor progress reports should be known to the contractor as well as to the engineer's representative.It is normally the practice for all civil engineering projects to make controlledconstruction stores available to the contractor.

## 2.5 Land records and Title Verification

The subject ofLand principally falls within the jurisdiction of the Governments of the State/UT, in accordance with the Constitution of India. The acquisition and possession of land which includes an interest in property by purchase/sale, transfer, mortgage, inheritance etc., is also regulated by laws enacted by the State/Central Government.

Any undisputed legal ownership of land for use/sale/transfer must rely on a valid title. Whether it's an agricultural property, a residential land or a commercial investment land, executing department needs to ensure that there is no ambiguous details about it. Any act, under which the use/purchase/transfer of land is uncertain, must be dealt with well in advance.

A title verification/investigation may be required for different purposes, including sale, lease, sub-lease, and mortgage. A land title, eventually, acts as an official record for land ownership, barring a legitimate legal dispute. Without the required title, an unfiled deed or unofficial contract would not be recognized by the legal system. Title verification survey can also be used by for the purposes of risk management and investment security protocol.

Before conceiving the construction of apublic building, of any category, on a given land, it must be a good practice for the intending department/executing department to get the title of land thoroughly verified, for a given building project, from the competent authority (Revenue Department), by referring to the concerned land-revenue extracts. The ownership and physical possession of land and disputes, if any, must be thoroughly confirmed by a dedicated visit to the land site, under consideration, along with revenue officials, to avoid prospective litigation and related delays in the execution of the projects, thereof. The project must also be formulated in due concurrence with the extant Master-Plan (as may be applicable specifically in case of cities/metropolis/towns), with special attention to the stipulated land-use classificationsuch as Residential, Commercial, Industrial & Manufacturing, Agriculture, Public/Semi-Public, Tourism, Traffic & Transportation, Defense, Special Investment Corridor, Leisure & Sports, Special Areas (Heritage/Protected Zones), Ecology & Environment/Ecological Reserves (Forests & Wild-Life/Green Belts/Wet-Lands), and Buffer Zones etc.

The process of land title and related verification protocol shall generally be the responsibility of intending department, for which a given public interest project is being executed.

## 2.6 Site Reconnaissance and Field Survey

### 2.6.1 Site investigation

Site investigation is an integral part of any construction project, and should be attributed as much significance as would be ascribed to any other part of the project. The risk associated with undertaking a project without adequate site investigation is monumental. It is advisable to proceed with utmost circumspection in the matter, as lack of the same may lead to undesirable consequences, which may thus have a great bearing on the construction project.

It has been proven over and over again that undertaking a project without site investigation is not only risky, it is in fact foolish and dangerous. Risk is something that can be managed or its consequences minimized, but it cannot be ignored. Reliable information obtained from a site investigation report is what enables designers to design strong and long lasting engineering projects. Proper planning is essential for any construction project. Unforeseen risks are still a large part of a project, and the finances related to the risk are allocated to the contractor. Site investigation is unique to every project and should be planned based on the project requirements. The reports are not transferable, even if another project is to be undertaken at the same site, but it can be used as a reference.

### 2.6.2 Stages of Site Investigation

Site investigation can be broadly classified into four stages: reconnaissance, data and map study, in-depth investigation and laboratory testing.

#### 2.6.2.1 Reconnaissance

Simply scouting around the site can sometimes provide a lot of information such as topography, vegetation, geological features and availability of utility lines. Observations, made during site reconnaissance include:

- ❖ Topography of the land including water bodies, estuaries, reserved land and quarries.
- ❖ Slopes' angles and orientation.
- ❖ Presence of structures, heritage structures, trees and utility lines
- ❖ Presence of hazardous industries or waste disposal sites that could be potential public health hazards.
- ❖ Areas with loose soil, patches of soil discoloration, excess growth of vegetation or foul smell.
- ❖ Comparison of available plan with current situation, i.e., addition of new structures or utility lines.

#### 2.6.2.2 Data and Map Study

Details obtained from reconnaissance now need to be thoroughly understood in order to determine the necessary tests and samples to be collected for the next stages of site investigation, i.e., in-depth investigation and lab testing. Data can be obtained from local municipalities, libraries, county record and survey offices, utility and service providers, and from commercial databases through the internet.Geological maps, old plans and photographs can be obtained from the survey or records department. The study includes:

- ❖ Presence of licensed water abstraction and discharge consents, landfills, and waste disposal sites.
- ❖ History, if any, of hazardous incidents.
- ❖ Quality of surface water and groundwater vulnerability.
- ❖ Past local borehole records.
- ❖ Presence of coal and other mines.
- ❖ Historical mapping.
- ❖ Buried and overhead supply and utility lines.

#### 2.6.2.3 In-depth Investigation

Based on the above study, locations for trial pits and boreholes can be selected. The selection should be such that a complete geologic sub-surface perspective can be obtained. At least three points should be selected with spacing of 10 to 30 meters depending on site conditions and type of project. Commonly boreholes, probes and trial pits are used to undertake in-depth investigation.

❖ **Boreholes**

Boreholes are used extensively for site investigation because they are less disruptive to the surface than trial pits, and can be taken to a greater depth. Also, boreholes can be drilled through any type of subsurface strata using percussion drilling, rotary drilling, wash boring and power auguring.

Boreholes drilled using the percussion methods are suitable for installation of groundwater monitoring systems, which provide valuable information. In rotary drilling, a drill bit is rotated at the bottom of the borehole using open-hole drilling or core drilling.

Core drilling is preferred because the core is retained within the core barrel and brought to the surface for investigation. Sometimes smaller, portable drilling equipment may be required where accessing ideal sampling locations is difficult.

❖ **Probing**

This method consists of dynamic and static cone penetration methods. Dynamic probing is similar to a standard penetration test (SPT) and the number of blows required to drive the cone 100 mm is recorded. In static probing, the head of the cone has a sensor that records the resistance to driving force.

❖ **Trial Pits**

These pits are excavated in soils that can support themselves for the required time needed to conduct the investigation. In loose soils, shoring may be required. There are depth restrictions in trial pits, and the consequent area of ground that is disturbed is also quite large.

In environmentally sensitive locations, trial pits may not be permitted. The advantages are that it indicates vertical and lateral variations in the subsoil strata.

### 2.6.3 Laboratory Testing

The soil recovered during the in-depth soil investigation is tested in the lab at this stage. The material obtained is classified and characterized, and based on the project, geotechnical parameters are provided for the design phase

**2.6.3.1 Classification Test**

For cohesive soils, the tests are done for moisture content, plasticity index, particle size distribution and bulk density. For granular soils, tests are done for particle size distribution and bulk density.

**2.6.3.2 Shear Strength Test**

For cohesive soils, tests are done for short-term stability, long-term stability and residual shear strength properties using the shear box test. For granular soils, the shear box test is done for both short-term and long-term stability analysis

**2.6.3.3 Conclusion**

Site investigation varies from project to project and needs to be as comprehensive as possible. Visual inspection and desk studies using maps and data should not be ignored, because they form the basis for in-depth investigation. Based on the project type, the most suitable intrusive investigation should be selected.

## 2.7 Surface and Subsurface Geotechnical Investigations

**2.7.1 General.**

The topography of J&K has naturally been gifted with one of the most diverse geological formations ranging from Greater/Intermediate/Lower Himalayas (Mountainous reaches) to Sub-Mountainous (Sub-montane or Foot-Hill reaches) to Plateau (Upland reaches) to Qasi-Alluvial (Trough reaches) to Alluvium (Alluvial reaches). While the sites of buildings and associated structures may be located across all such geological disposition, it is important to emphasize that very concentrated efforts are required, by executing divisions, to evaluate the surface and subsurface conditions at project sites, by way of coherent geotechnical investigation and application of appropriate geotechnique for facilitating/providing apposite foundation system, thereof.

Surface condition assessment generally includes geomorphology studies, geological mapping, geophysical and photogrammetry methods, while Sub-Surface condition assessment includes shallow or deep soil/rock sounding with sampling and testing so that design, constructability, soundness, safety, longevity of a given building project is duly achieved, with rational economics.

Such technical assessment may also, customarily, form a part of other Techno-Economic project feasibility studies, based on which final proposal of Building may be conceived. It may also help in working on economics/feasibilities within available alternate project sites.

The professional expertise, under subject domain of Surface and Sub-Surface investigation, for Building, shall include a Geo-Structural/Geotechnical engineer, an Engineering Geologist/Geophysicist and a Hydrologist/Hydrogeologist.

**2.7.2 Indian Standards Applicable:**The mandate of following BIS/MoRT&H/IRC Codes shall apply;

1) IS: 1498 2) IS:1888 3) IS: 1892 4) IS: 2131 5) IS:2132 6) IS:27207) IS:4434
8) IS: 4968 9) NBC-2016 10) MoRT&H 11) IS:7292 12)IS:7317 13) IS: 7746 14) IS: 5313
15) IS: 4464 16) IS: 4078 17) IS:10042 18) IS:2911 19) IS:6403 20) IS:8009 21) IS:1904
22) SP:36 23) IS:2950 24) IS:297425) IS:4332 26) IS:5249 27) IS:8763 28) IS:9214
29) IS: 9640 30) IS:10442 31) IS:10108 32) IS:9716 33) IS:10589 34) IS:13094 35) IS:15284
36) IS:148932001

***Note: For all technical topics, which may, intentionally/un-intentionally, not have been covered, in this compilation of concise building manual, the reader shall strictly make reference to pertinent section of***

***latest BIS/NBC/MoRT&H/IRC/ASTM/BS/DIN codes, in order, for comprehensive understanding of topic, thereof.***

**2.7.3 Objective/Scope of Geotechnical Investigations**

The principal objectives, that a competent surface/sub-surface investigation shall serve, for comprehensive planning, design and construction of building, are summarized below. This information may get compiled and eventually completed during course of process for preliminary and detailed stages of investigation. However, it is very important to emphasize that construction stage conformation of characteristics of sub-surface geo-materials shall also form a critical part of geotechnical investigations. This is to rationally evaluate the design choices made and check if any requirement arises to make adaptive changes, particularly with regards to sub-structure/foundation support system. To assess and evaluate the nature of soil overburden or rock deposits, which includes Bore-Log for type of geo-material (soil/rock), thickness and spatial variation of various deposits of soil/rock, which are likely to support the foundations of building structure.

**2.7.3.1** To determine location and extent of soft/compressible soil layers, presence of any potential localized gas bearing seams or gas pockets or cavities/hollows, which are critical to stability of foundations.

**2.7.3.2** To determine the orientation (dip & strike) of founding rock beds, their fault patterns, location of fault and their activity, fissure/fracture frequency and their permeability.

**2.7.3.3** Assessment of location of HFL/subsoil water/ground-water and quality of water encountered in foundation zone. This shall include information about any potential artesian condition.

**2.7.3.4** In-situ engineering property assessment during Surface and Sub-surface exploration (SRM, ERM, GPR, SPT, DCPT, SCPT, Vane Shear Test, PMT, Drill advancement rate, RQD etc.,)

**2.7.3.5** Assessment of Seismic Activity/Seismic disturbances based on past earthquakes and seismic-zonation of area. This may include liquefaction studies for major building projects and assessment of any reported potential liquefaction damages of proximate structures.

**2.7.3.6** Evaluation of all pertinent index, physical and engineering properties of soil/rock, based on testing of representative disturbed and un-disturbed samples, retrieved during sub-surface exploration and correlation of same with geophysical data established during surface exploration.

**2.7.3.7** To determine depth wise particle size distribution of representative samples of sub-soil, particularly for projects near river banks/bed of active non-regime rivers, up to significant depth, to assess silt-factor and depth/extent of scour, thereof.

**2.7.3.8** Clarity on stratum profiling and classification of soils/rocks, in particular, with details of density, frictional and pore structure properties, which can be prudent for determining sinking or driving or blasting efforts for foundation.

**2.7.3.9** Selection of foundation type and embedment depth, with assessment of load bearing capacity and settlement characteristics.

**2.7.3.10** Assessment of stability aspects of riverbanks/embankments, potential identification of slope instabilities or landslides with may have direct repercussions on stability of major project components.

**2.7.3.11** Assessment of potential subsidence of any part of building project due to mining in close proximity.

**2.7.3.12** Assessment of constructional difficulties.

**2.7.4 Field Investigation Program**

Field investigations of sub-surface has usually three phases:

#### 2.7.4.1 Reconnaissance

Site reconnaissance would help in deciding future programme of field investigations, that is, to assess the need for preliminary or detailed investigations. Information on some of these may be obtained from topographical maps, geological maps, pedological and soil survey maps, seismic maps and aerial photographs or consistent data from previous investigations.

Geological maps of the area give valuable information of the site conditions. The general topography will often give some indications of the soil conditions and their variations. In certain cases the earlier uses of the land (like quarries, agricultural land, buried canals, etc) may have a very important bearing on the proposed new structures.

The presence of harmful chemicals in the subsoil can be easily identified by geology or by reconnaissance. Data regarding removal of overburden by excavation, erosion or landslides should be obtained. This gives an idea of the amount of pre-consolidation the soil strata has undergone. Similarly, data regarding recent fills is also important to study the consolidation characteristics of the fill as well as the original strata. Data regarding swelling or expansive soils will be useful information.

The areas which have already been developed, information may be obtained regarding the existing local knowledge, records of trial pits, boreholes, etc, in the vicinity, and the behaviour of the existing structures, particularly those of a similar nature to those proposed. This information may be made use of for design of foundation of lightly loaded structures of not more than two storeys and also for deciding the scope of further investigation for other structures. If the existing information is not sufficient or is inconclusive, the proposed site should be explored in detail as per good practice, so as to obtain a knowledge of the type, uniformity, consistency, thickness, sequence and dip of the strata, hydrology of the area and also the engineering properties.

#### 2.7.4.2 Preliminary Explorations

The investigation at this stage is to explore the feasibility aspects. The scope of preliminary exploration is restricted to the determination of depths, thickness, extent and composition of each soil stratum, location of rock and ground water and also to obtain approximate information regarding strength in compressibility of the various strata. The number of boreholes to be explored depends upon the importance of the structure, the aerial extent of facility, the topography and the nature of sub-strata conditions. Less than five exploratory boreholes, few sounding tests and often few trial pits are generally adequate in the case of preliminary exploration. For large and important structures the information may be supplemented by geophysical methods. In some cases where no previous sub-strata data are available, exploratory geophysical investigation may need to be supplemented by resorting to a few bore-holes. These will help to narrow down the number of sites under consideration and also to locate the most desirable location for detailed sub-surface investigation like bore or drill holes, sounding probes, etc.

#### 2.7.4.3 Detailed Explorations

Detailed investigation follows preliminary investigation and should be planned on the basis of data obtained during review as the investigations progress. The scope of detailed exploration is generally to determine shear strength and compressibility of all types of soils, density, density index, natural moisture content and permeability. It is also necessary to determine the pre-consolidation pressure of the strata from oedometer tests and consolidation characteristics beyond the pre-consolidation pressure.

The detailed investigation includes boring, detailed sampling and laboratory tests to determine the physical, chemical and engineering properties of soil and rock. Field tests which may be performed are in-situ vane shear tests (suitable in case of soft cohesive soil) and plate load tests. In a situation of liquefaction possibility, exploratory boreholes with SPT and sampling at very close depth intervals should be carried out, while static cone penetration tests with or without pore water pressure measurement are very useful. The cross hole shear tests and laboratory cyclic shear tests are useful in assessing the liquefaction potential

**2.7.5 Field Work**

Soil investigation for foundations shall contain a programme for boring/drilling and retrieval of samples. The field work shall consist of excavation, drilling of bore-holes for the purposes of collection of undisturbed and disturbed samples, standard penetration tests, in-situ vane tests, static and dynamic cone penetration tests, other field tests, as specified by the Engineer and preparation of bore-logs. Collection, preservation and testing of disturbed and undisturbed samples, from bore holes, borrow pits, etc., as specified by the Engineer, shall form a part of the above. All in-situ tests shall be supplemented by laboratory investigations. Relevant Indian Standards such as IS: 1498, IS:1888, IS:1892, IS:2131, IS:2720, IS:4434 and IS:4698etc., shall be followed for guidance. The soundings by dynamic method shall be carried out in bore-holes using a standard sampler as specified in IS:2131.

Common methods of sub-soil exploration include, Open Trial Pits, Penetration Tests (SPT, SCPT, DCPT, LCPT, DPT), Auger Boring, Shell and Auger Boring, Wash Boring, Percussion Boring, Rotary Boring, Core Drilling, Geophysical Methods (Seismic/Electrical), Pressure Meter Test (PMT), Plate Load Test etc. Various methods of site exploration may be referred from relevant code of practice or NBC of India-2016 or later, as may be applicable.

**2.7.6 Extent / Number & Depth of Exploration:**

The number and disposition of various tests shall depend upon type of structure/buildings and the soil strata variations in the area. General guidelines are, however, given below

- For a compact building site covering an area of about 0.4 hectare, one borehole or trial pit in each corner and one in the centre should be adequate.
- For very smaller and less important buildings, even one borehole or trial pit in the centre will suffice.
- For very large areas covering industrial and residential colonies, the geological nature of the terrain will help in deciding the number of boreholes and trial pits. For various commercial, industrial, infrastructure, power plants, cement plants, petrochemical plants, steel plants, pump house on shore or offshore, etc, number of boreholes and/or trial pits should be decided considering the importance of structure and type as well as uniformity of strata. As a guide, dynamic or static cone penetration tests may be performed at every 100 m by dividing the area in a grid pattern and the number of boreholes or trial pits may be decided by examining the variation in the penetration curves. The cone penetration tests may not be possible at sites having generally gravelly/bouldery strata. In such cases, geophysical methods may be resorted to.

**2.7.6.1 Depth of Exploration**

The depth of exploration required depends on the type of proposed structure, its total weight, the size, shape and disposition of the loaded areas, soil profile, and the physical properties of the soil that constitutes each individual stratum. The borings should be extended to strata of adequate bearing capacity and should penetrate all deposits which are unsuitable for foundation purposes, such as, unconsolidated fill, peat, organic silt and very soft and compressible clay. The depth of exploration, normally, should be at least 1½ times the width of foundation below the proposed foundation level.

In certain cases, it may be necessary to take at least one borehole or cone test or both to twice the width of the foundation. If a number of loaded areas are in close proximity the effect of each is additive. In such cases, the whole of the area may be considered as loaded and exploration should be carried out up to one and a half times the lower dimension.

In weak soils, the exploration should be continued to a depth at which the loads can be carried by the stratum in question without undesirable settlement and shear failure. In any case, the depth to which seasonal variations affect the soil should be regarded as the minimum depth for the exploration of sites. But where industrial processes affect the soil characteristics, this depth may be more.

An estimate of the variation with depth of the vertical normal stress in the soil arising from foundation loads may be made on the basis of elastic theory. The net loading intensity at any level below a foundation may be obtained approximately by assuming a spread of load of two vertical to one horizontal from all sides of the foundations, due allowance being made for the overlapping effects of load from closely spaced footings. As a general guidance, the depth of exploration at the start of the work may be decided as given in Table-2.1& Figure-2.1, which may be modified as exploration proceeds, if required. However, for industrial plant and other main structures, the depth of exploration may be decided depending upon importance of structure, loading conditions and type as well as uniformity of strata. For piles or piers, the depth shall be at least 2/3 of pile length below the anticipated tip (that is, termination of pile) or 5.0 m in rock with rock quality designation (RQD) ≥ 50 percent, whichever is earlier.

TABLE-2.1 Depth of Exploration

| S.No. | Type of Foundation | Depth of Exploration (D) |
|---|---|---|
| **1.** | Isolated spread footing or raft | One and a half times the width (B) (Ref- Fig-1) |
| **2.** | Adjacent footings with clear spacing less than twice the width | One and a half times the length (L) of the footing (Ref- Fig-1) |
| **3.** | Adjacent rows of footings | (Ref- Fig-1) |
| **4.** | Pile and well foundations | To a depth of one and a half times the width of structure from the bearing (tip of pile or bottom of well) |
| **5.** | a) Road cuts<br>b) Fill | Equal to the bottom width of the cut<br>2 m below ground level or equal to the height of the fill, whichever is greater |

Where investigation end in any potentially unsuitable or questionable foundation material (or with doubtful bearing capacity) the exploration shall be extended to a sufficient depth into firm and stable soils or rock but not less than four times the width of foundation, below the earlier contemplated foundation level. In case of good sound rock with RQD of more than 75, the stipulation of minimum depth may be decreased based on difficulty to conduct core drilling and the minimum depth may be restricted to 3 meters.

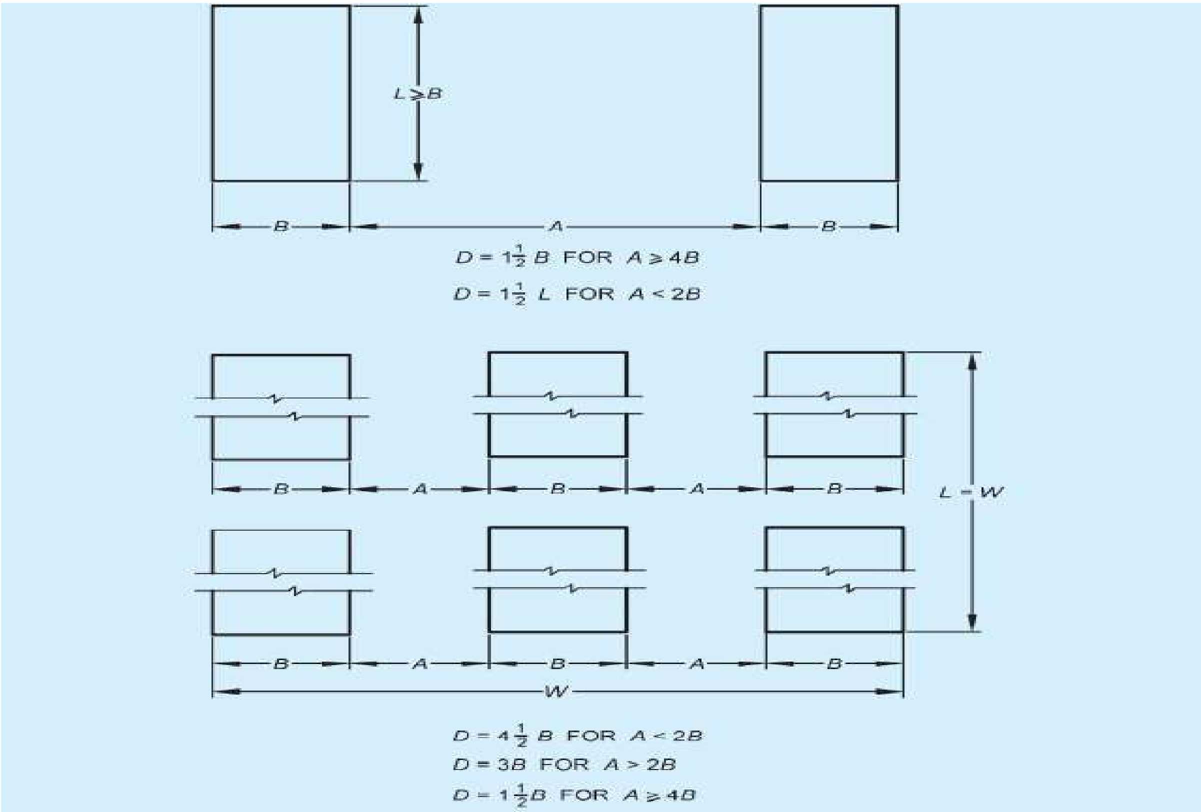



**Figure-2.1: Depth of Exploration**

**2.7.6.2 Subsurface investigation for Piles.**

The Specification under IS 2911/NBC-India/ MoRT&H, section 1102, shall apply under this section. The complete sub-surface investigation of strata in which pile foundations are proposed shall be carried out in advance and by in-situ pile tests. At least one bore-hole for every foundation of a Building shall be executed. Boring should be carried upto sufficient depths so as to ascertain the nature of strata around the pile shaft and below the pile tip. However, depth of boring shall not be less than following:

- ❖ 1.5 times estimated length of pile in soil but not less than 15 m beyond the probable length of pile.
- ❖ 15 times diameter of pile in weak/jointed rock but minimum 15 m in such rock.
- ❖ 4 times diameter of pile in sound, hard rock but minimum 3 m in such rock.

The sub-surface investigation shall define adequately stratification of sub-strata including the nature and type of strata, its variation and extent and specific properties of the same. The investigation shall be adequate for the purpose of selection of appropriate piling system and for estimating design capacities for different diameters and length of piles.

Pressure meter tests may be used in the case of rock, gravel of soil for direct evaluation of strength and compressibility characteristics. Though these tests are of specialized nature they are most appropriate for difficult/uncertain sub-strata especially for important projects.

For piles socketed into rocks, it is necessary to determine the uniaxial compressive strength of the rock and its quality. The investigation shall also include location of ground water table and other parameters including results of chemical tests showing sulphate and chloride content and any other deleterious chemical content in soil and/or ground water, likely to affect durability.

**2.7.6.3 Interval for Field Tests:**

Normally, once the type of foundation is decided as shallow footings based on initial findings, the test intervals shall be close to almost continuous at least for a depth equal to 1.5 times the foundation width. Similarly, in the case of pile foundations, the test intervals shall be significantly small within a depth range of eight times the pile diameter above the pile tip and five times the pilediameter above the pile tip and five times the pile diameter below the pile tip until incompressible stratum is encountered and confined geologically.

In case of housing colonies, the depth of borehole may be kept as 40 m or 5 m in rock with rock quality designation RQD ≥ 25 percent, whichever is earlier. In the case of ground improvement programme like preloading, stone columns, compaction, etc, the field tests and sampling shall be almost continuous so that presence of thin soil layers of different texture can be identified.

**2.7.7 Method of Site Exploration:**

The choice of the method of exploration generally depends upon following;

**2.7.7.1 Nature of Ground**

- **Soils**

In clayey soils, borings are suitable fordeep exploration and pits for shallow exploration. In case of soft sensitive clayey soils, field vane shear test may be carried out with advantage. In sandy soils, boring is easy but special equipment, such as, Bishop or Osterbergpiston samplers should be used for taking undisturbed samples below the water table. Where necessary, some form of ground water lowering is used. Standard penetration test, dynamic cone penetration test and static cone penetration test are used to assess engineering properties.

- **Gravel-boulder deposits**

In the deposits where gravel-boulder proportion is large (>30 percent), the subsoil strata should beexplored by open trial pits of about 5 m × 5 m but in no case less than 2 m × 2 m. The depth of excavation may be up to 6 m. For determining strata characteristics, in-situ tests should be preferred. For shear characteristics and allowable soil pressure, pressure meter tests, load tests on cast in-situ footing and in-situ shear tests that is, boulder-boulder test or concrete-boulder test are more appropriate. For detailed information on these tests reference shall be made to good practice. Depending on the structure, if required, the strata may be explored by drilling borehole using suitable method. Investigation for foundation in Gravel-Boulder Deposits shall conform to specifications of IS:10042.

- **Rocks**

Core drillings are suitable in hard rocks and pitsin soft rocks. Core borings are suitable for the identification of types of rock, but they provide limited data on joints and fissures. NX borehole camera is useful to photograph the stratification in drilled boreholes. For obtaining core, double tube core barrel with hydraulic feed is preferred. Triple tube core barrel may be used in fragmented or failure or sheared rock. Depending upon the design requirements, large diameter drilling may be explored iffeasible.

**2.7.7.2 Topography of Site**

In hilly country, the choice between vertical openings (for example, borings and trial pits) and horizontal openings (for example, headings) may depend on the geological structure, since steeply inclined strata are most effectively explored by headings and horizontal strata by trial pits or borings. Swamps and areas overlain by water are best explored by borings which may require use of a floating craft.

**2.7.7.3 Cost of Investigations**

The cost of investigation varies depending upon projectsize, stratigraphy, location, marshy areas, access or approaches, etc. The data to be obtained for founding purpose, with a view to reducing or minimizing the surprises, is however, important. It also helps in solutions in respect of selection of appropriate type of foundation, construction materials, etc. For deep exploration, borings are usual, as deep shafts are costly. Forshallow exploration in soil, the choice between pits and borings will depend on the nature of the ground and the information required by shallow exploration in rock; the cost of bringing a core drill to the site will be justified only, if several holes are required; otherwise, trial pits will be more economical.

**2.7.8 Provisions for investigations for High Rise/Important Building Foundations resting on Rock**

The Specification of BIS or MoRT&H, section 2405, shall apply under this section. Investigation and interpretation of data for rock is a recognized as aspecialized work, for which the services of an Engineering Geologist/Structural-Geologist, shall be necessarily availed. To arrive at the characteristic strength of rock mass, reliance shall be placed more on in-situ tests in comparison to laboratory tests.

Identification and classification of rock types for engineering purpose may, in general, be limited to broad, basic geological classes in accordance with accepted practice.Strength assessment shall be based on overall characteristics of rock formation like origin/nature of rocks, spacing and distribution of discontinuities of the rock mass, fracture/joint frequency, bedding planes, faults and presence of weathered seams. Another important factor affecting the behavior of the rock, as founding material, is the weathered zone at top. Assessment of foundations, resting over rock formations shall never be made based on strength of parent rock, alone.

Categorization of rocky subsurface shall also be explicitly made like; Sound Rock (≥85% core recovery), Medium Rock (≥50% core recovery), Intermediate Rock (≥35% core recovery) and Soft Rock (<35% core recovery but Standard Penetration Resistance value "N" is >50). For core recoveries less than 20%, the subsoil strata must be treated as soil, instead of rock.

**2.7.8.1 Information required from exploration/investigation within rock/rock-mass**

Following information shall be deemed mandatory:

- Identification and characterization of Geological System.
- Depth of rock strata and its variation over the site, particularly over extent of Construction Area.
- Whether subsurface consists of an isolated boulder or a massive/continuous rock formation, particularly if met with at shallow or erratic depths in adjacent bores,
- Extent/thickness and character of weathered zone,
- Structure of rock - including bedding planes, faults, fissures, solution cavities etc.,
- Properties of rock material-strength, geological formation, etc,
- Erodibility of rock to the extent possible, where relevant, particularly when met at shallow depths,
- Color, quality and quantity of water coming out during drilling operation.
- Seismicity of the area, based on macro/micro zonation.

**2.7.8.2 Extent of Investigation within rock/rock-mass**

If preliminary investigations have revealed presence of rock within levels where the foundation is to rest, it is essential to take up detailed investigation to collect necessary information mentioned, above. The exploratory bore-hole shall be drilled into the rock to a depth of about 3 meters to distinguish a boulder from a continuous rock formation.

The extent of exploration shall be adequate enough to cover the whole area of the building construction site for general characteristics and in particular, the foundation location, to obtain definite information regarding depth of rock and its variation over the foundation area. A complete picture of the rock profile both in depth and across the construction areais necessary to assess the constructional difficulties in reaching the foundation levels. The detailed programme of exploration will depend on the type and depth of over-burden, the size and importance of the structure, etc. To decide this, geophysical methods adopted at the preliminary investigation stage will be helpful, this data being supplemented by sounding, bore-holes and drill holes.

The depth of boring in rock depends primarily on local geology, erodibility of the rock, extent of structural loads to be transferred to foundation etc. Normally, it shall pass through the upper weathered or otherwise weak zone, well into the sound rock. Minimum depth of boring in sound rock shall be 3.0meters.

As stated earlier, the drilling through rock is a very specialized work and every care shall be taken to notice and record any small change during drilling. The time required to drill through a certain depth, amount of core recovery, physical condition, length of pieces of core, joints, color of water residue, weathering and evidence of disturbance and other effects shall be carefully noticed and entered in the drilling log. For guidance, IS: 5313 may be referred to. The data shall be presented in accordance with IS: 4464.The cores shall be stored properly in accordance with IS: 4078.

❖ **Testing of Rocks**

The rock cores obtained shall be subjected to following tests:

- ❖ Visual identification for texture, structure, composition, color and grain size.
- ❖ Laboratory tests shall be done for specific gravity, porosity and moisture content.

Use of in-situ tests for measuring strength and deformation characteristics shall be made. In-situ tests shall be made in accordance with IS: 7292; IS:7317; and IS:7746. Use of bore-holephotography will be desirable to evaluate the presence of faults, fissures or cavities, etc.

The quality of rock cores shall be classified according to Rock Quality Designation as presented in Table:2.2, below;

TABLE-2.2 Classification of Rocks as per RQD

| S.No | RQD Percent | Core Quality |
|---|---|---|
| 1. | 90-100 | Excellent |
| 2. | 75-90 | Good |
| 3. | 50-75 | Fair |
| 4. | 25-50 | Poor |
| 5. | 25 | Very Poor |

**2.7.8.3 Special Cases of investigation in rocks/ Gravel-Boulder Deposits**

❖ **Investigation for conglomerate**

A drill hole shall be made same as for rock. The samples collected shall be subjected to suitable tests depending upon the material, special care shall be taken to ascertain erodibility of the matrix. Where possible, especially for shallow foundation, Plate Load Test shall be conducted.

❖ **Investigation for laterites**

The investigation shall be generally similar to that required for cohesive soils, use of penetration tests shall be preferred, if suitable correlation charts are available. This may be static or dynamic penetration tests or vane shear tests. In the case of hard laterite, recourse may have to be made to core drilling as for soft rocks. For laterites at shallow depths, use of Plate Load Test may be advantageous.

❖ **Gravel-Boulder Deposits**

Investigation for foundation in Gravel-Boulder Deposits shall conform to specifications of IS:10042.

**2.7.8.4 Caution**

The interpretation of laboratory results on rock samples depends upon the relationship of the specimens tested to the overall rock characteristics. For this purpose, care shall be exercised in the choice of specimen size and its orientation in relation to the joint pattern.

In some cases, the foundation behaviour will be dominated by a possible mode of failure involving movement along some joint surface, fissures or weak layer within a generally strong rock system and also by possible weathering. In-situ shear tests may be conducted wherever feasible, as such tests are likely to give more representative data than the shear tests conducted on core samples.

**2.7.9 Boring/Drilling Operation (Ref: NBC Section 3.2, Part-6)**

The exploratory boreholes in soils/rocks shall be executed by any of the following methods, depending on the soil/rock type and types of samples required for the investigation, including conduction of desired Penetration Tests (SPT, SCPT, DCPT, LCPT, DPT) and other in-situ tests:

- ❖ Open trial pits
- ❖ Auger Boring
- ❖ Shell and Auger Boring
- ❖ Wash Boring
- ❖ Percussion Boring
- ❖ Rotary Boring
- ❖ Core Drilling.
- ❖ Pressure Meter Test (PMT)
- ❖ Geophysical Methods (Eletrical/Seismic)
- ❖ Plate Load Tests

Details specifications as per IS:1892, IS:2132 may be referred.

For preliminary and detailed sub-surface investigation only rotary drills shall be used, in case of rocks. The casing, in such cases, shall also be invariably provided with diameters not less than 150 mm up to the level of hard rock, if any. However, use of percussion or wash boring equipment shall be permitted only to penetrate through bouldery or gravelly strata for progressing the boring but not for the collection of samples. While conducting detailed borings, the resistance to the speed of drilling i.e. rate of penetration, core loss, etc., shall be carefully recorded, to evaluate the different types of strata and to distinguish specially sand from sandstone, clay from shale, etc.

**2.7.9.1 Records of Boring and Trial Pits**

The field records for the preliminary and detailed exploration shall contain the date when the boring was made, the location of the boring with reference to a permanent system of co-ordinates (Geo-tagging/GPS marking is desirable) and the elevation of the ground surface with respect to a permanent bench mark. They shall include elevation at which the water table and the upper boundary of each of the successive soil strata were encountered, the investigator's classification of the layer on the basis of general information obtained from field examination and the value of the resistance obtained by means of Standard or any other Penetration Test. The type of tools used for borings shall be recorded. If the tools were changed, the depth at which the change was made and the reason thereof shall also be noted. Incomplete and abandoned borings shall be described with no less care than successfully completed drill holes. The notes shall contain everything of significance observed on the job such as the elevation at which wash water was lost from the hole.

**2.7.9.2 Information in Boreholes/Trial pits.**

For all borings and trial pits, necessary information as detailed below shall be given. A site plan showing the disposition of the bore holes shall also be attached:

- ❖ Name of Agency.
- ❖ Location with reference map.
- ❖ Pit/Bore-hole number.
- ❖ Reduced level (RL) of ground surface or other reference point.
- ❖ Dates of starting and completion.
- ❖ Name of supervisor.
- ❖ Scales of plans and sections.
- ❖ Description of methods of advancing exploration such as; by hand tools, blasting, boring, etc.
- ❖ General description of strata met with and RLs at which they are met.
- ❖ Position and altitude of contracts, faults, strong joint, slicken sides, etc.
- ❖ Inflow of water, methods of controlling the water, required capacity of pumps for dewatering
- ❖ The level at which the sub-soil water is met with.
- ❖ Dip and strike of bedding and of cleavage
- ❖ Visual description of strata
- ❖ Results of field tests e.g. SPT/DCPT, in-situ vane shear test, in-situ permeability test etc.
- ❖ Any other information and remarks.
- ❖ The length of the sample in the tube and the length between the top of the tube and the top of the sample, in the tube, shall be measured and recorded, upon removal of sampling tube.

**2.7.10 Method of Sampling.**

The Specification of BIS-SP36/NBC of India-2016 or later//MoRT&H, shall apply under this section

**2.7.10.1 Soil Sampling.**

The details for method of sampling may be referred from IS:1892 & IS: 2132 and process of sampling shall conform to same. For proper identification of sub-surface material, sample should be recovered containing all the constituents of the materials in their proper proportion. In clayey deposits such samples could be collected by spilt spoon samplers. In the case of sandy deposits, sampling spoons shall be fitted with suitable devices for retaining samples. All data required for soil identificationshould be collected from the samples so extracted when undisturbed samples, which are more desirable for collection of some of the data, are not available. Penetration test should be carried out with the standard split spoon sampler or penetrometers if the soil is coarse grained. When it is known in advance that the soil profile is fairly regular, preliminary and detailed investigation may be combined. Tube samplers can be used in place of split spoon samplers for collecting samples in clayey strata.Generally there are two types of samples viz.

❖ **Disturbed sample**

These are taken by methods which modify or destroy the natural structure of the material though with suitable precautions the natural moisture content can be preserved.

❖ **Undisturbed sample for both soils and rocks**

These are taken by methods which preserve the structure and properties of the material. Thin walled tube samples may be used for undisturbed samples in soils of medium strength and tests for the same may be carried out in accordance with good practice. Minimum one UDS shall be obtained from each cohesive layer. For thick layers, the UDS shall be taken at every 3 m intervals. UDS need not be taken from cohesion less soils (silty sand, sand and gravel).

❖ **Representative sample**

These samples have all their constituent parts preserved, but may or may not be structurally disturbed. Washed samples from rotary boring should not be collected.

The method of sampling for various ground characteristics are presented below in Table-2.3.

**Table-2.3 Type and method of sampling for various ground characteristics.**

| Nature of Ground | Type of Sample | Method of Sampling |
|---|---|---|
| Soil | Disturbed | Hand Samples/Chunk samples<br>Auger Samples (in clays)<br>Shell Samples (in sands) |
| | Undisturbed | Hand Samples/Chunk samples<br>Tube Samples |
| Rock | Disturbed | Wash Samples from<br>Percussion of rotary drilling |
| | Undisturbed | Core barrel sampling |

**2.7.10.2 Mass of Soil Samples Required**

Sufficient disturbed soil/rock samples shall be obtained in the course of excavation and boring/drilling. For procuring samples from below the ground water level, where possible, special type of sampler shall be used. Where Standard Penetration Test is conducted, representative samples shall be obtained from the split spoon. While collecting disturbed samples from borrow areas it shall be ensured that the samples collected represent all types of borrow materials to be used in the construction of embankment and sub-grade.The size of sample generally required shall be as given in Table-2.4.

While taking out disturbed soil samples, Standard Penetration Test may also be conducted to find out the bearing capacity of the sub-soils at specified levels.

For undisturbed sampling procedure, the samples shall be obtained in such a manner that their moisture content and structure do not get altered. This may be ensured by use of correctly designed sampler and by careful preservation, packing and transportation.

Standard Penetration Test may have to be conducted in each case to obtain additional data as directed by the Engineer. In soft clay, in-situ vane shear test as per IS: 4434 may have to be conducted. Where all the three operations have to be carried out in one layer, the sequence shall be undisturbed soil sampling followed by in-situ vane shear test, followed by Standard Penetration Test.

For compaction test samples, a core of 40 mm diameter and about 150 to 200 mm length may be sufficient, but for other laboratory tests, a core of 100 mm diameter and 300 mm length shall be taken as far as possible, unless otherwise specified by the Engineer. The upper few millimeters of both types of sample shall be rejected as the soil at the bottom of the borehole usually gets disturbed by the boring tools.

**Table-2.4Size/Magnitude (Mass) of sample required.**

| S. NO. | PURPOSE OF SAMPLES | SOIL TYPE | WEIGHT OF SAMPLE REQUIRED (Kg) |
|---|---|---|---|
| 1. | Soil identification, natural moisture content tests, mechanical analysis and index properties, chemical tests | Cohesive soils<br>Sands and Gravels | 1<br>3 |
| 2. | Compaction tests | Cohesive soils and sand<br>Gravelly soils | 12.5<br>25 |
| 3. | Comprehensive examination of construction material and borrow area soil including soil stabilization. | Cohesive soils and sands<br>Gravelly soil | 25 - 50<br>50 - 100 |

While taking out disturbed soil samples, Standard Penetration Test may also be conducted to find out the bearing capacity of the sub-soils at specified levels.

For undisturbed sampling procedure, the samples shall be obtained in such a manner that their moisturecontent and structure do not get altered. This may be ensured by use of correctly designed sampler and by careful preservation, packing and transportation.

Standard Penetration Test may have to be conducted in each case to obtain additional data as directed by the Engineer. In soft clay, in-situ vane shear test as per IS: 4434 may have to be conducted. Where all the three operations have to be carried out in one layer, the sequence shall be undisturbed soil sampling followed by in-situ vane shear test, followed by Standard Penetration Test.

For compaction test samples, a core of 40 mm diameter and about 150 to 200 mm length may be sufficient, but for other laboratory tests, a core of 100 mm diameter and 300 mm length shall be taken as far as possible, unless otherwise specified by the Engineer.The upper few millimeters of both types of sample shall be rejected as the soil at the bottom of the borehole usually gets disturbed by the boring tools.

**2.7.10.3 Rock Sampling**

❖ **Disturbed samples**

The sludge from percussion borings or from rotary borings which have failed to yield a core, shall be collected for a disturbed sample. It may be recovered from circulating water by settlement in a trough.

❖ **Undisturbed samples**

Block samples taken from the rock formation shall be dressed to a size of about 90 x 75 x 50 mm.For core samples within rocks, the cores of rock shall be taken by means of rotary drills fitted with a coring bit with core retainer, if warranted.

In case of rock at shallow depths which can be conveniently reached, test pits or trenches are the most dependable and valuable methods since they permit a direct examination of the surface, the weathered zone and presence of any discontinuities. It is also possible to take representative samples for tests. For guidance, IS: 4453 may be referred.

**2.7.10.4 Water Samples**

Water samples have to be collected for chemical analysis. In cases, where mud circulation is used for advancing and stabilizing the boreholes, watersamples are to be collected only after 24-hrsof completion of the borehole. The other option is to collect water samples from open wellsin the close proximity. The sample shall be collected in a plastic container (about 500 ml) with airtight cover.

**2.7.10.5 Preservation, Handling and Labeling of samples.**

Care shall be taken in handling and labeling of samples so that they are received in a fit state for examination and testing and can be correctly identified as coming from a specified trial pit or boring.The disturbed material in the upper end of the tube shall be completely removed before applying wax for sealing the sample. The length and type of sample so removed should be recorded.

The soil at the lower end of the tube shall be removed to a distance of about 20 mm. After cleaning, both ends shall be sealed with wax applied in a way that will prevent wax from entering the sample. Wax used for sealing should not be heated to more than a few degrees above its melting temperature. The empty space in the samplers, if any, should be filled with moist soil, saw dust, etc., and the ends covered with tight fitting caps.

Labels giving the following information should be affixed to the tubes.

- ❖ Job designation
- ❖ Sample location
- ❖ Boring number
- ❖ Tube number
- ❖ Sample number
- ❖ Depth
- ❖ Penetration
- ❖ Gross recovery ratio

The tube and boring numbers should be marked in duplicate. The duplicate markings of the boring number and sample number on a sheet which will not be affected by moisture should be enclosed inside the tube.

**2.7.11 Examination and Testing of Samples.**

The following tests shall be carried out in accordance with accepted standard of testing as per BIS.

**2.7.11.1 Tests for Cohesionless soil**

❖ **Field tests**

- ❖ Plate Load test as per IS: 1888
- ❖ Standard Penetration test as per IS:2121.
- ❖ Dynamic Cone Penetration test as per IS: 4698 (Part 1 or Part 2)
- ❖ Static Cone Penetration test as per IS:4968 (Part 3)

❖ **Laboratory tests**

- ❖ Visual and engineering classification test, index tests, grain size distribution, density/density index, specific gravity etc.
- ❖ Compaction tests and CBR.
- ❖ Shear Strength by direct shear/triaxial shear test method.
- ❖ Permeability/hydraulic conductivity tests (Where dewatering is expected,IS: 2720 Part 17).

**2.7.11.2 Tests for Cohesive soil**

❖ **Field tests**

- ❖ Plate Load test as per IS: 1888.
- ❖ Standard Penetration test as per IS:2121.
- ❖ Dynamic Cone Penetration test as per IS: 4698 (Part 1 or Part 2)

- ❖ Static Cone Penetration test as per IS:4968 (Part 3)
- ❖ Vane Shear test as per IS:4434.

❖ **Laboratory tests**

- ❖ Visual and engineering classification test, index tests, grain size distribution, density/density index, specific gravity etc.
- ❖ Consistency tests like liquid limit, plastic limit and shrinkage limit.
- ❖ Swell pressure and free swell index test.
- ❖ Bulk density and moisture.
- ❖ Compaction tests and CBR.
- ❖ Shear Strength by Direct Shear/TriaxialShear test method.
- ❖ Unconfined Compression test as per IS:2720 Part-10.
- ❖ Consolidation test as per IS:2720 Part-5.
- ❖ Permeability/hydraulic conductivity tests (Where dewatering is expected, IS: 2720 Part 17).

**2.7.11.3 Tests for Subsoil Water**

The sub-soil water shall be tested for chemical properties to ascertain the hazard of deterioration to foundations. Chemical analysis for sulphates, chlorides and pH content of soil and ground water shall at least be determined.

**2.7.11.4 Tests on Rock samples**

- ❖ Visual classification;
- ❖ Water absorption, porosity and density;
- ❖ Specific gravity;
- ❖ Hardness;
- ❖ Slake durability;
- ❖ Unconfined compression test (both saturated and at in-situ water content);
- ❖ Point load strength index; and
- ❖ Deformability test (both saturated and dry samples).

***NOTE: These tests may be judiciously reduced according to engineering requirement and importance of project.***

**2.7.12 Presentation of Surface, Sub-Surface Investigation.**

Preliminary or Detailed surface or subsurface investigation shall be compiled and presented in the form of a Competent Geotechnical Investigation Report, with following minimum typical contents, as per Table-2.5.

**Table-2.5Typical Content of a Geotechnical Investigation Report**

| S.No | Content Description |
|---|---|
| 1 | General<br>1.1 Introduction.<br>1.2 Project Description & Scope of Investigation Work.<br>1.3 Previous preliminary investigation inputs/reports. |
| 2 | Geologic Condition & General Reconnaissance<br>2.1 Regional/Local Geologic Assessment.<br>2.2 Seismicity/Anticipated Geological Hazard.<br>2.3 Climatic Conditions.<br>2.4 Site Accessibility. |

| | |
|---|---|
| | 2.5 Reported Highest Flood Level & History of Scour from Water Courses. |
| 3 | Field/ Reconnaissance Exploration Protocol.<br>3.1 Site Selection and Extent of Investigation.<br>3.2 Exploration Methodology (Boring/Open Excavation/Drilling).<br>3.3 Sampling Practice (UDS/RD/DS).<br>3.4 Sub-Soil Water/Seepage Conditions.<br>3.5 Field Bore Logs & General Stratification/ Stratum Profiling. |
| 4 | Laboratory Investigations/Testing Protocol.<br>4.1 Soil/Rock Identification/Classification Tests (Index Properties).<br>4.2 Soil/Rock Strength Characterization.<br>4.3 Soil/Rock Compressibility/Compaction Characterization.<br>4.4 Ground /Soil-Water Characterization.<br>4.5 Chemical Analysis. |
| 5 | Foundation Analysis Criterion & Design Parameters.<br>5.1 Analysis Criterion (BIS-Code of Practice).<br>5.2 Geometrical Parameters & Assumptions for Analysis Criterion.<br>5.3 Liquefaction Potential & Probable Ground Damage.<br>5.4 Silt-Factor and Scour Depth (if applicable). |
| 6 | Analysis of Results & Recommendations.<br>6.1 Bearing Capacity Analysis & Results.<br>6.2 Pile Capacity Analysis & Results.<br>6.3 Design inputs for Well-Foundations.<br>6.4 Design inputs for Retaining Fronts.<br>6.5 Design inputs for Excavated Material and its suitability of use.<br>6.6 Design inputs for Approach Embankments.<br>6.7 Recommendations for Bearing Capacity/Ground Improvement. |
| 7 | Critical Comments/Discussions &All Technical Recommendations. |
| 8 | Appendix<br>Appendix-A1 (Field Bore Logs with location GPS coordinates).<br>Appendix-A2 (Longitudinal and transverse cross-section profiles of substrata)<br>Appendix-B (Laboratory Test Results).<br>Appendix-C (Nomenclature).<br>Appendix-D (References:Codal Specifications, Literature/Internet citations)<br>Appendix-E (Geo-tagged Site Photo Manifestations)<br>Appendix-F (Laboratory Photo Manifeststions) |

**2.7.13 Measurement for Payment and Rate.**

The work of boring and trial pits shall be considered as incidental to the foundation works and nothing extra shall be paid unless otherwise specified in the contract. In cases where it is specified to be paid separately, like contract for soil investigation, the work shall be measured in running meters for boring, in cubic meters for trial pits, in number of samples for collection of disturbed and undisturbed samples and in number of tests for each type of test.

The contract unit rate shall include the cost of all labour,materials, tools and plant and equipment required for doing the boring or making pits as per these specifications, taking out and packing the samples, sending and getting them tested in approved laboratories and making available the test report as specified or directed by the Engineer inclusive of all incidental costs to complete the work as per the specifications.

**2.7.14 Ground Improvement Techniques.**

In poor and weak sub-soils, the design of conventional foundation for structures and equipment may present problems with respect to both sizing of foundation as well as control of foundation settlements. A viable alternative in certain situations, is to improve the subsoil to an extent such that the subsoil would develop an adequate bearing capacity and foundations constructed after subsoil improvement would have resultant settlements within acceptance limits.

This method/technique is called ground improvement which is used to improve in-situ soil characteristics by improving its engineering performance as per the project requirement by altering its naturalstate, instead of having to alter the design in response to the existing ground limitations. The improvement is in terms of increase in bearing capacity, shear strength, reducing settlement and enhancing drainage facility, mitigating liquefaction potential, etc, of soil, as also in improving lateral capacity in case of deep foundations.

For provisions with regard to necessary data to be collected to establish the need for ground improvement at a site; considerationsfor establishing need for ground improvement methods;selection of ground improvement techniques; equipment and accessories for ground improvement; control of ground improvement works and recording of data, reference shall be made to good practice. Table-2.6presents various methods of ground improvement along with principles, applicability to various soil conditions, material requirements, equipment required, results likely to be achieved and limitations. This table may be referred to as guidance for selecting the proper method for a situation (Ref:IS 13094 covers the general guidelines for selection of ground improvement techniques for foundation in weak soils)

For provisions relating to ground improvement by reinforcing the ground using stone columns so as to meet the twin objective of increasing the bearing capacity with simultaneous reduction of settlements, reference shall be made to good practice [IS 15284 Part-1].

Whenever soft cohesive soil strata underlying a structure are unable to meet the basic requirements of safe bearing capacity and tolerable settlement, ground improvement is adopted to make it suitable for supporting the proposed structure. Both the design requirementsthat isshearstrength and settlement under loading, can be fulfilled by consolidating the soil by applying a preload, if necessary, before the construction of the foundation. This consolidation ofsoil is normally accelerated with the use of vertical drains. For provisions relating to ground improvement by pre-consolidation using vertical drains, reference shall be made to good practice [IS 15284 Part-2]. Use of suitable geo-synthetics/geo-textiles may be made in an approved manner for ground improvement, where applicable and as per relevant BIS standards.

## Table-2.5 Soils Improvement Methods

**SOIL IMPROVEMENT METHODS**

**Summary of Soil Improvement Methods**

| | Method | Principle | Most Suitable Soil Conditions/ Types | Maximum Effective Treatment Depth | Special Materials Required | Special Equipment Required | Properties of Treated Material | Special Advantages and Limitation | Relative Cost |
|---|---|---|---|---|---|---|---|---|---|
| *In-Situ Deep Compaction of Cohesionless Soils* | Blasting | Shock waves and vibrations cause liquefaction and displacement with settlement to higher density | Saturated, clean sands: partly saturated sands and silts (collapsible loess) after flooding | >30 m | Explosives, backfill to plug drill holes, hole casings | Jetting or drilling machine | Can obtain relative densities to 70-80, may get variable density strength gain | Rapid, inexpensive, can treat any size areas: variable properties, no improvement near surface, dangerous | Low |
| *In-Situ Deep Compaction of Cohesionless Soils* | Vibratory Probe | Densification by vibration; liquefaction induced settlement under overburden | Saturated or dry clean sand | 20 m (Ineffective above 3-4m depth) | None | Vibratory pile driver and 750 mm dia open steel pipe | Can obtain relative densities of up to 80. Ineffective in some sands | Rapid, simple, good underwater, soft under layers may damp vibrations, difficult to penetrate, stiff over layers, not good in partly saturated soils | Moderate |
| *In-Situ Deep Compaction of Cohesionless Soils* | Vibro-compaction | Densification by vibration and compaction of backfill material | Cohesionless soils with less than 20 fines | 30 m | Granular backfill, water supply | Vibroflot, crane, pumps | Can obtain high relative densities, good uniformity | Useful in saturated and partly saturated soils, uniformity | Moderate |
| *In-Situ Deep compaction of Cohesionless Soils* | Compaction piles | Densification by displacement of pile volume and by vibration during driving | Loose sandy soils: partly saturated clayey soils, loess | >20 m | Pile material (often sand or soil plus cement mixture) | Pile driver, special sand pile equipment | Can obtain high densities, good uniformity | Useful in soils with fines, uniform compaction, easy to check results, slow, limited improvement in upper 1-2 m | Moderate to high |
| *In-Situ Deep compaction of Cohesionless Soils* | Heavy tamping (Dynamic compaction/ consolidation) | Repeated application of high intensity impacts at surface | Cohesionless soils, waste fills, partly saturated soils | 30 m | None | Tampers of up to 200 tonne, high capacity crane | Can obtain good improvement and reasonable uniformity | Simple, rapid, suitable for some soils with fines; usable above and below water, requires control, shall be away from existing structures | Low |
| | **Method** | **Principle** | **Most Suitable Soil Conditions/ Types** | **Maximum Effective Treatment Depth** | **Special Materials Required** | **Special Equipment Required** | **Properties of Treated Material** | **Special Advantages and Limitation** | **Relative Cost** |
| *Injection and Grouting* | Particulate grouting | Penetration grouting-fill soil pores with soil, cement, and/or clay | Medium to coarse sand and gravel | Unlimited | Grout, water | Mixers, tanks, pumps, hoses | Impervious, high strength with cement grout, eliminate liquefaction danger | Low cost grouts, high strength; limited to coarse-grained soils, hard to evaluate | Lowest of the grout systems |
| *Injection and Grouting* | Chemical grouting | Solution of two or more chemicals react in soil pores to form a gel or a solid precipitate | Medium silts and coarser | Unlimited | Grout, water | Mixers, tanks, pumps, hoses | Impervious, high strength with cement grout, eliminate liquefaction danger | Low viscosity controllable gel time, good water shut-off; high cost, hard to evaluate | High to very high |
| *Injection and Grouting* | Pressure injected lime | Lime slurry injected to shallow depths under high pressure | Expansive clays | Unlimited, but 2-3 m usual | Lime, water surfactant | Slurry tanks, agitators, pumps, hoses | Lime in capsulated zones formed by channels resulting from cracks, root holes, hydraulic fracture | Only effective in narrow range of soil conditions | Competitive with other solutions to expansive soil problems |
| *Injection and Grouting* | Displacements grout | Highly viscous grout acts as radical hydraulic jack when pumped in under high pressure | Soft, fine-grained soils; foundation soils with large voids or cavities | Unlimited, but a few metre usual | Soil, cement water | Batching equipment, high pressure pumps, hoses | Grout bulbs within compressed soil matrix | Good for correction of differential settlements, filling large voids; careful control required | Low material high injection |
| *Injection and Grouting* | Electro-kinetic injection | Stabilization chemicals moved into soil by electro-osmosis or colloids into pores by electrophoresis | Saturated silts; silty clays (clean sands in case of colloid injection) | Unknown | Chemicals stabilizer colloidal void fillers | d.c. power supply, anodes, cathodes | Increased strength, reduced compressibility reduced liquefaction potential | Existing soil and structures not subjected to high pressures; not good in soils with high conductivity | Expansive |
| *Injection and Grouting* | Jet grouting | High speed jets at depth excavate, inject, and mix stabilizer with soil to form columns or panels | Sands, silts, clays | — | Water, stabilizing chemicals | Special jet nozzle, pumps, pipes and hoses | Solidified columns and walls | Useful in soils that can't be permeation grouted, precision in locating treated zones | — |

| | Method | Principle | Most Suitable Soil Conditions/ Types | Maximum Effective Treatment Depth | Special Materials Required | Special Equipment Required | Properties of Treated Material | Special Advantages and Limitation | Relative Cost |
|---|---|---|---|---|---|---|---|---|---|
| *Precompression* | Preloading with/without drain | Load is applied sufficiently in advance of construction so that compression of soft soils is completed prior to development of the site | Normally consolidated soft clays, silts, organic deposits, completed sanitary landfills | — | Earth fill or other material for loading the site; sand or gravel for drainage blanket | Earth moving equipment, large water tanks or vacuum drainage systems sometimes used; settlement markers, piezo-meters | Reduced water content and void ratio, increased strength | Easy, theory well developed, uniformity; requires long time (vertical drains can be used to reduce consolidation time) | Low (moderate, if vertical drains are required) |
| | Surcharge fills | Fill in excess of that required permanently is applied to achieve a given amount of settlement in a shorter time; excess fill then removed | Normally consolidated soft clays, silts, organic deposits, completed sanitary landfills | — | Earth fill or other material for loading the site; sand or gravel for drainage blanket | Earth moving equipment; settlement markers, piezometers | Reduced water content, void ratio and compressibility increased strength | Faster than preloading without surcharge, theory well developed, extra material handling; can use vertical drains to reduce consolidation time | Moderate |
| | Electro-osmosis | d.c. current causes water flow from anode towards cathode where it is removed | Normally consolidated silts and silty clays | — | Anodes (usually rebars or aluminium) cathodes (well points or rebars) | d.c. power supply, wiring, metering systems | Reduced water content and compressibility, increased strength, electrochemical hardening | No fill loading required, can be used in confined area, relatively fast; non-uniform properties between electrodes; not good in highly conductive soils | High |

| | Method | Principle | Most Suitable Soil Conditions/ Types | Maximum Effective Treatment Depth | Special Materials Required | Special Equipment Required | Properties of Treated Material | Special Advantages and Limitation | Relative Cost |
|---|---|---|---|---|---|---|---|---|---|
| *Admixtures* | Remove and replace | Foundation soil excavated, improved by drying or admixture, and re-compacted | Inorganic soils | 10 m | Admixture stabilizers | Excavating, mixing and com-paction equip-ment, dewate-ring system | Increased strength and stiffness, reduced compressibility | Uniform, contro-lled foundation soil when replaced; may require large area dewatering | High |
| | Structural fills | Structural fill distributes loads to underlying soft soils | Use over soft clays or organic soils, marsh deposits | — | Sand, gravel fly ash, bottom ash, slag, expanded aggregate, clam shell or oyster shell, incinerator ash | Mixing and compaction equipment | Soft subgrade protected by structural load-bearing fill | High strength, good load distribution to underlying soft soils | Low to high |
| | Mix-in-place piles and walls | Lime cement or asphalt introduced through rotating auger or special in-place mixer | All soft or loose inorganic soils | >20 m | Cement lime asphalt, or chemical stabilizer | Drill rig, rotary cutting and mixing head, additive proportioning equipment | Solidified soil piles for walls of relatively high strength | Use native soil, reduced lateral support require-ments during excavation; diffi-cult quality control | Moderate to high |
| *Thermal* | Heating | Drying at low temperatures; alteration of clays at intermediate temperatures (400-600°C); fusion at high temperatures (>1 000°C) | Fine- grained soils, especially partly saturated clays and silts, loess | 15 m | Fuel | Fuel tanks, burners, blowers | Reduced water content, plasticity, water sensitivity; increased strength | Can obtain irreversible improvements in properties; can introduce stabilizers with hot gases | High |
| | Freezing | Freeze soft, wet ground to increase its strength stiffness | All soils | Several metre | Refrigerant | Refrigeration system | Increased strength and stiffness, reduced permeability | No good in flowing ground water, temporary | High |

| | Method | Principle | Most Suitable Soil Conditions/ Types | Maximum Effective Treatment Depth | Special Materials Required | Special Equipment Required | Properties of Treated Material | Special Advantages and Limitation | Relative Cost |
|---|---|---|---|---|---|---|---|---|---|
| *Reinforcement* | Vibro replacement sand/stone columns | Hole jetted into soft, fine-grained soil and backfilled with densely compacted gravel or sand | Soft clays and alluvial deposits | 20 m | Gravel or crushed rock backfill | Vibroflot, crane or vibrocat, water | Increased bearing capacity, reduced settlement | Faster than precompression, avoids dewatering required for remove and replace; limited bearing capacity | Moderate to high |
| | Root piles, soils nailing | Inclusions used to carry tension, shear, compression | All soils | — | Reinforcing bars, cement grout | Drilling and grouting equipment | Reinforced zone behaves as a coherent mass | *In-situ* reinforcement for soils that can't be grouted or mixed in-place with admixtures | Moderate to high |
| | Strips and membranes | Horizontal tensile strips, membranes buried in soil under embankments, gravel base courses and footings | All soils | Can construct earth structures to heights of several metres | Metal or plastic strips, geotextiles | Excavating, earth handling, and compaction equipment | Self-supporting earth structures, increased bearing capacity, reduced deformations | Economical, earth structures coherent, can tolerate deformations; increased allowable bearing pressure | Low to moderate |

## 2.8 Building Functional Planning and Architectural Proposals

### 2.8.1 Introduction

A building is an assemblage that is firmly attached to the ground and that provides total or nearly total shelter for machines, processing equipment, performance of human activities, storage of human possessions, or any combination of these.

Building design is the process of providing all information necessary for construction of a building that will meet its owner's requirements and also satisfy public health, welfare, and safety requirements. Architecture is the art and science of building design. Building construction is the process of assembling materials to form a building.

Building design may be legally executed only by persons deemed competent to do so by the state in which the building is to be constructed. Competency is determined on the basis of education, experience, and ability to pass a written test of design skills.

Architects are persons legally permitted to practice architecture. Engineers are experts in specific scientific disciplines and are legally permitted to design parts of buildings; in some cases, complete buildings. In some states, persons licensed as building designers are permitted to design certain types of buildings.

Building construction is generally performed by laborers and craftspeople engaged for the purpose by an individual or organization, called a contractor. The contractor signs an agreement, or contract, with the building owner under which the contractor agrees to construct a specific building on a specified site and the owner agrees to pay for the materials and services provided.

In the design of a building, architects should be guided by the following principles:

**2.8.1.1** The building should be constructed to serve purposes specified by the client.

**2.8.1.2** The design should be constructable by known techniques and with available labor and equipment, within an acceptable time.

**2.8.1.3** The building should be capable of withstanding the elements and normal usage for a period of time specified by the client.
**2.8.1.4** Both inside and outside, the building should be visually pleasing.
**2.8.1.5** No part of the building should pose a hazard to the safety or health of its occupants under normal usage, and the building should provide for safe evacuation or refuge in emergencies.
**2.8.1.6** The building should provide the degree of shelter from the elements and of control of the interior environment—air, temperature, humidity, light, and acoustics—specified by the client and not less than the minimums required for safety and health of the occupants.
**2.8.1.7** The building should be constructed to minimize adverse impact on the environment.
**2.8.1.8** Operation of the building should consume a minimum of energy while permitting the structure to serve its purposes.
**2.8.1.9** The sum of costs of construction, operation, maintenance, repair, and anticipated future alterations should be kept within the limit specified by the client.

The ultimate objective of design is to provide all the information necessary for the construction of a building. This objective is achieved by the production of drawings, or plans, showing what are to be constructed, specifications stating what materials and equipment are to be incorporated in the building, and a construction contract between the client and a contractor. Designers also should observe constructionof the building while it is in process. This should be done not only toassist the client in ensuring that the building is being constructed in accordancewith plans and specifications but also to obtain information that will be useful indesign of future buildings.

**2.8.2 Site Analysis**

The site visit is the first gear in the design process. A detailed site analysis has to be done so as to understand the features of the site, which will be very important during the design.

The purpose of the site analysis is to record and evaluate information on the site and its surroundings, and to use this evaluation in the design response.

**2.8.2.1 Location**

This is the first aspect that one needs to look at. Where is the site located? How is the site approached? What is the name of the street, the road etc on which the site is located? How far away is the major junction?

**2.8.2.2 Orientation**

The orientation of the site plays a very important role in sitting of the building. This, when combined with the wind direction and sun path, would give a good idea as to how the design should be oriented so as to optimize the design. The orientation along with the sun path will also determine the placement of rooms inside buildings.

**2.8.2.3 Wind Direction**

Most of the locations will have a general major direction from which the wind comes. However, this will not always hold true and will vary from location to location. If we are to design a climatologically responsive building, it will be important to consider the direction of the wind so that it can be channelized through the interiors.

**2.8.2.4 Soil Type & Condition**

Soils vary from place to place. Their properties also vary according to the type of soil. Sandy soil, clayey soil, laterite etc, all have different properties, which affect the design of the building. This is very important from a structural point of view while designing buildings.

**2.8.2.5 Topography**

Topography refers to the slope and levelof the land – whether the land is flat andplain, or whether it is sloping? From adesign point of view, a sloping site willbe more challenging. If a site is sloping,the exact slope can be interpreted froma detailed Contour map. The contour locations and spacing of contours will play a big role in the sitting of the building. It isalways better to design buildings along with the contours, integrating it into the design toreduce unnecessary cutting and filling of soil.

**2.8.2.6 Vegetation & Natural Features**

The natural vegetation present on the site is very important. Any good design will integrateit into the design, highlight & accentuate it to create a harmonious whole. The vegetationwill consist of all the trees, flora and fauna present on the site. These should be markedonto the site plan so that it will assist during the design stage. Along with the location, thetype of trees, the size of the trees, diameter or spread of the branches, heights etc are tobe identified.

**2.8.2.7 Precipitation & Hydrology**

The amount of rainfall that the site receives and also the time period during which therainfall occurs are to be found out.

The Relative Humidity of the place also has to be found out to determine the moisturecontent in the atmosphere. A higher relative humidity suggests a humid climate, for whichcross circulation of wind at the body level is a must for comfort. A lower relative humiditywill suggest a dry climate.

**2.8.3 Neighborhood Character**

**2.8.3.1 Infrastructure Facilities**

This refers to the services present in the location. The major things to be consideredare the water supply, drainage connection, waste disposal, electricity supply etc. These are important while planning the zoning in the site.

**2.8.3.2 Surrounding land uses & buildings**

One also needs to pay attention to the surrounding land uses and building around the site.If the land uses are incompatible, it may lead to creation of issues in the design. Also, the height and setbacks of adjacent buildings are important in affecting the flow of air andalso sunlight.

**2.8.3.3 Prominent Vision Lines / Visual Linkages**

This becomes a very important element in the design process. The views to the site as wellas the views from the site are to be carefully considered while designing.

**2.8.3.4 Locally available resources**

One also needs to find out what materials are available in and around the site, which can beused in the design. This is especially relevant today when the design has to be as sustainableas possible, by reducing the transportation energy & costs.

**2.8.4 Site Planning**

Site planning and design require the professional to consider a broad range of concerns in the synthesis of a design concept. There are the physical aspects of the site itself, the vision or program of the client, the designer's own creative inclination, the concerns of the community, and the interests of the end user. The zoning requirements are intended to regulate the density and geometry of development, specifying roadway widths and parking and drainage requirements, and define natural resource protection areas.

**2.8.4.1 Neighborhood Character**

A comprehensive understanding and appreciation of context and the balancing of neighborhood character and strategic planning objectives must be the starting point for any design. This requires an understanding of a proposed development and its relationships to the surrounding public setting, neighboring properties, and any identified strategic issues relating to the site.

**2.8.4.2 Site Planning details**

Must incorporate an accurate description of:

- Shape, size, orientation of the site and easements.
- Levels and contours of the site and the difference in levels between the site and surrounding properties.
- The location and height of existing buildings on the site and surrounding properties.
- The use of surrounding buildings, including location of habitable rooms.
- The location of private open space of surrounding properties and the location of trees, fences and other.
- Landscape elements.
- Solar access to the site and surrounding properties.
- Street frontage features such as poles, street trees, footpaths and kerb crossovers.
- The location of shops, public transport services and public open space within walking distance.
- Movement systems through and around the site.
- Any other notable feature or characteristic of the site or surrounding areas.
- Constraints and opportunities such as heritage places.
- Current access to direct sunlight in summer and winter.
- Reduce/minimize total imperious area.
- Demarcate the zone of development.

**2.8.4.3 Site and Slopes**

Good designing follow grades and run along ridge lines. Steep site slopes often requireincreased cut and fill if building are sited using conventional. If incorporated into the initialsubdivision layout process, slope can be an asset to the development. For areas with rollingterrain with dissected ridges use multiple short branch cul-de-sacs off collector streets.

**2.8.4.4 Use Site Fingerprinting**

Site fingerprinting (minimal disturbance techniques) can be use to further reduce the limits of clearing and grading, thereby minimizing the hydrologic impacts. Site fingerprinting includes restricting ground disturbance by indentifying the smallest possible area and clearly delineating it on the site. Reduce paving and compaction of highly permeable soils.

**2.8.5 Site Planning Principles**

**2.8.5.1 Do not harm**

Make no changes to the site that will degrade the surrounding environment. Promote projects on sites where previous disturbance or development presents an opportunity to regenerate ecosystem services through sustainable design.

**2.8.5.2 Precautionary Principle**

Be cautious in making decisions that could create risk to human and environmental health. Some actions can cause irreversible damage. Examine the full range alternatives – includingno action and be open to contributions from all affected parties.

**2.8.5.3 Design with nature and culture**

Create and implant designs that are responsive to economic, environmental, and cultural conditions with respect to the local, regional, and global context.

**2.8.6 Survey Site Plan (Point to be considered)**

**2.8.6.1** Survey site plan should be prepared to the scale and scale indicated in the name plate of the drawing.

**2.8.6.2** Side Dimensions/Angles/diagonals, as measured during survey should only be indicated in the plan. Any dimension indicated on the basis on ‘scaled out’ form the plan may lead to confusion/ complication while drawing plans etc.

**2.8.6.3** S.S. Plans should contain ‘key plan’ indicating board features of the surroundings.

**2.8.6.4** R.O.W. of the roads if any surrounding the plot should also be given.

**2.8.6.5** Reference to zone of Master Plan of DA/MC should be given.

**2.8.6.6** Detailed information about existing services (i.e. Water supply, Sewerage, Drains,Electricity) to be given.

**2.8.6.7** Location and size of trees and or any other obstacle (like Electric over head line) in the plot to be given.

**2.8.6.8** Reference to land (area, Revenue Khasra No. etc. ) as handed over to be given.

**2.8.6.9** Compare the land area as handed over and area of land as worked out on the basis of survey and reconcile the discrepancy, if any. (Detailed calculation of areas of land on the basis of survey to be given in the plan itself under “notes”).

**2.8.6.10** ‘Name plate’ of drawing should be of standard size and should indicate following:

- ❖ Name of Division.
- ❖ Name of work.
- ❖ Name & Signature of the Person/official who has (have) done the survey.
- ❖ Date of Survey.
- ❖ Name & Signature of the Person/ Official who has (have) prepared and checked the plans.
- ❖ Scale.
- ❖ Name & Signature of J.E. , A.E. and Ex. Engr.
- ❖ Drawings No. (as recorded in the Drawing Register of the Division).
- ❖ North Line to be clearly indicated.
- ❖ Legend/Symbols should be indicated properly

**2.8.7 Building Envelope & Insulation**

The Building envelope building enclosure is the physical separator between the interior andthe exterior environments of a building. It serves as the outer shell to help maintain theindoor environment (together with the mechanical conditioning systems) and facilitate itsclimate control. Building envelope design is a specialized area of architectural functions ofthe building envelope

- ❖ Support
- ❖ Control
- ❖ Finish

The Control function is the core of good performance, rain control, air control, heat control, Control of air flow is important to ensure indoor air quality, control energy consumption, and avoid condensation and to provide comfort. Through components of the building envelope (interstitial) itself, as well as into and out of the interior space, affect building insulation , Hence air control includes the control of wind washing and convective loops.

Building envelopes – the location of buildings on their lot, their height and overall shapecan affect:-

- ❖ Neighborhood character.
- ❖ Sunlight to adjoining buildings.
- ❖ Open spaces.
- ❖ Privacy.
- ❖ Overlooking of other uses.
- ❖ The quality of spaces inside the building.
- ❖ The amenity and usability of private open spaces.
- ❖ The sense of pedestrian scale and amenity in nearby streets.

**2.8.7.1 Height and Massing**

Building height can reinforce an area's character. Appropriate building height is derived from local context, street conditions and character objectives for an area, specific design objectives. For example, the protection of view lines, the natural features of an area, or solar access to the public realm may be important objectives.

**2.8.7.2 Street Setbacks**

The setback of buildings from a street edge affects how uses relate to the public spaceof the street. Front setbacks, are also an important aspect, Setbacks add to the apparentbreadth of the adjoining street and provide space for plantings.

**2.8.7.3 Relationships to Adjoining Buildings**

The proximity of buildings to each other affects the amenity of spaces inside the building, the quality of space between buildings, visual and acoustic privacy and solar access to private and shared open spaces. The challenge is to provide appropriate separation between buildings to maximize light, air and outlook while meeting strategic planning goals and respecting neighborhood character.

**2.8.7.4 Views to and from Residential Units**

Views onto and across streets and other public spaces are encouraged. For these frontages,the design of each building (or the use of blinds or other screening devices) is to deal with issues of privacy. Views from one building into adjoining buildings are, generally notacceptable, and the design of new buildings is expected to limit intrusion into the privacyof existing properties. The location and design of buildings, and open spaces must becarefully orchestrated to maintain reasonable levels of privacy for adjacent development.

**2.8.7.5 Evaluation of Building Envelope**

“The area that separates conditioned space form unconditioned space or the outdoors. Abuilding envelope includes all components of a building that enclose conditioned space.
Building envelope components separate conditioned spaces from unconditioned spaces orfrom outside air.”

“A building envelop is the separation between the interior and the exterior environmentsof a building. It serves as the outer shell to protect the indoor environment as well as tofacilitate its climate control.”

**2.8.7.6 Improvement of Existing Building Envelope**

Reducing outside air infiltration into the building by improving building envelope tightnessis usually quite feasible, during re-roofing; extra insulation can typically be added withlittle difficulty.

Windows and insulation can be upgraded during more significant buildingimprovements and renovations.

Installing a system in a new building or upgrading the equipment in an existing structure, its optimal performance (and reduced energy demand) depends on a high- performancebuilding envelop. A tight, insulated shell including thermally efficient windows and doors,creates an environment that enables ultimate control of conditioned air and ventilationdemand and costs.

A radiant floor system, for instance geothermal or passive solar energy are hard to implementshort of gutting the place you call.

**2.8.7.7 Efficiency and Building Envelope**

U-factor measures heat loss form a window. The rate of loss given as the U-factor of afenestration assembly. The lower the number, the better the performance of the assembly,generally, those numbers ranges from 0.20 and 1.20. Most experts recommend that facilityexecutives seek out window assemblies with a U-factor lower than 0.35 in colder climates.

Solar Heat Gain (SHGC) measures how well limits radiant heat gain that is caused by sunlight. This radiation is transmitted directly to the occupied space and lessens the heatingload or increases the cooling load. The SHGC is expressed as a number between 0 and 1,and that fraction denotes how much radiation makes it into occupied space. As an example,a window with an SHGC of 0.35 would admit 35 percent of the radiant heat that hits thewindow and reflect 65 percent.Visible Transmittance is a metric that measures how much light – not heat – comesthrough a product, other worlds, this metric determines how clear the glass is. Fenestrationassemblies that reduce the visible transmittance the National Rating Council (NFRC), thevisible transmittance is expressed as a number between 0 and 1. The higher the number,the more light is transmitted.

**2.8.7.8 Walls and Roofing System**

Window assembly air leakage by a rating as the equivalent cubic feet of air passing through a square foot of window area – but it's also vitally important to determine heat loss throughopaque walls and roofing systems.Any roofing system is comprised, of two parts that affect energy efficiency roof materialand the insulation in the sub – roof assembly.

Reflectivity values are measured on a scale of 0 to 1. A reflectivity value of 0.0 indicatesthat the surface absorbs all solar radiation, and a 1.0 reflectivity value represents totalreflectivity.

**2.8.7.9 R Value**

All main building materials (be it walls, floor, ceiling, loft or roof components) have knownR-Values.

R-Value of a material can vary depending on the 'mode' of heat transfer you are tryingto block (radiant or conductive); so for different seasons it can be advantageous to usematerials with different qualities to suit whether you want to stop heat getting out (Winter)or heat getting in (Summer).

The higher the R-Value of a material the better an insulator it is, but this usually also implies higher costs. Also of importance is the degree of external temperature range need to deal with where you live.

**2.8.7.10 Passive Solar & R Value**

Value is quite important in passive solar building design, knowing the correct R-Values forthe external walls, floors and ceilings is key in working out what is termed 'Skin Losses'; i.e.amount of heat that gets lost from the passive solar building the surrounding environment.

The R-Value of a substance is its direct measure of its resistance to transferring energy orheat; R-Values are expressed using the metric units (m2.K/W). The higher the figure thebetter it is at resisting energy transfer, the easier it is to maintain a difference in temperaturesacross it for a longer time.

R-Value measures per meter squared the amount of degrees Kelvin temperature differencerequired to transfer one watt of energy. So an R-Value of 1 means per meter squared asingle degree difference will transfer one watt of energy. So an R-Value of 2 will transferhalf a watt of energy for a degree of difference.

**2.8.8 Architectural Planning**

An building must have flexible and technologically-advanced working environmentsthat are safe, healthy, comfortable, durable, aesthetically-pleasing, and accessible. It must beable to accommodate the specific space and equipment needs of the tenant. Special attention should be made to the selection of interior finishes and art installations, particularly in entry spaces rooms and other areas with access.

**2.8.9 Cost-Effective**

The high-performance office should be evaluated using life-cycle economic and materialevaluation models. To achieve the optimum performance value engineering provides ameans for assessing the performance versus cost of each design element and buildingcomponent. In the design phase building development, properly applied value engineeringconsiders alternative design solutions to optimize the expected cost/worth ratio of projectsat completion.

**2.8.10 Urban Planning**

The concentration of a large number of workers within one building can have a significantimpact on neighborhoods. Consideration of transportation issues must also be given whendeveloping office structures. Office buildings are often impacted by urban planning and municipal zoning, which attempt to promote compatible land use and vibrant neighborhoods.

**2.8.10.1** Consideration should be given when selecting office locations to the distance the majority of occupants will have to travel to reach the office.

**2.8.10.2** Once a building has been constructed and occupied, it is critical that long-term performance be confirmed through an aggressive process of metering, monitoring and reporting.

**2.8.11 Functional/Operational**

The building design must consider the integrated requirements of the intended department.This includes their desired image, degree of public access, operating hours, growthdemands, security issues and vulnerability assessment results, organization and group sizes, growth potential, long-term consistency of need, group assembly requirements, electronic equipment and technology requirements, acoustical requirements, special floor loading andfiling/storage requirements, special utility services, any material handling or operationalprocess flows, special health hazards, use of vehicles and types of vehicles used, andeconomic objectives.

**2.8.12 Flexibility**

The high-performance office must easily and economically accommodate frequentrenovation and alteration. These modifications may be due to management reorganization, personnel shifts, changes in business models, or the advent of technological innovation,but the office infrastructure, interior systems, and furnishings must be up to the challenge.

Consider raised floors to allow for easy access to cabling and power distribution, as wellas advanced air distribution capabilities to address individual occupant comfort.Incorporate features such as plug and-play floor boxes for power, data, voice and fiber, modular and harnessed wiring and buses, and conferencing hubs to allow for daily flexibility at work as well as future reorganization of office workstations.

**2.8.13 Productive**

Worker Satisfaction, Health, and Comfort of employees in a high-performance office are of paramount concern.

**2.8.13.1** Utilize strategies such as increased fresh air ventilation rates, the specification of nontoxic and low-polluting materials and systems, and indoor air quality monitoring.

**2.8.13.2** Provide individualized climate control that permits users to set their own, localized temperature, ventilation rate, and air movement preferences.

**2.8.13.3** Access to windows and view, opportunities for interaction, and control of one's immediate environment are some of the factors that contribute to improved workplace satisfaction.

**2.8.13.4** Natural light is important to the health and psychological well-being of office workers. The design of office environments must place emphasis on providing each occupant with access to natural light and views to the outside. A minimum of 100-150 LUX of diffused indirect natural light is desirable.

**2.8.13.5** The acoustical environment of the office must be designed and integrated with the other architectural systems and furnishings of the office. Special consideration must be given to noise control in open office settings, with absorptive finish materials, masking white noise, and sufficient separation of individual occupants.

**2.8.14 Technical Connectivity**

Technology has become an indispensable tool for business, industry, and education.Given that technology is consider the following issues when incorporating it, particularlyinformation technology (IT), into an office:

**2.8.14.1** Plan new office buildings to have a distributed, robust, and flexible IT infrastructure.

**2.8.14.2** During the planning stage, identify all necessary technological systems (e.g., voice/ cable/data systems such as audio/visual systems, speaker systems, Internet access, and Local Area Networks [LAN] / Wide-Area Networks [WAN] / Wireless Fidelity [WI-FI]), and provide adequate equipment rooms and conduit runs for them.

**2.8.14.3** Consider and accommodate for wireless technologies, as appropriate.

**2.8.14.4** For existing office buildings, consider improving access to the IT infrastructure as renovations are undertaken.

**2.8.15 Technical Tips For Roofs and Walls**

**2.8.15.1** Additional cost of insulation pays back in energy savings that result from correctly sizing the HVAC equipment to reduced cooling loads. Good insulation also extends the life of the roof system.

**2.8.15.2** Insulation of walls is important for reducing conduction losses especially where significant difference between inside and outside temperature. Many types of insulation are available, some that prevent air movement and moisture movement into and out of the conditioned space.

**2.8.15.3** Infiltration and exfiltration is the unwanted air movement through a building and is caused by a pressure difference (air move form high pressure to a lower pressure). Limiting air infiltration and exfiltration is key to improving energy efficiency.

**2.8.15.4** Optimize insulation by applying it to the outside of the wall components to minimize thermal bridging.

**2.8.16 Electrical Design**

The design of electrical systems in buildings is one of the important fields.Electrical engineer is responsible for the design of lighting systems and other low current systems such as fire alarm, CCTV, sound systems.Proper electric design shall be performed so that it serves the purpose for use of the building.

**2.8.17 Plumbing Design:**

A good design incorporates short runs between plumbing fixtures and uses state-of-the art materials. A plumbing design must include two systems: the system that supplies water and the system that gets rid of waste. The drain system also has vent stacks that allow drainpipes to breathe and move sewer waste through the sewer pipes. Proper Plumbing design shall be performed so that it serves the purpose.

**2.8.18 Mechanical, Fire and Life Safety**(Relevant Extract from NBC-2016)

**2.8.18.1 Fire Prevention**

❖ **Classification of Building Based on Occupancy**

All buildings, whether existing or hereafter erected shall be classified according to the use or the character of occupancy in one of the following groups:

| | |
|---|---|
| Group A | Residential |
| Group B | Educational |
| Group C | Institutional |
| Group D | Assembly |
| Group E | Business |
| Group F | Mercantile |
| Group G | Industrial |
| Group H | Storage |
| Group J | Hazardous |

❖ **Fire Zones**

The fire zones shall be made use of in land use development plan and shall be designatedas follows:

❖ **Fire Zone No. 1—** This shall comprise areas having residential (Group A), educational (Group B), institutional (Group C), and assembly (Group D), small business (Subdivisions E-1) and retail mercantile (Group F) buildings, or mess which are under development for such occupancies.
Buildings erected in Fire Zone No. 1 shall conform to construction of Type 1, 2, 3 or 4.

❖ **Openings in Separating Walls and Floors**

At the time of designing openings in separating walls and floors, particular attention shallbe paid to all such factors as will limit fire spread through these openings and maintain firerating of the structural member.

For Types 1 to 3 construction, a doorway or opening in a separating wall on any floor shallbe limited to 5.6 m2 in area with a maximum height /width of 2.75 m. Every wall openingshall be protected with fire-resisting doors having the fire rating of not less than 2 hr. Allopenings in the floors shall be protected by vertical enclosures extending above and belowsuch openings, the walls of such enclosures having a fire resistance of not less than 2 h.

Openings in walls or floors which are necessary to be provided to allow passages of allbuilding services like cables, electrical wirings, telephone cables, plumbing pipes, etc, shallbe protected by enclosure in the form of ducts/shafts having a fire resistance not less than2 h.

❖ **Vertical Opening**

Every vertical opening between the floors of a building shall be suitably enclosed orprotected, as necessary, to provide the following:

❖ Reasonable safety to the occupants while using the means of egress by preventing spread of fire, smoke, or fumes through vertical openings from floor to floor to allow occupants to complete their use of the means provide a clear height of 2 100 mm in the passage/escape path of the occupants.

❖ **Fire Stop or Enclosure of Openings**

Where openings are permitted, they shall not exceed three-fourths the area of the wallin the case of an external wall and they shall be protected with fire resisting assembliesor enclosures having a fire resistance equal to that of the wall or floor in which these aresituated.

❖ **Air-conditioning and Ventilation**

Air-conditioning and ventilating systems shall be so installed and maintained as to minimizethe danger of spread of fire, smoke or fumes from one floor to other or from outside toany occupied building. Air-conditioning and ventilating systems circulating air to more than one floor or fire areashall be provided with dampers designed to close automatically in case of fire.

❖ **Arrangement of Exits**

Exits shall be so located that the travel, distance on the floor shall not exceed the distancegiven in relevant IS codes.The travel distance to an exit from the dead end of a corridor shall not exceed half thedistance specified.

**2.8.18.2 Building Services-HVAC**

❖ **Heating, Ventilation and Air Conditioning**

HVAC systems have a significant effect on the health, comfort, and productivity ofoccupants. Issues like user discomfort, improper ventilation, and poor indoor air qualityare linked to HVAC system design and operation and can be improved by better mechanicaland ventilation system design.

❖ **Factors Affecting Thermal Comfort**

Thermodynamic processes take place between the human body and the surroundingthermal environment. Our perception of thermal comfort and acceptance of indoorthermal environment is a result of the heat generated by metabolic processes and theadjustments that the human body makes to achieve a thermal balance between our bodyand the environment.

❖ **Determining Loads**

Projected load for new buildings can be analyzed accurately by using Computer Simulation.Hourly simulation models designed for energy analysis, calculate hourly cooling loads fromdetailed building geometry, scheduling, and equipment data.

❖ **Types of Air-Conditioning Systems**

There are 4 primary types of heating and cooling systems: split systems, hybrid systems, ductfreesplit systems and packaged systems.

❖ **Room and Split Air-Conditioners**

Room air-conditioners cool rooms ratherthan the building. They provide cooling onlywhen needed Room air-conditioners areless expensive to operate than central units,even though their efficiency is generallylower than that of central air-conditioners.

In a split-system central air-conditioner,an outdoor metal cabinet contains thecondenser and compressor, and an indoor cabinet contains the evaporator. In many splitsystemair-conditioners, this indoor cabinet also contains a furnace or the indoor part ofheat pump.

❖ **Packaged Air-Conditioners**

In packaged air-conditioners, the evaporator, condenser, and compressor are all located inone cabinet, which usually is placed on a roof or on a concrete slab adjacent to the building.This type of air-conditioner is typical in small commercial buildings and also in residential buildings. Air supply and return ducts come from indoors through the building's exteriorwall or roof to connect with the packaged air-conditioners, which is usually locatedoutdoors. This combination of air-conditioner and central heater eliminates the need for aseparate furnace indoor.

❖ **Central Air-Conditioners**

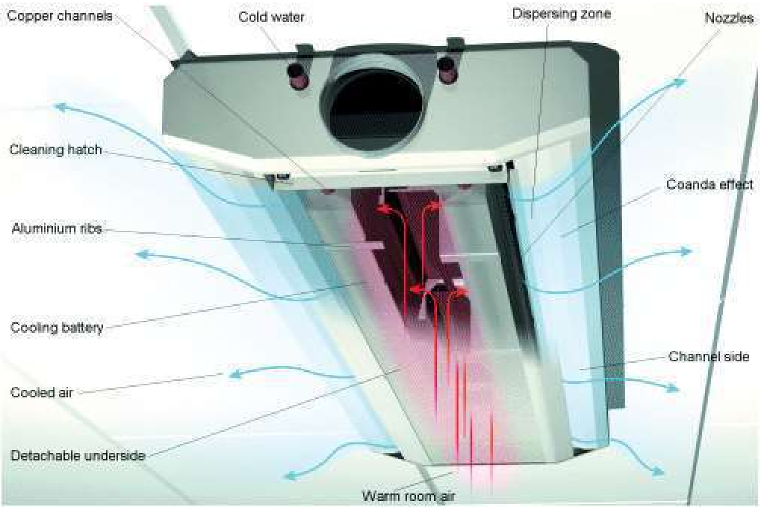
In central air-conditioning systems, cooling is generated in a chillers and distributed to airhandlingunits or fan-coil units with a chilled water system. This category includes systemswith air-cooled chillers as well as systems with cooling towers for heat rejection

❖ **VRV Air Conditioning System**

VRV is a multi and direct expansion type air conditioning system that one outdoor unit canbe connected with multiples of indoor units. The amount of refrigerant can be changed freely according to the load in the indoor unit because inverter compressor is used in the outdoor unit. Zoning in a small office is easily made possible with indoor unit whoseminimum capacity is very small. Energy conservation is easily handled because individualindoor unit can stop and start its operation as needed.

❖ **Chilled Beam**

Chilled beams are predominantly used for cooling and ventilating spaces, where a goodindoor environment and individual space control is valued. Chilled beams use water toremove heat from a room and are located in the room space. Chilled beams are primarilyused in locations where the humidity can be controlled.Chilled beams provide excellent thermal comfort, energy conservation and efficient useof space due to high heat capacity of water used as heat transfer medium. Chilled beamoperation is simple and trouble free due to having minimum maintenance requirements.Chilled beam also supplement the flexible use of available space, at the same time as thehigh temperature cooling and low temperature heating maximizing the opportunity for freecooling and heating. Operation of the chilled beams is used where the internal humidityloads are moderate, the primary air is dehumidified and any infiltration through the building is limited and controlled.



#### 2.8.19 Barrier Free Parameters

To accommodate the persons with disabilities and elderly, each building and its siteshould be planned and designed as an integral unit from the very beginning of the designprocess. Few integral components of the building design can be planned following theseconsiderations.

#### 2.8.19.1 Kerb Ramp

- ❖ Width should not be less than 1200mm
- ❖ Useful for a smooth transition.
- ❖ Footpath flushed with roadway, at a gradient not exceeding that 1:12.
- ❖ Warning strip to be provided on the kerb side edge of the slope.

#### 2.8.19.2 Foothpath

- ❖ Obstruction-free for the convenience of all users.
- ❖ Height of the footpath not to be more than 150 mm form the road level.
- ❖ Change in level on the footpath should be made clearly visible.
- ❖ Width of the footpath should 1800 mm and minimum clear unobstructed path should be 1200 mm.
- ❖ Street furniture should be placed outside the path of travel.
- ❖ Resting Places should be provided along travel routes.
- ❖ Protruding elements should be avoided.
- ❖ Bollards should be 1000 mm high, painted in contrasting color stripes with clear minimum gap of 1200 mm.

#### 2.8.19.3 Parking

- ❖ Parking should be within 30 meters of the main entrance the building.
- ❖ Two accessible parking lots with dimension 3600mm X 5000mm.
- ❖ International symbol of accessibility painted on the ground and also on a signpost/ board.
- ❖ Directional signs guiding people to the accessible parking.
- ❖ Wheel stoppers to be provided.

#### 2.8.19.4 Ramps

- ❖ Gentle slope: 1:12 max. 1800 x 1800 landing after 9m of travel distance.
- ❖ Width: 1800mm or more.
- ❖ Handrails to be on both sides and at two levels – 760mm and 900mm. Extend 300mm beyond top and bottom of ramp.
- ❖ Warning tile should be placed at 300mm before and the ramp edges.

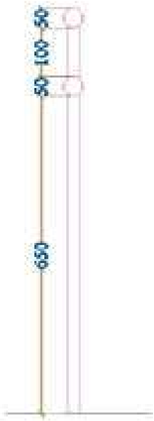
#### 2.8.19.5 Steps and Stairs

- ❖ Uniform risers: 150mm and tread: 300mm.
- ❖ Stair edges should have 50mm wide, bright/ contrast color band.
- ❖ Maximum height of a flight between landings to be 1200mm.
- ❖ Landing should be 1200mm clear of any door swing.
- ❖ The steps should have an unobstructed width of at least 1200mm.
- ❖ Continuous handrails on both sides including the wall (if any) and at two levels – 760mm and 900mm.
- ❖ Warning tile to be placed 300mm at the beginning and at the end of all stairs.
- ❖ Nosing should be avoided.

**2.8.19.6 Handrails**

Handrails/ Grab bars are extremely important features and must be designed to be easy tograsp and to provide a firm and comfortable grip so that the hand can slide along the railwithout obstruction.

Handrails should be circular with a diameter of 38mm, at least 50mm clear two levels – 760mm and 900mm form the finished floor, extend by at least 300mm.




Section of A Railing


Grab Bar Fixed on Wall

Grab bars should: -

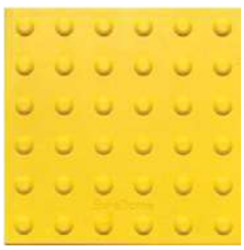
- ❖ Be slip-resistant with round ends;
- ❖ Have a circular section of 38-50 mm in diameter;
- ❖ Be free of any sharp or abrasive elements;
- ❖ Have continuous gripping surfaces, without interruptions or obstructions that can break a hand hold;
- ❖ Have a minimum clear space of 50 mm from the wall;
- ❖ Be installed at a height of 760 mm to 900 mm

**2.8.19.7 Tactile Surface**

❖ **Line-type blocks (Guiding tile):** indicate the correct path/ route to follow.

❖ **Dot-type blocks (Warning Tile):** indicate warning signal, to screen off obstacles, drops – offs or other hazards, to discourage movement in an incorrect direction and to warn of a corner or junction. These tiles shall be placed 300mm at the beginning and end of the ramps, stairs and entrance to any door.

Guiding Block



Warning Block

**2.8.19.8 Circulation Area**

- ❖ Corridors should have an unobstructed width of 1800mm.
- ❖ Level differences should be beveled.

- ❖ Thresholds and gratings should not be more that 10mm.
- ❖ Protruding objects (more that 100mm form the wall) to be placed either in a niche or above 2100mm form the floor.
- ❖ Open spaces below ramps, escalator and stairs should be blocked out completely by protective guard rails, raised curbs or marked with a tactile surface.

**2.8.19.9 Door**

- ❖ Should provide a clear opening of 900mm.
- ❖ Be fitted with lever action locks and D shape handles of circular section, between800mm and 1000mm form floor level.
- ❖ Also be fitted with vision panels at least between 900mm and 1500mm form floor level.
- ❖ Be colour contrasted with the surrounding walls and should not be heavier than 22N to open.
- ❖ A distance of 400mm to 600mm should be provided beyond the leading edge of door to enable a wheelchair user to maneuver and to reach the handle.
- ❖ Kick plates are recommended 300mm form the bottom, to resist wear and tear.

**2.8.19.10 Accessible Toilet**

A minimum of one toilet compartment with minimum size of 2000 x 1750mm is requiredon each floor having all barrier free provisions.

**2.8.19.11 Accessible Lift**

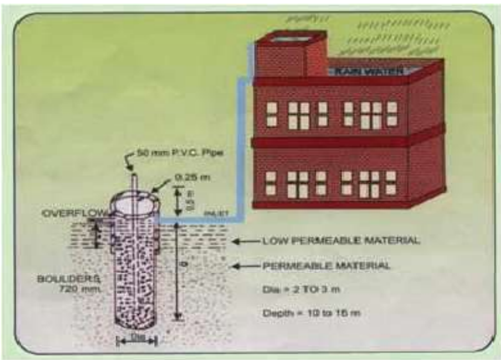
A minimum of one 13 passenger lift is required having all barrier free provision.

**2.8.20 Rain Water Harvesting**

Water conservation has become the need of the day. Rainwater harvesting is a way tocapture the rainwater at the time of downpour, recharge the underground water and use it later. In urban areas, the construction of houses, roads and footpaths has left little exposedparts of earth for water to soak in. Most of the water, therefore, runs wastefully throughdrains.

Rainwater harvesting has become a very popular method of conserving water, particularlyin the urban areas. It conserves water as a valuable source and stops it from running off wastefully as sewerage water. It recharges the aquifers or the reservoirs of water belowthe surface of the earth, thus raising the level of underground water table. This is highlybeneficial for trees and other vegetation cover which draw mainly from underground water.

- ❖ Since June 2001, the Ministry of Urban affairs and Poverty Alleviation has made rain water harvesting mandatory in all new buildings with a roof area of more than 100 sq m and in all plots with an area of more than 1000 sqm, that are being developed.
- ❖ The Central Ground Water Authority (CGWA) has made rainwater harvesting mandatory in all institutions.



## 2.9 Ductile Design and Detailing of Reinforced Concrete Structures Subjected to Seismic Forces

### 2.9.1 TERMINOLOGY

For the purpose of this standard, the following definitions shall apply.

- Beams — These are members (generally horizontal) of moment resisting frames with flexural and shearing actions.
- Boundary Elements — These are portions along the ends of a structural wall that are strengthened by longitudinal and transverse reinforcement. They may have the same thickness as that of the wall web.
- Columns — These are members (generally vertical) of moment resisting frames with axial, flexural and shearing actions.
- Cover Concrete — It is that concrete which is not confined by transverse reinforcement.
- Transverse Reinforcement — It is a continuous bar having a 135° hook with an extension of 6 times diameter (but not < 65 mm) at one end and a hook not less than 90° with an extension of 6 times diameter (but not < 65 mm) at the other end. The hooks shall engage peripheral longitudinal bars. In general, the 90° hooks of two successive crossties engaging the same longitudinal bars shall be alternated end for end. Transverse reinforcement (also called hoops) in columns is typically called stirrups and that in beams is called cross-ties.
- Gravity Columns in Buildings — It is a column, which is not part of the lateral load resisting system and designed only for force actions (that is, axial force, shear force and bending moments) due to gravity loads. But, it should be able to resist the gravity loads at lateral displacement imposed by the earthquake forces.
- Lateral Force Resisting System — It is that part of the structural system which participates in resisting forces induced by earthquake.
- Moment-Resisting Frame — It is a three- dimensional structural system composed of interconnected members, without structural walls, so as to function as a complete self-contained unit with or without the aid of horizontal diaphragms or floor bracing systems, in which the members resist gravity and lateral forces primarily by flexural actions.
- Special Moment Resisting Frame (SMRF) — It is a moment-resisting frame specially detailed to provide ductile behavior.
- Ordinary Moment Resisting Frame (OMRF) — It is a moment-resisting frame not meeting special detailing requirements for ductile behaviour.
- Link — It is a single steel bar bent into a closed loop having a 135° hook with an extension of 6 times diameter (but not < 65 mm) at each end, which is embedded in the confined core of the section, and placed normal to the longitudinal axis of the RC beam or column.
- Shear Wall (also Called Structural Wall) — It is a vertically oriented planar element that is primarily designed to resist lateral force effects (axial force, shear force and bending moment) in its own plane.
- Special Shear Wall : It is a structural wall meeting special detailing requirements for ductile behavior.

### 2.9.2 SYMBOLS

For the purpose of this standard, the following letter symbols shall have the meaning indicated against each; where other symbols are used, they are explained at the appropriate place. All dimensions are in millimetre, loads in Newton and stresses in MPa, unless otherwise specified.

Ae = Effective cross sectional area of a joint

Aej = Effective shear area of a joint

Ag = Gross cross-sectional area of column, wall

Ah = Horizontal reinforcement area within spacing Sv

Ak = Area of concrete core of column

Asd = Reinforcement along each diagonal of coupling beam

Ash = Area of cross section of bar forming spiral or link

Ast = Area of uniformly distributed vertical reinforcement

Av = Vertical reinforcement at a joint

bb = Width of beam

bc = Width of column

bj = Effective width of a joint

D = Overall depth of beam

Dk = Diameter of column core measured to the outside of spiral or link

d = Effective depth of memberdb = Diameter of longitudinal bar

dw = Effective depth of wall section

Es = Elastic modulus of steel

fck = Characteristic compressive strength of concrete cube

fy = Yield stress of steel reinforcing bars, or 0.2 percent proof strength of reinforcing steel

h = Longer dimension of rectangular confining link measured to its outer face

hc = Depth of column

hj = Effective depth of a joint

hst = Clear storeys height

hw = Overall height of RC structural wall

LAB= Clear span of beam

Ld= Development length of bar in tension

lo = Length of member over which special confining reinforcement is to be provided

Lw = Horizontal length of wall/longer cross- section dimension of wall

Ls = Clear span of couplings beam

Mu = Design moment of resistance of entire RC beam, column or wall section

Mct = Design moment of resistance of top column at a joint

Mcb = Design moment of resistance of bottom column at a joint

Mbl = Design moment of resistance of left beam at a joint

Mbr = Design moment of resistance of right beam at a joint M Ah = Hogging design moment of resistance of beam at end A

M As = Sagging design moment of resistance of beam at end A

M Bh = Hogging design moment of resistance beam at end B

$M_{Bs\ u}$ = Sagging design moment of resistance of beam at end B

$M_{BLu}$ = Design moment of resistance of beam framing into column from the left

$M_{BR}$ Design moment of resistance of beam framing into column from the right

Muw = Design moment of resistance of web of RC structural wall alone

Pu = Factored axial load

Sv = Spacing of links along the longitudinal direction of beam or column

Tw = Thickness of web of RC structural wall

$V_u$ D+L = Factored shear force demand at end A of beam due to dead and live loads

$V_u$ D+L = Factored shear force demand at end B of beam due to dead and live loads

V j = Design shear resistance of a joint Vu = Factored shear force

Vus = Design shear resistance offered at a section by steel links

xu,x* = Depth of neutral axis from extreme compression fibre

$\alpha$ = Inclination of diagonal reinforcement in coupling beam

$\rho$ = Area of longitudinal reinforcement as a fraction of gross area of cross-section in a RC beam, column or structural wall

$\rho_c$ = Area of longitudinal reinforcement on the compression face of a beam as a fraction of gross area of cross-section

$(\rho_h)_{min}$= Minimum area of horizontal reinforcement of a structural wall as a fraction of gross area of cross-section

$(\rho_{v,be})_{min}$ = Minimum area of vertical reinforcement in each boundary element of a structural wall as a fraction of gross area of cross-section of each boundary element

$(\rho_{v,net})_{min}$ = Minimum area of vertical reinforcement of a structural wall as a fraction of gross area of cross-section of the wall

$(\rho_{v,\ web})_{min}$ = Minimum area of vertical reinforcement in web of a structural wall as a fraction of gross area of cross-section of web gross area of cross-section of web

$\rho_{max}$ = Maximum area of longitudinal reinforcement permitted on the tension face of a beam as a fraction of gross area of cross-section

$\rho_{min}$ = Minimum area of longitudinal reinforcement to be ensured on the tension face of a beam as a fraction of gross area of cross-section

$\tau_c$ = Design shear strength of concrete

$\tau_{c,\ max}$ = Maximum nominal shear stress permitted at a section of RC beam, column or structural

wall

$\tau_v$ = Nominal shear stress at a section of RC beam, column or structural wall

### 2.9.3 GENERAL SPECIFICATIONS

The design and construction of reinforced concrete buildings shall be governed by provisions of IS 456, except as modified by the provisions of this standard for those elements participating in lateral force resistance

Minimum grade of structural concrete shall be M20, but M25 for buildings,

a) more than 15 m in height in Seismic Zones III, IV and V;
b) but not less than that required by IS 456 based on exposure conditions.

Steel reinforcement resisting earthquake-induced forces in RC frame members and in boundary elements of RC structural walls shall comply with 3.69., 3.70and 3.71.

Steel reinforcements used shall be,

c) of grade Fe 415 or less (conforming to IS 1786); and
d) of grade Fe 500 and Fe 550, that is; high strength deformed steel bars produced by thermo-mechanical treatment process having elongation more than 14.5 percent, and conforming to IS 1786

The actual 0.2 percent proof strength of steel bars based on tensile test must not exceed their characteristic 0.2 percent proof strength by more than 20 percent.

The ratio of the actual ultimate strength to the actual 0.2 percent proof strength shall be at least 1.15.

In RC frame buildings, lintel beams shall preferably not be integrated into the columns to avoid short column effect. When integrated, they shall be included in the analytical model for structural analysis. Similarly, plinth beams (where provided), and staircase beams and slabs framing into columns shall be included in the analytical model for structural analysis.

RC regular moment-resisting frame buildings shall have planar frames oriented along the two principal plan directions of buildings. Irregularities listed in IS 1893 (Part 1) shall be avoided. Buildings with any of the listed irregularities perform poorly during earthquake shaking; in addition, buildings with floating columns and set-back columns also perform poorly. When any such irregularities are adopted, detailed nonlinear analyses shall be performed to demonstrate that there is no threat to loss of life and property.

### 2.9.4 BEAMS

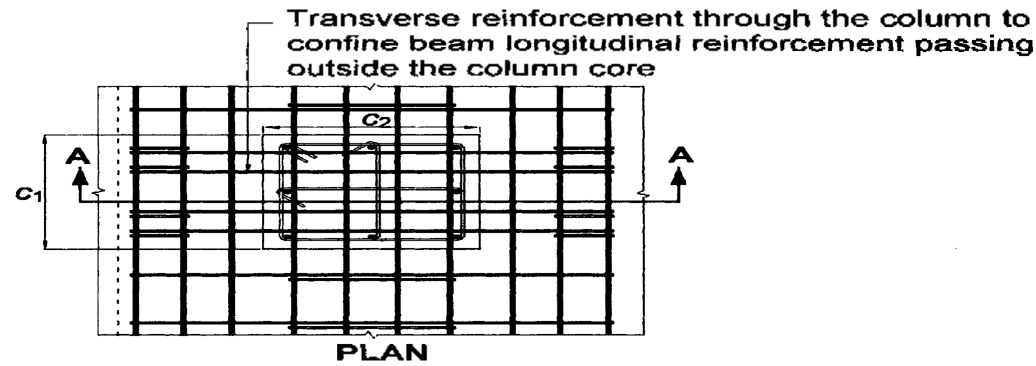
A. General

Requirements of this section shall apply to beams resisting earthquake-induced effects, in which the factored axial compressive stress does not exceed 0.08 fck. Beams, in which the factored axial compressive stress exceeds 0.08 fck, shall be designed as per requirements of 4.

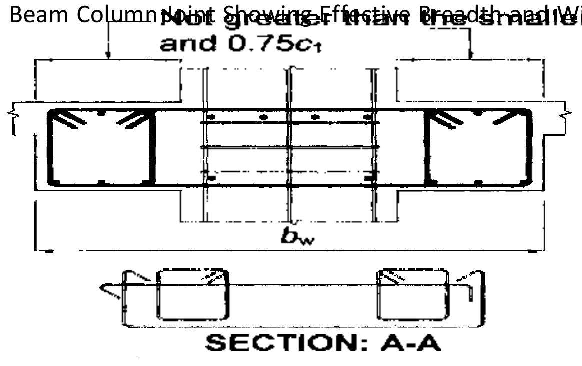
- Beams shall preferably have width-to-depth ratio of more than 0.3.
- Beams shall not have width less than 200 mm.
- Beams shall not have depth D more than 1/4th of clear span. This may not apply to the floor beam of frame staging of elevated RC water tanks.
- Width of beam bw shall not exceed the width of supporting member c2 plus distance on either side of supporting member equal to the smaller of (a) and (b)

a) Width of supporting member, c2

b) 0.75 times breadth of supporting member, c1 (see Fig. 1A and Fig. 1B)




1A Plan View of a Beam Column Joint Showing Effective Breadth and Width of Joint




1B Maximum Effective Width of Wide Beam and Required Transverse Reinforcement

**FIG. 1 BEAM COLUMN JUNCTIONS**

Transverse reinforcement for the width of a beam that exceeds width of the column c2 shall be provided as shown in Fig. 1B throughout the beam span including within the beam column joint

Longitudinal Reinforcement

The longitudinal reinforcement in beams shall be as given below:

a) Beams shall have at least two 12 mm diameter bars each at the top and bottom faces.

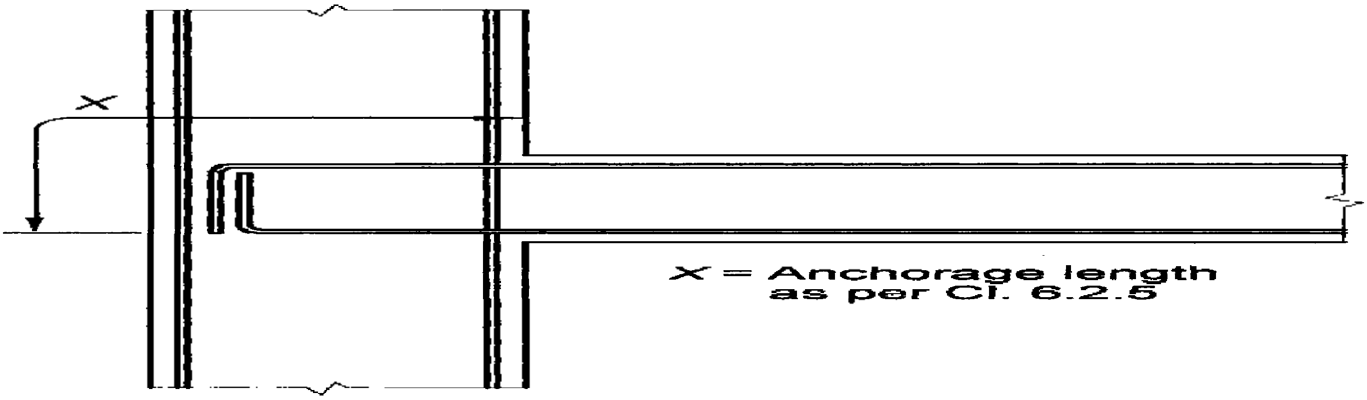
b) Minimum longitudinal steel ratio pmin required on any face at any section is:

$$\rho_{min} = 0.24 \frac{\sqrt{f_{ck}}}{f_y}$$

Maximum longitudinal steel ratio pmax provided on any face at any section is 0.025.

- Longitudinal steel on bottom face of a beam framing into a column (at the face of the column) shall be at least half the steel on its top face at the same section. At exterior joints, the anchorage length calculation shall consider this bottom steel to be tension steel.
- Longitudinal steel in beams at any section on top or bottom face shall be at least 1/4th of longitudinal steel provided at the top face of the beam at the face of the column; when the top longitudinal steel in the beam at the two supporting column faces is different, the larger of the two shall be considered.
- At an exterior joint, top and bottom bars of beams shall be provided with anchorage length beyond the inner face of the column, equal to development length of the bar in tension plus 10 times bar diameter minus the allowance for 90° bends (see Fig. 2).

FIG. 2 ANCHORAGE OF LONGITUDINAL BEAM BARS ATEXTERIOR BEAM-COLUMN JOINT




Splicing of Longitudinal Bars

Lap splices

When adopted, closed links shall be provided over the entire length over which the longitudinal bars are spliced. Further,

a) the spacing of these links shall not exceed 150 mm (see Fig. 3).

b) the lap length shall not be less than the development length of the largest longitudinal reinforcement bar in tension.

c) lap splices shall not be provided,

1) within a joint ;

d) within a distance of 2d from face of the column; and

e) within a quarter length of the beam adjoining the location where flexural yielding may occur under earthquake effects.

a. not more than 50 percent of area of steel bars on either top or bottom face shall be spliced at any one section.

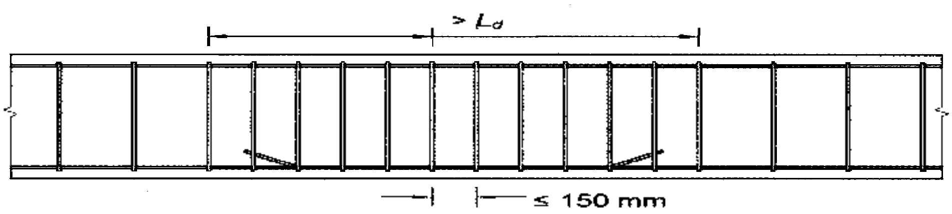



FIG. 3 LAP LENGTH AT LOCATION OF SPLICING OFLONGITUDINAL BARS IN BEAM

### 2.9.4.1 Mechanical couplers

Mechanical couplers (conforming to IS 16172) shall be used when longitudinal steel bars have to be continued for beam spans larger than their manufactured lengths. Further,

a) only those mechanical splices conforming to the above code and capable of developing the specified tensile strength of spliced bar shall be permitted within a distance equal to two times the depth of the member from the member face or in any location where yielding of reinforcement is likely to take place; and

b) the spacing between adjacent longitudinal bars shall be based also on the outer size of the coupler to allow easy flow of concrete.

c)

### 2.9.4.2 Welded splices

a) Welded splices shall not be used in beams for a distance equal to two times the depth of the member from the member face or in any location where yielding of reinforcement is likely to take place. At any location, not more than 50 percent of area of steel bars shall be spliced at any one section.

b) Welding of links, ties, inserts or other similar elements to vertical reinforcement bars required as per design is not permitted, in any seismic zone

### 2.9.4.3 Transverse Reinforcement

. Only vertical links shall be used in beams (see Fig. 4A); inclined links shall not be used. And

a) in normal practice, a link is made of a single bent bar. But, it may be made of two bars also, namely a U-link with a 135° hook with an extension of 6 times diameter (but not less than 65 mm) at each end, embedded in the core concrete, and a cross-tie (see Fig. 4B).

b) the hooks of the links and cross-ties shall engage around peripheral longitudinal bars. Consecutive crossties engaging the same longitudinal bars shall have their 90°hooks at opposite sides of the beam. When the longitudinal reinforcement bars are secured by cross-ties in beams that have a slab on one side, the 90° hooks of the cross-ties shall be placed on that side.

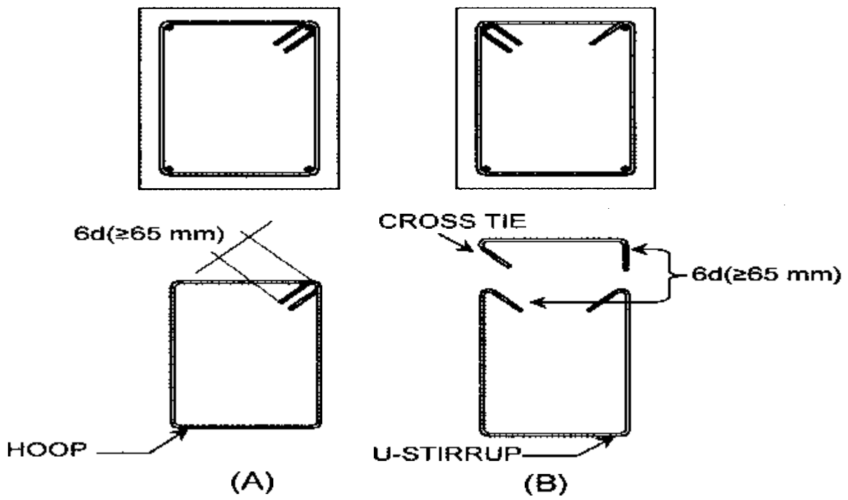



FIG. 4 DETAILS OF TRANSVERSE REINFORCEMENT IN BEAMS

The minimum diameter of a link shall be 8 mm
Shear force capacity of a beam shall be more than larger of,

a) factored shear force as per linear structural analysis; and

b) factored gravity shear force, plus equilibrium shear force when plastic hinges are formed at both ends of the beam.

1) For sway to right:

$$V_{u,a} = V_{u,a}^{D+L} - 1.4 \frac{M_u^{As} + M_u^{Bh}}{L_{AB}} \quad \text{and}$$

$$V_{u,b} = V_{u,b}^{D+L} + 1.4 \frac{M_u^{As} + M_u^{Bh}}{L_{AB}} .$$

2) For sway to left:

$$V_{u,a} = V_{u,a}^{D+L} - 1.4 \frac{M_u^{Ah} + M_u^{Bs}}{L_{AB}} \quad \text{and}$$

$$V_{u,b} = V_{u,b}^{D+L} + 1.4 \frac{M_u^{Ah} + M_u^{Bs}}{L_{AB}}$$

where $M_u^{As}$, $M_u^{Ah}$, $M_u^{Bs}$ and $M_u^{Bh}$ are sagging and hogging moments of resistance of the beam section at ends A and B, respectively. These shall be calculated as per IS 456. $L_{AB}$ is clear span of the beam. $V_{u,a}^{D+L}$ and $V_{u,b}^{D+L}$ are the factored shear forces at ends A and B, respectively, due to vertical loads acting on the span; the partial safety factor for dead and live loads shall be 1.2, and the beam shall be considered to be simply supported for this estimation.

The design shear force demand at end A of the beam shall be the larger of the two values of Vu,a computed above. Similarly, the design shear force demand at end B shall be the larger of the two values of Vu,b computed above.

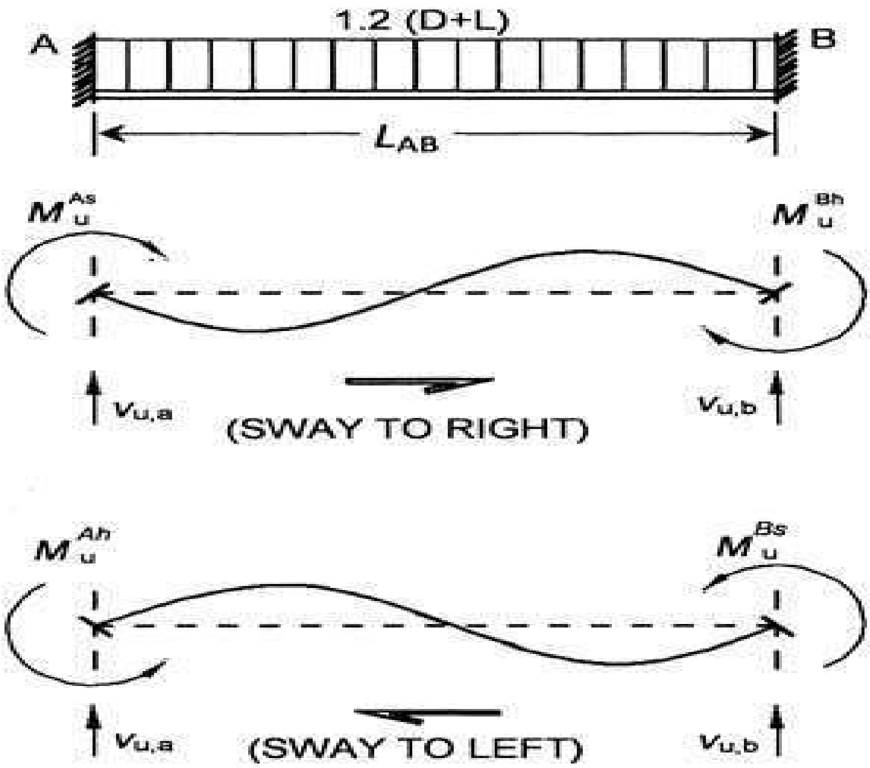



FIG. 5 CALCULATION OF DESIGN SHEAR FORCE DEMAND ON BEAMS UNDER PLASTIC HINGE ACTION AT THEIR ENDS

In the calculation of design shear force capacity of RC beams, contributions of the following shall not be considered:

a) Bent up bars
b) Inclined links, and
c) Concrete in the RC section.

#### 2.9.4.4 Close Spacing of Links

Spacing of links over a length of 2d at either end of a beam shall not exceed,

c) d/4;
b) 8 times the diameter of the smallest longitudinal bar; and
c) 100 mm (see Fig. 6).

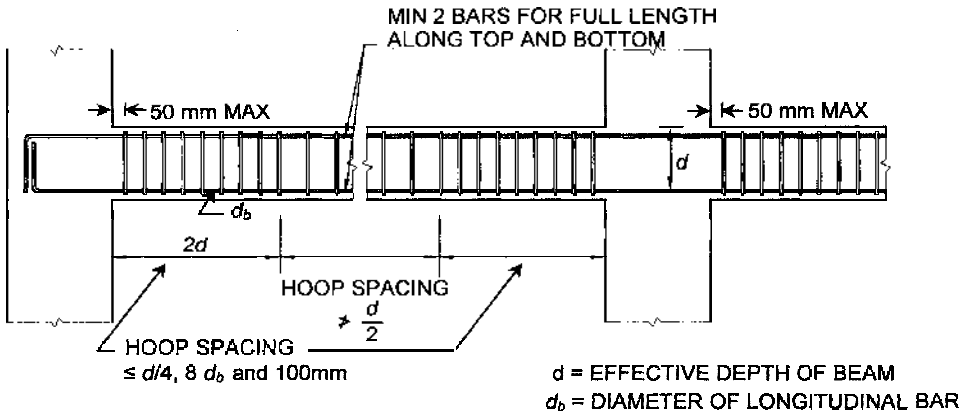



FIG. 6 DETAILS OF TRANSVERSE REINFORCEMENT IN BEAMS

The first link shall be at a distance not exceeding 50 mm from the joint face.

Closely spaced links shall be provided over a length equal to 2d on either side of a section where flexural yielding may occur under earthquake effects. Over the remaining length of the beam, vertical links shall be provided at a spacing not exceeding d/2.

### 2.9.5 COLUMNS AND INCLINED MEMBERS

#### 2.9.5.1 Geometry

Requirements of this section shall apply to columns and inclined members resisting earthquake-induced effects, in which the factored axial compressive stress due to gravity and earthquake effects exceeds 0.08 fck. The factored axial compressive stress considering all load combinations relating to seismic loads shall be limited to 0.40 fck in all such members, except in those covered in 8.

For various shapes of columns other than rectangular and circular like ‘T' shaped, ‘X' shaped, etc., appropriate designs and detailing shall be carried out using specialist literature where such columns are part of lateral load resisting systems.

The minimum dimension of a column shall not be less than,

a) 20 db, where db is diameter of the largest diameter longitudinal reinforcement bar in the beam passing through or anchoring into the column at the joint, or

b) 300 mm (see Fig. 7).

The cross-section aspect ratio (that is, ratio of smaller dimension to larger dimension of the cross- section of a column or inclined member) shall not be less than 0.45. Vertical members of RC buildings whose cross-section aspect ratio is less than 0.4 shall be designed as per requirements of 9.

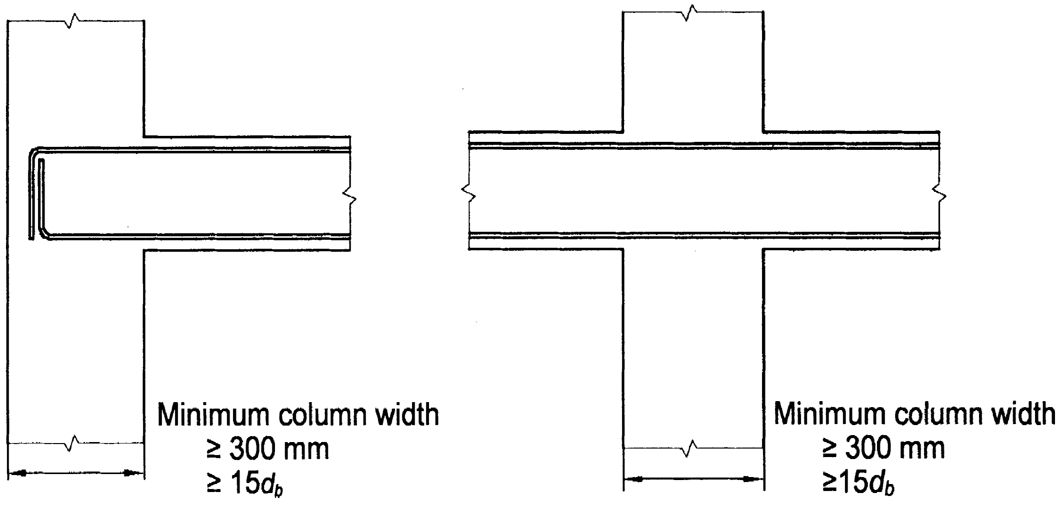



FIG. 7 MINIMUM SIZE OF RC COLUMNS BASED ON DIAMETER OF LARGEST LONGITUDINAL REINFORCEMENT BAR IN BEAMS FRAMING INTO IT

### 2.9.5.2 Relative Strengths of Beams and Columns at a Joint

At each beam-column joint of a moment-resisting frame, the sum of nominal design strength of columns meeting at that joint (with nominal strength calculated for the factored axial load in the direction of the lateral force under consideration so as to give least column nominal design strength) along each principal plane shall be at least 1.4 times the sum of nominal design strength of beams meeting at that joint in the same plane (see Fig. 8).

In the event of a beam-column joint not conforming to above, the columns at the joint shall be considered to be gravity columns only and shall not be considered as part of the lateral load resisting system.

The design moments of resistance of a beam shall be estimated based on the principles of mechanics and the limiting strain states of the limit state design method enunciated in IS 456. The design moment of the design moment of resistance of a column shall be estimated as in case of beams corresponding to zero axial force on the design P-M interaction diagram.

This check shall be performed at each joint for both positive and negative directions of shaking in the plane under consideration. Further, in this check, design moments of resistance in beam(s) meeting at a joint shall be considered in the same direction, and similarly the design moments of resistance of column(s) at the same joint shall be considered to be in the direction opposite to that of the moments in the beams.

This check shall be waived at all joints at roof level only, in buildings more than 4 storeys tall.

The provisions of 4.1.3 are not applicable for flat slab structures.

Longitudinal Reinforcement

Circular columns shall have minimum of 6 bars.

Splicing of Longitudinal Bars

Lap splices

When adopted, closed links shall be provided over the entire length over which the longitudinal bars are spliced. Further

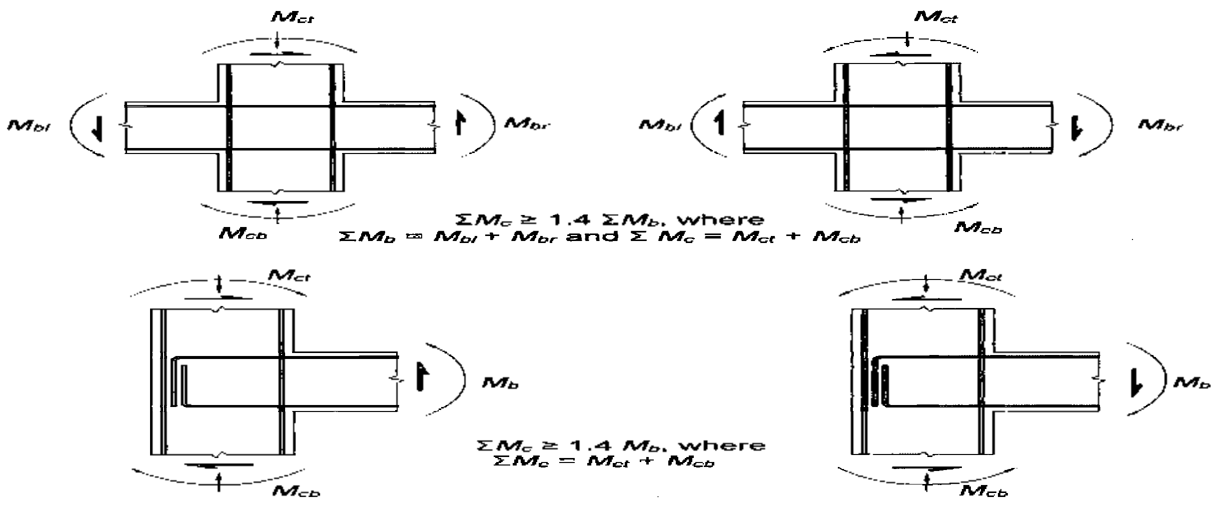



FIG. 8 STRONG COLUMN – WEAK BEAM REQUIREMENT

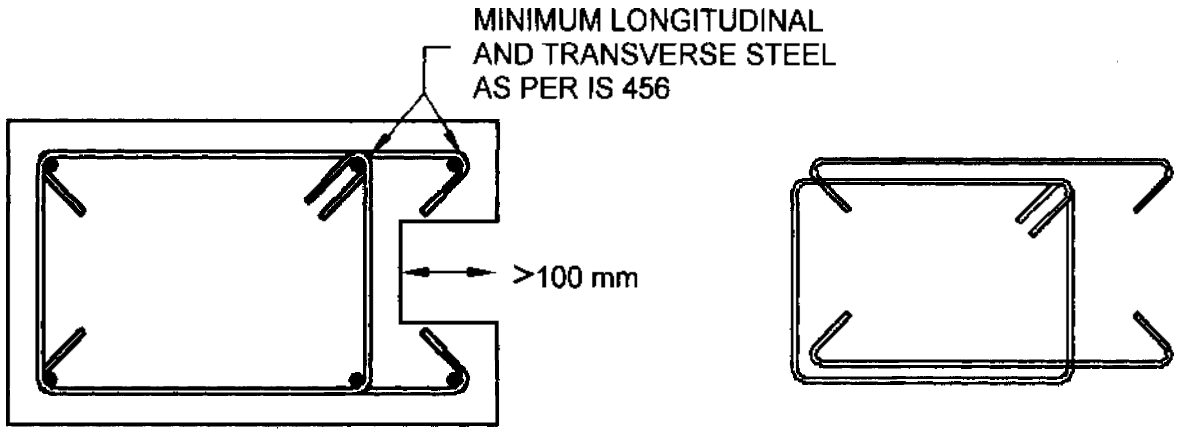



FIG. 9 REINFORCEMENT REQUIREMENT IN COLUMNS WITH PROJECTION MORE THAN 100 MM BEYOND CORE

a) the spacing of these links shall not exceed 100 mm.
b) the lap length shall not be less than the development length of the largest longitudinal reinforcement bar in tension.
c) lap splices shall be provided only in the central half of clear column height, and not
1) within a joint, or
2) within a distance of 2d from face of the beam.
d) not more than 50 percent of area of steel bars shall be spliced at any one section.
e) lap splices shall not be used for bars of diameter larger than 32 mm for which mechanical splicing shall be adopted.

### 2.9.5.3 Mechanical couplers

Mechanical couplers (conforming to IS 16172) shall be used. Further, only those mechanical splices conforming to the above standard and capable of developing the specified tensile strength of spliced bar shall be permitted within a distance equal to two times the depth of the member from the column face in any location where yielding of reinforcement is likely to take place.

### 2.9.5.4 Welded splices

Welded splices shall not be used in columns for a distance equal to two times the depth of the member from the member face or in any location where yielding of reinforcement is likely to take place. At any location, not more than 50 percent of area of steel bars shall be spliced at any one section. But, welding of links, ties, inserts or other similar elements to vertical reinforcement bars required as per design is not permitted, in any seismic zone.

A column that extends more than 100 mm beyond the confined core owing to architectural requirement (see Fig. 9) shall be detailed in the following manner:

a) When the contribution of this area is considered in the estimate of strength of columns, it shall have at least the minimum longitudinal and transverse reinforcement given in this standard.

b) When the contribution of this area is not considered in the estimate of strength of columns, it shall have at least the minimum longitudinal and transverse reinforcement given in IS 456.

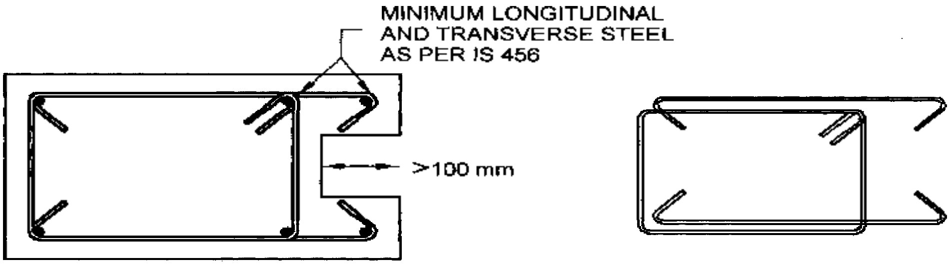



FIG. 9 REINFORCEMENT REQUIREMENT IN COLUMNS WITH PROJECTION MORE THAN 100 MM BEYOND CORE

Transverse Reinforcement

Transverse reinforcement shall consist of closed loop,

- spiral or circular links in circular columns, and rectangular links in rectangular columns.
- In either case, the closed link shall have 135° hook ends with an extension of 6 times its diameter (but not< 65 mm) at each end, which are embedded in the confined core of the column (see Fig. 10A).

When rectangular links are used,

a) the minimum diameter permitted of transverse reinforcement bars is 8 mm, when diameter of longitudinal bar is less than or equal to 32 mm, and 10 mm, when diameter of longitudinal bar is more than 32 mm;

b) the maximum spacing of parallel legs of links shall be 300 mm centre to centre;

c) a cross-tie shall be provided, if the length of any side of the link exceeds 300 mm (see Fig. 10B); the cross-tie shall be placed perpendicular to this link whose length exceeds 300 mm. Alternatively, a pair of overlapping links may be provided within the column (see Fig. 10C). In either case, the hook ends of the links and cross-ties shall engage around peripheral longitudinal bars. Consecutive cross-ties engaging the same longitudinal bars shall have their 90° hooks on opposite sides of the column. Crossties of the same or smaller bar size as the hoops shall be permitted; and,

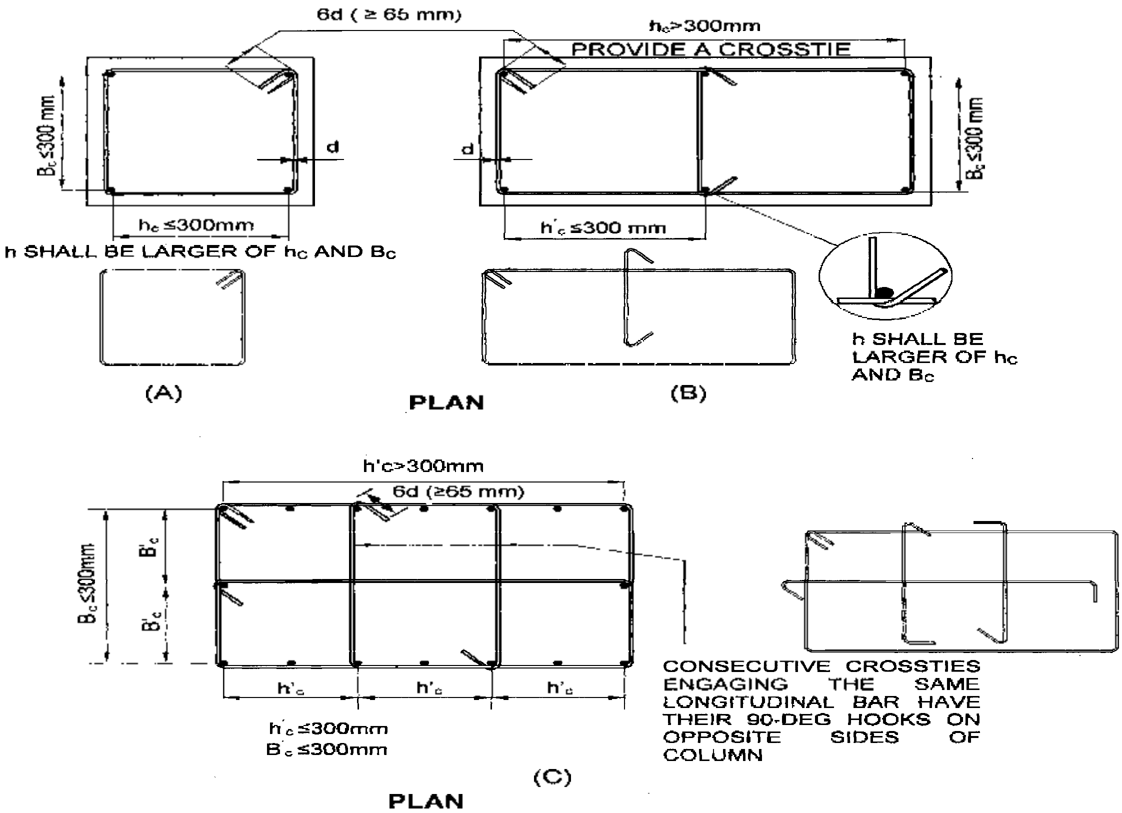



FIG. 10 DETAIL OF TRANSVERSE REINFORCEMENT IN COLUMNS

### 2.9.5.5 SPECIAL CONFINING REINFORCEMENT

The requirements of this section shall be met with in beams and columns, unless a larger amount of transverse reinforcement is required from shear strength considerations.

Flexural yielding is likely in beams during strong earthquake shaking and in columns when the shaking intensity exceeds the expected intensity of earthquake shaking (see Fig. 11). This special confining reinforcement shall

a) Be provided over a length lo from the face where lo is not less than
   1. larger lateral dimension of the member at the section where yielding occurs
   2) 1/6 of clear span of the member; or
   3) 450 mm.

b) have a spacing not more than,
   1) 1/4 of minimum member dimension of the beam or column;
   2) 6 times diameter of the smallest longitudinal reinforcement bars; and
   3) 100 mm link.

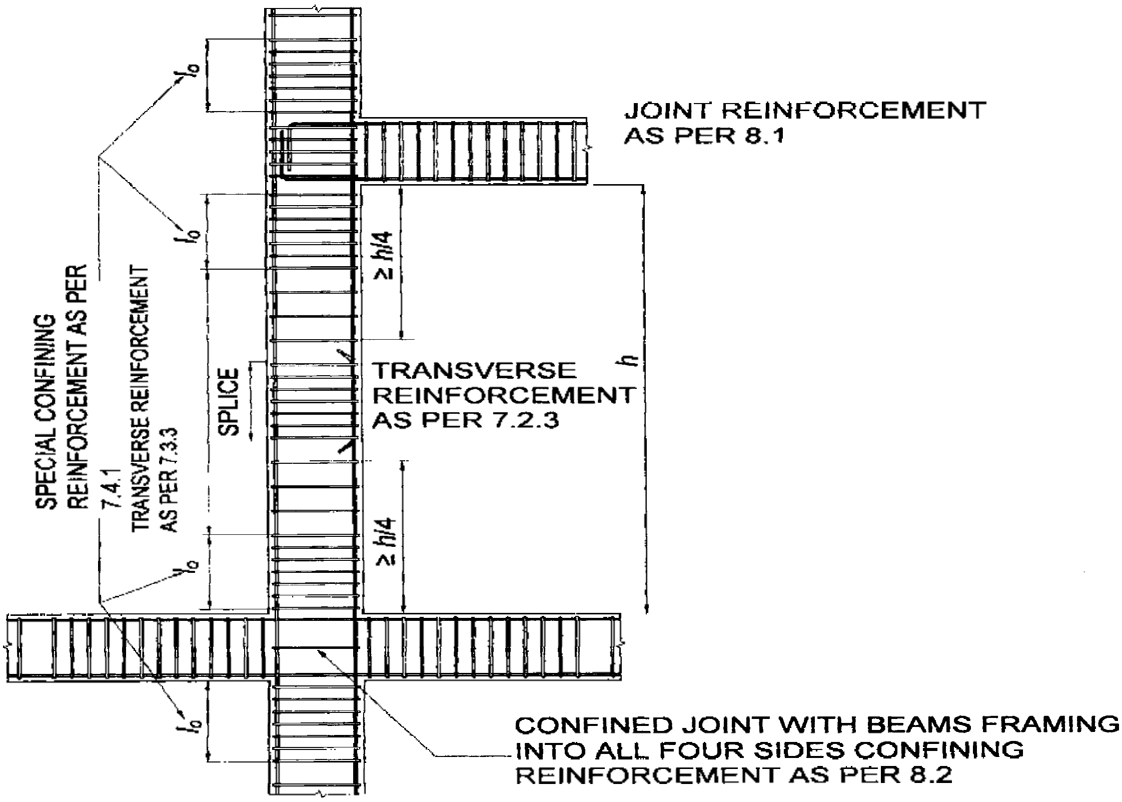



FIG. 11 COLUMN AND JOINT DETAILING

Where:

h = longer dimension of rectangular link measured to its outer face, which does not exceed 300 mm (see Fig. 10B), and

$A_k$ = area of confined concrete core in rectangular link measured to its outer dimensions.

h of the link could be reduced by introducing crossties (see Fig. 10C). In such cases, Ak shall be measured as overall core area, regardless of link arrangement. Hooks of cross-ties shall engage peripheral longitudinal bars

When a column terminates into a footing or mat, special confining reinforcement shall extend at least 300 mm into the footing or mat (see Fig. 12).

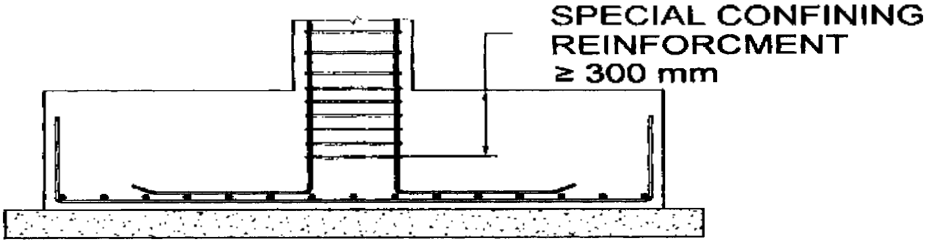



FIG. 12 Provision of special confirming reinforcement in footing.

When the calculated point of contra-flexure, under the effect of gravity and earthquake effects, is not within the middle half of the member clear height, special confining reinforcement shall be provided over the full height of the column

Special confining reinforcement shall be provided over the full height of a column which has significant variation in stiffness along its height. This variation in stiffness may result due to abrupt changes in cross- section size, or unintended restraint to the column provided by stair-slab, mezzanine floor, plinth or lintel beams framing into the columns, RC wall or masonry wall adjoining column and extending only for partial column height.

Columns supporting reactions from discontinued stiff members, such as walls, shall be provided with special confining reinforcement over their full height. (see Fig. 13). This reinforcement shall also be placed above the discontinuity for at least the development length of the largest longitudinal bar in the column. Where the column is supported on a wall, this reinforcement shall be provided over the full height of the column; it shall also be provided below the discontinuity for the same development length.

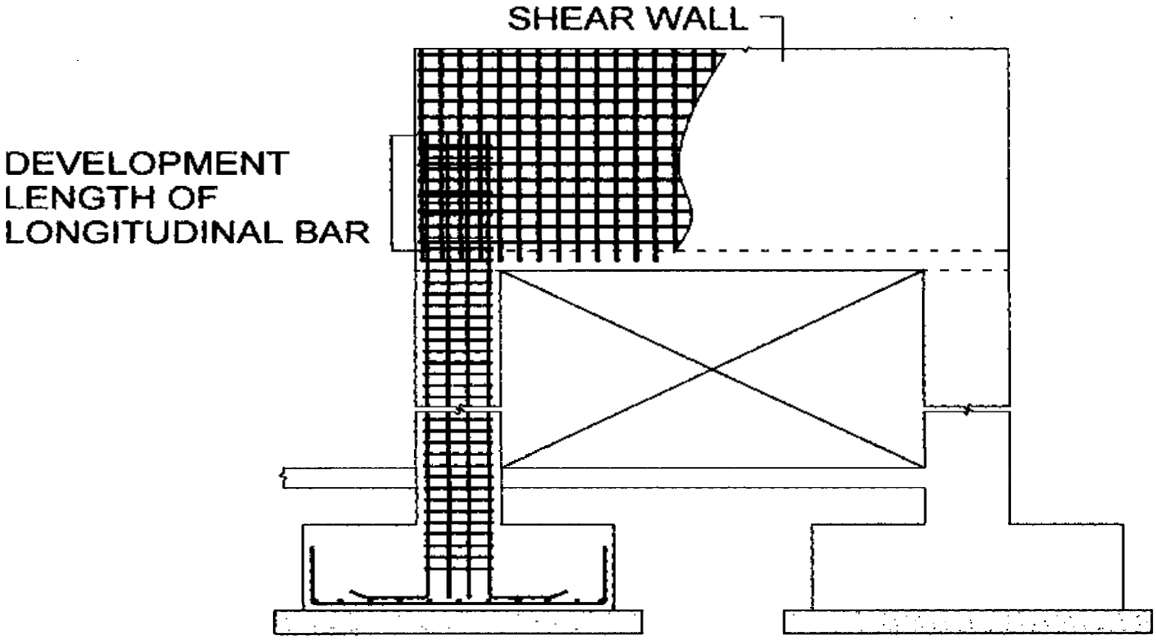



FIG. 13 COLUMNS WITH VARIABLE STIFFNESS

### 2.9.5.6 Width of Beam Column Joint

When beam reinforcement extends through beam- column joint, the minimum width of the column parallel to beam shall be 20 times the diameter of the largest longitudinal beam bar.

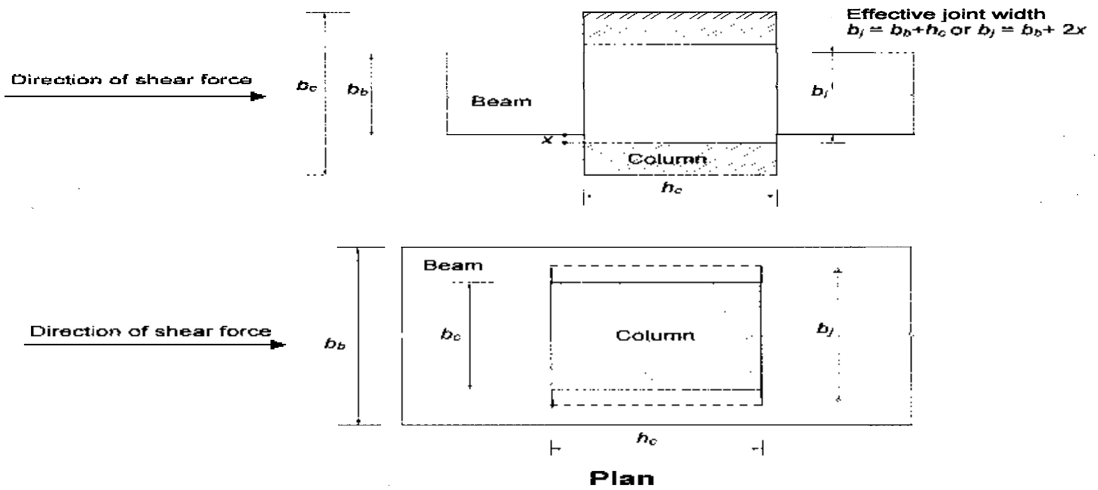



FIG. 14 PLAN VIEW OF A BEAM COLUMN JOINT SHOWING EFFECTIVE BREADTH AND WIDTH OF JOINT

### 2.9.5.7 Transverse Reinforcement

Confining Reinforcement in Joints

a) When all four vertical faces of the joint are having beams framing into them covering at least 75 percent of the width on each face,
   1) At least half the special confining reinforcement required as per 8 at the two ends of columns, shall be provided through the joint within the depth of the shallowest beam framing into it; and
   2) Spacing of these transverse links shall not exceed 150 mm.
b) When all four vertical faces of the joint are not having beams framing into them or when all four vertical faces have beams framing into them but do not cover at least 75 percent of the width on any face,
   1) special confining reinforcement required as per 8 at the two ends of columns shall be provided through the joint within the depth of the shallowest beam framing into it, and spacing of these transverse links shall not exceed 150 mm.

In the exterior and corner joints, all 135° hooks of cross-ties should be along the outer face of columns.

### 2.9.6 SPECIAL SHEAR WALLS

General Requirements

The requirements of this section apply to special shear walls that are part of lateral force resisting system of earthquake-resistant RC buildings.

The minimum thickness of special shear walls shall not be less than,

a) 150 mm; and
b) 300 mm for buildings with coupled shear walls in any seismic zone.

The minimum thickness provided must conform to the fire resistance requirements based on occupancy as laid down in IS 456.

The minimum ratio of length of wall to its thickness shall be 4.

Special shear walls shall be classified as squat, intermediate or slender depending on the overall height hw to length Lw ratio as

a) Squat walls: $hw / Lw < 1$,
b) Intermediate walls: $1 \le hw / Lw \le 2$, and
c) Slender walls: $hw / Lw > 2$.

In the design of flanged wall sections, only that part of the flange shall be considered which extends beyond the face of the web of the structural wall at least for a distance equal to smaller of,

a) actual width available;
b) half the distance to the adjacent structural wall
c) 1/10th of the total wall height.

Reinforcement bars shall be provided in two curtains within the cross-section of the wall, with each curtain having bars running along vertical and horizontal directions, when,

a) factored shear stress demand in the wall exceeds $0.25\sqrt{f_{ck}}$ MPa; or

b) wall thickness is 200 mm or higher.

When steel is provided in two layers, all vertical steel bars shall be contained within the horizontal steel bars; the horizontal bars shall form aclosed core concrete area with closed loops and cross-ties.

The largest diameter of longitudinal steel bars used in any part of a wall shall not exceed 1/10th of the thickness of that part.

The maximum spacing of vertical or horizontal reinforcement shall not exceed smaller of,

a) 1/5th horizontal length $L_w$ of wall;

b) 3 times thickness $t_w$ of web of wall; and

c) 450 mm.

Special shear walls shall be founded on properly designed foundations and shall not be discontinued to rest on beams, columns or inclined members.

## 2.10 Structural Design Including Earthquake Preventive Measures

### 2.10.1 General Introduction

Structural design is a methodical investigation of the stability, strength and rigidity of structures. The basic objective in structural analysis and design is to produce a structure, capable of resisting all applied loads without failure during its intended life. The primary purpose of a structure is to transmit or support loads. If the structure is improperly designed or fabricated, or if the actual applied loads exceed the design specifications, the device will probably fail to perform its intended function, with possible serious consequences. A well engineered structure greatly minimizes the possibility of costly failures.

### 2.10.2 Structural design process:

A structural design project may be divided into three phases, i.e. planning, design and construction.

#### 2.10.2.1 Planning

This phase involves the consideration of various requirements and factors affecting the general layout and dimensions of the structure and results in the choice of one or perhaps several alternative types of structure, which offer the best general solution. The primary consideration is the function of the structure. Secondary considerations, such as aesthetics, sociology, law, economics and the environment may also be taken into account. In addition, there are structural and constructional requirements and limitations, which may affect the type of structure to be designed.

#### 2.10.2.2 Design

This phase involves a detailed consideration of the alternative solutions defined in the planning phase and results in the determination of the most suitable proportions, dimensions and details of the structural elements and connections for constructing each alternative structural arrangement being considered.

#### 2.10.2.3 Construction

This phase involves mobilization of personnel, procurement of materials and equipment, including their transportation to the site, and actual on-site erection. During this phase, some redesign may be required, if unforeseen difficulties occur, such as unavailability of specified materials or foundation problems.

### 2.10.3 Philosophy of designing

The structural design of any structure, first involves establishing the loading and other design conditions, which must be supported by the structure and therefore, must be considered in its design. This is followed by the analysis and computation of internal gross forces, (i.e. thrust, shear, bending moments and twisting moments), as well as stress intensities, strain, deflection and reactions produced by loads, changes in temperature, shrinkage, creep and other design conditions. Finally comes the proportioning and selection of materials for the members and connections to respond adequately to the effects produced by the design conditions. The criteria used to judge whether particular proportions will result in the desired behavior reflect accumulated knowledge based on field and model tests, and practical experience. Intuition and judgment, are also important to this process. The traditional basis of design, called elastic design, is based on allowable stress intensities, which are chosen in accordance with the concept that stress or strain corresponds to the yield point of the material and should not be exceeded at the most highly stressed points of the structure, the selection of failure due to fatigue, buckling or brittle fracture or by consideration of the permissible deflection of the structure. The allowable stress method has the important disadvantage, that it does not provide a uniform overload capacity for all parts and all types of structures. The newer approach of design is called the Strength Design in reinforced concrete literature and Plastic Design in steel-design literature. The anticipated service loading is first multiplied by a suitable load factor, the magnitude of which depends upon uncertainty of the loading, the possibility of it changing during the life of the structure and for a combination of loadings, the likelihood, frequency, and duration of the particular combination. In this approach for Reinforced-Concrete Design, theoretical capacity of a structural element is reduced by a capacity reduction factor, to provide for small adverse variations in material strengths, workmanship and dimensions. The structure is then proportioned, depending on the governing conditions, the increased load cause fatigue / buckling or a brittle-facture, or just to produce yielding at one internal section or sections or to cause elastic-plastic displacement of the structure or cause the entire structure to be on the point of collapse.

### 2.10.4 Loads, Forces and Effects.

Basic design loads to be assumed in the design of buildings.

#### 2.10.4.1 DEAD LOAD.

The dead load in a building shall comprise the weight of all walls, partitions, floors and roofs, and shall include the weights of all other permanent constructions (including built-in partitions, finishes, cladding and other similarly incorporated architectural and structural items, weight of fixed service equipment) in the building and shall conform to good practice.

#### 2.10.4.2 IMPOSED LOAD.

This covers imposed loads to be assumed in the design of buildings. The imposed loads specified herein are minimum loads, which should be taken into consideration for the purpose of structural safety of buildings.

**NOTE—**: This Section does not cover detailed provisions for loads incidental to construction and special cases of vibration, such as moving machinery, heavy acceleration from cranes, hoists and the like. Such loads shall be dealt with individually in each case.

#### 2.10.4.3 Imposed Loads on Floors Due to Use and Occupancy

The imposed loads, to be assumed in the design of buildings shall be the greatest loads that probably will be produced by the intended use or occupancy, but shall not be less than the equivalent minimum loads, specified in Table 1, subject to any reductions permitted in 2.10.4.4

Floors shall be investigated for both the uniformly distributed load (UDL) and the corresponding concentrated load, specified in Table 1, and designed for the most adverse effects, but they shall not be considered to act simultaneously. The concentrated loads specified in Table 1, may be assumed to act over an area of 0.3 m × 0.3 m. However, the concentrated loads need not be considered where the floors are capable of effective lateral distribution of this load. All other structural elements shall be investigated for the effects of uniformly distributed loads on the floors specified in Table 1.

**NOTES**

1 Where, in Table 1, no values are given for concentrated load, it may be assumed that the tabulated distributed load is adequate for design purposes.

2 The loads specified in Table 1, are equivalent uniformly distributed loads on the plan area and provide for normal effects of impact and acceleration. They do not take into consideration special concentrated loads and other loads.

3 Where ever, the use of an area or floor is not provided in Table 1, the imposed load due to the use and occupancy of such an area shall be determined from the analysis of loads resulting from,

a) Weight of the probable assembly of persons;

b) Weight of the probable accumulation of equipment and furnishing;

c) Weight of the probable storage materials; and
d) Impact factor, if any.

4. While selecting a particular loading, the possible change in use or occupancy of the building should be kept in view. Designers should not necessarily select in every case the lower loading appropriate to the first occupancy. In doing this, they might introduce considerable restrictions in the use of the building at a later date, and thereby, reduce its utility.

5. The loads specified herein, which are based on estimations, may be considered as the characteristic loads for the purpose of Limit State Method of Design, till such time, statistical data are established based on load surveys to be conducted in the country.

6. When an existing building is altered by an extension in height or area, all existing structural parts affected by the addition shall be strengthened where necessary, and all new structural parts shall be designed to meet the requirements for building hereafter erected.

7. The loads specified in the Section does not include loads incidental to construction. Therefore, close supervision during construction is essential to ensure that overloading of the building due to loads by way of stacking of building materials or use of equipment (for example, cranes and trucks) during construction or loads which may be induced by floor to floor propping in multi-storied construction, does not occur. However, if construction loads, were of short duration, permissible increase in stresses in the case of working stress method or permissible decrease in load factors in limit state method, as applicable to relevant design codes, may be allowed for.

8. The loads in Table 1, are grouped together, as applicable to buildings having separate principal occupancy or use. For a building with multiple occupancies, the loads appropriate to the occupancy with comparable use, shall be chosen from other occupancies.

9. Regarding loading on lift machine rooms including storage space, used for repairing lift machines, designers should go by the recommendations of lift manufacturers, for the present. Regarding loading due to false ceiling, the same should be considered as imposed loads on the roof/floor to which it is fixed.

### 2.10.4.4 Reduction in Imposed Loads on Floors

#### 2.10.4.4.1 For members supporting floors

Except as provided for in 1.1.4.3(a), the following reductions in assumed total imposed loads on the floors may be made in designing columns, load bearing walls, piers, their supports and foundations:

| *Number of Floors (Including the Roof) to be Carried by Member Under Consideration* | *Reduction in Total Distributed Imposed Load on All Floors to be Carried by the Member Under Consideration* Percent |
|---|---|
| 1 | 0 |
| 2 | 10 |
| 3 | 20 |
| 4 | 30 |
| 5 to 10 | 40 |
| Over 10 | 50 |

a) No reduction shall be made, for any plant or machinery, which is specifically allowed for, or for buildings for storage purposes, warehouses and garages. However, for other buildings, where the floor is designed for an imposed floor load of 5.0 kN/m2 or more, the reductions shown in 2.10.4.4 may be taken, provided that the loading assumed is not less than it would have been, if all the floors had been designed for 5.0 kN/m2 with no reductions.

NOTE: - In case, if the reduced load in the lower floor is lesser than the reduced load in the upper floor, then the reduced load of the upper floor will be adopted.

b) An example is given in Annexure A, illustrating the reduction of imposed loads in a multi-storeyed building in the design of column members.

#### 2.10.4.4.2 For beams in each floor level

Where a single-span of beam, girder or truss supports not less than 50 m2 of floor at one general level, the imposed floor load may be reduced in the design of the beams, girders or trusses by 5 percent for each 50 m2 area supported, subject to a maximum reduction of 25 percent. However, no reduction shall be made in any of the following types of loads:

a) Any superimposed moving load,
b) Any actual load due to machinery or similar concentrated loads,
c) The additional load in respect of partition walls; and
d) Any impact or vibration**.**

**NOTE:** The above reduction does not apply to beams, girders or trusses supporting roof loads.

### 2.10.4.5Imposed Loads on Roofs

#### 2.10.4.5.1 Imposed Loads on Various Types of Roofs

On flat roofs, sloping roofs and curved roofs, the imposed loads due to use and occupancy of the buildings and the geometry of the types of roofs, shall be as given in Table 2.

Roofs of buildings used for promenade or incidental to assembly purposes, shall be designed for the appropriate imposed floor loads given in Table 1 ,for the occupancy.

#### 2.10.4.5.2 Concentrated Load on Roof Coverings

To provide for loads incidental to maintenance, unless otherwise specified by the Engineer-in-Charge, all roof coverings (other than glass or transparent sheets made of fibre glass) shall be capable of carrying an incidental load of 0.90 kN concentrated on an area of 1 250 mm2 so placed as to produce maximum stresses in the covering. The intensity of the concentrated load may be reduced with the approval of the Engineer-in-Charge, where it is ensured that the roof coverings would not be traversed without suitable aids. In any case, the roof coverings shall be capable of carrying the loads in accordance with 2.10.4.5.1, 2.10.4.6 and 2.10.4.7 and wind load.

### 2.10.4.6Loads Due to Rain

On surfaces, whose positioning, shape and drainage system are such as to make accumulation of rain water possible, loads due to such accumulation of water and the imposed loads for the roof as given in Table 2, shall be considered separately and the more critical of the two shall be adopted in the design.

### 2.10.4.7Dust Loads

In areas prone to settlement of dust on roofs (for example, steel plants, cement plants), provision for dust load, equivalent to probable thickness of accumulation of dust may be made.

**2.10.4.8Loads on Members Supporting Roof Coverings**

Every member of the supporting structure which is directly supporting the roof covering(s) shall be designed to carry the more severe of the following loads except as provided in 3.4.5.1: a) The load transmitted to the members from the roof covering(s) in accordance 2.10.4.5.1, 2.10.4.6 and 2.10.4.7 and b) An incidental concentrated load of 0.90 kN concentrated over a length of 125 mm placed at the most critical positions on the member.

**NOTE—** Where it is ensured that the roofs would be traversed only with the aid of planks and ladders capable of distributing the loads on them to two or more supporting members, the intensity of concentrated load indicated in 2.10.4.8 (b) may be reduced to 0.5 kN with the approval of the Engineer-in-Charge.

In case of sloping roofs with slope greater than 10°, members supporting the roof purlins, such as trusses, beams, girders, etc, may be designed for two-thirds of the imposed load on purlin or roofing sheet.

**2.10.4.9SEISMIC FORCE**

This clause primarily deals with earthquake hazard assessment and earthquake-resistant design of buildings. All structures, like parking structures, security cabins and ancillary structures need to be designed for appropriate earthquake effects, as per this clause. Also, temporary elements, such as scaffolding and temporary excavations, need to be designed as per this clause. This clause does not deal with construction features relating to earthquake-resistant buildings and other structures.

The provisions of this clause are applicable even to critical and special structures, like nuclear power plants and petroleum refinery plants. For such structures, additional requirements may be imposed based on special studies, such as site-specific hazard assessment. In such cases, the earthquake effects specified by this clause shall be taken as at least the minimum.

**Table 1 Imposed Floor Loads for Different Occupancies**
(*Clause* 3.3.1)

| Sl No. | Occupancy Classification | Uniformly Distributed Load (UDL) kN/m² | Concentrated Load kN |
|---|---|---|---|
| (1) | (2) | (3) | (4) |
| i) | Residential Buildings | | |
| | a) Dwelling houses: | | |
| | 1) All rooms and kitchens | 2.0 | 1.8 |
| | 2) Toilets and bath rooms | 2.0 | — |
| | 3) Corridors, passages, staircases including fire escapes and store rooms | 3.0 | 4.5 |
| | 4) Balconies | 3.0 | 1.5 per metre run concentrated at the outer edge |
| | b) Dwelling units planned and executed in accordance with good practice [6-1(2)] only: | | |
| | 1) Habitable rooms, kitchens, and toilets and bath rooms | 1.5 | 1.4 |
| | 2) Corridors, passages and staircases including fire escapes | 1.5 | 1.4 |
| | 3) Balconies | 3.0 | 1.5 per metre run concentrated at the outer edge |
| | c) Hotels, hostels, boarding houses, lodging houses, dormitories and residential clubs: | | |
| | 1) Living rooms, bed rooms and dormitories | 2.0 | 1.8 |
| | 2) Kitchen and laundries | 3.0 | 4.5 |
| | 3) Billiards room and public lounges | 3.0 | 2.7 |
| | 4) Store rooms | 5.0 | 4.5 |
| | 5) Dining rooms, cafeterias and restaurants | 4.0 | 2.7 |
| | 6) Office rooms | 2.5 | 2.7 |
| | 7) Rooms for indoor games | 3.0 | 1.8 |
| | 8) Baths and toilets | 2.0 | — |
| | 9) Corridors, passages staircases including fire escapes and lobbies – as per the floor serviced (excluding stores and the like) but not less than | 3.0 | 4.5 |
| | 10) Balconies | Same as rooms to which they give access but with a minimum of 4.0 | 1.5 per metre run concentrated at the outer edge |
| | d) Boiler rooms and plant rooms– to be calculated but not less than | 5.0 | 6.7 |
| | e) Garages: | | |
| | 1) Garage floors (including parking area and repair workshops for passenger cars and vehicles not exceeding 2.5 tonne gross weight, including access ways and ramps – to be calculated but not less than | 2.5 | 9.0 |
| | 2) Garage floors for vehicles not exceeding 4.0 tonne gross weight (including access ways and ramps ) – to be calculated but not less than | 5.0 | 9.0 |
| ii) | Educational Buildings | | |
| | a) Class rooms and lecture rooms (not used for assembly purposes) | 3.0 | 2.7 |
| | b) Dining rooms, cafeterias and restaurants | 3.0[1)] | 2.7 |
| | c) Offices, lounges and staff rooms | 2.5 | 2.7 |
| | d) Dormitories | 2.0 | 2.7 |
| | e) Projection rooms | 5.0 | – |
| | f) Kitchens | 3.0 | 4.5 |
| | g) Toilets and bath rooms | 2.0 | – |
| | h) Store rooms | 5.0 | 4.5 |
| | j) Libraries and archives: | | |
| | 1) Stack room/stack area | 6.0 kN/m² for a minimum height of 2.2 m + 2.0 kN/m² per metre height beyond 2.2 m | 4.5 |

**Table 1 — (*Continued*)**

| (1) | (2) | (3) | (4) |
|---|---|---|---|
| | 2) Reading rooms (without separate storage) | 4.0 | 4.5 |
| | 3) Reading rooms (with separate storage) | 3.0 | 4.5 |
| | k) Boiler rooms and plant rooms – to be calculated but not less than | 4.0 | 4.5 |
| | m) Corridors, passages, lobbies, staircases including fire escapes – as per the floor serviced (without accounting for storage and projection rooms) but not less than | 4.0 | 4.5 |
| | n) Balconies | Same as rooms to which they give access but with a minimum of 4.0 | 1.5 per metre run concentrated at the outer edge |
| iii) | Institutional Buildings | | |
| | a) Bed rooms, wards, dressing rooms, dormitories and lounges | 2.0 | 1.8 |
| | b) Kitchens, laundries and laboratories | 3.0 | 4.5 |
| | c) Dining rooms, cafeterias and restaurants | 3.0[1] | 2.7 |
| | d) Toilets and bathrooms | 2.0 | – |
| | e) X-ray rooms, operating rooms and general storage areas – to be calculated but not less than | 3.0 | 4.5 |
| | f) Office rooms and O.P.D. rooms | 2.5 | 2.7 |
| | g) Corridors, passages, lobbies, staircases including fire escapes – as per the floor serviced (without accounting for storage and projection rooms) but not less than | 4.0 | 4.5 |
| | h) Boiler rooms and plant rooms – to be calculated but not less than | 5.0 | 4.5 |
| | j) Balconies | Same as rooms to which they give access but with a minimum of 4.0 | 1.5 per metre run concentrated at the outer edge |
| iv) | Assembly Buildings | | |
| | a) Assembly areas : | | |
| | 1) With fixed seats[2] | 4.0 | – |
| | 2) Without fixed seats | 5.0 | 3.6 |
| | b) Restaurants (subject to assembly), museums and art galleries and gymnasia | 4.0 | 4.5 |
| | c) Projection rooms | 5.0 | — |
| | d) Stages | 5.0 | 4.5 |
| | e) Office rooms, kitchens and laundries | 3.0 | 4.5 |
| | f) Dressing rooms | 2.0 | 1.8 |
| | g) Lounges and billiards rooms | 2.0 | 2.7 |
| | h) Toilets and bathrooms | 2.0 | — |
| | j) Corridors, passages and staircases including fire escapes | 4.0 | 4.5 |
| | k) Balconies | Same as rooms to which they give access but with a minimum of 4.0 | 1.5 per metre run concentrated at the outer edge |
| | m) Boiler rooms and plant rooms including weight of machinery | 7.5 | 4.5 |
| | n) Corridors, passages, subject to loads greater than from crowds, such as wheeled vehicles, trolleys and the like corridors, staircases and passages in grandstands | 5.0 | 4.5 |
| v) | Business and Office Buildings (*see also* **3.2.1**) | | |
| | a) Rooms for general use with separate storage | 2.5 | 2.7 |
| | b) Rooms without separate storage | 4.0 | 4.5 |
| | c) Banking halls | 3.0 | 2.7 |
| | d) Business computing machine rooms (with fixed computers or similar equipment) | 3.5 | 4.5 |
| | e) Records/files store rooms and storage space | 5.0 | 4.5 |
| | f) Vaults and strong rooms – to be calculated but not less than | 5.0 | 4.5 |
| | g) Cafeterias and dining rooms | 3.0[1] | 2.7 |
| | h) Kitchens | 3.0 | 2.7 |
| | j) Corridors, passages, lobbies, staircases including fire escapes – as per the floor serviced (excluding stores) but not less than | 4.0 | 4.5 |
| | k) Bath and toilets rooms | 2.0 | — |

**Table 1 — (*Concluded*)**

| (1) | (2) | (3) | (4) |
|---|---|---|---|
| | m) Balconies | Same as rooms to which they give access but with a minimum of 4.0 | 1.5 per metre run concentrated at the outer edge |
| | n) Stationary stores | 4.0 for each metre of storage height | 9.0 |
| | p) Boiler rooms and plant rooms – to be calculated but not less than | 5.0 | 6.7 |
| | q) Libraries | *See* Sl No. (ii) | |
| vi) | Mercantile Buildings | | |
| | a) Retail shops | 4.0 | 3.6 |
| | b) Wholesale shops – to be calculated but not less than | 6.0 | 4.5 |
| | c) Office rooms | 2.5 | 2.7 |
| | d) Dining rooms, restaurants and cafeterias | 3.0[1] | 2.7 |
| | e) Toilets | 2.0 | – |
| | f) Kitchens and laundries | 3.0 | 4.5 |
| | g) Boiler rooms and plant rooms – to be calculated but not less than | 5.0 | 6.7 |
| | h) Corridors, passages, staircases including fire escapes and lobbies | 4.0 | 4.5 |
| | j) Corridors, passages, staircases subject to loads greater than from crowds, such as wheeled vehicles, trolleys and the like | 5.0 | 4.5 |
| | k) Balconies | Same as rooms to which they give access but with a minimum of 4.0 | 1.5 per metre run concentrated at the outer edge |
| vii) | Industrial Buildings[3] | | |
| | a) Work areas without machinery/equipment | 2.5 | 4.5 |
| | b) Work areas with machinery/equipment[4] | | |
| | 1) Light duty — To be calculated but not less than | 5.0 | 4.5 |
| | 2) Medium duty — To be calculated but not less than | 7.0 | 4.5 |
| | 3) Heavy duty — To be calculated but not less than | 10.0 | 4.5 |
| | c) Boiler rooms and plant rooms – to be calculated but not less than | 5.0 | 6.7 |
| | d) Cafeterias and dining rooms | 3.0[1] | 2.7 |
| | e) Corridors, passages, stair cases including fire escapes | 4.0 | 4.5 |
| | f) Corridors, passages, lobbies, staircases subject to machine loads and wheeled vehicles – to be calculated but not less than | 5.0 | 4.5 |
| | g) Kitchens | 3.0 | 4.5 |
| | h) Toilets and bathrooms | 2.0 | — |
| viii) | Storage Buildings[4] | | |
| | a) Storage rooms (other than cold storage) and warehouses — to be calculated based on the bulk density of materials stored but not less than | 2.4 $kN/m^2$ per metre of storage height with a minimum of 7.5 $kN/m^2$ | 7.0 |
| | b) Cold storage – to be calculated but not less than | 5.0 $kN/m^2$ per metre of storage height with a minimum of 15 $kN/m^2$ | 9.0 |
| | c) Corridors, passages, staircases including fire escapes – as per the floor serviced but not less than | 4.0 | 4.5 |
| | d) Corridors, passages subject to loads greater than from crowds, such as wheeled vehicles, trolleys and the like | 5.0 | 4.5 |
| | e) Boiler rooms and plant rooms | 7.5 | 4.5 |

[1] Where unrestricted assembly of persons is anticipated, the value of UDL should be increased to 4.0 $kN/m^2$.
[2] With fixed seats implies that the removal of the seating and the use of the space for other purposes is improbable. The maximum likely load in this case is, therefore, closely controlled.
[3] The loading in industrial buildings (workshops and factories) varies considerably and so three loadings under the terms 'light', 'medium' and 'heavy' are introduced in order to allow for more economical designs but the terms have no special meaning in themselves other than the imposed load for which the relevant floor is designed. It is, however important particularly in the case of heavy weight loads, to assess the actual loads to ensure that they are not in excess of 10 $kN/m^2$; in case where they are in excess, the design shall be based on the actual loadings.
[4] For various mechanical handling equipment which are used to transport goods, as in warehouses, workshops, store rooms, etc, the actual load coming from the use of such equipment shall be ascertained and design should cater to such loads.

**Table 2 Imposed Loads on Various Types of Roofs**
(*Clause* 3.4.1)

| Sl No. (1) | Type of Roof (2) | Imposed Load Measured on Plan Area (3) | Minimum Imposed Load Measured on Plan (4) |
|---|---|---|---|
| i) | Flat, sloping or curved roof with slopes up to and including 10°: | | |
| | a) Access provided | 1.5 kN/m$^2$ | 3.75 kN uniformly distributed over any span of one metre width of the roof slab and 9 kN uniformly distributed over the span of any beam or truss or wall |
| | b) Access not provided except for maintenance | 0.75 kN/m$^2$ | 1.9 kN uniformly distributed over any span of one metre width of the roof slab and 4.5 kN uniformly distributed over the span of any beam or truss or wall |
| ii) | Sloping roof with slope greater than 10° | For roof membrane sheets or purlins – 0.75 kN/m$^2$ less 0.02 kN/m$^2$ for every degree increase in slope over 10° | Subject to a minimum of 0.4 kN/m$^2$ |
| iii) | Curved roof with slope of line obtained by joining springing point to the crown with the horizontal, greater than 10° | $(0.75 - 0.52\ \alpha^2)$ kN/m$^2$<br>where<br>$\alpha$ = $h/l$<br>$h$ = height of the highest point of the structure measured from its springing; and<br>$l$ = chord width of the roof if singly curved and shorter of the two sides if doubly curved.<br>Alternatively, where structural analysis can be carried out for curved roofs of all slopes in a simple manner applying the laws of statistics, the curved roofs shall be divided into minimum 6 equal segments and for each segment imposed load shall be calculated appropriate to the slope of the chord of each segment as given in Sl No. (i) and (ii). | Subject to a minimum of 0.4 kN/m$^2$ |

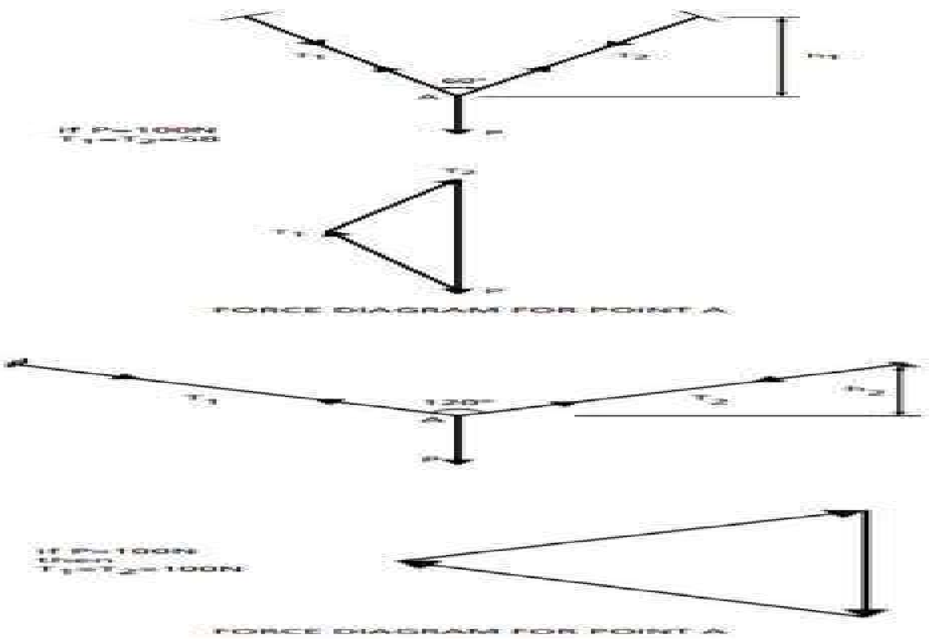
NOTES

**1** The loads given above do not include loads due to snow, rain, dust collection, etc. The roof shall be designed for imposed loads given above or for snow/rain load, whichever is greater.

**2** For special types of roofs with highly permeable and absorbent material, the contingency of roof material increasing in weight due to absorption of moisture shall be provided for.

### 2.10.5 Design Aids

The design of any structure requires many detailed computations. Some of these are of a routine nature. An example is the computation of allowable bending moments for standard sized, species and grades of dimension timber. The rapid development of the computer in the last decade has resulted in rapid adoption of Computer Structural Design Software that has now replaced the manual computation. This has greatly reduced the complexity of the analysis and design process as well as reducing the amount of time required to finish a project. Standard construction and assembly methods have evolved through experience and need for uniformity in the construction industry. These have resulted in standard details and standard components for building construction published in handbooks or guides.



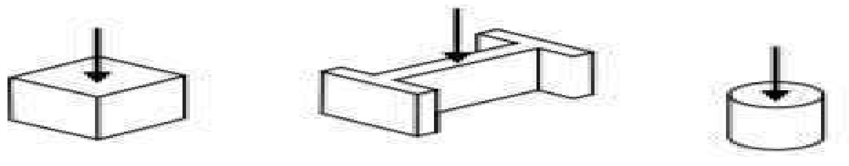
### 2.10.6 Design of Members in Direct Tension and Compression.

#### 2.10.6.1Tensile systems:

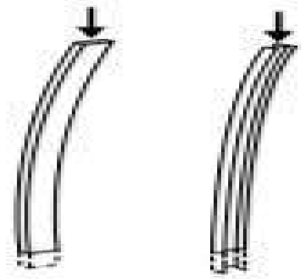
Tensile systems allow maximum use of the material, because every fibre of the cross-section can be extended to resist the applied loads up to any allowable stress. As with other structural systems, tensile systems require depth, to transfer loads economically across a span. As the sag (h) decreases, the tensions in the cable (T1 and T2) increase. Further decreases in the sag would again increase the magnitudes of T1 and T2 until the ultimate condition, an infinite force, would be required to transfer a vertical load across a cable that is horizontal (obviously an impossibility). A distinguishing feature of tensile systems is that vertical loads produce both vertical and horizontal reactions. As cables cannot resist bending or shear, they transfer all loads in tension along their lengths. The connection of a cable to its supports acts as a pin joint (hinge), with the result that the reaction (R) must be exactly equal and opposite to the tension in the cable (T). The R can be resolved into the vertical and horizontal directions producing the forces V and H. The horizontal reaction (H) is known as the thrust. The values of the components of the reactions can be obtained by using the conditions of static equilibrium and resolving the cable tensions into vertical and horizontal components at the support points.

**2.10.6.2Short columns:**

A column which is short (i.e. the height is small compared with the cross-section area) is likely to fail because of crushing of the material. Note, however, that slender columns, which are tall compared with the cross-section area, are more likely to fail from buckling under a load much smaller than that needed to cause failure from crushing. Buckling is dealt with later.



Short columns



Slender columns

**2.10.6.3Design of Simple Beams.**

### 2.10.6.3.1 Bending stresses

When a sponge is put across two supports and gently pressed downwards between the supports, the pores at the top will close, indicating compression, and the pores at the bottom will open wider, indicating tension. Similarly, a beam of any elastic material, such as wood or steel, will produce a change in shape when external loads are acting on it.

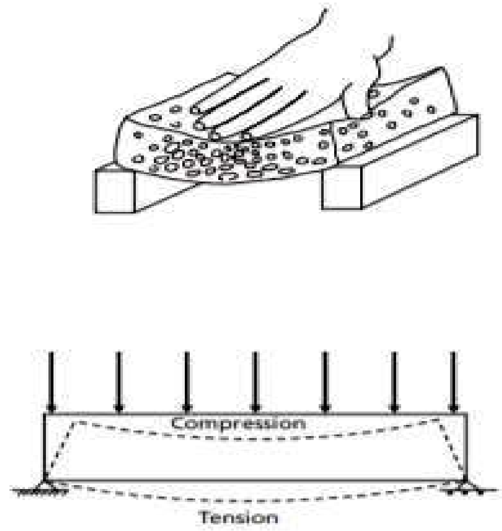
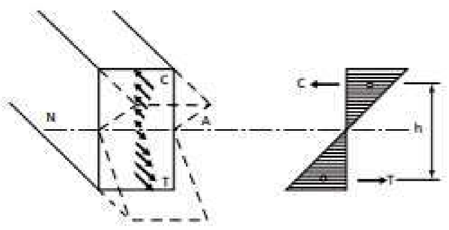



Figure 7.1 Bending effects on beams

The stresses will vary from maximum compression at the top to maximum tension at the bottom. Where the stress changes from compressive to tensile, there will be one layer that remains unstressed and this is called the neutral layer or the neutral axis (NA). This is why beams with an I-section are so effective. The main part of the material is concentrated in the flanges, away from the neutral axis. Hence, the maximum stresses occur where there is maximum material to resist them. If the material is assumed to be elastic, then the stress distribution can be represented by two triangular shapes with the line of action of the resultant force of each triangle of stress at its centroid. The couple produced by the compression and tension triangles of stress is the internal-reaction couple of the beam section.

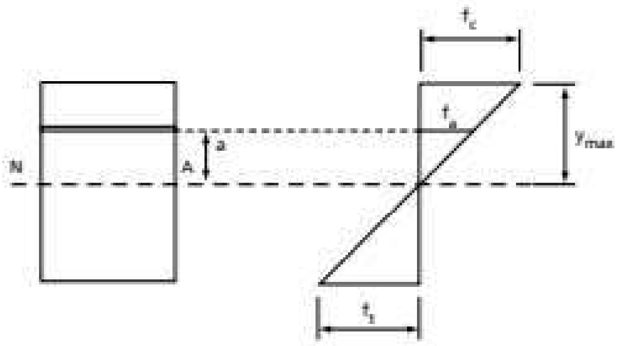



The moment caused by the external loads acting on the beam will be resisted by the moment of this internal couple. Therefore:

$$M = MR = C\ (or\ T)\ X\ h$$

Where: M = The external moment
MR = The internal resisting moment
C = Resultant of all compressive forces on the cross section of the beam
T = Resultant of all tensile forces on the cross-section of the beam
h = Lever arm of the reaction couple

Now consider a small element with the area (R) at a distance (a) from the neutral axis (NA).




Note that it is common practice to use the symbol f for bending stress, rather than the more general symbol. Maximum compressive stress ($f_c$) is assumed to occur in this case at the top of the beam. Therefore, by similar triangles, the stress in the chosen element is:

$$\frac{f_a}{a} = \frac{f_c}{y_{max}}, \quad f_a = a \times \frac{f_c}{y_{max}}$$

As force = stress × area, then the force on the element = $f_a \times R = a \times (f_c / y_{max}) \times R$

The resisting moment of the small element is:

force × distance (a) = $a \times (f_c / y_{max}) \times R \times a = Ra^2 \times (f_c / y_{max})$

The total resisting moment of all such small elements in the cross-section is:

$M_R = \sum Ra^2 \times (f_c / y_{max})$

But $\sum Ra^2 = I$, the moment of inertia about the neutral axis,

and therefore $M_R = I \times (f_c / y_{max})$

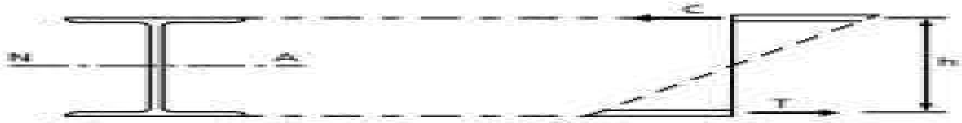
As the section modulus $Z_c = I / y_{max}$,

therefore $M_R = f_c \times Z_c = M$;

Similarly $M_R = f_t \times Z_t = M$.

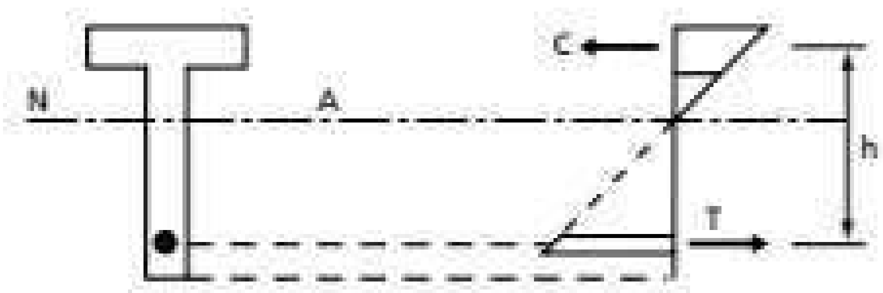
The maximum compressive stress ($f_c$) will occur in the cross-section area of the beam where the bending moment (M) is greatest. A size and shape of cross-section, i.e. its section modulus (Z), must be selected so that the $f_c$ does not exceed an allowable value. Allowable working stress values can be found in building codes or engineering handbooks. As the following diagrams show, the concept of a 'resisting' couple can be seen in many structural members and systems.


*Rectangular beams*




*Girders and I –beams (1/6 web area can be added to each flange area for moment resistance)*


*Rectangular reinforced-concrete beams (note that the steel bars are assumed to carry all the tensile forces).*




*Reinforced-concrete T-beams*

In summary the following equation is used to test for safe bending:

$f_w \geq f = M_{max} / Z$
where: $f_w$ = allowable bending stress
f = actual bending stress
$M_{max}$ = maximum bending moment
Z = section modulus.

#### 2.10.6.3.2 Horizontal Shear:

The horizontal shear force (Q) at a given cross-section in a beam induces a shearing stress that acts tangentially to the horizontal cross-sectional plane. The average value of this shear stress is:

$$\tau = \frac{Q}{A}$$

where A is the transverse cross-sectional area.

This average value is used when designing rivets, bolts and welded joints. The existence of such a horizontal stress can be illustrated by bending a paper pad. The papers will slide relative to each other, but in a beam this is prevented by the developed shear stress.

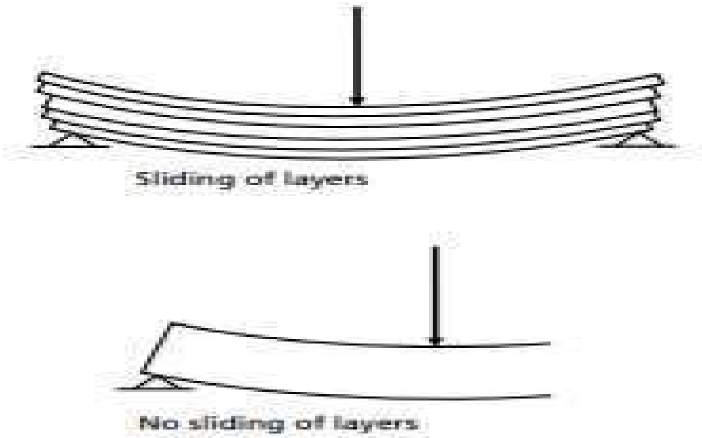
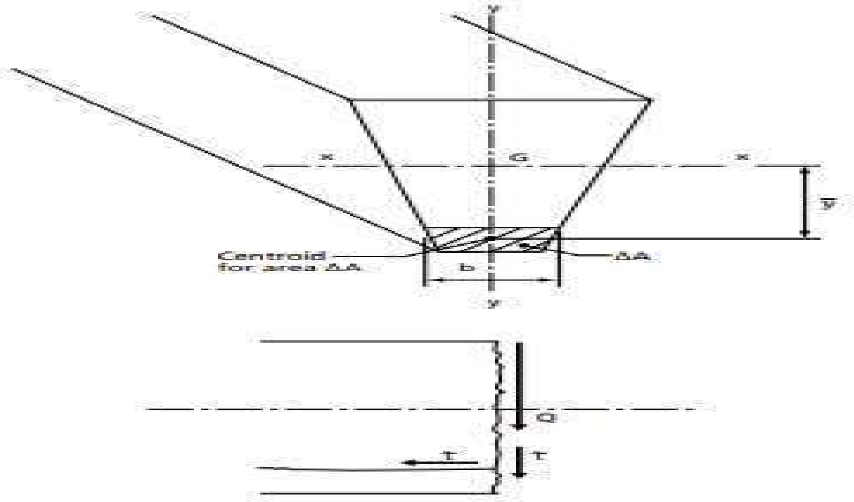



**Figure 7.2 Shearing effects on beams**

However, the shear stresses are not equal across the cross-section. At the top and bottom edge of the beam they must be zero, because no horizontal shear stresses can develop. If the shear stresses at a certain distance from the neutral axis are considered, their value can be determined according to the following formula:

$$\tau = \frac{Q \times \Delta A \times \bar{y}}{I \times b}$$

where: t = shear stress
Q = shear force
∆A = area for the part of the section being sheared off
¥= perpendicular distance from the centroid of PA to the neutral axis
I = moment of inertia for the entire cross-section
b = width of the section at the place where shear stress is being calculated.




Maximum horizontal shear force in beams It can be shown that the maximum shear stress tmax in a beam will occur at the neutral axis. Thus, the following relations for the maximum shear stress in beams of different shapes can be deduced, assuming the maximum shear force (Q) to be the end reaction at a beam support (column).

$$\text{For rectangular sections } \tau_{max} = \frac{3Q}{2bd} = \frac{3Q}{2A} = 1.5\,\frac{Q}{A}$$

$$\text{For square sections } \tau_{max} = \frac{3Q}{2a^2} = 1.5\,\frac{Q}{A}$$

$$\text{For circular sections } \tau_{max} = \frac{16Q}{3\pi D^2} = \frac{4Q}{3A}$$

For I-shaped sections of steel beams, a convenient approximation is to assume that all shearing resistance is afforded by the web plus the part of the flanges that forms a continuation of the web.

Thus:

For I-sections $\tau_{max} = \frac{Q}{d \times t}$

where:
d = depth of beam
t = thickness of web

If timber and steel beams with spans normally used in buildings are made large enough to resist the tensile and compressive stresses caused by bending, they are usually strong enough to resist the horizontal shear stresses also. However, the size or strength of short, heavily loaded timber beams may be limited by these stresses.

**2.10.6.3.3 Deflection of beams:**

Excessive deflections are unacceptable in building construction, as they can cause cracking of plaster in ceilings and can result in jamming of doors and windows. Most building codes limit the amount of allowable deflection as a proportion of the member's length, i.e. 1 /180, 1 /240 or 1 /360 of the length. For standard cases of loading, the deflection formulae can be expressed as:

$$\delta_{max} = K_c \times \frac{WL^3}{EI}$$

where:
$\delta_{max}$ = maximum deflection (mm)
$K_c$ = constant depending on the type of loading and the end support conditions
$W$ = total load (N)
$L$ = effective span (mm)
$E$ = modulus of elasticity (N/mm²)
$I$ = moment of inertia (mm⁴)

It can be seen that deflection is greatly influenced by the span L, and that the best resistance is provided by beams which have the most depth (d), resulting in a large moment of inertia.
Note that the effective span is greater than the clear span. It is convenient to use the centre to centre distance of the supports as an approximation of the effective span. Some standard cases of loading and resulting deflection for beams can be found later in this section

**2.10.7 Design criteria:**

The design of beams is dependent upon the following factors:

- Magnitude and type of loading
- Duration of loading
- Clear span
- Material of the beam
- Shape of the beam cross-section

Beams are designed using the following formulae:

*1. Bending stress*

$$f_a \geq f = \frac{M_{max}}{Z}$$

where:
$f_a$ = allowable bending stress
$f$ = actual bending stress
$M_{max}$ = maximum bending moment
$Z$ = section modulus

This relationship derives from simple beam theory and

$$\frac{M_{max}}{I_{NA}} = \frac{f_{max}}{y_{max}}$$

and

$$\frac{I_{NA}}{y_{max}} = Z$$

The maximum bending stress will be found in the section of the beam where the maximum bending moment occurs. The maximum moment can be obtained from the bending-moment diagram.

*2. Shear stress*

For rectangular cross-sections:

$$\tau_a \geq \tau = \frac{3 \times Q_{max}}{2 \times A} = \frac{3Q_{max}}{2bd}$$

For circular cross-sections:

$$\tau_a \geq \tau = \frac{4 \times Q_{max}}{3 \times A} = \frac{16Q_{max}}{3\pi d^2}$$

For I-shaped cross-sections of steel beams

$$\tau_w \geq \tau = \frac{Q_{max}}{A}$$

where:
$\tau_w$ = allowable shear stress
$\tau$ = actual shear stress
$Q_{max}$ = maximum shear force
$A$ = cross-section area

Like allowable bending stress, allowable shear stress varies for different materials and can be obtained from a building code. Maximum shear force is obtained from the shear-force diagram.

*3. Deflection*

In addition, limitations are sometimes placed on maximum deflection of the beam ($\delta_{max}$):

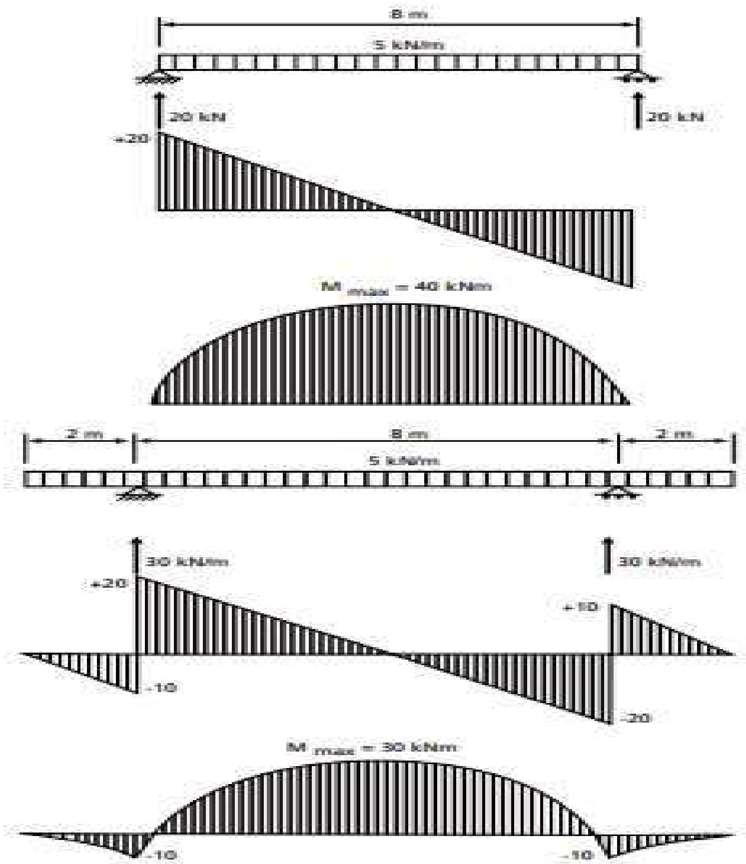
$$\delta_{max} = K_c \times \frac{WL^3}{EI}$$

### 2.10.7.1 Universal steel beams:

Steel beams of various cross-sectional shapes are commercially available. Even though the properties of their cross-sections can be calculated with the formulae given in the section 'Design of members in direct tension and compression', it is easier to obtain them from handbook tables. These tables will also take into consideration the effect of rounded edges, welds, etc. Sections of steel beams are indicated with a combination of letters and a number, where the letters represent the shape of the section and the number represents the dimension, usually the height, of the section in millimeters, e.g. IPE 100. In the case of HE sections, the number is followed by a letter indicating the thickness of the web and flanges, e.g. HE 180B. An example of an alternative method of notation is 305 × 102 UB 25, i.e. a 305 mm by 102 mm universal beam weighing 25 kg/m.

### 2.10.7.2 Continuous beams:

A single continuous beam extending over a number of supports will safely carry a greater load than a series of simple beams extending from support to support. Consider the shear force and bending moment diagrams for the following two beam loadings:




Although the total value of the load has increased, the maximum shear force remains the same but the maximum bending is reduced when the beam is cantilevered over the supports.

Although continuous beams are statically indeterminate and the calculations are complex, approximate values can be found with simplified equations. Conservative equations for two situations are as follows:

Load concentrated between supports: $BM = \frac{WL}{6}$

Load uniformly distributed: $BM = \frac{WL}{12}$

It is best to treat the two end sections as simple beams.

#### 2.10.7.3 Columns.

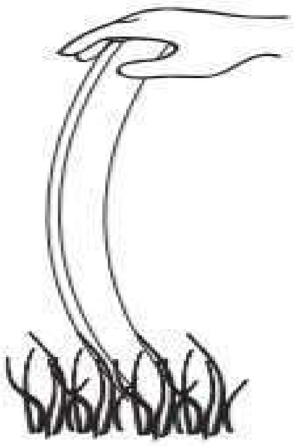
Although the column is essentially a compression member, the manner in which it tends to fail and the amount of load that causes failure depend on:

- ❖ The material of which the column is made.
- ❖ The shape of cross-section of the column.
- ❖ The end conditions of the column.

The first point is obvious: a steel column can carry a greater load than a timber column of similar size. Columns with a large cross-section area compared with the height are likely to fail by crushing.

#### 2.10.7.4 Buckling of slender columns:

If a long, thin, flexible rod is loaded axially in compression, it will deflect a noticeable amount. This phenomenon is called buckling and occurs when the stresses in the rod are still well below those required to cause a compression/shearing-type failure. Buckling is dangerous because it is sudden and, once started, is progressive.



Although the buckling of a column can be compared with the bending of a beam, there is an important difference in that the designer can choose the axis about which a beam bends, but normally the column will take the line of least resistance and buckle in the direction where the column has the least lateral unsupported dimension. As the loads on columns are never perfectly axial and the columns are not perfectly straight, there will always be small bending moments induced in the column when it is compressed. There may be parts of the cross-section area where the sum of the compressive stresses caused by the load on the column could reach values larger than the allowable or even the ultimate strength of the material.

Therefore the allowable compressive strength $\delta_{cw}$ is reduced by a factor $k_\lambda$, which depends on the slenderness ratio and the material used.

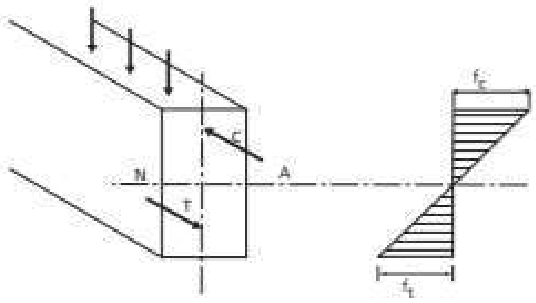
$$P_{bw} = k_\lambda \times \delta_{cw} \times A$$

where:
$P_{bw}$ = allowable load with respect to buckling
$k_\lambda$ = reduction factor, which depends on the slenderness ratio
$\delta_{cw}$ = allowable compressive stress
$A$ = cross-section area of the column

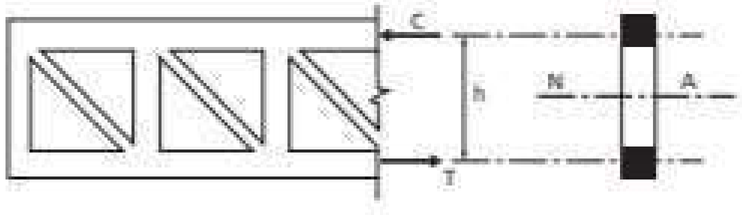
When the load on a column is not axial but eccentric, a bending stress is induced in the column as well as a direct compressive stress. This bending stress will need to be considered when designing the column with respect to buckling.

**2.10.7.5 Trusses:**

It can be seen from the stress distribution of a loaded beam that the greatest stress occurs at the top and bottom extremities of the beam.




This led to the improvement on a rectangular section by introducing the I-section in which the large flanges were situated at a distance from the neutral axis. In effect, the flanges carried the bending in the form of tension stress in one flange and compression stress in the other, while the shear was carried by the web. For these situations where bending is high but shear is low, for example in roof design, material can be saved by raising a framework design. A truss is a pinpointed framework.




A truss concentrates the maximum amount of materials as far away as possible from the neutral axis. With the resulting greater moment arm (h), much larger moments can be resisted. Resistance of a truss at a section is provided by:

$$M = C \times h = T \times h$$

where:
C = T in parallel chords and:
C = compression in the top chord of the truss.
T = tension in bottom chord of a simply supported truss.
h = vertical height of truss section.

If either C or T or h can be increased, then the truss will be capable of resisting heavier loads. The value of h can be increased by making a deeper truss. Allowable C- or T-stresses can be increased by choosing a larger cross-section for the chords of the truss, or by changing to a stronger material. A framework or truss can be considered as a beam with the major part of the web removed. This is possible where bending stresses are more significant than shear stresses. The simple beam has a constant section along its length, yet the bending and shear stresses vary. The truss, comprising a number of simple members, can be fabricated to take into account this change in stress along its length. The pitched-roof truss is the best example of this, although the original shape was probably designed to shed rainwater. Roof trusses consist of sloping rafters that meet at the ridge, a main tie connecting the feet of the rafters and internal bracing members. They are used to support a roof covering in conjunction with purlins, which are laid longitudinally across the rafters, with the roof cover attached to the purlin. The arrangement of the internal bracing depends on the span. Rafters are normally divided into equal lengths and, ideally, the purlins are supported at the joints so that the rafters are only subjected to axial forces. This is not always practicable, because purlin spacing is dependent on the type of roof covering. When the purlins are not supported at the panel joints, the rafter members must be designed for bending as well as axial force. The internal bracing members of a truss should be triangulated and, as far as possible, arranged so that long members are in tension and compression members are short to avoid buckling problems. The outlines in Figure 7.4 give typical forms for various spans. The thick lines indicate struts. The lattice girder, also called a truss, is a plane frame of open web construction, usually with parallel chords or booms at top and bottom. There are two main types, the N- (or Pratt) girder and the Warren girder. They are very useful in long-span construction, in which their small depth-to-span ratio, generally about 1 /10 to 1 /14, gives them a distinct advantage over roof trusses. Steel and timber trusses are usually designed assuming pin-jointed members. In practice, timber trusses are assembled with bolts, nails or special connectors, and steel trusses are bolted, riveted or welded. Although these rigid joints impose secondary stresses, it is seldom necessary to consider them in the design procedure.

The following steps should be considered when designing a truss:

- Select general layout of truss members and truss spacing.
- Estimate external loads to be applied including self-weight of truss, purlins and roof covering, together with wind loads.
- Determine critical (worst combinations) loading. It is usual to consider dead loads alone, and then dead and imposed loads combined.
- Analyse the framework to find forces in all members.
- Select the material and section to produce in each member a stress value that does not exceed the permissible value.

Particular care must be taken with compression members (struts), or members normally in tension but subject to stress reversal caused by wind uplift. Unless there are particular constructional requirements, roof trusses should, as far as possible, be spaced to achieve minimum weight and economy of materials used in the total roof structure. As the distance between trusses is increased, the weight of the purlins tends to increase more rapidly than that of the trusses. For spans up to around 20 m, the spacing of steel trusses is likely to be about 4 metres and, in the case of timber, 2 metres. The pitch, or slope, of a roof depends on locality, imposed loading and type of covering. Heavy rainfall may require steep slopes for rapid drainage; a slope of 26° is common for corrugated steel and asbestos roofing sheets. Manufacturers of roofing material usually make recommendations regarding suitable slopes and fixings.

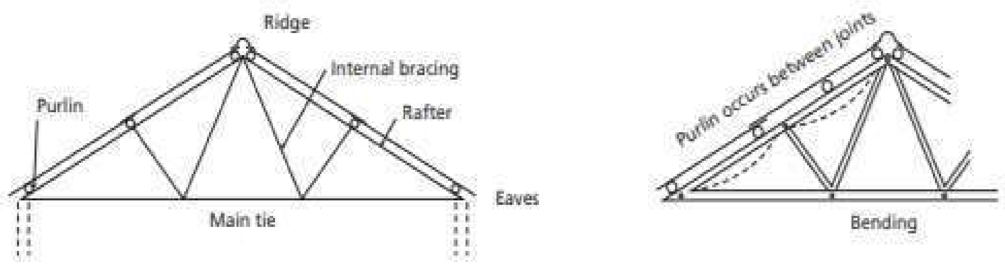
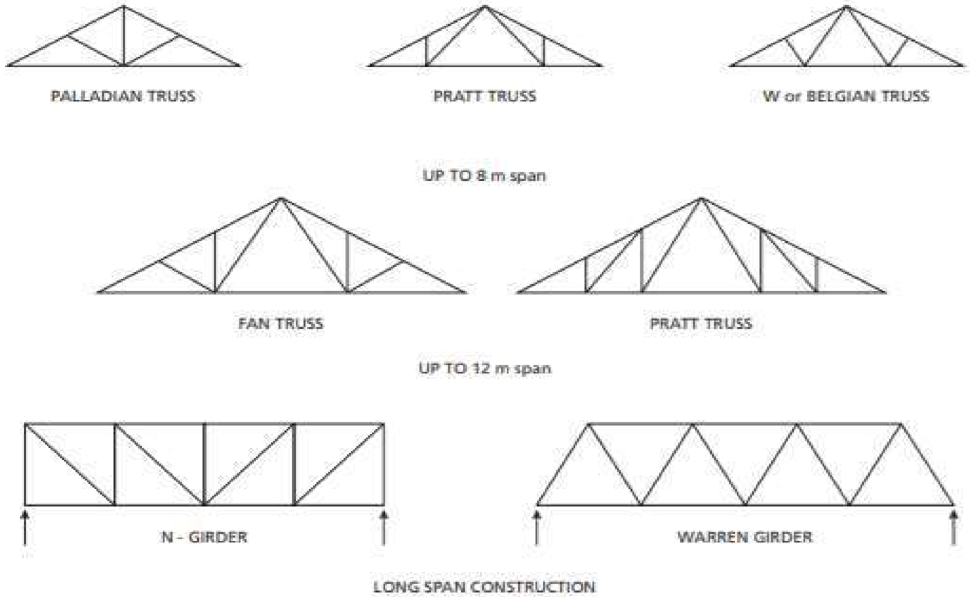



Figure 7.4 **Truss components**




To enable the designer to determine the maximum design load for each member, the member forces can be evaluated either by calculation or graphical means, and the results tabulated as shown:

| Member | Dead Load D | Imposed Load I | Dead + Imposed Load D + I | Wind Load W | Design Load |
|---|---|---|---|---|---|

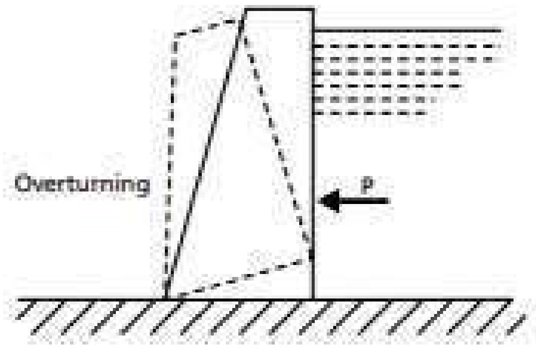
A simplified approach can be taken if the intention is to use a common section throughout. Once the layout has been chosen, the member that will carry the maximum load can be established. An understanding of the problems of instability of compression members will lead the designer to concentrate on the top chord or rafter members. A force diagram or method of sections can then be used to determine the load on these members and the necessary size.

### 2.10.7.6 Retaining Walls:

Wall failure Walls are commonly used to retain soil on sloping sites, water in a pond or bulk products within a storage area. There are several limiting conditions which, if exceeded, can lead to the failure of a retaining wall. Each must be addressed in designing a wall.

#### 2.10.7.6.1 Overturning:

This occurs when the turning moment resulting from lateral forces exceeds that exerted by the self-weight of the wall.

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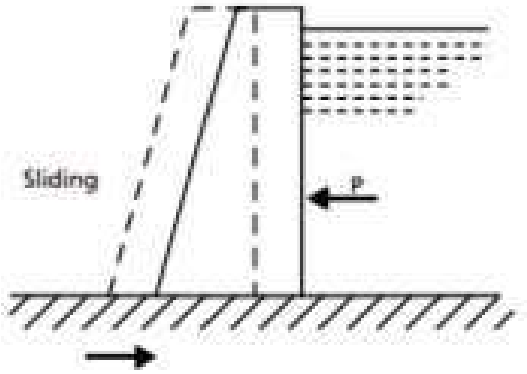
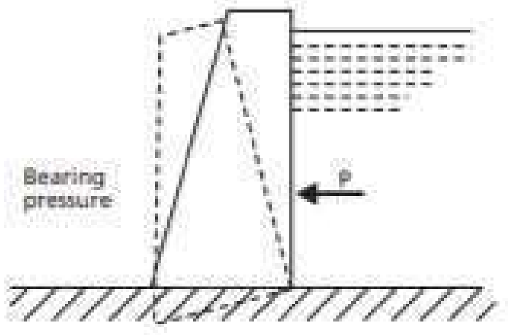
**2.10.7.6.2 Sliding:**

The wall will slide if the lateral thrust exceeds the frictional resistance developed between the base of the wall and the soil



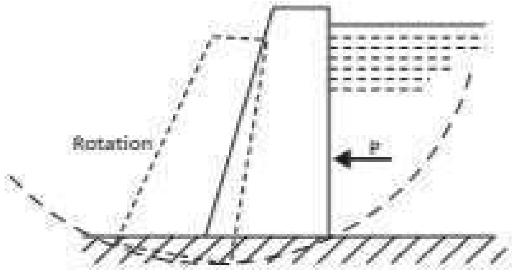

**2.10.7.6.3 Bearing on ground:**

The normal pressure between the base of the wall and the soil beneath can cause a bearing failure of the soil, if the ultimate bearing capacity is exceeded. Usually the allowable bearing pressure will be one-third of the ultimate value. Note that the pressure distribution across the base is not constant.



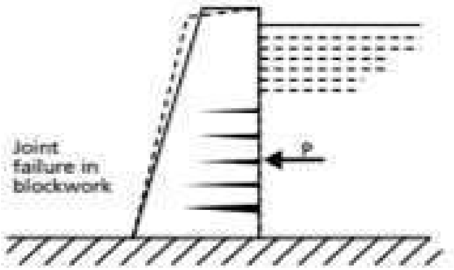
**2.10.7.6.4 Rotational Slip**:

The wall and a large amount of the retained material rotate about point O if the shear resistance developed along a circular arc is exceeded. The analysis is too complex to include here.

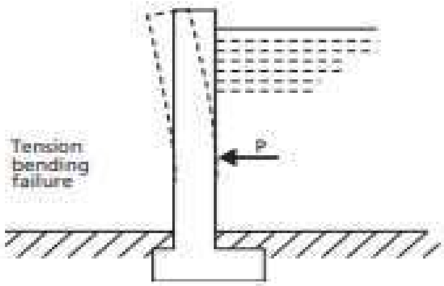



**2.10.7.6.5 Wall material failure:**

The structure itself must be capable of withstanding the internal stresses set up, that is to say, the stresses must not exceed allowable values. Factors of safety used here depend on the material and the level of the designer's knowledge of the loads actually applied. Naturally, both shear and bending must be considered, but the most critical condition is likely to be tension failure of the 'front' facet.




Gravity walls and dams are dependent on the effect of gravity, largely from the self-weight of the wall itself, for stability. Other types of wall rely on a rigid base, combined with a wall designed against bending, to provide an adequate structure.

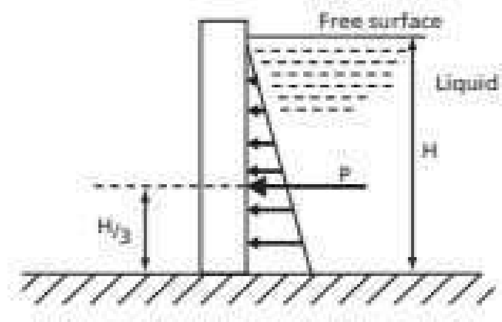



**2.10.7.6.6** Liquid pressure**:**

The pressure in a liquid is directly proportional to both the depth and the specific weight of the liquid (w) which is the weight per unit volume,

$$w = \rho g \ (N/m^3),$$

where: $\rho$ = density of liquid ($kg/m^3$)
g = gravitational acceleration (9.81 $m/s^2$)

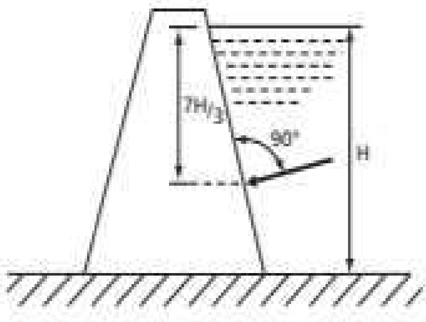



The pressure at a given depth acts equally in all directions, and the resultant force on a dam or wall face is normal to the face. The pressure from the liquid can be treated as a distributed load with linear variation in a triangular load form, with a centroid two-thirds of the way down the wet face.

$$p = \rho g H = wH \ (N/m^2) \text{ and:}$$

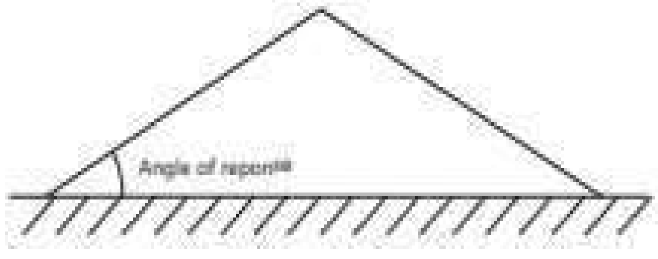
$$P = \frac{wH^2}{2} \text{ acting at a depth of } \frac{2}{3}H$$

It should be noted that a wall retaining a material that is saturated (waterlogged) must resist this liquid pressure in addition to the lateral pressure from the retained material.




**2.10.7.6.7 Pressure exerted by granular materials:**

Granular materials such as sandy soils, gravelly soils and grain possess the property of internal friction (friction between adjacent grains), but are assumed not to possess the property of cohesion. If a quantity of such material in a dry condition is tipped on to a flat surface, it will form a conical heap: the shape maintained by this internal friction between grains. The angle of the sloping side is known as the angle of repose.



For a dry material, the angle of repose is usually equal to the angle of shearing resistance of the material. This angle of shearing resistance is called the angle of internal friction (θ). The angle of friction is the essential property of a granular material on which Rankine's theory is based. This theory enables the lateral pressure to be expressed as a proportion of the vertical pressure, which was shown (before) to depend on specific weight and depth only. In this case, at a depth h the active lateral pressure is given by:

$$P = k \times w \times h$$ where:

k = a constant dependent on the materials involved.

Although there is some friction between the retained material and the wall face, usually this is disregarded, giving a relatively simple relationship for k:

$$k = \frac{1 - \sin\theta}{1 + \sin\theta}$$

where:

θ = the angle of friction

$$p_a = \frac{1 - \sin\theta}{1 + \sin\theta} \times wH \, (\mathrm{N/m^2})$$

where:

$p_a$ = total force per metre of wall-face (N)

$$P_a = \frac{1 - \sin\theta}{1 + \sin\theta} \times \frac{wH^2}{2} \quad \text{(N/m length of wall)}$$

$P_a$ = total force per metre of wall face (N)

This gives the approximate horizontal resultant force on a vertical wall face when it is retaining material that is level with the top of the wall. If the surface of the retained material is sloping up from the wall at an angle equal to its angle of repose, a modification is required.

### 2.10.7.7 Slabs:

A slab is a flat two dimensional planar structural element having thickness small compared to its other two dimensions. It provides a working flat surface or a covering shelter in buildings. It primarily transfer the load by bending in one or two directions. Reinforced concrete slabs are used in floors, roofs and walls of buildings and as the decks of bridges. The floor system of a structure can take many forms such as in situ solid slab, ribbed slab or pre-cast units. Slabs may be supported on monolithic concrete beam, steel beams, walls or directly over the columns. Concrete slab behave primarily as flexural members and the design is similar to that of beams.

### 2.10.7.8 Methods of Analysis:

The analysis of slabs is extremely complicated because of the influence of number of factors stated above. Thus the exact (close form) solutions are not easily available. The various methods are:

- ❖ Classical methods – Levy and Naviers solutions (Plate analysis)

- ❖ Yield line analysis – Used for ultimate /limit analysis
- ❖ Numerical techniques – Finite element and Finite difference method.
- ❖ Semi empirical – Prescribed by codes for practical design which uses coefficients.

**2.10.7.9 General Guidelines:**

2.10.7.9.1 **Effective span of slab** :

Effective span of slab shall be lesser of the two

- ❖ l = Clear span + d (effective depth )
- ❖ l = Center to center distance between the support

**2.10.7.9.2** Depth of slab:

The depth of slab depends on bending moment and deflection criterion. the trail depth can be obtained using:

- ❖ Effective depth d= Span /((l/d)Basic x modification factor)
- ❖ For obtaining modification factor, the percentage of steel for slab can be assumed from 0.2 to 0.5%
- ❖ The effective depth d of two way slabs can also be assumed using cl.24.1,IS 456 provided short span is ≤ 3.5m and loading class is < 3.5KN/m2

| Type of support | Fe-250 | Fe-415 |
|---|---|---|
| Simply supported | l/35 | l/28 |
| continuous | l/40 | l/32 |

**NOTES**

**1 For slabs spanning in two directions, the shorter of the two spans should be used for calculating the span to effective depth ratios.**

**2 For two-way slabs of shorter spans (up to 3.5 m) with mild steel reinforcement, the span to overall depth ratios given below may generally be assumed to satisfy vertical deflection limits for loading class up to 3 kN/m².**

| | |
|---|---|
| **Simply supported slabs** | **35** |
| **Continuous slabs** | **40** |

**For high strength deformed bars of grade Fe 415, the values given above should be multiplied by 0.8.**

OR

The following thumb rules can be used

- ❖ One way slab d=(l/22) to (l/28).
- ❖ Two way simply supported slab d=(l/20) to (l/30)
- ❖ Two way restrained slab d=(l/30) to (l/32)

❖ **Load on slab:**

The load on slab comprises of Dead load, floor finish and live load. The loads are calculated per unit area (load/$m^2$).

- ❖ Dead load = D x 25 kN/$m^2$ ( Where D is thickness of slab in m)

- ❖ Floor finish (Assumed as)= 1 to 2 kN/m$^2$
- ❖ Live load (Assumed as) = 2 to 5 kN/m$^2$ (depending on the occupancy of the building)

**2.10.7.10 Detailing Requirements as Per IS 456 : 2000:**

**2.10.7.10.1 Nominal Cover:**

IS 456 : 2000: clause 26.4.2 table 16

- ❖ For Mild exposure – 20 mm
- ❖ For Moderate exposure – 30 mm

However, if the diameter of bar do not exceed 12 mm, or cover may be reduced by 5 mm. Thus for main reinforcement up to 12 mm diameter bar and for mild exposure, the nominal cover is 15 mm

**Table 16 Nominal Cover to Meet Durability Requirements**
(*Clause* 26.4.2)

| Exposure | Nominal Concrete Cover in mm not Less Than |
|---|---|
| Mild | 20 |
| Moderate | 30 |
| Severe | 45 |
| Very severe | 50 |
| Extreme | 75 |

NOTES

1 For main reinforcement up to 12 mm diameter bar for mild exposure the nominal cover may be reduced by 5 mm.

2 Unless specified otherwise, actual concrete cover should not deviate from the required nominal cover by $^{+10}_{0}$ mm

3 For exposure condition 'severe' and 'very severe', reduction of 5 mm may be made, where concrete grade is M35 and above.

**2.10.7.10.2 Minimum reinforcement** :

The reinforcement in either direction in slab shall not be less than (IS 456 : 2000: clause 26.5.2.1)

- ❖ 0.15% of the total cross sectional area for Fe-250 steel
- ❖ 0.12% of the total cross sectional area for Fe-415 & Fe-500 steel.

**2.10.7.10.3 Spacing of bars** :

The maximum spacing of bars shall not exceed (IS 456 : 2000: clause 26.3.3(b))

- ❖ Main Steel – 3d or 300 mm whichever is smaller
- ❖ Distribution steel –5d or 450 mm whichever is smaller

Where, 'd' is the effective depth of slab.

***Note: The minimum clear spacing of bars is not kept less than 75 mm (Preferably 100 mm) though code do not recommend any value.***

**2.10.7.10.4 Maximum diameter of bar:**

The maximum diameter of bar in slab, shall not exceed D/8, where D is the total thickness of slab.(IS 456 : 2000: clause 26.5.2.2)

**2.10.7.11 Behavior of One Way Slab:**

When a slab is supported only on two parallel apposite edges, it spans only in the direction perpendicular to two supporting edges. Such a slab is called one way slab. Also, if the slab is supported on all four edges and the ratio of longer span (ly) to shorter span (lx) i.e ly/lx > 2, practically the slab spans across the shorter span. Such slabs are also designed as one way slabs. In this case, the main reinforcement is provided along the spanning direction to resist one way bending.

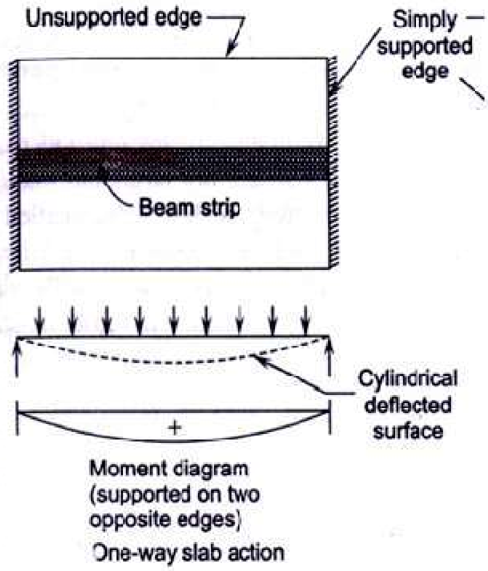



Fig.1: Behavior of one way slab

**2.10.7.12 Behavior of Two Way Slabs:**

A rectangular slab supported on four edge supports, which bends in two orthogonal directions and deflects in the form of dish or a saucer is called two way slabs. For a two way slab the ratio of ly/lx shall be ≤ 2.0.

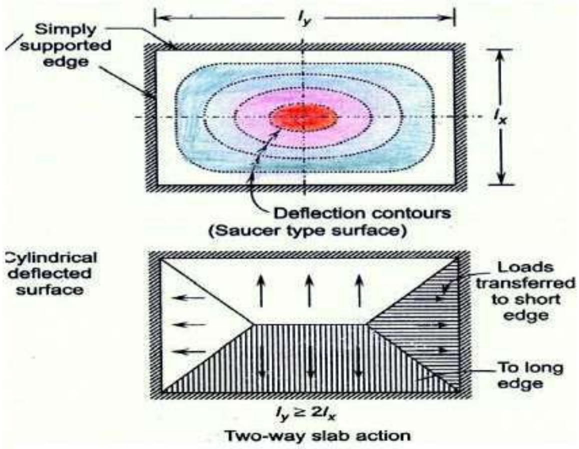



Fig. 2: Behavior of Two way slab

Since, the slab rest freely on all sides, due to transverse load the corners tend to curl up and lift up. The slab loses the contact over some region. This is known as lifting of corner. These slabs are called two way simply supported slabs. If the slabs are cast monolithic with the beams, the corners of the slab are restrained from lifting. These slabs are called restrained slabs. At corner, the rotation occurs in both the direction and causes the corners to lift. If the corners of slab are restrained from lifting, downward reaction results at corner & the end strips gets restrained against rotation. However, when the ends are restrained and the rotation of central strip still occurs and causing rotation at corner (slab is acting as unit) the end strip is subjected to torsion.

### 2.10.7.13 Foundation:

Building Foundation is the part of a building which is in direct contact with the ground and transmits loads of the superstructure to the supporting soil. The strength and stability of any building depends upon its foundation.

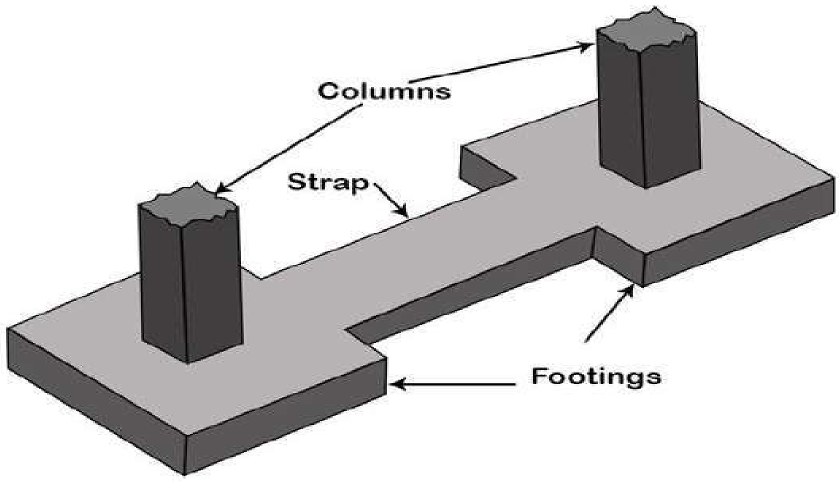
A strong foundation is must for any building. The load on the foundation increases due to the construction of the building. Loads are also responsible for settlement of the building. Lot of times, the failure of a foundation is responsible for the collapse/failure of the structure.

One should follow the following procedure while designing the building foundation;

- Carry out detailed site investigation, to obtain necessary information about the soil, its soil bearing capacity, settlement characteristics, safe bearing capacity at required/suitable depth for particular type of footing, water table level etc.
- Sketch the soil profile showing the stratification at the site along with the position of maximum water level. Note down the physical and engineering properties of each layer on the soil profile itself.
- Determine the magnitude and distribution of loads from the superstructure.
- On the basis of the type of structure, amount of loads coming on the foundation and soil profile and its safe bearing capacity decide the type of foundation and minimum depth of foundation.
- Select appropriate dimensions of the foundation. Determine safe bearing capacity of foundation, taking into consideration the engineering properties of soil, depth and plan dimensions of the foundation.
- Determine intensity of maximum base pressure which should be less than the safe bearing capacity.
- Determine the settlement, tilt and horizontal displacement of the foundation under the actual forces and moments and compare with the respective permissible values.
- Check the stability of the foundation against horizontal and uplift forces (Subsoil water pressure).
- Carry out the structural design of the foundation keeping in view the critical sections for bending moment and shear.
- Assess the need of foundation drains, waterproofing and damp proofing.
- Prepare the complete working drawing for execution of work on the field.

#### 2.10.7.13.1 Types of Foundation:

To understand the various types of foundation first, let us understand the concept of footing. Footing is the lowest unit of a foundation built with brickwork, masonry or concrete to transmit the load directly to the ground.




When a suitable site is selected having satisfactory subsoil, it is not difficult to decide the type of foundation. There are two main types of foundation,

- ❖ Shallow Foundation
- ❖ Deep Foundation

#### 2.10.7.13.2 Shallow Foundation

According to 'Terzaghi' (Austrian Civil Engineer, Geotechnical Engineer and Geologist also Known as the Father of Soil Mechanics), a foundation is shallow if the depth of footing is equal to or less than its width.

The shallow foundation is a building foundation to distribute the structural loads over a wide horizontal area at shallow depth below the ground level. The various types of shallow foundation are:

- ❖ Spread Footings
- ❖ Grillage Foundation
- ❖ Eccentrically Loaded Footings
- ❖ Combined Footings
- ❖ Raft Foundation

#### 2.10.7.13.3 Deep Foundation

According to 'Terzaghi' (Austrian Civil Engineer, Geotechnical Engineer and Geologist also Known as the Father of Soil Mechanics), a foundation is profound if its depth of footing is equal to or greater than its width. The deep foundation is a building foundation to distribute the structural loads at considerable depth below the ground level. the various types of deep foundations are:

- ❖ Pile foundation
- ❖ Caissons / Well Foundations

## 2.11 Seismic Design and Earthquake Preventive Measures in Structural Design

### 2.11.1 Basic Aspects Of Seismic Design:

The mass of the building being designed controls seismic design in addition to the building stiffness, because earthquake induces inertia forces that are proportional to the building mass. Designing buildings to behave elastically during earthquakes without damage may render the project economically unviable. As a consequence, it may be necessary for the structure to undergo damage and thereby dissipate the energy input to it during the earthquake. Therefore, the traditional earthquake-resistant design philosophy requires that normal buildings should be able to resist (a) Minor (and frequent) shaking with no damage to structural and non-structural elements; (b) Moderate shaking with minor damage to structural elements, and some damage to non-structural elements; and (c) Severe (and infrequent) shaking with damage to structural elements, but with no collapse (to save life and property inside/adjoining the building). Therefore, buildings are designed only for a fraction (~8-14%) of the force that they would experience, if they were designed to remain elastic during the expected strong ground shaking, and thereby permitting damage but, sufficient initial stiffness is required to be ensured to avoid structural damage under minor shaking. Thus, seismic design balances reduced cost and acceptable damage, to make the project viable. This careful balance is arrived based on extensive research and detailed post-earthquake damage assessment studies. A wealth of this information is translated into precise seismic design provisions. In contrast, structural damage is not acceptable under design wind forces. For this reason, design against earthquake effects is called as earthquake-resistant design and not earthquake-proof design.

The design for only a fraction of the elastic level of seismic forces is possible, only if the building can stably withstand large displacement demand through structural damage without collapse and undue loss of strength. This property is called ductility. It is relatively simple to design structures to possess certain lateral strength and initial stiffness by appropriately proportioning the size and material of the members. But, achieving sufficient ductility is more involved and requires extensive laboratory tests on full-scale specimen to identify preferable methods of detailing. In summary, the loading imposed by earthquake shaking under the building is of displacement-type and that by wind and all other hazards is of force-type. Earthquake shaking requires buildings to be capable of resisting certain relative displacement within it due to the imposed displacement at its base, while wind and other hazards require buildings to resist certain level of force applied on it. While it is possible to estimate with precision the maximum force that can be imposed on a building, the maximum displacement imposed under the building is not as precisely known. For the same maximum displacement to be sustained by a building, wind design requires only elastic behavior in the entire range of displacement, but in earthquake design there are two options, namely design the building to remain elastic or to undergo inelastic behavior. The latter option is adopted in normal buildings, and the former in special buildings, like critical buildings of nuclear power plants.

### 2.11.2 Earthquake Demand Versus Earthquake Capacity:

Unlike all other loading effects, e.g., wind loads, wave loads (excluding tsunami loads), blast loads, snow loads, imposed (live) loads and dead loads, earthquake shaking is the most severe, because it imposes displacement under the building, which is time varying. This, in turn, demands lateral deformation in the building between its base and upper elevations. Higher is the seismic zone, larger is the severity of this imposed relative deformation. Therefore, the main challenge is to meet the double demand – the building should be able to withstand this imposed deformation with damage under small intensity shaking, and with no collapse under high intensity shaking. The building needs to possess large inelastic deformation capacity and needs to have the strength in all its members to sustain the forces and moments induced in them. The method of design of buildings should therefore take into account the deformation demand on the building, and the deformation capacity of the building. The former depends on the seismo-tectonic setting of the location of the building, but the latter is within the control of the design professionals (i.e., architects and engineers). The concern is that both of these quantities have uncertainties. On one hand, even though some understanding is available on the maximum possible ground displacement at a location, earth scientists are not able to clearly provide the upper bound for these numbers. Each new damaging earthquake has always provided surprises. And, on the other hand, analytical tools are not available to estimate precisely the overall nonlinear behavior of an as-built structure, and its ultimate deformation capacity.

On part of the design engineer, a procedure should be employed that is known to result in higher confidence on the structural safety of the building being designed to withstand without collapse during expected severe earthquake shaking and render the requisite post-earthquake performance (e.g., at least a minimum desired ultimate deformation capacity). There are many procedures that are adopted/ suggested worldwide. One structural design procedure includes adherence to the following sequence:

❖ Arrive at a simple overall geometry of the building for the needed height. Building should be well-proportioned in keeping with the known tenets of acceptable upper limits of overall slenderness ratio and plan aspect ratio, and all the discussions available in earthquake design literature on acceptable seismic structural configurations;

❖ Adopt a structural system that will resist the vertical and lateral loads offering direct load paths in both plan directions of the building. It is preferable to use structural walls in RC building intended to resist strong earthquake shaking.

❖ Determine the preliminary sizing of individual structural elements, based on acceptable slenderness ratios and cross-sectional aspect ratios, and minimum reinforcement requirements.

❖ Identify a desired collapse mechanism in which the building should deform in, under the extreme condition of collapse, if ever, when the earthquake shaking well exceeds the design earthquake shaking for which buildings are normally designed. Usually, in frame structures, plastic moment hinges are desired at the ends of the beams with good rotational ductility. The hinge forms over a small length of the beam, often termed as plastic hinge length; this length depends on the depth, span and end connectivity of the member.

❖ Prepare a basic structural analysis model of the building with the dimensions and details obtained from preliminary design strategies. Impose a horizontal deformation on the building corresponding to permissible inter-storey drift at all storeys, and perform an elastic analysis of the building. Use concentrated loads at floor levels to push the building by the desired amounts. Note that this step is not usual adopted by common designers. Instead, they apply design lateral forces, perform structural analysis, and then design structural elements based on stress resultants obtained from structural analysis. In the sequence of steps suggested in this structural design procedure, that step appears later as Step 8 below.

❖ Perform seismic design of all structural elements of the building. For instance, in a moment resisting frame building: 1. Design the slabs of the building. 2. Design beams first for flexure, and then for shear, adopting the capacity design method for design of shear following the desired collapse mechanism identified. 3. Design all columns and structural walls, to be stronger than the connected beams, first for flexure, and then for shear, adopting the capacity design method for design of shear and following the desired collapse mechanism identified. 4. Design the beam-to-column, beam-to-wall and slab-to-wall joints. 5. Design the foundation(s) of the building. 6. Ensure that the soil underneath is capable of resisting the loads from above under strong shaking, and that it remains intact during the said shaking.

❖ Prepare the improved structural analysis model of the building with the dimensions and details obtained from the design calculations performed above. Estimate the fundamental translational natural period T of the building, and calculate the design seismic base shear VB on the building.

❖ Apply the design seismic base shear VB on the structural analysis model of the building. And, check the adequacy of the design of all structural elements, including beam-column and beam wall joints.

❖ Verify, if the desired mechanism is generated in the building through: 1. Nonlinear quasi-static displacement pushover analysis of the building to begin with, and then 2. Nonlinear time-history analysis of the building under different ground motions, whose intensities and spectrum are within the design shaking intensities and design spectrum, respectively. If the desired mechanism is not achieved, make suitable changes in the design (i.e., choice of the structural system, and/or proportioning of structural members) to achieve the same. The above steps should be repeated for the new design chosen. If the desired mechanism is achieved, requisite ductile detailing may be performed and the drawings prepared accordingly.

2.11.3 **Design Seismic Force**.

Earthquake produces ground motion due to which the structure is subjected to lateral seismic forces in horizontal directions and vertical seismic forces. The buildings are designed for these seismic forces. For seismic design of buildings, the lateral seismic forces are critical. The lateral seismic forces are determined at each floor level and their cumulative value from top to any floor level provides the storey shear at that floor level. Cumulative value of lateral forces from top floor to base gives the base shear. Revised provisions in the code have affected the factors to be considered for determining the design lateral forces and base shear which are discussed below. The seismic forces are determined either by static method or by dynamic method depending upon location, type, and configuration of structure. The revised provisions of the code affecting calculation of design seismic forces are discussed below for both these methods.

**2.11.3.1 Static Analysis:**

It is known as Equivalent Static Seismic Force Method. This method is used for simple buildings of low height in less severe seismic zones as per the criteria given in the codes. The revised codes have made this criterion more stringent. Now only regular buildings with height < 15M in seismic Zone II can be designed using static analysis. For all other buildings, dynamic analysis is made mandatory. In this method, primarily design base shear $V_B$ is calculated for the building. Then, this design base shear value is distributed to the various floor level at the corresponding centre of mass. And finally, this design seismic force at each floor shall be distributed to individual lateral load resisting elements by structural analysis considering the floor diaphragm action.

Design Seismic Base Shear,

$$V_B = A_h W$$

Where, W= Seismic Weight of the building

$A_h$ = Design Horizontal Seismic Coefficient = $(Z/2)(I/R)(S_a/g)$

Z= Zone Factor,

I = Importance Factor,

R= Response Reduction Factor,

$S_a/g$ = Design Acceleration coefficient of different soil

The design lateral force at any floor i is calculated using following formula

$Q_i = [\{W_i \times h_i^2\} / \{ \sum \boldsymbol{W_j h_j}\text{^}\boldsymbol{{}^2 n_j}=\mathbf{1} \}] V_B$

Where, Qi = Design lateral force at floor i

Wj = seismic weight of floor i

hi = height of floor i measured from base

n = number of story in building that is number of levels at which masses are located.

❖ **Important Factor (I):** IS-1893 Part I Clause 7.2.3 Besides the earlier importance factors of 1.5 and 1.0, an intermediate importance factor of 1.2 is introduced for residential or commercial buildings with occupancy more than 200 persons as shown in Table 8 of the code.

**Table 8 Importance Factor (*I*)**
(*Clause* 7.2.3)

| Sl No. (1) | Structure (2) | *I* (3) |
|---|---|---|
| i) | Important service and community buildings or structures (for example, critical governance buildings, schools), signature buildings, monument buildings, lifeline and emergency buildings (for example, hospital buildings, telephone exchange buildings, television station buildings, radio station buildings, bus station buildings, metro rail buildings and metro rail station buildings), railway stations, airports, food storage buildings (such as warehouses), fuel station buildings, power station buildings, and fire station buildings), and large community hall buildings (for example, cinema halls, shopping malls, assembly halls and subway stations) | 1.5 |
| ii) | Residential or commercial buildings [other than those listed in Sl No. (i)] with occupancy more than 200 persons | 1.2 |
| iii) | All other buildings | 1.0 |

NOTES

1 Owners and design engineers of buildings or structures may choose values of importance factor *I* more than those mentioned above.

2 Buildings or structures covered under Sl No. (iii) may be designed for higher value of importance factor *I*, depending on economy and strategy.

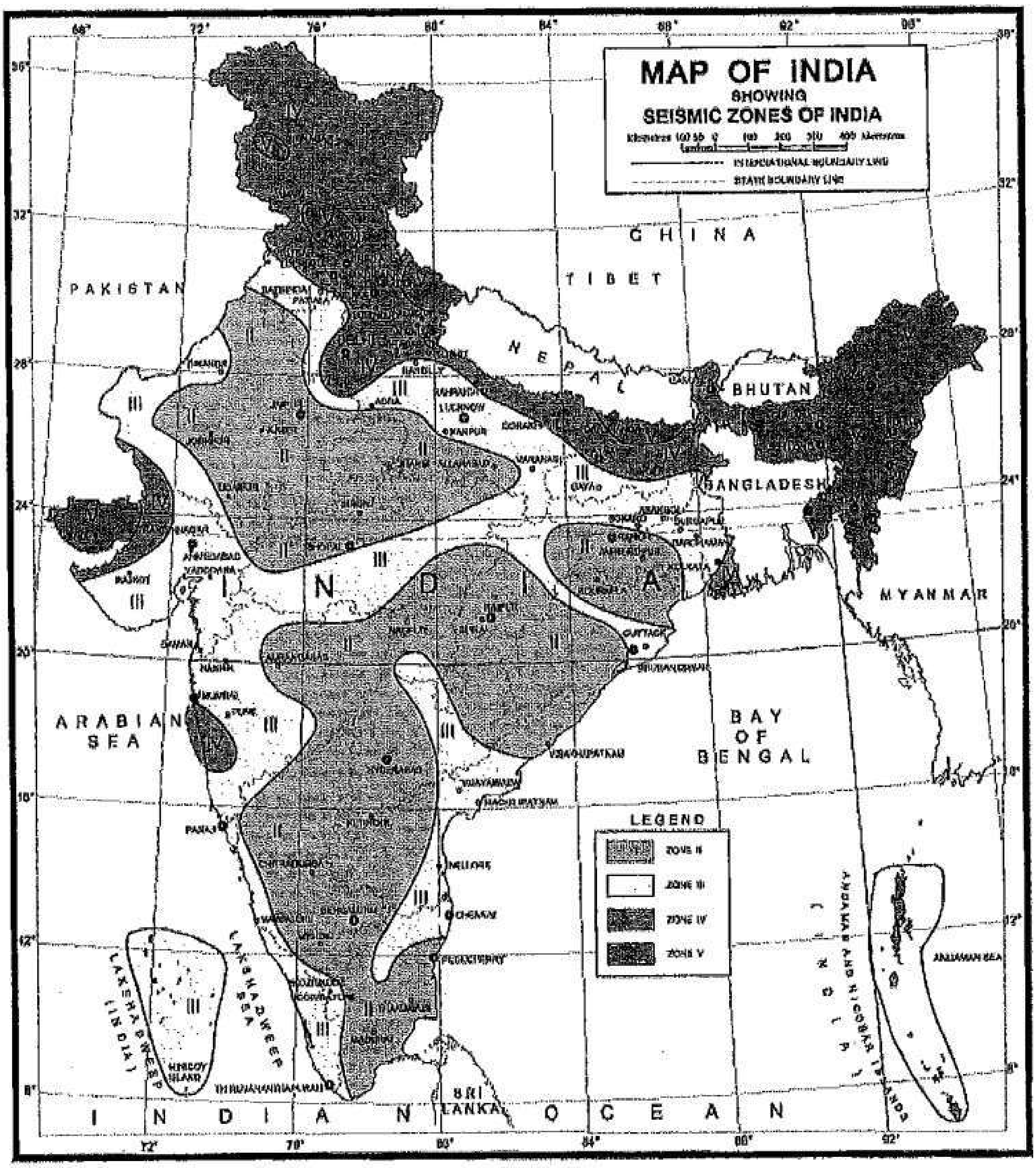
3 In Sl No. (ii), when a building is composed of more than one structurally independent unit, the occupancy size shall be for each of the structurally independent unit of the building.

4 In buildings with mixed occupancies, wherein different *I* factors are applicable for the respective occupancies, larger of the importance factor *I* values shall be used for estimating the design earthquake force of the building.

❖ **Zone Factor (Z):** IS-1893 Part I Clause 6.4.2 Table 3 Value of Z is 0.1, 0.16, 0.24 & 0.36 for seismic zones II, III, IV & V respectively.

**Table 3 Seismic Zone Factor *Z***
(*Clause* 6.4.2)

| Seismic Zone Factor (1) | II (2) | III (3) | IV (4) | V (5) |
|---|---|---|---|---|
| Z | 0.10 | 0.16 | 0.24 | 0.36 |






Based upon Survey of India Political map printed in 2002.

The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate baseline.
The interstate boundaries between Arunachal Pradesh, Assam and Meghalaya shown on this map are as interpreted from the North-Eastern Areas (Reorganization) Act, 1971, but have yet to be verified.
The state boundaries between Uttarakhand & Uttar Pradesh, Bihar & Jharkhand, and Chhattisgarh & Madhya Pradesh have not been verified by the Governments concerned.
The administrative headquarters of Chandigarh, Haryana and Punjab are at Chandigarh.
The external boundaries and coastlines of India agree with the Record/Master Copy certified by Survey of India.
The responsibility for the correctness of internal details rests with the publisher.

NOTE — Towns falling at the boundary of zones demarcation line between two zones shall be considered in higher zone.

FIG. 1 SEISMIC ZONES OF INDIA

❖ **Response Reduction Factor (R):** Values of 'R' are given for various types of buildings in Table 9 (IS-1893 Part I clause 7.2.6) Steel buildings, braced buildings and load bearing masonry buildings are classified into more categories. Value of 'R' is added for flat slab-structural wall system. More restrictions are added to adopt the type of building in higher seismic zones.

❖ Time Period, Ta: IS-1893 Part I clauses 7.6.2 (a), (b) & (c) Formulas for calculation of Time Period $T_a$, are given in clauses 7.6.2 (a), (b) & (c) for different types of buildings as follows:

a) **Bare MRF buildings (without any masonry infills):**

$$T_a = \begin{cases} 0.075h^{0.75} & \text{(for RC MRF building)} \\ 0.080h^{0.75} & \text{(for RC-Steel Composite MRF building)} \\ 0.085h^{0.75} & \text{(for steel MRF building)} \end{cases}$$

where

$h$ = height (in m) of building (*see* Fig. 5). This excludes the basement storeys, where basement storey, walls are connected with the ground floor deck or fitted between the building columns, but includes the basement storeys, when they are not so connected.

b) Buildings with RC structural walls:

$$T_a = \frac{0.075h^{0.75}}{\sqrt{A_w}} \geq \frac{0.09h}{\sqrt{d}}$$

where $A_w$ is total effective area ($m^2$) of walls in the first storey of the building given by:

$$A_w = \sum_{i=1}^{N_w} \left[ A_{wi} \left\{ 0.2 + \left( \frac{L_{wi}}{h} \right)^2 \right\} \right]$$

where

$h$ = height of building as defined in 7.6.2(a), in m;

$A_{wi}$ = effective cross-sectional area of wall $i$ in first storey of building, in $m^2$;

$L_{wi}$ = length of structural wall $i$ in first storey in the considered direction of lateral forces, in m;

$d$ = base dimension of the building at the plinth level along the considered direction of earthquake shaking, in m; and

$N_w$ = number of walls in the considered direction of earthquake shaking.

The value of $L_{wi}/h$ to be used in this equation shall not exceed 0.9.

c) All other buildings:

$$T_a = \frac{0.09h}{\sqrt{d}}$$

where

$h$ = height of building, as defined in 7.6.2(a), in m; and

$d$ = base dimension of the building at the plinth level along the considered direction of earthquake shaking, in m.

**Table 9 Response Reduction Factor *R* for Building Systems**
(*Clause* 7.2.6)

| Sl No. (1) | Lateral Load Resisting System (2) | R (3) |
|---|---|---|
| i) | **Moment Frame Systems** | |
| | a) RC buildings with ordinary moment resisting frame (OMRF) (*see* Note 1) | 3.0 |
| | b) RC buildings with special moment resisting frame (SMRF) | 5.0 |
| | c) Steel buildings with ordinary moment resisting frame (OMRF) (*see* Note 1) | 3.0 |
| | d) Steel buildings with special moment resisting frame (SMRF) | 5.0 |
| ii) | **Braced Frame Systems** (*see* Note 2) | |
| | a) Buildings with ordinary braced frame (OBF) having concentric braces | 4.0 |
| | b) Buildings with special braced frame (SBF) having concentric braces | 4.5 |
| | c) Buildings with special braced frame (SBF) having eccentric braces | 5.0 |
| iii) | **Structural Wall Systems** (*see* Note 3) | |
| | a) Load bearing masonry buildings | |
| | 1) Unreinforced masonry (designed as per IS 1905) without horizontal RC seismic bands (*see* Note 1) | 1.5 |
| | 2) Unreinforced masonry (designed as per IS 1905) with horizontal RC seismic bands | 2.0 |
| | 3) Unreinforced masonry (designed as per IS 1905) with horizontal RC seismic bands and vertical reinforcing bars at corners of rooms and jambs of openings (with reinforcement as per IS 4326) | 2.5 |
| | 4) Reinforced masonry [*see* SP 7 (Part 6) Section 4] | 3.0 |
| | 5) Confined masonry | 3.0 |
| | b) Buildings with ordinary RC structural walls (*see* Note 1) | 3.0 |
| | c) Buildings with ductile RC structural walls | 4.0 |
| iv) | **Dual Systems** (*see* Note 3) | |
| | a) Buildings with ordinary RC structural walls and RC OMRFs (*see* Note 1) | 3.0 |
| | b) Buildings with ordinary RC structural walls and RC SMRFs (*see* Note 1) | 4.0 |
| | c) Buildings with ductile RC structural walls with RC OMRFs (*see* Note 1) | 4.0 |
| | d) Buildings with ductile RC structural walls with RC SMRFs | 5.0 |
| v) | **Flat Slab – Structural Wall Systems** (*see* Note 4) | |
| | RC building with the three features given below: a) Ductile RC structural walls (which are designed to resist 100 percent of the design lateral force), b) Perimeter RC SMRFs (which are designed to independently resist 25 percent of the design lateral force), and preferably c) An outrigger and belt truss system connecting the core ductile RC structural walls and the perimeter RC SMRFs (*see* Note 1). | 3.0 |

NOTES

1 RC and steel structures in Seismic Zones III, IV and V

shall be designed to be ductile. Hence, this system is not allowed in these seismic zones.

2 Eccentric braces shall be used only with SBFs.

3 Buildings with structural walls also include buildings having structural walls and moment frames, but where,
a) frames are not designed to carry design lateral loads, or
b) frames are designed to carry design lateral loads, but do not fulfill the requirements of 'Dual Systems'.

4 In these buildings, (a) punching shear failure shall be avoided, and (b) lateral drift at the roof under design lateral force shall not exceed 0.1 percent.

❖ **Design Seismic Acceleration Spectrum:** IS-1893 Part I Clause 6.4.2 and Fig.2.2 The response spectra for different soil types for 5% damping are given for period range up to 6 seconds in Fig.2.2 of the code. The figure is as follows:

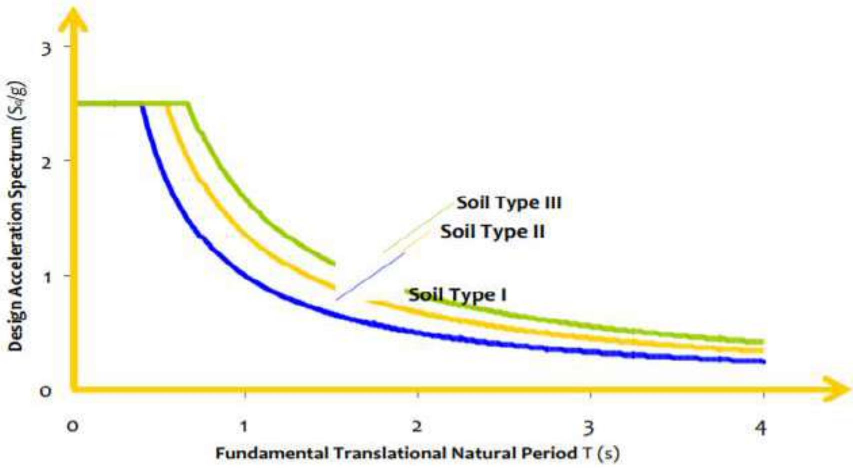



**Figure 2.2:** *Design Acceleration Spectrum:* This is based on fundamental translational natural period *T* of the building; this is defined in the following

Damping ratio of 5% is fixed for all type of buildings as per IS-1893 Clause 7.2.4 of the code for static as well as dynamic analysis.

❖ **Design Acceleration Coefficient (Sa/g):** IS-1893 Clause 6.4.2 and Fig.2A Design Acceleration Coefficient (Sa/g) for different soil types for 5% damping are given in IS-1893 clause 6.4.2 and Fig.2.2

Damping ratio of 5% is fixed for all type of buildings as per IS-1893 Clause 7.2.4 of the code for static as well as dynamic analysis. For equivalent static method, the values are:

$$\frac{S_a}{g} = \begin{cases} \text{For rocky or hard soil sites} & \begin{cases} 2.5 & 0 < T < 0.40\text{ s} \\ \frac{1}{T} & 0.40\text{ s} < T < 4.00\text{ s} \\ 0.25 & T > 4.00\text{ s} \end{cases} \\ \text{For medium stiff soil sites} & \begin{cases} 2.5 & 0 < T < 0.55\text{ s} \\ \frac{1.36}{T} & 0.55\text{ s} < T < 4.00\text{ s} \\ 0.34 & T > 4.00\text{ s} \end{cases} \\ \text{For soft soil sites} & \begin{cases} 2.5 & 0 < T < 0.67\text{ s} \\ \frac{1.67}{T} & 0.67\text{ s} < T < 4.00\text{ s} \\ 0.42 & T > 4.00\text{ s} \end{cases} \end{cases}$$

❖ **Damping Ratio: IS-1893 Clause 7.2.4:** Damping ratio is fixed as 5% of the critical damping for all types of buildings irrespective of the material of construction (steel, reinforced concrete, masonry, or combination of these three materials) for use in static as well as dynamic analysis.

❖ **Minimum Design Lateral Force:** IS-1893 Clause7.2.2, Table 7 Buildings and portions thereof, are to be designed for a minimum horizontal force not less than (VB)min equal to 0.7, 1.1, 1.6 and 2.4 percent of the seismic weight of the building, in seismic zones II, III, IV and V respectively.

**Table 7 Minimum Design Earthquake Horizontal Lateral Force for Buildings**
(*Clause* 7.2.2)

| Sl No. (1) | Seismic Zone (2) | ρ Percent (3) |
|---|---|---|
| i) | II | 0.7 |
| ii) | III | 1.1 |
| iii) | IV | 1.6 |
| iv) | V | 2.4 |

❖ **Design Acceleration Spectra for Vertical Motion:** IS-1893 Part I Clauses 6.3.3 and 6.4.6

**As per clause 6.**4.6 the design seismic acceleration spectral value $A_v$ or vertical motions shall be taken as

**6.4.6** The design seismic acceleration spectral value $A_v$ or vertical motions shall be taken as:

$$A_v = \begin{cases} \dfrac{\left(\frac{2}{3}\times\frac{Z}{2}\right)(2.5)}{\left(\frac{R}{I}\right)} & \text{For buildings governed by IS 1893 (Part 1)} \\[2ex] \dfrac{\left(\frac{2}{3}\times\frac{Z}{2}\right)(2.5)}{\left(\frac{R}{I}\right)} & \text{For liquid retaining tanks governed by IS 1893 (Part 2)} \\[2ex] \dfrac{\left(\frac{2}{3}\times\frac{Z}{2}\right)\left(\frac{S_a}{g}\right)}{\left(\frac{R}{I}\right)} & \text{For bridges governed by IS 1893 (Part 3)} \\[2ex] \dfrac{\left(\frac{2}{3}\times\frac{Z}{2}\right)\left(\frac{S_a}{g}\right)}{\left(\frac{R}{I}\right)} & \text{For industrial structures governed by IS 1893 (Part 4)} \end{cases}$$

The value of $S_a/g$ shall be based on natural period $T$ corresponding to the first vertical mode of oscillation, using 6.4.2.

Clause 6.3.3.1 specifies that effects due to vertical earthquake shaking shall be considered when any one of the following conditions apply:

- Structure is located in seismic zone IV or V;
- Structure has vertical or plan irregularities;
- Structure is rested on soft soil;
- Bridges;
- Structure has long spans; or
- Structure has large horizontal overhangs of members or sub-system.

**2.11.3.2 Dynamic Analysis:**

Simplified analysis i.e. static analysis (Equivalent Static Seismic Force Method) is used for simple buildings of low height in less severe seismic zones. Buildings having irregularities of plan and elevation have uneven distribution of mass and they require more rigorous analysis i.e. dynamic analysis. Even regular structures in higher seismic zones or regular high-rise structures in all zones require dynamic analysis. The revised code IS: 1893 has made criterion more stringent and brought more buildings under the purview of dynamic analysis. Now only regular buildings with height < 15M in seismic Zone II can be designed using static analysis. For all other buildings, dynamic analysis is made mandatory. For buildings, linear dynamic analysis is carried out to obtain the design seismic force and its distribution at different floor levels and to different structural elements. Three methods are mentioned in the revised code for dynamic analysis as mentioned below-

- ❖ Response spectrum method,
- ❖ Modal time history method and
- ❖ Time History Method

The IS: 1893 recommends methods 1 and 3 above and provides detailed procedure for the Response Spectrum Method. Design base shear calculated from dynamic analysis is compared with the base shear calculated using fundamental time (static method) period and if it is less than the fundamental base shear value, the lateral force is multiplied by the ratio of fundamental base shear to calculated design base shear in order to obtain the design base shear.

❖ **Dynamic Analysis Condition:** IS-1893 Part I Clause 7.7.1 Dynamic analysis is required in following cases:

- ❖ For regular type of buildings
  - ▪ Zone III, IV, V – All buildings
  - ▪ Zone II – All buildings with height >= 15 m
- ❖ For irregular type of buildings
  - ▪ Zone II, III, IV, V – All buildings

❖ **Design Seismic Acceleration Spectrum:** IS-1893 Clause 6.4.2 and Fig.2.2 For dynamic analysis using response spectrum method, the response spectra for different soil types for 5% damping are given for period range up to 6 seconds in Fig.2.2 of the code (above).

Damping ratio of 5% is fixed for all type of buildings as per IS-1893 Clause 7.2.4 of the code for static as well as dynamic analysis.

❖ **Design Acceleration Coefficient (Sa/g):** IS-1893 Clause 6.4.2 and Fig.2.2

Design Acceleration Coefficient (Sa/g) for different soil types for 5% damping are given in clause 6.4.2 and Fig.2.2 for dynamic analysis using response spectrum method.

Damping ratio of 5% is fixed for all type of buildings as per IS-1893 Clause 7.2.4 of the code for static as well as dynamic analysis.

$\left(\frac{S_a}{g}\right)$ = design acceleration coefficient for different soil types, normalized with peak ground acceleration, corresponding to natural period $T$ of structure (considering soil-structure interaction, if required). It shall be as given in Parts 1 to 5 of IS 1893 for the corresponding structures; when not specified, it shall be taken as that corresponding to 5 percent **Damping given by expression below:**

b) For use in response spectrum method [*see* Fig. 2(b)]

$$\frac{S_a}{g} = \begin{cases} \text{For rocky or hard soil sites} \begin{cases} 1+15T & T < 0.10 \text{ s} \\ 2.5 & 0.10 \text{ s} < T < 0.40 \text{ s} \\ \dfrac{1}{T} & 0.40 \text{ s} < T < 4.00 \text{ s} \\ 0.25 & T > 4.00 \text{ s} \end{cases} \\ \text{For medium stiff soil sites} \begin{cases} 1+15T & T < 0.10 \text{ s} \\ 2.5 & 0.10 \text{ s} < T < 0.55 \text{ s} \\ \dfrac{1.36}{T} & 0.55 \text{ s} < T < 4.00 \text{ s} \\ 0.34 & T > 4.00 \text{ s} \end{cases} \\ \text{For soft soil sites} \begin{cases} 1+15T & T < 0.10 \text{ s} \\ 2.5 & 0.10 \text{ s} < T < 0.67 \text{ s} \\ \dfrac{1.67}{T} & 0.67 \text{ s} < T < 4.00 \text{ s} \\ 0.42 & T > 4.00 \text{ s} \end{cases} \end{cases}$$

❖ **Damping Ratio:** IS-1893 Clause 7.2.4 Damping ratio is fixed as 5% of the critical damping for all types of buildings irrespective of the material of construction (steel, reinforced concrete, masonry, or combination of these three materials) for use in static as well as dynamic analysis.

❖ **Treatment of buildings with re-entrant corners:**

Table 5 Buildings with re-entrant corners (as defined in the codeIS-1893) are included in Table 5, which shows buildings having plan irregularities. Here code specifically mentions that for such buildings, three-dimensional dynamic analysis method shall be adopted.

Table 5 Definitions of Irregular Buildings – Plan Irregularities (*see* Fig. 3)
(*Clause* 7.1)

| Sl No. (1) | Type of Plan Irregularity (2) |
|---|---|
| i) | **Torsional Irregularity**<br>Usually, a well-proportioned building does not twist about its vertical axis, when<br>a) the stiffness distribution of the vertical elements resisting lateral loads is balanced in plan according to the distribution of mass in plan (at each storey level); and<br>b) the floor slabs are stiff in their own plane (this happens when its plan aspect ratio is less than 3)<br>A building is said to be torsionally irregular, when,<br>1) the maximum horizontal displacement of any floor in the direction of the lateral force at one end of the floor is more than 1.5 times its minimum horizontal displacement at the far end of the same floor in that direction; and<br>2) the natural period corresponding to the fundamental torsional mode of oscillation is more than those of the first two translational modes of oscillation along each principal plan directions<br>*In torsionally irregular buildings, when the ratio of maximum horizontal displacement at one end and the minimum horizontal displacement at the other end is,* |

Table 5 — (*Concluded*)

i) *in the range 1.5 – 2.0, (a) the building configuration shall be revised to ensure that the natural period of the fundamental torsional mode of oscillation shall be smaller than those of the first two translational modes along each of the principal plan directions, and then (b) three dimensional dynamic analysis method shall be adopted; and*

ii) *more than 2.0, the building configuration shall be revised*

ii) **Re-entrant Corners**

A building is said to have a re-entrant corner in any plan direction, when its structural configuration in plan has a projection of size greater than 15 percent of its overall plan dimension in that direction

*In buildings with re-entrant corners, three-dimensional dynamic analysis method shall be adopted.*

iii) **Floor Slabs having Excessive Cut-Outs or Openings**

Openings in slabs result in flexible diaphragm behaviour, and hence the lateral shear force is not shared by the frames and/or vertical members in proportion to their lateral translational stiffness. The problem is particularly accentuated when the opening is close to the edge of the slab. A building is said to have discontinuity in their in-plane stiffness, when floor slabs have cut-outs or openings of area more than 50 percent of the full area of the floor slab

*In buildings with discontinuity in their in-plane stiffness, if the area of the geometric cut-out is,*

a) *less than or equal to 50 percent, the floor slab shall be taken as rigid or flexible depending on the location of and size of openings; and*

b) *more than 50 percent, the floor slab shall be taken as flexible.*

iv) **Out-of-Plane Offsets in Vertical Elements**

Out-of-plane offsets in vertical elements resisting lateral loads cause discontinuities and detours in the load path, which is known to be detrimental to the earthquake safety of the building. A building is said to have out-of-plane offset in vertical elements, when structural walls or frames are moved out of plane in any storey along the height of the building

*In a building with out-of-plane offsets in vertical elements,*

a) *specialist literature shall be referred for design of such a building, if the building is located in Seismic Zone II; and*

b) *the following two conditions shall be satisfied, if the building is located in Seismic Zones III, IV and V:*

   1) *Lateral drift shall be less than 0.2 percent in the storey having the offset and in the storeys below; and*

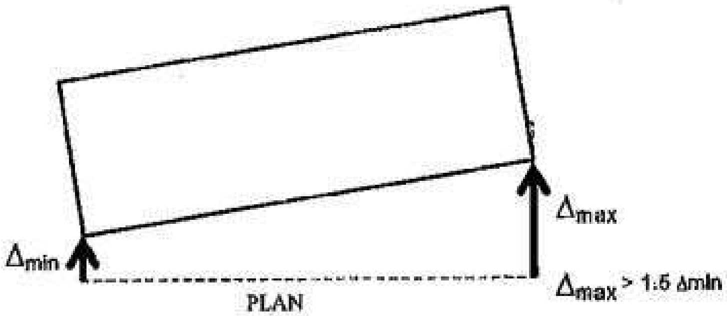
   2) *Specialist literature shall be referred for removing the irregularity arising due to out-of-plane offsets in vertical elements.*

v) **Non-Parallel Lateral Force System**

Buildings undergo complex earthquake behaviour and hence damage, when they do not have lateral force resisting systems oriented along two plan directions that are orthogonal to each other. A building is said to have non-parallel system when the vertically oriented structural systems resisting lateral forces are not oriented along the two principal orthogonal axes in plan

*Buildings with non-parallel lateral force resisting system shall be analyzed for load combinations mentioned in* **6.3.2.2** *or* **6.3.4.1**.

❖ **Treatment of buildings with Torsional Irregularities:** IS-1893 Table 5 When Δmax. = (1.5-2.0) Δmin. (ref. Fig.3A), the building configuration needs revision and also 3D dynamic analysis.




3A TORSIONAL IRREGULARITY

**2.12 Statutory/Regulatory Permissions, Green Building & EHSS Requirements**
**2.12.1 Adhering to Statutory & Regulatory protocol for Buildings Construction**

While a proposed building land title is duly verified and cleared for construction from competent authority and building is being planned for a specific public convenience, it is very important that, depending upon the type of contract (PPP, EPC, LSTK, BOT, DBFO, HAM etc),which is prospectively proposed for project construction, all mandatory provisions for Statutory permissions (Enactment Governed by State/Central Laws) or Regulatory Requirements (Enactment Governed by rules of regulatory bodies, appointed by the State/Central Government), are complied with, by Intending Department/Executing Department/Project Implementation Agency. The works which are to be executed under jurisdiction of Urban Areas including J&K MRDA, the necessary guidelines / instructions as laid down in the Municipal Act, J&K MRDA Act, 2018, along with the circulars issued from time to time may be strictly followed.

For Statutory/Regulatory Approvals, the Intending Department, through Executing Department/Project Implementation Agency, shall plan and prepare drawings, as necessary for statutory approvals, from authorities like Municipal Corporations/Authorities, Master-Plan Implementation Authority (Town Planning Department), Fire Department,Pollution Control Board, Atomic Energy Regulatory Board (AERB), State/UT Electricity Board/Department (PDD, if applicable),and ensure compliance with codes, standards and legislation, as applicable.. However, in case of different contract modes like EPC, the contractor shall have to assist the executing department/agency in obtaining statutory approvals thereof, if required. The contractor shall be solely responsible to comply with all norms, as applicable under the jurisdiction of appropriate authorities, in such and similar cases. The compliance to the statutory requirements shall be inherent to the design and solutions. For the obligations related to employer, the contractor shall provide such guidance well ahead in time. All costs related to any Statutory/Regulatory permissions must be embedded in the original estimates of the building project.

The drawings and documents shall be submitted by the Executing Department/Project Implementing Agency/Contractor in the format / template, scale, multiple copies and at the stage of project as necessary for the project and / or required by Statutory/Regulatory Authority.Detailed drawings of all services including, but not limited to, electrical & mechanical services, HVAC, LV, Data/telecommunication, fire detection & suppression, plumbing & drainage, waste water treatment, Municipal/Bio-medical waste management, rain water harvesting, recycling of waste water, use of solar energy, HSD/Explosive Storage and other such services, shall be included for obtaining Statutory/Regulatory permissions.

Designing the structure and services shall be as per provisions made in relevant Codes & specifications, as applicable & be in complete compliance with the applicable provisions of the National Building Code of India 2016 and provisions of the relevant acts and rules. The architect shall also prepare an integrated layout plan of building campus showing location of all the external services. The architect shall also assist in obtaining approval of plans & schemes of all services from the concerned local statutory authorities.

With regard to waste disposal, in particular, final disposal has to be planned to keep in view the relevant laws as are applicable to particular filed, as notified by the Ministry of Environment or any other statutory authority like CPCB / SPCB.

### 2.12.2 Green/Sustainable Building and EHSS Implementation

It is highly desired that dedicated efforts are placed by Intending/Executing/Implementing department and Contracting Agency to plan a building which is sustainable in design, construction, operation, maintenance, renovation and dismantling/demolition. It also encompasses application of all processes that are environmentally responsible and resource-efficient throughout a building's life cycle.

IGBC (Indian Green Building Council) being India's premier body for green building certification and related services, reference may be made to same for basic components of sustainable design (www.igbc.in).

IGBC Green New Buildings rating system broadly addresses green features under the following categories:

- ❖ Sustainable Architecture and Design
- ❖ Site Selection and Planning
- ❖ Water Conservation
- ❖ Energy Efficiency
- ❖ Building Materials and Resources
- ❖ Indoor Environmental Quality
- ❖ Innovation and Development

### 2.12.3 Environmental, Health, Safety & Social (EHSS) Impact Assessment

Provisions of Environmental, Health, Safety & Social (EHSS) Impact Assessment must also form an embedded part of the building project management protocol, for all High Value/Important Buildings, and necessary statutory/regulatory compliances must be adhered. Cost of conducting a regular/thorough EHSS Impact Assessment or EHSS Audit and preparing the project specific environment, health, safety and social management plan, viz-a-viz the Statutory/Regulatory requirements, before, during and after completion of project must be duly incorporated in the project cost under appropriate head. Judicious reference may also be made to OSHA (Occupational Safety and Health Act), which is an International standard for health and safety protocol. Any other pertinent National or Equivalent standard may also be consulted, if required.

## 2.13 Water Supply and Drainage Systems

### 2.13.1 Water Supply

Enough water to meet the needs of occupants must be available for all the buildings.Further water needs for fire protection, heating, air conditioning, and possibly processuse must also be met. This section provides specific data on all these waterneeds, except those for process use. Water needs for process use must be computedseparately because the demand depends on the process served.

### 2.13.2 Water Quality

Sources of water for buildings include public water supplies, groundwater, andsurface water. Each source requires careful study to determine if a sufficient quantityof safe water is available for the building being designed.

Water for human consumption, commonly called potable water, must be of suitablequality to meet local, state, and national requirements. Public water suppliesgenerally furnish suitably treated water to a building, eliminating the need for treatmentin the building. However, ground and surface waters may require treatmentprior to distribution for human consumption.

### 2.13.3 Water-Pipe Sizing

The required domestic-water pipe sizes should be determined by application of theprinciples of hydraulics. While economy dictates use of the smallest sizes of pipepermitted by building-code requirements, other factors often make larger sizes advisable.

These factors include:

- Pressure at the water-supply source, usually the public main, psi
- Pressure required at the outlets of each fixture, psi
- Loss of pressure because of height of outlets above the source, pressure loss due to friction caused by the flow of water through water meters and backflow preventers, and friction from water flow in the piping.
- Limitations on velocity of water flow, ft / s, to prevent noise and erosion
- Additional capacity for future expansion (normally 10% minimum)

### 2.13.4 Water supply system

The water supply systems of most buildings make integrated use of 3 types of systems, namely the direct supply system, indirect supply system and sump and pump supply system.

- Under the direct supply system, fresh water is transmitted directly from the public water mains to households at lower floors by means of hydraulic pressure inside the mains.

- ❖ Under the indirect supply system, a water pump is used to draw water from the storage tank installed at the ground level of the building, and fresh water drawn into the rooftop water tank is then transmitted to each household through a network of sub-mains.
- ❖ Under the sump and pump supply system, water is transmitted to the receiving end by fitting a pressure pump to the supply: a fire main is one that functions in this way.
- ❖ A water supply system comprises water pumps, risers, storage tanks, automatic float switches and sub-mains;
- ❖ All integral parts of the water supply system should be regularly checked and properly maintained.
- ❖ All water storage tanks should be cleansed at regular times for quality control.

## 2.14 Drainage System

### 2.14.1 Wastewater Piping

Human, natural, and industrial wastes resulting from building occupancy and usemust be disposed of in a safe, quick manner if occupant health and comfort are tobe safeguarded. Design of an adequate plumbing system requires careful planningand adherence to the codes in effect and to state or municipal regulations governingthese systems.

### 2.14.2 Wastewater Disposal

There are three main types of wastewater: domestic, storm, and industrial. Separateplumbing systems are generally required for each type.

Domestic wastewater is primarily spent water from the building water supply,to which is added wastes from bathrooms, kitchens, and laundries. It generally canbe disposed of by discharge into a municipal sanitary sewer, if one is available.

Storm water is primarily the water that runs off the roof or the site of thebuilding. The water usually is directed to roof drains or gutters. These then feedthe water to drainpipes, which convey it to a municipal or private storm-water sewersystem. Special conditions at some building sites, such as large paved areas or steepslopes, may require the capture of storm water in retention areas or ponds to preventthe municipal storm sewer systems from being overloaded. From these areas orponds, the storm water is generally conveyed to the storm sewers through outfallstructures designed to delay and control the flow of storm water to the municipalstorm sewer systems. Discharge into sanitary sewers is objectionable, because thelarge flows interfere with effective wastewater treatment and increase treatmentcosts. If kept separate from other types of wastewater, storm water usually can besafely discharged into a large body of water. Raw domestic wastewater and industrialwastes, on the other hand, have objectionable characteristics that make somedegree of treatment necessary before they can be discharged. Nevertheless, municipalcombined sewers (sanitary and storm wastes) exist in some areas. Appropriatelocal authorities should be consulted to determine which type of system is availableand specific regulations that relate to connection to these systems.

In areas where municipal sanitary sewers are not available, some form of wastewatertreatment is required. Prefabricated treatment plants are available in variousssizes and configurations. Most treatment systems are complex and require manysteps. These include filtration and activated-sludge and aeration methods. The degreeof treatment necessary generally depends on the assimilation potential of thebody of water to receive the effluent, primarily the ability of the body to dilute theimpurities and to supply oxygen for decomposition of organic matter present in thewastewater.

Industrial waste may present special problems because (1) the flow volume maybe beyond the public sewer capacity, and (2) local regulations may prohibit thedischarge of industrial waste into public sewers. Furthermore, many pollution regulationsprohibit discharge of industrial waste into streams, lakes, rivers, and tidalwaters without suitable prior treatment. Industrial wastes generally require treatmentsengineered to remove the specific elements injected by industrial processesthat make the wastes objectionable. Often, these treatments cannot be carried outin public wastewater treatment plants. Special treatment plants may have to be built for the purpose.

Drainage systems can be classified into the rain-water pipe system and sewage pipe system. The integral parts of a drainage system comprise the drain pipes, traps and manholes.

- ❖ Drain pipes should by no means be connected in an improper way, e.g. sewage discharged from sinks should not be emptied into any rain-water pipe.
- ❖ Drainage outlets should be clear of rubbish or fitted with gratings to prevent rubbish from blocking the pipes.
- ❖ All drain pipes, including soil pipes, waste pipes, ventilating pipes and underground drain pipes should be maintained in good working order without defects. All such pipes should be inspected regularly, and where leakage, blockage or defects are detected, they should be rectified immediately.
- ❖ In order to prevent putrid air and insects in the soil pipe from entering the premises, sanitary installations including hand basin, sinks, bathtubs and showers toilets and floor drains should be fitted with a trap (U-shaped water trap, bottle traps or anti-siphon traps). If the installation is not used regularly, pour about half a litre of water into each drain outlet once a week. Then, pour a teaspoon of 1:99 diluted household bleach solution into the drain outlet. For floor drains, spray insecticide into the drain outlets after cleansing.
- ❖ Manholes should be checked regularly and any blockage detected should be dealt with immediately.
- ❖ Manholes should be readily accessible for regular maintenance. Access to them should not be obstructed by floor finishes, planters or furniture items. Foul air leaking from manholes can be stopped by using double seal type manhole covers, or repairing the edges of the manhole openings or cracks in the manhole covers.
- ❖ Responsibilities for repair and maintenance of the drainage system are determined on whether the defective section of the pipe is for common use or for individual use. For example, if a rain-water pipe bursts, the owners' corporation or all owners shall be liable for repairing it. However, if a branch pipe connected to an individual flat is damaged, the owner or occupant of that flat shall be responsible for repairing it.

### 2.14.3 Sewers

A sewer is a conduit for water carriage of wastes. For the purpose of this section,any piping for wastewater inside a building will be considered plumbing or process piping; outside the building, wastewater lines are called sewers. Sewers carry wastewater and a system of sewers and appurtenances is sewerage. Sanitary sewers carry domestic wastes or industrial wastes. Where buildingsare located on large sites, or structures with large roof areas are involved, a stormsewer is used for fast disposal of rain and is laid out to drain inlets located for bestcollection of runoff.

### 2.14.4 Rainwater Drainage

Exterior sheet-metal gutters and leaders for rainwater drainage are not normally included as part of the plumbing work. Interior leaders or storm-water drains, however, are considered part of the plumbing work. Depending on local codes or ordinances in the locality, rainwater from various roof areas may or may not be led into the sanitary sewer. Where separate rainwater leaders or storm drains are used, the building drains are then called sanitary drains because they convey only the wastes from the various plumbing fixtures in the building. Interior storm-water drain pipes may be made of cast iron, steel, plastic, or wrought iron. All joints must be tight enough to prevent gas and water leakage.When a combined system is utilized, it is common practice to insert a cast-ironrunning trap between the storm drain and the building drain to maintain a trap sealon the storm drain at all times. Use of a combined system does not eliminate theneed for separate drains and vents for wastewater. All codes prohibit use of storm drains for any type of wastewater.

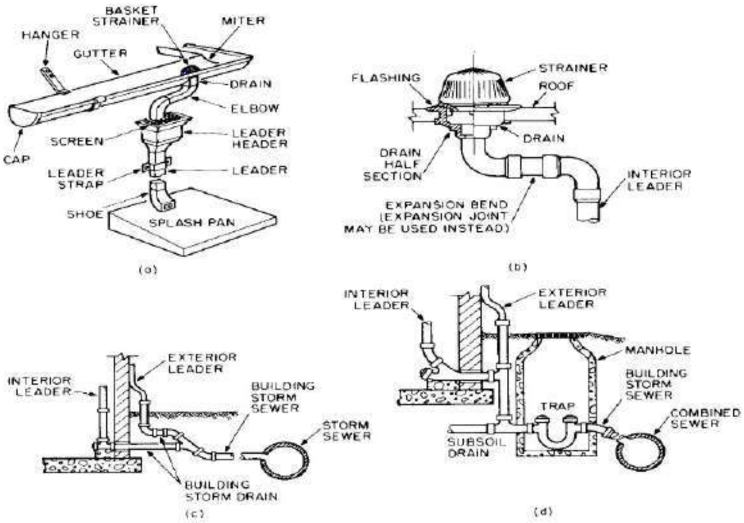



**FIGURE:** Elements of a storm-drainage system: (*a)* roof gutter, exterior leader, and splash pan; (*b* ) roof drain and top portion of interior leader; (*c* ) piping to a storm sewer; (*d* ) piping to a combined sewer.

**2.15 Detailed Project Preparation**

**2.15.1 Detailed project report:**

Detailed Project Report should contain the following live volumes namely:

- ❖ Final Report
- ❖ Detailed Designs
- ❖ Detailed Estimate
- ❖ Detailed Bill of Quantities and Specifications
- ❖ Detailed Drawings.

**2.15.2** Final Report:**The final Report should contain:**

- ❖ Introductory report indicating the location of the building, the need for thesame, the population and economic activities likely to be served by thebuilding, alternative sites considered and the aspects in favor of the site finally selected.
- ❖ Design data for the building including survey data and subsoil data.
- ❖ Report on the environmental impact assessment as per the format laid in JKPWD Manual 2020 appendix 100.2.
- ❖ A schedule of construction including a CPM chart in case of major projects; and at least a Bar chart indicating important mile stones in other cases.
- ❖ After analyzing various economical options in preliminary designs, the final most economical design should be adopted in detailed project report.

2.15.3 **Detailed Designs**:

Detailed design sheets of all components of the building have to be included in this volume.

**2.15.4** Detailed Estimate:

This volume should contain all the items including in the construction of building.

**2.15.5** Detailed bill of quantities and specifications:

The detailed bill of quantities should contain the reasonably firm quantities of each item of work forming part of the project worked out on the basis of detailed drawings. The detailed specifications of each of the items of the project.

2.15.6 Detailed drawings:

This volume should contain the following:-

- ❖ Index plan
- ❖ Site plan.
- ❖ A contour survey plan
- ❖ Bore log data
- ❖ Detailed drawings of all the components of the building
- ❖ Complete details of existing buildings, if any
- ❖ Detailed drawings of CD. Works
- ❖ Miscellaneous drawings

# 3. BUILDING MATERIALS AND PROCUREMENT OF MATERIALS

## 3.1 Materials

Every material used in fulfillment of the requirements of this Part, unless otherwise specified in the Code or approved, shall conform to the relevant Indian Standards. A list of Indian Standard specifications as the 'accepted standards' is given at the end of this Part of the Code. At the time of publication of the Code, the editions indicated were valid. All standards are subject to amendments and revisions. The Authority shall take cognizance of such amendments and revisions. The latest version of the specification shall, as far as possible, be adopted at the time of enforcement of this Part of the Code.

## 3.2 Sustainable Materials

Choice of building materials is important in sustainable design because of the extensive network of activities such as extraction, processing and transportation steps required for making a material, and activities involved thereafter till building construction and even thereafter. These activities may pollute the air, soil and water, as well as destroy natural habitats and deplete natural resources. One of the most effective strategies for minimizing the environmental impacts of material usage is to reuse existing buildings. Rehabilitation of existing building, and their shell and non-shell components, not only reduces the volume of solid waste generated and its subsequent diversion to landfills but also the environmental impacts associated with the production, delivery and use or installation of new building materials. However, the use of sustainable building materials is one of the best strategies in the pursuit of sustainable buildings. An ideal sustainable building material is not only environment friendly but also causes no adverse impact on health of occupants, is readily available, can be reclaimed and recycled, and is not only made from renewable raw material, but also uses predominantly renewable energy in its extraction, production, transportation, fixing and ultimate disposal. Practically, this kind of ideal material may not be available and hence, when selecting sustainable materials, it may be best to choose materials which fulfill most of these criteria. Sustainable building materials also offer specific benefits to the building owner and building occupants, such as, reduced maintenance/replacement costs over the life of the building; energy conservation; improved occupant health and productivity; lower costs associated with changing space configurations; and greater design flexibility.

### 3.2.1 New or Alternative Materials

**3.2.1.1** The provisions of this Part are not intended to prevent the use of any material not specifically prescribed. Any such material may be approved by the Authority or an agency appointed by them for the purpose, provided it is established that the material is satisfactory for the purpose intended and the equivalent of that required in this Part or any other specification issued or approved by the Authority. The Authority or an agency appointed by them shall take into account the following parameters, as applicable to the concerned new or alternative building material:

- Requirements of the material specified/ expected in terms of the provisions given in the standards on its usage, including its applicability in geo-climatic condition;
- General appearance;
- Dimension and dimensional stability;
- Structural stability including strength properties;
- Fire safety;
- Durability;
- Thermal properties;
- Mechanical properties;

- ❖ Acoustical properties;
- ❖ Optical properties;
- ❖ Biological effect;
- ❖ Environmental aspects;
- ❖ Working characteristics;
- ❖ Ease of handling;
- ❖ Consistency and workability;
- ❖ UV resistance; and
- ❖ Toxicity.

Some of such new/alternative materials may be ferrocement, decorative concrete, polymer concrete, micro-concrete repair materials, dry-mix mortar, non-shrink grout, optical fibres, special materials for bunkers/blast resistant structures, artificial stones used in restoration of heritage structures, nanotechnology based advanced materials, aluminium composite panels, vermiculite based boards, exfoliated perlite, geopolymeric cement, pervious concrete, UPVC doors and windows, stainless steel insulated water tanks, etc. For establishing the performance of the material/ component, laboratory/field tests, and field trials, as required, and study of historical data are recommended. For sampling and frequency of tests for new or alternate materials, similar product standards shall be referred to. The above materials would no longer be treated as new/ alternative materials as soon as Indian Standards for the same are established.

**3.2.1.2** Approval in writing of the Authority or an agent appointed by them for the purpose of approval of material shall be obtained by the owner or his agent before any new, alternative or equivalent material is used. The Authority or their agent shall base such approval on the principle set forth in 3.1.2.1 and shall require that tests be madeor sufficient evidence or proof be submitted, at the expense of the owner or his agent, to substantiate any claim for the proposed material.

**3.2.2 Third Party Certification**

For ensuring the conformity of materials for which Indian Standards exist and for new or alternative building materials, to requisite quality parameters the services under the third party certification schemes of the Government, may be utilized with advantage.

**3.2.3 Used Materials**

Utilization of used materials may not be precluded provided these meet the requirements of this Part for new materials (see Part 2 ‘Administration’ National Building Code 2019)

**3.2.4 Methods of Test**

**3.2.4.1** Every test of material as required in this Part or by the Authority shall be carried out in accordance with the methods of test prescribed in relevant Indian Standards. In cases of methods of tests for which Indian Standards are not available, the same shall conform to the methods of tests issued by the Authority or their agent. A list of Indian Standard methods of test is given at the end of this Part of the Code as the ‘accepted standards’. Laboratory tests shall be conducted by recognized laboratories acceptable to the Authority.

**3.2.4.2** The manufacturer/supplier shall satisfy himself that materials conform to the requirements of the specifications and if requested shall supply a certificate to this effect to the purchaser or his representative. When such test certificates are not available, the specimen of the material shall be tested.

**3.2.5 List of Standards**

Following are the Indian Standards for various building materials and components, to be complied with in fulfillment of the requirements of the Code. In the following list, while enlisting the

Indian Standards, the materials have been categorized in such a way as to make the list user friendly. In the process, if so required, some of the standards have been included even in more than one category of products, such as in the category based on composition as well as on end application of the materials. The list has been arranged in alphabetical order of their principal category as given below:

- Aluminium and other light metals and their alloys
- Bricks, blocks and other masonry building units
- Building chemicals
- Building hardware
- Building lime and products
- Clay and stabilized soil products
- Cement and concrete (including steel reinforcement for concrete)
- Composite matrix products (including cement and resin matrix products)
- Doors, windows and ventilators
- Fillers, stoppers and putties
- Floor covering, roofing and other finishes
- Glass
- Gypsum based materials
- Mortar (including sand for mortar)
- Paints and allied products
- Polymers, plastics and geosynthetics/ geotextiles
- Steel and its alloys
- Stones
- Structural sections
- Timber, bamboo and other lignocellulosic building materials
- Waterproofing and damp-proofing materials

**Aluminium And Other Light Metals And Their Alloys**

| IS No. | Title |
|---|---|
| 733: 1983 | Specification for wrought aluminium and aluminium alloys bars, rods and sections for general engineering purposes (third revision) |
| 734: 1975 | Wrought aluminium and aluminium alloys forging stock and forgings (for general engineering purposes) (second revision) |
| 736: 1986 | Specification for wrought aluminium and aluminium alloys plate for general engineering purposes (third revision) |
| 737: 2008 | Specification for wrought aluminium and aluminium alloys sheet and strip for general engineering purposes (fourth revision) |
| 738: 1994 | Specification for wrought aluminium and aluminium alloys drawn tube for general engineering purposes (third revision) |
| 739: 1992 | Specification for wrought aluminium and aluminium alloys Wire for general engineering purposes (third revision) |
| 740: 1977 | Specification for wrought aluminium and aluminium alloys rivet stock for general engineering purposes (second revision) 1254: 2007 Corrugated aluminium sheet (fourth revision) |
| 1254 : 2007 | Corrugated aluminium sheet (fourth revision) |

| | |
|---|---|
| 1284 : 1975 | Wrought aluminium alloys bolt and screw stock for general engineering purposes (second revision) |
| 1285 : 2002 | Specification for wrought aluminium and aluminium alloys Extruded round tube and hollow sections for general engineering purposes (third revision) |
| 2479 : 1981 | Colour code for the identification of aluminium and aluminium alloys for general engineering purposes (second revision) |
| 2676 : 1981 | Dimensions for wrought aluminium and aluminium alloy sheet and strip |
| 2677 : 1979 | Dimensions for wrought aluminium and aluminium alloys, plates and hot rolled sheets |
| 3577 : 1992 | Wrought aluminium and its alloys Rivet, bolt and screw stock Dimensions and tolerances (first revision) |
| 3965 : 1981 | Dimensions for wrought aluminium and aluminium alloys bar, rod and section (first revision) |
| 6477 : 1983 | Dimensions for wrought aluminium and aluminium alloys extruded hollow sections |
| 14712 : 1999 | Specification for wrought aluminium and its alloys Chequered/tread sheets for general engineering purposes |
| 15965 : 2012 | Pre-painted aluminium zinc alloy metallic coated steel strip and sheet (Plain) |

**3.2.5.1 Bricks, Blocks and other Masonry Building Units**

| IS No. | Title |
|---|---|
| 1077: 1992 | Specification for common burnt clay building bricks (fifth revision) |
| 1725: 2013 | Specification for stabilized soil blocks used in general building construction (second revision) |
| 2180: 1988 | Specification for heavy duty burnt clay building bricks (third revision) |
| 2185 | Specification for concrete masonry units |
| (Part 1): 2005 | Hollow and solid concrete blocks (third revision) |
| (Part 2): 1983 | Hollow and solid lightweight concrete blocks (first revision) |
| (Part 3): 1984 | Autoclaved cellular (aerated) concrete blocks (first revision) |
| (Part 4): 2008 | Cellular concrete blocks using preformed foam |
| 2222: 1991 | Specification for burnt clay perforated building bricks (third revision) |
| 2691: 1988 | Specification for burnt clay facing bricks (second revision) |
| 2849: 1983 | Specification for non-load bearing gypsum partition blocks (solid and hollow types) |
| 3115: 1992 | Specification for lime based blocks (second revision) |
| 3316: 1974 | Specification for structural granite (first revision) |
| 3495 (Parts 1 to 4) : 1992 | Methods of test of burnt clay building bricks (third revision)<br>Determination of compressive strength<br>Determination of water absorption<br>Determination of efflorescence<br>Determination of warpage |
| 3583: 1988 | Specification for burnt clay paving bricks (second revision) |
| 3620: 1979 | Specification for laterite stone block for masonry (first revision) |
| 3952: 2013 | Specification for burnt clay hollow bricks and blocks for walls and partitions (third revision) |

| | |
|---|---|
| 4139: 1989 | Specification for calcium silicate bricks (second revision) |
| 4860: 1968 | Specification for acid resistant bricks |
| 4885: 1988 | Specification for sewer bricks (first revision) |
| 5454: 1978 | Methods for sampling of clay building bricks (first revision) |
| 5751: 1984 | Specification for precast concrete coping blocks (first revision) |
| 5779: 1986 | Specification for burnt clay soling bricks (first revision) |
| 6165: 1992 | Dimensions for special shapes of clay bricks (first revision) |
| 9893: 1981 | Specification for precast concrete blocks for lintels and sills |
| 10360: 1982 | Specification for lime pozzolana concrete blocks for paving |
| 12440: 1988 | Specification for precast concrete stone masonry blocks |
| 12894: 2002 | Specification for pulverized fuel ash lime bricks (first revision) |
| 13757: 1993 | Specification for burnt clay fly ash building bricks |
| 15658: 2006 | Specification for precast concrete blocks for paving |

**3.2.5.2 Building Chemicals**

❖ **Anti-termite Chemicals**

| IS No. | Title |
|---|---|
| 8944: 2005 | Specification for chlorpyrifos emulsifiable concentrates (first revision) |
| 16131 : 2015 | Specification for imidacloprid suspension concentrate (sc) |

❖ **Chemical Admixture/Water Proofing Compounds**

| IS No. | Title |
|---|---|
| 2645: 2003 | Specification for integral waterproofing compounds for cement mortar and concrete (second revision) |
| 6925: 1973 | Methods of test for determination of water soluble chlorides in concrete admixtures |
| 9103: 1999 | Specification for concrete admixtures (first revision) |

❖ **Sealants/Fillers**

| IS No. | Title |
|---|---|
| 1834: 1984 | Specification for hot applied sealing compound for joint in concrete (first revision) |
| 1838 | Specification for preformed fillers for expansion joint in concrete pavements and structures (nonextruding and resilient type) |
| (Part 1): 1983 | Bitumen impregnated fibre (first revision) |
| (Part 2): 1984 | CNSL aldehyde resin and coconut pith |
| (Part 3): 2011 | Polymer based |
| 10566: 1983 | Methods of tests for preformed fillers for expansion joint in concrete paving and structural construction |
| 11433 | Specification for one grade polysulphide based joint sealant |
| (Part 1): 1985 | General requirements |
| (Part 2): 1986 | Methods of test |
| 12118 | Specification for two parts polysulphide based sealants |
| (Part 1): 1987 | General requirements |
| (Part 2): 1987 | Methods of test |

- **Adhesives**

| IS No. | Title |
|---|---|
| 848: 2006 | Specification for synthetic resin adhesives for plywood (phenolic and aminoplastic) (second revision) |
| 849: 1994 | Specification for cold setting case in glue for wood (first revision) |
| 851: 1978 | Specification for synthetic resin adhesives for construction work(nonstructural) in wood (firs revision) |
| 852: 1994 | Specification for animal glue for general wood-working purposes (second revision) |
| 1508: 1972 | Specification for extenders for use in synthetic resin adhesives (ureaformaldehyde) for plywood (first revision) |
| 4835: 1979 | Specification for polyvinyl acetate dispersion-based adhesives for wood (first revision) |
| 9188: 1979 | Performance requirements for adhesive for structural laminated wood products for use under exterior exposure condition |
| 12830: 1989 | Rubber based adhesives for fixing PVC tiles to cement |
| 12994: 1990 | Epoxy adhesives, room temperature curing general purpose |
| 15477: 2004 | Specification for adhesives for use with ceramic tiles and mosaics |

**3.2.5.3 Building Hardware**

| IS No. | Title |
|---|---|
| 204 | Specification for tower bolts |
| (Part 1): 1991 | Ferrous metals (fifth revision) |
| (Part 2): 1992 | Non-ferrous metals (fifth revision) |
| 205: 1992 | Specification for non-ferrous metal butt hinges (fourth revision) |
| 206: 2010 | Specification for tee and strap hinges (fifth revision) |
| 208: 1996 | Specification for door handles (fifth revision) |
| 281: 2009 | Specification for mild steel sliding door bolts for use with padlocks (fourth revision) |
| 362: 1991 | Specification for parliament hinges (fifth revision) |
| 363: 1993 | Specification for hasps and staples (fourth revision) |
| 364: 1993 | Specification for fanlight catch (third revision) |
| 452: 1973 | Specification for door springs, rat-tail type (second revision) |
| 453: 1993 | Specification for double-acting spring hinges (third revision) |
| 729: 1979 | Specification for drawer locks, cupboard locks and box locks (third revision) |
| 1019: 1974 | Specification for rim latches (second revision) |
| 1341: 1992 | Specification for steel butt hinges (sixth revision) |
| 1823: 1980 | Specification for floor door stoppers (third revision) |
| 1837: 1966 | Specification for fanlight pivots (first revision) |
| 2209: 1976 | Specification for mortice locks (vertical type) (third revision) |
| 2681: 1993 | Specification for nonferrous metal sliding door bolts for use with padlocks (third revision) |
| 3564: 1995 | Specification for door closers (hydraulically regulated) (second revision) |
| 3818: 1992 | Specification for continuous (piano) hinges (third revision) |
| 3828: 1966 | Specification for ventilator chains |
| 3843: 1995 | Specification for steel backflap hinges (first revision) |

| | |
|---|---|
| 3847: 1992 | Specification for mortice night latches (second revision) |
| 4621: 1975 | Specification for indicating bolts for use in public baths and lavatories (first revision) |
| 4948: 2002 | Specification for welded steel wire fabric for general use (second revision) |
| 4992: 1975 | Specification for door handles for mortice locks (vertical type) (first revision) |
| 5187: 1972 | Specification for flush bolts (first revision) |
| 5899: 1970 | Specification for bathroom latches |
| 5930: 1970 | Specification for mortice latch (vertical type) |
| 6315: 1992 | Specification for floor springs (hydraulically regulated) for heavy doors (second revision) |
| 6318: 1971 | Specification for plastic window stays and fasteners |
| 6343: 1982 | Specification for door closers (pneumatically regulated) for light door weighing up to 40 kg (first revision) |
| 6607: 1972 | Specification for rebated mortice locks (vertical type) |
| 7196: 1974 | Specification for hold fast |
| 7197: 1974 | Specification for double action floor springs (without oil check) for heavy doors |
| 7534: 1985 | Specification for sliding locking bolts for use with padlocks (first revision) |
| 8756: 1978 | Specification for ball catches for use in wooden almirah |
| 9106: 1979 | Specification for rising butt hinges |
| 9131: 1979 | Specification for rim locks |
| 9460: 1980 | Specification for flush drop handle for drawer |
| 9899: 1981 | Specification for hat coat and wardrobe hooks |
| 10019: 1981 | Specification for mild steel stays and fasteners |
| 10090: 1982 | Specification for numericals |
| 10342: 1982 | Specification for curtain rail system |
| 12817: 2013 | Specification for stainless steel butt hinges (second revision) |
| 12867: 1989 | Specification for PVC hand rails covers |
| 14912: 2001 | Specification for door closers concealed type (hydraulically regulated) |
| 15833: 2009 | Specification for stainless steel tower bolts |
| 15834: 2008 | Specification for stainless steel sliding door bolts for use with padlocks |
| 16015: 2013 | Specification for mortice locks with lever mechanism (vertical type, sliding door locks and dead locks) |
| 16016: 2013 | Specification for cylindrical locks with pin tumbler mechanism |

**3.2.5.4 Building Lime And Products**

| IS No. | Title |
|---|---|
| 712: 1984 | Specification for building limes (third revision) |
| 1624: 1986 | Method of field testing of building lime (second revision) |
| 2686: 1977 | Specification for cinder as fine aggregates for use in lime concrete (first revision) |
| 3068: 1986 | Specification for broken brick (burntclay) coarse aggregates for use in lime concrete (second revision) |
| 3115: 1992 | Specification for lime based blocks (second revision) |
| 3182: 1986 | Specification for broken bricks (burnt clay) fine aggregates for use in lime mortar (second revision) |
| 4098: 1983 | Specification for lime-pozzolana mixture (first revision) |

| | |
|---|---|
| 4139: 1989 | Specification for calcium silicate bricks (second revision) |
| 6932 | Method of tests for building limes |
| (Part 1): 1973 | Determination of insoluble residue, loss on ignition, insoluble matter, silicon dioxide, ferric and aluminium oxide, calcium oxide and magnesium oxide |
| (Part 2): 1973 | Determination of carbon dioxide content |
| (Part 3): 1973 | Determination of residue on slaking of quicklime |
| (Part 4): 1973 | Determination of fineness of hydrated lime |
| (Part 5): 1973 | Determination of unhydrated oxide |
| (Part 6): 1973 | Determination of volume yield of quicklime |
| (Part 7): 1973 | Determination of compressive and transverse strength |
| (Part 8): 1973 | Determination of workability |
| (Part 9): 1973 | Determination of soundness |
| (Part 10): 1973 | Determination of popping and pitting of hydrated lime |
| (Part 11): 1984 | Determination of setting time of hydrated lime |
| 10360: 1982 | Specification for lime pozzolana concrete blocks for paving |
| 10772: 1983 | Specification for quick setting lime pozzolana mixture |
| 12894: 2002 | Specification for pulverized fuel ash lime bricks (first revision) |
| 15648: 2006 | Specification for pulverized fuel ash for lime-pozzolana mixture applications |

**3.2.5.5 Clay And Stabilized Soil Products**

❖ **Blocks**

| IS No. | Title |
|---|---|
| 3952: 2013 | Specification for burnt clay hollow bricks and blocks for walls and partitions (third revision) |

❖ **Stabilized Soil Products**

| IS No. | Title |
|---|---|
| 1725: 2013 | Specification for stabilized soil blocks used in general building construction (second revision) |

❖ **Bricks**

| IS No. | Title |
|---|---|
| 1077: 1992 | Specification for common burnt clay building bricks (fifth revision) |
| 2180: 1988 | Specification for heavy duty burnt clay building bricks (third revision) |
| 2222: 1991 | Specification for burnt clay perforated building bricks (third revision) |
| 2691: 1988 | Specification for burnt clay facing bricks (second revision) |
| 3583: 1988 | Specification for burnt clay paving bricks (second revision) |
| 3952: 2013 | Specification for burnt clay hollow bricks and blocks for walls and partitions (third revision) |
| 4885: 1988 | Specification for sewer bricks (first revision) 5454 : 1978 Methods for sampling of clay building bricks (first revision) |
| 4885: 1988 | Specification for sewer bricks (first revision) |
| 5454: 1978 | Methods for sampling of clay building bricks (first revision) |
| 5779: 1986 | Specification for burnt clay soling bricks (first revision) |
| 6165: 1992 | Dimensions for special shapes of clay bricks (first revision) |
| 13757: 1993 | Specification for burnt clay fly ash building bricks |

❖ **Jallies**

| IS No. | Title |
|---|---|
| 7556: 1988 | Specification for burnt clay jallies (first revision) |

❖ **Tiles**

| IS No. | Title |
|---|---|
| 654: 1992 | Specification for clay roofing tiles, Mangalore pattern (third revision) |
| 1464: 1992 | Specification for clay ridge and ceiling tiles (second revision) |
| 1478: 1992 | Specification for clay flooring tiles (second revision) |
| 2690 | Specification for burnt clay flat terracing tiles |
| (Part 1): 1993 | Machine made (second revision) |
| (Part 2): 1992 | Hand made (second revision) |
| 3367: 1993 | Specification for burnt clay tiles for use in lining irrigation and drainage works (second revision) |
| 3951 | Specification for hollow clay tiles for floor and roofs |
| (Part 1): 2009 | Filler type (second revision) |
| (Part 2): 2009 | Structural type (second revision) |
| 8920: 1978 | Methods for sampling of burnt clay tiles |
| 13317: 1992 | Specification for clay roofing county tiles, half round and flat tiles |

**3.2.5.6 Cement And Concrete (Including Steel Reinforcement For Concrete)**

❖ **Aggregates**

| IS No. | Title |
|---|---|
| 383: 2016 | Specification for coarse and fine aggregates for concrete (third revision) |
| 650: 1991 | Specification for standard sand for testing of cement (second revision) |
| 1542: 1992 | Specification for sand for plaster (second revision) |
| 2116: 1980 | Specification for sand for masonry mortars (first revision) |
| 2386 | Methods of test for aggregates for concrete |
| (Part 1): 1963 | Particle size and shape |
| (Part 2): 1963 | Estimation of deleterious materials and organic impurities |
| (Part 3): 1963 | Specific gravity, density, voids, absorption and bulking |
| (Part 4): 1963 | Mechanical properties |
| (Part 5): 1963 | Soundness |
| (Part 6): 1963 | Measuring mortar making properties of fine aggregates |
| (Part 7): 1963 | Alkali aggregate reactivity |
| (Part 8): 1963 | Petrographic examination |
| 2430: 1986 | Methods of sampling of aggregates of concrete (first revision) |
| 6579: 1981 | Specification for coarse aggregate for water bound macadam (first revision) |
| 9142: 1979 | Specification for artificial light-weight aggregates for concrete masonry units |

❖ **Cement**

| IS No. | Title |
|---|---|
| 269: 2015 | Specification for ordinary Portland cement (sixth revision) |
| 455: 2015 | Specification for Portland slag cement (fifth revision) |
| 1489 | Specification for Portland pozzolana cement |
| (Part 1): 2015 | Flyash based (fourth revision) |
| (Part 2): 2015 | Calcined clay based (fourth revision) |
| 3466: 1988 | Specification for masonry cement (second revision) |

| | |
|---|---|
| 6452: 1989 | Specification for high alumina cement for structural use (first revision) |
| 6909: 1990 | Specification for supersulphated cement (first revision) |
| 8041: 1990 | Specification for rapid hardening Portland cement (second revision) |
| 8042: 2015 | Specification for white Portland cement (third revision) |
| 8043: 1991 | Specification for hydrophobic Portland cement (second revision) |
| 12330: 1988 | Specification for sulphate resisting Portland cement |
| 12600: 1989 | Specification for low heat Portland cement |
| 16415: 2015 | Specification for composite cement |

❖ **Supplementary Cementious Materials (Mineral Admixtures including Pozzolanas)**

| **IS No.** | **Title** |
|---|---|
| 1344: 1981 | Specification for calcined clay pozzolana (second revision) |
| 1727: 1967 | Methods of test for pozzolanic materials (first revision) |
| 3812 | Specification for pulverized fuel ash |
| (Part 1): 2013 | For use as pozzolana in cement, cement mortar and concrete (third revision) |
| (Part 2): 2013 | For use as admixture in cement mortar and concrete (third revision) |
| 6491: 1972 | Method of sampling of flyash |
| 12089: 1987 | Specification for granulated slag for manufacture of Portland slag cement |
| 12870: 1989 | Methods of sampling calcined clay pozzolana |
| 15388: 2003 | Specification for silica fume |
| 16354: 2015 | Specification for metakaolin for use in cement, cement mortar and concrete |

❖ **Chemical Admixtures**

| **IS No.** | **Title** |
|---|---|
| 6925: 1973 | Methods of test for determination of water soluble chlorides in concrete admixtures |
| 9103: 1999 | Specification for admixtures for concrete (first revision) |

❖ **Concrete**

| | |
|---|---|
| 456: 2000 | Code of Practice for plain and reinforced concrete (fourth revision) |
| 1343: 2012 | Code of Practice for prestressed concrete (second revision) |
| 4926: 2003 | Code of Practice for ready-mixed concrete (second revision) |

❖ **Cement and Concrete Sampling and Methods of Test**

| | |
|---|---|
| 516: 1959 | Methods of test for strength of concrete |
| 1199: 1959 | Methods of sampling and analysis of concrete |
| 2770 | Methods of testing bond in reinforced |
| (Part 1): 1967 | Concrete: Pullout test |
| 3085: 1965 | Methods of test for permeability of cement mortar and concrete |
| 3535: 1986 | Methods of sampling hydraulic cement (first revision) |
| 4031 | Methods of physical tests for hydraulic cement |
| (Part 1): 1996 | Determination of fineness by dry sieving (second revision) |
| (Part 2): 1999 | Determination of fineness by specific surface by Blaine air permeability method (second revision) |
| (Part 3): 1988 | Determination of soundness (first revision) |
| (Part 4): 1988 | Determination of consistency of standard cement paste (first revision) |
| (Part 5): 1988 | Determination of initial and final setting times (first revision) |
| (Part 6): 1988 | Determination of compressive strength of hydraulic cement (other than masonry cement)(first revision) |

| | |
|---|---|
| (Part 7): 1988 | Determination of compressive strength of masonry cement (first revision) |
| (Part 8): 1988 | Determination of transverse and compressive strength of plastic mortar using prism (first revision) |
| (Part 9): 1988 | Determination of heat of hydration (first revision) |
| (Part 10): 1988 | Determination of drying shrinkage (first revision) |
| (Part 11): 1988 | Determination of density (first revision) |
| (Part 12): 1988 | Determination of air content of hydraulic cement mortar (first revision) |
| (Part 13): 1988 | Measurement of water retentivity of masonry cement (first revision) |
| (Part 14): 1989 | Determination of false set |
| (Part 15): 1991 | Determination of fineness by wet sieving |
| 4032: 1985 | Methods of chemical analysis for hydraulic cement (first revision) |
| 5816: 1999 | Method of test for splitting tensile strength of concrete (first revision) |
| 8142: 1976 | Methods of test for determining setting time of concrete by penetration resistance |
| 9013: 1978 | Method of making, curing and determining compressive strength of accelerated cured concrete test specimens |
| 9284: 1979 | Method of test for abrasion resistance of concrete |
| 12423: 1988 | Methods for colorimetric analysis of hydraulic cement |
| 12803: 1989 | Methods of analysis of hydraulic cement by X-ray fluorescen spectrometer |
| 12813: 1989 | Method of analysis of hydraulic cement by atomic absorption spectrophotometer |
| 13311 | Methods of non-destructive testing of concrete |
| (Part 1): 1992 | Ultrasonic pulse velocity |
| (Part 2): 1992 | Rebound hammer |
| 14959 | Method of test for determination of water soluble and acid soluble chlorides in mortar and concrete |
| (Part 1): 2001 | Fresh mortar |
| (Part 2): 2001 | Hardened mortar and concrete |

❖ **Treatment of Concrete Joints**

| **IS No.** | **Title** |
|---|---|
| 1834: 1984 | Specification for hot applied sealing compound for joint in concrete (first revision) |
| 1838 | Specification for preformed fillers for expansion joint in concrete pavements and structures (non extruding and resilient type) |
| (Part 1): 1983 | Bitumen impregnated fibre (first revision) |
| (Part 2): 1984 | CNSL aldehyde resin and coconut pith |
| (Part 3): 2011 | Polymer based |
| 10566: 1983 | Methods of test for preformed fillers for expansion joints in concrete paving and structural construction 11433 Specification for one grade polysulphide based joint sealant |
| 11433 | Specification for one grade polysulphide based joint sealant |
| (Part 1): 1985 | General requirements |
| (Part 2): 1986 | Methods of test |
| 12118 | Specification for two parts polysulphide based sealants |
| (Part 1): 1987 | General requirements |

| | |
|---|---|
| (Part 2): 1987 | Methods of test |

❖ **Steel Reinforcement and Prestressing Steel for Concrete**

| **IS No.** | **Title** |
|---|---|
| 432 | Specification for mild steel and medium tensile steel bars and hard drawn steel wire for concrete reinforcement |
| (Part 1): 1982 | Mild steel and medium tensile steel bars (third revision) |
| (Part 2): 1982 | Hard drawn steel wire (third revision) |
| 1566: 1982 | Specification for hard drawn steel wire fabric for concrete reinforcement (second revision) |
| 1608: 2005 | Metallic materials Tensile testing at ambient temperature (third revision) |
| 1785 | Specification for plain hard drawn steel wire for pre-stressed concrete |
| (Part 1): 1983 | Cold drawn stress-relieved wire (second revision) |
| (Part 2): 1983 | As drawn wire (first revision) |
| 1786: 2008 | Specification for high strength deformed steel bars and wires for concrete reinforcement (fourth revision) |
| 2090: 1983 | Specification for high tensile steel bars used in prestressed concrete (first revision) |
| 6003: 2010 | Specification for indented wire for prestressed concrete (second revision) |
| 6006: 2014 | Specification for uncoated stressrelieved strand for prestressed concrete (second revision) |
| 10790 | Methods of sampling of steel for prestressed and reinforced concrete |
| (Part 1): 1984 | Prestressing steel |
| (Part 2): 1984 | Reinforcing steel |
| 13620: 1993 | Specification for fusion bonded epoxy coated reinforcing bars |
| 14268: 1995 | Specification for uncoated stress relieved low relaxation seven ply strand for prestressed concrete |
| 16172: 2014 | Specification for reinforcement couplers for mechanical splices of bars in concrete |

**3.2.5.7 Composite Matrix Products**

❖ **Cement Matrix Products**

❖ **Precast Concrete Products**

| | |
|---|---|
| 2174: 1962 | Specification for reinforced concrete dust bins |
| 2185 | Specification for concrete masonry units |
| (Part 1): 2005 | Hollow and solid concrete blocks (third revision) |
| (Part 2): 1983 | Hollow and solid lightweight concrete blocks (first revision) |
| (Part 3): 1984 | Autoclaved cellular (aerated) concrete blocks (first revision) |
| (Part 4): 2008 | Cellular concrete blocks using preformed foam |
| 4996: 1984 | Specification for reinforced concrete fence posts (first revision) |
| 5751: 1984 | Specification for precast concrete coping blocks (first revision) |
| 5758: 1984 | Specification for precast concrete kerbs (first revision) |
| 5820: 1970 | Specification for precast concrete cable covers |
| 6072: 1971 | Specification for autoclaved reinforced cellular concrete wall slabs |
| 6073: 2006 | Specification for autoclaved reinforced cellular concrete floor and roof slabs (first revision) |
| 6441 | Methods of test for autoclaved cellular concrete products |

| | |
|---|---|
| (Part 1): 1972 | Determination of unit weight or bulk density and moisture content |
| (Part 2): 1972 | Determination of drying shrinkage |
| (Part 4): 1972 | Corrosion protection of steel reinforcement in autoclaved cellular concrete |
| (Part 5): 1972 | Determination of compressive strength |
| (Part 6): 1973 | Strength, deformation and cracking of flexural members subject to bending Short duration loading test |
| (Part 7): 1973 | Strength, deformation and cracking of flexural members subject to bending Sustained loading test |
| (Part 8): 1973 | Loading tests for flexural members in diagonal tension |
| (Part 9): 1973 | Jointing of autoclaved cellular concrete elements |
| 6523: 1983 | Specification for precast reinforced concrete door and window frames (first revision) |
| 9375: 1979 | Specification for precast reinforced concrete plant guards |
| 9872: 1981 | Specification for precast concrete septic tanks |
| 9893: 1981 | Specification for precast concrete blocks for lintels and sills |
| 12440: 1988 | Specification for precast concrete stone masonry blocks |
| 12592: 2002 | Specification for precast concrete manhole covers and frames (first revision) |
| 13356: 1992 | Specification for precast ferrocement water tanks (250 to 10 000 litres capacity) |
| 13990: 1994 | Specification for precast reinforced concrete planks and joists for flooring and roofing |
| 14143: 1994 | Specification for prefabricated brick panel and partially precast concrete joist for flooring and roofing |
| 14201: 1994 | Specification for precast reinforced concrete channel unit for construction of floors and roofs |
| 14241: 1995 | Specification for precast L-Panel units for roofing |

❖ **Asbestos Fibre Cement Products**

| IS No. | Title |
|---|---|
| 459: 1992 | Specification for corrugated and semi-corrugated asbestos cement sheets (third revision) |
| 1592: 2003 | Specification for asbestos cement pressure pipes and joints (fourth revision) |
| 1626 | Specification for asbestos cement building pipes and pipe fittings, gutters and gutter fittings and roofing fittings |
| (Part 1): 1994 | Pipes and pipe fittings (second revision) |
| (Part 2): 1994 | Gutters and gutter fittings (second revision) |
| (Part 3): 1994 | Roofing fittings (second revision) |
| 2096: 1992 | Specification for asbestos cement flat sheets (first revision) |
| 2098: 1997 | Specification for asbestos cement building boards (first revision) |
| 5913: 2003 | Methods of test for asbestos cement products (second revision) |
| 6908: 1991 | Specification for asbestos cement pipes and fittings for sewerage and drainage (first revision) |
| 7639: 1975 | Method of sampling asbestos cement products |
| 9627: 1980 | Specification for asbestos cement pressure pipes (light duty) |
| 13000: 1990 | Specification for silica-asbestoscement flat sheets |
| 13008: 1990 | Specification for shallow corrugated asbestos cement sheets |

- **Other Fibre Cement Products**

| IS No. | Title |
|---|---|
| 14862: 2000 | Specification for fibre cement flat sheets |
| 14871: 2000 | Specification for products in fibre reinforced cement long corrugated or asymmetrical section sheets and fittings for roofing and cladding |

- **Concrete Pipes and Pipes Lined/Coated with Concrete or Mortar**

| IS No. | Title |
|---|---|
| 458 : 2003 | Specification for precast concrete pipes (with and without reinforcement) (fourth revision) |
| 784 : 2001 | Specification for prestressed concrete pipes (including specials) (second revision) |
| 1916 : 1989 | Specification for steel cylinder pipe with concrete lining and coating (first revision) |
| 3597 : 1998 | Methods of test for concrete pipes (second revision) |
| 4350 : 1967 | Specification for concrete porous pipes for under drainage |
| 7319 : 1974 | Specification for perforated concrete pipes |
| 7322 : 1985 | Specification for specials for steel cylinder reinforced concrete pipes (first revision) |
| 15155 : 2002 | Specification for bar/wire wrapped steel cylinder pipe with mortar lining and coating |

- **Resin Matrix Products**

| IS No. | Title |
|---|---|
| 1998 : 1962 | Methods of test for thermosetting synthetic resin bonded laminated sheets |
| 2036 : 1995 | Specification for phenolic laminated sheets (second revision) |

**3.2.5.8 Doors, Windows and Ventilators**

- **Wooden Doors, Windows and Ventilators**

| IS No. | Title |
|---|---|
| 1003 | Specification for timber panelled and glazed shutters |
| (Part 1) : 2003 | Door shutters (fourth revision) |
| (Part 2) : 1994 | Window and ventilator shutters (third revision) |
| 2191 | Specification for wooden flush door shutters (cellular and hollow core type) |
| (Part 1) : 1983 | Plywood face panels (fourth revision) |
| (Part 2) : 1983 | Particle board face panels and hardboard face panels (third revision) |
| 2202 | Specification for wooden flush door shutters (solid core type) |
| (Part 1) : 1999 | Plywood face panels (sixth revision) |
| (Part 2) : 1983 | Particle board face panels and hardboard face panels (third revision) |
| 4020 | Method of tests for door shutters |
| (Part 1) : 1998 | General (third revision) |
| (Part 2) : 1998 | Measurement of dimensions and squareness (third revision) |
| (Part 3) : 1998 | Measurement of general flatness (third revision) |
| (Part 4) : 1998 | Local planeness test (third revision) |
| (Part 5) : 1998 | Impact indentation test (third revision) |
| (Part 6) : 1998 | Flexure test (third revision) |
| (Part 7) : 1998 | Edge loading test (third revision) |
| (Part 8) : 1998 | Shock resistance test (third revision) |

| | |
|---|---|
| (Part 9) : 1998 | Buckling resistance test (third revision) |
| (Part 10) : 1998 | Slamming test (third revision) |
| (Part 11) : 1998 | Misuse test (third revision) |
| (Part 12) : 1998 | Varying humidity test (third revision) |
| (Part 13) : 1998 | End immersion test (third revision) |
| (Part 14) : 1998 | Knife test (third revision) |
| (Part 15) : 1998 | Glue adhesion test (third revision) |
| (Part 16) : 1998 | Screw withdrawal resistance test (third revision) |
| 4021 : 1995 | Specification for timber door, window and ventilator frames |
| 6198 : 1992 | Specification for ledged, braced and battened timber shutters (second revision) |

❖ **Metal Doors, Windows and Ventilators**

| **IS No.** | **Title** |
|---|---|
| 1038 : 1983 | Specification for steel doors, windows and ventilators (third revision) |
| 1361 : 1978 | Specification for steel windows for industrial buildings (first revision) |
| 1948 : 1961 | Specification for aluminium doors, windows and ventilators |
| 1949 : 1961 | Specification for aluminium windows for industrial buildings |
| 4351 : 2003 | Specification for steel door frames (second revision) |
| 6248 : 1979 | Specification for metal rolling shutters and rolling grills (first revision) |
| 7452 : 1990 | Specification for hot rolled steel sections for doors, windows and ventilators (second revision) |
| 10451 : 1983 | Specification for steel sliding shutters (top hung type) |
| 10521 : 1983 | Specification for collapsible gates |

❖ **Plastic Doors and Windows**

| **IS No.** | **Title** |
|---|---|
| 14856 : 2000 | Specification for glass fibre reinforced (GRP) panel type door shutters for internal use |
| 15380 : 2003 | Specification for moulded raised high density fibre (HDF) panel doors |
| 15931 : 2012 | Specification for solid panel foam UPVC door shutters |

❖ **Concrete Door and Window Frames**

| **IS No.** | **Title** |
|---|---|
| 6523 : 1983 | Specification for precast reinforced concrete door and window frames (first revision) |

❖ **Other Composite Material Doors and Windows**

| **IS No.** | **Title** |
|---|---|
| 16073 : 2013 | Specification for bamboo-jute composite panel door shutter |
| 16074 : 2014 | Specification for steel flush door shutters |
| 16096 : 2013 | Specification for phenol bonded bamboo-jute composite hollow door shutter |

❖ **Fire Check Doors**

| **IS No.** | **Title** |
|---|---|
| 3614 | Specification for fire-check doors |
| (Part 1 ) : 1966 | Plate, metal covered and rolling type |
| (Part 2) : 1992 | Metallic and non-metallic fire check doors Resistance test and performance criteria |

- **Mesh/Net for Mosquito/Vector Prevention**

| IS No. | Title |
|---|---|
| 1568 : 1970 | Specification for wire cloth for general purposes (first revision) |
| 3150 : 1982 | Specification for hexagonal wire netting for general purposes (second revision) |
| 11199 : 1985 | Specification for HDPE monofilament twine door nets |

**3.2.5.9 Fillers, Stoppers And Putties**

| IS No. | Title |
|---|---|
| 110 : 1983 | Specification for ready mixed paint, brushing, grey filler, for enamels, for use over primers (second revision) |
| 419 : 1967 | Specification for putty for use on window frames (first revision) |
| 423 : 1961 | Specification for plastic wood, for joiner's filler (revised) |
| 3709 : 1966 | Specification for mastic cement for bedding of metal windows |
| 7164 : 1973 | Specification for stopper |
| 13184 : 1991 | Specification for mastic filler, epoxy based (two pack) |

**3.2.5.10 Floor Covering, Roofing And Other Finishes**

- **Concrete Flooring**

| IS No. | Title |
|---|---|
| 1237 : 2012 | Specification for cement concrete flooring tiles (second revision) |
| 6073 : 2006 | Specification for autoclaved reinforced cellular concrete floor and roof slabs (first revision) |
| 13801 : 2013 | Specification for chequered cement concrete tiles (first revision) |
| 13990 : 1994 | Specification for precast reinforced concrete planks and joists for flooring and roofing |
| 14201 : 1994 | Specification for precast reinforced concrete channel units for construction of floors and roofs |
| 15658 : 2006 | Specification for precast concrete blocks for paving |

- **Flooring Compositions**

| IS No. | Title |
|---|---|
| 657 : 1982 | Specification for materials for use in the manufacture of magnesium oxychloride flooring compositions (second revision) |
| 9162 : 1979 | Methods of tests for epoxy resin, hardeners and epoxy resin composition for floor topping |
| 9197 : 1979 | Specification for epoxy resin, hardness and epoxy resin compositions for floor topping |
| 10132 : 1982 | Method of test for materials for use in the preparation of magnesium oxychloride flooring composition |

- **Linoleum Flooring**

| IS No. | Title |
|---|---|
| 653 : 1992 | Specification for linoleum sheets and tiles (third revision) |
| 9704 : 1980 | Methods of tests for linoleum sheets and tiles |

- **Rubber Flooring**

| IS No. | Title |
|---|---|
| 809 : 1992 | Specification for rubber flooring materials for general purposes (first revision) |

- **Stone Flooring**

| IS No. | Title |
|---|---|
| 1128 : 1974 | Specification for limestone (slab and tiles) (first revision) |
| 1130 : 1969 | Specification for marble (blocks, slabs and tiles) |
| 3316 : 1974 | Specification for structural granite (first revision) |
| 3622 : 1977 | Specification for sand stone (slabs and tiles) (first revision) |
| 14223 (Part 1) : 1994 | Specification for polished building stone : Part 1 Granite |

- **Bituminous Flooring**

| IS No. | Title |
|---|---|
| 1195 : 2002 | Specification for bitumen mastic for flooring (third revision) |
| 5317 : 2002 | Specification for pitch-mastic for bridge decking and roads (second revision) |
| 8374 : 1977 | Specification for bitumen mastic, anti-static and electrically conducting grade |
| 9510 : 1980 | Specification for bitumen mastic acid resisting grade |
| 13026 : 1991 | Specification for bitumen mastic for flooring for industries handling LPG and other light hydrocarbon products |
| 15194 : 2002 | Specification for pitch-mastic flooring for industries handling heavy hydrocarbon products like kerosene, diesel and furnace oil |

- **Plastic Flooring**

| IS No. | Title |
|---|---|
| 3461 : 1980 | Specification for PVC asbestos floor tiles (first revision) |
| 3462 : 1986 | Specification for unbacked flexible PVC flooring (second revision) |
| 3464 : 1986 | Methods of test for plastic flooring and wall tiles (second revision) |

- **Ceramic/Vitreous Flooring and Wall Finishing**

| IS No. | Title |
|---|---|
| 2333 : 1992 | Specification for plaster of Paris for ceramic industry (second revision) |
| 4457 : 2007 | Specification for ceramic unglazed vitreous acid resisting tile (second revision) |
| 13630 | Ceramic tiles Methods of test, sampling and basis for acceptance |
| (Part 1) : 2006 | Determination of dimensions and surface quality (first revision) |
| (Part 2) : 2006 | Determination of water absorption and bulk density (first revision) |
| (Part 3) : 2006 | Determination of moisture expansion using boiling water Unglazed tiles (first revision) |
| (Part 4) : 2006 | Determination of linear thermal expansion (first revision) |
| (Part 5) : 2006 | Determination of resistance to thermal shock (first revision) |
| (Part 6) : 2006 | Determination of modulus of rupture and breaking strength (first revision) |
| (Part 7) : 2006 | Determination of chemical resistance Unglazed tiles (first revision) |
| (Part 8) : 2006 | Determination of chemical resistance Glazed tiles (first revision) |
| (Part 9) : 2006 | Determination of crazing resistance Glazed tiles (first revision) |
| (Part 10) : 2006 | Determination of frost resistance (first revision) |
| (Part 11) : 2006 | Determination of resistance to surface abrasion Glazed tiles (first revision) |
| (Part 12) : 2006 | Determination of resistance to deep abrasion Unglazed tiles (first revision) |
| (Part 13) : 2006 | Determination of scratch hardness of surface according to Mohs'(first revision) |
| (Part 14) : 2006 | Determination of impact resistance by measurement of coefficient of restitution |
| (Part 15) : 2006 | Ceramic tiles Sampling and basis for acceptance |

| | |
|---|---|
| 13712 : 2006 | Ceramic tiles Definitions, classifications, characteristics and marking (first revision) |
| 15622 : 2006 | Specification for pressed ceramic tiles |

❖ **Clay Flooring**

| **IS No.** | **Title** |
|---|---|
| 1478 : 1992 | Specification for clay flooring tiles (second revision) |
| 3951 | Specification for hollow clay tiles for floor and roofs |
| (Part 1) : 2009 | Filler type (second revision) |
| (Part 2) : 2009 | Structural type (second revision) |

❖ **Roofing**

| **IS No.** | **Title** |
|---|---|
| 277 : 2003 | Galvanized steel sheets (plain and corrugated) Specification (sixth revision) |
| 459 : 1992 | Specification for corrugated and semi-corrugated asbestos cement sheets (third revision) |
| 654 : 1992 | Specification for clay roofing tiles, Mangalore pattern (third revision) |
| 1464 : 1992 | Specification for clay ridge and ceiling tiles (second revision) |
| 2690 | Specification for burnt clay flat terracing tiles |
| (Part 1) : 1993 | Machine made (second revision) |
| (Part 2) : 1992 | Handmade (second revision) |
| 3951 | Specification for hollow clay tiles for floor and roofs |
| (Part 1) : 2009 | Filler type (second revision) |
| (Part 2) : 2009 | Structural type (second revision) |
| 6073 : 2006 | Specification for autoclaved reinforced cellular concrete floor and roof slabs (first revision) |
| 6250 : 1981 | Specification for roofing slate tiles (first revision) |
| 10388 : 1982 | Specification for corrugated coir wood wool cement roofing sheets |
| 12583 : 1988 | Specification for corrugated bitumen roofing sheets |
| 12866 : 1989 | Specification for plastic translucent sheets made from thermosetting polyester resin (glass fibre reinforced) |
| 13317 : 1992 | Specification for clay roofing country tiles, half round and flat tiles |
| 13990 : 1994 | Specification for precast reinforced concrete planks and joists for flooring and roofing |
| 14201 : 1994 | Specification for precast reinforced concrete channel units for construction of floors and roofs |
| 14241 : 1995 | Specification for precast L-Panel units for roofing |

❖ **Other Floorings and Roofings**

| **IS No.** | **Title** |
|---|---|
| 4456 | Methods of test for chemical resistant mortars |
| (Part 1) : 1967 | Silicate type and resin type |
| (Part 2) : 1967 | Sulphur type |
| 4457 : 2007 | Specification for ceramic unglazed vitreous acid resisting tile (second revision) |
| 4832 | Specification for chemical resistant mortars |
| (Part 1) : 1969 | Silicate type |
| (Part 2) : 1969 | Resin type |
| (Part 3) : 1968 | Sulphur type |

| | |
|---|---|
| 4860 : 1968 | Specification for acid resistant bricks |
| 14862 : 2000 | Specification for fibre cement flat sheets |
| 14143 : 1994 | Specification for prefabricated brick panel and partially precast concrete joist for flooring and roofing |
| 14871 : 2000 | Specification for products in fibre reinforced cement Long corrugated or asymmetrical section sheets and fittings for roofing and cladding |

❖ **Wall Coverings/Finishing**

| **IS No.** | **Title** |
|---|---|
| 1542 : 1992 | Specification for sand for plaster (second revision) |
| 3952 : 2013 | Specification for burnt clay hollow bricks and blocks for walls and partitions (third revision) |
| 4456 | Methods of test for chemical resistant mortars |
| (Part 1) : 1967 | Silicate type and resin type |
| (Part 2) : 1967 | Sulphur type |
| 4832 | Specification for chemical resistant mortars |
| (Part 1) : 1969 | Silicate type |
| (Part 2) : 1969 | Resin type |
| (Part 3) : 1968 | Sulphur type |
| 15418 : 2003 | Specification for finished wall papers, wall vinyls and plastic wall coverings in roll form |

**3.2.5.11 Glass**

| **IS No.** | **Title** |
|---|---|
| 2553 (Part 1) : | Specification for safety glass: Part 1 1990 General purpose (third revision) |
| 2835 : 1987 | Specification for flat transparent sheet glass (third revision) |
| 3438 : 1994 | Specification for silvered glass mirrors for general purposes (second revision) |
| 5437 : 1994 | Specification for figured rolled and wired glass (first revision) |
| 14900 : 2000 | Specification for transparent float glass |

**3.2.5.12 Gypsum Based Materials**

| **IS No.** | **Title** |
|---|---|
| 2095 | Specification for gypsum plaster boards |
| (Part 1) : 2011 | Plain gypsum plaster boards (third revision) |
| (Part 2) : 2001 | Coated/laminated gypsum plaster boards (second revision) |
| (Part 3) : 1996 | Reinforced gypsum plaster boards (second revision) |
| 2542 | Methods of test for gypsum plaster, concrete and products |
| (Part 1/Sec 1) : | Plaster and concrete, Section 1 |
| 1978 | Normal consistency of gypsum plaster (first revision) |
| (Part 1/Sec 2) : | Plaster and concrete, Section 2 |
| 1978 | Normal consistency of gypsum concrete (first revision) |
| (Part 1/Sec 3) : | Plaster and concrete, Section 3 |
| 1978 | Setting time of plaster and concrete (first revision) |
| (Part 1/Sec 4) : | Plaster and concrete, Section 4 |
| 1978 | Transverse strength of gypsum plaster (first revision) |
| (Part 1/Sec 5) : | Plaster and concrete, Section 5 |
| 1978 | Compressive strength and dry set density of gypsum plaster (first revision) |
| (Part 1/Sec 6) : | Plaster and concrete, Section 6 |

| | |
|---|---|
| 1978 | Soundness of gypsum plaster (first revision) |
| (Part 1/Sec 7) : | Plaster and concrete, Section 7 |
| 1978 | Mechanical resistance of gypsum plaster by dropping ball test (first revision) |
| (Part 1/Sec 8) : | Plaster and concrete, Section 8 |
| 1978 | Freedom from coarse particles (first revision) |
| (Part 1/Sec 9) : | Plaster and concrete, Section 9 |
| 1978 | Expansion of plaster (first revision) |
| (Part 1/Sec 10) : | Plaster and concrete, Section 10 Sand 1978 in set plaster (first revision) |
| (Part 1/Sec 11) : | Plaster and concrete, Section 11 1978 Wood fibre content in gypsum plaster (first revision) |
| (Part 1/Sec 12) : | Plaster and concrete, Section 12 Dry 1978 bulk density (first revision) |
| (Part 2/Sec 1) : | Gypsum products, Section 1 1981 Measurement of dimensions (first revision) |
| (Part 2/Sec 2) : | Gypsum products, Section 2 1981 Determination of mass (first revision) |
| (Part 2/Sec 3) : | Gypsum products, Section 3 1981 Determination of mass and thickness of paper surfacing (first revision) |
| (Part 2/Sec 4) : | Gypsum products, Section 4 1981 Transverse strength (first revision) |
| (Part 2/Sec 5) : | Gypsum products, Section 5 1981 Compressive strength (first revision) |
| (Part 2/Sec 6) : | Gypsum products, Section 6 Water 1981 absorption (first revision) |
| (Part 2/Sec 7) : | Gypsum products, Section 7 |
| 1981 | Moisture content (first revision) |
| (Part 2/Sec 8) : | Gypsum products, Section 8 Nail 1981 retention of precast reinforced gypsum slabs (first revision) |
| 2547 | Specification for gypsum building plaster |
| (Part 1) : 1976 | Excluding premixed lightweight plaster (first revision) |
| (Part 2) : 1976 | Premixed lightweight plaster (first revision) |
| 2849 : 1983 | Specification for non-load bearing gypsum partition blocks (solid and hollow types) (first revision) |
| 8272 : 1984 | Specification for gypsum plaster for use in the manufacture of fibrous plasterboards (first revision) |
| 9498 : 1980 | Specification for inorganic aggregates for use in gypsum plaster |
| 12679 : 1989 | Specification for by-product gypsum for use in plaster, blocks and boards |

**3.2.5.13 Mortar (Including Sand For Mortar)**

| IS No. | Title |
|---|---|
| 2116 : 1980 | Specification for sand for masonry mortars (first revision) |
| 2250 : 1981 | Code of Practice for preparation and use of masonry mortars (first revision) |
| 3085 : 1965 | Method of test for permeability of cement mortar and concrete |
| 4098 : 1983 | Specification for lime-pozzolana mixture (first revision) |
| 4456 | Methods of test for chemical resistant mortars |
| (Part 1) : 1967 | Silicate type and resin type |
| (Part 2) : 1967 | Sulphur type |
| 4832 | Chemical resistant mortars |
| (Part 1) : 1969 | Silicate type |
| (Part 2) : 1969 | Resin type |
| (Part 3) : 1968 | Sulphur type |

| | |
|---|---|
| 13077 : 1991 | Guide for preparation and use of mud mortar in masonry |
| 14959 | Method of test determination of water soluble and acid soluble chlorides in mortar and concrete |
| (Part 1) : 2001 | Fresh mortar and concrete |
| (Part 2) : 2001 | Hardened mortar and concrete |

**3.2.5.14 Paints and Allied Products**

❖ **Water Based Paints and Pigments**

| IS No. | Title |
|---|---|
| 427 : 2013 | Specification for distemper, dry, colour as required (third revision) |
| 428 : 2013 | Specification for washable distemper (third revision) |
| 5410 : 2013 | Specification for cement paint (second revision) |
| 15489 : 2013 | Specification for paint, plastic emulsion (first revision) |

❖ **Ready Mixed Paints, Enamels and Powder Coatings**

| IS No. | Title |
|---|---|
| 101 | Methods of sampling and test for paints, varnishes and related products |
| (Part 1/Sec 1) : | Test on liquid paints (general and 1986 (general and physical), Section 1 Sampling (third revision) |
| (Part 1/Sec 2) : | Test on liquid paints (general and 1987 physical), Section 2 Preliminary examination and preparation of samples for testing (third revision) |
| (Part 1/Sec 3) : | Test on liquid paints (general 1986 and physical), Section 3 Preparation of panels (third revision) |
| (Part 1/Sec 4) : | Test on liquid paints (general and 1987 physical), Section 4 Brushing test (third revision) |
| (Part 1/Sec 5) : | Test on liquid paints (general and 1989 physical), Section 5 Consistency (third revision) |
| (Part 1/Sec 6) : | Test on liquid paints (general and 1987 physical), Section 6 Flash point (third revision) |
| (Part 1/Sec 7) : | Test on liquid paints (general and 1987 physical), Section 7 Mass per 10 litres (third revision) |
| (Part 2/Sec 1) : | Test on liquid paints (Chemical 1988 examination), Section 1 Water content (third revision) |
| (Part 2/Sec 2) : | Test on liquid paints (Chemical 1986 examination), Section 2 Volatile matter (third revision) |
| (Part 3/Sec 1) : | Tests on paint film formation, Section 1986 1 Drying time (third revision) |
| (Part 3/Sec 2) : | Tests on paint film formation, Section 1989 2 Film thickness (third revision) |
| (Part 3/Sec 4) : | Tests on paint film formation, Section 1987 4 Finish (third revision) |
| (Part 3/Sec 5) : | Tests on paint film formation, Section 1987 5 Fineness of grind (third revision) |
| (Part 4/Sec 1) : | Optical test, Section 1 Opacity (third 1988 revision) |
| (Part 4/Sec 2) : | Optical test, Section 2 Colour (third 1989 revision) |
| (Part 4/Sec 3) : | Optical test, Section 3 Light fastness 1988 test (third revision) |
| (Part 4/Sec 4) : | Optical test, Section 4 Gloss (third 1988 revision) |
| (Part 5/Sec 1) : | Mechanical test on paint films, 1988 Section 1 Hardness tests (third revision) |
| (Part 5/Sec 2) : | Mechanical test on paint films, 1988 Section 2 Flexibility and adhesion (third revision) |

| | |
|---|---|
| (Part 5/Sec 3) : | Mechanical test on paint films, 1999 Section 3 Impact resistance (fourth revision) |
| (Part 5/Sec 4) : | Mechanical test on paint films, 1988 Section 4 Print free test (third revision) |
| (Part 6/Sec 1) : | Durability tests, Section 1 Resistance 1988 to humidity under conditions of condensation (third revision) |
| (Part 6/Sec 2) : | Durability tests, Section 2 Keeping 1989 properties (third revision) |
| (Part 6/Sec 3) : | Durability tests, Section 3 Moisture 1990 vapour permeability (third revision) |
| (Part 6/Sec 4) : | Durability tests, Section 4 1991 Degradation of coatings (pictorial aids for evaluation) (third revision) |
| (Part 6/Sec 5) : | Durability tests, Section 5 1997 Accelerated weathering test |
| (Part 7/Sec 1) : | Environmental tests on paint films, 1989 Section 1 Resistance to water (third revision) |
| (Part 7/Sec 2) : | Environmental tests on paint films, 1989 Section 2 Resistance to liquids (third revision) |
| (Part 7/Sec 3) : | Environmental tests on paint films, 1990 Section 3 Resistance to heat (third revision) |
| (Part 7/Sec 4) : | Environmental tests on paint films, 1990 Section 4 Resistance to bleeding of pigments (third revision) |
| (Part 8/Sec 1) : | Tests for pigments and other solids, 1989 Section 1 Residue on sieve (third revision) |
| (Part 8/Sec 2) : | Tests for pigments and other solids, 1990 Section 2 Pigments and non volatile matter (third revision) |
| (Part 8/Sec 3) : | Tests for pigments and other solids, 1993 Section 3 Ash content (third revision) |
| (Part 8/Sec 4) : | Tests for pigments and other solids, 2015 Section 4 Phthalic anhydride (fourth revision) |
| (Part 8/Sec 5) : | Tests for pigments and other solids, 1993 Section 5 Lead restriction test (third revision) |
| (Part 8/Sec 6) : | Tests for pigments and other solids, 1993 Section 6 Volume solids |
| (Part 9/Sec 1) : | Tests for lacquers and varnish, 1993 Section 1 Acid value (third revision) |
| (Part 9/Sec 2) : | Tests for lacquers and varnish, 1993 Section 2 Rosin test (third revision) |
| 104 : 1979 | Specification for ready mixed paint, brushing, zinc chrome, priming (second revision) |
| 109 : 1968 | Specification for ready mixed paint, brushing, priming, plaster to Indian Standard colours No. 361 and 631 (first revision) |
| 133 : 2004 | Specification for enamel, interior (a) undercoating, (b) finishing (fourth revision) |
| 133 (Part 1) : | Specification for enamel, interior 2013 (a) undercoating, |

- **Finishing:**

| | |
|---|---|
| 137 : 1965 | Specification for ready mixed paint, brushing, matt or egg-shell flat, finishing, interior, to Indian Standard colour, as required (revised) |
| 158 : 2015 | Specification for ready mixed paint, brushing, bituminous, black, leadfree, acid, alkali, and heat resisting (fourth revision) |
| 164 : 1981 | Specification for ready mixed paint for road marking (second revision) |
| 168 : 1993 | Specification for ready mixed paint, air-drying semi-glossy/matt, for general purposes (third revision) |

341 : 1973 Specification for black Japan, Types A, B and C (first revision)

2074 : 1992 Specification for ready mixed paint, air drying red oxide-zinc chrome, priming (second revision)

2075 : 2000 Specification for ready mixed paint, stoving, red oxide-zinc chrome, priming (second revision)

2339 : 2013 Specification for aluminium paint for general purposes (first revision)

2932 (Part 1) : Specification for enamel, synthetic, 2013 exterior

❖ **undercoating,**

finishing: Part 1 For household and decorative applications (fourth revision) 2933 (Part 1) : Specification for enamel, exterior: 2013 (a) undercoating (b) finishing: Part 1 for domesic and decorative applications 3536 : 1999 Specification for ready mixed paint, brushing, wood primer (first revision) 3537 : 1966 Specification for ready mixed paint, finishing, interior for general purposes, to Indian Standard colours No. 101, 216, 217, 219, 275, 281, 352, 353, 358 to 361, 363, 364, 388, 410, 442, 444, 628, 631, 632, 634, 693, 697, white and black 3539 : 1966 Specification for ready mixed paint, undercoating, for use under oil finishes, to Indian Standard colours, as required

3585 : 1966 Specification for ready mixed paint, aluminium, brushing, priming, water resistant, for wood work

3678 : 1966 Specification for ready mixed paint, thick white, for lettering

9862 : 1981 Specification for ready mixed paint, brushing, bituminous black lead free, acid, alkali, water and chlorine resisting

11883 : 1986 Specification for ready mixed paint, brushing, red oxide, priming for metals

12744 (Part 1) : Specification for ready mixed paint, 2013 air drying, red oxide, zinc phosphate, priming: Part 1 for domestic and decorative applications (fourth revision)

13183 : 1991 Specification for aluminium paints, heat resistant

13213 : 1991 Specification for polyurethane full gloss enamel (two pack)

13607 : 1992 Specification for ready mixed paint, finishing, general purposes, synthetic

13871 : 1993 Specification for powder coatings

14506 : 1998 Specification for epoxy redoxide zinc phosphate weldable primer, two component

14589 : 1999 Specification for zinc priming paint, epoxy based, two pack

❖ **Thinners and Solvents**

| IS No. | Title |
|---|---|
| 82 : 1973 | Methods of sampling and test for thinners and solvents for paints (first revision) |
| 430 : 1972 | Paint remover, solvent type, nonflammable (second revision) |
| 431 : 1972 | Paint remover, solvent type, flammable (second revision) |
| 533 : 2007 | Specification for gum spirit of turpentine (oil of turpentine) (third revision) |
| 5667 : 1970 | Specification for thinner for cellulose nitrate based paints and lacquers |
| 14314 : 1995 | Specification for thinner general purposes for synthetic paints and varnishes |

❖ **Varnishes and Lacquers**

| IS No. | Title |
|---|---|
| 337 : 1975 | Specification for varnish, finishing, interior (first revision) |
| 344 : 1976 | Specification for varnish, stoving (first revision) |

| | |
|---|---|
| 347 : 1975 | Specification for varnish, shellac, for general purposes (first revision) |
| 348 : 1968 | Specification for French polish (first revision) |
| 524 : 1983 | Specification for varnish, finishing, exterior, synthetic (second revision) |
| 525 : 1968 | Specification for varnish, finishing, exterior and general purposes (first revision) |
| 642 : 1963 | Specification for varnish medium for aluminium paint (revised) |
| 10018 : 1981 | Specification for lacquer, cellulose, nitrate clear, finishing, glossy for wood |

**3.2.5.15 Polymers, Plastics and Geosynthetics/Geotextiles**

| IS No. | Title |
|---|---|
| 1998 : 1962 | Methods of test for thermosetting synthetic resin bonded laminated sheets |
| 2036 : 1995 | Specification for phenolic laminated sheets (second revision) |
| 2046 : 1995 | Specification for decorative thermosetting synthetics resin bonded laminated sheets (second revision) |
| 2076 : 1981 | Specification for unsupported polyvinyl chloride sheeting (first revision) |
| 2508 : 1984 | Specification for low density polyethylene films (second revision) |
| 6307 : 1985 | Specification for rigid PVC sheets (first revision) |
| 10889 : 2004 | Specification for high density polyethylene films (first revision) |
| 12830 : 1989 | Specification for rubber based adhesives for fixing PVC tiles to cement |
| 13162 | Methods of test for geotextiles |
| (Part 2) : 1991 | Determination of resistance to exposure of ultra-violet light and water (Xenon arc type apparatus) |
| (Part 3) : 1992 | Determination of thickness at specified pressure |
| (Part 4) : 1992 | Determination of puncture resistance by falling cone method |
| (Part 5) : 1992 | Determination of tensile properties using a wide width strip |
| 13262 : 1992 | Specification for pressure sensitive adhesive tapes with plastic base |
| 13325 : 1992 | Method of test for the determination to tensile properties of extruded polymer geogrids using the wide strip |
| 13326 (Part 1) : | Method of test for the evaluation of 1992 interface friction between geosynthetics and soil: Part 1 Modified direct shear technique |
| 14182 : 1994 | Specification for solvent cement for use with unplasticized polyvinylchloride plastic pipe and fittings |
| 14293 : 1995 | Method of test for trapezoid tearing Geotextiles |
| 14294 : 1995 | Method of determination of apparent opening size by dry sieving technique Geotextiles |
| 14324 : 1995 | Method of test for determination of water permeability-permittivity Geotextiles |
| 14443 : 1997 | Specification for polycarbonate sheets |
| 14500 : 1998 | Specification for linear low-density polyethylene (LLDPE) films |
| 14643 : 1999 | Specification for unsintered polytetrafluoroethylene (PTFE) tape for thread sealing applications |
| 14706 : 1999 | Sampling and preparation of test specimen of geotextiles |
| 14714 : 1999 | Determination of abrasion resistance of geotextiles |
| 14715 : 2000 | Specification for woven jute geotextiles |
| 14716 : 1999 | Determination of mass per unit area of geotextiles |
| 14739 : 1999 | Methods for determination of creep of geotextiles |
| 14753 : 1999 | Specification for poly(methyl) methacrylate (PMMA) (Acrylic) sheets |

| | |
|---|---|
| 14986 : 2001 | Jute geo-grid for rain water erosion control in road and railway embankments and hill slopes |
| 15060 : 2001 | Tensile test for joints/seams by wide width method of geotextiles |
| 15351 : 2015 | Specification for textiles Laminated high density polyethylene (HDPE) woven fabric (geomembrane) for waterproof lining (second revision) |

**3.2.5.16 Steel and its Alloys**

❖ **General**

| IS No. | Title |
|---|---|
| 1030 : 1998 | Carbon steel castings for general engineering purposes (fifth revision) |
| 1136 : 2008 | Preferred sizes for wrought metal products (third revision) |
| 1762 (Part 1) : | Code for designation of steels: |
| Part 1 1974 | Based on letter symbols (first revision) |
| 2049 : 1978 | Colour code for the identification of wrought steel for general engineering purposes (first revision) |
| 2644 : 1994 | High tensile steel castings (fourth revision) |
| 2708 : 1993 | Specification for 1.5 percent manganese steel castings for general engineering purposes (third revision) |
| 7598 : 1990 | Classification of steels (first revision) |
| 10461 | Resistance to inter-granular corrosionof austenitic stainless steels Method for determination |
| (Part 1) : 1994 | Corrosion test in nitric acid medium by measurement of loss in mass (Huey test) (first revision) |
| (Part 2) : 1994 | Corrosion test in a sulphuric acid/ copper sulphate medium in the presence of copper turnings (Monypenny Strauss Test) (first revision) b) Structural Steel |

❖ **Structural Steel**

| | |
|---|---|
| 2062 : 2011 | Specification for hot rolled medium and high tensile structural steel (seventh revision) |
| 2830 : 2012 | Specification for carbon steel cast billet ingots, billets, blooms and slabs for re-rolling into steel for general structural purposes (third revision) |
| 2831 : 2012 | Specification for carbon steel cast billets ingots, blooms and slabs for re-rolling into structural steel (Ordinary quality) (fourth revision) |
| 8052 : 2006 | Specification for steel ingots, billets and blooms for the production of springs, rivets and screws for general engineering applications (second revision) |
| 8952 : 1995 | Steel ingots, blooms and billets for production of mild steel wire rods for general engineering purposes (first revision) |
| 11587 : 1986 | Specification for structural weather resistant steels |
| 15103 : 2002 | Fire resistant steel |
| 15911 : 2010 | Structural steel (Ordinary quality) |
| 15962 : 2012 | Structural steels for buildings and structures with improved seismic resistance |

❖ **Sheet and Strip**

| IS No. | Title |
|---|---|
| 277 : 2003 | Specification for galvanized steel sheets (plain and corrugated) (sixth revision) |
| 412 : 1975 | Specification for expanded metal steel sheets for general purposes (second revision) |
| 513 : 2008 | Specification for cold reduced low carbon steel sheets and strips (fifth revision) |

| | |
|---|---|
| 1079 : 2009 | Specification for hot rolled carbon steel sheet and strip (sixth revision) |
| 6911 : 1992 | Stainless steel plate, sheet and strip (first revision) |
| 7226 : 1974 | Specification for cold rolled medium, high carbon and low alloy steel strip for general engineering purposes |
| 14246 : 2013 | Specification for continuously prepainted galvanized steel sheets and coils (first revision) |
| 15961 : 2012 | Hot-dip |
| 15965 : 2012 | Pre-painted aluminium zinc alloy metallic coated steel strip and sheet (plain) |
| 12313: 1988 | Specification for hot-dip terne coated carbon steel sheets |

- **Bars, Rods, Wire and Wire Rods**

| IS No. | Title |
|---|---|
| 280 : 2006 | Specification for mild steel wire for general engineering purposes (fourth revision) |
| 1148 : 2009 | Steel rivet bars (medium and high tensile) for structural purposes (fourth revision) |
| 1673 : 1984 | Specification for mild steel wire cold heading quality (second revision) |
| 1812 : 1982 | Specification for carbon steel wire for the manufacture of wood screw (second revision) |
| 1835 : 1976 | Specification for round steel wire for ropes (third revision) |
| 1875 : 1992 | Carbon steel billets, blooms, slabs and bars for forgings (fifth revision) |
| 1921 : 2005 | Specification for resin cored solder wire (second revision) |
| 2591 : 1982 | Dimensions for hot rolled bars for threaded components (second revision) |
| 3150 : 1982 | Specification for hexagonal wire netting for general purposes |
| 4826 : 1979 | Specification for hot-dipped galvanized coatings on round steel wires (first revision) |
| 6527 : 1995 | Stainless steel wire rod (first revision) |
| 6528 : 1995 | Specification for stainless steel wire (first revision) |
| 6603 : 2001 | Specification for stainless steel bars and flats (first revision) |
| 7887 : 1992 | Specification for mild steel wire rods for general engineering purposes (first revision) |
| 7904 : 1995 | Specification for high-carbon steel wire rods (first revision) |
| 10631 : 1983 | Stainless steel for welding electrode core wire IS/ISO |
| 16124 : 2004 | Steel wire rod Dimensions and 2004 tolerances |

- **Plates and Studs**

| IS No. | Title |
|---|---|
| 1862 : 1975 | Specification for studs (second revision) |
| 3502 : 2009 | Specification for steel chequered plates (third revision) |

- **Tubes and Tubulars**

| IS No. | Title |
|---|---|
| 1161 : 2014 | Specification for steel tubes for structural purposes (fifth revision) |
| 4923 : 1997 | Specification for hollow mild steel sections for structural use (second revision) |

- **Slotted Sections**

| IS No. | Title |
|---|---|
| 8081 : 1976 | Specification for slotted sections |

### 3.2.5.17 Stones

| IS No. | Title |
|---|---|
| 1121 | Methods of test for determination of strength properties of natural building stones |
| (Part 1): 2013 | Compressive strength (second revision) |
| (Part 2): 2013 | Transverse strength (second revision) |
| (Part 3): 2012 | Tensile strength (second revision) |
| (Part 4): 2013 | Shear strength (second revision) |
| 1122: 1974 | Method of test for determination of true specific gravity of natural building stones (first revision) |
| 1123: 1975 | Method of identification of natural building stones (first revision) |
| 1124: 1974 | Method of test for determination of water absorption, apparent specific gravity and porosity of natural building stones (first revision) |
| 1125: 2013 | Method of test for determination of weathering of natural building stones (second revision) |
| 1126: 2013 | Method of test for determination of durability of natural building stones (second revision) |
| 1127: 1970 | Recommendations for dimensions and workmanship of natural building stones for masonry work (first revision) |
| 1128: 1974 | Specification for limestone (slab and tiles) (first revision) |
| 1129: 1972 | Recommendation for dressing of natural building stones (first revision) |
| 1130: 1969 | Specification for marble (blocks, slabs and tiles) |
| 1706: 1972 | Method of determination of resistance to wear by abrasion of natural building stones (first revision) |
| 3316: 1974 | Specification for structural granite (first revision) |
| 3620: 1979 | Specification for laterite stone block for masonry (first revision) |
| 3622: 1977 | Specification for sand stone (slabs and tiles) (first revision) |
| 4121: 1967 | Method of test for determination of water transmission rate by capillary action through natural building stones |
| 4122: 1967 | Method of test for surface softening of natural building stones by exposure to acidic atmospheres |
| 4348: 1973 | Methods of test for determination of permeability of natural building stones (first revision) |
| 5218: 1969 | Method of test for toughness of natural building stones |
| 5640: 1970 | Method of test for determining the aggregate impact value of soft coarse aggregates |
| 6241: 1971 | Method of test for determination of stripping value of road aggregates |
| 6250: 1981 | Specification for roofing slate tiles (first revision) |
| 6579: 1981 | Specification for coarse aggregate for water bound macadam (first revision) |
| 7779 | Schedule for properties and availability of stones for construction purposes |
| (Part 1/ Sec 1): | Gujarat state, Section 1 Availability 1975 of stones |
| (Part 1/ Sec 2): | Gujarat state, Section 2 Engineering 1975 properties of building stones |
| (Part 1/Sec 3): | Gujarat state, Section 3 Engineering 1975 properties of stone aggregates |
| (Part 2/ Sec 1): | Maharashtra state, Section 1 1979 Availability of stones |
| (Part 2/ Sec 2): | Maharashtra state, Section 2 1979 Engineering properties of building stones |

| | |
|---|---|
| (Part 2/ Sec 3): | Maharashtra state, Section 3 1979 Engineering properties of stone aggregates |
| (Part 3/ Sec 2): | Tamil Nadu state, Section 2 1990 Engineering properties of building stones |
| (Part 3/ Sec 3): | Tamil Nadu state, Section 3 1980 Engineering properties of stone aggregates |
| (Part 4/Sec 1 to 3 | Karnataka state, Sections (1 to 3) 3) : 1996 |
| (Part 5/ Sec 1): | Andhra Pradesh, Section 1 1997 Availability of stones |
| (Part 5/ Sec 2): | Andhra Pradesh, Section 2 1997 Engineering properties of building stones |
| (Part 5/ Sec 3): | Andhra Pradesh, Section 3 1997 Engineering properties of stone aggregates |
| 9394: 1979 | Specification for stone lintels |
| 14223 (Part 1): | Specification for polished building 1994 stones: Part 1 Granite |

**3.2.5.18 Structural Sections**

❖ **Structural Shapes**

| IS No. | Title |
|---|---|
| 811 : 1987 | Specification for cold formed light gauge structural steel sections (revised) |
| 1173 : 1978 | Specification for hot rolled and slit steel tee bars (second revision) |
| 1863 : 1979 | Specification for hot rolled steel bulb flats (first revision) |
| 2314 : 1986 | Specification for steel sheet piling sections (first revision) |
| 3443 : 1980 | Specification for crane rail sections (first revision) |
| 3908 : 1986 | Specification for aluminium equal leg angles (first revision) |
| 3909 : 1986 | Specification for aluminium unequal leg angles (first revision) |
| 3921 : 1985 | Specification for aluminium channels (first revision) |
| 3964 : 1980 | Specification for light rails (first revision) |
| 5384 : 1985 | Specification for aluminium I-beams (first revision) |
| 6445 : 1985 | Specification for aluminium tee sections (first revision) |

❖ **Dimensional Standards**

| IS No. | Title |
|---|---|
| 808 : 1989 | Dimensions for hot rolled steel beam, column channel and angle sections (third revision) |
| 1730 : 1989 | Dimensions for steel plates, sheets strips and flats for general engineering purposes (second revision) |
| 1732 : 1989 | Dimensions for round and square steel bars for structural and general engineering purposes (second revision) |
| 1852 : 1985 | Rolling and cutting tolerances for hot rolled steel products (fourth revision) |
| 2525 : 1982 | Dimensions for wrought aluminium and aluminium alloy wire (first revision) |
| 2591 : 1982 | Dimensions for hot rolled steel bars for threaded components (second revision) |
| 2673 : 2002 | Dimensions for wrought aluminium and aluminium alloys, extruded round tube (second revision) |
| 2676 : 1981 | Dimensions for wrought aluminium and aluminium alloys, sheet and strip (first revision) |
| 2677 : 1979 | Dimensions for wrought aluminium and aluminium alloys, plates and hot rolled sheets (first revision) |
| 2678 : 1987 | Dimensions and tolerances for wrought aluminium and aluminium alloy, drawn round tubes (second revision) |
| 3577 : 1992 | Dimensions and tolerances for wrought aluminium and aluminium alloys rivet, bolt and screw stock (first revision) |

| | |
|---|---|
| 3954 : 1991 | Hot rolled steel channel sections for general engineering purposes Dimension (first revision) |
| 3965 : 1981 | Dimensions for wrought aluminiumand aluminium alloys, bar, rod and section (first revision) |
| 6477 : 1983 | Dimensions for wrought aluminium and aluminium alloys, extruded hollow sections (first revision) |
| IS/ISO 7452 : | Hot-rolled structural steel plates 2002 Tolerances on dimensions and shape |
| 12778 : 2004 | Hot rolled parallel flange steel sections for beams, columns and bearing piles Dimensions and section properties (first revision) |
| 12779 : | 1989 Rolling and cutting tolerances for hot rolled parallel flange beam and column sections IS/ISO |
| 16124 : | Steel wire rod Dimensions and 2004 tolerances IS/ISO 16160 : Continuously hot rolled steel sheet 2012 products Dimensional and shape tolerances (first revision) IS/ISO |
| 16162 : | Continuously cold-rolled steel sheet 2012 products Dimensional and shape tolerances (first revision) IS/ISO 1 |
| 6163 : | Continuously hot dipped coated steel 2012 products Dimensional and shape tolerances (first revision) |

**3.2.5.19 Timber, Bamboo and other Lignocellulosic Building Materials**

- ❖ **Timber and Bamboo**
- ❖ **Timber Classification**

| IS No. | Title |
|---|---|
| 287 : 1993 | Permissible moisture content for timber used for different purposes Recommendations (third revision) |
| 399 : 1963 | Classification of commercial timbers and their zonal distribution (revised) |
| 1150 : 2000 | Trade names and abbreviated symbols for timber species (third revision) |
| 4970 : 1973 | Key for identification of commercial timber (first revision) |

- ❖ **Timber Conversion and Grading**

| IS No. | Title |
|---|---|
| 190 : 1991 | Specification for coniferous sawn timber (baulks and scantlings) (fourth revision) |
| 1326 : 1992 | Specification for non-coniferous sawn timber (baulks and scantlings) (secondrevision) |
| 1331 : 1971 | Specification for cut sizes of timber (second revision) |
| 2377 : 1967 | Tables for volumes of cut sizes of timber (first revision) |
| 3337 : 1978 | Specification for ballies for general purposes (first revision) |
| 3386 : 1979 | Specification for wooden fence posts (first revision) |
| 5966 : 1993 | Specification for non-coniferous timber in converted form for general purpose (first revision) |
| 14960 : 2001 | Specification for preservative treated and seasoned sawn timber from rubberwood (Hevea brasiliensis) |

- ❖ **Timber Testing**

| IS No. | Title |
|---|---|
| 1708 | Methods of testing small clear specimens of timber |
| (Part 1) : 1986 | Determination of moisture content (second revision) |

| | |
|---|---|
| (Part 2) : 1986 | Determination of specific gravity (second revision) |
| (Part 3) : 1986 | Determination of volumetric shrinkage (second revision) |
| (Part 4) : 1986 | Determination of radial and tangential shrinkage and fibre saturation point (second revision) |
| (Part 5) : 1986 | Determination of static bending strength (second revision) |
| (Part 6) : 1986 | Determination of static bending strength under two point loading (second revision) |
| (Part 7) : 1986 | Determination of impact bending strength (second revision) |
| (Part 8) : 1986 | Determination of compressive strength parallel to grain (second revision) |
| (Part 9) : 1986 | Determination of compressive strength perpendicular to grain (second revision) |
| (Part 10) : 1986 | Determination of hardness under static indentation (second revision) |
| (Part 11) : 1986 | Determination of shear strength parallel to grain (second revision) |
| (Part 12) : 1986 | Determination of tensile strength parallel to grain (second revision) |
| (Part 13) : 1986 | Determination of tensile strength perpendicular to grain (second revision) |
| (Part 14) : 1986 | Determination of cleavage strength parallel to grain (second revision) |
| (Part 15) : 1986 | Determination of nail and screw holding power (second revision) |
| (Part 16) : 1986 | Determination of brittleness by izod impact (second revision) |
| (Part 17) : 1986 | Determination of brittleness by Charpy impact (second revision) |
| (Part 18) : 1986 | Determination of torsional strength (second revision) |
| 2408 : 1963 | Methods of static tests of timbers in structural sizes |
| 2455 : 1990 | Method of sampling of model trees and logs for timber testing and their conversion (second revision) |
| 2753 | Methods for estimation of preservatives in treated timber and treating solutions |
| (Part 1) : 1991 | Determination of copper, arsenic, chromium, zinc, boron, creosote and fuel oil (first revision) |
| (Part 2) : 2014 | Determination of copper in copper organic preservative salt (second revision) |
| 4907 : 2004 | Method of testing timber connectors (first revision) |
| 8292 : 1992 | Methods for evaluation of working quality of timber under different wood operations Method of test (first revision) |
| 8720 : 1978 | Methods of sampling of timber scantlings from depots and their conversion for testing |
| 8745 : 1994 | Methods of presentation of data of physical and mechanical properties of timber (first revision) |
| 10420 : 1982 | Method of determination of sound absorption coefficient of timber by standing wave method |
| 10754 : 1983 | Method of determination of thermal conductivity of timber |
| 11215 : 1991 | Methods for determination of moisture content of timber and timber products (first revision) |
| 13621 : 1993 | Method of test for determination of dielectric constant of wood under microwave frequencies |

- **Structural Timber and Tests**

| IS No. | Title |
|---|---|
| 3629 : 1986 | Specification for structural timber in building (first revision) |
| 4891 : 1988 | Specification for preferred cut sizes of structural timber (first revision) |

| | |
|---|---|
| 4924 : | Method of test for nail jointed timber trusses |
| (Part 1) : 1968 | Destructive test |
| (Part 2) : 1968 | Proof test |

❖ **Logs**

| **IS No.** | **Title** |
|---|---|
| 3364: | Method of measurement and evaluation of defects in timber |
| (Part 1) : 1976 | Logs (first revision) |
| (Part 2) : 1976 | Converted timber (first revision) |
| 4895 : 1985 | Specification for teak logs (first revision) |
| 5246 : 2000 | Specification for coniferous logs (first revision) |
| 7308 : 1999 | Specification for non-coniferous logs (first revision) |

❖ **Bamboo**

| **IS No.** | **Title** |
|---|---|
| 6874 : 2008 | Method of tests for bamboos (first revision) |
| 8242 : 1976 | Methods of tests for split bamboos |

❖ **Reconstituted Products**

❖ **Plywood**

| **IS No.** | **Title** |
|---|---|
| 303 : 1989 | Specification for plywood for general purposes (third revision) |
| 710 : 2010 | Specification for marine plywood (second revision) |
| 1328 : 1996 | Specification for veneered decorative plywood (third revision) |
| 1734 : | Methods of test for plywood |
| (Part 1) : 1983 | Determination of density and moisture content (second revision) |
| (Part 2) : 1983 | Determination of resistance of dry heat (second revision) |
| (Part 3) : 1983 | Determination of fire resistance (second revision) |
| (Part 4) : 1983 | Determination of glue shear strength (second revision) |
| (Part 5) : 1983 | Test for adhesion of plies (second revision) |
| Part 6) : 1983 | Determination of water resistance (second revision) |
| (Part 7) : 1983 | Mycological test (second revision) |
| (Part 8) : 1983 | Determination of pH value (second revision) |
| (Part 9) : 1983 | Determination of tensile strength (second revision) |
| (Part 10 : 1983 | Determination of compressive strength (second revision) |
| (Part 11) : 1983 | Determination of static bending strength (second revision) |
| (Part 12) : 1983 | Determination of scarf joint strength (second revision) |
| (Part 13) : 1983 | Determination of panel shear strength (second revision) |
| (Part 14) : 1983 | Determination of plate shear strength (second revision) |
| (Part 15) : 1983 | Central loading of plate test (second revision) |
| (Part 16) : 1983 | Vibration of plywood plate test (second revision) |
| (Part 17) : 1983 | Long time loading test of plywood strips (second revision) |
| (Part 18) : 1983 | Impact resistance test on the surface of plywood (secondrevision) |
| (Part 19) : 1983 | Determination of nail and screw holding power (second revision) |
| (Part 20) : 1983 | Acidity and alkalinity resistance test (second revision) |
| 4990 : 2011 | Specification for plywood for concrete shuttering work (third revision) |
| 5509 : 2000 | Specification for fire retardant plywood (second revision) |
| 5539 : 1969 | Specification for preservative treated plywood |

| | |
|---|---|
| 7316 : 1974 | Specification for decorative plywood using plurality of veneers for decorative faces |
| 10701 : 2012 | Specification for structural plywood (first revision) |
| 13957 : 1994 | Specification for metal faced plywood |
| 15791 : 2007 | Specification for museum plywood |

❖ **Block boards, Particle Boards and Fibre Boards**

| IS No. | Title |
|---|---|
| 1658 : 2006 | Specification for fibre hardboards (third revision) |
| 1659 : 2004 | Specification for block boards (fourth revision) |
| 2380 | Methods of test for wood particle boards and boards from other lignocellulosic materials |
| (Part 1) : 1977 | Preparation and conditioning of test specimens (first revision) |
| (Part 2) : 1977 | Accuracy of dimensions of boards (first revision) |
| (Part 3) : 1977 | Determination of moisture content and density (first revision) |
| (Part 4) : 1977 | Determination of static bending strength (first revision) |
| (Part 5) : 1977 | Determination of tensile strength perpendicular to surface (first revision) |
| (Part 6) : 1977 | Determination of tensile strength parallel to surface (first revision) |
| (Part 7) : 1977 | Determination of compressionperpendicular to plane of the board (first revision) |
| (Part 8) : 1977 | Compression parallel to surface test (first revision) |
| (Part 9) : 1977 | Determination of resistance to shear in plane of the board (first revision) |
| (Part 10) : 1977 | Falling hammer impact test (first revision) |
| (Part 11) : 1977 | Surface hardness (first revision) |
| (Part 12) : 1977 | Central loading of plate test (first revision) |
| (Part 13) : 1977 | Long time loading bending test (first revision) |
| (Part 14) : 1977 | Screw and nail withdrawal test (first revision) |
| (Part 15) : 1977 | Lateral nail resistance (first revision) |
| (Part 16) : 1977 | Determination of water absorption (first revision) |
| (Part 17) : 1977 | Determination of swelling in water (first revision) |
| (Part 18) : 1977 | Determination of mass and dimensional changes caused by moisture changes (first revision) |
| (Part 19) : 1977 | Durability cyclic test for interior use (first revision) |
| (Part 20) : 1977 | Accelerated weathering cyclic test for exterior use (first revision) |
| (Part 21) : 1977 | Planeness test under uniform moisture content (first revision) |
| (Part 22) : 1981 | Determination of surface glueability test |
| (Part 23) : 1981 | Vibration test for particle boards |
| 3087 : 2005 | Specification for particle boards of wood and other lignocellulosic materials (medium density) for general purposes (second revision) |
| 3097 : 2006 | Specification for veneered particle boards (second revision) |
| 3129 : 1985 | Specification for low density particle boards (first revision) |
| 3308 : 1981 | Specification for wood wool building slabs (first revision) |
| 3348 : 1965 | Specification for fibre insulation boards |
| 3478 : 1966 | Specification for high density wood particle boards |
| 12406 : 2003 | Specification for medium density fibreboards for general purposes (first revision) |

| | |
|---|---|
| 12823 : 2015 | Specification for wood products Prelaminated particle boards (first revision) |
| 13745 : 1993 | Method for determination of formaldehyde content in particle board by extraction method called perforator method |
| 14276 : 1995 | Specification for cement bonded particle boards |
| 14587 : 1998 | Specification for prelaminated medium density fibre board |
| 15786 : 2008 | Specification for prelaminated cement bonded particle boards |

❖ **Wood-Based Laminates and Lumber**

| IS No. | Title |
|---|---|
| 3513 (Part 3) : Part 3 | Specification for resin treated 1989 compressed wood laminates (compregs): For general purposes (first revision) |
| 3513 (Part 4) : Part 4 | Specification for high and medium 1966 density wood laminates (compregs): Sampling and tests |
| 7638 : 1999 | Methods of sampling for wood/ lignocellulosic based panel products (secondrevision) |
| 9307 | Methods of tests for wood-based structural sandwich construction |
| (Part 1) : 1979 | Flexure test |
| (Part 2) : 1979 | Edgewise compression test |
| (Part 3) : 1979 | Flatwise compression test |
| (Part 4) : 1979 | Shear test |
| (Part 5) : 1979 | Flatwise tension test |
| (Part 6) : 1979 | Flexure creep test |
| (Part 7) : 1979 | Cantilever vibration test |
| (Part 8) : 1979 | Weathering test |
| 14315 : 1995 | Specification for commercial veneers |
| 14616 : 1999 | Specification for laminated veneer lumber |
| 16171 : 2014 | Specification for veneer laminated lumber |

❖ **Bamboo and Coir Board Products**

| IS No. | Title |
|---|---|
| 13958 : 1994 | Specification for bamboo mat board for general purposes |
| 14588 : 1999 | Specification for bamboo mat veneer composite for general purposes |
| 14842 : 2000 | Specification for coir veneer board for general purposes |
| 15476 : 2004 | Specification for bamboo mat corrugated sheets |
| 15491 : 2004 | Specification for medium density coir boards for general purposes |
| 15877 : 2010 | Specification for coir faced block boards |
| 15878 : 2010 | Specification for coir hardboard for general purposes |
| 15972 : 2012 | Specification for bamboo-jute corrugated and semi-corrugated sheets |

❖ **Adhesives**

| IS No. | Title |
|---|---|
| 848 : 2006 | Specification for synthetic resin adhesives for plywood (phenolic and aminoplastic) (second revision) |
| 851 : 1978 | Specification for synthetic resin adhesives for construction work (nonstructural) in wood (first revision) |
| 852 : 1994 | Specification for animal glue for general wood-working purposes (second revision) |

| | |
|---|---|
| 1508 : 1972 | Specification for extenders for use in synthetic resin adhesives (ureaformaldehyde) for plywood (first revision) |
| 4835 : 1979 | Specification for polyvinyl acetate dispersion-based adhesives for wood (first revision) |
| 9188 : 1979 | Performance requirements for adhesive for structural laminated wood products for use under exterior exposure condition |

**3.2.5.20 Waterproofing and Damp-Proofing Materials**

| IS No. | Title |
|---|---|
| 1322 : 1993 | Specification for bitumen felts for waterproofing and damp-proofing (fourth revision) |
| 1580 : 1991 | Specification for bituminous compound for waterproofing and caulking purposes (second revision) |
| 3037 : 1986 | Specification for bitumen mastic for use in waterproofing of roofs ( first revision) |
| 3384 : 1986 | Specification for bitumen primer for use in waterproofing and dampproofing (first revision) |
| 5871 : 1987 | Specification for bitumen mastic for tanking and damp-proofing (first revision) |
| 7193 : 2013 | Specification for glass fibre base bitumen felts (second revision) |
| 12027 : 1987 | Specification for silicone-based water repellents |
| 13435 | Method of tests for acrylic based polymer waterproofing materials |
| (Part 1) : 1992 | Determination of solid content |
| (Part 2) : 1992 | Determination of coarse particle |
| (Part 3) : 1992 | Determination of capillary water take-up |
| (Part 4) : 1992 | Determination of pH value |
| 13826 | Method of test for bitumen based felts |
| (Part 1) : 1993 | Breaking strength test |
| (Part 2) : 1993 | Pliability test |
| (Part 3) : 1993 | Storage sticking test |
| (Part 4) : 1993 | Pressure head test |
| (Part 5) : 1993 | Heat resistance test |
| (Part 6) : 1993 | Water absorption test |
| (Part 7) : 1993 | Determination of binder content |
| 14695 : 1999 | Specification for glass fibre base coal tar pitch outer wrap IS No. |

## 3.3 Material Procurement:

Procurement is a term describing the purchasing process for goods and services. In building construction, material procurement is the process by which the materials required to construct a building are selected, ordered, invoiced, paid for and delivered to the site. A procurement team or one or more construction buyers may be responsible for procurement activities for products, materials, plant and subcontractors. They typically work for the main contractor (although sub-contractors may also have buyers on large projects) to ensure that supplies are provided in accordance with the project programme, specification and budget. Procuring materials is a crucial aspect of the construction process as contractors will normally be inundated with requests from suppliers for the provision of goods and services. They must therefore order materials that align with both the client’s and contractor’s objectives.

The Objectives of material procurement are stated as buying the best item at right Quality, Quantity, Time and Cost. The planning of material procurement and supply in the construction process is accomplished by identifying the optimal ordering period of each material that is changing dynamically to consider the fluctuating demand over the project duration. The construction duration is divided into stages that can be specified by project planners to account for the changing demand rate of materials and site space availability. Material procurement in each stage is formulated as a fixed-ordering period (FOP) system that replenishes the inventory at the beginning of fixed intervals when new orders are acquired to cover the demand for the succeeding intervals. Accordingly, procurement decision variables are represented by the fixed-ordering period of each material in every construction stage. A preliminary set of these procurement decisions is generated during the planning phase established on the initial construction plan. During the construction phase, the model can also be used to update the generated optimal logistics plans to consider any changes in schedule, site layout, or procurement decisions that may occur during the actual progress of construction operations.

Project management for procurement is usually divided into four major processes: planning, selection, administering and closing procurements. The first part, planning, involves the creation of the official procurement management plan. The decisions made involve which items will be internally procured and which items will be externally outsourced. This information, in turn, will heavily impact the project's budget and financial scope. Sample procurement documents will be prepared and criteria frameworks will be developed to create a selection of potential vendors. This selection matrix is based on the project's scope, schedule, and requirements. Risk factors and budgetary constraints are also considered. Procurement shall be made as per the latest Manuals issued by the Department of Expenditure, GoI.

## 3.4 Storage of Material

Handling and storage of building materials used in the construction industry form essential operations till their final use. Handling of such materials has, to be mostly multi-stage, but their storage too may become multi-stage when the materials are first received in a central depot or where the first unloading site is far from the work site or the storage site has to be shifted for any reason. Unloading, stacking, lifting, loading and conveying operations involved are, at present, mostly performed manually; but, gradually, more and more mechanical aids and gadgets are being brought into use. With the expanding construction activity, larger quantities of material have to be handled / stored and also newer and bulkier materials are coming in and, consequently, the risks involved to workmen employed on handling and storage operations also would increase. Reference shall also be made to IS: 7293-1974 where mechanical means are used for handling materials.

**3.4.1 Stacking and Piling:**

Materials shall be segregated as to kind, size and length and placed in a neat, orderly piles that arc safe against falling. If the piles are high, they shall be stepped back at suitable intervals in height. Piles of materials shall be arranged so as to allow a passageway of not less than 1 m width in between the piles or stacks for inspection and removal. All passageways shall be kept clear of dry vegetation.

Materials shall be stacked on well drained, firm and unyielding surface. Material shall not be stacked so as to impose any undue stresses on walls or other structures.

Materials shall be stacked in such a manner as not to constitute a hazard to passersby. At such places the stacks shall have suitable warning signs in day time and red lights on and around them at night.

**3.4.2 Manual Lifting:**

When the materials have to be handled manually each workman shall be instructed by his foreman or supervisor in the proper method of lifting heavy objects. Workmen shall be provided with suitable equipment for his personal safety as necessary. Supervisors shall also take care to assign enough men to each Lifting job; the weight carried by each man shall be determined by the distance to be moved, difficulty of movement presented, time required, etc.

Whenever any stack exceeds l-5 m height, suitable and safe means of access shall be provided for the use of workers and such means of access shall not disturb the stability of the stack

Posting Storage. .areas -Appropriate signs shall be placed at all storage locations where special conditions exist or where special precautions are necessary.

**3.4.3 Storage and Handling of Different Materials**

The stacking, storage and handling of different types of materials generally used in constructions shall be given as below:

**3.4.3.1 Timber**

Timber shall be stacked on unyielding and level dunnage. Cross strips or cross piling shall be used where the pile is more than 1 m high.The top of each pile shall be kept as level as possible when timber is being removed.No nails shall be allowed to protrude so as to cause any injury hazard.Two men shall carry long boards, and care shall be exercised at corners and cross-walks.

**3.4.3.2 Cement, Lime and Pozzolana**

❖ Handling**-**

Workmen, handling bulk cement, lime or fine pozzolana shall wear protective clothing, respirators, and goggles shall be instructed in the need of cleanliness to prevent dermatitis; and shall be provided with hand cream, petroleum jelly, or similar preparation for protection of exposed skin.

❖ Stacking **–**

Stacks shall not be higher than 15 bags. If the stack has to be more than 8 bags high, the bags shall be arranged in header and stretcher fashion, that is, alternate layers lengthwise and crosswise, so as to tie the piles together to lessen the danger of toppling over. Bags shall be removed uniformly from the top of the piles to avoid tipping of the stack.

❖ Silos **–**

Bulk cement and pozzolana stored in silos or bins may fail to feed to the ejections system. When necessary to enter a silo or bin for any purpose, the ejection system employed shall be shut down and locked out.When necessary for a workman to enter such storage area he shall wear a life-line, with another workman outside the silo or hopper attending the rope.

❖ Lime **–**

**Unslaked** lime **shall place in a place inaccessible to water and because of fire hazards, shall be segregated form combustible materials**,

**3.4.3.3** Sheet Glass and Fiber Glass

Glass panes used in building construction shall be stacked on edge with suitable supports.Glass edges shall be covered or otherwise protected to prevent injuries to workmen passing-by.Waste glass pieces shall be stored or disposed of in such a manner as to avoid injuries to workmen.Workmen handling glass panes, waste glass pieces and fiber glass shall be provided with suitable hand protection.

**3.4.3.4** Pipe

❖ Stacking –

Pipe shall be stacked on solid, level sills and contained in a manner to prevent spreading or rolling of the pile. Where quantity storage is necessary, suitable packing shall be placed between succeeding layers to reduce the pressure and resulting spreading of the pile.

❖ Site and Length –

Orderly storage as to sizes and lengths enhances access and removal operations.

❖ Removal –

Removal of pipe from a pile shall be accomplished by working from the ends of the pipe.

❖ Transporting –

In loading pipe or transit, it shall be so secured as to insure against displacement.

❖ Power Lines –

In stacking and handling of pipes and other conducting materials the following minimum safety distances shall be ensured from the overhead power lines:

| | |
|---|---|
| 11 KV and Below | 1.40 m |
| Above 11 KV and below 33 KV | 3.60m |
| Above 33 KV and below 132 KV | 4.70m |
| Above 132 KV and below 275 KV | 5.70m |
| Above 275 KV and below 400 KV | 6.50m |

**3.4.3.5** Piling and Poles

**3.4.3.6** Stacking –

Piling and poles shall be carefully stacked on solid, level sills and shall be so piled and blocked as to prevent rolling or spreading of the pile.

❖ Placing and Removing –

When placing piling or poles on the pile, workmen shall work from the ends of the pole. Like precautions shall be observed in removal from the pile.

❖ Tag Lines –

Tag lines shall be used to control piling and poles when handling for any purpose

❖ Fire Hazard –

The storage area shall be maintained free of vegetation and flammable materials.

❖ Power Lines –

Precautions as laid down in 3.2.4.4.5 shall be followed.

**3.4.3.7** Reinforcing and Structural Steel

❖ Stacking Reinforcing Steel –

Reinforcing steel shall be stored according to length, size and shape, and shall be piled in such a manner as to prevent tipping or falling.

❖ Lagging –

Steel shall be stored on a solid foundation, utilizing lagging as necessary to ensure stable piles.

❖ Safe Access –

Adequate spacing shall be maintained between piles to ensure safe access.

❖ Gloves –

Workmen handling deformed steel bars, barbed wire, expan.ded metal and the like shall be required to wear gloves.

❖ Stacking Structural Steel –

Structural steel shall be carefully piled to prevent sliding or tipping.

❖ Power Lines –

Precautionsas laid down in 3.2.4.4.5 shall be followed.

❖ Tag Lines –

Tag lines shall be used to control the load in handling reinforcing or structural steel when a crane is employed.

❖ Manual Handling **–**

Heavy steel sections and bundles shall be lifted and carried with the help of slings and tackles and shall not be carried on the shoulders of the workman.

**3.4.3.8** Sand, Gravel and Crushed Stone

❖ Location of Stockpiles **–**

❖ Stockpiles.

These materials shall be so locatedas to provide easy access for withdrawing. In stacking these materials minimum safety distances as mentioned under shall be ensured between the material and the overhead power lines.

❖ Overhanging Prohibited –

When withdrawals are made from stock-piles, no overhang shall be permitted.

❖ Superimposed Loading –

Materials shall not be piled against walls that will be endangered by thrust, nor along the sides of any excavation or on the top of an embankment so as to cause slips.

❖ Hoppers –

Employees required to enter hoppers shall be equipped with safety belts and lifelines, attended by another person. Machine drivenhoppers, feeders, and loaders shall be locked in the off position prior to entry.

**3.4.3.9** Paints, Varnishes and Thinners

❖ Method of Storage **–**

Paints, varnishes, lacquers, thinners and other flammable materials shall be kept m a properly sealed or closed containers. The container shall be kept in a well ventilated location, free from excessive heat, smoke, sparks or flame.

❖ Limited Storage Areas **–**

Paint materials in quantities other than required for daily use shall be kept stocked under regular storage place.

❖ Supply of Milk **–**

Each workman handling lead based paints shall be issued half liter milk per day for his personal consumption.

❖ Cleanup **–**

be removed daily at a safe place. Paint scrapings and paint-saturated rags and debris shall from the premises and, preferably destroyed by burning

❖ Ventilation and Lighting **–**

Ventilation adequate to prevent the accumulation of flammable vapours to hazardous levels of concentration shall be provided in all areas where painting is done. When electric lights, switches or electrical equipment are necessary, they shall be of explosion-proof design.

❖ Fire Protection –

Buckets containing sand shall be kept ready for use in case of fire. Fire extinguishers, when required, shall be of foam type conforming to IS: 933-1967.

❖ Spray Painting –

No smoke or open flame, exposed heating elements, or other sources of ignition of any kind shall be permitted in areas or rooms where spray painting is being done.

❖ Heating –

When painting is done in confined spaces where flammable or explosive vapours may develop, any necessary heat shall be provided through ductwork remote from the source of flame.

**3.4.3.10** Flammable Materials

**3.4.3.11 Regulations-**

Flammable materials shall be stored in accordance with the relevant regulations and rules so as to ensure the desired safety during storage. Explosives like detonators shall be stored in accordance with the existing regulations of Indian Explosives Act.

**3.4.3.12** Personnel –

Operations **in connection with handling, storage and issuance of flammable liquids shall be under the supervision of qualified and experienced persons.**

**3.4.3.13 Clothing –**

Workmen shall be required to guard carefully against any part of their clothing becoming contaminated with flammable fluids. They shall not be allowed to continue work when their clothing becomes so contaminated.

**3.4.3.14 Handling –**

Petroleum products delivered to the job site and stored there in drums shall be protected during handling to prevent loss of identification through damage to drum markings, tags, etc. Unidentifiable petroleum products may result in improper use, with possible fire hazard, damage to equipment, or operating failure. Bulk delivery and storage of petroleum products requires the same cart in identification and particular attention to fire hazards during handling.

**3.4.3.15 Storage –**

Outdoor storage of drums requires some care to avoid Contaminations. Moisture and dirt in hydraulic brake and transmission fluid, gasoline, or lubricants may easily cause malfunction or failure of equipment, with possible danger to personnel. The storage area should be free of accumulations of spilled products, debris and other hazards.Compressed gases and petroleum products shall notbe stored in the same building or close to each other. .

**3.4.3.16 Bulk Storage –**

For bulk storage of petroleum, kerosene oil and the like, the storage shall comply strictly with the specifications given in the Petroleum rules (and with the relevant act).

**3.4.3.17 Unloading Rail Road Wagons and Motor Vehicles**

❖ **Loading and Unloading Rail Road Wagons**

- **Appropriate** warning signals shall be displayed to indicate that the wagons must not be coupled or moved. Other equipment may not be placed on tracks that would interfere with the view of the signals at any time, without notifying the workman responsible for placing the signals.
- The **wheels** of wagons shall always be sprigged or chained while the wagons are being unloaded and their brakes alone shall not be depended upon to hold them stationary.

❖ **Loading and Unloading from Motor Vehicles**

- The motor vehicles shall be properly blocked while being loaded or unloaded; brakes alone shall not be dependent upon to hold them.
- When motor vehicles are being loaded or unloaded near passage-ways or walkways, adequate warning signs shall be placed on each end of the vehicle to warn the pedestrians.

**3.4.3.18 Handling Heavy / Long Items**

- Loading and unloading of heavy items, shall, as far as possible, be done with cranes or gantries. The workman shall stand clear of the material being moved by mechanical equipment. The slings and the ropes used shall be of adequate load carrying capacity, so as not to give way and result in accidents.
- While heavy and long components are being manually loaded into motor vehicle, wagons, trailer, etc, either wooden sleepers or steel rails of sufficient length shall be put in a gentle slope against the body of the wagon/vehicle at 3 or 4 places for loading. These long items shall be dragged, one by one, gently and uniformly along these supports by means of ropes, being pulled by men with feet properly anchored against firm surface. As soon as the items come on the floor of the vehicle, the same may be shifted by crow bars and other suitable leverage mechanism, but not by hands to avoid causing accident to the workmen.
- Similar procedure as outlined under 3.2.4.11.1 above shall be followed for manual unloading of long heavy items.

**3.4.3.19 Disposal of Waste Material**

❖ **Scrap Lumber and Waste-**

- Scrap lumber, waste materials, and similar debris shall be collected and stored in piles or containers daily for removal and disposal.

❖ **Pollution Control –**

- All applicable regulations relating to the pollution of streams, reservoirs, lakes, ground water or water courses shall be fully complied with. The manner of disposing of waste materials shall be subject to the approval of the engineer-in-charge/depot-in-charge.

**3.4.3.20 Fire Extinguishing Equipment**

- Appropriate and adequate fire extinguishing equipment shall be provided at all storage locations (see IS: 2190-1971).
- **Bulk Storage Depots -** Where flammable and combustible materials are stored in bulk, for considerable period an automatic fire alarm of suitable design shall preferably be installed.
- Workers handling excavated earth from foundation, particularly if the site happens to be reclaimed area or marshy area, shall be protected against infection affecting their exposed portions of the bodies.

3.4.3.20.1 **Use of Fire Extinguisher Balls in Buildings:**

Fire Extinguisher Ball is a fully automatic fire extinguisher which is self activated once in contact with fire flame. When thrown or rolled into fire, it will burst with sound and alarm the surrounding area besides extinguishing the fire within its range. It can also be placed near hotspots are such as flammable objects, fireplaces, kitchens, circuit breaker box, gas tank etc., as it can work even in the absence of humans. These can be placed on shelf tops, table tops, along hallways or any visible area for easy access. In case of fire, it will put out the fire by itself thus guarding lives and property.

**Technical Characteristics**

| | | | |
|---|---|---|---|
| Medium | Dry Powder (Mono Ammonium Phosphate) | Activation Time | 3 seconds |
| Coverage Area | 8-10 $m^2$ | Activation Trigger | Flame |
| Weight | 1.3 kg | Warning Audio | 120 B |
| Diameter | 147 mm | Fire Types | Classes A (solids) B (liquids) C (gasses) E (electrical) |

**Advantages of Fire Ball**

1. Fast Response

   The ultra-efficient fire stopping powder ball is the fastest way to stop any fire as it is activated in just 3 seconds once in contact with fire flame.

2. Automatic Activation

   When a fire occurs and nobody is present or it is not possible to call fire brigade, Fire Balls can be useful as they are self activated when in contact with fire flame.

3. Distance Safe

   There is no need to move closer to fire as the Fire extinguisher ball can be tossed into the flame safely from a distance.

4. Human & Environmental Friendly

   These are not toxic for humans and the environment besides no special skills or training is required for operating them.

5. Zero Maintenance

   It does not require any inspection or maintenance during the service life of 5 years.

6. Easy to Handle

   The fire extinguishing ball is lightweight weighing about 1.5 kg, and can be used by women, children and the elderly.

**Disadvantages of Fire Ball**

1. Limited coverage area

   Single Fire Ball would not be effective in large rooms, as well as in the open air. Solution: Proper planning and installation of numerous Balls at certain distance from each other as per OEM recommendations.

2. Coverage limitations

   Can cover only certain fire source whereas extinguishers can be directed in different directions

3. Accessibility

   Personnel attempting fire fighting might not be able to access the Ball installed behind the fire point, in contrast to fire extinguishers that are typically installed at the access points to the hazardous zone.

4. Late activation

   It will be activated only when the fire evolves, temperature rises, flames engulf the whole area reaching the ball which might cause loss of asset.

**Comparison between Conventional Fire Extinguishers and Fire Ball**

**Comparison between Conventional Fire Extinguishers and Fire Ball**

| Title | Conventional Fire Extinguishers | Fire Extinguishing Ball |
|---|---|---|
| Training requirement | Required | Not required |
| Fire classification | Extinguishers are selected as per class of fire | Same caters class A,B,C,E fires |
| Weight | • Domestic 2-7 kg<br>• Industrial 5-9 kg | 1.3 kg |
| Operating distance | 2 m from fire | No distance restriction – it can be tossed from safe distance |
| Maintenances | Regular inspection & maintenance required | No maintenance required for 5 years |
| Refilling | Required | Not required |
| Operation method | Manual | Self-Activated |
| Extinguishing time | Can takes average 2-10 minutes | 3-10 sec. as soon as comes in contact with flame, the extinguisher ball automatically explodes |

| | | |
|---|---|---|
| Coverage area | Depends on the<br>• size of the extinguisher;<br>• fire intensity;<br>• user proficiency<br><br>5 kg cylinder finishes within 18-20 sec. | • 360⁰ coverage<br>• Single ball can cover area of 8 -10 $m^2$ |
| Failure chances | • Body Rust;<br>• Nozzle chocked;<br>• Powder settles;<br>• Cover explodes towards user | Failure chances are almost negligible |
| Environmental concerns | Powder could be made from CFC (ozone depleting substance) or other (non-toxic) materials | Free of CFC |
| Possibility of theft | There is a possibility of theft due scrap value | Doesn't have any scrap value |
| Space required | Minimum 2 ft x 6 inch area | only 6 inch x 6 inch area |

### 3.4.3.21 House Keeping

- **Safe Access** - Stairways, walkways, scaffolds, and access ways shall be kept free of materials, debris and obstructions.
- **Scaffolds and Walkways** - The engineer-in-charge/the foreman shall initiate and carry out a programme requiring routine removal of scrap and debris from scaffolds and walkways.
- **General** - Efficient and orderly storage of materials coupled with routine housekeeping are most important factors in safety and fire prevention. It is essential that good housekeeping be maintained throughout all storage areas.

# 4. QUALITY CONTROL OF BUILDINGS DURING EXECUTION

## 4.1 Quality Management System for Building Project.

For a given Building Construction Project, the Contractor’s part of various processes involved in a Quality Monitoring System (QMS) is referred as Quality Control (QC) while the Executing Department/Project Implementation Agencies’ part of the QMS process is referred as Quality Assurance (QA) and if any third party monitoring/check is part of the contract, it is referred as Quality Audit (QA).

The Contractor shall be responsible to mobilize competent resources (personnel and laboratory equipment) to perform his/her quality control as per its Quality Control Plan, and the Executing Department/Project Implementation Agencies shall be responsible to provide competent personnel to perform and implement the Quality Assurance Plan. An authorized/approved third party monitoring/checking department/agency shall be responsible to mobilize competent personnel to perform quality audit as per its Quality Audit Plan.

However, it is to be understood unequivocally that the contractor/ concessionary shall explicitly be responsible for its product/assignments, from the beginning to the end, of all the works till the final acceptance.

## 4.2 Quality Control

Quality Control is defined as the procedure adopted and controls exercised to ensure that the materials proposed to be used in construction, processes adopted for construction and workmanship of construction conform to the prescribed standards and laid down acceptance criteria.

During the construction period it is critically required to control the quality of works and construction materials including their production so that the constructed would have the desired quality (as per the prepared design and specification) and provide the envisaged services during its design life. Hence, the contractor has to make utmost effort to control the quality of works and construction materials by proper sampling, testing and inspection.

The Quality control is exercised by construction agency that ensures that the defined objective is achieved through appropriate tests, checks and inspections by suitable qualified personnel. Furthermore, the objective evidences of all tests, checks and inspections carried out from time to time are documented in formally prescribed formats, for reference and record.

The contractors need to maintain Construction Quality Control (CQC) through two elements of quality control, i.e. Testing & Inspection. Testing control will cover the type of tests to be carried out, frequency of testing and stage of testing while Inspection control will cover the timing of inspections, what has to be inspected and the procedures for inspection.

## 4.3 Supervision / Inspection

The day-to-day site supervision of all construction activities will be carried out by the Executing Department/Project Implementation Agencies and its supervisory team. This includes checking of lines, levels and layouts and on-site checks and carry out the execution as per approved designs, drawings and specifications via-a-viz the all the relevant codes. Progress monitoring and expediting shall also be carried out by Executing Department/ Project Implementation Agencies. The supervisory team of the Executing Department/ Project Implementation Agencies shall ensure that materials that have been rejected or for which a conformance report has not yet been issued are not used in works.

Construction Quality Control can generally be maintained by the contractor at five stages:

- ❖ Input Materials and equipment components
- ❖ In-process activities
- ❖ Stage Completion
- ❖ Final Completion

## 4.4 Construction Quality Control (CQC) and Procedure

Construction Quality Control (CQC) is intended to provide a comprehensive, common and consistent framework for quality control across various contract package. Construction Quality Control procedures may be divided as below:

- ❖ Construction Quality Control of Material, Civil Works and Equipment Components
  - Through Material Tested on Site
  - Through Material and Equipment Certified by Manufacturer
  - Through Material and Equipment Inspected by Third Party
- ❖ Construction Quality Control of General Civil, Structural Works & Road Works (if any)
- ❖ Construction Quality Control of Electro-mechanical Works

### 4.4.1 Construction Quality Control of Material and Equipment Components

For exercising CQC effectively, some of the material may be required to be tested at site, for which contractor shall have a well-established site laboratory, with valid equipment calibrations, Incase of manufactured equipment components,acceptance of the quality shall be based on the test certificate(s) from the manufacturer, as and when demanded.

Construction Agency in consultation with Executing Department/ Project Implementation Agencies shall devise suitable testing formats (testing protocol), for various quality control procedures.

Referral may be made to National Building Code of INDIA-2016 or later, Part-5 (BUILDING MATERIALS) for List of Standards Specifications/Testing for following principal categories of building materials;

- ❖ Aluminium and other light metals and their alloys
- ❖ Bitumen and tar products
- ❖ Bricks, blocks and other masonry building units
- ❖ Builder’s hardware
- ❖ Building chemicals
- ❖ Building lime and products
- ❖ Clay and stabilized soil products
- ❖ Cement and concrete (including steel reinforcement for concrete)
- ❖ Composite matrix products (including cement and resin matrix products)
- ❖ Conductors and cables
- ❖ Doors, windows and ventilators
- ❖ Electrical wiring, fittings and accessories
- ❖ Fillers, stoppers and putties
- ❖ Floor covering, roofing and other finishes
- ❖ Glass
- ❖ Gypsum based materials

**4.4.1.1 Material Tested on Site:** Materials like Cement, Sand, Water for Construction, Bricks, Size Stones, Coarse/Fine Aggregates, Soil/Earth/Sub-Grade, Granular Sub-Base shall be tested at site.

**4.4.1.2 Material and Equipment Certified by Manufacture:**As stipulated in the contract, following list provides an instance of the material & equipment, where acceptance of the quality will be based on the test certificate(s) from the manufacturer, conforming to pertinent IS-Specifications and on visual inspection. These items generally shall bear IS mark.Contractor,at the direction of in charge engineer, may be required to produce test certificate(s) of these items, from the manufacturer, before delivery at site. The Executing Department/ Project Implementation Agencies,along with approved third party testing facility/audit team (if any) may further inspect the condition of these items, upon their delivery or before their installation or otherwise during incorporation in the works.

| S. No | Material and equipment | S. No | Material and equipment |
|---|---|---|---|
| 1 | Steel/Reinforcing Steel | 19 | Electrical Poles |
| 2 | Paint, Primers and Protective Coatings | 20 | Distribution Boards |
| 3 | Glazing | 21 | Batteries & Battery Chargers |
| 4 | Water Proofing Compound / Joint Filler Material | 22 | Lightening Arrestor |
| 5 | Switches & Sockets / Lights, Fans and Fixtures | 23 | Insulators / Earthing Material |
| 6 | Sanitary Fittings/ Manhole Covers/ Gratings & Plates | 24 | Joint Filler Material |
| 7 | Metal Works such as windows, barbed wire, MS ladder, footrest, rolling shutters, etc. | 25 | Electrical Wires/Cables of Generic and Special nature/ Electrical Conduits |
| 8 | Pre-fabricated Water Tanks | 26 | Foot Rests |
| 9 | Pre-fabricated manholes | 27 | Flow Measuring Devices – General/Special |
| 10 | Traffic Signs | 28 | Fire Fighting Equipment |
| 11 | Cable Termination Kit | 29 | Level Indicator & Controllers |
| 12 | Reduction Gearboxes | 30 | Waste Water Systems |
| 13 | Laboratory Equipment | 31 | All specials and fittings for Water Supply and |
| 14 | Current/ Voltage/ Power Transformers | 32 | DI, CI ad PVC pipes for PHED works |
| 15 | GSW pipes for sewers / AC Pipes/ NP Pipes for Sewers/ GSW pipes for sewers/ GI, CI and PVC Pipes/ Pre-stressed Concrete (PSC) Pipes and all other types of pipes. | 33 | Other Steel Pipes – Lined & Coated |
| 16 | Bus Ducts / Capacitors | 34 | Cranes & Lifting Tackles |
| 17 | Switch Boards (HV/MV/LV) / DC Distribution Panel | 35 | Indication-cum-Enunciation Panel |
| 18 | Control Valves / Air Valves/ Reflux Valves/ Sluice Valves/ Butterfly Valves | 36 | All other manufactured items as specified in the contract documents |

**4.4.2 Construction Quality Control of General Civil and Structural Works**

All the materials proposed to be used in Civil & Structural works must have been tested by the contractor on site or through a recognized third party laboratory facility, as may be approved by theExecuting Department/ Project Implementation Agencies. As stated earlier, the contractor, in consultation with Executing Department/ Project Implementation Agencies shall devise suitable testing formats/protocols, for various quality control procedures, and have same ratified during quality assurance and third party audits protocols.

**4.4.3 Construction Quality Control of Electro-Mechanical Works**

A series of inspections and tests during installation and completion of electromechanical works shall be performed by the contractor or the equipment manufacturer as given below:

**4.4.3.1 Preparatory Inspections:**Prior to installation, the civil and structural works where electromechanical equipment is to be installed shall be inspected to ensure conformance with designs and equipment installation requirements;

**4.4.3.2 Installation Inspections and Tests:** A system of inspections and tests, as specified in the contract or recommended by the equipment manufacturer, shall be employed throughout movement to position and installation of equipment and systems. Inspections shall be performed by Executing Department/ Project Implementation Agencies, at critical points during installation. All field modifications and retrofit work shall be performed under the surveillance of the Executing Department/ Project Implementation Agencies;

**4.4.3.3 Installation Verification Inspections:** Prior to all mechanical and electrical testing, verification inspections shall be performed by Executing Department/ Project Implementation Agencies, to ensure that equipment has been satisfactorily installed;

**4.4.3.4 System Tests:** These tests shall be conducted as appropriate to demonstrate that the installed systems are free from damage due to shipment and installation, and that equipment performs in accordance with specifications; Executing Department/ Project Implementation Agencies shall witness all such test.

**4.4.3.5 Integrated Tests:** After completion of system tests, integrated tests shall be performed to demonstrate that the system performs satisfactorily when connected to its interfacing systems or sub-systems. Commissioning Tests will follow up these tests. Executing Department/ Project Implementation Agencies shall witness all such test

**4.4.3.6 Commissioning Tests:** These consist of a series of tests performed under service operating procedures to demonstrate compatibility of the physical plant with operating procedures; and

**4.4.3.7 Final Inspections:** Final inspections by Executing Department/ Project Implementation Agencies shall be performed to ensure that the completed work is in accordance with the contract and that all previously identified discrepancies have been resolved satisfactorily.

## 4.5 Other Special Tests

In case the tests which cannot be conducted in the field laboratory or not specified in the contract, the Team Leader would order special tests on the material / finished work for acceptance as part of permanent work. In case of non-compliance, he would order removal and substitution of improper materials and/or works as required.

## 4.6 Quality Assurance

Quality assurance of a job is defined as a process which exercises various checks at different stages of a work right from its inception till its acceptance, to put it in service to ensure, by the Executing Department/ Project Implementation Agencies,that the work has been properly constructed as per approved designs, drawings and specifications. At times it is extended to cover the prescribed Defects Liability period. Sometimes its scope is enlarged to encompass the maintenance aspect over the defect liability period.

Engineers from Executing Department/ Project Implementation Agencies shall devise suitable testing formats for various quality assurance procedures and have same ratified during final third party audits protocols (if any).

**4.6.1 Quality Audit**

Quality Audit is periodic, independent and documented examination and verification of activities, records processes and other elements of a "Quality System" to determine their conformity in accordance with the relevant drawing, methodology, codes & specifications.It is discretion of Executing Department/ Project Implementation Agencies to place Quality Audit a binding part of Contract for small/low value projects, but same is recommended to be incorporated for all important and high-value projects of public prominence.

**4.6.2 Structural Concrete, Bricks, Stones & Steel Material**

**4.6.2.1 General.**

Structural Concrete, Bricks, Stones and Steel has been specifically impressed, in this manual, for its generic and major use in almost all Building Works. All such material/or its constituents, to be used in the work, shall strictly conform to the specifications mentioned on the drawings and other specifications as may be mentioned in other design document, including BOQ.Mandate of following important IS codes shall apply;

| | | | | | |
|---|---|---|---|---|---|
| 1) IS: 383 | 2) IS: 456 | 3) IS: 516 | 4) IS:1199 | 5) IS: 2386 | 6) IS:10262 |
| 7) IS:3812 | 8) IS:4032 | 9) 6461 | 10) IS:8112 | 11) 9103 | 12) IS:4925-4926 |
| 13) IS:6461 | 14) IS:13311 | 15) IS:2185 | 16) IS:2572 | 17) IS: 2770 | |

Material, not covered in this section, which may be required to be used in the work, shall conform to relevant Indian Standards, or to the requirements specified by the Engineer from Executing Department/ Project Implementation Agencies.

***Note: For all technical topics, which may, intentionally/un-intentionally, not have been covered, in this compilation of concise building manual, the reader shall strictly make reference to pertinent section of latest BIS/NBC/MoRT&H/IRC/ASTM/BS/DIN codes, in order, for comprehensive understanding and implementation, of topic, thereof.***

The Contractor shall notify the Engineer of his proposed sources of materials prior to delivery and same shall be duly approved by the engineer. If it is found after trial that sources of supply previously approved do not produce uniform and satisfactory products, or if the product from any other source proves unacceptable at any time, the Contractor shall furnish acceptable material from other sources, at his own expense.Samples of material from the approved source shall be tested for all relevant parameters for conformity to applicable specifications.

For manufactured items like cement, steel reinforcement, structural steel and admixtures etc., the contractor shall intimate the Engineer the details of the source, testing facilities available with the manufacturer and arrangements for transport and storage of material at site. At the demand of an engineer, the contractor shall be able to furnish samples and test results of recently received batch of material. The engineer, at his discretion, in case of observing and inconsistency, may require the contractor to test the material in an independent laboratory, duly approved by the engineer, as part of third party evaluation. The cost of such additional tests shall be borne by the contractor.

If any proprietary items are proposed to be used in the works, they shall be governed by the provisions of relevant BIS/NBC/MoRT&H specification.

**4.6.3 Bricks & Stones.**

Burnt clay bricks shall conform to the requirements of IS:1077, except that the minimum compressive strength when tested flat shall not be less than 8.4 Mpa for individual bricks and 10.5 Mpa for average of 5 specimens. They shall be free from cracks and flaws and nodules of free lime. The brick shall have smooth rectangular faces with sharp corners and emit a clear ringing sound when struck. The size may be according to local practice with a tolerance of $\pm$ 5 per cent.

Stones shall be of the type specified. It shall be hard, sound, free from cracks, decay and weathering and shall be freshly quarried from an approved quarry. Stone with round surface shall not be used.The stones, when immersed in water for 24 hours, shall not absorb water by more than 5 per cent of their dry weight when tested in accordance with IS: 1124.The length of stones shall not exceed 3 times its height nor shall they be less than twice its height plus one joint. No stone shall be less in width than the height and width on the base shall not be greater than three-fourth of the thickness of the wall nor less than 150 mm.

**4.6.4 Cement.**

Cement to be used in the works shall be any of the following types with the prior approval of the Engineer:

- Ordinary Portland Cement, 33 Grade, conforming to IS: 269.
- Ordinary Portland Cement, 43 Grade, conforming to IS: 8112.
- Ordinary Portland Cement, 53 Grade, conforming to IS: 12269.
- Sulphate Resistant Portland Cement, conforming to IS: 12330.
- Portland Pozzolana Cement, conforming to IS: 12330.
- Rapid Hardening Portland Cement, conforming to IS: 8041.
- Portland Slag Cement, conforming to IS:455.
- Low Heat Portland Cement, conforming to IS:12600.

Manufacturers test certificate shall be submitted to the engineer by the contractor for every consignment of cement, for high-value/important project of public interest. The certificate shall cover all the tests for chemical requirements, physical requirements and chloride content as per relevant codes/specifications.

Independent tests of samples drawn from the consignment, shall be carried out at the site laboratory or in an independent authorized laboratory, as may be approved by an engineer. The tests like Setting time, Compressive Strength must be mandatory, invariably. Any cement still in storage, in bags, for more than 3-months, from the date of last test, may be got re-tested.

Cement conforming to IS:269 (33-Grade) shall be used only after ensuring that the minimum required design strength can be achieved without exceeding the maximum permissible cement content of 450 kg/cum of concrete, without use of mineral admixtures.

Cement conforming to IS: 8112 and IS: 12269 (43 & 53 Grade) may be used provided the minimum cement content mentioned elsewhere from durability considerations is not reduced.

Details on use of other types of cement and limitations may be referred from BIS/NBC or MoRT&H Specification (Section:1006).

**4.6.5 Aggregates (Mineral Aggregates).**

**4.6.5.1 Coarse Aggregates.**

For plain and reinforced cement concrete (PCC and RCC) or prestressed concrete (PSC) works, coarse aggregate shall consist of clean, hard, strong, dense, non-porous and durable pieces of crushed stone, crushed gravel, natural gravel or a suitable combination thereof or other approved inert material. They shall not consist pieces of disintegrated stones, soft, flaky, elongated particles, salt, alkali, vegetable matter or other deleterious materials in such quantities as to reduce the strength and durability of the concrete, or to attack the steel reinforcement. Coarse aggregate having positive alkali-silica reaction shall not be used. All coarse aggregates shall conform to IS: 383 and tests for conformity shall be carried out as per IS: 2386, Parts I to VIII.

The contractor shall submit for the approval of the Engineer, the entire information, indicated in Appendix A of IS: 383.

Maximum nominal size of coarse aggregate for various structural components in PCC, RCC or PSC, shall conform to Section 1700 of Specification for Road & Bridge Works, MoRT&HOR relevant BIS Specifications. The maximum value for flakiness index for coarse aggregate shall not exceed 35 per cent. The coarse aggregate shall satisfy the following requirements of grading(Table-4.1).

**Table-4.1 Grading Requirements of Coarse Aggregates**

| **IS Sieve size** | **Per cent by Weight Passing the Sieve** | | |
|---|---|---|---|
| | **40 mm** | **20 mm** | **12.5 mm** |
| **63 mm** | - | – | – |
| **40 mm** | 95-100 | 100 | – |
| **20 mm** | 30-70 | 95-100 | 100 |
| **12.5 mm** | – | – | 90-100 |
| **10 mm** | 10-35 | 25-55 | 40-85 |
| **4.75 mm** | 0-5 | 0-10 | 0-10 |

**4.6.5.2 Fine Aggregates.**

For plain and reinforced cement concrete (PCC and RCC) or prestressed concrete (PSC) works, fine aggregate shall consist of clean, hard, strong, dense and durable pieces (<4.75mm) of crushed stone, crushed gravel, which must be free of veins and adherent coating or other deleterious substances. Suitable combination of natural sand, crushed stone sand, crushed gravel sand may also be adopted. They shall not contain dust, lumps, soft or flaky, materials, mica or other deleterious materials in such quantities as to reduce the strength and durability of the concrete, or to attack the embedded steel.

Motorized/Mechanized sand washing machines should be used to remove impurities from sand. Fine aggregate having positive alkali-silica reaction shall not be used. All fine aggregates shall conform to IS:383, with test conformity to IS: 2386, (Parts 1 to VIII). The Contractor shall submit to the Engineer the entire information indicated in Appendix A of IS: 383. The fitness modulus of fine aggregate shall neither be less than 2.0 nor greater than 3.5.

Sand/fine aggregate for structural concrete shall conform to the following grading requirements (Table-4.2):

**Table-4.2 Grading Requirements of Fine Aggregates**

| IS Sieve size | Per cent by Weight Passing the Sieve | | |
|---|---|---|---|
| | **Zone I** | **Zone II** | **None III** |
| **10 mm** | 100 | 100 | 100 |
| **4.75 mm** | 90-100 | 90-100 | 90-100 |
| **2.36 mm** | 60-95 | 75-100 | 85-100 |
| **1.18 mm** | 30-70 | 55-90 | 75-100 |
| **600 micron** | 15-34 | 35-59 | 60-79 |
| **300 micron** | 5-20 | 8-30 | 12-40 |
| **150 micron** | 0-10 | 0-10 | 0-10 |

*Note: When the grading falls outside the limits of any particular grading zone (other than 600micron IS-sieve) by total amount not exceeding 5%, it shall be regarded as falling within that zone. However, for crushed stone sand, the permissible limit on 150-micron IS sieve is increased to 20% (Ref: IS:383, Clause:4.3).*

#### 4.6.6 Structural Concrete

Materials of structural concrete shall conform to ingredient material requirements under BIS (IS:456-2000) or MoRT&H Specification (Section: 1000). The detailed specification on Structural Concrete may also be referred from Section 1700 of Specification for Road & Bridge Works, MoRT&H, which cover following.

#### 4.6.6.1 Grades of Concrete, for Nominal, Standard and High Performance Concrete.

The grades of concrete shall be designated by the characteristic strength as given in Table-4.3 below, where the characteristic strength is defined as the strength of concrete below which not more than 5 percent of the test results are expected to fall.

| Table-4.3 Grades of Concrete | | | | |
|---|---|---|---|---|
| **S.No** | **Types of Concrete/Grade Designation** | | | **Characteristic Strength in MPa** |
| | **Nominal Mix** | **Standard Designed Mix Concrete** | **High Performance Designed Mix Concrete** | |
| **1.** | M15 | M15 | | 15 |
| **2.** | M20 | M20 | | 20 |
| **3.** | | M25 | | 25 |
| **4.** | | M30 | M30 | 30 |
| **5.** | | - | M35 | 35 |
| **6.** | | M40 | M40 | 40 |
| **7.** | | M45 | M45 | 45 |
| **8.** | | M50 | M50 | 50 |
| **9.** | | | M55 | 55 |
| **10.** | | | M60 | 60 |
| **11.** | | | M65 | 65 |
| **12.** | | | M70 | 70 |
| **13.** | | | M75 | 75 |
| **14.** | | | M80 | 80 |
| **15.** | | | M85 | 85 |
| **16.** | | | M90 | 90 |

**Note:**

a) Definition of Nominal, Standard & High Performance Concrete may be referred from MoRT&H, Section 17030.1.

b) Requirements of High Performance Concrete shall be referred to Section 1715 of MoRT&H Specification.

The minimum grades of concrete and corresponding minimum cement content and maximum water/cement ratios for different exposure conditions shall be as per Table-4.4, below:

| Table-4.4 Requirements of Concrete for different exposure conditions | | | |
|---|---|---|---|
| Exposure Condition | Maximum W/C Ratio | Minimum Cement Content, kg/cm$^3$ | Minimum Grade of Concrete |
| Moderate | 0.45 | 340 | M25 |
| Severe | 0.45 | 360 | M30 |
| Very Severe | 0.40 | 380 | M40 |

Note:

a) Above table is applicable for 20mm mineral aggregates.

b) Cement content shown above shall be increased by 40kg/m$^3$ for use of 12.50mm nominal maximum size of aggregate (NMSA) and decreased by 30kg/m$^3$ for use of 40mm NMSA.

c) The maximum cement content excluding any mineral admixtures (Portland Cement Content alone) shall not exceed 450 kg/m3.

d) Use of Designed Mix concrete shall invariably be preferred. Nominal mix shall however be permitted only for minor works or other incidental construction where requirement is up to M20 only.

**4.6.6.2 Proportioning of Concrete.**

Proportioning of concrete shall be as per requirements of relevant IS Specifications (IS:10262) and section 1704 of MoRT&H-2013 or later. Contractor shall design the mix in case of "Design Mix Concrete" or propose nominal mix in case of "Nominal Mix Concrete", and submit same to the Engineer for approval of the proportions of materials, including admixtures to be used.

Water-reducing admixtures (including plasticisers or super-plasticisers) may be used at the Contractor's option, subject to the approval of the Engineer. However, if design mix specifically has been recommended with any admixtures, same shall be binding on contractor. Other types of admixtures shall be prohibited, unless specifically permitted by the Engineer. Design Mix shall be encouraged from an Approved/Authorized or NABL accredited laboratory.

The optimum consistency of various types of structures shall be as per Table-4.5, below.

| **Table-4.5 Requirements of Consistency** | | |
|---|---|---|
| **S.No** | **Type** | **Slump (mm) at the time of Placing** |
| **1** | (a) Structures with exposed inclined surface requiring low slump concrete to allow proper compaction.<br>(b) Plain cement concrete. | 25<br>25 |
| **2** | RCC structures with widely spaced reinforcements; e.g. solid columns, piers, abutments, footings, well steining | 40 – 50 |
| **3** | RCC structures with fair degree of congestion of reinforcement; e.g. pier and abutment caps, box culverts well curb, well cap, walls with thickness greater than 300 mm. | 50 – 75 |
| **4** | RCC and PSC structures with highly congested reinforcements e.g. deck slab girders, box girders, walls with thickness less than 300 mm | 75 – 125 |
| **5** | Underwater concreting through tremie e.g. bottom plug, cast-in-situ piling | 100 – 200 |
| **Note:** Refer IS-456 or Section 1704.1 of Specification for Road & Bridge Works, MoRT&H, for additional requirements of optimum consistency | | |

**4.6.6.3 Requirements of Design Mixes for Major Projects Works**

For specific requirements under design mixes, IS:456 or section 1704.2 of MoRT&H, shall be adhered.

The target mean strength of specimen shall exceed the specified characteristic compressive strength by at least the "current margin".

❖ The current margin for a concrete mix shall be determined by the Contractor and shall be taken as 1.64 times the standard deviation of sample test results taken from at least 40 separate batches of concrete of nominally similar proportions produced at site by the same plant under similar supervision over a period exceeding 5 days, but not exceeding 6 months.

❖ Where there is insufficient data to satisfy the above, the current margin for the initial design mix shall be taken as given in Table-4.6 below, till sufficient data is available to determine the current margin.

| Table-4.6 Current Margin for Initial Design Mix | | |
|---|---|---|
| **Concrete Grade** | **Current Margin (MPa)** | **Target Mean Strength (MPa)** |
| M 15 | 10 | 25 |
| M 20 | 10 | 30 |
| M 25 | 11 | 36 |
| M 30 | 12 | 42 |
| M 35 | 12 | 47 |
| M 40 | 12 | 52 |
| M 45 | 13 | 58 |
| M 50 | 13 | 63 |
| M 55 | 14 | 69 |
| M 60 | 14 | 74 |
| M 65 | 15 | 80 |
| M 70 | 15 | 85 |
| M 75 | 15 | 90 |
| M 80 | 15 | 95 |
| M 85 | 16 | 101 |
| M 90 | 16 | 106 |

The requirements of Trial Mixes and Control of Strength of Design Mixes shall be adhered as relevant BIS Specifications or as per MoRT&H (Section 1704.2.2 &Section 1704.2.3).

**4.6.6.4 Requirements of Nominal Mixes**

Requirements for nominal mix concrete unless otherwise specified, shall be as detailed in Table-4.7, below.

| Table-4.7 Requirements of Nominal Mix Concrete | | | | |
|---|---|---|---|---|
| **Concrete Grade** | **Total Quantity of dry aggregate by mass per 50 kg of cement to be taken as the sum of individual masses of fine and coarse aggregates (kg)** | **Proportion of fine to Coarse aggregate (by mass)** | **Maximum Quantity of Water for 50kg of Cement** | |
| | | | **PCC** | **RCC** |
| **M 15** | 350 | Generally 1:2, subject to upper limit 1:1:5 and lower limit of 1:2:5 | 25 | - |
| **M20** | 250 | | 25 | 22 |

**4.6.6.5 Additional Requirements.**

Concrete shall meet with any other requirements as specified on the drawing or as directed by the Engineer. Additional requirements shall also consist of the following overall limits of deleterious substances in concrete:

- ❖ The total chloride content of all constituents of concrete as a percentage of mass of cement in mix shall be limited to values given below:

  Prestressed Concrete : 0.1 per cent

  Reinforced concrete exposed to chlorides in service (e.g. structures located near sea coast) : 0.2 per cent
- ❖ Other reinforced concrete construction : 0.3 per cent

- The total water soluble sulphate content of the concrete mix expressed as ($SO_3$), shall not exceed :4 percent by mass in the mix.

Proper checks shall be exercised on Suitability of proposed Mix Proportions, Mix Proportioning process and Water/Cement Ratio as per relevant BIS (IS:456) specifications or guidelines of section 1704.5 & 1704.6 of Specification from MoRT&H. Grading of aggregates for pumped concrete shall be adhered as perrelevant BIS specifications or section 1704.7 of MoRT&H specification.

**4.6.7 Concrete in Piles**

The basic materials and the specifications for steel reinforcement, structural concrete and structural steel to be used in pile foundations shall be as given in the relevant sections of BIS or as per Specification ofMoRT&H,section: 1000, 1700,1800 & 1900.

Requirements of concrete to be used in cast-in-situ and precast piles shall be as per following Table-4.8below;

**Table-4.8Requirement of Concrete in Piles**

| | **Cast in-situ Concrete by Tremie** | **Precast Concrete** |
|---|---|---|
| **GradeDesignation** | M35 | M35 |
| **Minimum Cement Content** | 400kg/$m^3$ | 400kg/$m^3$ |
| **Minimum w/c ratio** | 0.40 | 0.40 |
| **Slump (mm) at placement** | 150-200 | 50-75 |

*Note: minimum cement content and minimum w/c ratio are to be based on total cementitious material, including mineral admixtures.*

Concrete mix should have homogeneous mixture with required workability for the system of piling adopted. Suitable and approved admixtures (mineral/chemical) may be used in concrete mix where necessary, as cement reducing agents or water reducing agents/plasticizers/superplasticizers.

Where piles are exposed to action of harmful chemicals or severe conditions of exposure due to presence of sulphate, chloride etc, it may be preferable to opt for higher grades of concrete restricting water cement ratio to 0.45. For improving resistance against the penetration of chlorides and sulphates from surrounding soils or water, mineral admixtures such as fly ash, silica fumes, GGBFS conforming to BIS/International Standards, may be used.

**4.6.8 Admixtures**

Admixtures are materials added to the concrete before or during mixing with a view to modify one or more of the properties of concrete in the plastic or hardened state.Concrete admixtures are proprietary items of manufacture and shall be obtained only from established manufacturers with proven track record, quality assurance and full-fledged laboratory facilities for the manufacture and testing of concrete. Use of admixtures such as Superplasticisers, or air entraining, water reducing, accelerating and retarding agents for concrete, may be used with the approval of the Engineer.

As the selection of an appropriate concrete admixture is an integral part of the mix design, the manufacturers shall recommend the use of any one of his products only after obtaining complete knowledge of all the actual constituents of concrete as well as methodologies of manufacture, transportation and compaction of concrete proposed to be used in the project work. Same shall be subjected to approval of the Engineer.

The general requirements of admixtures may be referred as per section 1007 of MoRT&H Specification. However, use of mineral admixtures shall be used as per clause 1714.1 and 1715.2 of MoRT&H Specification.

Mineral admixtures, as part of replacement of Portland Cement, with approval of engineer, shall include Fly-Ash (conforming IS:3812-3), Granulated slag (conforming IS:12089), and Silca fumes (conforming IS:15388)

Admixtures shall confirm to the requirements of IS: 9103. In addition, other conditions as mentioned in MoRT&H Specification, Section: 1012, for physical and chemical requirements, shall be satisfied

**4.6.9 Equipment for Batching, Mixing, Transportation, Placing and Compactions**

The various requirements of various Equipment, including that used for Batching, Mixing, Transportation, Placing and Compactionshall be as per Section 1707 and 1708 of MoRT&H Specification.

**4.6.10 Protection and Curing**

Concreting operations shall not commence until adequate arrangements for concrete curing have been made by the contractor. Curing and protection of concrete shall start immediately after compaction of the concrete to protect it from:

- Premature drying out particularly by solar radiation and wind
- High internal thermal gradients
- Leaching out by rain and flowing water.
- Rapid cooling during the first few days after placing.
- Low temperature or frost
- Vibration and impact which may disrupt the concrete and interfere with its bond to the reinforcement.

Where members are of considerable size and length, with high cement content, accelerated curing methods may be applied, as approved by the Engineer. The additional requirements under Curing using Water Curing, Steam Curing and use of Curing Compound may be referred from relevant BIS Standards and under section 1712 of MoRT&H Specification.

**4.6.11 Finishing**

Immediately after the removal of forms, exposed bars or bolts, if any, shall be cut inside the concrete member to a depth of at least 50 mm below the surface of the concrete and the resulting holes filled with cement mortar.

All fins caused by form joints, all cavities produced by the removal of form ties and all other holes and depressions, honey comb spots, broken edges or corners, and other defects, shall be thoroughly cleaned, saturated with water, and carefully pointed and rendered true with mortar of cement and fine aggregate mixed in the proportions used in the grade of concrete that is being finished and of as dry a consistency as is possible to use.

Considerable pressure shall be applied in filling and pointing to ensure thorough filling in all voids. Surfaces which have been pointed shall be kept moist for a period of twenty-four hours. Special pre-packaged proprietary mortars shall be used where appropriate or where specified in the drawing.

All construction and expansion joints in the completed work shall be left carefully tooled and free from any mortar and concrete. Expansion joint filler shall be left exposed for its full length with clean and true edges.

Immediately on removal of forms, the concrete work shall be examined by the engineer and before any defects are made good;

- The work that has sagged or contains honeycombing to an extent detrimental to structural safety or architectural appearance shall be rejected.
- Surface defect of a minor nature may be accepted. On acceptance of such work by the Engineer, the same shall be rectified as directed by the Engineer.

**4.6.12 Reinforcement / Untensioned Steel**

For plain and reinforced cement concrete (PCC and RCC) or prestressed concrete (PSC) works, the reinforcement/untensioned steel, as the case may be shall consist of the following grades of reinforcing bars.

**Table-4.9Grading Requirements of Fine Aggregates**

| Grade Designation | Bar Type conforming to governing IS Specification | Characteristic Strength $f_y$MPa | Elastic Modulus GPa |
|---|---|---|---|
| **Fe 240** | IS:432 Part I Mild Steel Bar | 240 | 200 |
| **Fe 415** | IS: 1786 High Yield Strength Deformed Bars (HSD) | 415 | 200 |
| **Fe 500 or Fe 500D** | IS: 1786 High Yield Strength Deformed Bars (HSD) | 500 | 200 |
| **Fe 550 or Fe 550D** | IS: 1786 High Yield Strength Deformed Bars (HSD) | 550 | 200 |
| **Fe 600** | IS: 1786 High Yield Strength Deformed Bars (HSD) | 600 | 200 |

*Note: If any grade of steel, above, is not commercially available, steel of next higher grade may be used.*

All steel shall be procured from original producers, no re-rolled steel shall be incorporated in the work.Only new steel shall be delivered to the site. Every bar shall be inspected before assembling on the work and defective, brittle or burnt bar shall be discarded. Cracked ends of bars shall be discarded.

Purchase of steel, as far as possible must be made from Original Manufacturer and as per Specifications conforming IS:1786. Engineer may allow the procurement of steel from other suppliers, provided same is conforming IS:1786. Further, is such case, apart from having the manufacturer's test certificate, the steel shall be got tested by approved/authorized third party test facility or from a NABL accredited laboratory, ensuring conformity to IS: 1786. However, regular third party evaluation of lots of steel may carried out, at the discretion of engineer.

**4.6.13 Structural Steel**

Unless otherwise permitted herein, all structural steel shall before fabrication comply with the requirements of the following Indian Standards:

IS: 226 : Structural Steel (Standard Quality).
IS: 961 : Structural Steel (High Tensile).
IS: 2062 : Weldable Structural Steel.
IS: 8500 : Weldable Structural Steel (medium & high strength qualities).
IS: 1148 : Hot rolled rivet bars (upto 40 mm dia) for structural purposes.
IS: 1149 : High tensile rivet bars for structural purposes.
IS: 1161 : Steel tubes for structural purposes.
IS: 4923 : Hollow Steel sections for structural use.
IS: 11587 :Structural weather resistant steel.
IS: 808 : Specifications for Rolled Steel Beam, Channel and Angle Sections.
IS: 1239 : Mild Steel Tubes.
IS: 1730: Dimension for Steel Plate, sheet and strip for structural and general engineering purposes.
IS: 1731 : Dimension for Steel flats for structural and general engineering purposes

IS: 1732 : Dimension for round and square steel bars for structural and general engineering purposes

IS: 1852 : Rolling and cutting tolerances for hot rolled steel products

The use of structural steel not covered by the above standards may be permitted with the specific approval of the authority.

**4.6.14 Water**

Water used for mixing and curing shall be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to concrete or steel. Potable water is generally considered satisfactory for mixing concrete. Mixing and curing with sea water shall not be permitted. pH value of water shall not be less than 6.

In case of any doubt about the quality of water, test samples may be casted, with same water, to ascertain critical test parameters like compressive strength and initial/final setting time of cement. Sample of water referred for testing shall represent the water proposed to be used for concreting.

Average 28 days compressive strength of at least three 150mm concrete cubes, prepared with proposed water, shall not be less than 90% of average strength of other three samples of concrete, prepared with distilled water. Guidelines and conformity of IS:516, shall apply.

Maximum permissible values for concentrations within water, shall be referred from MoRT&HSpecification, Section: 1010.

**4.6.15 Tests & Standards of Acceptance**

All materials, even though stored, in an approved manner, shall be subjected to an acceptance test, prior to their immediate use, as per applicable standard.Independent testing of cement for every consignment shall be subjected to an acceptance test prior to their immediate use.

Independent testing of cement for every consignment shall be done by the Contractor at site in the laboratory approved by the Engineer before use. Any cement with lower quality than those shown in manufacturer's certificate shall be debarred from use. In case of imported cement, the same series of tests shall be carried out before acceptance.

## 4.7 Testing and Approval of Material

The Contractor shall furnish test certificates from the manufacturer/supplier of materials along with each batch of materials, finished products used in the construction as per requirements of conditions of contract and the relevant specifications. As stated earlier the contractor shall invariably set up a field laboratory with all necessary equipment for testing of all materials. The testing of all the materials shall be carried out by the Engineer or his representative for which the Contractor shall make all the necessary arrangements and bear the entire cost.

Tests which cannot be carried out in the field laboratory have to be got done at the Contractor's cost at any recognized laboratory/testing establishments,duly approved by the Engineer.

**4.7.1 Sampling of Materials**

In normal course of work, all tests and sampling of material shall conform to the relevant standards specifications/code of practices, for carrying out the specific tests. In normal working deviation, to establish Sampling, Testing & Frequency of Tests, on various materials, shall not be permitted on adhoc basis. Testing samples shall be collected as per sampling procedures described in relevant standards of code and then only testing shall commence.

Samples provided to the Engineer or his representative for their inspection/retention are to be in labelled boxes/bags, suitable for storage.Samples required for approval and testing must be supplied well in advance by at least 48 hours or minimum period required for carrying out relevant tests to allow for testing and approval.Delay to works arising from the late submission of samples will not be acceptable as a reason for delay in **the completion of the works**.If materials are brought from abroad, the cost of sampling/testing whether in India or abroad shall be borne by the Contractor.

**4.7.2 Rejection of Materials not conforming to the Specifications**

Any stack or batch of material(s) of which sample(s) do not conform to the prescribed tests and quality, shall be rejected by the Engineer, or his representative, and such materials shall be removed from site by the Contractor, at his own cost. Such rejected materials shall not be made acceptable by any modifications/rectification.

**4.7.3 Testing and Approval of Plant and Equipment**

All plants and equipment used for preparing, testing and production of materials for incorporation into the permanent works shall be in accordance with manufacturer's specifications and shall be got approved by the Engineer, before use.

**4.7.4 Sampling and Testing Frequency of Testing Material**

**4.7.4.1 Sampling:** The testing of material shall be conducted based on samples collected from field or quarries or batching plants as per relevant standards codes / prescribed procedures. The minimum weight of sample shall be adequate to conduct test for which it has been sampled. For sampling, random numbering statistical method shall be used. The random sampling procedure to be followed as given in BIS/MoRT&H/ASTM/BS/DIN codes, in order.

**4.7.4.2 Testing:** The Contractor and the Executing Departments/Project Implementing Agency's Quality Control Engineer shall ensure that any test is carried out as per relevant code mentioned therein and the record of testing is maintained in laboratory. Tests which could not be conducted in field / lab shall be conducted in an independent approved laboratory.

The tests shall be conducted on unbiased samples, taken from field, as per relevant Specification for BIS/MoRT&H or any other relevant and acceptable standard. Where the said specifications are silent in regard to the specifications in question, in that case, the specifications under the Bureau of Indian Standards/MoRT&H/AASHTO/ ASTM/BS and DIN code shall apply in that order. All tests shall be conducted in Engineering Testing Laboratory established by Contractor under the supervision of qualified Quality Control Engineer, from the Executing Department/Project Implementing Agency.

All test results shall be properly maintained in laboratory. Any substandard material in the work shall be identified immediately and Contractor shall be informed in writing for removing as per concession agreement.

**4.7.4.3 Frequency of Testing:** The type and frequencies of various quality control tests conducted on unbiased samples collected form field/quarry/source, shall be deemed mandatory. The Contractor's QC Engineer/Material Engineer and Executing Departments/Project Implementing Agency's field/site engineer or dedicated QA/QC Engineer shall ensure that frequencies of test are maintained as per relevant specifications. Confirmatory test if desired shall be carried out in IndependentAuthorized/Approved Laboratory. Any sub-standard material incorporated in work should be identified immediately and the Executing Department/Project Implementing Agency shall inform the Contractor, in writing, for the removal, of same, from the site. The frequencies of various tests to be conducted shall be as per relevant BIS code and MORT&H specification

The brief account of various Tests & their Frequency, which is required to be maintained as per relevant provisions of codes/specifications is presented as per Table-4.10below or same may be referred as per well documented Contract Agreement:

## Table-4.10Brief Requirement of various Tests & Frequency

| Sr. No. | Description of Work / Tests | Ref. Codes | Frequency | Acceptance Standards |
|---|---|---|---|---|
| **NOTE: Most latest mandate of BIS/IRC/MoRT&H code/specifications shall apply, wherever applicable** | | | | |
| **1. Coarse Aggregate for Structures (MORTH Specification clause 1007 & I.S 383- 1970)** | | | | |
| i. | Grading | IS:2386 (Part 1) | Before starting of work | As per Table 1000-1 of MORTH Specifications & As per Table -1 of IS 383. |
| ii. | Estimation of deleterious materials and organic impurities | IS:2386 (Part 2) | Once for source approval | Table -1 of IS 383. |
| a. | Coal and Lignite | - | One test per source | Max. 1% |
| b. | Clay Lumps | - | One test per source | Max. 1% |
| c. | Material finer than 75 micron. | - | One test per source & one test per day | Max. 3% |
| d. | Total of all Deleterious Matters | - | One test per source | Max. 5% As per table- 2 of IS: 383 |
| iii. | Specific gravity, density, voids, water absorption and bulking | IS:2386 (Part 3) | One test per source | Water absorption max-2% |
| iv. | Mechanical properties (Aggregate Impact Value-AIV or Loss Angeles Abrasion Value-LAAV) | IS:2386 (Part 4) | One each source of supply and when called for by the Engineer In charge | AIV - 45% max for concrete LAAV - 50% max for concrete |
| v. | Soundness in Sodium Sulphate and Magnesium Sulphate | IS:2386 (Part 5) | One test per source | Max. 12% and Max. 18% respectively. |
| vi. | Alkali aggregate reactivity | IS:2386 (Part 7) & IS: 383 | One test per source | Innocuous aggregate |
| vii. | Petrography examination | IS: 2386 (Part 8) & IS:383 | One test per source | Information required for approval of source |
| viii. | Flakiness Index | IS: 2386 (Part 1) | Before starting of work | Not greater than 35% |
| Maximum Nominal Size of Coarse Aggregates Shall be referred from MoRT&H Table 1700-7 | | | | |
| **2. Sand/ Fine Aggregate for Structures (MORTH Specifications Section 1008 & IS: 383-1970)** | | | | |
| i. | Fineness modulus of fine aggregate | IS: 383 | One test for 15 $m^3$ | Min. 2.0 and Max. 3.5 |
| ii. | Soundness in Sodium Sulphate and Magnesium Sulphate | IS: 2386 (Part 5) | One test per source | Max. 10% and Max. 15% respectively. |
| iii. | Deleterious Constituents | IS: 2386 (Part 2) | One test for 15 $m^3$ | |
| a. | Coal and Lignite | - | One test for 15 $m^3$ | Max. 1% |
| b. | Clay Lumps | - | One test for 15 $m^3$ | Max. 1% |
| c. | Shale | - | One test for 15 $m^3$ | Max. 1% |
| d. | Total of all Deleterious Matters | - | One test for 15 $m^3$ | Max. 5% |

| Sr. No. | Description of Work / Tests | Ref. Codes | Frequency | Acceptance Standards |
|---|---|---|---|---|
| **NOTE: Most latest mandate of BIS/IRC/MoRT&H code/specifications shall apply, wherever applicable** | | | | |
| v. | Material Passing 75 micron | IS: 2386 (Part 1) | Before starting of work | Max. 3% for natural sand and 15% for crushed aggregate (As per IS 383-1970) |
| vi. | Specific Gravity | IS: 2386 (Part 3) | One test per source | Min 2.5 |
| vii. | Water Absorption | IS: 2386 (Part 3) | One test per source | Max. 2% |
| viii. | Surface Moisture Content (Free moisture) | IS: 2386 (Part 3) | When required | Max. 5% |
| ix. | Alkali – Aggregate Reactivity | IS: 2386 (Part 7) | One test per source | Innocuous aggregate |
| x. | Grading Requirement | IS: 2386 (Part 1) | Before starting of work | As per Table 1000-2 of MORTH Specifications |
| xi | Bulking | IS: 2386 | One test per source | As per Engineers Direction |
| **3. Admixture** | | | | |
| i | Chemical Tests | As per IS: 9103 | Once per source | As per IS: 9103 |
| **4. Construction Water** | | | | |
| i | Alkalinity and Acidity | MORT&H clause 1010 | Once per source | MORT&H clause 1010 |
| ii | Solids | As per IS: 3025 | One test per source | As per IS 3025 |
| **5. Steel** | | | | |
| i | Physical & Chemical test | As per IS:1786 | As per IS 1786 | As per IS 1786 |
| **6. Size Stones** | | | | |
| i | Water absorption | As per relevant IS:1124 | One each source of supply and when called by the Engineer In charge | Not more than 5% of its dry weight |
| ii | Dimension check | - | As directed by Engineer | - |
| Iii | Type of rock | As per IS: 2386 | As directed by Engineer | - |
| **7. Cement** | | | | |
| i | Fineness | As per IS: 4031 | One each source of supply and when called by the Engineer In charge | Limit as per IS 269: 2015 |

| Sr. No. | Description of Work / Tests | Ref. Codes | Frequency | Acceptance Standards |
|---|---|---|---|---|
| NOTE: Most latest mandate of BIS/IRC/MoRT&H code/specifications shall apply, wherever applicable | | | | |
| ii | Initial/ Final setting time | As per IS: 4031 | One each source of supply and when called by the Engineer In charge | Limit as per IS 269: 2015 |
| iii | Compressive strength (3days,7days,28days) | As per IS: 4031 | One each source of supply and when called by the Engineer In charge | Limit as per IS 269: 2015 |
| **8. Mortar** | | | | |
| i | Compressive strength | As per IS: 2250 | One sample for every 2 $m^3$ of mortar subject to a minimum of three samples for a day work | As per IS 2250 |
| **9. Lime** | | | | |
| i | Chemical properties | as per IS: 6932, 1514 | Three final test sample for a lot size up to 100 tones as per table 3 in IS 712- 1984 | as per IS 6932, 1514 |
| ii | Physical properties | As per IS: 6932 | Three final test sample for a lot size up to 100 tones as per table 3 in IS 712- 1984 | as per IS 6932 |

## 10. Structural Concrete (IS:456/ MORTH Specifications Section 1700)

| Sr. No. | Description of Work / Tests | Ref. Codes | Frequency | Acceptance Standards | | |
|---|---|---|---|---|---|---|
| i | a) Maximum water cement ratio of concrete works | Mix Design | Throughout | **Member** | **Normal Exposure** | **Severe Exposure** |
| | | | | PCC | 0.45-0.50 | 0.40-0.45 |
| | | | | RCC | 0.45 | 0.40 |
| | b) Minimum strength of concrete for small otherworks | Mix Design | Throughout | Member | Moderate Exposure | Severe Exposure |
| | | | | PCC | M15 | M20 |
| | | | | RCC | M20 | M25 |
| | Requirements of Nominal Mix Concrete as per IS:456/ MoRT&H, Section 1704.3, shall be referred. | | | | | |
| | c) Minimum cement contents for concrete for generic concrete works, (in kg/m³), without use of admixtures. | Mix Design | Throughout | Member | Normal Exposure Min – Max | Severe Exposure Min – Max |
| | | | | PCC | 250 – 540 | 310 – 540 |

| Sr. No. | Description of Work / Tests | Ref. Codes | Frequency | Acceptance Standards | | |
|---|---|---|---|---|---|---|
| | | | | RCC | 310 – 540 | 400 – 540 |
| | Minimum Grades of Concrete and corresponding minimum cement content and maximum w/c ratios for different exposure conditions for Major Building Structures/Components shall be as per relevant BIS Practice &MoRT&H, Clause 1703.2, Table-1700-2. The maximum cement content excluding any mineral admixtures (Portland cement component alone) shall not exceed 450kg/cu.m. | | | | | |
| ii | Current margin and target mean strength (MoRT&H, Table-1700-8) | - | | Concrete Grade | Current Margin (MPa) | Target Mean Strength (MPa) |
| | | | | M15 | 10 | 25 |
| | | | | M20 | 10 | 30 |
| | | | | M25 | 11 | 36 |
| | | | | M30 | 12 | 42 |
| | | | | M35 | 12 | 47 |
| | | | | M40 | 12 | 52 |
| | | | | M45 | 13 | 58 |
| | | | | M50 | 13 | 63 |
| | | | | M55 | 14 | 69 |
| | | | | M60 | 14 | 74 |
| | | | | M65 | 15 | 80 |
| | | | | M70 | 15 | 85 |
| | | | | M75 | 15 | 90 |
| | | | | M80 | 15 | 95 |
| | | | | M85 | 16 | 101 |
| | | | | M90 | 16 | 106 |
| iii | Optimum consistency by slump test | IS:1199, IS:516. IS: 456 | Each trial mix | a) PCC 25mm<br>b) RCC structure inclined exposed surface: 25mm<br>c) RCC with widely spaced reinforcement: 40-50mm.<br>d) RCC with fairly congested reinforcement: 50-75mm<br>e) RCC & PSC with highly congested reinforcement: 75-125mm<br>f) Under water concreting through tremie: 150-200mm | | |
| iv | Total Chloride content of all constituents of concrete as a percentage of mass of cement in mix | BS:1377 (Part 17) | Each Trial Mix | a) Pre stressed concrete: 0.1%<br>b) Reinforced concrete exposed to chlorides in service (i.e. structures located near sea coast): 0.2%<br>c) Other RCC: 0.3% | | |
| v | Total sulphate content | BS:1377 | Each Trial Mix | Max 4% | | |

| Sr. No. | Description of Work / Tests | Ref. Codes | Frequency | | Acceptance Standards | |
|---|---|---|---|---|---|---|
| | | (Part 18) | | | | |
| vi | Maximum normal size of aggregate | Sieving | Each Trial Mix | | Components | Max nominal size of Coarse Aggregate |
| | | | | | a) Normal RCC Structural Components, including Piles | 20 mm |
| vii | Sampling of cubes of each mix | - | 3 cubes for 7 days & 6 cubes for 28 days Comp. strength test | | IS:1199 | |
| viii | Cube strength (3 cubes on 7 days & 9 cubes on 28 days) | IS:516 | Each trial mix | | 7 days strength: for preliminary assessment only<br>b) 28 days cubes strength shall achieved Target mean strength | |
| XI | Sampling of concrete for each grade at site and compressive strength<br>(At least one sample shall be taken from each shift of work) | IS: 1199<br>IS: 456 | Qty of concrete (m3) | No. of Samples | MORTH Specifications Clause 1716.2.5<br>a) The mean strength determined from any group of four consecutive samples should exceed the specified characteristic compressive strength.<br>b) Strength of any sample is not less than the specified characteristic compressive strength minus 3 MPa | |
| | | | 1 – 5<br>6 – 15<br>16 – 30<br>31 – 50<br>51 and above | 1<br>2<br>3<br>4<br>4 plus one additional sample for each additional 50 m3 are part thereof | | |
| **Note**:EachSample will contain 3 cubes for testing at 28 days, additional cubes be taken for strength of concrete at 7 days. | | | | | | |

### 4.7.5 Other Quality Control Parameters

The guidelines on other quality parameters like dimensional control, surface regularity, tolerances on concrete elements and ratification, thereof, shall be referred from relevant BIS/MoRT&H Standards.

### 4.7.6 Calibration of Instruments of Material Testing & Manufacturing:

All measuring instruments and testing equipment (field and laboratory) shall be uniquely numbered, properly stored, suitably handled in a manner appropriate to its sensitivity & calibration. Each equipment shall be maintained in a known state of calibration. If any instrument is repaired, steps shall be taken to ensure that calibration is carried out to restore its calibration status. Calibration of Concrete Batching Plant, etc. is to be checked periodically.

### 4.7.7 Quality Records & Non-Conformity Reporting (NCR)

Executing Department/Project Implementing Agency with the assistance of the Consultant shall maintain Quality records that contain sufficient information to permit verification of any report. Records pertaining to inspections and testing shall include original observations, calculations, derived data and an identification of personal involved i.e. inspection and testing. All records shall be indexed, filed and maintained in a secure location for the entire concession period.

Executing Department/Project Implementing Agencyshall also incorporate nonconformity evaluation in their work. The purpose of NCR is to establish how to control nonconformity that does not conform to specific requirements, and to prevent them from unintended use or installation, which occurs at the site during construction. The construction activities carried out by contractor at site, which are not conforming to Quality Control Plan as well as construction drawing and required corrective measure, the field engineer of Executing Department/Project Implementing Agency, at site, shall instruct the contractor for taking corrective action of particular items. If the instructions given by Executing Department/Project Implementing Agencyare overlooked, then, in such incident, Non conformity of such work should be issued to the contractor. The contractor should take immediate action by repair or rework, which are recognized as cause of nonconformity. If necessary measures to implement the corrective action to eliminate the cause of non-conformity and to prevent recurrence shall be established.

# 5. BUILDING CONSTRUCTION

## 5.1 Introduction

Building construction is one of the important subjects of civil engineering, which deals with the materials and methods of construction of various elements of a building like walls, roofs, floors, stairs etc. the meaning of a building has changed from being a shelter to means of not only providing protection but also to serve its intended function by providing sufficient accommodation, comfort, ventilation and appealing appearance to the user. In civil engineering, building is defined as a structure consisting of various components like foundation, walls, columns, beams, roofs, floors and doors etc. to provide adequate covered space for specific uses like residential, educational, industrial and business etc.

## 5.2 General Principles of Construction

Whatever approach we take to the design and erection of our buildings there are a number of fundamental principles that hold true. The building has to resist gravity and hence remain safe throughout its design life and substantial advice is provided in regulations and standards. Parts of a building fall under two broad categories, viz., substructure and superstructure and all components of a building fall in any one of these categories. Every building in general is composed of the following elements:

- Foundation
- Masonry construction
- Framed structure
- Arches and Lintels
- Windows and doors
- Stairs and ramps
- Floors
- Roof
- Damp Proofing
- Concept of Seismic Planning of Buildings.
- Surface finishes
- Services

It is vital for the success of the building project and the use of the constructed building that an integrated approach is adopted. It is impossible to consider the choice of, for example, a window without considering its interaction with the wall in which it is to be positioned and fixed.

## 5.3 Foundation

Foundation is that part of the structure which is in direct contact with the ground and transmits the load of the structure to the ground. It includes the soil or rock of the earth's crust or any special part of the structure which serves to transmit the loads into the soil or rock. The main purpose of the transmissions of load can be satisfied by a particular type of foundation that takes into account the properties of the supporting soil. Thus the supporting soil plays a major role in the performance of foundation. Hence it is of prime importance to know the soil which is done by a proper soil investigation. It is necessary to know about the types of soils and their distribution to decide a particular type of foundation. The structural support is actually being provided by a soil-foundation system. This combination of soil and foundation (now referred to as soil-structure interaction) cannot be separated. Although engineers are aware of this relationship, it is common practice to consider the structure to be sound and to attribute the failure of the foundations to the failure of the supporting soil.Structural foundations may be grouped under two broad categories – shallow foundations and deep foundations. This classification indicates the depth of foundation installation. A shallow foundation is one which is placed on a firm soil near the ground, and beneath the lowest part of the super-structure. A deep foundation is one which is placed on a soil that is not firm, and which is considerably below the lowest part of the super-structure.

The basic types of the foundations and their design procedures are discussed in this section. For detailed discussion, reference may be made to IS-1080:1986 and IS- 2911:1979.

**5.3.1 Types and Suitability of Shallow Foundations**

Shallow foundations are all suitable for building and are sub-divided into a number of types according to their size, shape and general configuration. They are discussed below.

**5.3.1.1 Spread Footings**

These footings are the most common of all types of footings with minimum cost and complexityof construction (Fig. 5.1(a)). It necessarily provides the function of distributing the column load over a wide area taking care of the strength and deformation characteristics of the soil. These types of footings are also known as pad footings, isolated footings and square or rectangular footings (for length of footing, *L*, and width of footing, *B*, ratio less than 5)

**5.3.1.2 Combined Footing**

These footings are formed by combing two or more equally or unequally loaded columnsinto one footing. This arrangement averages out and provides a more or less uniform loaddistribution in the supporting soil. Further distribution prevents variation of settlementalong the footing. These footings are usually rectangular in shape. It may be modified to atrapezoidal shape so as to accommodate unequal column loadings or column close to propertyline. It may be provided with a strap to accommodate wide column spacing or columnsclose to property line (Fig. 5.1(b)).

**5.3.1.3 Continuous Footing**

These footings carry closely spaced columns or a continuous wall such that the load distributionis uniform and load intensity is low on the supporting soil (Fig. 5.1(c)). These footings are also named as strip footings or wall footings (for *L*/*B* ratio greater than 5).

**5.3.1.4 Mat or Raft Foundation**

These are characterised by the feature that columns frame into the footing in two directions.Any number of columns can be accommodated with as low as four columns (Fig. 5.1(d)).In the majority of the cases, mat foundations are used where the soil has low bearing capacity.By combining all individual footings into one large mat, the unit pressure in the sub-soil isreduced.Since the bearing capacity increases with increasing depth and width of the foundationand the settlement decreases with the increasing depth of foundation, the advantage of matfoundation is two-fold. Mat foundation is also preferred when the total area of the footingsexceeds 50% of the total plinth area.

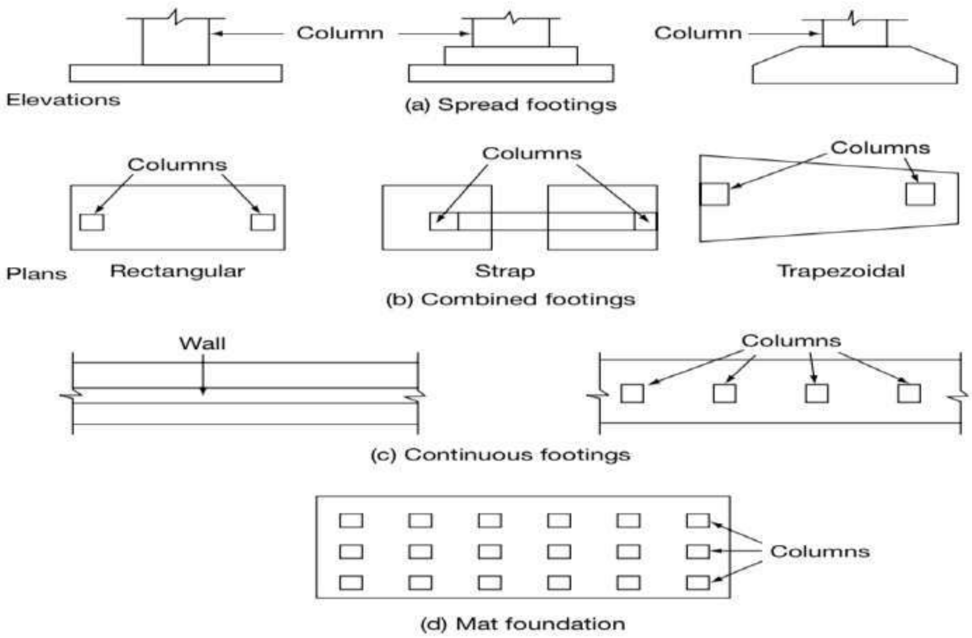



**Figure 5.1: Types of shallow foundations.**

### 5.3.2 Types and Suitability of Deep Foundations

The design and construction of deep foundations for transferring the weight of the superstructure through soft or weak soils, to deep load bearing strata is a challenging job for a civil engineer. Piles, piers and caissons are the most common types of deep foundations. For any system the mechanism of deriving support from the soil or rock below and adjacent to the foundation is similar. However, each system differs in its method of construction.

#### 5.3.2.1 Pile Foundations

Piles are slender structural members normally installed by driving by hummer or by any other suitable means. The piles are usually placed in groups to provide foundations for structures. Piles may be classified according to their material composition, installation method, group effect and their function as a foundation. For design and construction of pile foundations refer to IS- 2911 (Part 4):1984.

#### 5.3.2.2 Pile Groups

Where piles are used for foundation support, they are always used in a group. This requirementis essential so as to assure that the imposed structural load lies within the support area provided by the foundation. As per the building codes at least three piles should be used to support a major column and two piles to support a foundation wall. A pile cap is provided near the ground encompassing all the top ends of piles. Pile caps are almost invariably made of reinforced concrete. The axial and the lateral load carrying capacity of a pile group is significantly affected by a pile cap. In order to keep the stresses in the pile cap to a minimum the piles should be arranged in the most compact geometric form.

#### 5.3.2.3 Drilled Piers

Drilled piers are structural members of relatively large diameter massive struts constructed of concrete placed in a pre-excavated hole. They are also called bored piles, large-diameter piles, foundation piers and drilled caissons. The shaft can be enlarged at the base resulting in a belled or under-reamed pier. The common type of drilled pier is the straight shafted type. The shaft is taken through the upper soil layers and the end is placed on the firm ground or rock. Drilled piers which are provided with a broad base (called a bell) at the bottom of the straight shaft are referred to as belled piers. The bell may have a shape of a dome or it may be angled.

#### 5.3.2.4 Caissons

Caissons are structural boxes or chambers that are sunk in place through ground or water.The sinking is systematically done by excavating below the bottom of the unit which thereby descends to the final depth. These have large cross-sectional area and hence provide high bearing capacity.

### 5.3.3 Design Procedure

The following general steps have to be adopted in the design of foundations:

- A soil investigation has to be carried out.
- It is necessary to compute the total load (both dead and live load) and the distribution has to be assessed.
- It is to assess the total and differential settlement which the structure may undergo.
- Based on the type of soil and the structure and load the type of foundation is decided.
- The appropriate allowable soil pressure has to be determined for the selected type of foundation.
- The type of material for the foundation has to be decided.
- Alternate designs are to be made before finalization.
- Cost estimate has to be made and any further modification may be made keeping in view economy and life of the structure.

#### 5.3.3.1 Design of Shallow Foundations

Following guidelines may be taken while designing shallow foundation other than rafts and mats.

- ❖ In case of wall footing the width of foundation should be computed based on the allowable soil pressure.
- ❖ In case no footings are to be provided to the walls the width of foundation should be equal to three times the width of the wall.
- ❖ In case of piers the width of foundation is equal to square roots of total load of the pier divided by the allowable soil pressure.
- ❖ For unreinforced strip footings the thickness should not be less than the projection from the base of the wall. It should not be less than 150 mm where the foundations are laid at more than one level.
- ❖ For unreinforced column footing the spread of footing may be 1 vertical to one horizontal.
- ❖ As a general rule, the shallow foundation should be taken down to a depth where the allowable bearing capacity is adequate.
- ❖ As for as possible the foundation should be kept above the ground water table.
  - In order to safeguard a against minor soil erosion, a minimum depth of 500 mm is provided for strip or column foundation
  - The depth of foundation can be also determined by plotting the pressure distribution lines (Fig:5.2).

$h_1$, h2 = Depth of footing, Depth of base concrete
h =Depth of foundation
Then h= $h_1$+$h_2$

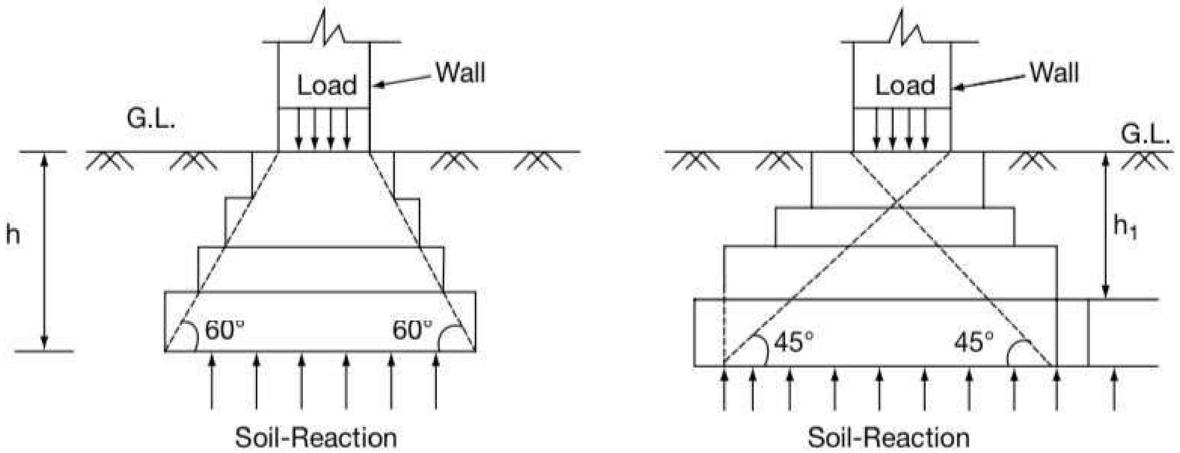



Figure 5.2 Pressure distribution diagram

- Minimum depth of foundation for loose soils may be obtained from Rankine'sformula, i.e.,

$$\boldsymbol{h} = \frac{\boldsymbol{p}}{\boldsymbol{w}}\left(\frac{\mathbf{1} - \boldsymbol{sin}\emptyset}{\mathbf{1} + \boldsymbol{sin}\emptyset}\right)^{\mathbf{2}}$$

Where *h* = Minimum depth of foundation in m
*w* = Weight of soil in kg/$m^3$
f = Angle of repose
*p* = Load in soil kg/$m^2$

The depth of concrete block is given as

$h_2 = \frac{1}{58}\sqrt{\frac{pa^2}{f}}$ in cm.

where a = offset of concrete in cm
f = safe modulus of rupture in kg/m$^2$

**5.3.3.2 Design of Piles**

Following guidelines may be considered in design of piles:

- Direct vertical load coming on the pile should be considered.
- In case of driven piles, the impact stresses induced due to pile driven is taken into account.
- Bending stresses induced due to bending in piles and due to eccentricity to be accounted.
- Lateral forces due to wind, waves, water, current, ice sheets, impact of ships are to be accounted.
- Forces due to uplift may also to be considered.
- If the area is earthquake – prone area necessary modifications have to be made.
- Load carrying capacity of pile is computed based on the type of pile. Pile load tests can be done for all type of piles. For driven piles, pile driving formulas can be used.

One such formula is ENR formula which is derived on the basis of work-energytheory. The ENR formula has been modified by Hiley as the ultimate pile load, $Q_u$,is given as

$$Q_U = \frac{\eta W h \eta_b}{S + C/2}$$

Where η = Hammer efficiency
W = Weight of hammer
h = Height of fall
S = Final set
$\eta_b$= Efficiency of the blow.
C = Sum of the temporary elastic compression of the pile.

**5.3.4 Construction of Foundations for Buildings**

The construction procedure adopted in each of the building foundations are brieflyexplained below.

**5.3.4.1 Construction of Spread Footing**

Spread footing is called as isolated or column footing. They are used to support individualcolumns. They can be of stepped type or provided with projections in the concrete base.Main reinforcement is placed at the bottom. In case of heavily loaded columns reinforcementis provided in both the directions in the concrete bed. The concrete mix is based on thestrength requirement. In general 1:2:4 mix is used. Generally 15 cm offset is provided on allsides of the concrete bed. In case of brick masonry columns an offset of 5 cm is provided.

**5.3.4.2 Construction of Combined Footing**

Combined footings are designed keeping the following aspects in view:

- The shape of the footing is so selected such that the centre of gravity of the columnloads and of soil reaction remains in the same vertical line. Unusually a rectangular or trapezoidal shape of foundation will generally satisfy this requirement.
- The area of the combined footing should be equal or greater than the ratio of thetotal load and the bearing capacity of the soil.

- ❖ The combined footing is treated as an inverted floor, loaded by earth reaction andSupported by columns.

  Other procedure adopted for column footing may be adopted here too.

**5.3.4.3 Construction of Continuous Footing**

A wall footing is a typical case of continuous footing. This may have a base course ofConcrete or may be made of the same material as that used for the wall. This type of footingmay be simple or stepped. For light loads a simple base with a projection of 15 cm on either side is provided. As a general rule the base width of concrete bedding should be twice the width of the wall and the depth of the base concrete is at least twice the projections.In another type of wall footing no base concrete is provided. In such a case in order to transmit the load gradually the width of the wall is gradually increased. This is adopted by projecting bricks regularly to a distance not greater than 1/4 of a brick beyond the edge of the wall. Cement mortar is used in both the cases for walls. For foundation part a richer mix has to be used. In another type of continuous footing series of columns in a line are provided with a footing. Here reinforced concrete slabs extends over the series of columns. In order to increase the stability a deep beam is constructed in between the columns. Such type of footings resists differential settlements.

**5.3.4.4 Construction of Mat Foundation**

As discussed earlier this type of foundation is used when the bearing capacity is low andtotal area of spread footing exceeds 50% of the total plinth area.Mat foundation consists of rows of columns built monolithic with a continuous slabcovering the entire foundation area, with or without depressions or openings.A true mat is a flat concrete slab with uniform thickness throughout the entire area. Thistype is most suitable where the column spacing is fairly small and uniform and the columnloads relatively small. For large column loads a portion of the slab under the column maybe thickened. If bending stresses become large, thickened bands may be used along thecolumnlines in both directions. Under extremely heavy column loads, two-way grid structuremade of cellular construction may be used. Basement walls are also sometimes usedas ribs or as deep beams.

The choice of mat type depends on one or more of the following factors:

- ❖ For fairly small loading and uniform column spacing and the supporting soil is notvery much compressible a flat concrete slab with uniform thickness of mat may beprovided.
- ❖ In order to provide adequate strength against shear and negative bending momentfor heavy loaded columns the slab is thickened.
- ❖ For unequal column loading and wide spaced columns beam and slab type of raft ismore economical.
- ❖ For heavy structures, cellular rafts or rigid frames may be adopted.

## 5.4 Masonry Construction

As per the old convention, masonry is a term used to indicate the art of building structures in stones using mortar and stone. But in a simplified form, it may be defined as construction of building units bonded together with mortar. IS 2250:1981 covers the requirements of various mortars. The building units may be brick, stone, concrete, hollow blocks, etc. The selection of the type of unit for the masonry is made keeping in view the requirements of strength, water proofing, thermal insulation, fire resistance, durability and economy. For design and construction of masonry reference may be made to SP 20(S&T): 1991.

**5.4.1 Brick Masonry**

As bricks are comparatively small in size, they can be handled easily. Further, brick being uniform in size can be arranged systematically and bonded together with mortar to form a homogeneous mass, which is called brick masonry. The materials used for brick masonry are bricks, mortar and specially shaped bricks. Mortar helps to bind the individual bricks and to form a cushion to take up the inequalities in the brick and to distribute the pressure evenly and also to fill up the interstices in the bricks. For detailed discussion, refer to Code of practice for brick work:IS 2212:1991.

Some of the terms which are used in brick masonry are defined below.

- ❖ **Header:** A brick laid with its breadth or width parallel to the face or direction of a wall.
- ❖ **Stretcher:** A brick laid with its length parallel to the face or direction of the wall.
- ❖ **Bed:** The lower surface of a brick when laid flat.
- ❖ **Bat:**A portion of a brick cut across the width.
- ❖ **Closer:**A part of brick that is used to close up the bond at the end of brick course. The different closers are: (i) king closer, (ii) queen closer and (iii) bevelled closer.
- ❖ **Quoin:** A corner of the external angle on the face side of a wall.
- ❖ **Squint:**A brick cut to a special shape and used at oblique quoins.

**5.4.1.1 Bonds in Brickwork**

It is the process of arranging bricks in courses to ensure that vertical joints do not come one over the other. A wall built without any continuous vertical joint shall distribute the load properly and shall also be more strong and durable.

❖ **Stretcher Band**

In this type of bond, all courses are laid as stretchers. As only stretchers are visible in elevation,this bond is referred to as stretcher bond. This is used for partition walls (Fig. 5.3(a)).

❖ **Header Bond**

In this type of bond, all courses are laid as headers. As only headers are visible in elevation, this bond is referred to as header bond. This is used for one brick and curved walls (Fig.5.3(b)).

❖ **English Bond**

This bond is produced by laying alternate courses of stretchers and headers. In order to break the joints vertically, it is essential to use a closer after the header quoin in the heading course. This is the most commonly used bond which is also the strongest. This type of bond is used for walls carrying heavy loads. Figure 5.3(c) shows formation of a wall adopting English bond.

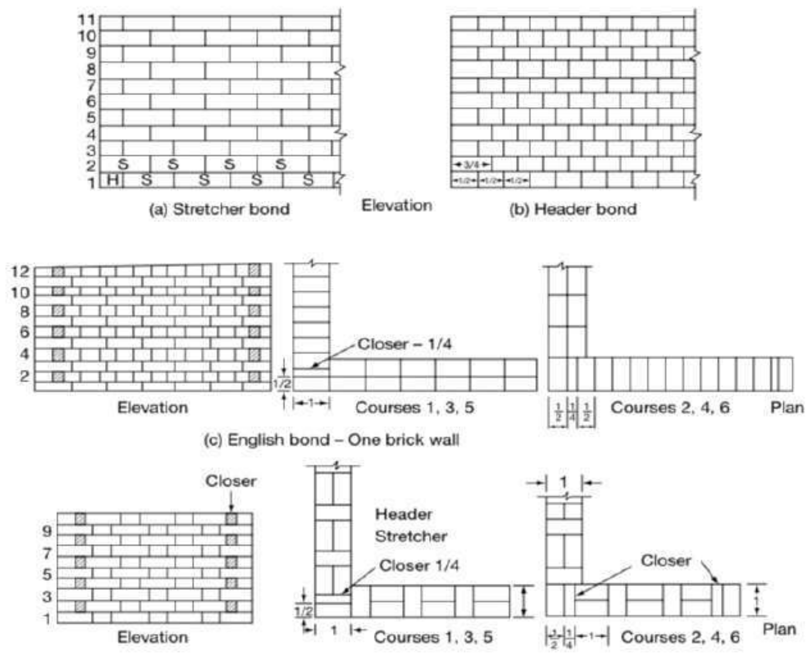



Figure 5.3 Bonds in brickwork

❖ **Flemish Bond**

This bond is produced by laying alternate stretchers and headers in each course. The headers and stretchers appear in the same course alternately on the front and the faces. The queen closer is used next to the quoin header in alternate courses in order to break the continuity of the vertical joints. A header in any course is in the centre of a stretcher in the course above or below it. This bond is also used for walls to carry moderate loads. Figure 5.3(d) shows formation of wall adopting Flemish bond.

**5.4.1.2 General Principles of Construction of Brick Masonry**

Brickwork should be systematically done keeping in view the bonding, jointing and finishing. The laying of brick masonry is practically the same for all types of constructions. But some special considerations have to be given to each case. Mortar of 10 cm thickness is first spread. Bricks soaked in water (so as to prevent absorption of moisture from the mortar) are placed over the mortar and pressed to ensure adequate adhesion. Both the longitudinal and cross joints are packed well with mortar. Proper bond is adopted and the brickwork is to be constructed in uniform layers. It is essential to check frequently the verticality of the walls and perpendicularity between the walls. The joints which are exposed are carefully finished by jointing or painting. At the end of a day's work, the brickwork is raked back by stepping the brickwork. After construction, brickwork should be kept wet for two weeks.

The following points should be observed while supervising the construction of brick masonry:

- ❖ Bricks should conform to the specification and requirements of the work.
- ❖ Bricks should be saturated well with water before use.
- ❖ Bricks should be laid with frog upwards, with mortar completely covering the bed.
- ❖ A suitable bond has to be used to avoid continuous vertical joints anywhere in the work.
- ❖ A good quality mortar has to be used and the thickness of mortar should not be more than 10 mm.
- ❖ The brickwork should be raised uniformly.
- ❖ Brickbats should be minimised and to be used only in the required places.
- ❖ In no case the height of masonry should be greater than 1 m in a day's work.
- ❖ All vertical faces should be checked with a plumb bob and wall junctions should be checked for perpendicularity.
- ❖ After the construction is over, the brickwork should be watered well for two weeks.

**5.4.2 Stone Masonry**

Stones are abundantly available in nature which can be properly shaped and used for construction of various parts of a building. Similar to brick masonry, stones also can be systematicallyarranged to form a homogeneous mass called stone masonry. The materials used for stone masonry are stones and mortar. The common types of stones used for stone masonry in India are: granites, sandstones, limestones, marbles and slates. Stone masonry is strong and durable. Some of the terms which are used in stone masonry are defined below:

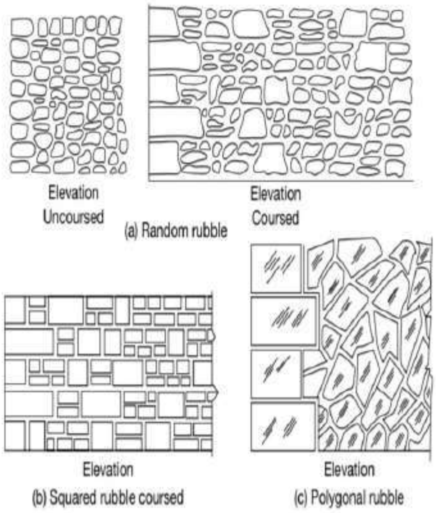
- ❖ **Bed Surface:** Surface of a stone perpendicular to the line of pressure.
- ❖ **String Course:** A horizontal course of masonry continuously projecting from the face of the wall.
- ❖ **Corbel:** A stone embedded in a wall to support a structural member.
- ❖ **Cornice:** A moulded projection of masonry on the top of a wall.
- ❖ **Through Stone:** Stone extending throughout the thickness of the wall.
- ❖ **Hearting:** A filled-up core of a rubble wall.
- ❖ **Jam:** A masonry portion forming the side of an opening.

**5.4.2.1 Types of Stone Masonry**

Stone masonry is classified based on the thickness of joints, continuity of courses and Finish of face. Rubble Masonry and Ashlar Masonry are discussed below. For construction of stone masonry, refer to (IS: 1597(Part1 & 2):1992).

❖ **Rubble Masonry**

Rubble masonry is a stonework wherein blocks of stones are either undressed or roughly dressed and have wider joints. The stones used are not of uniform size and shape but generally of pyramidal in shape to some extent. Vertical and transverse bonds have to be attained. Through stones are provided from back to the face of wall to ensure better bonding. The strength of this masonry depends on the quality of mortar, use of through stones and filling of spaces. There are different types of rubble masonry, viz., random rubble, squared rubble and polygonal rubble. Figure 5.4 shows the various types of rubble masonry.



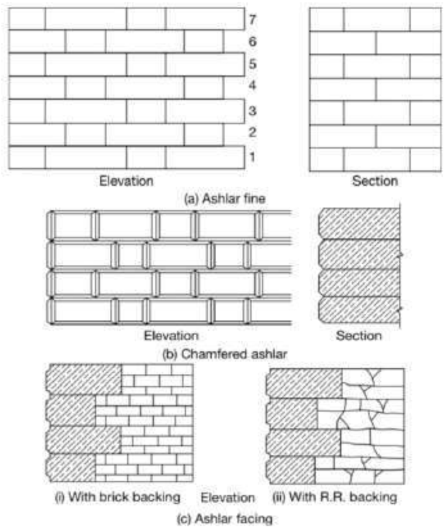




Figure 5.4 : Types of Rubble masonry.Figure 5.5 :Types of Ashlar masonry.

❖ **Ashlar Masonry**

Ashlar masonry is a stonework wherein blocks of stones are accurately dressed with very fine joints of 3 mm thickness. It is essential to ensure that the sizes of individual stones are in conformity with the general properties of the wall. In this masonry the beds, sides and faces are finely chisel dressed. The backing of such walls may be rubble or ashlar masonry. It is the highest grade of masonry and costly. There are different types of ashlar masonry, viz., ashlar fine, ashlar rough tooled, ashlar rock or quarry faced, ashlar chamfered and ashlar facing. Figure 5.5 shows some of the types of ashlar masonry.

**5.4.2.2 General Principles of Construction of Stone Masonry**

The construction procedure for stone masonry is slightly different from that of brick masonry. Unlike in brick masonry, in stone masonry stones of different sizes and shapes are used and accordingly there is slight variation in construction. The following general principles of construction should be observed while supervising the stone masonry construction:

- ❖ Stones should be hard, tough and durable.
- ❖ Pressure acting on the stone should be perpendicular to the bedding planes.
- ❖ Stone masonry work should not be designed to take any tension.
- ❖ Stones should be well watered before use.
- ❖ Through stones should be used sufficiently such that they cover about 15–25% of the area in elevation.
- ❖ Stones should be laid on its natural bed.
- ❖ Extreme care has to be taken by providing proper bond to prevent formation of vertical joints.
- ❖ Hearting of masonry should be properly packed with chips and mortar.
- ❖ Verticality of the faces of the masonry walls should be checked with a plumb rule.
- ❖ Portions of the masonry should be raised uniformly throughout its length.
- ❖ Cement mortar and sometimes rich lime mortar may be used.
- ❖ Proper dressing of stones has to be done wherever needed.
- ❖ Surfaces of the stone masonry should be kept wet while the work is in progress and also till the mortar has set.
- ❖ All laid fine dressed stonework should be protected against damage during further construction.

### 5.4.3 Concrete Hollow Block Masonry

Cement concrete hollow blocks have been in use for several masonry constructions. Several advantages have given room for rapid development and use of the same in place of traditional construction materials like stones and bricks.

#### 5.4.3.1 Laying of Concrete Hollow Block Masonry

Different types of hollow blocks used in construction of a building are discussed below:

❖ **Construction of Walls**

A mortar bed is spread on the foundation concrete and levelled to have a uniform thickness everywhere. The corner block is first placed and positioned accurately. Mortar is applied to the other end and one block is positioned to the end and aligned. The level of the course is checked after placing a few blocks. If necessary, the blocks are tapped with additional mortar such that the mortar thickness is 2 cm below and on the ends. The first course is checked to be in plumb before planning second and additional courses. As done in brick laying, the successive courses are laid in such a manner so as to break the joints vertically. For vertical joints the mortar is applied to the projection at the sides of the block. As followed for the first course, the courses are built starting from the corners only. Every time, the verticality and horizontality are checked. All the four vertical edges of the final block and the edges of the opening are covered with mortar and pushed in position. The face of the masonry may be pointed by running a tool. The type of joint recommended are weathered, V-shaped or concave, such that the joints shed off water easily.. Based on functional aspects, walls may be classified under the following two broad groups:

❖ **Load-bearing walls:** In general, masonry used for exterior walls, central main walls and some cross walls in a building are of load-bearing walls. These walls should have adequate thickness such that it will sustain a slight eccentricity in loading. The mortar used for such walls should give adequate bonding to hold the structure even when there is a slight buckling. This load bearing wall, apart from supporting the loads, subdivides the space, provides thermal and acoustic insulation, and affords fire and weather protection.The masonry types explained above may be used for load-bearing Structures.

❖ **Non-load-bearing walls:** In general, non-load bearing walls have adequate strength, stability, sound insulation and fire resistance. Non-load bearing walls may be interior walls or exterior walls. Different types of materials are used for non-load bearing walls, viz., brick, wood, hollow block, metal lath, corrugated sheet, etc.

❖ **Construction of Columns**

Columns are used wherever a large pressure to be transferred through large bearing surface. The columns may form an integral part of the wall or it can be a separate unit. The columns are made of standard stretcher and corner blocks or other special shapes are used. For better stability, the hollows within the blocks may be filled with plain or reinforced concrete (Fig. 5.6(a)).

❖ **Construction of Window and Door Openings**

Blocks with hole (jamb) near the opening should be filled with concrete and wooden plugs (Fig. 5.6(b)). The door or window frames are screwed to the wooden plugs. It is also fixed in the lintel with small dowels of mild steel. Under the base of the window or door, a course of solid concrete block masonry is laid which is extended into the adjacent walls up to a distance of at least 30 cm on either side. Lintels are also of hollow channel-shaped sections which can be filled with concrete and provided with steel reinforcement at their bottom.

❖ **Construction of Reinforced Walls**

This is made by providing vertical reinforcement in the hollow with concrete. In order to increase the strength of the wall, reinforcement is provided at the horizontal joints. Because of this provision, expansion cracks which may occur due to moisture and change of temperature may be reduced. Further, two horizontal bars of 6 mm diameter are placed on each on the face of the wall. Instead of steel rods, welded steel mesh may be used wherever needed.

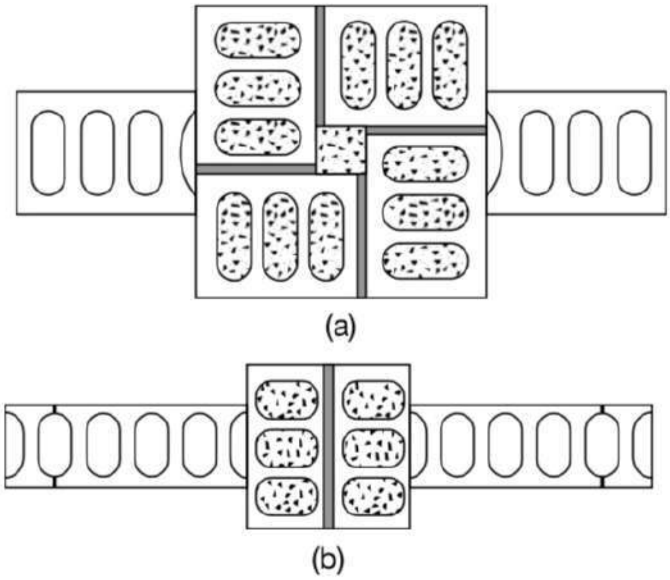



Figure 5.6: Pilasters and piers

**5.4.3.2 Concrete Blocks with Concrete Filling**

Concrete hollow blocks constructed with two through holes to form continuous vertical hole are ideal for concrete filling. These holes can be completely or partly filled with concrete during the process of construction itself. For this purpose, mixes with large size aggregates may be used. This provision will add greater strength to walls. It has been found from the tests that filling of hollow blocks with plain concrete will give basic strength approximately halfway between these for unfilled blocks and the solid blocks with the same quality of concrete.

**5.4.3.3 Reinforced Concrete Hollow Block Masonry**

In the conventional hollow block masonry, the vertical holes may be made to accommodate steel reinforcement and can thus be made of reinforced concrete construction. Similarly special concrete blocks can be made to accommodate horizontal reinforcements. Such a horizontally reinforced hollow block can be used as lintels and horizontally strengthened reinforced concrete bonds can be built up with these blocks. This type of construction is known as reinforced concrete hollow block masonry construction.

**5.4.3.4 Special Features of Concrete Block Masonry**

The important features to be incorporated, compared to regular brick masonry, are control joints, band beams and joint reinforcements. These factors are to be provided failing which the block masonry is bound to result in random cracking due to shrinkage and moisture movements. These factors are discussed below.

❖ **Control Joints**

Concrete has higher coefficient of expansion than brickwork. In order to control thermal movements, these joints are built as continuous and vertical. Further, to minimise cutting of units, they are to be located at change of sections. These joints may be shrinkage joints and expansion joints. The shrinkage joints are continuous vertical joints approximately 18 mm thick. These joints are later raked and caulked. Expansion joints are located at spacing of 45–60 m in suitable locations. These joints are filled with joint filers, which are compressible materials that close the gap but allow movement.

❖ **Bond Beams**

Bond beams are similar to lintels which are to be provided on top of openings or top of walls such as compound walls. This is constructed using special channel-shaped units which are reinforced and filled with concrete. It serves as a structural element as that of a lintel to control cracks on top of openings.

- **Joint Reinforcement**

For crack control, horizontal joint reinforcements in the form of minimum two No. 9 gauge wires at intervals can be used. As they are expensive, they are not generally provided. When used as load-bearing walls with RCC slabs resting on the walls, the top three courses at least should be provided with joint reinforcement.

#### 5.4.3.5 Compound Walls in Hollow Block

Compound walls are nowadays preferred to be of unplastered concrete block work. The construction is cheap and no maintenance is needed. There are many variations in the construction of these walls. The convenient method is to install under-reamed or cast-in-situ piles at stipulated intervals (of 3–4 m) with grade beam on top of the piles and the block work built on top of the grade beams. Vertical reinforcements are provided in the hollow blocks at regular intervals from the piles. This provision strengthens the wall along its length giving lateral resistance to wing loads or earth pressure. The top of these walls are finished with a coping cast in a channel shaped block on top.

### 5.4.4 Reinforced Brick Masonry

Ordinary brick masonry cannot take tensile stresses as the mortar joints separate out and the bricks pulled out. In order to increase the load-carrying capacity, in particular tensile stresses, of ordinary brick masonry steel reinforcement is introduced in between mortar joints. This type of construction can withstand tensile and shear stresses for moderate loading.Reinforced brick masonry is recommended in the following cases:

- When excessive compressive loads are to be supported.
- When the brickwork has to withstand tensile and shear stresses.
- When the supporting soil may be subjected to differential settlement.
- When the brick masonry is to be provided over openings of doors, windows and passages.
- When the brick masonry has to sustain lateral stress.
- When it is intended to strengthen the longitudinal bond.
- When constructions in earthquake-prone areas are to be made.

#### 5.4.4.1 Reinforced Brick Masonry Walls

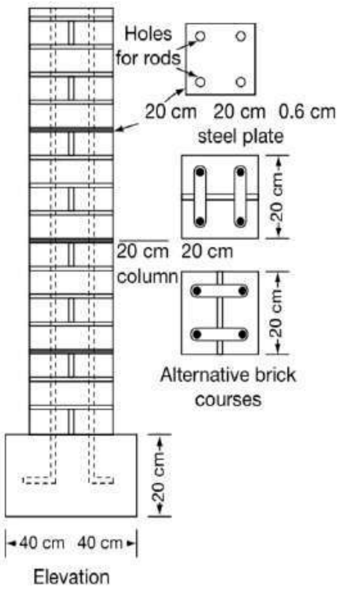
Here the reinforcement may be iron base or expanded metal mash provided at every third or fourth course. Flat bars of section about 25 mm × 2 mm may be used as hoop iron reinforcement for walls. They are hooked at corners and junctions. In order to increase the resistance against rusting, the bars are dipped in tar and sanded immediately. Reinforcement in vertical direction is provided by using special bricks or blocks. Mild steel bars of 6 mm diameter may also be used as longitudinal reinforcement in walls.

#### 5.4.4.2 Reinforced Brick Masonry Columns

These columns are made with special-purpose bricks and vertical bars running through them. In order to keep the bars in position and to strengthen the brickwork, steel plates of 6 mm thick are introduced. Bent bars of small diameters of about 12 mm can be used in the horizontal joints (Fig. 5.8).

#### 5.4.4.3 Reinforced Brick Masonry Lintel

In lintels, bars are provided longitudinally in between the vertical joints and extending from joint to joint. Further, to resist the vertical shear, additional 6 mm diameter steel stirrups may be used (Fig. 5.9).



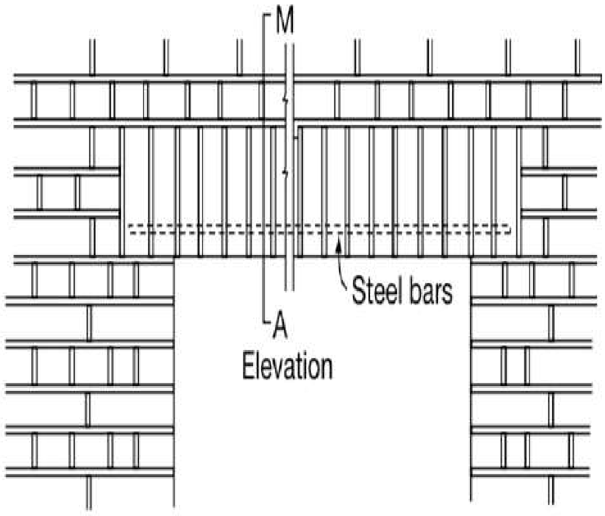




**Figure 5.8:** Reinforcement of brick masonry Column

**Figure 5.9:** Reinforcement in brick masonry lintels.

#### 5.4.4.4 Reinforced Brick Masonry Slab

Floor slabs of brickwork with reinforcement are also done. The conventional centring is made. The centring is covered with earth for a depth of about 20–25 mm and well compacted and sand sprinkled on the top.Then the reinforcement is placed in the correct direction. The bricks are laid in one or two directions. The joints are then filled with mortar such that the reinforcement is fully closed. The work is kept moist for a period of two days and then kept fully wet for 14 days. The centering is then removed. The top and bottom surface of slab are then suitably finished.

## 5.4.5. Confined Masonry Construction.

## 5.4.5.1. Introduction.

Confined masonry construction was introduced in Mexico in the 1940's to control the wall cracking caused by large differential settlements under the soft soil conditions. Several years later, this system became popular in other areas of highest seismic hazard due to its excellent earthquake performance. Confined masonry construction has evolved though an informal process based on its satisfactory performance in past earthquakes .The use of confined masonry is currently widely used for housing construction, from single-storey to five-storey apartment buildings . The limit of a five-storey building height usually coincides with most construction codes' height restrictions for buildings without elevators. Note that each masonry panel is confined by tie-columns at its ends, around larger openings (doors and windows), and additional locations depending on the panellength and/or height/thickness ratio.

Confined masonry construction consists of masonry walls (made either of clay brick or concrete block units) and horizontal and vertical RC confining members built on all four sides of a masonry wall panel. Vertical members, called tie-columns or practical columns, resemble columns in RC frame construction except that they tend to be of far smaller cross-section.

Horizontal elements, called tie-beams, resemble beams in RC frame construction. To emphasize that confining elements are not beams and columns, alternative terms horizontal ties and vertical ties could be used instead of tie-beams and tie-columns.

The confining members are effective in enhancing the stability and integrity of masonry walls for in-plane and out-of plane earthquake loads (confining members can effectively contain damaged masonry walls), Enhancing the strength (resistance) of masonry walls under lateral earthquake loads, and reducing the brittleness of masonry walls under earthquake loads and hence improving their earthquake performance.

The structural components of a confined masonry building are (see Figure 1):

### 5.4.5.2. Masonry walls

Transmit the gravity load from the slab(s) above down to the foundation. The walls act as bracing panels, which resist horizontal earthquake forces. The walls must be confined by concrete tie- beams and tie-columns to ensure satisfactory earthquake performance.

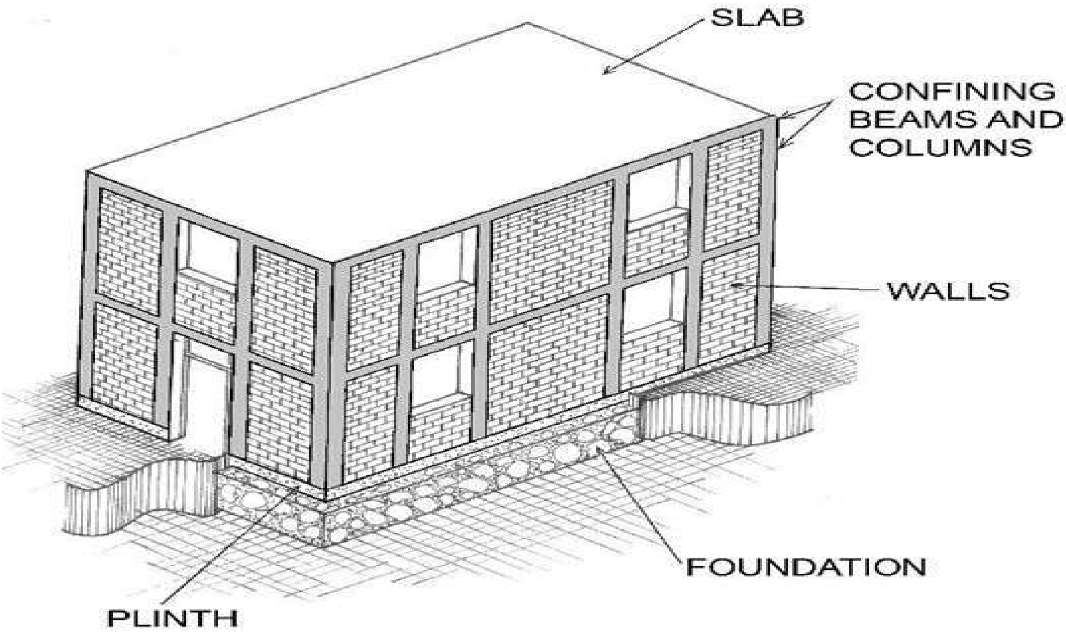



**Figure1. A typical confined masonry building**

### 5.4.5.3. Confining elements (tie-columns and tie-beams) —

provide restraint to masonry walls and protect them from complete disintegration even in major earthquakes. These elements resist gravity loads and have important role in ensuring vertical stability of a building in an earthquake.

### 5.4.5.4. Floor and roof slabs —

Transmit both gravity and lateral loads to the walls. In an earthquake, slabs behave like horizontal beams and are called diaphragms.

### 5.4.5.5. Plinth band —

Transmits the load from the walls down to the foundation. It also protects the ground floor walls from excessive settlement in soft soil conditions.

### 5.4.5.6. Foundation —

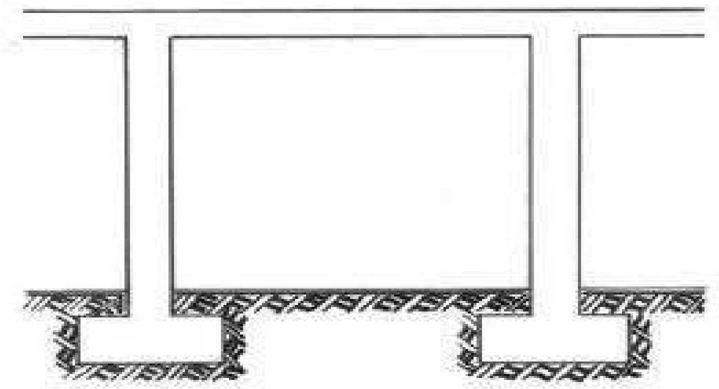
Transmits the loads from the structure to the ground.

It should be noted that the term "confined masonry" is used in a general sense for different forms of masonry construction reinforced with additional steel, timber, or concrete elements. However, the focus is on clay brick or concrete block masonry walls "confined" with reinforced concrete tie- beams and tie-columns. Confined masonry construction is somewhat similar to reinforced masonry. In reinforced masonry, vertical and horizontal reinforcement bars are provided to enhance the strength of masonry walls. Masonry units are usually hollow and are made of concrete or clay. Vertical reinforcement bars are placed in the hollow cores, which are subsequently grouted with a cement-based grout to protect the reinforcement from corrosion. Vertical reinforcement is placed at the wall corners and intersections, around the openings, and additional locations depending on expected seismic loads. Horizontal reinforcement is provided in the form of ladder reinforcement (placed in horizontal joints) or deformed reinforcement bars placed in bond beams typically located at the lintel level (similar to RC lintel bands ). In reinforced masonry construction, vertical reinforcement mainly resists the effects of axial load and bending, whereas horizontal reinforcement resists shear.

In confined masonry, the reinforcement is concentrated in vertical and horizontal confining elements whereas the masonry walls are usually free of reinforcement. Figure 3 illustrates the difference between reinforced and confined masonry construction

Figure 2. confined masonry construction with hollow block and clay brick

### 5.4.5.7. Confined Masonry Different from RC Frame Construction



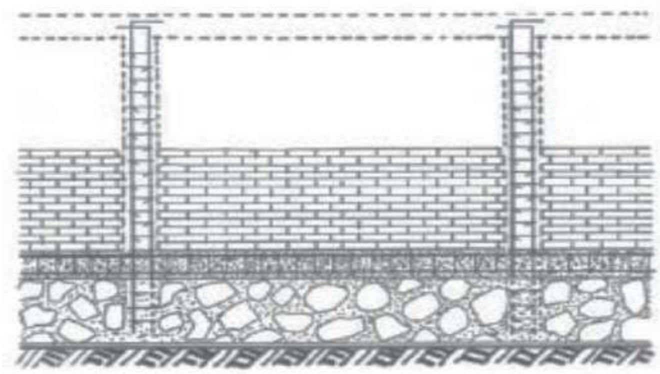


Figure 3. RC frame construction and confined masonry construction

| | Confined masonry construction | RC frame construction |
|---|---|---|
| Gravity and lateral load resisting system | Masonry walls are the main load bearing elements and are expected to resist both gravity and lateral loads. confining elements (tie –beam and tie columns )are significantly smaller in size than RC beams and columns | RC frames resist both gravity and lateral loads through their relatively large beam ,column, and their connections. Masonry infill's are not load bearing walls |
| Foundation construction sequence | Strip footing beneath the wall and the RC plinth band | Isolated footing beneath each column |
| Superstructure construction sequence | i) Masonry walls are constructed first | i) The frame constructed first |
| | ii) Subsequently tie column are cast in place.<br>iii) Finally tie beams are constructed on top of the walls simultaneously with the floor/roof slab construction. | iv) Masonry walls are constructed at a later stage and are not bounded to the frame member these walls are non structural, that is non-load bearing walls. |
| | In confined masonry construction, confining elements are not designed to act as a moment-resisting frame; as a result, detailing of reinforcement is simple. In general, confining elements have smaller cross-sectional dimensions than the corresponding beams and columns in a RC frame building. It should be noted that the most important difference between the confined masonry walls and infill walls is that infill walls are not load-bearing walls, while the walls in a confined masonry building are load-bearing walls. | In some instances, there is a thin line between RC frame and confined masonry construction practices. Some RC frame buildings may use smaller column sizes and/or inadequate reinforcement detailing for effective moment transfer between the beams and the columns. It should be noted that, in spite of a few details typical for confined masonry construction, such RC buildings are likely not going to demonstrate good seismic performance |
| | | characteristic for properly built confined masonry; instead, they are going to perform poorly in an earthquake due to inadequate design and/or construction. |
| | Economical | Not Economical |

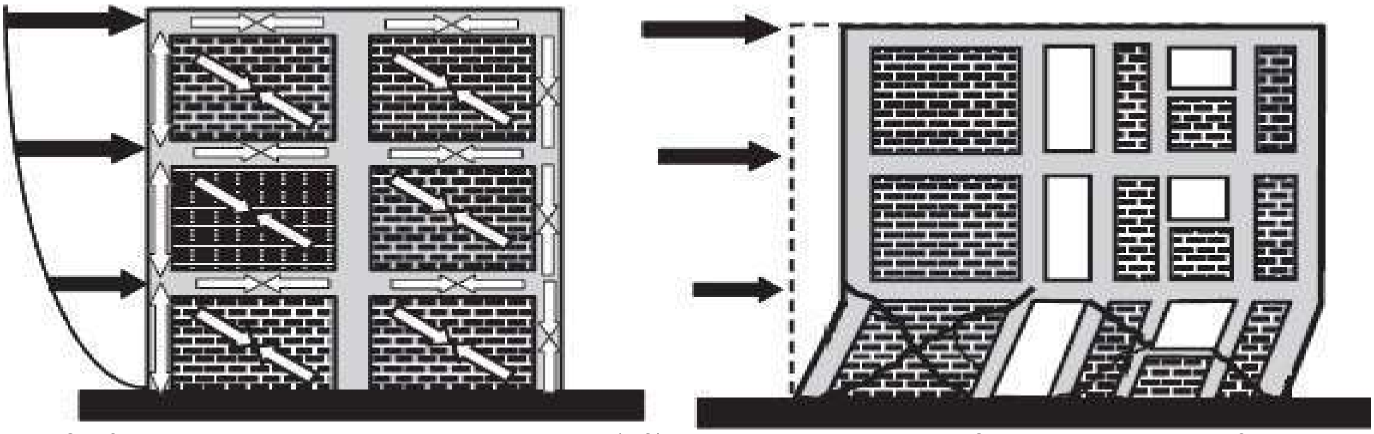
## 5.4.5.8. Confined Masonry Buildings Resist Earthquake Effects

A confined masonry building subjected to earthquake ground shaking can be modeled as a vertical truss, as shown in Figure --- (left).Masonry walls act as diagonal struts subjected to compression, while reinforced concrete confining members act in tension and/or compression, depending on the direction of lateral earthquake forces. This model is appropriate before the cracking in the walls takes place. Subsequently, the cracking is concentrated at the ground floor level and significant lateral deformations take place. Under severe earthquake ground shaking, the collapse of confined masonry buildings may take place due to soft storey effect similarto the one observed in RC frames with masonry infills, as shown in Figure ---(right). An effective way to avoid the fragile behaviour associated with the soft storey effect is to provide horizontal reinforcement in masonry walls in order to enhance their shear resistance.

Research studies that focused on lateral load resistance of confined masonry walls identified the following failure modes characteristic of confined masonry walls:

- Shear failure mode, and
- Flexural failure mode.

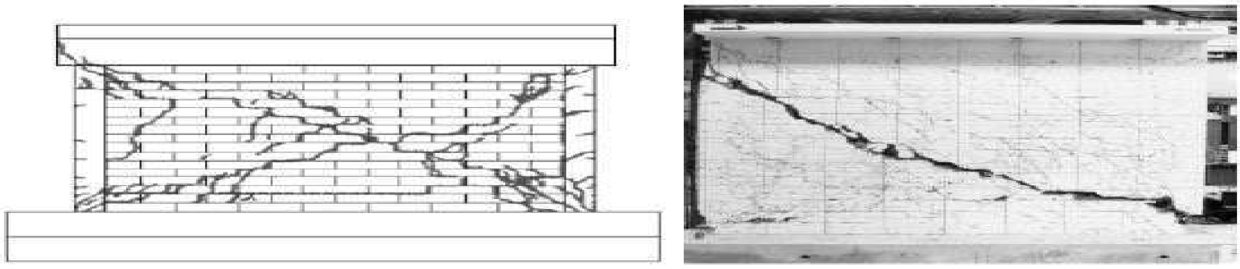
In the confined masonry structures, shear failure mode develops due to in-plane seismic loads (acting along in the plane of the wall), whereas flexural failure mode may develop either due to in- plane or out-of-plane loads (acting perpendicular to the wall plane).



Confined masonry building: vertical truss model (left) Collapse at the ground floor level (right)

**5.4.5.8.1. Shear failure mode**:

It is characterized by distributed diagonal cracking in the wall. These cracks propagate into the tie-columns at higher load levels, as shown in Figure 11. Initially, a masonry wall panel resists the effects of lateral earthquake loads by itself while the confining elements (tie- columns) do not play a significant role. However, once the cracking takes place, the wall pushes the tie-columns sideways. At that stage, vertical reinforcement in tie-columns becomes engaged in resisting tension and compression stresses . Damage in the tie-columns at the ultimate load level is concentrated at the top and the bottom of the panel. These locations, characterized by extensive crushing of concrete and yielding of steel reinforcement, are called plastic hinges (see Figure 12). Note that the term plastic hinge has a different meaning in the context of confined masonry components than that referred to in relation to RC beams and columns, where these hinges form due to flexure and axial loads. In confined masonry construction, tie-beams and tie-columns resist axial loads. Shear failure can lead to severe damage in the masonry wall and the top and bottom of the tie- columns.



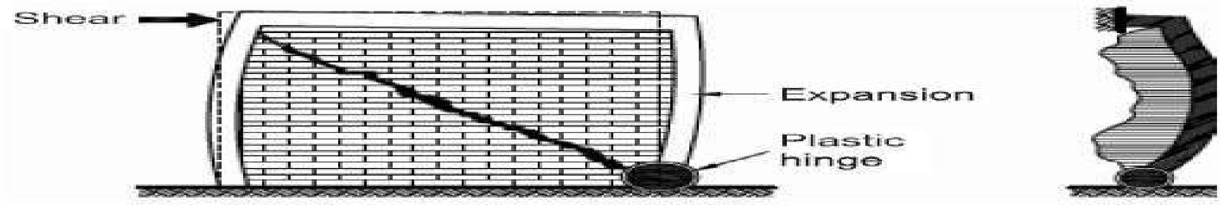



*Figure 12. Plastic hinge developed in a confined masonry wall[4]*

**Shear failure of confined masonry walls Figure 11 Plastic hinge developed in a confined masonry wall'**

Shear-induced damage in confined masonry buildings was observed in past earthquakes, It should be noted that, once cracked, a wall is more vulnerable to fall out of the confining frame under the loading perpendicular to the wall surface.In some cases, shear failure in confined masonry walls is preceded by the crushing of masonry in the middle portion of the wall. Similar damage patterns were also observed following the earthquakes that affected this type of construction. In some cases, out-of-plane failure of confined masonry walls took place without crushing in the middle portion of the wall this confirms the importance of tie-columns in maintaining the vertical stability of masonry walls.

### 5.4.5.8.2. Flexural failure:

It is caused by in-plane lateral loads is characterized by horizontal cracking in the mortar bed joints on the tension side of the wall, as shown in Figure 13. Separation of tie-columns from the wall was observed in some cases (when toothed wall-to-column connection was absent). Extensive horizontal cracking, which usually takes place in tie-columns, as well as shear cracking can be observed on Figure 13

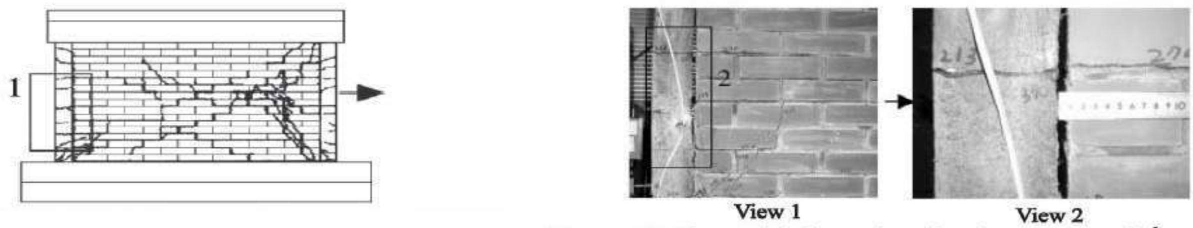



Figure 13 ----. Flexural failure of confined masonry walls

It is observed that, irrespective of the failure mechanism, tie-columns resist the major portion of gravity load when masonry walls suffer severe damage (this is due to their high axial stiffness and load resistance). The failure of a tie-column usually takes place when cracks propagate from the masonry wall into the tie-column and shear it off. Subsequently, the vertical stability of the entire wall is compromised. Further the vertical strains in the confined masonry walls decrease at an increased damage level, thereby indicating that a major portion of the gravity load is resisted by tie-columns. This finding confirms the notion that tie-columns have a critical role in resisting the gravity load in damaged confined masonry buildings and ensuring their vertical stability.

### 5.4.5.8.3. Key Factors Influencing Seismic Resistance of Confined Masonry Structures

### 5.4.5.8.4. Wall Density

Wall density is believed to be one of the key parameters influencing the seismic performance of confined masonry buildings. It can be determined as the transverse area of walls in each principal direction divided by the total floor area of the building. The extent of damage in masonry buildings was related to the wall density in the following way: buildings with a wall density of less than 0.5% sustained severe damage, while the buildings with wall density of 1.15% sustained only light damage. The confined masonry buildings have a wall density of over 1.15%. An average wall density for confined masonry buildings to be on the order of 3.3%

### 5.4.5.8.5. Masonry Units and Mortar

The lateral load resistance of confined masonry walls strongly depends on the strength of the masonry units and the mortar used. The walls built using low-strength bricks or un-grouted hollow block units had the lowest strength while the ones built using grouted or solid units had the largest strength. However, the use of grouted and solid units results in an increase both in wall mass and seismic loads. Also, the weaker the mortar the lower the masonry strength (due to the unit-mortar interaction, the masonry strength is always lower than the unit strength).

### 5.4.5.8.6. Tie-Columns

Tie-columns significantly influence the ductility and stability of cracked confined masonry walls. The provision of closely spaced transverse reinforcement (ties) at the top and bottom ends of tie- columns results in improved wall stability and ductility in the post-cracking stage.

### 5.4.5.8.7. Horizontal Wall Reinforcement

In confined masonry construction practices, reinforcement is usually provided in masonry walls to provide horizontal reinforcement in the form of one or two wires laid in the mortar bed joints as shown in Figure 15. It should be placed continuously along the wall length. Horizontal rebars should be anchored into the tie-columns; the anchorage should be provided with 90° hooks at the far end of the tie-column. The hooks should be embedded in the concrete within the tie-column and the minimum diameter of bar is 6 mm. The horizontal reinforcement showed a more uniform distribution of inclined shear cracks than the unreinforced specimens and the contribution of horizontal reinforcement to the overall shear strength of confined masonry walls.

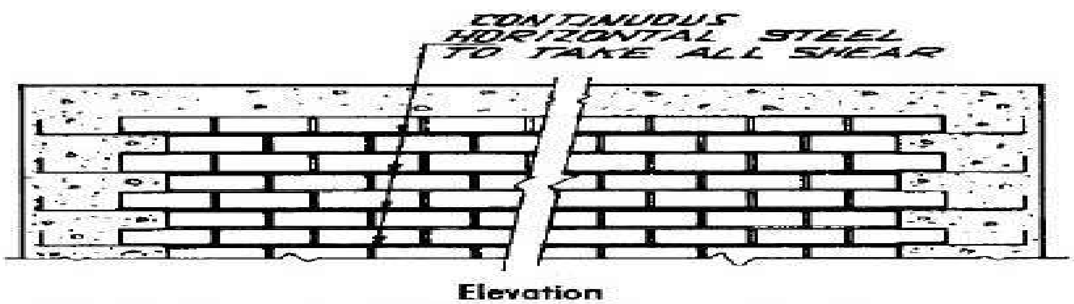



*Figure 15. Horizontal reinforcement in confined masonry walls*[2]

### 5.4.5.8.8. Openings

An experimental research study showed that, when the opening area is less than approximately 10% of the total wall area, the wall lateral load resistance is not significantly reduced as compared to a solid wall (i.e. wall without openings). The walls with larger openings develop diagonal cracks (same as solid walls), except that the cracks are formed in the piers between the openings; thus, diagonal struts form in the piers, as shown in Figure 16. The vertical reinforcement bars must be provided around the openings or the maximum permitted opening size beyond which the tie- columns need to be provided.

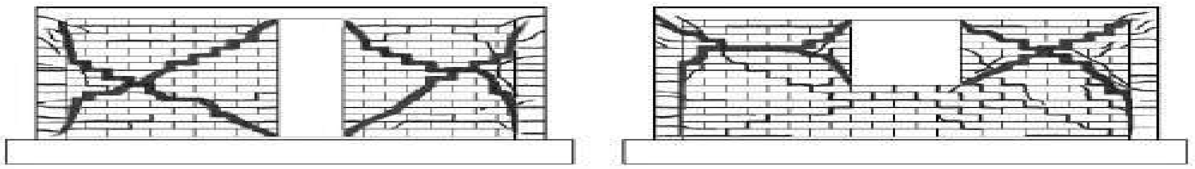


*Figure 16. Failure modes in the confined masonry walls with openings[3]*

### 5.4.5.8.9. Material Quality… Masonry Units

Seismic resistance of confined masonry house designs depends upon strength and quality of masonry units used. Acceptable masonry units for confined masonry construction

| | |
|---|---|
| **Burnt Clay Building Bricks** | **IS: 1077-1992 or IS: 2180-1988 or IS: 2222-1991** |
| **Concrete Blocks (Solid and Hollow)** | **IS: 2185 (Part 1)-2005** |
| **Burnt Clay Hollow Bricks** | **IS: 3952-1988** |
| **Autoclaved Cellular (Aerated) Concrete Blocks** | **IS: 2185 (Part 3)-1984** |

### 5.4.5.8.10. Units not permitted for confined masonry construction:

Masonry units with horizontal perforations, and natural stone masonry and adobe (sun-dried earthen units)

### 5.4.5.8.11. Minimum Compressive Strength of masonry units

(determined based on the net area)

**A.Clay brick units**

- Upto 2-storey building– 3.5 MPa
- More than 2-storey building - 7.0 MPa
- Concrete blocks - 7.0 MPa

**B.Material Quality… Mortar**

Type M1, M2, H1 and H2 mortars per IS 1905 shall be used.

| Mortar mix (cement: lime: sand) | Min strength (28 days) |
|---|---|
| Type H1 – 1 : 1/4 : 3 | 10.0 |
| Type H2 – 1 : ½ : 4½ | 6.0 |
| Type M1 – 1 : 1 : 6 | 3.0 |
| Type M2 – 1 : 2 : 9 | 2.0 |

- Requirements of a good mortar are workability, flow, water retentivity in the plastic state and bond, extensibility, compressive strength, and durability in the hardened state.
- Compressive strength of mortar, in general, should not be greater than Masonry unit
- Bond strength, in general, is more important (Lime-based mortars should be preferred)

**C. Material Quality… Concrete and Reinforcement**

**a)Concrete**

- Minimum grade of concrete shall be M15 as per IS 456
- Concrete mix should provide adequate workability (slump = 75-100 mm)
- Size of the coarse aggregate should be less than 12.5 mm

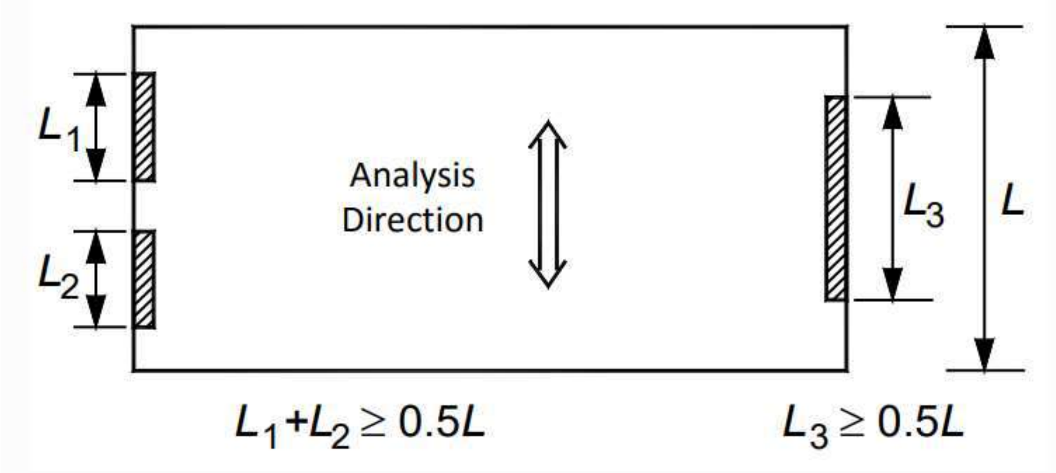
**b) Reinforcement**

- Fe 415 grade steel (see IS: 1786-2008) shall be used for reinforced concrete tie-columns and tie-beams. Mild steel bars may be used for the stirrups in tie-columns and tie-beams

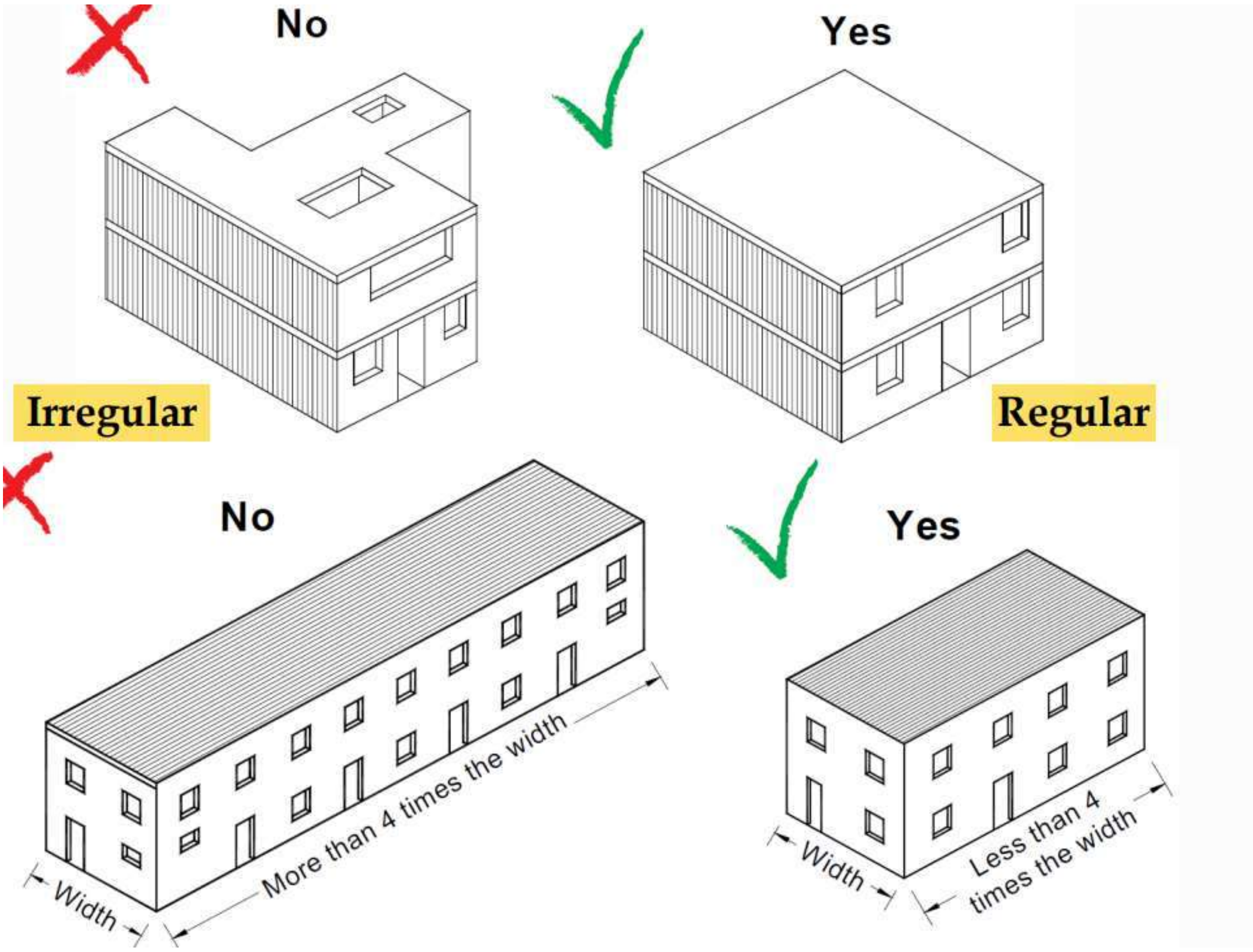
**5.4.5.8.12. Design Considerations:**

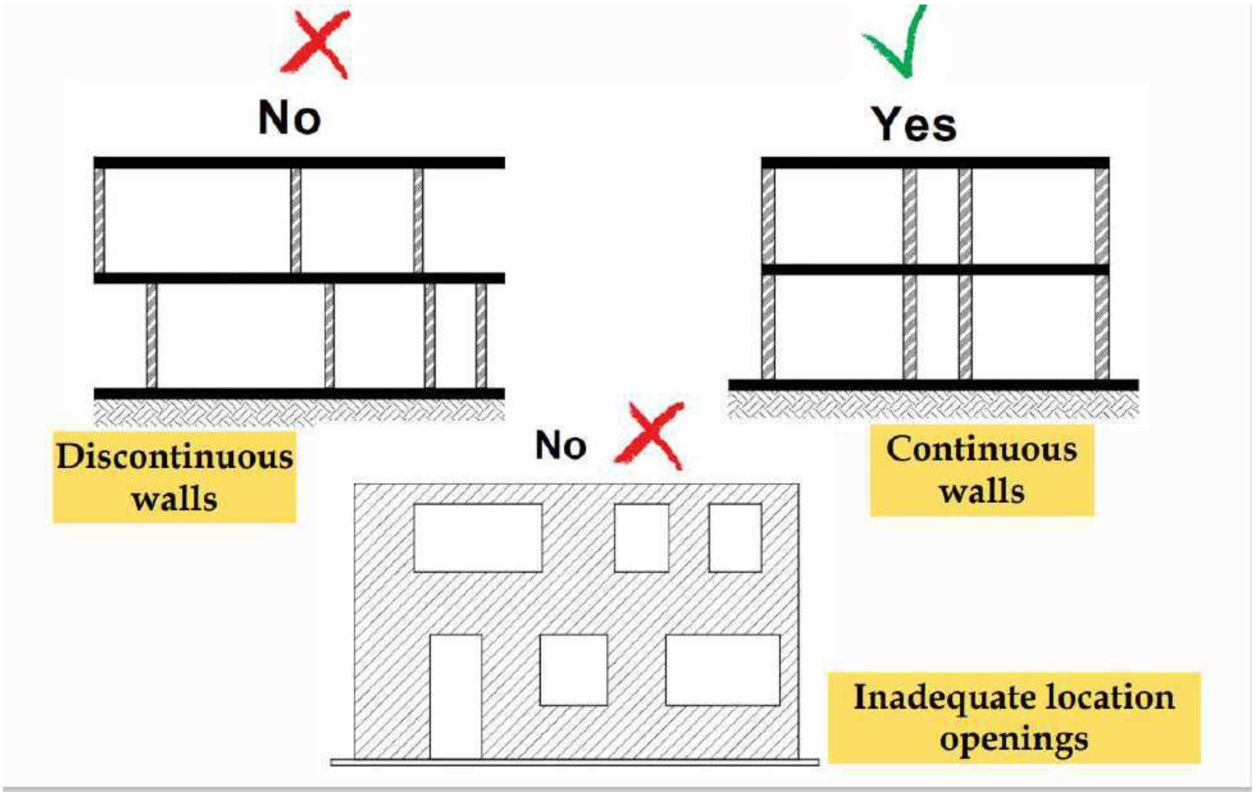
**Building Configuration**

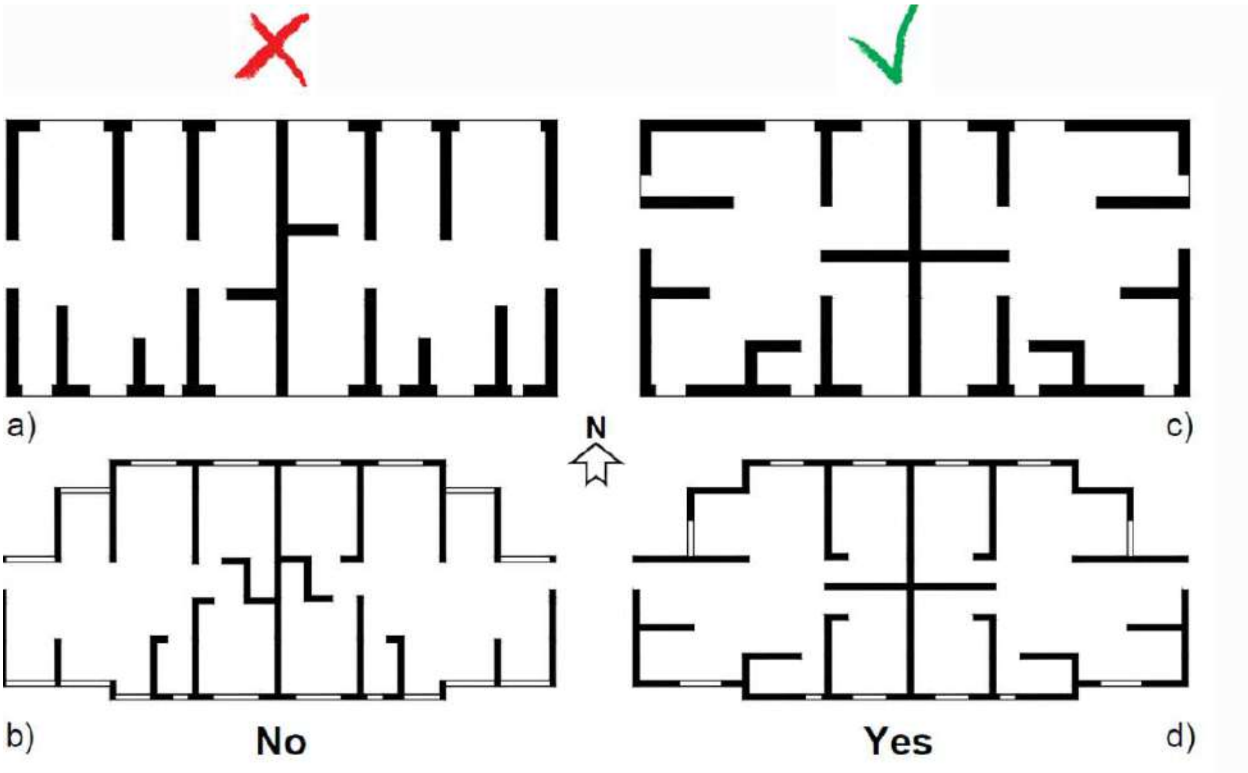
- A regular building configuration is one of the key requirements for satisfactory earthquake performance
- The building plan should be of a regular shape
- The building's length-to-width ratio in plan shall not exceed 4
- The walls should be built in a symmetrical manner
- The walls should be placed as far apart as possible, preferably at the façade, to avoid twisting (torsion) of the building in an earthquake.
- There are at least two lines of walls in each orthogonal direction of the building plan, and the walls along each line extend over at least 50% of the building dimension



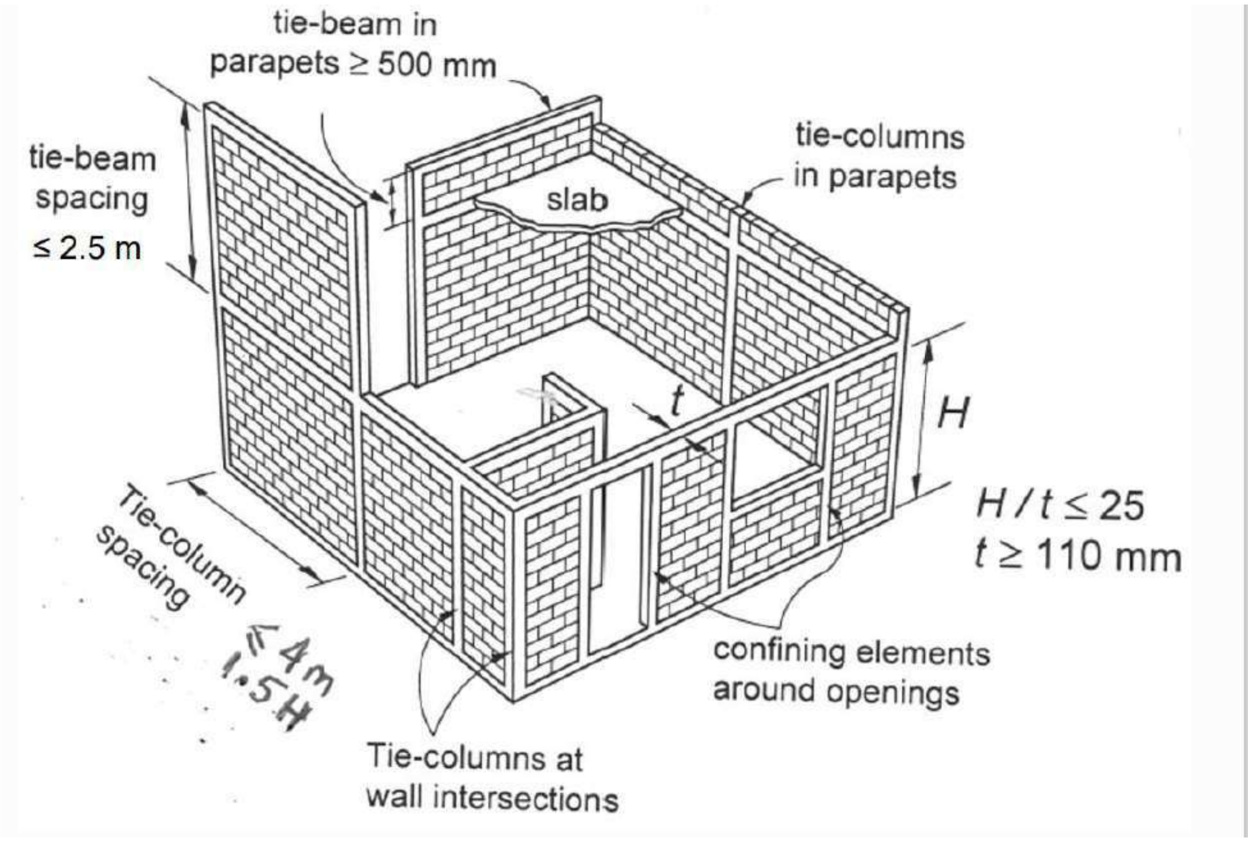

- ❖ The walls should always be continuous up the building height – vertical offsets are not permitted
- ❖ Openings (doors and windows) should be placed in the same position on each floor




No
Yes
Discontinuous walls
No
Continuous walls
Inadequate location openings


a)
N
c)
b)
No
Yes
d)

#### 5.4.5.8.13. Minimum Design Dimensions Requirements

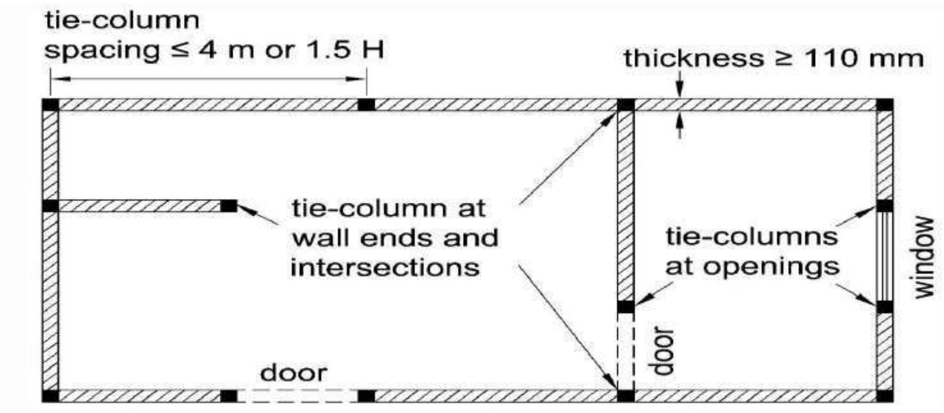



#### 5.4.5.10.1. Minimum Dimension of Masonry Walls

- Wall thickness (t) should not be less than 110 mm.
- Maximum wall height/thickness (H/t) ratio shall not exceed 25
- Unsupported wall height (H) shall not exceed 2.5 m
- Height-to-width ratio of wall should be kept less than 2 for the better lateral load transfer.

#### 5.4.5.10.2. Parapets

- When a parapet is not confined by tie-beams, height should not exceed 500 mm, Otherwise the height limit is 1.2 m



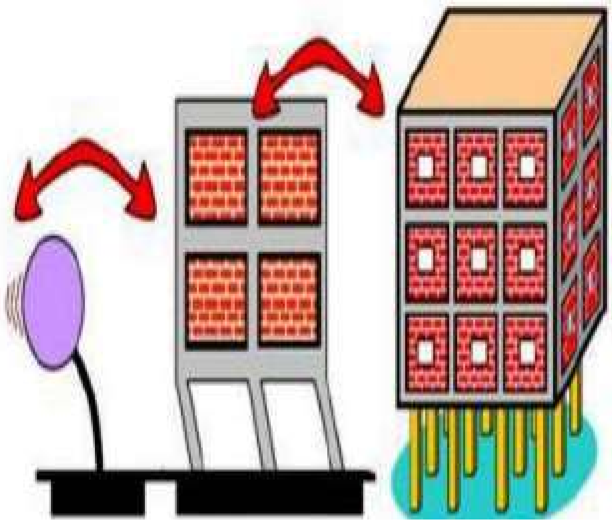

Minimum tie-column and tie-beam dimensions **(depth × width)** shall be **150 mm × *t*** (*where t is wall thickness*)

**5.4.5.8.14. Earthquake Performance of Confined Masonry Construction**

Confined masonry buildings have demonstrated satisfactory performance in past earthquakes. In general, buildings of this type do experience some damage in earthquakes, however when properly designed and constructed they are able to sustain earthquake effects without collapse. The confined masonry construction is widely used and was tested in several significant earthquakes associated with the region's high seismic risk. The low-rise confined masonry buildings have performed very well in past earthquakes and the most damage was inflicted to medium-rise buildings (3-to-5-storeys high);

5.4.5.9. **Soft Storey Construction:**

Soft first storey is a typical feature in the modern multi-storey constructions in urban India. Though multi-storeyed buildings with soft storey floor are inherently vulnerable to collapse due to earthquake, their construction is still widespread in the developing country like India. Functional and Social need to provide car parking space at ground level and for offices open stories at different level of structure far out-weighs the warning against such buildings from engineering community. Soft Storey is irregular building configurations that are a significant source of serious earthquake damage. In terms of seismic regulations their irregular condition requires the application of special considerations in their structural design and analysis. An investigation made to study the seismic behaviour of soft storey building with different models (Bare frame, Infill frame, Bracing Frame, Shear wall frame) observes that when subjected to earthquake loading, different models improve resistant behaviour of the structure when compared to soft storey provided.

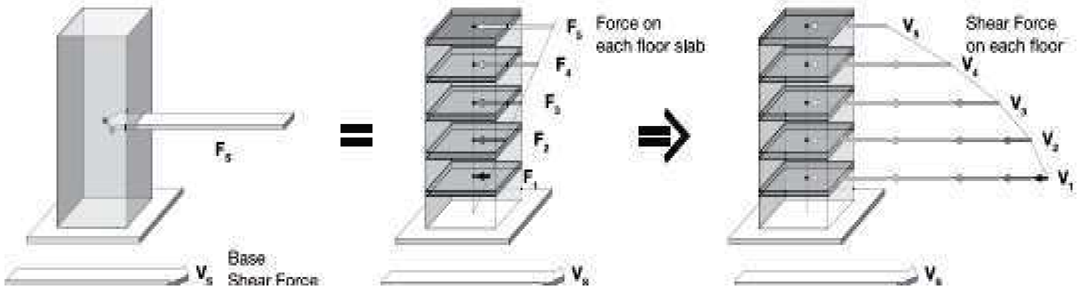


Behaviour of soft storey building as inverted pendulum

5.4.5.9.1 **Soft Story Irregularity:**

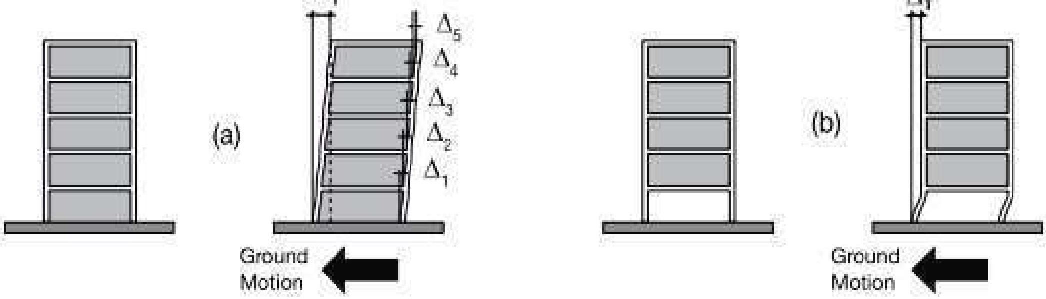
The soft story irregularity, refers to the existence of a building floor that presents a significantly lower stiffness than the others, hence it is also called flexible story. It is commonly generated unconscientiously due to the elimination or reduction in number of rigid non-structural walls in one of the floors of a building, or for not considering on the structural design and analysis, the restriction to free deformation that enforces on the rest of the floors, the attachment of rigid elements to structural components that were not originally taken into consideration.

The Indian seismic code IS 1893 (Part1): 2002 classifies a soft storey as one where in the lateral stiffness is less than 70 percentage of that within the storey above or less than 80 percentage of the common lateral stiffness of the three storeys above. If the soft story effect is not foreseen on the structural design, irreversible damage will generally be present on both the structural and non structural components of that floor. This may cause the local collapse, and in some cases even the total collapse of the building. The soft first storey is the most common feature of soft storey irregularity. It usually is present in modern frame buildings when a large number of non structural rigid components, such as masonry walls, are attached to the columns of the upper floors of a reinforced concrete frame structure while the first story is left empty of walls or with a reduced number of walls in comparison to the upper floors. The rigid non structural components limit the ability to deform of the columns, modifying the structural performance of the building to horizontal forces. In a regular building, the earthquake shear forces increase towards the first story.




*Lateral forces and shear forces generated in buildings due to ground motion*

The total displacement (ΔT) induced by an earthquake tend to distribute homogeneously in each floor throughout the height of the building. Deformation in each floor (Δn) would be similar. When a more flexible portion of the lower part of the building supports a rigid and more massive portion, the bulk of the energy will be absorbed by the lower significantly more flexible story while the small remainder of energy will be distributed amongst the upper more rigid stories, producing on the most flexible floor, larger relative displacement between the lower and the upper slab of the soft story (inter story drift) and therefore, the columns of this floor will be subjected to large deformations.




*Distribution of total displacement generated by an earthquake in: (a) a regular building; and (b) an building with soft story irregularity.*

The lowest more flexible portion, in the path of force transmission, at first story may create a critical situation during an earthquake; the stiffness discontinuity between the first and the second stories might cause significant structural damage, or even the total collapse of the building. One of the most common examples of soft story can be observed on the so called "Open floor" in the first story of modern residential buildings. The structural elements are homogenously distributed throughout the building, but the apartments are located on the upper floors with many masonry walls, while the lowest floor is left totally or partially free of partitions for parking vehicles and for social areas that require wide spaces. In the case of double height first soft stories, columns are very flexible not only due to the total or partial absence of walls but as a result of their significantly greater height in relation with those from the upper floors. This configuration is one of the characteristic models of modern design for office buildings, hotels and hospitals, in which the access for general public has a great importance. This configuration is also very common in mixed-use buildings, in which the urban code requires that the lower floors are of a greater height in order to accommodate shops with mezzanines for storage. As a variant of this configuration, we can find the use of columns of different heights in a corner of the building in order to give more importance to that space.

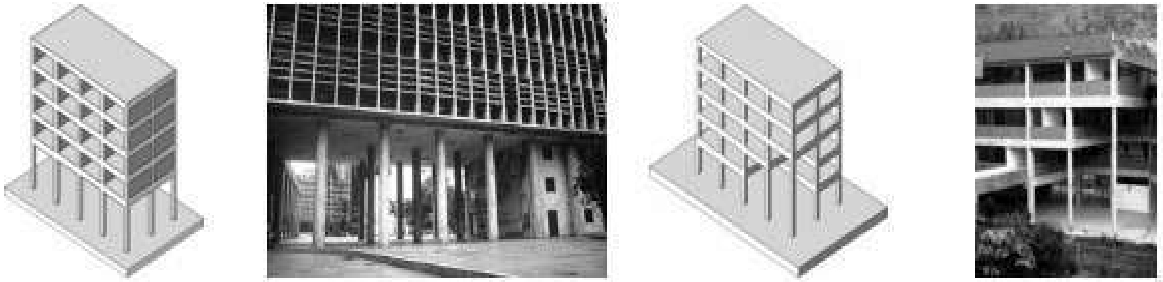


*Figure shows two examples of modern buildings with double height first soft story configuration. In most of the earthquakes that occur in contemporary cities, there are always cases of collapsed soft first story.*

**5.4.5.9.2 Recommendations :**

If in contemporary cities in seismic zones the widespread use of the architectural configuration of open first floor is unavoidable, the recommendation is to include measures to avoid at formation of soft storey on the design of new buildings. At present, there are many analytical studies available in the structural engineering field providing solutions regarding formation of soft storeys which must be considered by the structural engineer while designing the buildings. From the past earthquakes it has been noticed that the buildings have performed poorly as open storey building. Hence to understand the behaviour of the structure, performance based analysis is very useful. All the structures are influenced by dead, live and seismic loads. Out of these three loads, a seismic load proves to be major concern. Dead load mostly includes self-weight of the building, while the live load is something we can easily predict that will come on the structure in its entire lifetime. When it comes to seismic analysis it is very difficult to predict seismic load or rather say that, the seismic load or earthquake load comes to the structure is highly unpredictable. So to understand the nature of these types of loads seismic analysis is done using the code recommended i.e. IS 1893:2002. The values are adopted from the code such that the structure should remain stable during its lifetime against the maximum considered earthquake on that particular zone. Proper study needs to be done for achieving an acceptable limit of safety for the structure so that it should not fail to that particular limit. The safety of the structure must always be considered most important by structural engineer.

### 5.4.6 Scaffolding ,Shoring and Underpinning

### 5.4.6.1 Scaffolding

While constructing any type of building, it is necessary to have some temporary structure or supports to carry on with the work beyond a certain height. These temporary structures or supports are removed after the work is over. It is the temporary rigid structure which provides a safe platform for working and for materials required during the construction works. Scaffolding is usually in the form of a framework made up of timber or steel tubes. Scaffolding shall be designed to withstand the loads coming in it. They should conform to IS 3696(Part 1):1987, IS 4014(Part 2):1967.The commonly used scaffolding are of following types:

❖ **Brick Layer's Scaffolding or Single Scaffolding**

It is the most common and cheap scaffolding which is made up of timber (Bamboo) framework.This is also called as putlog scaffolding.

This scaffolding consists of a single row of standards (vertical members 10 mx 8 m) (horizontal member) are fixed on the standards firmly with the help of ropes at a spacing of 12 placed at a distance of about 1.20 m from the wall at a spacing of 2 to 2.5m The ledgers to 16 m The putlogs are then placed on the ledger with other end on the wall in the holes made for supporting them. The spacing of putlogs is generally kept as 1.2 to 15 m. The putlogs support the timber boards which provide the working platform to the workers Guard rails, toeboards etc are also fixed at appropriate places to make the scaffolding safer.

❖ **Mason' Scaffolding or Double Scaffolding**

Mason's scaffolding has two rows of standards, so it is called as double scaffolding .It is stronger than single scaffolding.

Masons scaffolding is almost similar to the brick layer's scaffolding with the difference that it consists of two rows of standards and ledgers. The first row of standards is kept, firmly into the ground, at a distance of 20 to 30 cm from the wall. The second row of standard is spaced at about 1m from the first row. Transoms (putlogs) are suitably tied andfixed on the standards and no holes are required in the wall to support putlogs. Guard rails, toe boards and working platforms are provided just like in bricklayer's scaffolding. It is also known as independent scaffolding. The rakers and cross braces can also be used for increasing the strength of scaffolding.

❖ **Steel Scaffolding or Tubular Scaffolding**

This scaffolding is made up of steel tubes and is similar in construction to the mason's scaffolding.This scaffolding can be used upto any height.

This scaffolding is made up of steel tubes of about 40-60 mm diameter and 5 mm thickness. These tubes are available in standard lengths. The standards (steel tubes) are placed at 2.5 to 3 m apart and ledgers are placed about 1.8 m apart. Each standard is welded to a base plate. The base plate has holes so standards can be fixed to the timber or concrete base by bolts or spikes. Putlogs are supported on the ledgers and projected part of putlog is supported on angle iron.

**5.4.6.2 Shoring:**

Shoring is the temporary framework or support constructed to support an unsafe structure or to a structure which is undergoing some addition and alterations Temporary shores are made up of timber or steel tubes or a combination of both. Different types of shoring are explained below:

❖ **Raking Shores :**

These are also known as inclined shore Raking shore consists of rakers, wall plate, cleats, needles, bracing and sole plate. Rakes are the inclined supports which are supported at bottom sole plate, bedded in an inclined position in the ground. The top end of raker is fixed into the w with the help of needles and cleats. The rakers are connected by braces struts which strengthen them Rakers are used to support an unsafe wall.

❖ **Flying Shores:**

Shores do not rest on ground and hence are called as flyingor Horizontal shores. In flying shores, wall plates are secured into the walls with the help of needles shores. Horizontal shores are put between the wall plates and are secured by needles and cleats. The inclined struts are supported at top by the needle and at bottom by the straining pieces which are spiked to the horizontal .Flying shores are used to support the parallel walls of two buildings which have become unsafe due to the intermediate buildings being removed or collapsed.

❖ **Dead Shores:**

It is also known as vertical shore. This shoring is used to provide vertical support to walls. roofs and floors etc. The needles are driven at right angles to the wall through the holes made in the wall. The dead stores stand away from wall on either side so as to allow for working space when the needle and props are in position. The props are tightened up by folding wedges provided at their bases.

**5.4.6.3 Underpinning**

It is the process of providing a new foundation below an existing foundation or strengthening the existing foundation for greater loads, without disturbing the stability of the structure. Commonly used methods of underpinning are Pit method and Pile method.

## 5.5 Framed Structures

Framed structures are comprised of series of frames with horizontal and vertical components. These framed structures concept are effectively used in the construction of multi-storey buildings. Although timber, steel and RCC can be used for framed structures, RCC plays the topmost role in space frame technology. Apart from construction of framed structures using the conventional construction techniques, the technique of pre-fabrication has also been used to economise the cost and time. These tall buildings and pre-fabricated buildings are discussed in the following sections with introduction of framed structures.

**5.5.1 Principles of Framed Structures**

Framed structures are the structures which are formed by connecting a series of horizontal and vertical structural members in suitable positions. The framed structures primarily comprise of columns and beams. Columns are connected by beams at floor and roof levels. The floors are divided into rooms and passages of required sizes by walls. The walls may be load-bearing walls or partition walls. The materials used for framed structures, in general, may be wood, steel or RCC. Light framed structures are constructed of wood, steel or RCC, whereas multi-storeyed framed structures are constructed of mild steel.For Designing Framed Structure, reference may be made to IS 456-2000.

**5.5.2 Tall Buildings**

Important aspects which are to be considered in the construction of RCC tall buildings are given below:

- ❖ RCC frames are monolithic construction of columns, beams and slabs. Because of monolithic construction, deflection and bending moments are reduced which results in economical construction. Further adequate safety is ensured.
- ❖ An RCC frame essentially consists of beams, columns and slabs (as floor or roof). In case of large spans for better distribution of load, secondary beams spanning across main beams can be introduced.
- ❖ A typical frame of an RCC multi-storeyed building is shown in Fig. 5.10. It shows the monolithic construction of columns, beams, slabs and girders.
- ❖ The concreting procedure is the same as for other structures. However, a sequential procedure has to be followed. Here the formworks for different members to be cast are first installed or erected in position. Necessary reinforcement is then placed and concreted. The formwork is removed after the concrete has attained adequate strength.
- ❖ The next member to be formed is taken up and formwork is fixed and concreting done. The general sequence is construction of columns followed by beams, cross beams and slabs together.
- ❖ As the entire construction cannot be done in one stretch, construction joints are required to be provided at intervals. Further, in framed construction the joints should be at the point of minimum shear.
- ❖ The height of the columns is concreted so as to provide proper lap with the sides of the beams and columns in upper storeys.

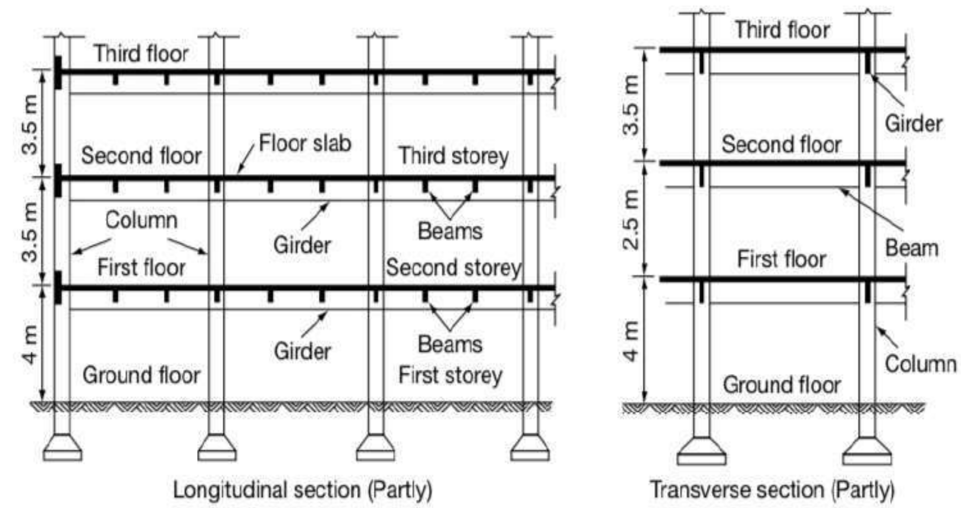



Figure 5.10 : A typical frame of RCC multi-storeyed building.

### 5.5.3 Pre-fabricated buildings

Pre-fabricated buildings are constructed based on the articulated structure concept. Articulated structure means, the separation of a structure into two or more elements and join the entire structural elements such that it functions as a monolithic structure. The elements are pre-fabricated and are assembled and erected. This technique is applied to framed structures also.

While designing pre-fabricated buildings, manufacturing and effective installation techniques should be taken into account. That is, the design of structural parts, utilisation of structural parts and their joints should be installed with minimum use of materials and manpower for manufacture and erection.

In fully pre-fabricated construction, it is the practice to use larger elements while simultaneously reducing the relative mass. This is achieved by using more efficient design, light-weight concrete, synthetic heat insulation and other efficient materials.

## 5.6 Arches and Lintels

Arch and lintel are provided above doors, windows and passages. The function of an arch and a lintel is to carry the weight of the structure above the opening. In an arch because of the shape, the blocks support each other by the mutual pressure of their own weight and the structure remains in position by the resistance from the supports. A lintel is a horizontal member used to span openings in walls. It functions similar to that of an arch. Lintels provided over windows are connected to a sunshade to provide shade and shelter. Materials such as wood, stone, steel, brick and concrete are used both for arches and lintels. Now-a-days, reinforced cement concrete (RCC) lintels are preferred for its simplicity and easy construction. In walls, at certain levels, beams are constructed to have uniform pressure and even out settlements if any. Such beams are called plinth beams and grade beams. Arches, lintels, and plinth and grade beams are discussed in this section.

### 5.6.1 Arches

An arch is a mechanical arrangement of wedge-shaped blocks of stones or bricks mutually supporting each other and in turn supported at the ends by piers or abutments. However, arches made of steel and RCC are built as a single unit without the use of wedge-shaped units.

#### 5.6.1.1 Method of Construction of Arches:

Construction of arches is done under the following three operations:

- ❖ Installation of Centring.
- ❖ Laying the Arch.
- ❖ Removal of Centring.

**❖ Installation of Centring**

Arches are generally built over a centring made to the shape of the arch needed. The centring is a temporary structure which has to support the arch till it develops strengths. For small spans, mud masonry is used. The masonry is made to the shape of the soffit of the arch to be built and plastered, over which the arch is constructed. After attainment of adequate strength, the masonry can be dismantled. Timber centring is preferred generally as it is easier to erect and dismantle. Further, the material can be re-used. Thick wooden planks are used to get the shape of the soffit and are supported by vertical timber posts. Wedges are used to tighten or loosen the centring. For heavy arches, the shape is got by suitable braces and struts. In such cases it is necessary to support the posts on boxes containing sand. A hole is kept plugged into the box. The post sinks slowly when the plug is removed and the sand flows out, thereby relieving the arch centring without any shock.

**❖ Laying of Arch**

Skewbacks at the springing of the arch are prepared first and placed very carefully in the correct angles. Voussoirs are then laid on either side of the crown. In case of brick arch, bricks may be placed as showing stretcher-face or header-face. More than one ring may be used. Joints are to be filled with mortar not less than 5 mm and not more than 15 mm thick. Finally the key stone is fitted in to lock the whole arch in position. In order to counteract the thrust, the masonry above the skewback at the haunches should be loaded by filling up the spandrels up to the level of the crown of the arch or at least two-thirds of the height of the arch. This has to be done on both sides of the arch. Before hardening of the mortar, the centring is slightly slackened by means of easing the wedges thereby permitting the voussoirs to rest on their beds properly. The skewback is kept wet during the work. The above procedure is followed for stone and brick arches. For concrete arches the procedure followed for lintels may be followed.

❖ **Removal of Centring**

Sandbox method may be followed, which permits removal of centring without any shock. Releasing of wedges in order may also be followed. Whatever may be the material used for centring, the design should be proper such that the centring is lowered with ease and without any shock.

**5.6.2 Lintels**

A lintel is a horizontal structural member placed to span openings for doors, windows and corridors. Lintels are usually rectangular in shape. Lintels may be made out of several materials such as wood, stone, brick, reinforced brickwork, RCC or rolled steel sections embedded in cement concrete. The purpose of providing a lintel is just the same as that of an arch. Lintels take the load of the wall above the opening and transfer to the walls. The effective load causing on a lintel is shown in Fig. 5.11. The lintels are easy and simple in construction and do not need special form work. The ends of lintels are built into the masonry and thus the load carried by lintel is transferred to the masonry in jambs. The bearing of lintel should be either 10 cm or 40 cm for every 30 cm of span, whichever is greater. As a general rule, the depth of the lintel can be adopted as 1/12th of the span or 15 cm, whichever is greater.

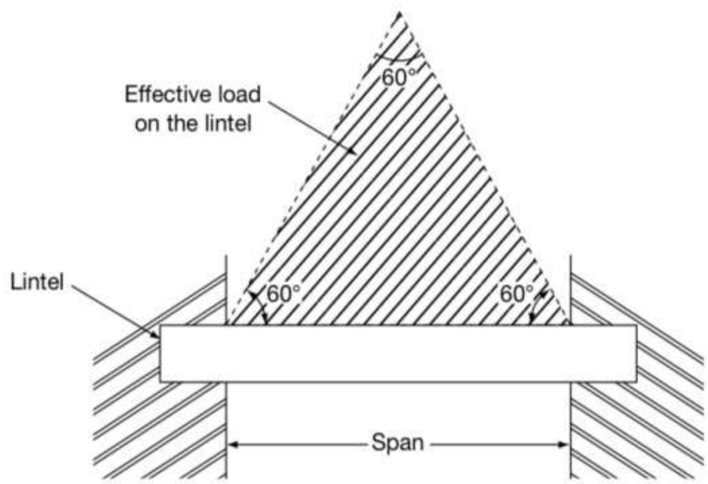



Figure 5.11 : Effective load on a Lintel.

**5.6.3 Plinth Beams and Grade Beams**

Two types of beams, viz., plinth beam and grade beam are constructed in walls for load distribution which are discussed below.

**5.6.3.1 Plinth Beams**

Plinth beams are constructed at plinth level in load-bearing wall for uniform load distribution and to even out settlement of buildings. They also allow providing Damp Proof course at this level. Such beams are very much helpful to buildings in seismic areas. Similar types of beams are provided at lintel level and roof level. Through beams provided at lintel level and roof level are very much helpful for any alternations to be made in future. Further, they are also helpful in any underpinning work to be taken at a later date The minimum depth of plinth beams is 10–15 cm and should be provided to the full width of the wall above the plinth beam. The minimum reinforcement recommended is three numbers of 6 mm MS bars at top and bottom and longitudinal bars with 6 mm stirrups at 23 cm spacing.(see IS 13920:1993).

**5.6.3.2 Grade Beams**

Grade beams are provided in between isolated footings. Thus under reamed piles and column on isolated footing are connected by grade beams and then the wall is constructed over it. These beams are stronger than the plinth beams. The recommended minimum depth of grade beam is 150 mm and minimum three numbers of 8 mm bars of Fe415 should be provided at top and bottom.

## 5.7 Doors and Windows

The cost of providing doors, windows and ventilators in a building can work out to about 18 to 25 per cent of the total cost of civil works. This is due to the fact that expensive materials such as wood, fittings and skilled labour are involved in making them. One of the important details to be thought of in designing the width of shutters of windows and doors opening to the outside of the building is that the cantilevering portion of the chajja above these shutters should fully cover the shutter when opened and they do not become wet during rainy seasons

**5.7.1 Introduction**

Doors are provided as external doors at the various entries and exits of the building and also as internal doors in the interior places where we want to divide the space into separate parts. External doors should be more robust than internal doors since they should give protection from pilferage and the elements. Windows are provided on outer walls for natural light and ventilation. Ventilators are necessary for air circulation in various places such as bathrooms, stores and where windows are not usually provided. The old practice to provide ventilators on top of doors and windows is not generally practiced today. Small ventilators at roof or underside of top floors in all the main rooms with conventional ventilators in stores,bathrooms etc. is the common practice followed nowadays. Bedroom windows can be provided in two halves so that the lower halves can be closed for safety and convenience.

**5.7.2 Fixing Sizes and Heights of doors and windows**

The dimensions and other details of steel Metal doors windows and ventilators may be required. Doors, windows and ventilators shall conform to IS-1038:1983. Timber frames for doors and windows shall conform to IS-4021:1983.Steel door frames to receive wooden shutters shall conform to IS-4351:1976.Shutters can be of several kinds as below:

- ❖ Timber panelled and glazed shutters shall con form to IS-1003(Part 1):1991 for doors and to IS-1003 (Part 2):1983 for windows.
- ❖ Wooden flush door shutters shall conform to IS-2191 (Part 1):1983 with plywood face panels (cellular and hollow core) and to IS-2191(Part 2):1983 for particle board and hard board face panels (cellular and hollow core). Wooden flush door shutters shall conform to IS-2202 (Part 1):1991 plywood face panels (solid core); and to IS-2202(Part 2):1983 for particle board face panels and hard board face panels (solid core).
- ❖ Wooden sliding doors shall conform IS-4962:1968.
- ❖ Ledged, Braced and Battened Doors shall con form to IS-6198 :1992.

**5.7.3 Method of fixing Door and Window Frames**

The fixing place of door and window frames needs special attention. It will depend on the way the shutters are to open out. Usually the front doors open to inside the building. Usually the door of shutters are planned to swing 90° or 180° and be parallel to a wall when fully opened. Similarly ventilators can be fixed to be flush with the inside walls of the room or the outside the wall. When we fix window frames flush with the outside walls in a one-brick (9 inch) wall, we get a ledge on the inside of the room. If we fix the frames on the inside, they will be flushed with the inside walls. We must decide these positions well in advance of the construction. The following methods are used to fix frames to the walls of the building.

In modern building construction, where concrete lintels are used over openings, door and window frames are fixed after roof construction and before plastering of masonry is taken. Before fixing all the surfaces of the wood of the door and window frames that come into contact with masonry, they should be treated by painting with coal tar mixed with anti-termite solution. The door frames are fixed by three holdfasts on each side whereas windows are usually provided only two holdfasts on each side.

**5.7.3.1 Fixing to Masonry:** There are many methods to fix door and window frames to the wall masonry. Broadly theycan be in two ways-prepared opening method and built-in method. These methods are discussed further:

❖ **Method.1: Prepared opening method of fixing in masonry:**

We use this method for door opening with lintels. In this method, the doors are fixed after the masonry is fully built but before the plastering. This method is preferred for superior type of doors and also for other modern type of doors. It can also be carried out by any of the following procedures:

- ❖ In the conventional method, holes are left or made in the masonry by Z-type holdfasts. These are 30 mm wide and 5 mm thick flats 200 mm in length bent into Z shape. They are inserted into the holes and the holes are filled with concrete. The portion of the holdfast inside the wall should point downwards and the portion on the frame upwards. For fixing a door, three holdfasts are used. One holdfast is fixed at the centre of the frame and the other two at 30 cm from top and bottom of the frame. For a window, two holdfasts are used-each at 30 cm from its top and bottom.
- ❖ Hard wood plugs can be embedded in the masonry at appropriate points with their ends flush with the face of the opening. The frames are then screwed into the plug by means of 75 mm galvanized wood screws for door frames and 50 mm screws for windows. This type of installation makes replacement of door frames later on easy.
- ❖ Instead of wood plugs, we may install a cast in situ concrete block with a nut and greased bolt. The door frame can then be fixed to this nut by a bolt.
- ❖ Where the window or door frame has to be placed adjacent to a concrete column, prior planning should be made to cast a 15 mm GI pipe in the column at predetermined positions (where the frames are to be fixed). A corresponding hole can be made in the window or door frame when it is to be fixed by bolt head on the frame side and a nut on the other side of the column. The countersunk hole in the frame is filled up with the same type of wood as that of the frame. Before fixing the frames, we plaster the jamb with fine plaster and when the mortar is still wet, we force the frame into the opening covered with mortar so that a close fit can be obtained.

❖ **Method 2: Built-in method of fixing in masonry:**

This is the old practice where the modern RCC lintels were not used. In this method, the doors are fixed to the wall as construction proceeds. This ensures a good and clear joint without any space between the wall and the frame. Two crossbattens are provided diagonally to keep the frame from deforming during construction. However, as it takes very long time to complete the roof, till then the frames are subjected to heat and moisture leading to warping of wood. Hence this practice is not recommended to be followed nowadays.

## 5.8 Stairs and Elevators

A stair is a sequence of arrangement of steps which is provided as a means of easy ascent and decent between the floors or landings. Stairs are of different types which are designed and used based on the location and usage. Stairs are provided in almost all types of buildings starting from residential building to multi-storeyed buildings. Different materials are used for the construction of stairs, viz., stone, wood, brick, metal and concrete. In order to have a comfortable climb and descend, proper design has to be stipulated as regards to size of stairs, slope, landing space, etc. Other modes of transportation between floors are lifts, ramps and moving stairs.

### 5.8.1 Requirements of A Good Stair

A well-planned and designed stair should be comfortable, quick, safe and easy to use.Various components of a stair are shown in Fig. 5.12. Different aspects which are to be considered in the planning and design of stairs are discussed below.

**5.8.1.1 Location:**The location of stairway should be so chosen such that sufficient ventilation and lightshould be available. If it is feasible, it may be located centrally so as to be of easily accessible from different parts of a building.

**5.8.1.2 Width of Stair:** Width of a stair, in general, should be adequate for the users without much crowd. It dependsvery much on the type of building and the number of users. In general, 1.0 m width isadopted for residential building and about 1.5 m width for public buildings.

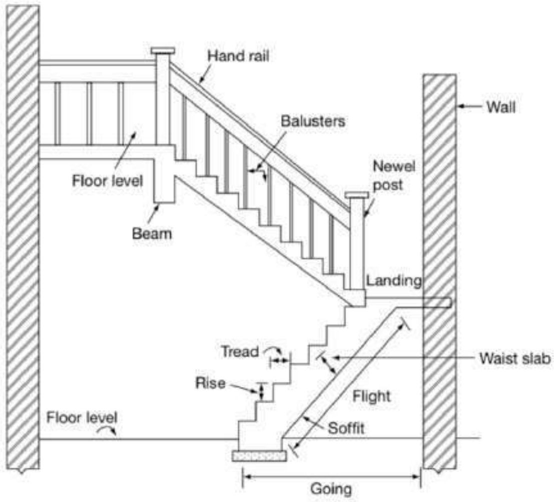



Figure 5.12: Various components of a stair.

**5.8.1.3 Pitch of a Stair:**The pitch or slope of a stair should prevent undue exortion to the user and at the same timethere should not be any waste of space. Normally the slope of a stair should not exceed 40°and should not be flatter than 20°.

**5.8.1.4 Length of a Flight:** In order to make the ascend comfortably, the stairway should not have steps more than 12and a minimum of 3.

**5.8.1.5 Headroom:**The headroom or the clear distance between the tread and the soffit of the flight immediatelyshould be adequate. This should be at least 2.14 m.

**5.8.1.6 Materials of a Stair:** Construction of a stair should be carried out with sound and fireproof materials. Further, itshould be adequately durable so as to have long life as that of the other materials used forthe construction of the building.

**5.8.1.7 Landing:** The width of landing should not be less than the width of a stair.

**5.8.1.8 Winder:** As far as possible, the introduction of a winder should be avoided. They are liable to bedangerous. If it is inevitable, it may be provided near the lower end of a flight. Thus insteadof quarter-space landing, three winders may be used. Similarly for half-space landing five winders or four radiating risers may be adopted.

**5.8.1.9 Step Proportions:** All the risers and treads should be of uniform dimensions. The steps should neither be toowide or too short. Further high rise may cause inconvenience and fatigue to the user.The following empirical rules may be followed:

- Rise + Tread : not $<40$ and not $>45$
- 2 Rise + Tread : not $<58$ and not $>63$
- (Rise) × (Tread) : not $<400$ and not $>500$

For residential buildings, the common size of step is 15 × 28 cm. Rise greater than 20 cm and tread less than 22 cm should not be used. In general, (2 Rise + Tread) approximately equal to 60 will give a comfortable flight.

**5.8.2 Design Principles of Staircase**

The following provisions are to be adopted as per IS: 456–2000 in the design of staircases.

**5.8.2.1 Dead Loads**

Dead loads to be considered for staircase design comprise of self-weight of the waist slab, treads and risers, and self-weight of finishes. Finishes include hand rail, balusters and newel post.

**5.8.2.2 Live Loads**

For residential buildings, a uniformly distributed load of 2–3 kN/m2 may be adopted depending on the users. For public buildings, a uniformly distributed load of 5 kN/m2 is specified.

**5.8.2.3 Effective Span of Stairs**

- When the flight of the stair is supported at the ends of landing beams, the effective span is taken as the projected horizontal distance between the centre lines of landing beam.
- When the stairs are not provided with stringer beam, then the effective span shall be taken as the following horizontal distances:
  - Where supported at top and bottom risers by beams standing parallel with the risers, the distance centre-to-centre of beams.
  - Where spanning on to the edge of a landing slab, which spans parallel with the risers (Fig. 5.15) a distance equal to the going of the stairs plus at each one, either half the width of landing or 1 m, whichever is smaller.
  - Where the landing slab spans in the same direction as the stairs, they shall be considered as acting together to form a single slab and the span is determined as the distance centre-to-centre of the supporting beam or walls, the going being measured horizontally.

**5.8.3 Rise and Tread**

Following are the norms for the size of rise and tread:

| | Rise (mm) | Tread (mm) |
|---|---|---|
| (i) Public buildings | 150 | 300 |
| (ii) Residential buildings | 150–200 | 200–300 |

Table 5.3:Norms for Riser And Tread.

The following guidelines may be followed while deciding the size of rise and tread of a stair:

- 400 mm <(Rise + Tread) <450 mm
- 580 mm <(Rise + Tread) <630 mm

**5.8.4 Distribution of Load**

Distribution of load for two conditions is given below:

- In the case of stairs with open-well where spans partly crossing at right angles occur, the load on areas common to any two such spans may be taken as one-half in each direction.
- Where flights or landings are embedded into walls for a length not less than 110 mm and are designed to span in the direction of the flight a 150 mm strip may be deducted from the loaded area and the effective breadth of the section increased to 75 mm for the purpose of design.

**5.8.5 Ramps, Elevators and Escalators**

Ramps are sloping surfaces that join two floors. These are provided where large numbers of people or vehicles or equipment have to be moved from floor to floor. Now-a-days, ramps are specially provided in all public places like hospitals, railway stations, etc., for movement of aged and physically challenged persons. Multi-storey car parks that are generally provided at the heart of the cities have ramps.

Buildings which are having more than four storey are provided with elevators or also called as lifts. The function of an elevator is to provide vertical transportation of passengers or freight. The elevators may be of two types, viz., electric traction elevators or hydraulic elevators. For a low-rise freight service, hydraulic elevators are provided which can rise up to about six storeys. It is also used for low-rise passenger service.Electric traction elevators can be provided for all rise buildings and structures. According to building regulations, it is mandatory to provide lift or ramp in all public buildings.

Escalators are also known as moving stairs or even moving flights. By a revolving drum, the escalator is kept in motion. A few steps at top and bottom are kept level through moving individually. A person has to occupy a step (preferably the first step) of the escalator for the upward or downward motion.The anticipated load on the escalator has to be properly assessed before design. The main factor which affects the design is the floor-to-floor height. The stair way should be kept independent by providing a structural framework around the stair well. The structural frame is designed to take care of the load of floor, hand rail, etc.

## 5.9 Ground and Upper Floors

Floors are the horizontal units of a building structure which divide the building into different levels. The purpose of separation or division is to create more accommodation within a restricted space one above the other for different purposes, viz., to provide support for the occupants, to allow space for furniture and equipment, etc. Strictly, the division of vertical occupation is called floors and the exposed top surfaces of floors are termed as floorings. The floor of a building immediately above the ground is known as ground floor. The construction below the ground level or the building has basement, the floor is termed as basement floor. The top portion of a ceiling forms the first floor or an upper floor. Any subsequent top portions of ceilings form upper floors. The major problems of ground and basement floors are dampness removal and protection from heat. Generally there will be no problem regarding strength and stability for ground and basement floors as they get the full support from the ground. The major problems of upper floors are the strength and stability.

In this section we will be discussing about the commonly used types of floors and floorings. Indian standards available for different floor and floorings are IS 5766:1970 and IS 13074:1991.

### 5.9.1 Types of Ground Floor

As the ground floor directly rests on the ground, there is no need for a sub-floor. In orderto drain the water outside completely, adequate drainage arrangements have to be madebeneath the floor.In normal practice, the space above the ground, up to a height of about 25–30 cmbelow the plinth level, called the basement, is filled with some inert materials like sand, gravel, crushed stone, cinder, etc. Over this course, a damp-proof course if needed is laid.Otherwisethe floor covering is laid directly on the uniform bed.The materials used for ground floor construction are: bricks, stones, concrete, hollowconcrete blocks or wooden blocks.The materials generally used for floor coverings are bricks, concrete, terrazo tiles,marbles,stones, mosaic, wood, etc.

#### 5.9.1.1 Stone Floors

Usual sizes of stones of 30 cm × 30 cm, 45 cm × 45 cm or 60 cm × 60 cm with a thickness of 2–4 cm are used. Generally square stone slabs of the above sizes are used but the slabs can be of rectangular or oblong in shape with square edges. Stone slabs are laid on concrete bedding.Before laying the slab a base is prepared after excavating to the required depth andthe earthen base is levelled, rammed and watered. A layer of lime concrete of thickness10–45 cm is spread over which the concrete bed or sub-grade is laid.After setting the stone floor with a slope of 1 in 40, the mortar joints are raked out to adepth of 2 cm and flush pointed with cement mortar of 1:3.

#### 5.9.1.2 Brick Floors

This type of flooring is used in case of warehouses, stores and godowns. This is a cheapconstruction and used in areas when stones are not available but good quality bricks areavailable.This flooring may be laid flat or on edge. They may be arranged in herring bone pattern orat right angles to the walls. Brick on edge is preferred compared to bricks laid flat as the brickon edge is less liable for crack under pressure because of the higher depths. The bricks, inboth the cases, are laid on ordinary mortar and pointed with cement or set in hydraulic mortar.For construction of brick flooring an excavation of about 40 cm depth below the intended level of the floor is made.The earth surface is levelled, watered and well rimmed until it is dry and hard. Over the earth, above a sub-grade of 25 cm depth consisting of rubble or brickbatsis laid. Over this, a 10–15 cm thick layer of lime concrete or lean cement concrete (1:3:6)is laid. Upon this prepared sub-grade, bricks are laid in the desired shape.

**5.9.1.3 Concrete Floors**

Concrete floorings are mostly used in all residential, commercial and public buildings. Theflooring is constructed adopting either monolithic or non-monolithic construction.In the monolithic construction, after laying the base course layer, immediately a concretetopping is provided. In this type of construction, only a small thickness is needed for wearingsurface as the bond between the base course and the wearing surface is good. Non-monolithic construction is sound as the wearing surface is laid only after adequatedrying of base course. The floor finish generally used is ordinary concrete finish of 1:1.5:3.Under controlled conditions, a mix of 1:2:4 ratio with carefully selected aggregatesmay be used. For non-monolithic construction, the surface of the base concrete is brushed with a stiff broom and cleaned thoroughly. The surface is wetted and excess water removed. The flooris laid in rectangular panels not greater than 2 × 2 m. Generally alternate bays are concretedso as to avoid initial shrinkages. When the concrete layer is even, the surface is rapidlycompacted by remaining or beating and screeded to a uniform level. Then toweling isdone to give a level smooth surface. Adequate curing is done for 7 days by spreading a layerof wet sand or special membrane may be used.

**5.9.2 Types of Upper Floors**

Upper floors should be strong to take heavy loads, should have sound insulation andfire resistance and also have a good wearing resistance. The upper floors are generallyclassified based on the materials of construction arrangement of beams and girders ormaterials used.

Commonly used floors are explained below.

**5.9.2.1 Timber Floors**

Timber floors are used only in areas where more timber is available at reasonable cost.Further they are used for residential buildings where the span is less and load on the flooris less.The floors may be of single joist, double joist or triple joist. Joists of floors should bestrong enough and not deflect too much causing any cracking of plaster of ceiling. Furtherlong joists need strutting to avoid buckling. The planking consists of wooden boards of4 cm thickness and 10–15 cm wide.

**5.9.2.2 Jack Arch Brick Floors**

Bricks and plain concrete cannot be used directly as flooring system without properstrengthening. Either reinforcement can be provided or provision can be made so as todevelop arch action.

Rolled steel joists (RSJ) are used to build arches so as to form jack arch floorings. The arches have spares varying from 1.25 to 2 m and the rise is 1/12th to 1/16th of the span. In order to accomplish the end thrusts the rods of 2–2.5 cm are run at 2–2.75m apart. The rods are encased in the wall along with a RSJ. The spandulus are filled with concrete.

Brick jack arches are constructed by bringing up the arches by laying the bricks on edges starting from the ends where the bottom of an RSJ is concreted. Lime or cement mortar is used. After laying the brick from ends, the key brick is introduced to set the arch action. Next layer is laid by pushing the centering ahead. This operation is continued till the work is completed.

**5.9.2.3 RCC Slab Floors**

All modern buildings are invariably constructed with reinforced cement concrete. For small spans a simple RCC slab floor is generally suitable. For rooms, with the ratio of length of the room to its width is greater than 1.5, slabs are designed to span along the shorter width. That is, the main reinforcements are placed to the shorter width. The thickness of the slab depends on the type of concrete used, the span, floor loads, etc. These slabs are considered along with a frame then it is made monolithically with the supporting frames.

#### 5.9.2.4 Flat Slab Floors

This type of floor is called as beamless slab floor. This flat slab floor is directly supported on columns without any intermediate beams. This type of floor is preferred where heavy loads are anticipated and where there is head room restriction. The columns supporting the floor are invariably circular in cross-section and tops of the column are flared or tapered, which is called as capital. Sometimes certain portion of the slab, symmetrical with the column, is thickened which is called drop panel.

#### 5.9.2.5 RCC Beam and Slab Floors

For larger spans and heavy loading conditions RCC beam and slab construction is generallyresorted to. This type of construction is commonly used for most of the important buildings

#### 5.9.2.6 RCC T-Beam Slab Floors

In this type of floor, beams and slabs are designed as rectangular sections and the slabsare supported on beams. It is a monolithic construction both the beams and slabs are casttogether. The beam used in monolithic construction is called a T-beam (i.e., a part of slabacts as a flange of the T-beam).The main reinforcement of the slab runs parallel to the short span. However, some reinforcementis provided on the other, as in RCC slab floor, as distributors. In case of equal spanstwo-way slabs may be constructed with reinforcement provided on both directions. Sometimesthe projecting beams are covered by providing a false ceiling underneath it.

### 5.9.3 Floorings

#### 5.9.3.1 Granolithic Floors

It is concrete flooring with a different type of floor finish called granolithic. Granolithicfinish is a concrete made of special selected aggregate. The thickness of layer varies from1.25 to 4 cm. When it is greater than 4 cm this may be laid monolithically or after the baseconcrete has hardened.This flooring is made with very hard and tough quality aggregate in rich concrete of1:1: 2.

#### 5.9.3.2 Terrazo Floors

Terrazo is a special type of concrete flooring containing marble chips as aggregates. Anydesigned colour and designs can be obtained by using marble chips of different shades and colour cement.Terrazo mix of 1: 2 or 1: 3 (1 cement to 2–3 marble chips) is used depending on the sizeof marble chips. Terrazo finish is of 10 mm thick.

#### 5.9.3.3 Mosaic Floors

For construction of this type of flooring, a hard concrete base is laid first. When the base iswet, a 2 cm thick layer of cement mortar (1: 2) is evenly laid. Over this layer small piecesof broken tiles are arranged in different pattern. After this the inner space between tiles isfilled with coloured pieces of marble in the desired fashion.

#### 5.9.3.4 Tiled Floors

In this type of flooring tiles either of clay or cement concrete, manufactured in differentshapes, are used. A 15 cm thick layer or lime or cement concrete is laid over the leveled ground. In order to receive the tiles at 25 mm thick layer of lime mortar (1: 3) or cementmortar (1:1) is laid. A cement slurry is spread over the hardened mortar. Tiles are laid flaton this bed and a cement paste is applied on the sides.

#### 5.9.3.5 Asphalt Floors

Asphalt floorings are of two types, viz., (i) using asphalt tiles and (ii) using mastic asphalt.Asphalt tiles are made from asphalt, asbestos fibres and other materials and pressed underpressure. Asphalt mastic is a mixture of fine aggregates and natural or artificial asphalt.

#### 5.9.3.6 Marble Floors

High quality marble slabs in the required sizes and colours are available in the market. Theconstruction procedure is same as that of mosaic flooring except that marble slabs or piecesare used instead of mosaic tiles or pieces

#### 5.9.3.7 Timber Floors

Timber flooring is not generally preferred for ground floors. If it is used as a ground floor,the prevention of dampness is most important. Timber floorings can be provided in anyone of the following methods. Strip flooring consists of narrow and thin strips of woodjointed to each others by tongue and groove joint. Planked flooring is one type in whichwider planks are used and they are also of tongued and grooved type.

## 5.10 Damp Proofing and Water Proofing

One of the basic requirements of all types of buildings is that they should remain dry and for from all types of moisture. Dampness in building is caused due to absorption of moisture. It happen because of defective and improper construction, bad design or use of sub-standard quality of materials. Dampness results in unhygienic environment for the occupants. The treatment/techniques used to prevent the entry of moisture/dampness into a building at various levels of entry points is called as damp proofing. Generally the treatment given to the wall floors and basement to keep the moisture/dampness away is called as damp proofing, whereas, the treatment given to the roof is called as water proofing.

### 5.10.1 Causes of Dampness In Building

Dampness in a building can be caused by many sources as explained below:

#### 5.10.1.1 Moisture Penetrating the Building from Outside

The various sources of moisture which penetrate the building from outside are Rain Water, Surface Water, Ground Water, Moisture in the Air due to condensation the moisture present in the atmosphere etc.

#### 5.10.1.2 Moisture Entrapped During Construction

During construction, water is used in making concrete mixes, plaster, masonry mixes etc. The materials are used in wet conditions and cured properly for development of strength and prevention of cracking. Sometimes, this moisture does not dry and persists for a long time even after construction work is finished. This moisture can cause dampness in the building. If the water we during the construction work, is alkaline or saline then it may cause dampness and efflorescence the building. Use of defective building materials like porous bricks, stones etc can also cause dampness because these materials may entrap moisture in their pores.

#### 5.10.1.3 Moisture which Originates in the Building Itself

Water is used in all types of buildings. In case, there is any leakage or faulty joints in the sea traps or pipes or other water and sanitary fittings, then the water will not be drained out property and may penetrate into the other building components like walls, floors etc and may cause dampness. The wet areas of the building i.c. bathroom, WC and kitchen are also prone to dampness as they remain wet for most time of a day. These areas are to be constructed properly to prevent in dampness in the building. For example, if the slope of the floor of the bathroom, WC and kitchen is carefully constructed to drain off the water, then it will lead to stagnation of water and dampness in the building. Use of sub-standard plumbing fittings and fixtures or bad workmanship also causes leakage and dampness.

#### 5.10.1.4 Improper Roof Slopes

The improper roof slopes, faulty rain water pipe connection and improperly constructed junction between roof slab and wall may cause dampness in the building.

### 5.10.2 Methods of Damp proofing

General Preparatory Work- IS 3067:1988 covers general details and preparatory work for damp-proofing and waterproofing of buildings.Depending upon the nature of surface, amount of dampness and quality of the structure, various methods of damp-proofing are available. Following methods are generally used in building construction to prevent dampness.

#### 5.10.2.1 Membrane Damp Proofing

It consists of providing a layer (membrane) of water repellent material between the source of dampness and the part of the building which is adjacent to the source. This layer or membrane is called is Damp proof course or D.P.C in short. The water repellent materials used in damp proof course are bitumen, mastic asphalt, plastic or polythene sheets, cement concrete, bituminous felt, silicon and epoxy etc. It may be provided either vertically or horizontally,

- **Horizontal DPC:** The method of laying horizontal damp proof course is as follow:
  - First of all a 40-50 mm thick layer of cement concrete (1:2:4) is spread.
  - Two coats of hot bitumen are spread at the rate of 1.75 kg/m on the top of concrete layer,
  - Instead of hot bitumen, felt can also be used.
  - At junctions and corners of the wall, DPC should be continuous.
  - DPC should not be exposed on the surface of the wall to prevent damage.

#### 5.10.2.2 Integral Damp Proofing

This method consists of adding certain water proofing chemical compounds to the concrete mix so that the resulting mix becomes impermeable. These water proofing compounds may be of void filling type such as chalk, talc, fuller's earth, clay etc. which fill up the voids of concrete mix and make it impermeable or water proof. Other type of compounds used for damp proofing are alkaline silicates such as aluminium sulphates and calcium chloride etc. which react chemically with concrete to produce a water proof concrete.Examples of commercially available water proofing compounds are Publo, Impermo and shellcrete etc.

#### 5.10.2.3 Surface Treatment

This method consists of applying a layer of water repellent material on the surface through which the moisture is likely to penetrate into the building. The water repellent material used for surface treatment fills up the voids/pores of the basic material used for construction thus preventing dampness. Commonly used water repellent surface treatment material are calcium, aluminium and stearates. Bituminous coating paints and cement coatings are very effective in reducing the dampness caused by rain water and are extensively used for surface treatment. Exposed surfaces must be done carefully in a building. For example, while doing plastering and pointing works, water repellent materials should be mixed with the construction material or applied on the finished surfaces to prevent dampness.

#### 5.10.2.4 Guniting

It is commonly used repair technique which is also used for water proofing. In this method, an impervious layer of rich cement mortar, usually 1:3 or 1:4 (cement sand), is applied under pressure over the surface to be water proofed. This mixture is applied on the cleaned surface with the help of a machine called cement gun, under a pressure of 2 kg/cm to 3 kg/em. The nozzle of the cement gun is held at a distance 75 to 90 cm from the area of application and cement mortar is applied evenly under the specific pressure which gives dense and compacted surface. This dense and compacted surface of required thickness acts an impervious layer and prevents entry of water.

#### 5.10.2.5 Cavity Wall Construction

Cavity wall is made up of two walls (leaves) with a cavity (space) of 5 to 8 cm between them. The main wall is on the inner side and is protected by an outer wall, also known as skin wall. The cavity between the two walls prevents the moisture from reaching the main wall as there is not contact between the two walls through which the moisture can travel. Sometimes this cavity is filled with material like cork etc.

### 5.10.3 Damp proofing treatments in Buildings

Various damp proofing treatments are given at various levels in a building to prevent the entry moisture into the buildings. Some of these are explained below:

**5.10.3.1 DPC at Basement**

Basements are constructed below the ground level. There is a possibility of moisture/ground to penetrate into the building during rains (due to rise in water table) or otherwise. Therefore very important to construct basement well protected against dampness. Following methods are set for providing damp proof course in basements.

❖ DPC treatment in basement in undrained soil consists of a horizontal DPC above the foundation concrete and a vertical DPC in walls along with open jointed drains all around and under the basement to collect the ground water as shown in Fig. 5.13.

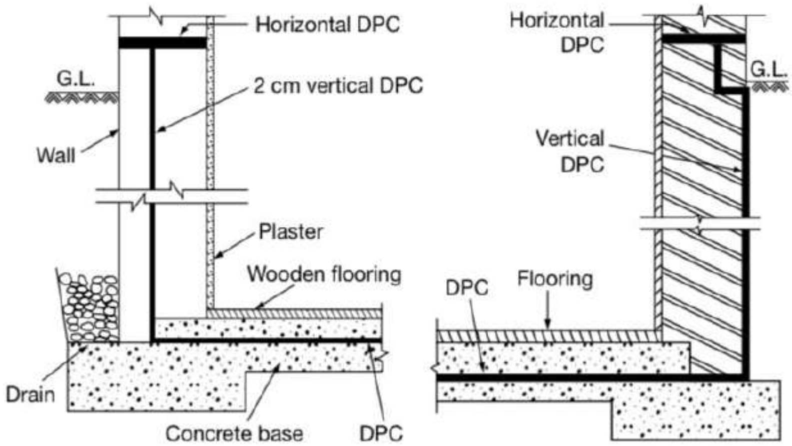



Figure 5.13: DPC in Basement.

❖ Asphalt Tanking: Tanking is a method of providing DPC on the entire area of floor and the walls .This method of laying DPC is explained below:

A layer of levelled concrete (lean concrete) is laid over the prepared soil. Horizontal DPC in the form of asphalt of 30 mm thick, in three coats is laid over the concrete.A layer of bricks is provided to protect DPC from possible damage during flooring. Vertical DPC in the form of asphaltic layer, 20 mm thick is applied in two coats on the external faces of the walls of basement.A half brick thick protective layer is provided to cover vertical DPC. Over the horizontal DPC, a 50 mm thick layer of concrete or brick is laid over which theflooring is laid.

**5.10.3.2 Damp Proofing of Floors**

Damp proofing of floors especially ground floor is very important to check the entry of sub surface moisture into the building. Damp proof course at ground floor is given as follows:

- ❖ For places where soil moisture is very less or not present. The DPC treatment consists of a rammed well compacted sub-soil and a 10 cm thick layer of sand is spread over the entire floor area.
- ❖ In the case of soils where water table is near the ground level, the DPC treatment consists of a water proof membrane like mastic asphalts or bitumen felt below the concrete floor over the entire floor area. A layer of bricks is laid on a layer of fine sand over the water proofing membrane to act as a cushion to protect it from the damage as shown in Fig. 5.14. Another arrangement is to provide a continuous plastic sheet over the lean concrete.

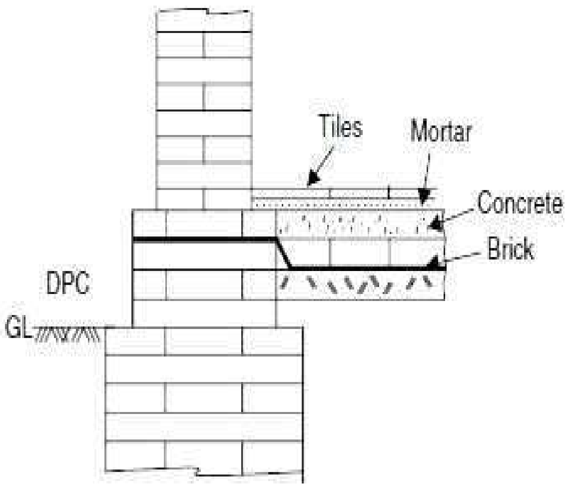


Figure 5.14: DPC at Floor Level.

**5.10.3.3 Special Water Proofing Arrangements in Bathrooms, WC and Kitchen**

Toilets, bathrooms and areas below sinks remain wet most of the time of the day so they are called as wet areas. Leakage from these areas is a very common problem which can be seen in many households. The leakage/dampness results in dirty wet patches, peeling of paints and loosening ofplaster. Therefore it is very important to give special attention while water proofing, these areas during the construction.

Water proofing of these wet areas is done in following ways:

- Damp Proofing of Floor
- Careful Construction of Water Tight joints of the Water Supply and Sanitary System.

**5.10.3.4 Damp Proofing Arrangement in Walls**

- **Basement Walls:** In basement, vertical DPC in provided on all the enclosing walls as shown in Figure 5.13.
- **Other Walls:** Horizontal and vertical DPC treatment is given to the walls as explained below:

For normal rainfall, external walls are plastered with cement lime plaster (1:1:6) For heavy rainfall, the external walls are plastered with rich cement plaster (1:3) having some water proofing compounds like permo etc. The wall can also be painted by some water proofing cement paints or compounds also to prevent dampness. (iii) In external walls, a horizontal DPC is provided at 15 cm above the ground level and avertical DPC is also provided .In internal walls, horizontal. DPC in always provided at plinth level Damp Proofing

**5.10.3.5 Arrangement at WindowSill**: The window sill should always be given a slope away from the wall. The sill should be throated on the underside to prevent the trickling down of water on the surface of the wall. The sunshade should also be sloped away from the wall properly to drain off the water quickly.

## 5.11 Roof

Roof is the upper most part of a building which is constructed on structural members andprovided with a covering material.Roofs may be grouped under three major categories, viz., sloping or pitched roofs, flatroofsand curved roofs. Slope or pitched roofs are those which have the surfaces with considerable slope forcovering the building structure. The modern construction like shells may also be groupedunder this category.A roof which is nearly flat is known as a flat roof. It is the convention if the slope is lessthan 10°, it is considered as a flat roof. As a matter of fact no roof is laid flat. Curved roofs are just the modifications of pitchedroofs.

**5.11.1 Sloping roofs**

Sloping roofs are comparatively light in weight and can be used in large to very large spans. They are quite suitable in areas where there are heavy rain and snow. Shapes of slopingroofs are dependent on the area to be covered, material used, light, ventilation needed, etc. Different parts of sloping roof are shown in Fig. 5.15.

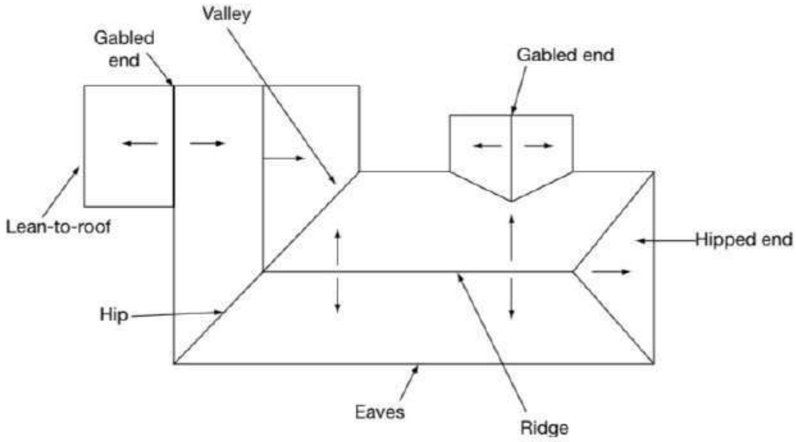



Figure 5.15: Parts of Sloping Roof.

**5.11.1.1 Types of Timber Sloping Roofs**

Different types of timber sloping roofs are discussed below.

❖ **Lean to Roof**

This is a roof which is usually used to cover verandah. This is used for spans up to 2.5 m.The roof covering is fixed to battens running across the rafters. It is usually constructed asa mono-pitched roof

❖ **Couple Roof**

This is a roof which has two rafters with a central ridge piece at the top. The rafters are fixedto the wall plates. The roof covering is fixed to battens running across the rafters. This canbe used only up to spans of 3.5 m.

❖ **Couple Close Roof**

This is similar to that of couple roof and the rafters are connected by wooden tie. Thetie has two functions:

- ❖ Prevents the outward spreading of the walls and
- ❖ Acts as a support for any ceiling which might be fixed on it. This is suitable for spans up to 4.5 m.

❖ **Collar Tie Roof**

This is similar to the couple close roof but with a difference that the tie (called collar) isfixed at a height of 1/2–1/3 of vertical height between the wall and the ridge. In order togain the maximum strength the collar has to be placed as low as possible. This roof is suitablefor spans of 4–5.5 m

❖ **King-Post Truss**

For large spans, King- and Queen-post trusses are used. In king-post truss, the total weightof the roof is transferred to the walls vertically. The frame work of the truss is built suchthat the shape is not altered when loaded. Members in this truss are subjected either tocompression or tension. The shape of the truss being triangular in shape gives a greaterrigidity. This type is suitable for spans of 6–9 m.

❖ **Queen-Post Truss**

This consists of two Queen posts instead of one as in King-post truss and also has onestraining beam. The members which are subjected to compression are straining beam an struts whereas the Queen-posts and the tie beam will be under tension. This type of trussis suitable for spans up to 13.5 m. Different load bearing members and parts of the Queenposttruss.

### 5.11.1.2 Types of Steel Sloping Roofs

Shape and positioning of members in a steel roof truss are designed in such a way that themembers are subjected to either compression or tension. Trusses do not have any bendingstress in them. The compression members of the truss are based on the span, slope, thecoveringmaterial, and centre to centre of trusses. For large spans steel trusses are generally preferred. This alsocan be used for small spans.

Various types of steel roof trusses are shown in Fig. 5.16 and 5.17. Steel rooftrusses are designed in such a way that the members are either in compression or in tensiononly. Members of a truss which form the roof base depends upon the span, roof slope,coveringmaterials, centre to centre of trusses, etc.

Tee-section is the most suitable section for principal rafter. For struts either angle iron orchannel section may be used. Round or flat sections are used for tension members. Built-upsections are also used in certain cases.

❖ **Trusses for Small Spans**

Small trusses (span up to 15 m) are rested on bed plates at the ends. The bed plates may beof stone or concrete. The ends are bolted down with rag bolts which hold the truss down.Small trusses generally consist of angles connected with gusset plates. In order to seatthe foot of the truss on the bed plate short angles are fitted. For spans up the 7 m, 15 mmdiameter rivets are used (Fig. 5.16)

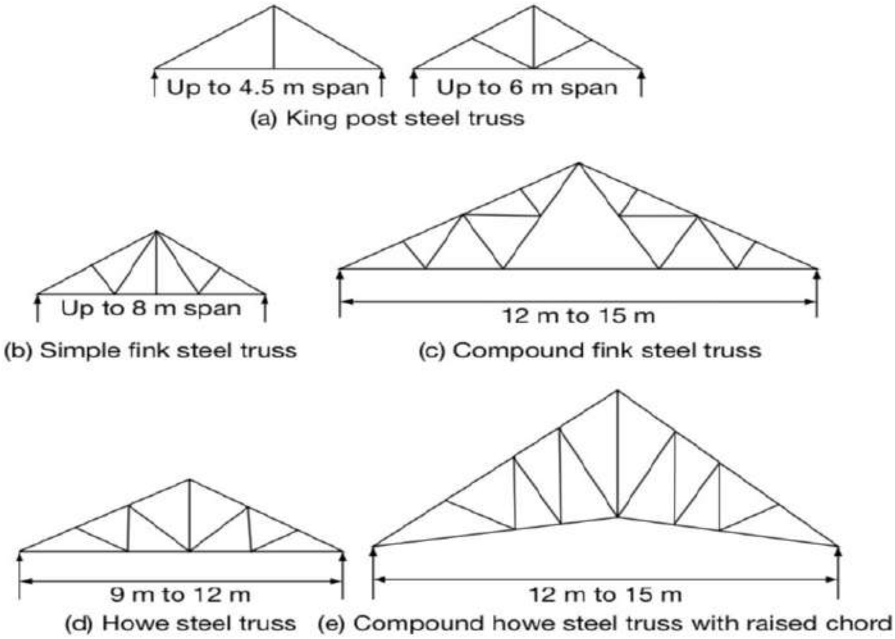



Figure 5.16 :Small Span Trusses.

❖ **Trusses for Large Spans**

In large-span trusses the members may consist of more than one section. Two angles orchannels or flats may be connected in the gusset with other members at the joints. As thetruss is hung, handling may be difficult. Thus the trusses are riveted into two portions atthe fabrication centre and gusset plates at the connected ends are riveted to them. The twohalves are erected at the site and riveted. Bigger bearing plates are used for these trusses. Figure 5.17 show different types of trusses grouped under large span trusses.

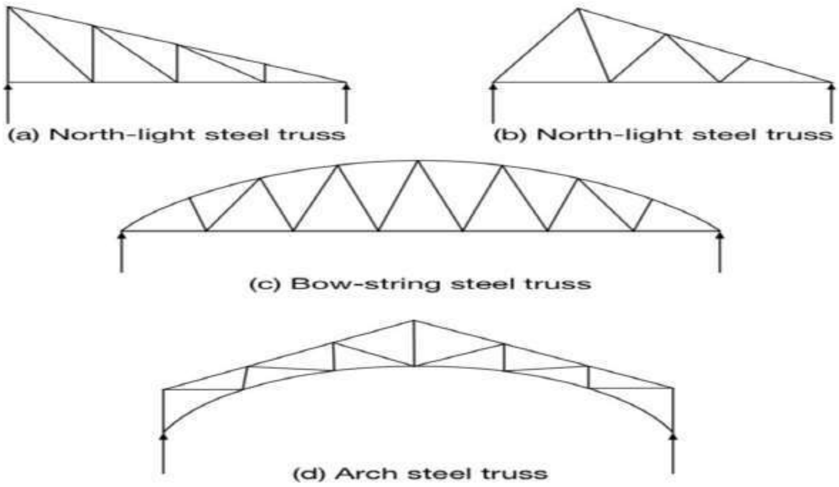


Figure 5.17: Large Span Trusses.

**5.11.2 Flat roofs**

Flat roofs are used in the areas which have less rainfall and no-snow fall during the year. Drainage in a flat roof is a major problem unlike a sloping roof which has an excellent drainage facility. On a basic level, flat roof construction comes in the form of roofing timbers, or joists as they are more commonly known or steels that are laid across two uprights (walls in most cases).The steels, or RSJ's (Rolled Steel Joists) are often built into one or both walls to give added stability to the roof structure. The joists are then either laid on top of the steels or cut into them. These joists are spaced at a specified distance apart, usually 400mm depending on the width or span they are covering and the surface that is to be applied. In the majority of cases the covering will be plywood or OSB timber which is more commonly called Stirling board. When timbers are used in flat roofing they obviously need to be waterproofed so boards are normally laid across the joists and then a felt or rubber is used to cover the boards to make them waterproof. Where two boards meet and the joint is not on a joist, tongue and grooved decking boards make the joint strong enough to support the flat roof load. These roofs are not usually laid in Jammu & Kashmir .For detailed discussion, refer to IS 2118:1980, IS-2119:1980, IS- 2115 : 1980 etc.

**5.11.3 Curved roofs**

These are the just the modifications of pitched roofs and are frequently employed in modern age to cover large areas shed/roofs and domes are the varieties of curved roofs. They are useful for big structures such as factories, monumental works etc curved roofs may be constructed of timber or R.C.C. the latter material being very common now-a-days. Procedure of construction is as under:

- Pre-cast units of cement concrete tilis of size 70 x 70cm with a uniform minimum thickness of 20mm in the form of domes with a rise of about 50mm are used.
- Pre-cast units of R.C.C. 1:2:4 beams are prepared as per design usually 90mm deep and 130mm wide as per design usually 90mm deep and 130mm wide.
- The beams are suitably laid across the supporting walls.
- The tiles are placed in position after spreading some mortar on the edges of beams. The minimum bearing of tiles on beams should be 25mm and that on walls should be 50mm to 70mm.
- The haunches between the humps of tiles are filled up with cement concrete of proportion 1:2:4.
- Suitable water-proofing treatment to the roof is given at the top. The roof thus exhibits a flat surface at the top and curved surface at bottom.

**5.11.4 Roof Coverings of Sloping Roofs**

A roof covering is a material which is placed over a sloping roof to give protective surface. The primary function of the covering is to prevent the direct entry of heat, rain and snow into the building. Choice of roofing material depends on the type of roof structure, local conditions, cost, the type of building, etc. For laying and fixing of sloped roof covering, refer to IS- 5119(Part 1):1968 and IS-12093:1987. Different types of roof coverings for sloping roofs are discussed below.

**5.11.4.1 Thatch**

It is one of the most ancient and simple type of roof covering used in rural areas. It is usedbecause of its abundant availability, cheap cost and need of unskilled labour. Thatch iseither from straw or reed. Thatch is less resistant to fire, unless it is treated by a fire proofingmaterial.

**5.11.4.2 Slate**

It is basically a sedimentary rock which could be split into thin sheets. Slates are availablein different natural colours. Most common colour is various shades of grey. A good quality slate should have even colour, should be hard,impervious and should give a ringingsound when struck. It should not be tough and have white patches.The sizes of slates vary from 60 cm × 35 cm to 25 cm × 12.5 cm and the thickness variesfrom 1.5 to 4.5 mm for smaller sizes and 10 to 12 mm for large sizes. There are variousmethods of fixing slates.

**5.11.4.3 Tile**

Like thatch, tile has been in use from olden days. The sizes and shapes have improved fromtime to time. Clay tiles are made similar to bricks. Concrete tiles are used to a limited extent.Plain tiles are of sizes varying from 25 cm × 15 cm to 28 cm × 18 cm with thicknessvarying from 9 to 15 mm. These tiles are used along with special tiles such as hip and valleytiles.Pan tiles are made of clay and it is the oldest type. The roof is covered by the use ofbent tiles. This is comparatively less weight. The tiles are of sizes 30–35 cm in length and20–2.5 cm width. There is little chance of leakage at joints.

Mangalore tile is one of the most popular type of patented tiles. These tiles are machinepressedclay tiles which have better interlocking, enabling better protection against heavy rains.Asbestos cement tiles of square or rectangular in shape are also in use. These tiles canbe laid on boards of the roof or directly on the battens which are nailed to the rafters.

**5.11.4.4 AC Sheet**

The combination of cement and asbestos produced in different sizes and shapes form theasbestos cement sheets. Asbestos cement sheets are available as corrugated roofing sheetsand as well boards. This type of roof covering has several advantages, viz., durable, notheavy, impervious, fire and vermin proof, less labour cost, etc. These sheets are fixed onwood or steel purlins

**5.11.4.5 CGI Sheets**

Corrugated Galvanised Iron (CGI) sheets is yet another type of roof covering widely usedalthough the appearance is not that good. Like AC sheets, it has high durability, light inweight and fire proof. This consists of thin metal sheets which are galvanised and given thecorrugation of bent shape for additional strength. These sheets are fixed on purlins withspecial screws.

**5.11.4.6 Aluminium or PVC Sheets**

Now-a-days Aluminium or PVC sheets similar to corrugated sheets are available which arelight in weight, easy to handle and available in different colours.

## 5.12 Concept of Seismic Planning Of Buildings.

Earthquakes are a major cause of concern for civil engineers because the effect of this disaster is measured in terms of extent of damage. This damage includes loss of lives and property both. Somebody has rightly said that "Earthquakes do not kill people but it is the structures built by them that do so." Thus it is very necessary to make the structures earthquake resistant. So, the study of earthquake engineering is important for civil engineers to equip them with the basic knowledge of earthquakes, its effect on structures and various principles and techniques to be followed while designing and constructing earthquake resistant structures. The list of Indian standard codes for earthquake design of structures include IS-1893:2002, IS-4928:1993, IS-13827:1992, IS-13920:1997, IS-13935:1993. These codes take several parameters into considerations for instance local seismology, accepted level of seismic risk, building typologies, construction materials, and methods used in construction.

**5.12.1 Seismic Zones in India.**

The different geology at different locations in the country implies that the possibility of damaging earthquakes taking place at different locations is different. Thus a seismic zone map is required to identify these region. Based on the levels of intensities during past earthquakes, the 1970 zone map divided India into five zones I, II, III, IV and V .The maximum modified Mercalli (MMI) intensity of shaking expected in these zones were V or less, VI, VII, VIII and IX and higher, respectively. Parts of Himalayan boundary in the north and north east and Kutch area in the west were classified as zone V.

The seismic zone maps are revised from time to time as more knowledge is gained about earthquakes, the tectonics and Seismic characteristics of the country. The Indian Standards published the first seismic zone map in 1962 which was later revised in 1967 and again in 1970. The map has been revised lastly in 2002 and it now has only four seismic zone-II, III, IV and V. The areas of zone 1 of the earlier 1970 map are merged with the seismic zone II. Also the zones in Peninsular region has been modified and Chennai now comes in Zone III (earlier it was in zone II).

**5.12.2 General Principles of earthquake resistant buildings**

The earthquake resistance of buildings can be improved by following simple design and good building construction practices. These principles are explained below:

**5.12.2.1 Lightness:** The earthquake force depends on mass of the structure. Heavier structure means large inertia force and collapse of these structures results in heavier damage and loss of lives. Thus, a building should be as light as possible, especially the roofs and upper storeys.

**5.12.2.2 Building Configuration:** The behaviour of a building during earthquake depends on its shape, size and geometry. A good building configuration can result in less damage during earthquakes.

The various components of building configuration are explained below:

- ❖ **Symmetry:** The building as a whole or its various blocks should be kept symmetrical about both the axes. The asymmetrical buildings are subjected to twist or torsion during earthquakes. This twist make different portions at the same floor level to move horizontally by different amounts.This causes more damage. This damage can be minimized by planning symmetrical buildings.If asymmetry is not avoidable than the additional forces due to torsion should be taken while designing the structures.
- ❖ **Simplicity and Regularity:** The building should have a simple rectangular plan. It is seen that simple shapes behave better during earthquake than complex shapes like L. T. E. H. U and T etc. as in Fig. 5.18. It is seen that during earthquakes the buildings with re-entrant corners have suffered great damage. These types of buildings can be broken into rectangular blocks which are separated properly. Thus, separation of a large building into smaller blocks can lead to symmetry and regularity. For preventing pounding or hammering between blocks, a separation of 3 to 4 cm throughout the height above plinth level is required. This separation section is just like an expansion joint or it may be filled with a weak material which can easily crush during earthquake shaking.
- ❖ **Simple Building** without much Projections and Suspended Parts behave well during earthquake: Long cornices, vertical or horizontal projections, etc. should be avoided and are dangerous during earthquakes. If these parts cannot be avoided, they should be reinforced properly and tied firmly to the main structure. Ceiling plaster should not be done and if done, it should be as thin as possible.
- ❖ **Size of the Building:** In tall buildings, the horizontal movement of the floors during ground shaking is large. In short, but very long buildings the damaging effects of earthquake are more Buildings with one of their dimension much larger or smaller than the other two do not perform well during earthquakes. Thus the buildings length should not be more than three times its width. If longer lengths are needed, two separate blocks with separation should be provided.
- ❖ **Enclosed Area:** A small building with properly interconnected walls acts like a rigid box and more earthquake resistant. Therefore it is advisable to have separate small rooms than one long room.

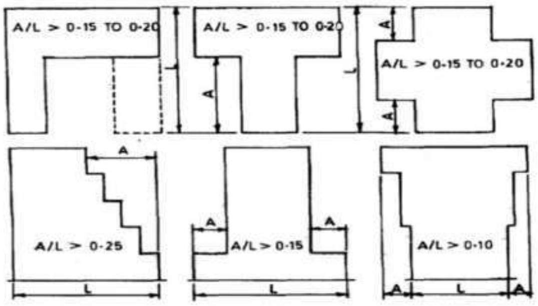



Figure 5:18 : Plan and Vertical Iregularities.

**5.12.2.3 Strength in Various Directions:** The structure should have adequate strength along both the axes. The design should also be safe and take into account the reversible nature of earthquake motion.
**5.12.2.4 Stability of Slope:** Hill side slopes are liable to slide during an earthquake. Hence buildings should not be constructed on them only stable slopes should be chosen. Similarly buildings withunequal members will also twist underground movement and may result in damage and collapse.
**5.12.2.5 Foundation:** The buildings should not be constructed on loose soils. These soils will compact and subside and result in unequal settlement of building and damage it. Although such soil can be compacted properly for small buildings. But for large buildings this operation is costly. For large buildings, rigid raft foundation or piles taken to firm stratum can be used.
**5.12.2.6 Ductility:** Ductility is the most desirable property for good earthquake performance. The brittle masonry can be strengthened by providing steel reinforcing bars at critical sections which will also improve ductility of the structure.
**5.12.2.7 Fire Resistance:** It is very common to see fire after earthquake. It may be because of electrical short circuits, leaking of gas pipes/cylinders kerosene lamps and kitchen fires. The fire hazard is sometimes more serious than the earthquake damage. Hence, the buildings should be made fire resistant according to Indian standards.
**5.12.2.8 Irregularities in RCC Buildings:** In addition to above principles, in the case of reinforced cement concrete buildings, following irregularities should be avoided or properly taken care of in the design of buildings.

- Soft storey
- Floating column

Any type of irregularity or discontinuity in a building results in obstruction in the path of load transfer and causes lot of damage during earthquakes.

❖ **Soft Storey:** It is a common practice of constructing open and taller ground storey in multi storeyed RC buildings, for parking of vehicles, shopping centres and large halls etc. This storey has less strength and is called as soft storey.

❖ **Floating Column:** The buildings in cities are constructed in such a way that balconies cover more areas in the upper floors. These balconies extend 1.2 to 1.5 m beyond the columns of ground storey. In the upper stories the floating columns are provided which rests at the tip of the overhanging beams. These columns do not continue up to ground and hence are called as floating columns.

**5.12.3 Seismic Strengthening Arrangements:**

All masonry buildings should be strengthened in horizontal as well as vertical direction for improving the earthquake resistance. These are very important and are explained below.

**5.12.3.1 Horizontal Reinforcement**

The horizontal reinforcing of walls is required for imparting them horizontal bending strength against inertia force. It also helps in tying the walls together. In the exterior walls horizontal reinforcement helps in preventing shrinkage and temperature cracks. The following arrangements of horizontal reinforcement are necessary for earthquake resistant buildings.

❖ **Horizontal Bands or Ring Beams**. The most important seismic, strengthening arrangement for buildings is through reinforced concrete bands. A band is reinforced concrete or reinforced brick runner provided in the walls to tie them together and to impart horizontal bending strength to them. These bands are provided continuous through all the load bearing walls at plinth, lintel, roof caves level and also at top of gables.

❖ **Lintel Band:** This is the most important band and provided at lintel level in all load bearing and all cross walls. It must be provided in all storeys of building. Lintel band ties all the walls together and resist out of plane bending of the walls. The lintel band also improves the stability of walls during severe earthquake.

❖ **Plinth Band:** This band should be provided in those cases where the soil is soft or uneven in hilly areas. This band helps in reducing the differential settlement of building. This as in band will also serve as damp proof course. This band is provided at plinth level of walls on top of the foundation wall. Its section same as lintel band.

❖ **Roof Band:** Roof band is a band provided immediately below the roof or floors. This band improves the resistance against diaphragm failure thus it is a must for flexible diaphragms. This band need not be provided under reinforced concrete or reinforced brick roof.

❖ **Gable Band:** Gable band is a band which is provided at the top of gable masonry below the purlins. This band shall be made continuous with the roof band at the eaves level. This band resists out of plane failure of gable walls.

#### 5.12.3.2 Vertical Reinforcement

Vertical reinforcement is also provided in walls to improve the seismic resistance of buildings. Various points to be considered for vertical reinforcement are as follows:

- ❖ Vertical steel should be provided at corners and junctions of walls.
- ❖ The amount of vertical steel depends upon number of storeys and category of building.
- ❖ The vertical reinforcement should be property embedded in the plinth masonry and roofslab or roof band.
- ❖ The vertical reinforcement should pass through the lintel bands and floor level bands in all storeys.
- ❖ Vertical reinforcement for window and door openings should start from foundation of floor and upto the lintel band.

## 5.13 Surface Finishes

The finished surface of walls, pillars and ceilings etc. constructed in brick masonry, stone masonry, timber or steel are rough, uneven, irregular water absorbent and not very pleasing in appearance. It is also easily affected by the weather such as rain, wind, and extreme temperatures. Therefore, these surfaces are to be covered with a suitable material which give it a smooth, even, regular, water repellant surface which is also pleasing in appearance. This covering is in the form of plaster, paints, white washing and pointing etc.This section focuses on all the important topics related with surface finishes like plastering.pointing, painting etc. The process of covering the surface of masonry work, steel work or timber work with a suitable protective covering to make it weather resistant and pleasing in appearance is called as surfacefinishing. Surface finishing can be done in following ways:

### 5.13.1 Plastering:

The art of covering the rough surfaces of masonry work, (wall, columns, ceilings etc, constructed with brick or stone) with thin coats of suitable mortar to form a smooth, even, durable and weather resistant surface is called as plastering.Plastering is done by plastic mortar called as plaster. The plaster obtained by mixing somebinding material with fine aggregate and water in suitable proportions. Cement, lime or mud areused as binding materials. Plasters are classified on the basis of their binding materials as follows: Cement plaster, Lime plaster, Mud plaster, and Stucco plasterFor detailed plastering techniques and types,refer to IS-2402: 1963.

**5.13.1.1 Preparation of surface:** The preparation of surface to be plastered is a very important part of plastering. A properlyprepared surface will result in longer life and better finishing after plastering. For this the plaster should have proper adhesion with the surface to be plastered. For achieving better adhesion, the surface is to be prepared as follows:

- ❖ The surface is made even by knocking off the projections extending 10 mm from the surface. This will also result in thinner layer of plaster.
- ❖ All the masonry joints should be raked to a depth of 15 mm to obtain a good key (bonding) of plaster with the surface of wall.
- ❖ The surface is cleaned and all dust, dirt and loose mortar removed by a wire brush.
- ❖ In case of old walls, the surface should be made rough by hacking it with some tool, forproper adhesion of the plaster.
- ❖ After cleaning, the surface is thoroughly washed with water and kept wet till plastering coats applied.

  (vi) To get the required thickness, patches of plaster of size 150 mm x 150 mm are made at a suitable spacing (generally 2 m), on the wall surface, in vertical as well as horizontal direction. These patches act like screeds and helps in checking and maintaining the thickness of the plaster.

**5.13.2 Pointing**

Pointing is the process of finishing mortar joints in exposed brick or stone masonry. In masonry, joints are then critical places from where the rainwater or dampness can find a way into the building. Pointing refers to the treatment given to the joints of masonry with cement mortar or lime mortar thus, forming a protective layer over the joints and enhancing its appearance also.

❖ **Types of Pointing**

Pointing can be done in many ways depending upon the type of masonry to be pointed and thequality of appearance required. Following are the common types in which pointing are carried out.

- ❖ Flush or Flat Pointing
- ❖ Struck Pointing
- ❖ Recessed Pointing
- ❖ V- Pointing
- ❖ Weather Pointing
- ❖ Grooved Pointing
- ❖ Tuck Pointing

❖ **Method of Pointing**

- ❖ **Preparation of Surface:** All the loose mortar, dust and dirt is removed from the joints. The joints are raked to a depth 8 to 15 mm. wetted for few hours. The surface and joints are cleaned and thoroughly.
- ❖ **Filling of Joints:** Joints are carefully filled with the specified mortar with the help of a small trowel. The mortar is pressed against the joint to go deep and make contact with the oldmortar. Extra mortar should be removed away and the desired type of pointing is done.
- ❖ **Curing:** The pointed surface is cured for about 5 days in case of lime mortar and 7 days incase of cement mortar.

**5.13.3 Painting, White Washing, Distempering:**

Painting is the process of covering a surface with a liquid mixture of pigments and binders in thin coats. This forms a smooth hard covering on the surface which not only gives a decorative finish but also provides protection against weather.

The process of applying white wash on the plastered surface is called as white washing. The plastered surface is given two or more coats of white wash for following reasons :White washing gives a pleasing appearance to the dull plastered surface.White washing also helps in better distribution of light in a room.White washing also results in better sanitation.

Distempers are water based paints. Distemper consists of a powdered chalk (whiting), colouring pigments, glue and water. Various types of readymade distempers are available in the market in the form of dry powder or paste as washable, nonwashable and oil bound distempers etc. Distempers are cheaper than paints and are used as finishing coat over white washed surfaces.

## 5.14 Essential Services in Buildings

Essential elements for the human beings to live in a house with a minimum comfort are water supply, drainage arrangements and electrical power supply.

### 5.14.1 Plumbing services

Plumbing services is the entire system of piping, fixtures, applications, etc., for providingwater supply or drainage to a building or premises. A plumbing water supply systemconsistsof water supply and distribution with the use of pipes, control valves, pipe layout,storage tanks, etc. A plumbing drainage system consists of collection and disposal ofwastewater with the use of water closets, urinals, traps, vents, anti-siphonage pipes, housedrains, house sewers, etc.

**5.14.1.1 Water supply system :** Water distribution system needed for a conventional residential building depends on thefollowing aspects:

- ❖ Estimation of water requirement
- ❖ Determination of pipe sizes
- ❖ Pipe layout principles

The water supply requirements of buildings and design of distribution systems shall be as per IS 1172 : 1993 and IS 2065 : 1983 respectively. Following rules may be adopted in laying of water supply lines :

❖ There should not be any cross connection and backflow. Backflow can be eliminated by ensuring the under mentioned conditions.

- ❖ Adequate air gap is to be provided between the inlet and final flood level in all places particularly washbasins.
- ❖ While connecting cistern to water closet, the inlet and float valve should be suitably fixed.
- ❖ Positive pressure at the outlet pipes should always be assured.

❖ Drainage pipes and water supply pipes should not be laid very close to each other. Especially drainage stoneware pipe which are liable to leak if damaged should not be laid above the water supply line. Further, water supply pipes should not be laid alongside of the pipes carrying foul water.

❖ Planning of the distribution line should be such that it is accessible for inspection, replacement and repairs. GI pipes should not be buried as they tend to corrode in contact with soils, but they can be laid on walls.

❖ All pipes including PVC pipes laid inside the building as concealed pipes should be tested for leakage.

### 5.14.1.2 Plumbing Drainage System

Plumbing system of drainage is one through which discharge from sanitary fixtures orappliances is conveyed. The three principal systems are single stack system, the one-pipesystem and the two-pipe system.

❖ **Single Stack System**

In this system all waste matters such as from bath, kitchen and sink and foul matter fromurinals or excreta from water closets are discharged into a single soil pipe. This pipe alsoacts as a ventilating pipe. In this system complete reliance is built entirely on the effectivenessof water seal with the assurance that the entry of gases from sewers are blocked.

- **One-Pipe System**

In this system separate vent pipes are provided. All the traps of water closets, basins, bathsetc., are adequately ventilated to preserve the water seal. In this system a caged dome isprovided projecting above the roof top such that to allow a natural outlet to the foul gas. This system requires a difficult arrangement of pipe work and also costlier than the singlestacksystem.

- **Two-Pipe System**

In this system all soil appliances such as water closets and urinals are connected to a verticalsoil pipe. All wastewater appliances such as baths, washbasins, sinks, etc., are connectedto separate waste pipe which is disconnected from the drain by means of a gully trap. Thus in this system there are two sets of vertical pipes, viz., the soil pipe and the waste pipe,each one is provided with a vent pipe. This system is the best plumbing system which ismost efficient in the conveyance of sanitary waste and also largely favoured for adoption.However, this is the costliest of all systems.

### 5.14.2 Electrical Supply

Electrical power is provided to the building by the Government. Electricity is distributed insmall towns and villages by overhead wires. But in large cities and towns the distributionis done through underground cables. The supply of electricity is including the cables up tothe electric metre. In order to isolate the main supply from the building, a system of fusesis installed between the supply inlet and the electric metre board. From the fuses, the wiresare led to the metre and from there to the consumer unit. From this point the electricity isdistributed to the various parts of the building. It is the responsibility of the owner of thebuilding to provide wiring and other fixtures from the metre to the distribution board andother parts of the building.

#### 5.14.2.1 Wiring of Buildings

The following are three types of wires:

- Sheathed wiring by surface fixing
- Conduit installation on walls and ceilings
- Concealed conduit wiring

Now-a-days in most of the buildings concealed PVC conduit wiring is used. The PVC conduits may be laid on the surface or concealed. In both the cases care has to be taken tosee that no water enters the pipes. In the case of concealed pipe, it is safe to surround theconduit in chicken mesh reinforcement.

# 6. BUILDING CONSTRUCTION SCHEDULING, MONITORING &MANAGEMENT

## 6.1 Scheduling

In construction project it is very important to identify the risk factors affecting the project at the early stage in order to control and monitor the progress at every stage of the construction work to avoid the time and cost overruns of the project. This can be achieved by proper project management process.

For all important building projects, it is essential to have a CPM/ PERT chart for the entire project. Construction agency should submit the chart preferably along with the tender, and in any case before commencement of work. For minor projects, bar charts fixing the targets for the major activities along with the construction schedule may be submitted.

The various activities involved in the completion of the project right from the award of work to its completion shall be identified both in terms of time and money as also the resources like manpower, T&P and materials etc., required for the completion of the activity, the entire purpose being to streamline the construction procedures and take advance action in respect of those activities which affect the subsequent activities and in particular, the activities in critical path, so as to avoid any delay arising in the completion of the project. The inter-dependency of different activities should be correctly shown and the activity durations considered shall be realistic. The CPM chart should be updated regularly as the work progresses.

Availability of resources, viz, manpower, material, plant and machinery and funds shall be clearly identified to enable their mobilization / procurement well in time.

### 6.1.1 Scheduling Procedures

Various scheduling procedures are discussed below.

#### 6.1.1.1 Construction Schedule

This schedule consists of duration of construction of various components of the work. Based on the availability of the following data, the construction schedule can be made:

- Number of activities
- Quantity of various items of works
- Labour contribution and number of field workers
- Machinery required
- Stages of activities to be executed

#### 6.1.1.2 Labour Schedule

Under this schedule one can know in advance the type of labour and their numbers requiredfrom time to time. This is needed to recruit the persons (both skilled and unskilled labour)needed so as to have a continuous flow of work without any disruption.

#### 6.1.1.3 Material Schedule

This is an important schedule by which one will be in a position to know the requirement ofvarious construction materials well ahead. This helps to start the work and continue withoutany dearth for materials at any stage. If adequate fund and storage facility are available, materials which cannot be spoiled with time may be stored to some extent.

#### 6.1.1.4 Equipment Schedule

The success of any project depends to a large extent on the proper use of constructionequipment. Properly maintained equipment and application in construction can bring downconstruction time and cost. Further proper deployment of equipment judiciously yieldseconomical result without heavy financial burden in the project. Thus project managementshould properly plan the judicious deployment of equipment.

#### 6.1.1.5 Expenditure Schedule

The project engineer and his team have to primarily judge to give the most economicalconstruction. Thus it is essential to review the financial position of the project at regularintervals so as to ensure the following:

- ❖ The annual expenditure, if any, of the project has to be kept within the allotment.
- ❖ A properly balanced expenditure will result in an early completion of work

### 6.1.2 Scheduling Techniques

In any project the sequence through which the project is to develop should be decided. Therequirement is met in a systematic manner by scheduling techniques. The project schedulingtechniques are concerned with the resource time. One of the objectives of projectmanagement is to optimise the use of resources. Scheduling techniques offer solutions tooptimisation of project time.Technical scheduling can be done by different methods depending on the size of theproject. The methods used are as follows:

- ❖ Bar charts
- ❖ Milestone charts
- ❖ Network analysis

#### 6.1.2.1 Bar Charts

In dealing with complex projects, a pictorial representation showing the various jobs to be done and the time and money they involve is generally helpful. One such pictorial chart, also known as the bar chart, was developed by Henry Gantt around 1900. Bar chart is also referred to as Gantt chart. A typical bar chart form of project schedule depicts the various activities on a calendar time scale in the form of bars in their relative positions with start and finish dates and length of bar indicating probable activity duration. Linked bars represent the interdependencies between the activities. Bar chart type of schedule shall be used to comprehend, summarize and display the results of complex project network analysis and further monitoring and controlling process.

A bar chart consists of two coordinate axes, viz., one representing the time elapsed andthe other representing the job or activities to be performed. The jobs are represented in theform of bars as shown in Fig. 6.1.

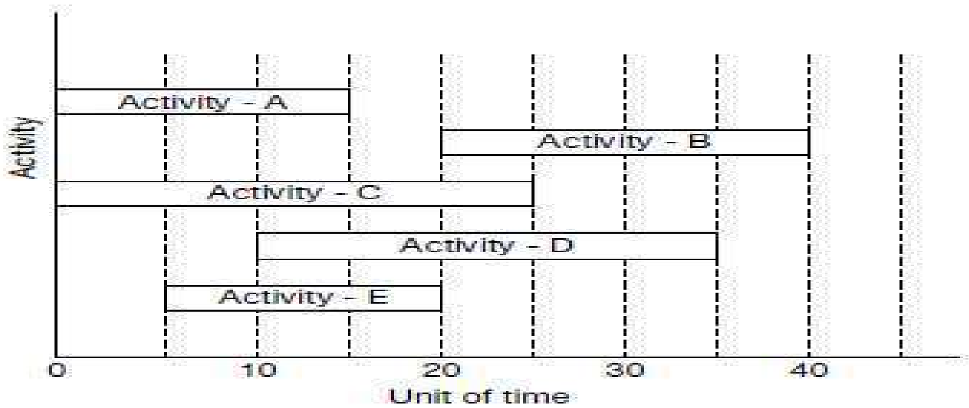



Fig. 6.1 Bar Chart

In any project there may be some activities which are to be taken up simultaneouslybut may take different lengths of time for their completion (e.g., Activities *A*and *C*) andsome activities have to be taken up only after the completion of some other activity (e.g.,Activities*A* and *B*). There may also be some activities which are independent of all otheractivities (e.g., Activities *D* and *E*).

### 6.1.2.2 Milestone Charts

The shortcomings or the inadequacies of the bar chart have been modified to some extentin milestone chart. In every activity, there are certain key events which are to be carriedout for the completion of the activity. Such key events are called milestones and they arerepresented by a square or circle. These events are those which can be easily identified overthe main bar representing the activity.

It has been observed in a long time activity the details will be lacking. If the activityis broken into a number of sub-activities or key events each one can be recognised duringthe progress of the project. In such cases controlling can be done easily and some interrelationshipsmay be established between the activities. In a milestone chart, the events arein chronological, but in a logical sequence. Figures 6.2 and 6.3 show the conventionalbar chart and milestone chart.

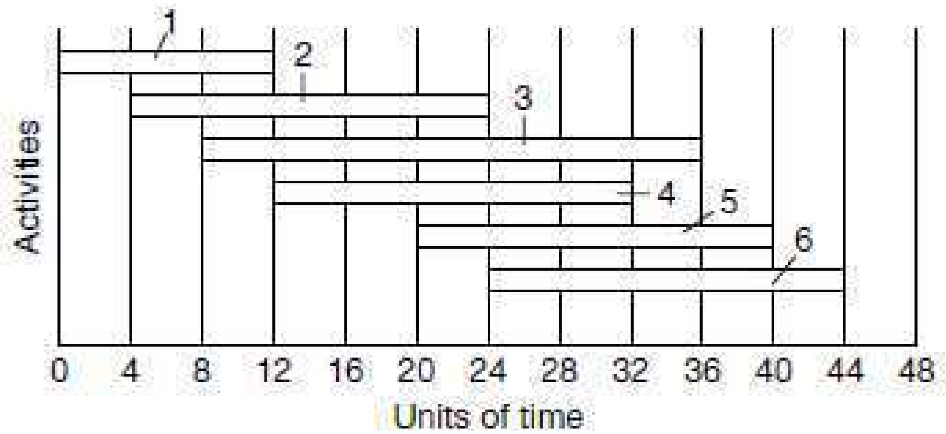



Fig. 6.2 Conventional Bar Chart

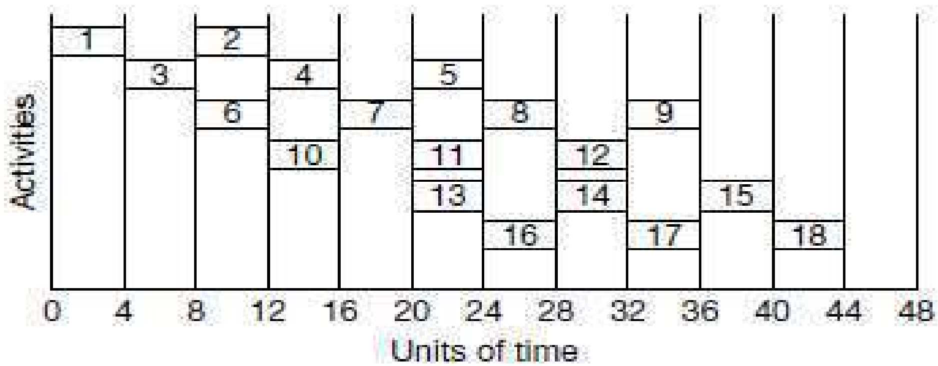



Fig. 6.3 Milestone Chart

### 6.1.2.3 Network Analysis

❖ **Principle of Network Analysis**

The network analysis techniques, developed between 1950s and 1960s, have now cometo be used as an effective management tool for planning, scheduling and controlling ofcomplex projects.

The term project network analysis is a general term covers all the network techniquesused for planning, scheduling and controlling of projects. The three techniques commonlyused are as follows:

- ❖ Critical Path Method (CPM)
- ❖ Program Evaluation and Review Technique (PERT) and
- ❖ Precedence Diagramming Method (PDM) or Precedence Network Analysis (PNA).

These network techniques produce time-oriented diagrams having activities organised into a logical order.

❖ **Network Diagram**

Network Diagram is a graphical flow plan of the activities that are to be accomplished forcompleting the project. The precedence and succedence relationships between activitiesare identified first.

Sequencing activities refers to finding out the logical relationships among the activitiesof a project and arranging them accordingly. By studying the project features the differentactivities involved in a project, the concerned officer-in-charge of the project establishes theprecedence-succedence relationships between the activities.

While deciding the logical relationships between the different activities, activities whichare mandatory to be operated before some of the activities to be taken up have to be identified.In addition there may be certain activities which may not be mandatory dependencies(such activities are called discretionary dependencies) are to be identified. After finalisingall the activities and finding their characteristics the network diagram for the project can bedrawn.

Activities of construction of a building are given in Table 6.1 and shown as networkdiagram in Fig. 6.4.

**Table 6.1**Activities of construction of a building

| Activity | Description | Immediate predecessors |
|---|---|---|
| A | Plan approval | – |
| B | Site preparation | – |
| C | Arranging foundation materials | A |
| D | Excavation for foundation | B |
| E | Carpentry work for Doors and Windows formain supporting frames | A |
| F | Laying foundation | C, D |
| G | Raising wall from foundation to sill | F |
| H | Raising wall from sill to lintel level | E, G |
| I | Casting of lintels | H |
| J | Raising wall above lintel up to roof base | I |
| K | Electrical wiring | I, J |
| L | Casting of roof | J |
| M | Fixing frames of doors and windows | L |
| N | Making of shutters | J |
| O | Plumbing works | L |
| P | Plastering | O |
| Q | Making ready shutters to Doors and Windows | P |
| R | White washing and painting | Q |
| S | Fitting Electrical and plumbing parts | R |
| T | Clearing the site before handing over | S |

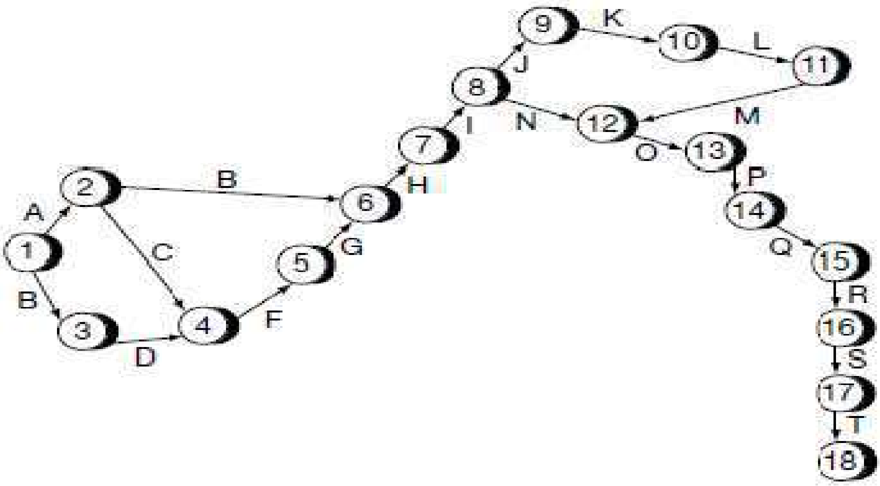



Fig. 6.4 Network Diagram

❖ **Definitions of Network Techniques**

❖ **Critical Path Method (CPM)**

In a network the sequence of activities arranged in each path will have different duration.The path that has the longest duration is called critical paths.

❖ **Program Evaluation and Review Technique (PERT)**

It uses three times, viz., optimistic time estimate, pessimistic time estimate and most likelytime estimate.

❖ **Precedence Network**

Here each activity is represented by a rectangular or square box. The time duration of the activity is incorporated inside the modal box.

## 6.2 Construction Project Management

### 6.2.1 General

A project is generally a non-recurring task having a definable beginning and end, with a definite mission and has a set of objectives and achievements. Project Management is application of knowledge, skills, tools and techniques to achieve the objectives of a definedproject with the aim to ensure that a project is completed within the scheduled time, authorized costand to the requirement of quality standards. TheConstruction Project Management refers to suchproject management when applied to construction of built facility. Project objectives depend on therequirements of the built facility. From the point ofview of Construction Project Management, projectobjectives may be defined in terms of scope, time, cost and quality. This may usually take place in projectappraisal stage. Information and guidelines givenunder 6.3.2 to 6.3.6 shall be appropriately utilized underdifferent stages for Construction Project Management.

### 6.2.2 Construction Project Life Cycle

Construction project life cycle consists of projectappraisal, project development, planning forconstruction, tender action, construction, andcommissioning and handing over, as main stages. Thesestages involve defined decisions, deliverables andcompletion of milestones for control of project,ensuring that the adverse impact of uncertainties isovercome at each stage in the progress.

Accordingly, the responsibilities of project team should be definedand measured for acceptance and liabilities determinedobjectively.

Project objectives, drawn out of feasibility established in the appraisal stage, are achieved progressively through each of the project life cycle stages. The stage wise break-up of project objectives, tasks, compliance and authorization to proceed further in the next stage should be structured comprehensively through variousstages of life cycle. Each stage of construction projectlife cycle may be considered as a sub-project, thusmaking overall complexities of a project moremanageable.A typical construction project life cycle is given inFig. 6.5.

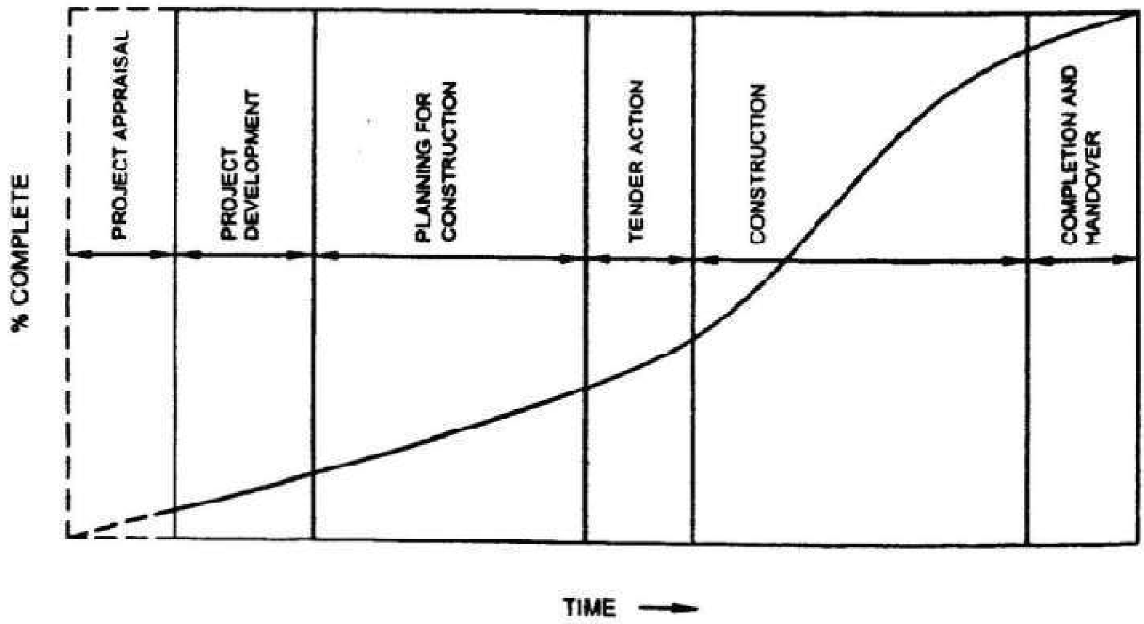



Fig. 6.5 Typical Construction Project Life Cycle

### 6.2.3 Construction Project Delivery Models

Projectdelivery modeldetermines the manner in whichthe project is planned, designed, executed and contractadministration carried out. It also determines thecontractual relationships between the owner/client,design consultants and construction agency. Thedelivery model shall define the span of control androle and responsibilities of each of the above parties.The main types of project delivery models that are invogue in the construction projects are:

- ❖ Traditional design-bid-build,
- ❖ Design-build with variants,
- ❖ Turn-key, and
- ❖ Build, operate and transfer and its variants.

Each of the delivery models can adoptdifferent types of contracts depending upon thesuitability of the contract type in relation to the natureand type of projects, project objectives and otherproject specific considerations.

### 6.2.4 Construction Methodologies/Techniques

Suitable construction methodologies/techniques, including conventional, prefabrication, systemsbuilding approach, mixed/composite construction, mechanization in construction, other innovativetechnologies, etc. shall be considered and anappropriate choice made depending upon the projectobjectives in terms of factors such as scope, time, cost and quality requirements.

**6.2.5 Organizational Structures**

Organizational structure depends on the projectdelivery model. As an example, a typical organizationchart for Design-Bid-Build model is given in Fig. 6.6.

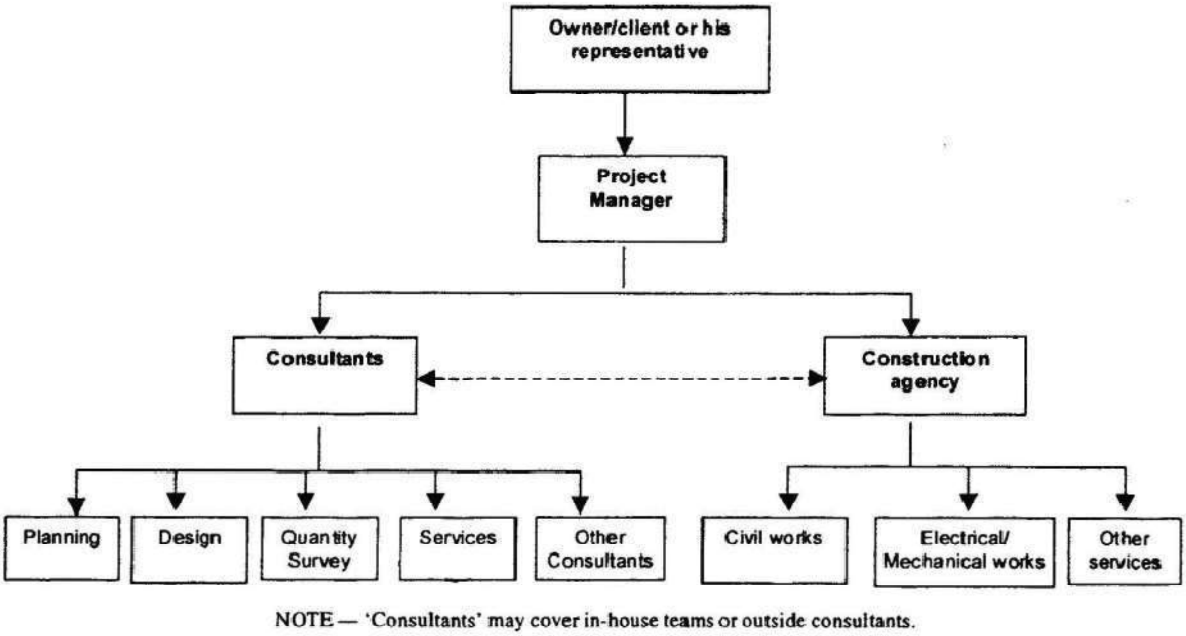



Fig. 6.6 Typical Organization Structure for Design-Bid-Build Model

**6.2.6 Construction Project Management Stages**

Typically a construction project (whether small orlarge) may be considered to involve the followingdistinct broad stages:

- ❖ Project appraisal stage
  - Inception,
  - Feasibility, and
  - Strategic planning.
- ❖ Pre-construction stage :
  - Project development.
  - Planning for construction, and
  - Tender action.
- ❖ Construction stage, and
- ❖ Commissioning and handing over stage.

Under each of the above stages, the relevantconstruction management function guidelines givenin 6.2.7should be employed for achieving the intendedobjectives.

**6.2.6.1 Pre-construction stage**

❖ **Project Development**

This will involve:

- ❖ Formalization of design brief;
- ❖ Site survey and soil investigation;
- ❖ Hazard risk vulnerability analysis;
- ❖ Alternative concept designs with costing and finalization;
- ❖ Preliminary designs and drawings;

- ❖ Development of design of each discipline and their integration;
- ❖ Obtaining statutory approvals;
- ❖ Decision on construction methodology;
- ❖ Preliminary cost estimates;
- ❖ Detailed design of each discipline;
- ❖ Construction working drawings and related specifications with integration of engineering inputs of all concerned disciplines;
- ❖ Detailed cost estimate;
- ❖ Detailed specifications and bill of quantities; and
- ❖ Tender documents.

Peer review/proof checking of the drawings/designs/estimates shall be done in case of important projects,depending upon their complexity and sensitivity.Environment impact analysis and social impact analysisshall be done in applicable cases.

❖ **Planning for Construction**

The following aspects shall be considered:

❖ **Sequencing of project components,**

Methodology of construction shall be detailed before the start of the project. Sequencing of project components shall be done on the basis of methodology adopted and availability of resources. This shall be reviewed during the progress of the project and revised, if necessary.

❖ **Planning tools:**

The planning tools described below may be employed for effective management of a construction project:

- ❖ **Work Breakdown Structure (WBS) –** The WBS shall identify the total scope of works involved in the project and shall form the basis for the development of detailed project schedule. Through WBS, the project shall be sub-divided into major sub-divisions (work packages) and each major sub-division shall be further sub-divided into additional levels as required up to the level of activities that could form the basis for monitoring and control of project performance in terms of time, cost and quality parameters.WBS shall provide activity listing with associated cost account codes for the preparation of project schedule either by bar charts or by network diagramming methods.
- ❖ **Bar Chart -** Bar chart is the simplest form of project scheduling and used for small and complex projects and in preliminary planning and tender stages of major projects. Other details already mentioned at 6.1.2.1.
- ❖ **Network Techniques and Scheduling**
  - **Network Diagramming** Methods Network based project schedule shall be used for major and complex projects. In this method, the network of project activities identified through WBS is developed incorporating their logical relationships and interdependencies. The two available approaches for network diagramming techniques are Arrow Diagramming Method (ADM) and Precedence Diagramming Method (PDM).
  - **Network Analysis and Scheduling** – The project network incorporating the activity durations and logical relationships shall be analyzed with forward and backward pass schedule calculations to establish early and late start and finish time of activities with their available floats, critical activities, critical path and overall project duration. The project schedule is prepared in terms of calendar dates of start and finish of activities with available floats. The network schedule shall also be presented in the form of linked bar chart or in tabular format.

For details on network preparation and analysis, reference shall be made to IS 14580 (Part 1) and IS 14580 (Part 2). Network schedule shall be prepared for all disciplines and they shall be integrated into a Master Control Schedule

❖ **Resource planning**

This shall involve the following:

- ❖ **Resource Allocation -** The feasibility of the network shall be checked with respect to manpower, equipment, other resources required at the site.
- ❖ **Resource Levelling** - It shall be done by reallocating the slack resources from non-critical path to critical path activity in order to obtain a reduction of time or by shifting the activities within the floats available with them, to obtain optimum uniform resource requirements.
- ❖ **Resource Schedule** - Schedule of following resource requirements with respect to time shall be prepared on the basis of network developed and kept in the database for project control purposes:
  - Technology,
  - Manpower (Technical staff, Skilled labour, andUnskilled labour)
  - Machinery,
  - Materials, and
  - Cash flow.

Resource schedule shall be prepared separately for client, consultant and construction agency.

❖ **Time cost trade-off.**

Time cost trade-off analysis shall be done to obtain aminimum total cost of the project within the specifiedtime. This shall bedone taking into consideration directcost and indirect cost of the project.

- ❖ **Tender Action**
  - **Preparation of tender documents:** The bill of quantities, specifications, drawings and conditions of contract should be prepared on the basis of design and details finalized in project proposal development stage keeping in view the construction project delivery model selected. The format, terminologies and terms and conditions should be as per the standard engineering practices. In case of any special item or condition, the same shall be described clearly to avoid any ambiguity.
  - **Selection of Construction agency:** Selection of construction agency shall be done by eitherOpen Competitive Bidding- In this case, tender notice should be publicized adequatelyto obtain competitive tenders from competent agencies for the project ; orLimited Competitive Bidding - In large, specialized and important works,pre-qualification of contractors shall be doneconsidering their financial capability, bidcapacity, experience of similar type of works,past performance; technical staff; and plantsand machinery available.
  - **Bid evaluation,negotiation and award of work***:* After due evaluation and negotiationwith the bidders, if required, the work shall be awarded to theconstruction agency based on competitive technical andfinancial bids.

**6.2.6.2 Construction Stage**

This is one ofthe most important stages of constructionmanagement where pre-construction stage outputs arerealized into physical tangible form within theconstraints of time and cost. The intent or need forfunctional and physical characteristics, defined in thepre-construction stage outputs through specifications,drawings and consolidated project brief is realizedthrough various construction project managementfunctions described in6.3.7 and particularly through:

- ❖ Time management,
- ❖ Cost management, and
- ❖ Quality management.

**6.2.6.3 Commissioning and Handing Over**

After the project is complete as per specifications anddesigns, project commissioning and handing over stagefollows. It shall need the compliance of the following:

- ❖ Clearing of site,
- ❖ Removal of all defects at the time of completion and during defect liability period,
- ❖ Preparation of list of inventories,
- ❖ Certification and settlement of construction agency's final bills for payment,
- ❖ Obtaining completion certificate from local government bodies/departments,
- ❖ Preparation of maintenance manual,
- ❖ Performance compliance verification of built facility,
- ❖ Handing over all other required documents to the client/owner.
- ❖ Restoration of surroundings. and
- ❖ Preparation and handing over all as-built drawings.

**6.2.7 Construction Project Management Functions**

Construction Project Management consists of numberof processes and these can be grouped under thefollowing management functions:

- ❖ Scope management,
- ❖ Procurement management,
- ❖ Time management,
- ❖ Cost management,
- ❖ Quality management,
- ❖ Risk management,
- ❖ Communication management.
- ❖ Human resources management.
- ❖ Safety, health and environment management,
- ❖ Integration management, and
- ❖ Other management processes.

The project management functions briefly describedbelow may be employed for effective management ofconstruction project during its different stages asapplicable. Some of the processes may, however, overlap more than one function.

**6.2.7.1 Scope Management**

It should be ensured that project features and functionsremained as established during the finalization stage.Scope management includes the processes of scopeplanning, scope definition, scope verifications.

Scope monitoring and change control are critical tothe construction stage in order to control time and costover-runs. The work breakdown structure of the projectshall be the basic tool for defining the scope baseline.Scope control should aim to identify factors influencingscope change, determine the impact of scope changesand establish the system for scope change approvaland revision of scope baseline. Accordingly, a detailedscope management plan should be drawn to lay downall the necessary practices including technical andorganizational interfaces.For further details on scope management, reference shall be made to IS 15883 (Part 6).

#### 6.2.7.2 Procurement Management

Procurement management includes processes forpurchase of materials, equipment, products, solicitingservices of consultants and engaging agencies forexecution of works under a contract. Projectprocurement processes, which depend on type ofproject delivery model include identification of procurement needs, preparation for procurement, soliciting proposals, selection of suppliers/consultants/works contractors, administering of contract, contractmanagement and closure of contract. Project manager is charged with the responsibility to help structure and develop contract to suit the specific needs of the project. As contract, which is an output of project procurement management processes, is a legal document, theprocurement processes should follow detailedprocedures with adequate review and stakeholderappraisal opportunities.

One of the fundamental issues in construction projects,managed through project managers, is to determinewhat needs may be met by procuring products, servicesand works from external agencies and what should beaccomplished by the project team. This decision is bestarrived at the earlier stages of the project (so that theopportunities of procurement initiation at earlier stagesis not lost) and reviewed at each of the subsequent lifecycle stages of the project. Such decisions should draw inputs from the time, cost, quality and scopemanagement processes. Various procurement routesshould be analyzed on their suitability to both time and cost criteria of project. As a strategy forprocurement, a project procurement management planshould be developed to document: contract types to be used; procurement documents; coordination ofprocurement with schedules; constraints andassumptions; risk mitigation activities (performance bonds, insurances etc); and pre -qualification of suppliers. In addition, specifications, quality standards,performance data at work locations, etc. which are part of project scope statement should be described.Inventory management plays an important role in theprocurement management process.

Provision of establishment of suitable dispute redressalsystem should be inbuilt to take care of any disputes that may arise. For further details on procurement management, reference shall be made to IS 15883 (Part 7).

#### 6.2.7.3 Time Management

Time management aims to complete the project withinthe stipulated time period. Time managementessentially involves the following processes:

- Defining project scope in the form of work breakdown structure to generate activity identification and listing,
- Activity duration estimating,
- Activity sequencing with interactivity dependencies,
- Project schedule development. and
- Project schedule control.

Work breakdown structure should be used as a tool to prepare the project schedule by defining the projectscope and identifying and listing of the activities inthe work packages. For the quantum of work involvedin the activities, the activity durations are estimatedbased on the standard productivity norms for differenttrades of work. Past-documented experience andexpertise should also be used for determination of theactivity durations with the construction technologyadopted and manpower and equipment resources used.Based on the construction methodology proposed withthe consideration of project specific constraints. Thesequencing and interdependencies of the activities aredetermined and the graphical representation ofactivities in the form of network should be prepared.The network thus prepared should be analyzed todevelop the project schedule with information on earlyand late start and finishing of activities with theiravailable floats and the critical path/critical activitieson the network. Incorporating the calendar dates, thebaseline schedule may be finalized with theincorporation of milestones for subsequent schedulemonitoring and control processes.

During the construction stage, schedule monitoringinvolves methods of tracking and comparing the actualschedule with the baseline schedule and schedulecontrol activities should ensure to remove deficienciesand slippages corrected to acceptable levels.

Project scheduling and monitoring is adynamic processand periodic schedule updating should be done foreffective monitoring and control process. In theprocess, the status of each activity should be examined.For completed activities, actual durations utilized, areincorporated; and for activities in progress, balance tocomplete revised durations and estimated finish datesare determined and incorporated. If the actual schedulelags behind the baseline schedule, various optionsshould be considered to control and bring back theschedule to acceptable levels. The possible controlactions, which may be considered are: possiblereduction in activity duration of future activities withalternate technology options,increasing the resources,alteration in the construction logic and activitysequencing, etc.For further details on time management, reference shall be made to IS 15883 (Part 2).

**6.2.7.4 Cost Management**

The objective of the project cost management is toensure that the project is completed within theauthorized budget. The major processes involved inthe cost management are: resource planning, costestimation, cost budgeting/cost planning and costmonitoring and control. The resource planning involvesdetermination of various types of resources, such asappropriate technology, workforce, materials,equipments and infrastructure facilities, their quantumand their requirements during different stages of theproject. Preliminary cost estimate with defined scopeof work is required for obtaining the project sanction.Detailed item wise cost estimates with bill of quantitiesand specifications should he made for tendering andsubsequent project execution. The type of contractadopted such as item rate, percentage rate, lump sumand cost plus, influences the cost management strategy.

Most of the cost optimization techniques through valuemanagement studies are achieved during the pre-construction stage of the project. Valuemanagement is a useful technique for application in costmanagement. It is a systematic multi-disciplinary effortdirected towards analyzing the functions of project oritem for the purpose of achieving the best value at thelowest overall life cycle project cost. It is an establishedtechnique for determining value based decisions ratherthan cost reduction based on change in specifications.Suitability of construction techniques, selection ofequipments for specific purposes, consideringalternative materials and other design changes are someof the areas of application of value engineering .

During construction stage, the efforts are more oncontrol mode for adherence to the budgeted cost. Forthe purpose of cost control during execution, the timebased cost baseline of the project which forms the basisfor the measurement and monitoring of cost performance, should be generated. The cost baselineis generated by allocating the overall cost estimate toindividual project activities based on the projectschedule. Using the cost baseline, the cost control,which comprises the following, should he exercised:

- Periodical cost reporting,
- Comparison of the actual cost against the planned cost,
- Obtaining early warning for corrective actions,
- Control and monitoring cost chanres,
- Forecasting of final cost at completion based on cost trend and cost changes, and

- ❖ Modification of the cost baseline for authorized cost changes and preparation of revised estimates.

For further details on cost management, reference shall be made to IS 15883 (Part 3).

**6.2.7.5 Quality Management**

Quality management in construction aims to achieverequired functional and physical characteristics of aconstructed facility through management actionsincluding planning, direction and control. Quality isthe key determinant of requirements which is expressedthrough drawings and specifications. Main function ofquality management is to achieve quality objective ofsatisfying requirements through performanceevaluation of construction processes and ensure thatthey are directed towards overall quality. Qualitymanagement during construction stag assumes thatthe design and specifications comprehensivelyincorporate requirements of users and otherstakeholders.Prior to selling out for the construction, the client should completely understand theimplications of changes to the design and specificationsduring the construction stage, which may affect quality.

Although quality is an all-encompassing concept which also has bearing on time and cost aspects, the specificscope of quality management may be limited toits keyfunctions of quality planning, quality assurance and quality control. Quality planning refer, to theidentification of relevant quality standards anddetermining how to satisfy them. Quality assuranceactivities include consistent evaluation of projectperformance to provide confidence that the projectsatisfies the relevant quality standards. Qualitycontrolmonitors project results related till the compliance toquality standards and identifying means to eliminatenon-conformity.

On-site operations constitute most of the constructionprocesses. Scope of quality management for on-site operations may be categorized broadly in three distinctstages. In the 'receiving stage', materials and suppliesare inspected and tested for conformance to the specified standards. During, ‘in-process stage’, materials and supplies are processed to form projectproduct components wherein process control ensuresconformance to the specified standards. In the 'finalstage', inspections and tests monitor the functional andphysical performance of the product/service to ensurethat they satisfy the requirements.

Planning being an integral part of the qualitymanagement, may also consider efficient site layoutand its management for on-site operations. In additionto time and cost implications of the site management,the quality performance improves by efficientorganization of activities by way of providing adequateand appropriate conditions for the work processes. Sitemanagement needs to consider construction technologyconstraints with reference to aspects related to spaceavailability such as permanent services, access to site,temporary services, location of material stores, stackingand storage areas and plants, fencing and othertemporary structures.

The various organizations connected with the projectshould have their own quality management systems. For further details on quality management, reference shall be made to IS 15883 (Part 4).

**6.2.7.6 Risk Management**

Project risks have an impact on the project objectivesand need a planned response. Project risk managementprocesses ensure proper planning, identification,analysis, monitoring and control to the best interest ofthe project.

Risk management planning processes develop anapproach to risk management activities which include planning, execution and monitoring . A riskmanagement plan should define lead and support roleresponsibilities of project team in relation to management, budgeting, risk responsive scheduling, classification of risk activities based on risk break-downstructure and explanation of probability and impact forrisk context.

Risk response planning determines actions required forreducing impact of risks. Risk responses are establishedand assigned to appropriate project participants.Suitable risk mitigation measures should be evolvedfor identified risks.For further details on risk management, reference shall be made to IS 15883 (Part 8).

**6.2.7.7 Information and Communication Management**

For information and communication management, Management Information System (MIS) is used as animportant tool for systemized approach to furnishinformation. It comprises a system that collects, stores, sorts and analyzes data to generate and communicateinformation. It may be a combination of manual andcomputerized systems.

At the construction stage of a project, there are many agencies involved like client, architect, engineer,project manager, various consultants, materialsuppliers, construction agencies and sub-contractors.Each agency is divided into top level managementtaking policy decisions, middle level managementmonitoring the project and lower level managementinvolved in day to day operations of the project.

Each level of management requires information of varying details, at different periodicities and in differentformats. Project progress information flows from lower level to the top level management and policy decisionsflow from top level to the lower level management.

MIS integrates the work and information flow withineach agency and flow of information between differentagencies.

In construction stage of the projects, the informationmay be in the form of data reflecting status of projectin terms of actual execution time for each activity, cost Incurred, resources used, quality control, material management, bills, organization management and otheradministrative aspects like disputes that may come up.This data should beanalyzed to understand the overallprogress achieved and to update schedules of theproject.

Basic objectives of MIS of a construction project maybe summarized as:

- Providing benchmark against which to measure or compare progress and costs, like time network schedules, cost estimates, material and labour schedules, specifications, working drawings.
- Providing an organized and efficient means of measuring, collecting, verifying and reflecting the progress and status of operations on the project with respect to progress, cost, resources and quality.
- Providing an organized, accurate and efficient means of converting the data from operations into information.
- Reporting the correct and necessary information in the required format and at the required level of detail to managers at all levels and to the supervisors.
- Identifying and isolating the most important and critical information at various stages to be communicated to the managers and supervisors for taking decisions.
- Communicating the information to the managers and supervisors in time so that decisions may be taken at the right time.

Total MIS configuration of the construction projectmay bedivided into the following modules:

- Planning and scheduling module.
- Cost control and accounting module.
- Trend and forecast module.
- Project administrative and financial module.
- Historical and documentation module.

All modules should be interlinked in flow ofinformation and generation of reports. For large public projects, suitable mechanism may beestablished for communication of relevant informationto public at large.For further details on Information and Communication Management, reference shall be made to IS 15883 (Part 9).

**6.2.7.8 Human Resource Management**

All construction projects involve large number ofskilled/unskilled persons. Human resources in a projectshould be adequately qualified, trained and competent.

Quality of construction work depends on the quality of labour resource. For skilled and unskilled labour, the requirement for technical knowledge, skill andgeneral awareness are varied for different constructionprocesses. Labour is required to understand theirrespective responsibilities especially towards the work. Therefore, construction management practices should emphasize on development of competence ofthis critical human resource through trainingprogrammes.

The critical activities should be identified from thepoint of view of technological innovations, workmanship and environmental conditions whichdetermine labour behaviour and performance. In eachconstruction project, there are certain work relatedpeculiarities which call for job specific orientation.There should be a clearly defined competencerequirement for the workmen. As far as possible, a formal training or a certified course undertaken shouldbe a preferred selection criterion for the workers. Aperiodic review of the performance may be made toestablish the nature of training required and methodsfor imparting training. There is a need to address themotivational aspects, for better performance.For further details on human resource management, reference shall be made to IS 15883 (Part 10).

**6.2.7.9 Health, Safety and Environment Management**

❖ Health management issues include looking into the risk factors to health of construction personnel and providing hygiene conditions at construction sites and methods of their management. It includes managing,

- ❖ Occupational/physical health hazards.
- ❖ Short term as well as long-term ill effects of the activities and the working environment of the construction sites.
- ❖ Provision of personal protective equipment required for specific health hazards. And
- ❖ Laying down of construction hygiene control methods.

❖ Safety management issues include managing work processes, equipment and material handling at site for striving to achieve zero accident status at site. For prevention and management of accidents, a proper organizational and administrative mechanism is required. Following steps should be taken for achieving the same:

- ❖ Laying down of safety regulations or mandatory prescriptions concerning different work processes.
- ❖ Standardization of work processes and management actions.
- ❖ Regular and stipulated inspection of works and machinery/equipments for enforcement of mandatory regulations.
- ❖ Providing education and training to workers on safety issues.
- ❖ Publicity and appeal to develop safety consciousness.
- ❖ Insurance of built facilities. Construction personnel and third party.
- ❖ Regular safety audit of construction sites.
- ❖ Effective post accident action including accident analysis and reporting.
- ❖ Effective post accident management including corrective measures to avoid repetition of suchaccidents.

Safety Officer shall be appointed in accordance withthe concerned provisions of the Building and other Construction Works (Regulation ofEmployment andConditions of Service) Act. 1996. Safety officer whois posted at a medium to major construction site shall:

- ❖ Look after the safety of the personnel. Safe handling of materials and machinery, safe work practices and standard operating procedures;
- ❖ Be responsible for compliance of all statutory obligations of the employer in regard to safety of personnel and structures;
- ❖ Guide and assist the site managers/engineers to make their sites safe and accident free;
- ❖ Train personnel in construction safety, conduct safety surveys and design suitable documents for recording and promoting safety on sites and in the construction industry.
- ❖ Arrange for safety briefing for all the persons entering the construction area .

❖ Environment management issues include the following:

- ❖ Minimizing adverse environmental impact of activities, products and services.
- ❖ Limiting any adverse impact within the laws/ prescribed norms and their monitoring.
- ❖ Safety of environment while working with hazardous materials and maintaining material safety data sheets.
- ❖ Management of disposal of waste from the construction sites.
- ❖ Considering positive environmental contribution particularly after completion of construction.
- ❖ Mechanism to review concerns of interested parties.

.For further details on Health, Safety and Environment Management, reference shall be made to IS 15883 (Part 5).

**6.2.7.10 Integration Management**

Integration management aims to provide processesnecessary for coordination amongst variousorganizations and their teams involved. It ensures thatvarious organizational teams perform in an integratedmanner, with their actions coordinated to the mutualinterests towards the project. Integrated managementprocesses provide opportunities for resolving conflictsand competing interests through appropriate trade-offs.Integration is necessary where processes interact,especially when process responsibilities belong todifferent organizational groups. Such processinteractions need organizational interfaces to be defined and resolved at an overall level.

Integration management may also be required forspecific situations when impact of one managementfunctions is a cause for concern for other management functions. For example, if there is a time delay inperforming a particular construction process, it mayoften have impact on the cost aspects of nor only thatprocess but other processes involving otherorganizational groups; the rescheduling may affectcoordination amongst performing groups in the downstreamprocesses and activities.For further details on Integration Management, reference shall be made to IS 15883 (Part 12).

**6.2.7.11 Other Management Issues**

With the steady increase in global population and therapid depletion of natural resources, the projectmanager may have to address various other issues suchas energy management and sustainability.For further details on sustainability Management, reference shall be made to IS 15883 (Part 11).

## 6.3 Monitoring

It is important to monitor the progress of work during execution so that time frame already set for completion of the work is not exceeded. So to complete the project on time the site Supervisor shall maintain progress of the work on daily, weekly and monthly basis and same shall be forwarded to higher authorities.

**6.3.1** To monitor the progress of the work at various stages, necessary data must be maintained at site showing the position of each activity, targets to be achieved, bottlenecks, if any, expenditure and position of funds, etc.

**6.3.2** Monthly/quarterly progress reports may be prepared in the Performa prescribed by the department and submitted regularly to the concerned officers for their information and for keeping a close watch on the progress of the work and the problems encountered in the field with a view to sort them out.

## 6.4 Record Keeping and Documentation.

It is important to record an activity or conversation in writing and not leave these events to memory. It is extremely difficult to recall events that have occurred five or six years in the past. If an activity or event is not recorded in writing and there is a conflict in those positions, then the arbitrator or judge is left in a difficult position of determining which witness is more credible.

Good record keeping is based on a fair and unbiased recording of actual facts and not speculation or denigration of personalities. Written factual records of any event will always be preferred over oral recollections or reconstruction of the event.

If a claim or dispute appears to arise this should be recorded with the other parties. Relevant photographs of change in work and circumstances forming the basis of a claim often lead to a quick resolution of the dispute.

Record of design and drawings as approved for construction and completion of drawings as per actual construction should be maintained meticulously at the division / circle office or at Chief Engineer's office. To save storage space micro filming system may be introduced.

## 7. SPECIAL CONSTRUCTION PROCEDURES - EARTHQUAKE EFFECTS

The Special construction procedures / techniques shall be followed to make our buildings Earthquake resistant. For this relevant IS codes of practices ( IS-1893, IS-13920, IS-4326 etc) shall be followed. However general guidelines are summarized as below:

### 7.1 Earthquake-Resistant Design of Buildings:

Buildings should be designed like the ductile chain. For example, consider the common urban residential apartment construction - the multi-storey building made of reinforced concrete. It consists of horizontal and vertical members, namely beams and columns. The seismic inertia forces generated at its floor levels are transferred through the various beams and columns to the ground. The correct building components need to be made ductile. The failure of a column can affect the stability of the whole building, but the failure of a beam causes localized effect. Therefore, it is better to make beams to be the ductile weak links than columns. This method of designing RC buildings is called the strong-column weak-beam design method (Figure 4). By using the routine design codes (meant for design against non-earthquake effects), designers may not be able to achieve a ductile structure. Special design provisions are required to help designers improve the ductility of the structure. Such provisions are usually put together in the form of a special seismic design code, e.g., IS:13920-2016 for RC structures. These codes also ensure that adequate ductility is provided in the members where damage is expected.

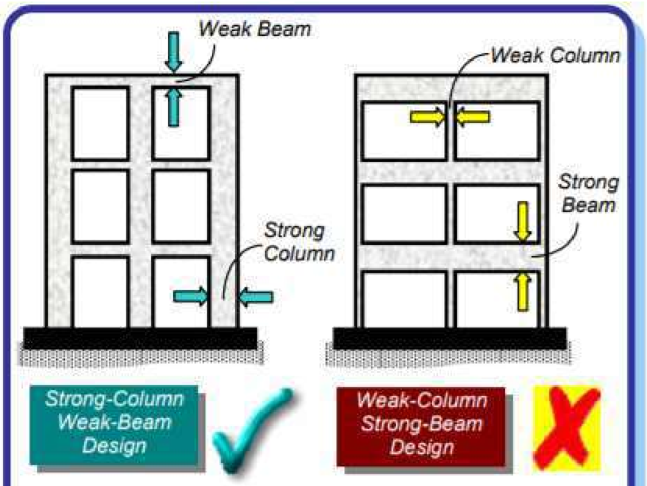



**Figure 4: Reinforced Concrete Building Design:** *the beams must be the weakest links and not the columns – this can be achieved by appropriately sizing the members and providing correct amount of steel reinforcement in them.*

### 7.2 Quality Control in Construction:

The capacity design concept in earthquake resistant design of buildings will fail if the strengths of the brittle links fall below their minimum assured values. The strength of brittle construction materials, like masonry and concrete, is highly sensitive to the quality of construction materials, workmanship, supervision, and construction methods. Similarly, special care is needed in construction to ensure that the elements meant to be ductile are indeed provided with features that give adequate ductility. Thus, strict adherence to prescribed standards of construction materials and construction processes is essential in assuring an earthquake-resistant building. Regular testing of construction materials at qualified laboratories (at site or away), periodic training of workmen at professional training houses, and on-site evaluation of the technical work are elements of good quality control.

## 7.3 Behaviour of Brick Masonry Walls.

Masonry buildings are brittle structures and one of the most vulnerable of the entire building stock under strong earthquake shaking. The large number of human fatalities in such constructions during the past earthquakes in India corroborates this. Thus, it is very important to improve the seismic behaviour of masonry buildings. A number of earthquake-resistant features can be introduced to achieve this objective. Ground vibrations during earthquakes cause inertia forces at locations of mass in the building. These forces travel through the roof and walls to the foundation. The main emphasis is on ensuring that these forces reach the ground without causing major damage or collapse. Of the three components of a masonry building (roof, wall and foundation) (Figure 1a), the walls are most vulnerable to damage caused by horizontal forces due to earthquake. A wall topples down easily if pushed horizontally at the top in a direction perpendicular to its plane (termed weak direction), but offers much greater resistance if pushed along its length (termed strong direction) (Figure 1b). The ground shakes simultaneously in the vertical and two horizontal directions during earthquakes. However, the horizontal vibrations are the most damaging to normal masonry buildings. Horizontal inertia force developed at the roof transfers to the walls acting either in the weak or in the strong direction. If all the walls are not tied together like a box, the walls loaded in their weak direction tend to topple (Figure 2a). To ensure good seismic performance, all walls must be joined properly to the adjacent walls. In this way, walls loaded in their weak direction can take advantage of the good lateral resistance offered by walls loaded in their strong direction (Figure 2b). Further, walls also need to be tied to the roof and foundation to preserve their overall integrity.

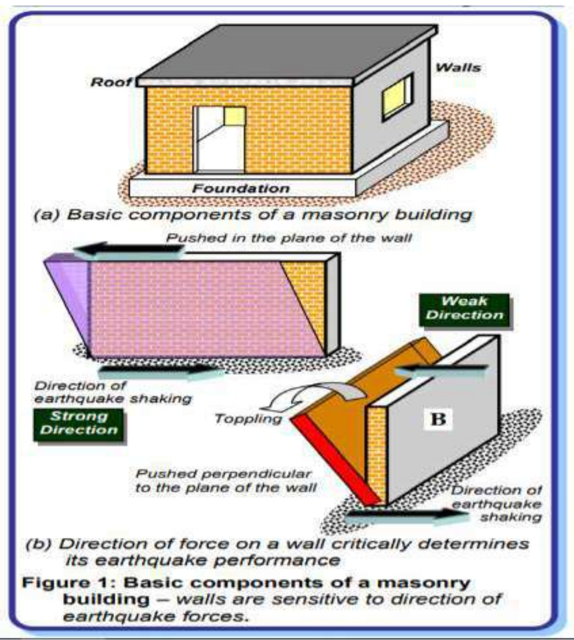



**Figure 1: Basic components of a masonry building** – *walls are sensitive to direction of earthquake forces.*

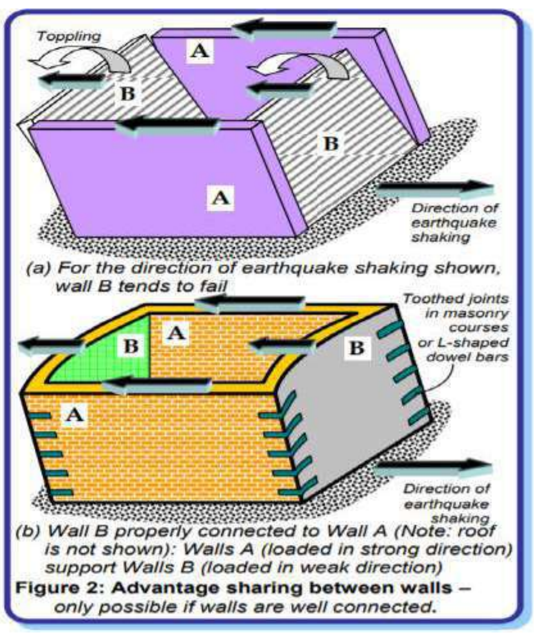



**Figure 2: Advantage sharing between walls** – *only possible if walls are well connected.*

### 7.3.1 How to Improve Behaviour of Masonry Walls:

Masonry walls are slender because of their small thickness compared to their height and length. A simple way of making these walls behave well during earthquake shaking is by making them act together as a box along with the roof at the top and with the foundation at the bottom. A number of construction aspects are required to ensure this box action. Firstly, connections between the walls should be good. This can be achieved by (a) ensuring good interlocking of the masonry courses at the junctions, and (b) employing horizontal bands at various levels, particularly at the lintel level. Secondly, the sizes of door and window openings need to be kept small. The smaller the openings, the larger is the resistance offered by the wall. Thirdly, the tendency of a wall to topple when pushed in the weak direction can be reduced by limiting its length-to-thickness and height to-thickness ratios (Figure 3). Design codes specify limits for these ratios. A wall that is too tall or too long in comparison to its thickness, is particularly vulnerable to shaking in its weak direction (Figure 3).

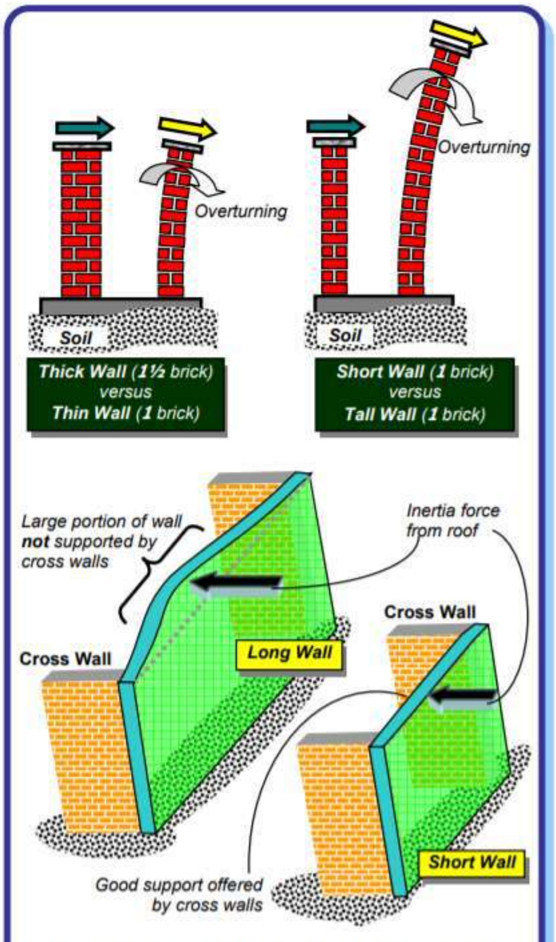



**Figure 3: Slender walls are vulnerable** – *height and length to be kept within limits. Note: In this figure, the effect of roof on walls is not shown.*

### 7.3.2 Choice and Quality of Building Materials:

Earthquake performance of a masonry wall is very sensitive to the properties of its constituents, namely masonry units and mortar. The properties of these materials vary across India due to variation in raw materials and construction methods. A variety of masonry units are used in the country, e.g., clay bricks (burnt and unburnt), concrete blocks (solid and hollow), stone blocks. Burnt clay bricks are most commonly used. These bricks are inherently porous, and so they absorb water. Excessive porosity is detrimental to good masonry behaviour because the bricks suck away water from the adjoining mortar, which results in poor bond between brick and mortar, and in difficulty in positioning masonry units. For this reason, bricks with low porosity are to be used, and they must be soaked in water before use to minimise the amount of water drawn away from the mortar. Various mortars are used, e.g., mud, cement-sand, or cement-sand-lime. Of these, mud mortar is the weakest; it crushes easily when dry, flows outward and has very low earthquake resistance. Cement-sand mortar with lime is the most suitable. This mortar mix provides excellent workability for laying bricks, stretches without crumbling at low earthquake shaking, and bonds well with bricks. The earthquake response of masonry walls depends on the relative strengths of brick and mortar. Bricks must be stronger than mortar. Excessive thickness of mortar is not desirable. A 10mm thick mortar layer is generally satisfactory from practical and aesthetic considerations. Indian Standards prescribe the preferred types and grades of bricks and mortars to be used in buildings in each seismic zone.

## 7.4 Simple Structural Configuration of Masonry Buildings:

### 7.4.1 Box Action in Masonry Buildings:

Brick masonry buildings have large mass and hence attract large horizontal forces during earthquake shaking. They develop numerous cracks under both compressive and tensile forces caused by earthquake shaking. The focus of earthquake resistant masonry building construction is to ensure that these effects are sustained without major damage or collapse. Appropriate choice of structural configuration can help achieve this. The structural configuration of masonry buildings includes aspects like (a) overall shape and size of the building, and (b) distribution of mass and (horizontal) lateral load resisting elements across the building. Large, tall, long and asymmetric buildings perform poorly during earthquakes . A strategy used in making them earthquake resistant is developing good box action between all the elements of the building, i.e., between roof, walls and foundation (Figure 1). Loosely connected roof or unduly slender walls are threats to good seismic behaviour. For example, a horizontal band introduced at the lintel level ties the walls together and helps to make them behave as a single unit.

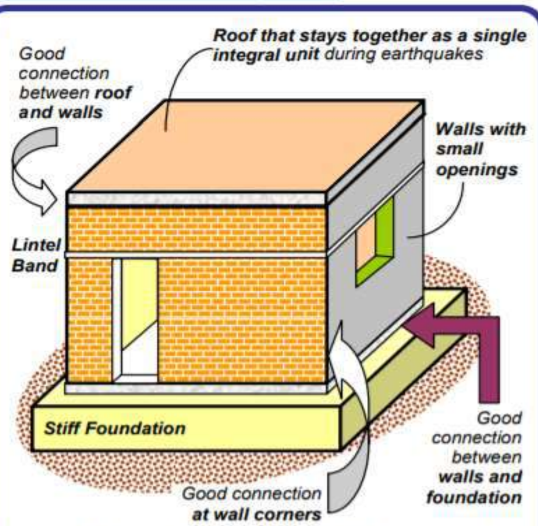



**Figure 1: Essential requirements to ensure *box action* in a masonry building.**

### 7.4.2 Influence of Openings:

Openings are functional necessities in buildings. However, location and size of openings in walls assume significance in deciding the performance of masonry buildings in earthquakes. To understand this, consider a four-wall system of a single storey masonry building (Figure 2). During earthquake shaking, inertia forces act in the strong direction of some walls and in the weak direction of others. Walls shaken in the weak direction seek support from the other walls, i.e., walls B1 and B2 seek support from walls A1 and A2 for shaking in the direction shown in Figure 2. To be more specific, wall B1 pulls walls A1 and A2, while wall B2 pushes against them. At the next instance, the direction of shaking could change to the horizontal direction perpendicular to that shown in Figure 2. Then, walls A and B change their roles; Walls B1 and B2 become the strong ones and A1 and A2 weak. Thus, walls transfer loads to each other at their junctions (and through the lintel bands and roof). Hence, the masonry courses from the walls meeting at corners must have good interlocking. For this reason, openings near the wall corners are detrimental to good seismic performance. Openings too close to wall corners hamper the flow of forces from one wall to another (Figure 3). Further, large openings weaken walls from carrying the inertia forces in their own plane. Thus, it is best to keep all openings as small as possible and as far away from the corners as possible.

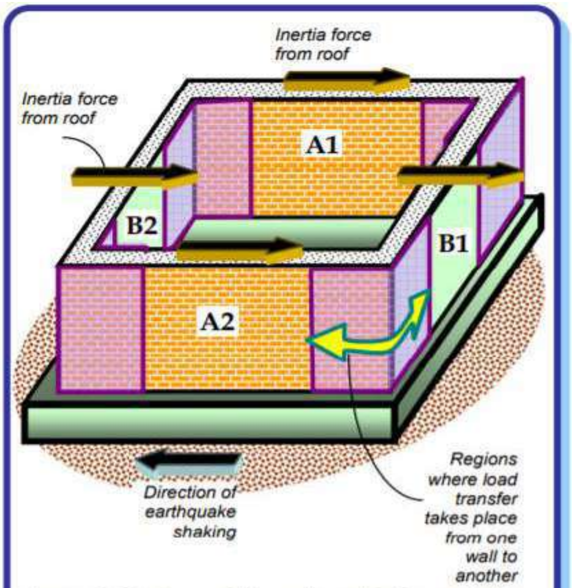



**Figure 2: Regions of force transfer from weak walls to strong walls in a masonry building** – *wall B1 pulls walls A1 and A2, while wall B2 pushes walls A1 and A2.*

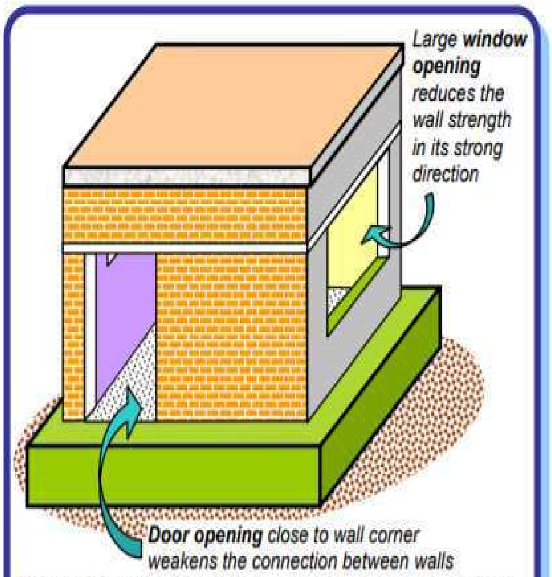



**Figure 3: Openings weaken walls in a masonry building** *–a single closed horizontal band must be provided above all of them.*

### 7.4.3 Earthquake-Resistant Features:

Indian Standards suggest a number of earthquake resistant measures to develop good box-type action in masonry buildings and improve their seismic performance. For instance, it is suggested that a building having horizontal projections when seen from the top, e.g., like a building with plan shapes L, T, E and Y, be separated into (almost) simple rectangular blocks in plan, each of which has simple and good earthquake behavior. During earthquakes, separated blocks can oscillate independently and even hammer each other if they are too close. Thus, adequate gap is necessary between these different blocks of the building. The Indian Standards suggest minimum seismic separations between blocks of buildings. However, it may not be necessary to provide such separations between blocks, if horizontal projections in buildings are small, say up to ~15-20% of the length of building in that direction. Inclined staircase slabs in masonry buildings offer another concern. An integrally connected staircase slab acts like a cross-brace between floors and transfers large horizontal forces at the roof and lower levels (Figure 4a). These are areas of potential damage in masonry buildings, if not accounted for in staircase design and construction. To overcome this, sometimes, staircases are completely separated (Figure 4b) and built on a separate reinforced concrete structure. Adequate gap is provided between the staircase tower and the masonry building to ensure that they do not pound each other during strong earthquake shaking.

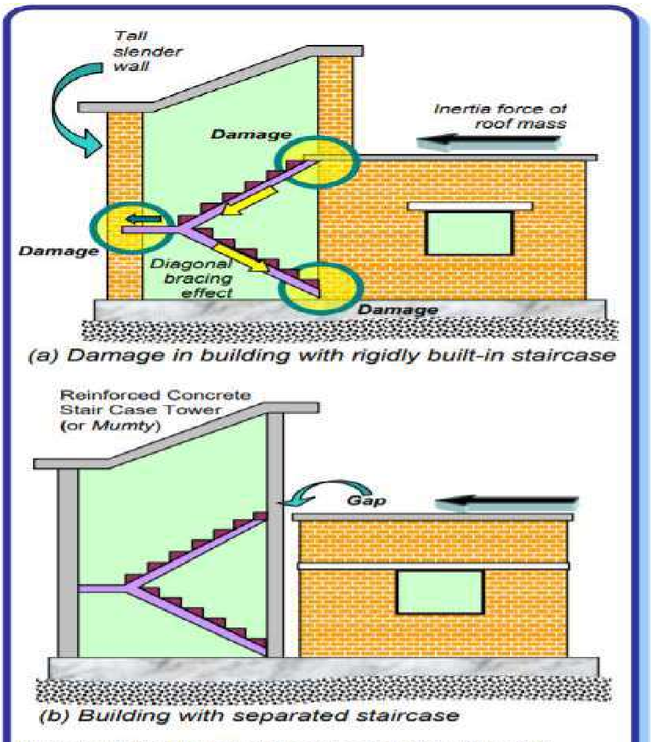
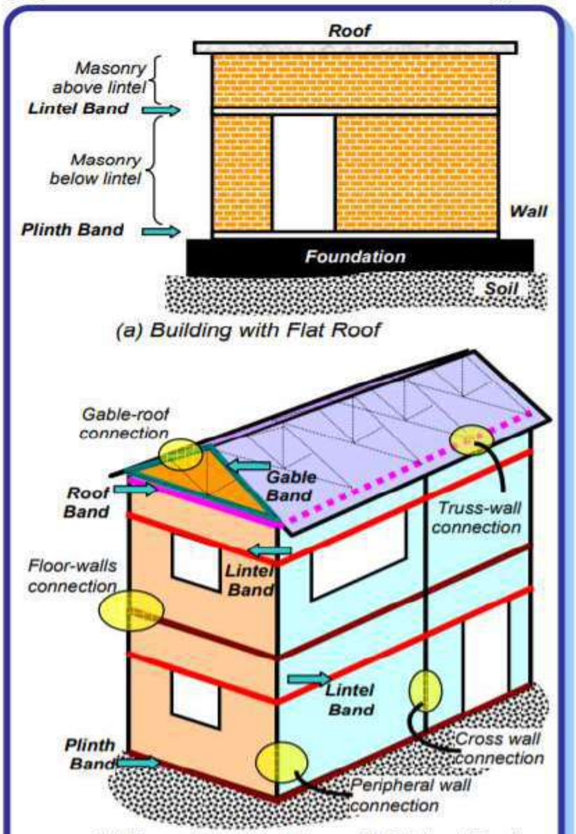



Figure 4: Earthquake-resistant detailing of staircase in masonry building – must be carefully designed and constructed.

## 7.5 Necessity of Horizontal Bands In Masonry.

### 7.5.1 Role of Horizontal Bands:

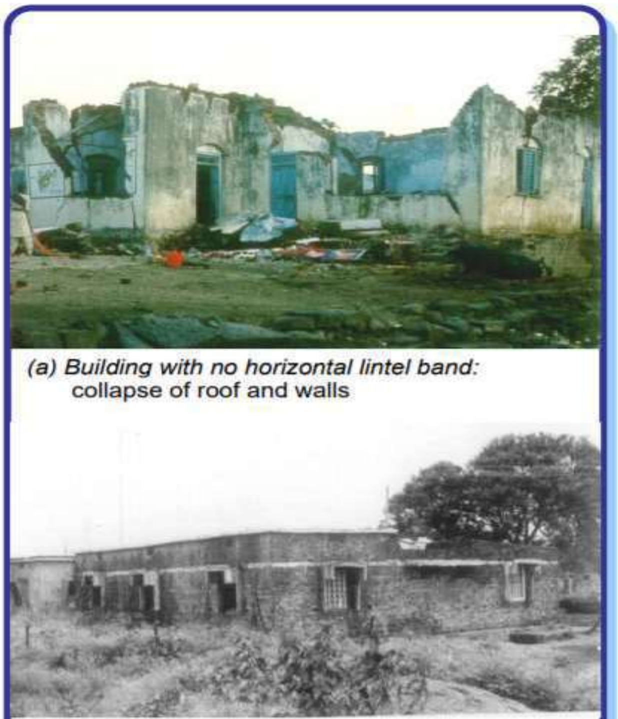
Horizontal bands are the most important earthquake-resistant feature in masonry buildings. The bands are provided to hold a masonry building as a single unit by tying all the walls together, and are similar to a closed belt provided around cardboard boxes. There are four types of bands in a typical masonry building, namely gable band, roof band, lintel band and plinth band (Figure 1), named after their location in the building. The lintel band is the most important of all, and needs to be provided in almost all buildings. The gable band is employed only in buildings with pitched or sloped roofs. In buildings with flat reinforced concrete or reinforced brick roofs, the roof band is not required, because the roof slab also plays the role of a band. However, in buildings with flat timber or flat CGI sheet roof, roof band needs to be provided. In buildings with pitched or sloped roof, the roof band is very important. Plinth bands are primarily used when there is concern about uneven settlement of foundation soil. The lintel band ties the walls together and creates a support for walls loaded along weak direction from walls loaded in strong direction. This band also reduces the unsupported height of the walls and thereby improves their stability in the weak direction. During the 1993 Latur earthquake (Central India), the intensity of shaking in Killari village was IX on MSK scale. Most masonry houses sustained partial or complete collapse (Figure 2a). On the other hand, there was one masonry building in the village, which had a lintel band and it sustained the shaking very well with hardly any damage (Figure 2b).




(a) Building with Flat Roof

(b) Two-storey Building with Pitched Roof

**Figure 1: Horizontal Bands in masonry building** – *Improve earthquake-resistance.*



(a) Building with no horizontal lintel band: collapse of roof and walls

(b) A building with horizontal lintel band in Killari village: no damage

**Figure 2: The 1993 Latur Earthquake (Central India)** - one masonry house in Killari village had horizontal lintel band and sustained the shaking without damage.

### 7.5.2 Design of Lintel Bands:

During earthquake shaking, the lintel band undergoes bending and pulling actions (Figure 3). To resist these actions, the construction of lintel band requires special attention. Bands can be made of wood (including bamboo splits) or of reinforced concrete (RC) (Figure 4); the RC bands are the best. The straight lengths of the band must be properly connected at the wall corners. This will allow the band to support walls loaded in their weak direction by walls loaded in their strong direction. Small lengths of wood spacers (in wooden bands) or steel links (in RC bands) are used to make the straight lengths of wood runners or steel bars act together. In wooden bands, proper nailing of straight lengths with spacers is important. Likewise, in RC bands, adequate anchoring of steel links with steel bars is necessary.

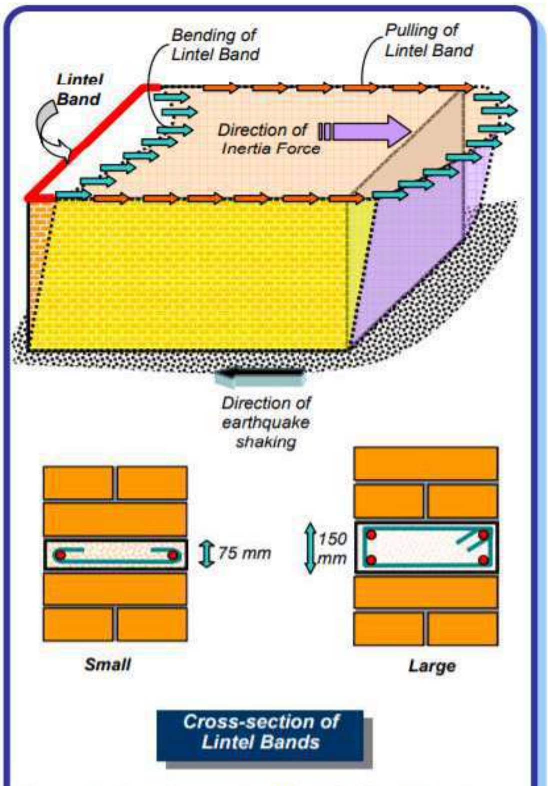


**Figure 3: Bending and pulling in lintel bands –** *Bands must be capable of resisting these.*

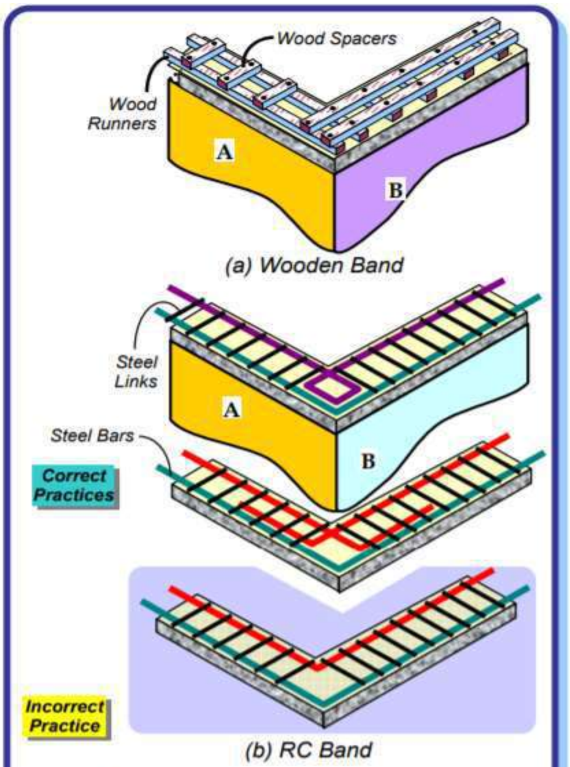


**Figure 4: Horizontal Bands in masonry buildings** *– RC bands are the best.*

**7.5.3 Indian Standards:**

The Indian Standards IS:4326-1993 and IS:13828 (1993) provide sizes and details of the bands. When wooden bands are used, the cross-section of runners is to be at least 75mm×38mm and of spacers at least 50mm×30mm. When RC bands are used, the minimum thickness is 75mm, and at least two bars of 8mm diameter are required, tied across with steel links of at least 6mm diameter at a spacing of 150 mm centers.

## 7.6 Vertical Reinforcement in Masonry Buildings:

**7.6.1 Response of Masonry Walls:**

Horizontal bands are provided in masonry buildings to improve their earthquake performance. These bands include plinth band, lintel band and roof band. Even if horizontal bands are provided, masonry buildings are weakened by the openings in their walls (Figure 1). During earthquake shaking, the masonry walls get grouped into three sub-units, namely spandrel masonry, wall pier masonry and sill masonry.

Consider a hipped roof building with two window openings and one door opening in a wall (Figure 2a). It has lintel and plinth bands. Since the roof is a hipped one, a roof band is also provided. When the ground shakes, the inertia force causes the small-sized masonry wall piers to disconnect from the masonry above and below. These masonry sub-units rock back and forth, developing contact only at the opposite diagonals (Figure 2b). The rocking of a masonry pier can crush the masonry at the corners. Rocking is possible when masonry piers are slender, and when weight of the structure above is small. Otherwise, the piers are more likely to develop diagonal (X-type) shear cracking (Figure 2c); this is the most common failure type in masonry buildings. In un-reinforced masonry buildings (Figure 3), the cross-section area of the masonry wall reduces at the opening. During strong earthquake shaking, the building may slide just under the roof, below the lintel band or at the sill level. Sometimes, the building may also slide at the plinth level. The exact location of sliding depends on numerous factors including building weight, the earthquake-induced inertia force, the area of openings, and type of doorframes used.

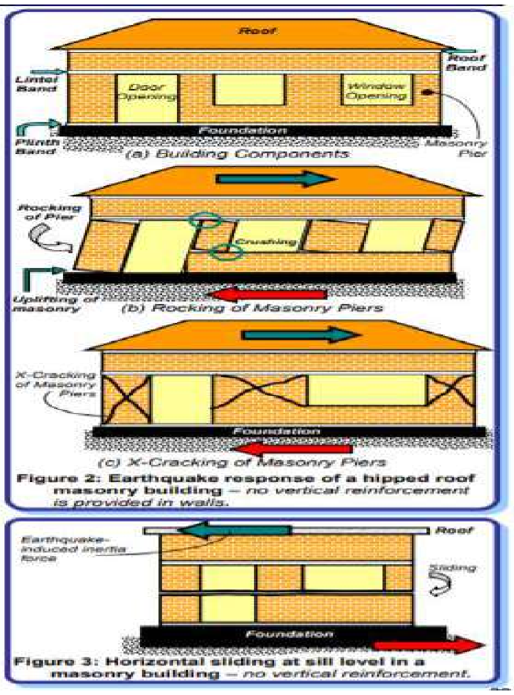


Figure 2: Earthquake response of a hipped roof masonry building – no vertical reinforcement is provided in walls.

Figure 3: Horizontal sliding at sill level in a masonry building – no vertical reinforcement.

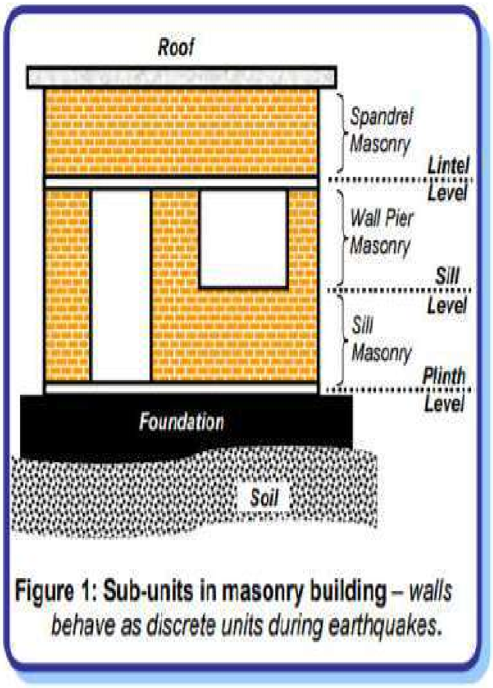
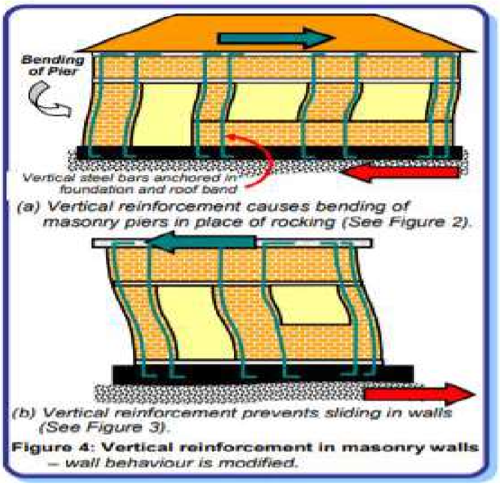


Figure 1: Sub-units in masonry building – walls behave as discrete units during earthquakes.

### 7.6.2 How Vertical Reinforcement Helps:

Embedding vertical reinforcement bars in the edges of the wall piers and anchoring them in the foundation at the bottom and in the roof band at the top (Figure 4), forces the slender masonry piers to undergo bending instead of rocking. In wider wall piers, the vertical bars enhance their capability to resist horizontal earthquake forces and delay the X-cracking. Adequate cross-sectional area of these vertical bars prevents the bar from yielding in tension. Further, the vertical bars also help protect the wall from sliding as well as from collapsing in the weak direction.



(a) Vertical reinforcement causes bending of masonry piers in place of rocking (See Figure 2).

(b) Vertical reinforcement prevents sliding in walls (See Figure 3).

Figure 4: Vertical reinforcement in masonry walls – wall behaviour is modified.

### 7.6.3 Protection of Openings in Walls:

Sliding failure mentioned above is rare, even in unconfined masonry buildings. However, the most common damage, observed after an earthquake, is diagonal X-cracking of wall piers, and also inclined cracks at the corners of door and window openings. When a wall with an opening deforms during earthquake shaking, the shape of the opening distorts and becomes more like a rhombus - two opposite corners move away and the other two come closer. Under this type of deformation, the corners that come closer develop cracks (Figure 5a). The cracks are bigger when the opening sizes are larger. Steel bars provided in the wall masonry all around the openings restrict these cracks at the corners (Figure 5b). In summary, lintel and sill bands above and below openings, and vertical reinforcement adjacent to vertical edges, provide protection against this type of damage.

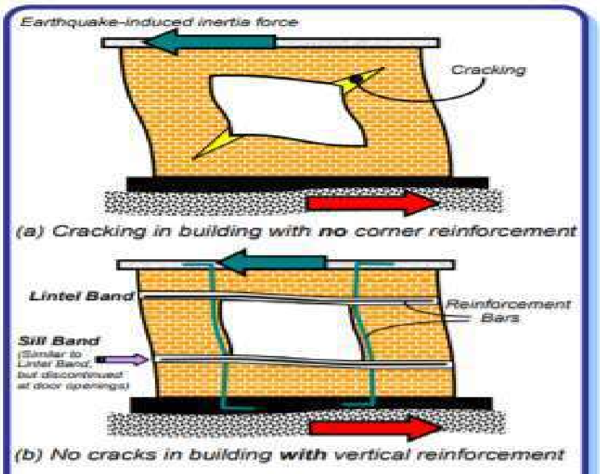



**Figure 5: Cracks at corners of openings in a masonry building** – *reinforcement around them*

## 7.7 Earthquake Resistant Stone-Masonary Buildings:

### 7.7.1 Behaviour during Past India Earthquakes:

Stone has been used in building construction in India since ancient times since it is durable and locally available. There are huge numbers of stone buildings in the country, ranging from rural houses to royal palaces and temples. In a typical rural stone house, there are thick stone masonry walls (thickness ranges from 600 to 1200 mm) built using rounded stones from riverbeds bound with mud mortar. These walls are constructed with stones placed in a random manner, and hence do not have the usual layers (or courses) seen in brick walls. These uncoursed walls have two exterior vertical layers (called wythes) of large stones, filled in between with loose stone rubble and mud mortar. A typical uncoursed random (UCR) stone masonry wall is illustrated in Figure 1. In many cases, these walls support heavy roofs (for example, timber roof with thick mud overlay).

Laypersons may consider such stone masonry buildings robust due to the large wall thickness and robust appearance of stone construction. But, these buildings are one of the most deficient building systems from earthquake-resistance point of view. The main deficiencies include excessive wall thickness, absence of any connection between the two wythes of the wall, and use of round stones (instead of shaped ones). Such dwellings have shown very poor performance during past earthquakes in India and other countries (e.g., Greece, Iran, Turkey, former Yugoslavia). In the 1993 Killari (Maharashtra) earthquake alone, over 8,000 people died, most of them buried under the rubble of traditional stone masonry dwellings. Likewise, a majority of the over 13,800 deaths during 2001 Bhuj (Gujarat) earthquake is attributed to the collapse of this type of construction. The main patterns of earthquake damage include: (a) bulging/separation of walls in the horizontal direction into two distinct wythes (Figure 2a), (b) separation of walls at corners and T-junctions (Figure 2b), (c) separation of poorly constructed roof from walls, and eventual collapse of roof, and (d) disintegration of walls and eventual collapse of the whole dwelling.

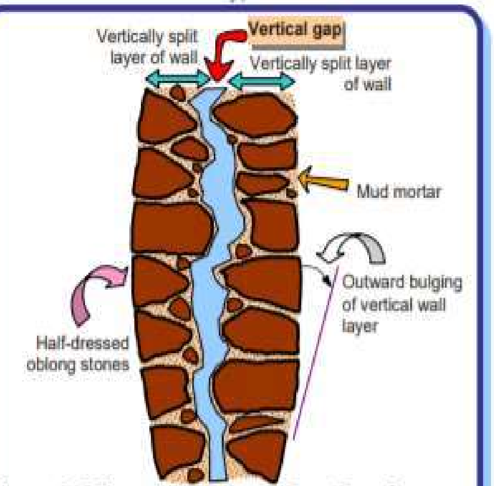



**Figure 1: Schematic of the wall section of a traditional stone house** – *thick walls without stones that go across split into 2 vertical layers.*

*(a) Separation of a thick wall into two layers*

*(b) Separation of unconnected adjacent walls at junctions*

**Figure 2: Major concerns in a traditional stone house** – *deficiencies in walls, roof and in their connections have been prime causes for failure.*

Earthquake Resistant Features Low strength stone masonry buildings are weak against earthquakes, and should be avoided in high seismic zones. The Indian Standard IS: 13828-1993 states that inclusion of special earthquake-resistant design and construction features may raise the earthquake resistance of these buildings and reduce the loss of life. However, in spite of the seismic features these buildings may not become totally free from heavy damage and even collapse in case of a major earthquake. The contribution of the each of these features is difficult to quantify, but qualitatively these features have been observed to improve the performance of stone masonry dwellings during past earthquakes. These features include:

**7.7.1.1** Ensure proper wall construction The wall thickness should not exceed 450mm. Round stone boulders should not be used in the construction! Instead, the stones should be shaped using chisels and hammers. Use of mud mortar should be avoided in higher seismic zones. Instead, cement-sand mortar should be 1:6 (or richer) and lime-sand mortar 1:3 (or richer) should be used.

**7.7.1.2** Ensure proper bond in masonry courses: The masonry walls should be built in construction lifts not exceeding 600mm. Through-stones (each extending over full thickness of wall) or a pair of overlapping bond-stones (each extending over at least ¾ths thickness of wall) must be used at every 600mm along the height and at a maximum spacing of 1.2m along the length (Figure 3).

**7.7.1.3** Provide horizontal reinforcing elements: The stone masonry dwellings must have horizontal bands. These bands can be constructed out of wood or reinforced concrete, and chosen based on economy. It is important to provide at least one band (either lintel band or roof band) in stone masonry construction (Figure 4). (d) Control on overall dimensions and heights: The unsupported length of walls between cross-walls should be limited to 5m; for longer walls, cross supports raised from the ground level called buttresses should be provided at spacing not more than 4m. The height of each storey should not exceed 3.0m. In general, stone masonry buildings should not be taller than 2 storeys when built in cement mortar, and 1 storey when built in lime or mud mortar. The wall should have a thickness of at least one-sixth its height. Although, this type of stone masonry construction practice is deficient with regards to earthquake resistance, its extensive use is likely to continue due to tradition and low cost. But, to protect human lives and property in future earthquakes, it is necessary to follow proper stone masonry construction as described above (especially features (a) and (b) in seismic zones III and higher). Also, the use of seismic bands is highly recommended.

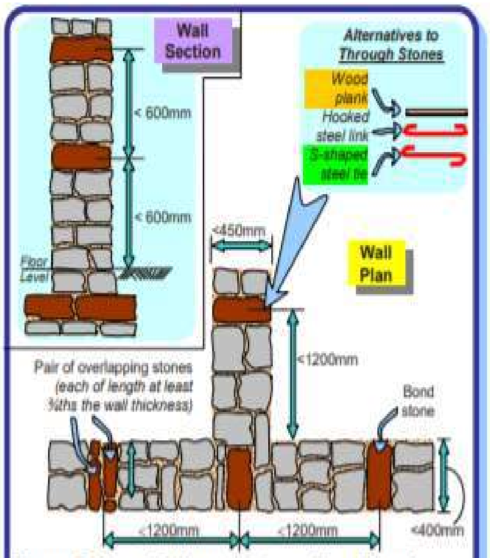



**Figure 3: Use of "through stones" or "bond stones" in stone masonry walls** – *vital in preventing the wall from separating into wythes.*

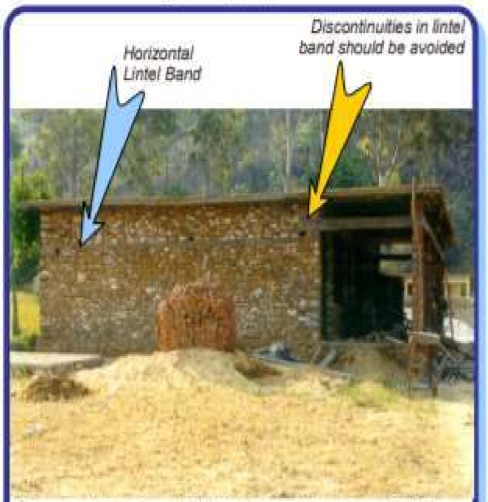



**Figure 4: Horizontal lintel band is essential in random rubble stone masonry walls** – *provides integrity to the dwelling, and holds the walls together to resist horizontal earthquake effects.*

## 7.8 Earthquake Effect on Beams in RC Buildings.

### 7.8.1 Reinforcement and Seismic Damage:

In RC buildings, the vertical and horizontal members (i.e., the columns and beams) are built integrally with each other. Thus, under the action of loads, they act together as a frame transferring forces from one to another. This Tip is meant for beams that are part of a building frame and carry earthquake induced forces. Beams in RC buildings have two sets of steel reinforcement, namely: (a) long straight bars (called longitudinal bars) placed along its length, and (b) closed loops of small diameter steel bars (called stirrups) placed vertically at regular intervals along its full length (Figure 1).

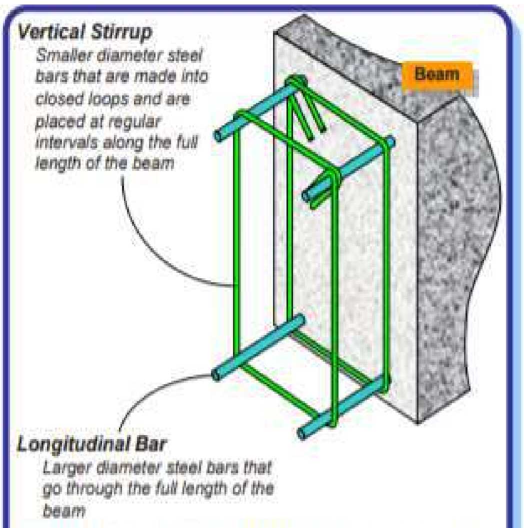



**Figure 1: Steel reinforcement in beams** - *stirrups prevent longitudinal bars from bending outwards.*

Beams sustain two basic types of failures, namely: (a)Flexural (or Bending) Failure: As the beam sags under increased loading, it can fail in two possible ways. If relatively more steel is present on the tension face, concrete crushes in compression; this is a brittle failure and is therefore undesirable. If relatively less steel is present on the tension face, the steel yields first (it keeps elongating but does not snap, as steel has ability to stretch large amounts before it snapsand redistribution occurs in the beam until eventually the concrete crushes in compression; this is a ductile failure and hence is desirable. Thus, more steel on tension face is not necessarily desirable! The ductile failure is characterized with many vertical cracks starting from the stretched beam face, and going towards its mid-depth (Figure 2a). (b) Shear Failure: A beam may also fail due to shearing action. A shear crack is inclined at 45° to the horizontal; it develops at mid-depth near the support and grows towards the top and bottom faces (Figure 2b). Closed loop stirrups are provided to avoid such shearing action. Shear damage occurs when the area of these stirrups is insufficient. Shear failure is brittle, and therefore, shear failure must be avoided in the design of RC beams.

**7.8.2 Design Strategy:**

Designing a beam involves the selection of its material properties (i.e, grades of steel bars and concrete) and shape and size; these are usually selected as a part of an overall design strategy of the whole building. And, the amount and distribution of steel to be provided in the beam must be determined by performing design calculations as per is:456-2000 and IS13920-2016.

Longitudinal bars are provided to resist flexural cracking on the side of the beam that stretches. Since both top and bottom faces stretch during strong earthquake shaking, longitudinal steel bars are required on both faces at the ends and on the bottom face at mid-length (Figure 3). The Indian Ductile Detailing Code IS13920-2016 prescribes that: (a) At least two bars go through the full length of the beam at the top as well as the bottom of the beam. (b) At the ends of beams, the amount of steel provided at the bottom is at least half that at top.

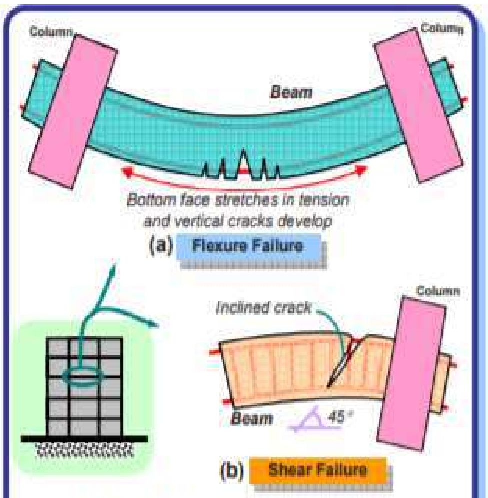



**Figure 2: Two types of damage in a beam:** *flexure damage is preferred. Longitudinal bars resist the tension forces due to bending while vertical stirrups resist shear forces.*

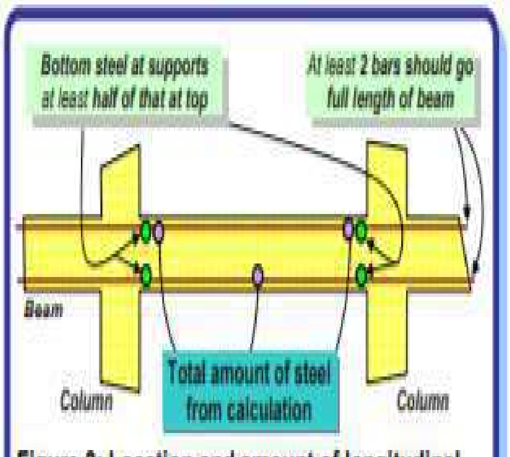



**Figure 3: Location and amount of longitudinal steel bars in beams** – *these resist tension due to flexure.*

Stirrups in RC beams help in three ways, namely (i) they carry the vertical shear force and thereby resist diagonal shear cracks (Figure 2b), (ii) they protect the concrete from bulging outwards due to flexure, and (iii) they prevent the buckling of the compressed longitudinal bars due to flexure. In moderate to severe seismic zones, the Indian Standard IS13920-2016 prescribes the following requirements related to stirrups in reinforced concrete beams: (a) The diameter of stirrup must be at least 6mm; in beams more than 5m long, it must be at least 8mm. (b) Both ends of the vertical stirrups should be bent into a 135° hook (Figure 4) and extended sufficiently beyond this hook to ensure that the stirrup does not open out in an earthquake. (b) The spacing of vertical stirrups in any portion of the beam should be determined from calculations (c) The maximum spacing of stirrups is less than half the depth of the beam (Figure 5). (d) For a length of twice the depth of the beam from the face of the column, an even more stringent spacing of stirrups is specified, namely half the spacing mentioned in (c) above (Figure 5).

Steel reinforcement bars are available usually in lengths of 12-14m. Thus, it becomes necessary to overlap bars when beams of longer lengths are to be made. At the location of the lap, the bars transfer large forces from one to another. Thus, the Indian Standard IS:13920-2016 prescribes that such laps of longitudinal bars are (a) made away from the face of the column, and (b) not made at locations where they are likely to stretch by large amounts and yield (e.g., bottom bars at mid-length of the beam). Moreover, at the locations of laps, vertical stirrups should be provided at a closer spacing (Figure 6).

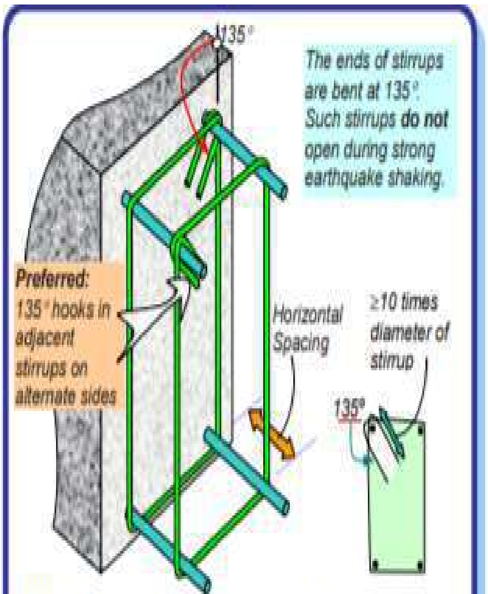



Figure 4: Steel reinforcement in seismic beams - stirrups with 135° hooks at ends required as per IS:13920-1993.

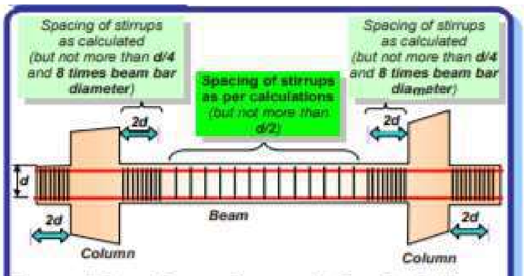



Figure 5: Location and amount of vertical stirrups in beams – IS:13920-1993 limit on maximum spacing ensures good earthquake behaviour.

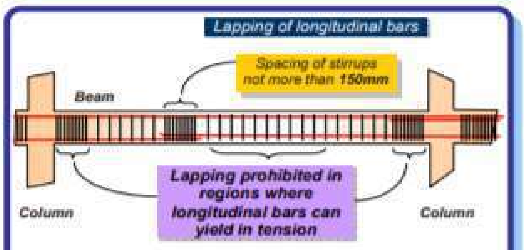



Figure 6: Details of lapping steel reinforcement in seismic beams – as per IS13920-1993.

## 7.9 Earthquake Effect on Columns in RC Buildings.

### 7.9.1 Possible Earthquake Damage:

Columns, the vertical members in RC buildings, contain two types of steel reinforcement, namely: (a) long straight bars (called longitudinal bars) placed vertically along the length, and (b) closed loops of smaller diameter steel bars (called transverse ties) placed horizontally at regular intervals along its full length (Figure 1). Columns can sustain two types of damage, namely axial-flexural (or combined compression bending) failure and shear failure. Shear damage is brittle and must be avoided in columns by providing transverse ties at close spacing (Figure 2b).

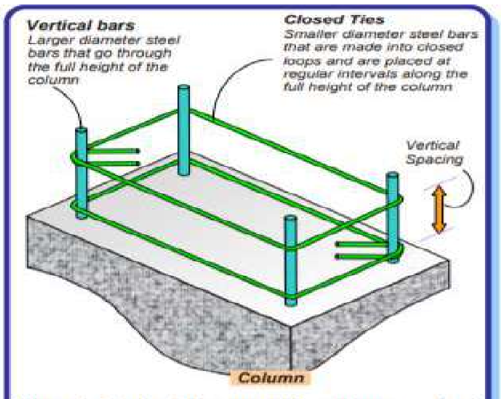


**Figure 1: Steel reinforcement in columns** – *closed ties at close spacing improve the performance of columns under strong earthquake shaking.*

**7.9.2 Design Strategy:**

Designing a column involves selection of materials to be used (i.e, grades of concrete and steel bars), choosing shape and size of the cross-section, and calculating amount and distribution of steel reinforcement. The first two aspects are part of the overall design strategy of the whole building. The Indian Standard IS:13920-2016 requires building columns in seismic zones III, IV and V to be not less than 300mm wide in each direction of the cross-section or at least 20 times the diameter of largest longitudinal bar used in adjoining beam.Columns that are required to resist earthquake forces must be designed to prevent shear failure by a skillful selection of reinforcement.

**7.9.3 Vertical Bars tied together with Closed Ties:**

Closely spaced horizontal closed ties help in three ways, namely (i) they carry the horizontal shear forces induced by earthquakes, and thereby resist diagonal shear cracks, (ii) they hold together the vertical bars and prevent them from excessively bending outwards (in technical terms, this bending phenomenon is called buckling), and (iii) they contain the concrete in the column within the closed loops. The ends of the ties must be bent as 135° hooks (Figure 2). Such hook ends prevent opening of loops and consequently bulging of concrete and buckling of vertical bars.

The Indian Standard IS13920-2016 prescribes following details for earthquake-resistant columns:

**7.9.3.1** Closely spaced ties must be provided at the two ends of the column over a length not less than larger dimension of the column, one-sixth the column height or 450mm.

**7.9.3.2** Over the distance specified in item (a) above and below a beam-column junction, the vertical spacing of ties in columns should not exceed D/4 for where D is the smallest dimension of the column (e.g., in a rectangular column, D is the length of the small side). This spacing need not be less than 75mm nor more than 100mm. At other locations, ties are spaced as per calculations but not more than D/2.

**7.9.3.3** The length of tie beyond the 135° bends must be at least 10 times diameter of steel bar used to make the closed tie; this extension beyond the bend should not be less than 75mm.

Construction drawings with clear details of closed ties are helpful in the effective implementation at construction site. In columns where the spacing between the corner bars exceeds 300mm, the Indian Standard prescribes additional links with 180° hook ends for ties to be effective in holding the concrete in its place and to prevent the buckling of vertical bars. These links need to go around both vertical bars and horizontal closed ties (Figure 3); special care is required to implement this properly at site.

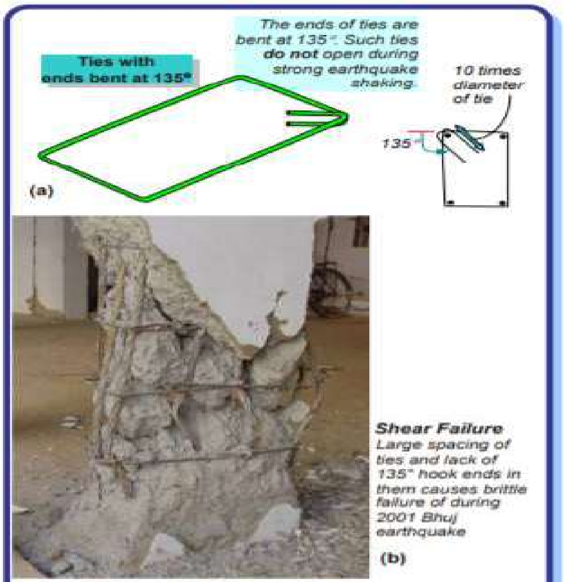



**Figure 2: Steel reinforcement in seismic columns** – *closed ties with 135° hooks are required as per Indian Ductile Detailing Code IS:13920-1993.*

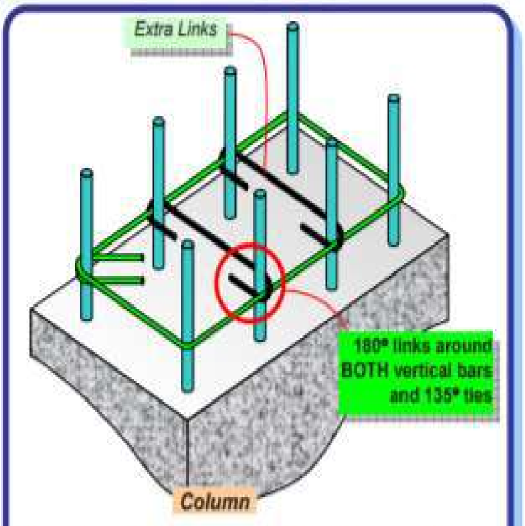



**Figure 3: Extra links are required to keep the concrete in place** – *180° links are necessary to prevent the 135° tie from bulging outwards.*

### 7.9.4 Lapping Vertical Bars:

In the construction of RC buildings, due to the limitations in available length of bars and due to constraints in construction, there are numerous occasions when column bars have to be joined. A simple way of achieving this is by overlapping the two bars over at least a minimum specified length, called lap length. The lap length depends on types of reinforcement and concrete. For ordinary situations, it is about 50 times bar diameter. Further, IS:13920-2016 prescribes that the lap length be provided only in the middle half of column and not near its top or bottom ends (Figure 4). Also, only half the vertical bars in the column are to be lapped at a time in any storey. Further, when laps are provided, ties must be provided along the length of the lap at a spacing not more than 150mm.

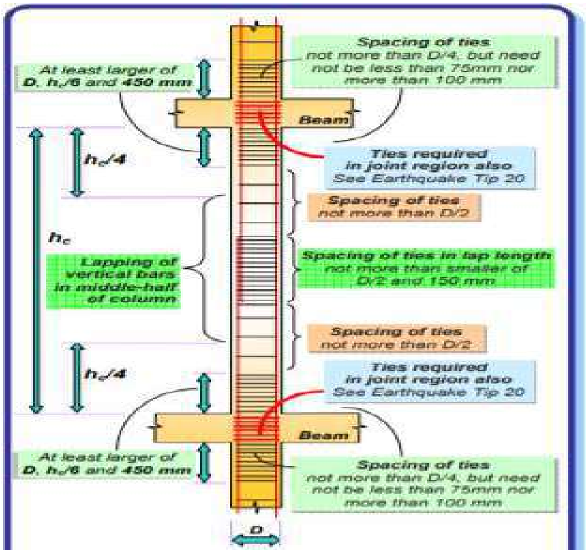



**Figure 4: Placing vertical bars and closed ties in columns** – *column ends and lap lengths are to be protected with closely spaced ties.*

## 7.10 Earthquake Effect on Beam-Columns in RC Buildings.

### 7.10.1 Why Beam-Column Joints are Special:

In RC buildings, portions of columns that are common to beams at their intersections are called beam column joints (Figure 1). Since their constituent materials have limited strengths, the joints have limited force carrying capacity. When forces larger than these are applied during earthquakes, joints are severely damaged. Repairing damaged joints is difficult, and so damage must be avoided. Thus, beam-column joints must be designed to resist earthquake effects.

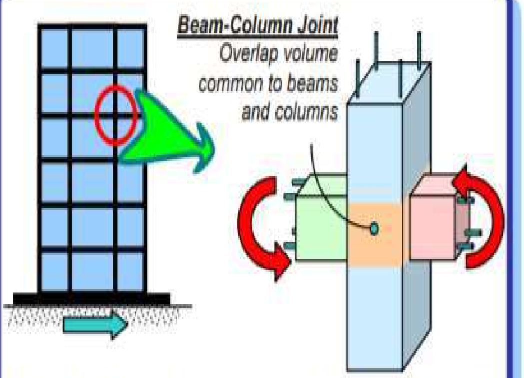
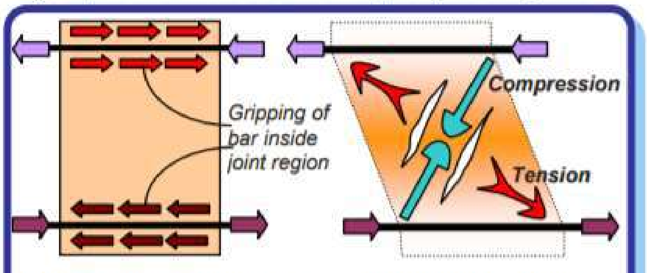



Figure 1: Beam-Column Joints are critical parts of a building – *they need to be designed.*

### 7.10.2 Earthquake Behaviour of Joints:

Under earthquake shaking, the beams adjoining a joint are subjected to moments in the same (clockwise or counter-clockwise) direction (Figure 1). Under these moments, the top bars in the beam-column joint are pulled in one direction and the bottom ones in the opposite direction (Figure 2a). These forces are balanced by bond stress developed between concrete and steel in the joint region. If the column is not wide enough or if the strength of concrete in the joint is low, there is insufficient grip of concrete on the steel bars. In such circumstances, the bar slips inside the joint region, and beams loose their capacity to carry load.




**(a) Loss of grip on beam bars in joint region:** *Large column width and good concrete help in holding the beam bars*

**(b) Distortion of joint:** *causes diagonal cracking and crushing of concrete*

**Figure 2: Pull-push forces on joints cause two problems** – these result in irreparable *damage in joints under strong seismic shaking.*

Further, under the action of the above pull-push forces at top and bottom ends, joints undergo geometric distortion; one diagonal length of the joint elongates and the other compresses

(Figure 2b). If the column cross-sectional size is insufficient, the concrete in the joint develops diagonal cracks.

**7.10.3 Reinforcing the Beam-Column Joint:**

Diagonal cracking & crushing of concrete in joint region should be prevented to ensure good earthquake performance of RC frame buildings. Using large column sizes is the most effective way of achieving this. In addition, closely spaced closed-loop steel ties are required around column bars (Figure 3) to hold together concrete in joint region and to resist shear forces. Intermediate column bars also are effective in confining the joint concrete and resisting horizontal shear forces.

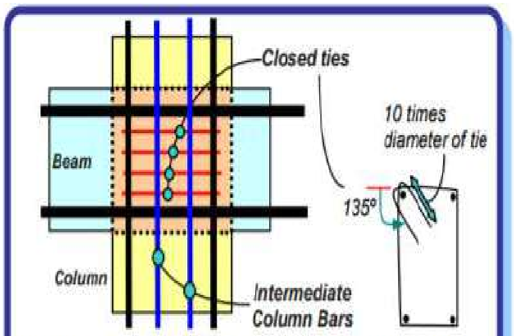



**Figure 3: Closed loop steel ties in beam-column joints** – *such ties with 135° hooks resist the ill effects of distortion of joints.*

Providing closed-loop ties in the joint requires some extra effort. Indian Standard IS:13920-2016 recommends continuing the transverse loops around the column bars through the joint region. In practice, this is achieved by preparing the cage of the reinforcement (both longitudinal bars and stirrups) of all beams at a floor level to be prepared on top of the beam formwork of that level and lowered into the cage (Figures 4a and 4b). However, this may not always be possible particularly when the beams are long and the entire reinforcement cage becomes heavy.

**7.10.4 Anchoring Beam Bars:**

The gripping of beam bars in the joint region is improved first by using columns of reasonably large cross-sectional size. The Indian Standard IS:13920-2016 requires building columns in seismic zones III, IV and V to be not less than 300mm wide in each direction of the cross-section or at least 20 times the diameter of largest longitudinal bar used in adjoining beam.

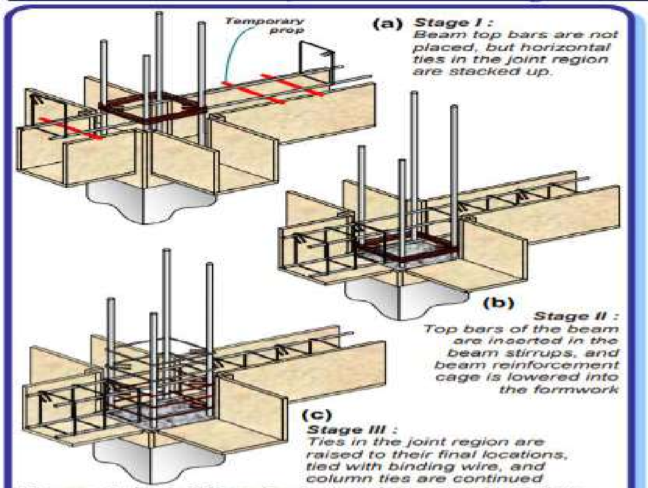



**Figure 4: Providing horizontal ties in the joints** – *three-stage procedure is required.*

In exterior joints where beams terminate at columns (Figure 5), longitudinal beam bars need to be anchored into the column to ensure proper gripping of bar in joint. The length of anchorage for a bar of grade Fe415 (characteristic tensile strength of 415MPa) is about 50 times its diameter. This length is measured from the face of the column to the end of the bar anchored in the column. In columns of small widths and when beam bars are of large diameter (Figure 5a), a portion of beam top bar is embedded in the column that is cast up to the soffit of the beam, and a part of it overhangs. It is difficult to hold such an overhanging beam top bar in position while casting the column up to the soffit of the beam. Moreover, the vertical distance beyond the 90º bend in beam bars is not very effective in providing anchorage. On the other hand, if column width is large, beam bars may not extend below soffit of the beam (Figure 5b). Thus, it is preferable to have columns with sufficient width. Such an approach is used in many codes [e.g., ACI318, 2005]. In interior joints, the beam bars (both top and bottom) need to go through the joint without any cut in the joint region. Also, these bars must be placed within the column bars and with no bends (Figure 6).

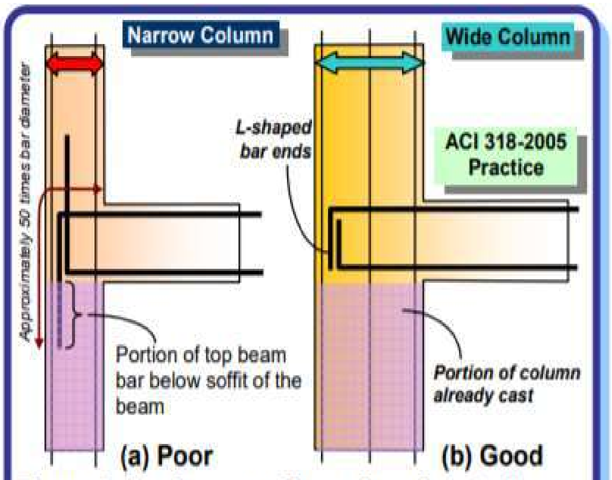



**Figure 5: Anchorage of beam bars in exterior joints** – *diagrams show elevation of joint region.*

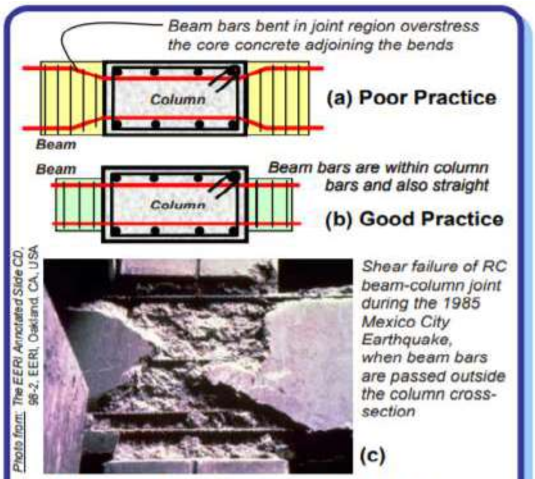



**Figure 6: Anchorage of beam bars in interior joints** – *diagrams (a) and (b) show cross-sectional views in plan of joint region.*

## 7.11 Buildings With Shear Wall In Earthquake Regions.

### 7.11.1 What is a Shear Wall Building:

Reinforced concrete (RC) buildings often have vertical plate-like RC walls called Shear Walls (Figure 1) in addition to slabs, beams and columns. These walls generally start at foundation level and are continuous throughout the building height. Their thickness can be as low as 150mm, or as high as 400mm in high rise buildings. Shear walls are usually provided along both length and width of buildings (Figure 1). Shear walls are like vertically-oriented wide beams that carry earthquake loads downwards to the foundation.

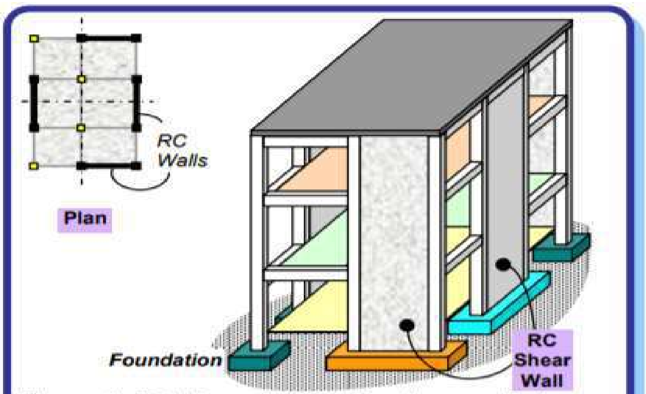


**Figure 1: Reinforced concrete shear walls in buildings** – *an excellent structural system for earthquake resistance.*

**7.11.2 Advantages of Shear Walls in RC Buildings:**

Properly designed and detailed buildings with shear walls have shown very good performance in past earthquakes. The overwhelming success of buildings with shear walls in resisting strong earthquakes is summarized in the quote: "We cannot afford to build concrete buildings meant to resist severe earthquakes without shear walls." Mark Fintel, a noted consulting engineer in USA. Shear walls in high seismic regions require special detailing. However, in past earthquakes, even buildings with sufficient amount of walls that were not specially detailed for seismic performance (but had enough well-distributed reinforcement) were saved from collapse. Shear wall buildings are a popular choice in many earthquake prone countries, like Chile, New Zealand and USA. Shear walls are easy to construct, because reinforcement detailing of walls is relatively straight-forward and therefore easily implemented at site. Shear walls are efficient, both in terms of construction cost and effectiveness in minimizing earthquake damage in structural and nonstructural elements (like glass windows and building contents).

**7.11.3 Architectural Aspects of Shear Walls:**

Most RC buildings with shear walls also have columns; these columns primarily carry gravity loads (i.e., those due to self-weight and contents of building). Shear walls provide large strength and stiffness to buildings in the direction of their orientation, which significantly reduces lateral sway of the building and thereby reduces damage to structure and its contents. Since shear walls carry large horizontal earthquake forces, the overturning effects on them are large. Thus, design of their foundations requires special attention. Shear walls should be provided along preferably both length and width. However, if they are provided along only one direction, a proper grid of beams and columns in the vertical plane (called a moment-resistant frame) must be provided along the other direction to resist strong earthquake effects. Door or window openings can be provided in shear walls, but their size must be small to ensure least interruption to force flow through walls. Moreover, openings should be symmetrically located. Special design checks are required to ensure that the net crosssectional area of a wall at an opening is sufficient to carry the horizontal earthquake force. Shear walls in buildings must be symmetrically located in plan to reduce ill-effects of twist in buildings (Figure 2). They could be placed symmetrically along one or both directions in plan. Shear walls are more effective when located along exterior perimeter of the building – such a layout increases resistance of the building to twisting.

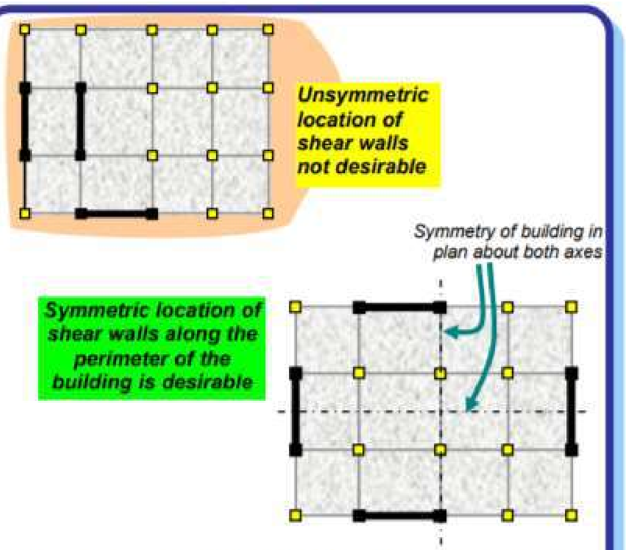


**Figure 2: Shear walls must be symmetric in plan layout** – *twist in buildings can be avoided.*

**7.11.4 Ductile Design of Shear Walls:**

Just like reinforced concrete (RC) beams and columns, RC shear walls also perform much better if designed to be ductile. Overall geometric proportions of the wall, types and amount of reinforcement, and connection with remaining elements in the building help in improving the ductility of walls. The Indian Standard Ductile Detailing Code for RC members (IS:13920-2016) provides special design guidelines for ductile detailing of shear walls.

**7.11.5 Overall Geometry of Walls:**

Shear walls are oblong in cross-section, i.e., one dimension of the cross-section is much larger than the other. While rectangular cross-section is common, L- and U-shaped sections are also used (Figure 3). Thin-walled hollow RC shafts around the elevator core of buildings also act as shear walls, and should be taken advantage of to resist earthquake forces.

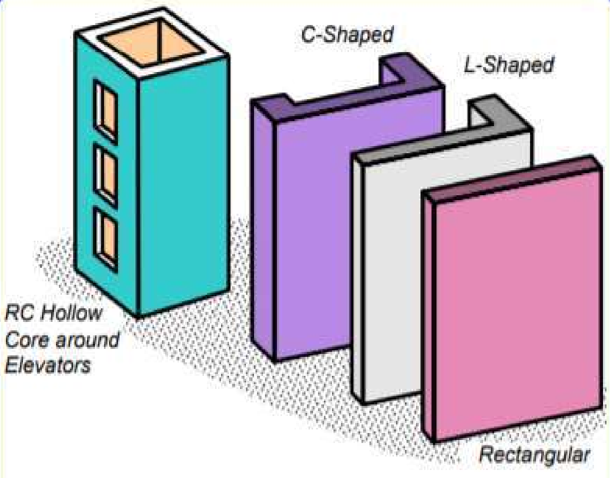


**Figure 3: Shear walls in RC Buildings** – *different geometries are possible.*

**7.11.6 Reinforcement Bars in RC Walls:**

Steel reinforcing bars are to be provided in walls in regularly spaced vertical and horizontal grids (Figure 4a). The vertical and horizontal reinforcement in the wall can be placed in one or two parallel layers called curtains. Horizontal reinforcement needs to be anchored at the ends of walls. The minimum area of reinforcing steel to be provided is 0.0025 times the cross-sectional area, along each of the horizontal and vertical directions. This vertical reinforcement should be distributed uniformly across the wall cross-section.

**7.11.7 Boundary Elements:**

Under the large overturning effects caused by horizontal earthquake forces, edges of shear walls experience high compressive and tensile stresses. To ensure that shear walls behave in a ductile way, concrete in the wall end regions must be reinforced in a special manner to sustain these load reversals without loosing strength (Figure 4b). End regions of a wall with increased confinement are called boundary elements. This special confining transverse reinforcement in boundary elements is similar to that provided in columns of RC frames . Sometimes, the thickness of the shear wall in these boundary elements is also increased. RC walls with boundary elements have substantially higher bending strength and horizontal shear force carrying capacity, and are therefore less susceptible to earthquake damage than walls without boundary elements.

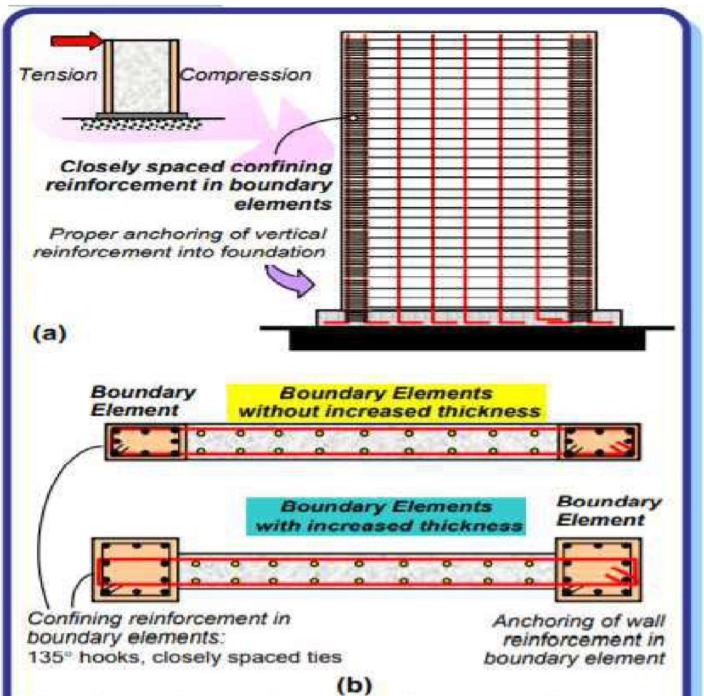



**Figure 4: Layout of main reinforcement in shear walls as per IS:13920-1993** – *detailing is the key to good seismic performance.*

# 8. HERITAGE BUILDINGS AND THEIR CONSERVATION

## 8.1 General

Heritage buildings are defined as existing buildings with significant cultural value to society. Modern societies ascribe cultural value to existing buildings, so they are seen as cultural heritage. In general terms, it can be said that the cultural value of an existing building is as high as it is old.

Rehabilitation of heritage buildings has become an issue of great importance around the world, particularly in the most developed societies. It is the result of the need to improve existing buildings for new conditions of use, and also of the recognition of the importance of conservation of the architectural heritage.

Existing buildings are subjected to processes of degradation with time, which leads to a situation in which they became not able to fulfill the purpose for which they have been built. Sometimes, there is also the need to improve the conditions offered by the existing buildings or to adapt them to new functions. Rehabilitation of heritage buildings is a way of sustainable development and also an act of culture.

The most sensitive aspect of the rehabilitation of existing buildings is their structural rehabilitation, i.e., that which is related to their structural safety. However, the assessment of the structural safety of existing buildings is, in general, a complex task, because the methodologies used differ from those adopted in the design of new structures. Furthermore, the eventual strengthening of existing buildings can conflict with their cultural value.

Therefore, the type of intervention on the heritage building will depend on the existing situation of the building, and also, on its cultural value, going from simple maintenance, where the objective is not to change the cultural value of the building, to deep rehabilitation, when it is intended to improve the performance of the building.

### 8.1.1 Conservation

Prevention of decay is conservation that focuses on prolonging the life of cultural and natural heritage. The least effective action is the best, possibly the action should be reversible and not narrow the possible future interventions. Conservation of heritage requires a wide range of skills that includes town planner, valuation surveyor, urban designer, landscape architect, engineers of several specifications, conservation architect, quantity surveyor, building contractor and craftsmen, art historians and antiquarian, biologist, physicist, geologist and seismologist. It is difficult to come to an agreement with a multi-disciplinary team working. The conservation of heritage buildings and monuments shall be in synchronization with National Standards and Heritage guidelines for conservation of buildings.

### 8.1.2 Structural Conservation

Structure is the prime determinant of a building's shape and hence it ultimately determines the building's aesthetic value, notwithstanding the frequent denial of structure that can be traced throughout the history of architecture. The need for substitute analytical and assessment models that acknowledge the substantial difference in behaviour between traditional and engineered materials – masonry and timber as opposed to steel and reinforced concrete. The historic buildings are vulnerable to natural hazards – earthquakes, fire and flood-and thus there is need for damage mitigation strategies and strengthening interventions that constitute structural conservation.

## 8.2 Causes of Defects in Heritage Structures

The defects in the building can result from the degradation of the building materials or from the damage of the building elements due to mechanical actions.

The degradation of the building materials is a process that develops naturally with time, and can be accelerated by chemical, physical or biological actions. The main effects are the deterioration of the surfaces of the elements, the loss of material and the reduction of their strength.

The phenomena of degradation are different according to the type of building material: masonry, timber or steel (iron).

The damage to the building elements due to mechanical actions occurs when the actions in certain zones of the building element exceed the strength of their materials. They can be produced, or be aggravated by actions, or by insufficient strength. Alterations on the constitution of the building can also be the source of damage of this type.

The manifestation of damage to building elements due to mechanical actions will depend on the type of action, the type of building material and the type of building element.

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**8.2.1 Degradation of Building Materials**

**Masonry**

The degradation of masonry is linked to the characteristics of the constituent materials: bricks, blocks (of stone or concrete), and mortar filling the joints. It will be necessary to correctly identify the materials: the stone (limestone, sandstone, etc.), the bricks (fired or sun dried, etc.), and the type of mortar (cement, lime, etc.).

Masonry is affected by the presence of water (rain, moisture, etc.), temperature variations (freeze/thaw cycles, etc.) and microclimatic conditions (pollution, etc.), which can provoke its weakness through the development of micro-cracks, with the consequent loss of material, particularly if the masonry is not protected by rendering (Fig. 8.1a). The excessive dryness, as well as, wind, also can weaken masonry.

Degradation of masonry due to the presence of salts (sulphates, nitrates, etc.), in the case of brick masonry, and to biological colonisation (moss, etc.) in the case of stone masonry, can also be very significant (Fig. 8.1b). The excrement of birds (pigeons, etc.) is, usually, the greatest source of these types of problems. A very important problem with masonry is the action of water resulting from the rupture of pipes embedded in walls, which can quickly cause damage.

a) Loss of material in columns b) Biological colonisation

Figure8.1:Degradationsinstonemasonry

**Timber**

The main causes of the degradation of timber are the attack by fungus and insects. Timber species are variably susceptible to degradation and attack, so, a very important issue is the correct identification of the specie of the timber element. The favourable conditions for the development of fungus in timber are water content higher than about 20% and high temperatures (25 to 35ºC). The insects xylophages (worms, etc.) develop in drier environments

Timber elements of roofs, particularly in the vicinity of their supports, are the most susceptible to fungus attack, due to the presence of rain water (Fig. 8.2a). The support zones of timber floors on masonry walls are also, often, a source of moisture, due to the infiltration of water through the walls (Fig. 8.2b).

a) In roof elements b) In floor elements

Figure-8.2: Degradation of timber

Attention has also to be given to situations in which the timber is integrated in masonry, as are the cases of walls reinforced with timber trusses or wooden partitions. Particularly delicate are the situations in which there are alternate dry/moist conditions, as is the case of timber piles enclosed in soil having a variable water table; this can lead to the quick rotting of the timber. The presence of cracks in timber elements, parallel to the fibres, due to the shrinkage of the timber, generally is not a problem, except in the case of very thick elements, when a significant reduction of the shear resistance can occur.

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**Steel (iron)**

The greatest problem with steel and iron elements is corrosion, in particular, of the connections by rivets or bolts. Another important problem to be taken into consideration is the eventual corrosion of the steel elements embedded in masonry elements, which can lead to the rupture of those elements, due to the increase of volume resulting from the rust. It is also to be noted that the iron or steel of old buildings are, in general, less ductile and less resistant to fatigue than the iron or steel produced nowadays.

**8.2.2 Damage to Building Elements**

**Walls and Columns**

The relevant actions for the damage to walls and columns are, in general, the vertical loads: self-weights, weights of the floors, etc. Lateral actions, namely the thrust of arches and earth pressure, and, particularly, the effects of earthquakes are also, sometimes, very relevant.

In the case of masonry elements, due to their low tensile strength, vertical loads can cause vertical cracks, which can lead to the development of lateral deformations and to the detachment of material. In the case of composite walls, with two exterior leaves and an interior in-fill, separation of the exterior leaves from the interior in-fill can also occur.

This kind of damage can develop slowly (over centuries), or rapidly, but, once the process starts, it can lead to the collapse by crushing of the structural element, even if the actions do not increase. The creep of masonry (not recognized in the past), can aggravate cracking and lead to collapse, even when stresses are moderate.

If the vertical loads are eccentric they can cause rotation of the element around the base, with the development of vertical cracks and the crushing of the material on the most compressed zone. Concentrated loads of high magnitude can also lead to the localized crushing of the building element.

Lateral actions in masonry walls can cause diagonal cracks (Fig. 8.3) or disruption between elements (Fig. 8.4), due to the low tensile strength of the units and of the joints. In masonry columns, lateral actions can also lead to their loss of stability, overturning, or to horizontal displacements the joints between blocks (Fig. 8.5).

Figure 8.3: Damage in walls due to earthquakes

Figure 8.4: Damage in walls due to earth pressure

Figure8.5:Damage in column due to earthquakes

**Arches, vaults and domes**

In arches, vaults or domes in masonry the main source of problems is the movement at the supports, with the development of tension, and, as a consequence, the opening of cracks

Such movements are related to the occurrence of the following conditions:

- Deficient conception or execution of the element: inadequate geometry for the distribution of loads; insufficient resistance or stiffness of tie-rods and buttresses; poor quality of the constituent materials, etc.
- Alteration of the distribution of loads (sometimes, loads are taken off or added in certain zones of the element, particularly, fillings).
- Actions not foreseen: differential settlements of the supports (Fig. 8.6), etc.
- Inadequate maintenance: degradation of the constituent materials, weakness of tie- rods and buttresses, etc,
- Masonry vaults supported by steel beams in building floors are particularly sensitive to lateral movements of the supports, due totheir,usually,lowrise.

Figure 8.6: Cracks in a masonry vault

**Towers and chimneys**

These types of elements are characterized by being, in general, subjected to high compression stresses in the bottom zone, which can lead to the development of vertical cracks, as referred to for walls (Fig. 8.7). They are particularly sensitive to movements of the foundations and to alterations, namely to the introduction of openings. Prismatic elements can also be weakened by imperfect connections between walls.

Figure 8.7: Vertical cracking in a masonry chimney

**Framed elements**

The main problems encountered with framed elements of timber or steel, used as the structure of the roofs or floors of buildings, are the deformation of the elements or of the joints, due to excessive loads or to actions not took into account in the design, such as earthquakes, for example.

## 8.3 Conservation Process

**INVENTORIES**

Recording the site both graphically and descriptively, along with subsequent categorizing following the principles laid down in the Indian National Trust for Art and Cultural Heritage (INTACH) Charter Articles' 2.6 and 7.2.5

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**CONDITION ASSESSMENT**

- Visual inspection
- Non-destructive tests

1. Thermal method (infrared thermography)
2. Radar technique
3. Ultrasonic pulse velocity test
4. Ambient vibration test
5. Endoscopy

- Intrusive tests

    1. Core test
    2. In-situ shear test
    3. Dond-wrench test
    4. Test of masonry prisms

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**ESTIMATION**

Preparing alternative repair technique lists depending on the damage area, impact and material.

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**CONSERVATION**

Application of the most effective technique keeping in mind the reversible and minimal intervention approach.

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**CONTINUING DOCUMENTATION**

Recording of the entire process, material specification, tests results, labour details, maintenance period etc.

Figure 8.8: Process chart for conservation

## 8.4 Criteria for Intervention

Heritage buildings, by their very nature and history (material and assembly), present challenges in diagnosis, analysis and rehabilitation, which limits the application of modern legal codes and building standards.

Furthermore, the structural rehabilitation of heritage buildings has implications of architectural, structural, economic, historic and social order, depending on the degree and extension of the intervention. All these aspects will be taken into consideration.

The intervention for structural rehabilitation will involve the application of technical knowledge, and also, cultural sensitivity. Only when technique and culture are present, can the best decisions about the intervention be taken.

To succeed well, from the technical and the cultural points of view, intervention will be carried out on the basis of the following principles:

1. Guarantee of structural safety;
2. Respect for the cultural value of the building;
3. Minimum intervention;
4. Reversibility of the intervention;
5. Integration on the whole building;
6. Compatibility of the materials;
7. Minimum cost.

It is not always possible to follow all these principles at the same time, because, sometimes, they conflict with each other. For example, the achievement of structural safety conflicts, very often, with respect for the cultural value of the building. Another case is the reversibility of the repair of cracks in masonry elements, which to be adequately solved, will not be reversible.

In each specific case, compromises between those principles will be necessary, hopefully, subjected to common sense. Maybe, instead of principles, it will be more appropriate to consider them, simply, as references; i.e., reference terms for the interventions.

## 8.5 Repair and Strengthening

### 8.5.1 The Design of the Rehabilitation Works

The design of the work for the structural rehabilitation of heritage buildings will be similar to the design of new buildings, consisting of written documents and drawings to enable the execution of the works.

The design can be developed in phases, as for new buildings (preliminary design, execution design, etc.), but, in general, it will be developed in a single phase, after, and as consequence of, the structural assessment that has been carried out on the building.

The works proposed for the intervention should be accompanied by detailed specifications for their execution, namely about the materials to be used and their conditions of application, the phases of execution, and the equipment necessary. An estimate of the cost of each work, established in a realistic way, should also be included.

In the case of buildings that continue to be used during the execution of the works, that fact should be taken into account in the establishment of the phases of the execution and in the estimate of the costs.

The rehabilitation works can be of two kinds: repair, when the purpose is simply to restore the load-bearing capacity of the building elements, and strengthening, when the purpose is to increase the load bearing-capacity.

The choice of the solution to be adopted for an intervention of rehabilitation should be justified and be the object of cost-benefit analysis, in order to provide an efficient design at a cost as low as possible, whilst respecting, as much as possible, the cultural value of the building.

The huge research effort carried out around the world, during the last decade, with the purpose of evaluating the performance of solutions for the repair and/or strengthening of structures, in particular of heritage buildings, should not be overlooked. As a result, there are, nowadays, multiple solutions that have proved to be efficient for the repair or the strengthening of heritage buildings, depending on the defects to be corrected.

In the following clauses, the most common solutions for the repair of building materials and for the strengthening of building elements are presented, as well as solutions for upgrading foundations and for the improvement of safety against earthquakes of heritage buildings.

**8.5.2 Repair of the degradation of materials**

The repair of the degradation of building materials is, in general, achieved through the restoration of the geometry of the structural elements. When the loss of a section is not very significant, it will be sufficient the adoption of protective measures of the existing materials.

When restoring the geometry of elements, in principle, materials identical to the original ones should be used. The use of new materials should take into account the type of the original material and the defects that are associated with it.

**Masonry**

The repair of masonry elements is, in general, obtained through re-pointing the cracks with mortar, or the injection of appropriate grout (Fig. 8.9). Sometimes, the appropriate solution will include the replacement of the deteriorated masonry units.

The composition of the mortar or the grout to be used (cement, resin, etc.) will depend on the characteristics of the masonry, itself. Particular attention should be given to the compatibility of the repair materials and the existing masonry.

For example, in the repair of masonry built with mortar that contains gypsum, mortar or grout of cement should not be used, because of the reaction between the gypsum and the cement.

For the elimination of bio-deterioration in masonry elements, several solutions also exist, nowadays, (biocides, laser, etc.). The appropriate solution should also be analyzed in each specific case.

For the superficial repair of a masonry crack, chemical emulsions (silicates, etc.) can be used.The appropriate solution on case specific basis should be developed.

Figure 8.9: Injections of epoxy resins in a masonry vault

The elimination of infiltration of water and the rise by capillarity of moisture in the masonry, coming from the foundations is, in general, difficult to achieve. The injection of hydro-activegrouts, based on polyurethane resins is, sometimes, adequate. When possible, the bestsolution will be, always, the elimination of the source of contamination, through the adequate drainage and desalinization of the soil.

**Timber**

Concerning the action of xylophages insects, preservative materials with insecticide properties exist nowadays, and are adequate for timber protection.

Concerning the effect of moisture on the outside of elements of coverings and of the floors embedded in walls, an adequate solution will be their protection against the infiltration from rain water. When those elements have deteriorated significantly they should be substituted by new ones.

For the problem of the existence of longitudinal cracking in timber elements, some solutions also exist, such as the use of lateral fastenings or ties, or the injection with special products (synthetic resins, etc.). When steel elements are used in this strengthening, they should be adequately protected against corrosion. When consolidating materials are used in timber, their compatibility should also be verified.

**Steel and iron**

The main problem with steel or iron elements is corrosion. Their repair requires, firstly, the elimination of the rust, for which several techniques exist (sand blast, etc.), then covering of the surfaces with appropriate products, usually, paint.

When there is a significant reduction of their sections, structural elements should be substituted by new ones. Depending on the specific conditions, reductions of more than 20% are, in principle, considered significant.

### 8.5.3 Repair and strengthening of the structural elements

The repair and strengthening of structural elements affected by mechanical actions usually requires the introduction of additional components in order to restore or increase their strength. In particular situations, partial demolition followed by the reconstruction of the elements, using, as much as possible, techniques identical to the original ones, can also be adequate.

**Walls and columns**

Concerning walls, to counteract the effects of vertical loads, the most efficient measures are the consolidation of the material itself, through injection or re-pointing, as has been referred to for the masonry material.

In the case of composite walls, with two exterior skins and an interior core (usually, rubble of low quality), steel connectors, anchored in the exterior skins constitute an efficient measure to assure their integrity, impeding their separation from the interior core (Fig.8.10).

When the walls are cracked due to in-plane loading, an adequate solution will be the installation of anchorages (anchor bolts) in the thickness of the wall, crossing the cracks (Fig. 8.11a).

In particular situations it can be adequate to simply clamp the cracks with appropriate clamps, anchored on the surface of the wall (Fig. 8.11b).

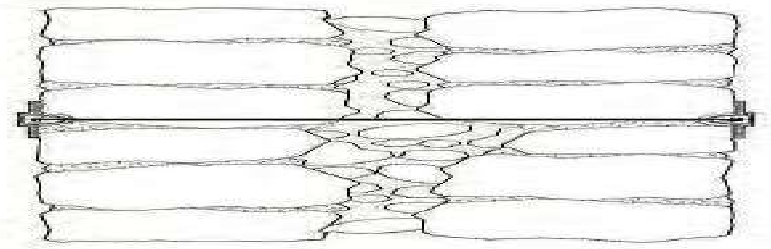
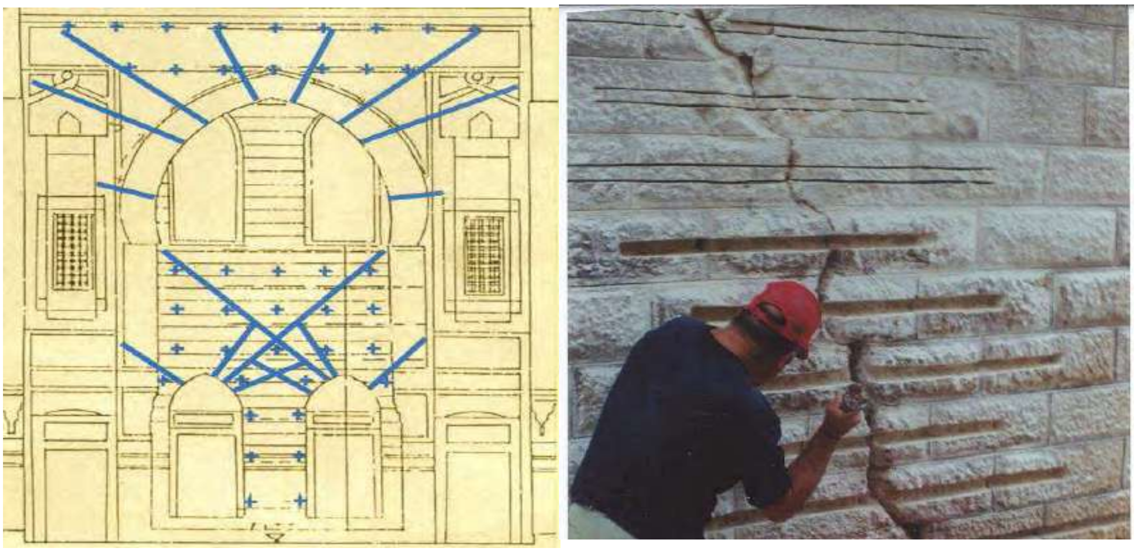


Figure 8.10: Strengthening of a masonary wall with steel connectors



a) With anchor bolts b)With clamps in cracks

Figure 8.11: Strengthening of masonry walls for in-plane actions

To counter the effects of lateral loads on walls they can be strengthened with metallic reinforcement or strips of composites: carbon fibres (CFRP) (Fig. 8.12), glass fibres (GRC), etc., applied on their faces. In some situations, strutting can also be adequate

In the case of buildings with timber floors, an important measure will be the improvement of the connections of the walls to the floors with metallic elements, envisaging, in particular, the seismic strengthening (see, Fig. 8.20 and Fig. 8.21). These metallic elements should be adequately protected against corrosion.

Concerning columns, injection, the application of ties and lateral confinement by wrapping with metallic sheets or composites (CFRP, GRC, etc.) are the measures usually used.The best solution will depend on the specific conditions.

Figure8.12:Strengthening of a masonry wall with glued CFRP strips

**Arches,vaults and domes**

For this type of element, in addition to the injection and the re-pointing (as referred to for walls), other measures can be adopted, such as the introduction of tie-rods, generally, in steel, to compensate for the thrust induced on the supports (Fig. 8.13).

The tie-rods should be placed, preferably, at the level of the bearing (in arches and vaults), or along parallel circles (in domes). They should be installed with a slight degree of pre-stressing, in order to guarantee that they will always be under tension.

When it is possible to install, another solution will be the jacketing of the extrados of the vaults with strips of glued composite materials. However, in this case, attention should be paid to the barrier effect that is created along the vault.

An alternative solution, very useful in particular situations, will be the insertion of strengthening components (in steel or timber), glued to the extrados of the masonry, which provides stiffness to the vault and in which the barrier effect is much less sensitive (Fig. 8.14)

Figure 8.13 Tying of masonry vaults with tie-rods in steel

Figure 8.14: Strengthening of masonry vault with timber ribs glued on the extrados

In the case of filled vaults, one possible solutionwill be the reduction of weight or, if appropriate, the adjustment of its distribution

In the case of floors made with brick vaults supported on steel beams, an adequate measure to restrict their lateral separation will consist in the placing of tie-rods, in steel, welded onto the bottom flange of the beams.

**Towers and chimneys**

The most common solution for the strengthening of this type of element consists ofn tying them with horizontal ties, usually, steel strips or cables (Fig. 8.15), or by wrapping them with glued composites (CFRP, GRC, etc.).

In the case of prismatic towers an appropriate measure will be the provision of diaphragms (in concrete or steel), at intermediate levels, for the confinement of the walls

Figure 8.15: Tying of masonry tower with steel strips

**Framed elements**

In the case of timber elements the most common solution for theirstrengthening is the substitution of the damaged elements by newones. In the case of steel elements the best solution will also be the substitution of the damaged members by identical new ones, eventually, stronger. Sometimes, the existing members can be strengthened, for example, through the gluing of strips or wraps of composites: CFRP, etc. (Fig. 8.16).

Figure 8.16: Strengthening of timber floor with composites

**8.5.4 Upgrading of foundations**

Concerning the strengthening or underpinning of foundations of walls or columns, the traditional technique of constructing piers in pits is still common.

The use of micro piles (Fig. 8.17) and the improvement of the soil through injection with jet-grouting or with hydro-active grouts are solutions that are also becoming increasingly popular. However, when these types of measures are adopted, they should be extended to the entire building, in order to avoid differential deformation of the building. Injection has the advantage of the creation of a barrier to protect the capillary rise of water to the building.

Another solution, sometimes possible, is the widening of the foundation, usually, with additional reinforced concrete elements. In this case, it will be necessary to effectively connect the old and the new elements.

To avoid the cracking of buildings during excavations (for the execution of tunnels, for example), beams in reinforced concrete can be constructed under the walls and columns, in order to transmit the weight of the building to the surrounding soil during the execution of the works. Concerning arches, vaults and domes, when they are subjected to differential settlement of the foundations, underpinning, using solutions identical to those referred for walls and columnsshould be carried out.

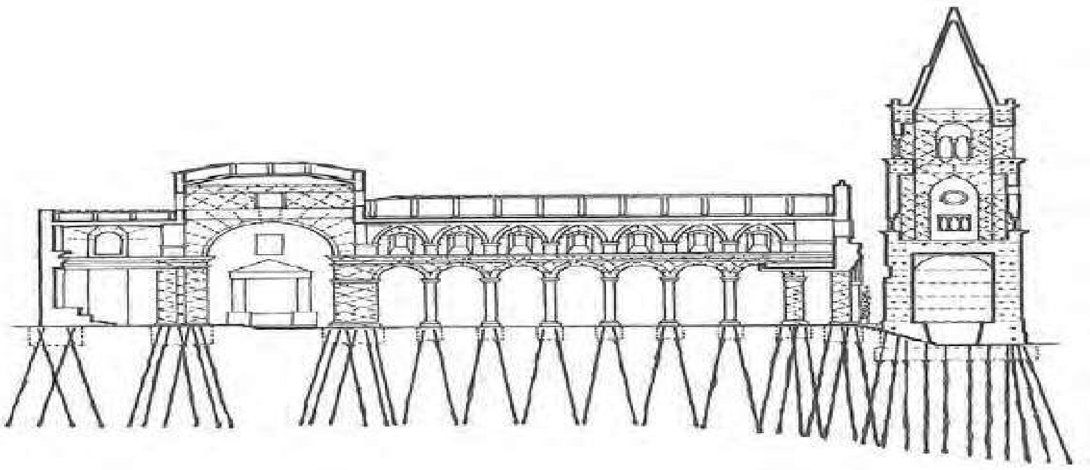


Figure 8.17: Strengthening of foundations with micro-piles

When towers and chimneys are subjected to differential settlements, the solutions referred to above can also be used. Sometimes, the adequate solution will be the increasing of the deformability of the soil in the zone where it is more rigid, for example, through the execution of horizontal holes in the soil.

The upgrading of foundations for framed elements can also be achieved using solutions identical to those referred to above for walls and columns.

**8.5.5 Improvement of safety against earthquakes**

The improvement of the safety of heritage buildings against earthquakes can be obtained by intervening, at least in one of the two following areas: resistance or ductility. The main problem is that these types of intervention are, in general, very intrusive and also very costly.

In the case of buildings in which elements are required to be strengthened, an adequate solution will be the local strengthening of those elements, as has been referred to above in relation to the effect of mechanical actions.

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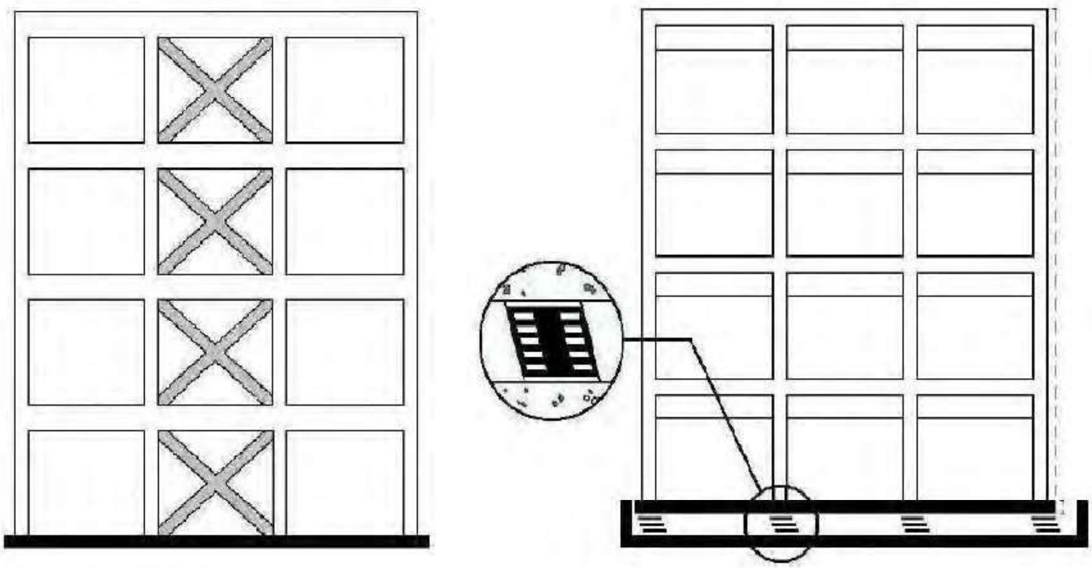
Another possible solution will be the insertion of additional very stiff elements into the building, such as shear walls or diagonal stiffening elements (Fig. 8.18a), but these solutions are ingeneral,very intrusive.



a) With diagonal elements b) With base-isolation

Figure 8.18: Solutions for the improvement of the safety against earthquakes

An alternative solution will consist in building an additional, autonomous, resistant system (in steel, for example), connected to the existing building, in order to assure combined behavior of the two systems under earthquakes.

In the case of buildings with great importance, it can be adequate to introduce dissipative devices, such the isolation of the building on its base, through energy dissipating bearings on the foundations (Fig. 8.18b). Another possibility will be the installation of visco-elastic dampers in the connections between the main parts of the building, or the insertion of additional diagonal elements (similar to that on Fig. 8.18a).

Elimination of existing irregularities in the building, namely, the distribution of stiffness, strength, or mass, will also be a positive measure, but it will be possible only in buildings without significant cultural value. In any case, the reduction of dead weights in floors and roofs (filling cabinets, etc.), when possible, is usually beneficial for the building.

Relatively simple measures also exist that although not completely solving the problem, can significantly improve the safety of a building against earthquakes. They are the measures aimed at insuring that the building behaves as a whole, through the realization of good interaction between walls and floors, in order to achieve the "box-effect" in the building. The most common solution is the insertion of tie-rods, whether metallic or of other material, (as referred to for arches and vaults), placed in the two principal directions of the building, at the level of floor diaphragms, and corresponding to bearing walls, anchored to the masonry by plates (Fig 8.19).Another solution will be the installation of ring beams in the periphery of the floors, connected to the masonry walls with pins (Fig 8.20). When the floors have limited stiffness to act as diaphragms, they should also be strengthened, for example, through the placing of another plank floor over the existing one (Fig.8.19)

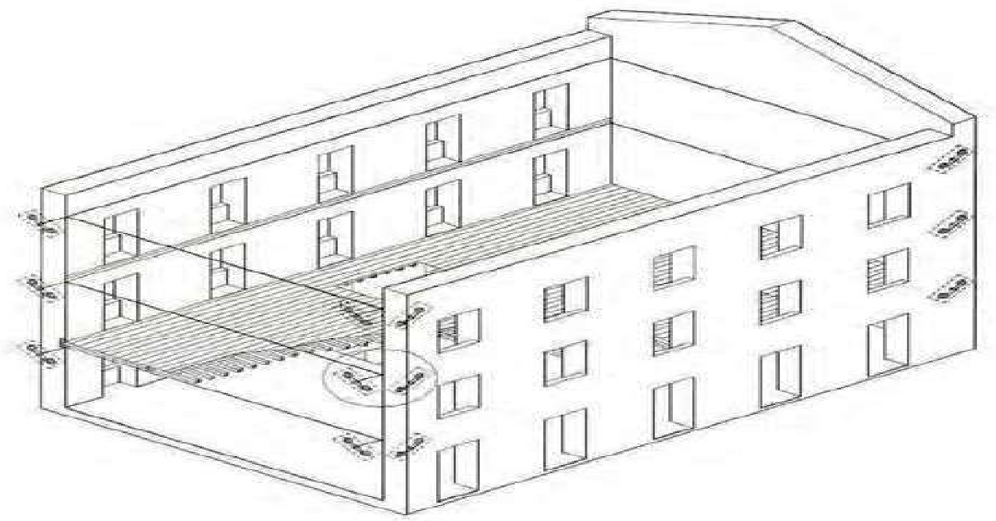


Figure 8.19: Tying of the building with tie-rods for the achievement of the"box-effect"

Figure 8.20: Steel device to connect a wooden floor with walls integrating wooden elements

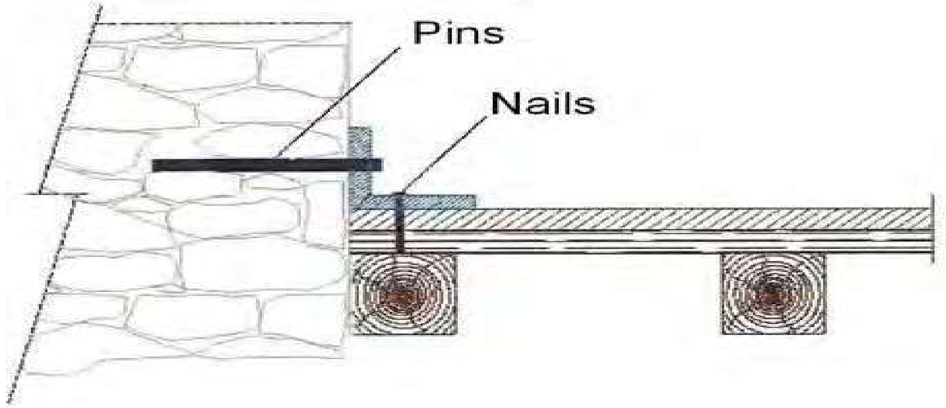



Figure 8.21: Connection system between wooden floors and masonry walls

## 8.6 Quality of the Intervention Work

### 8.6.1 Quality control of the execution of the work

The intervention work for structural rehabilitation of heritage buildings should be planned andbe executed accompanied by a quality control plan, to be implemented during the executionofthe works. The quality control plan should describe the objective of each control operation and indicatethe equipment of control to be used. On the intervention for structural rehabilitation, only solutions whose quality can be verified or controlled insitu, should,thus, be adopted.

In some situations it can be justified to carry out execution tests in the field,in order to assess the efficiency of the strengthening measures that have been adopted, as well as theadequacyofthemodelling adoptedinthestructural assessmentofthebuilding.

In some cases it can be justified to install a monitoring system to observe the response of the buildingduringtheexecutionof theworks, or for the control of it sbehaviour with time. As a rule, all the actions carried out during any intervention of structural rehabilitation shouldbedocumented.

After the intervention, the building should be the object of a plan of conservation, with thecarrying of periodic inspections, in order to identify any anomaly that has occurred in themeantime. The building should also be the object of periodic operations of conservation (cleaning, etc.),in order to impede the progression of any deterioration that can occur, and thus, to avoid thedegradationofthe building. As it has been said above, this strategy can ensure the structural safety of the building withless intrusive and lowercostinterventions.

### 8.6.2 Qualification of the interveners

As referred to above, the intervention of structural rehabilitation of heritage buildings has many diverse implications, namely, architectural, structural, economic, historical and social, constituting a combination of technique and culture.

The intervention of structural rehabilitation of heritage buildings should, thus, be carried out by multidisciplinary teams, under the guidance of experts having both great technical capacity and cultural sensibility.

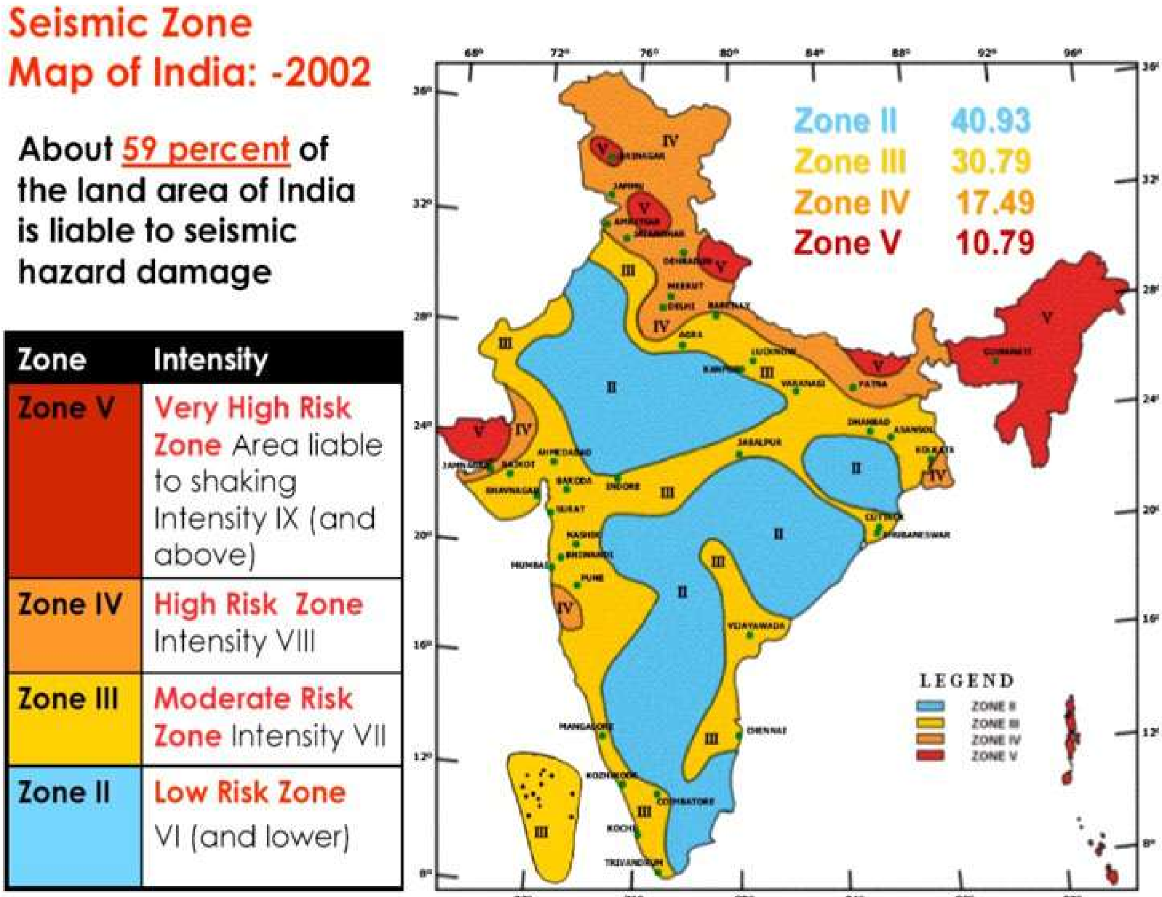
The teams for the inspection, the design and the execution of the works should also be staffed by qualified technicians, with specific knowledge in these areas.

In particular, the design engineer, besides having a high technical capacity, should have great sensibility for the cultural aspects of heritage buildings.

**8.7 Dajji Deewari**

India has been classified into different zones indicating the intensity of damage or frequency of earthquake occurrences. These zoning maps indicate broadly the seismic coefficient that could generally be adopted for design of buildings in different parts of the country. The capital cities of Guwahati and Srinagar are located in seismic zone V which falls under very high risk zone.

Kashmir on account of unique geo-physical setting is highly prone to earthquakes of varying intensities. It has faced several devastating earthquakes in the past resulting in a large number of casualties and severe property damage.




Seismic zonation and intensity map of India

**Introduction:**

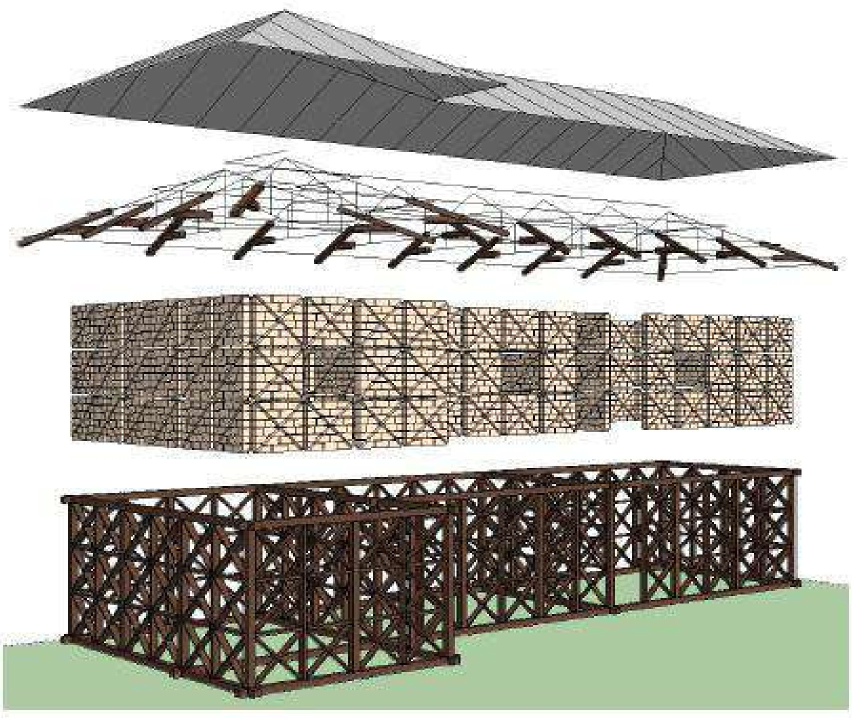
Dhajji Dewari is one of the classic traditional construction systems of the Himalayan region found in India and Pakistan. This construction technique played an underdog before a massive earthquake hit the Kashmir region in the year 2005 which killed about 86,000 people, 69,000 were injured and about 2.8 million displaced. That time Dhajji Dewari proved to be surprisingly earthquake resistant while other millions of buildings got collapsed and that’s when it got worldwide recognition.

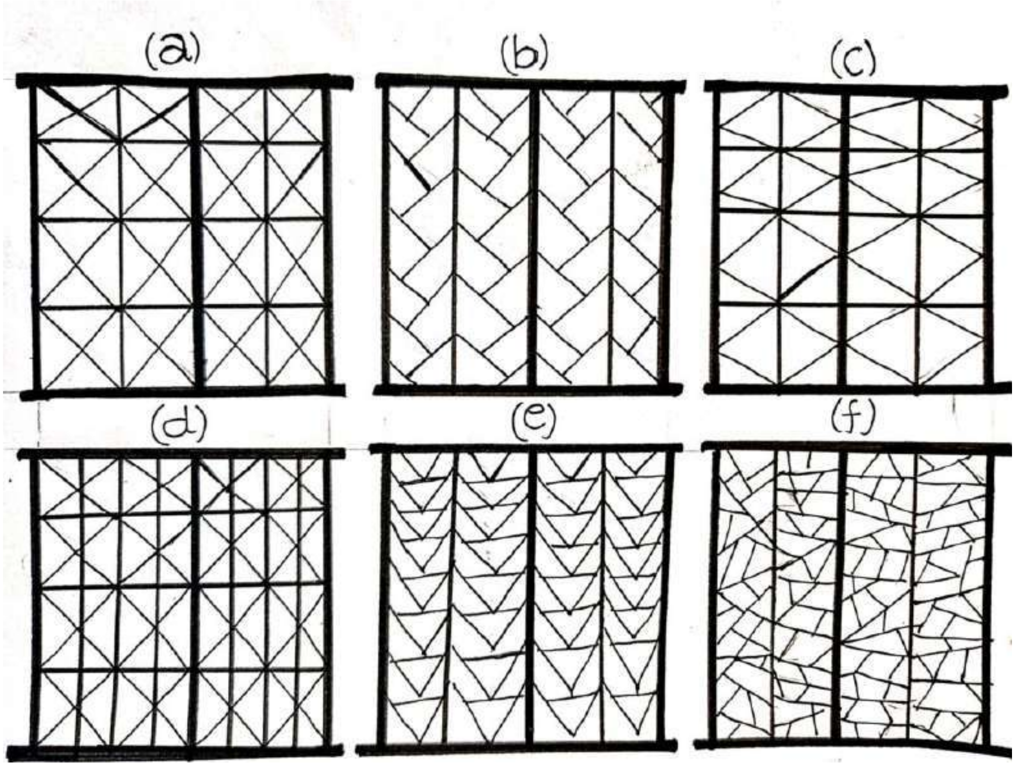
**Concept of Dhajji Dewari:**

The term dhajji dewari is thought to be derived from a Persian word meaning “patchwork quilt wall” and is a traditional building type found in the western Himalayas. Due to its resemblance in the appearance of the Dewari (which means wall) with Dhajji art work it is known as Dhajji Dewari.

Persian quilt patch work- Dhajji Dewari

As per ENVIS center on human settlements, Dhajji Dewari has been in practice for more than 200 years. As the name itself describe, the construction seems as patchwork done using different types of patterns and it is also referred in the Indian Standard Codes as brick nogged timber frame construction.





Different types of Dhajji dewari patterns

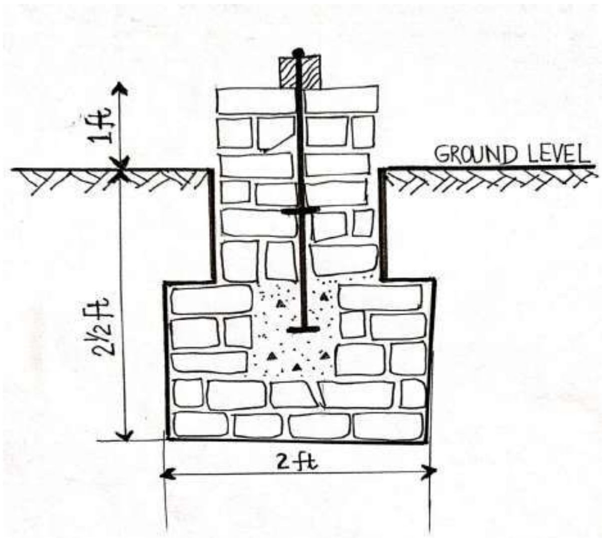
**Building design for Dhajji Dewari construction:**
Following are few points that are necessary for designing a building for Dhajji Dewari construction:

Planning of the building:

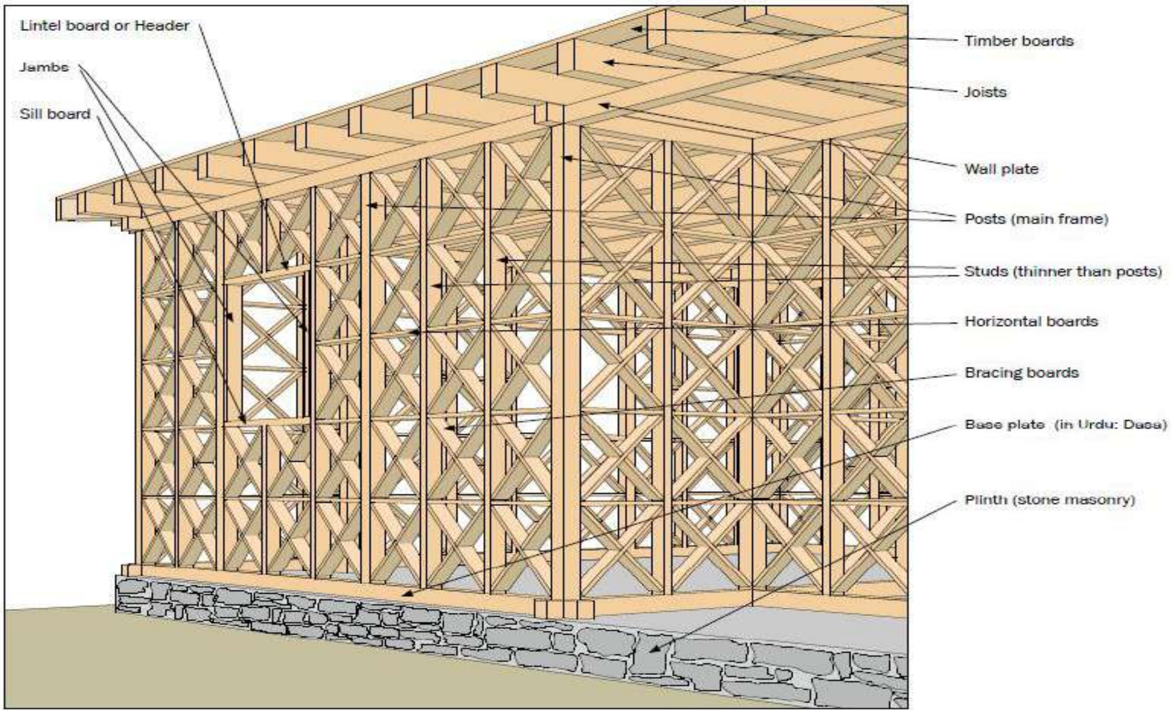
- Planning of the building for Dhajji Dewari is best if kept simple. The building form is preferred either square or rectangle in shape which can be further subdivided into smaller squares or rectangles (rooms) as per the requirement of the spaces.

- The spaces inside the building should be evenly distributed or symmetric in order to balance the structure.

Foundations:
Foundation should be firm and strong, prepared with stone and cement mortar. 1 foot foundation should be above the ground to support the plinth beam also known as Dasa. The Dasa (Plinth beam) in case of Dhajji Dewari construction is made of timber. It is important to anchor dasa properly with the foundation.



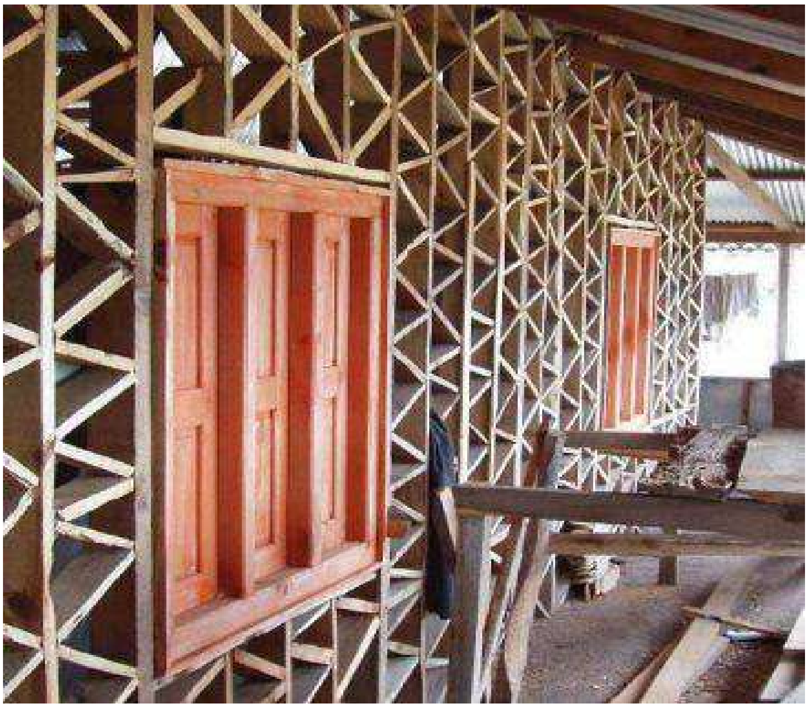

The frame structure:
The frame is made up of timber posts of different sizes which are combined together to form a basic structure.



The main post must be 4″x4″ in size which should be at a distance of 4-6 feet apart (Vertically). Then there are posts which are in between the main post which must be 4″x2″ in size and should be maximum 2 feet apart (both horizontally and vertically)

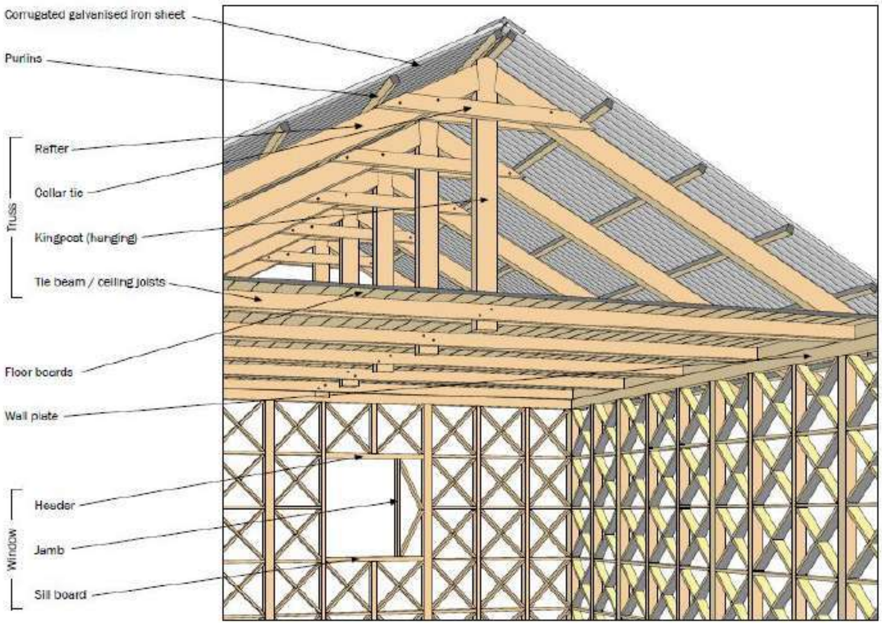
**Openings of the structure:**

- Traditionally the openings (doors and windows) were kept smaller in size, typically timber frame is made around the windows. Wooden shutters were used instead of glass for windows.



## Roof of the building:

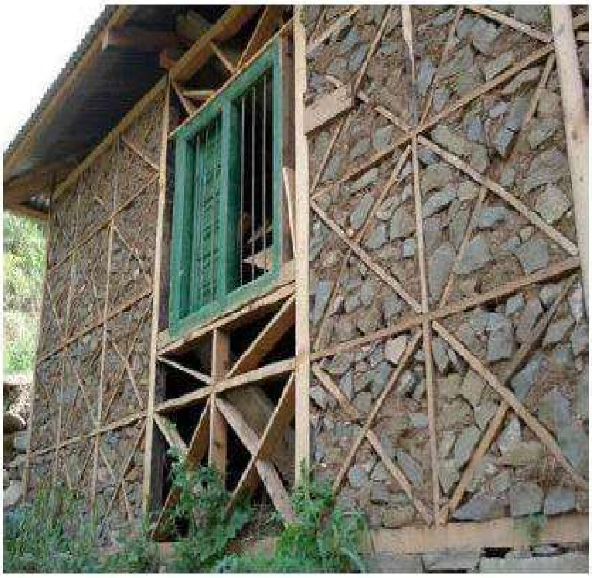
- The roof of these vernacular buildings can be flat timber and mud roof, or a pitched roof with timber/metal sheeting.




## Use of Vernacular Materials for Dhajji Dewari construction:

As it is the traditional construction system there is maximum use of local materials. Following are the major building materials:

1. Timber
2. Stone or Brick,
3. Mud,
4. Metal sheeting

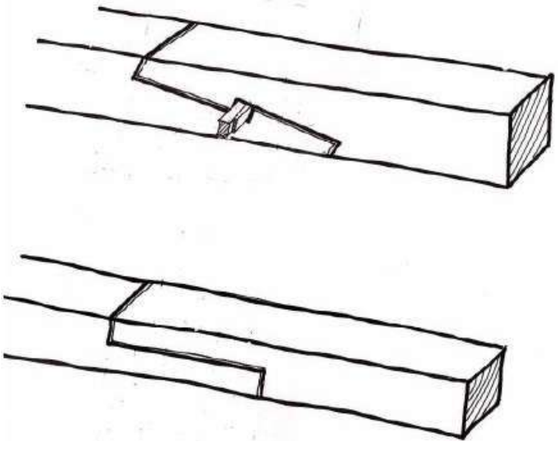


**Construction technique for Dhajji Dewari:**

Dhajji Dewari is timber frame construction rather than masonry bearing wall construction. It is basically a braced timber frame structure which can be achieved using different patterns. Further these timber bracing or frames is filled with thin layer of either stone or brick masonry which result in a wall and it is done in order to create patchwork of small size masonry panels.
Mud mortar is used to fill the gaps created between the stone or brick. At the end the walls are plastered with mud plaster to give it a sealed and smooth finish. The building can be made 1-4 stories using Dhajji Dewari construction technique.

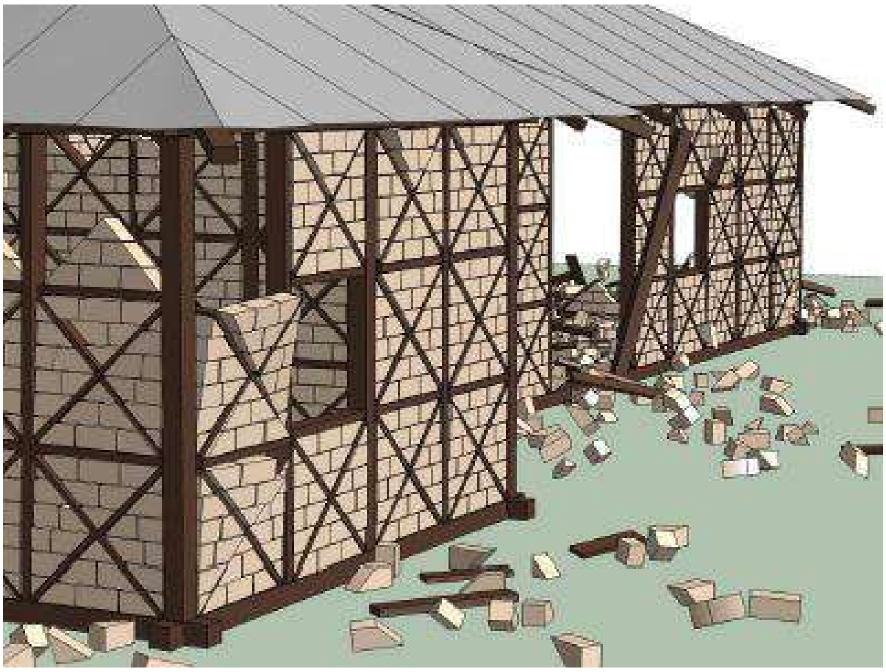
**Joints in Dhajji Dewari construction:**

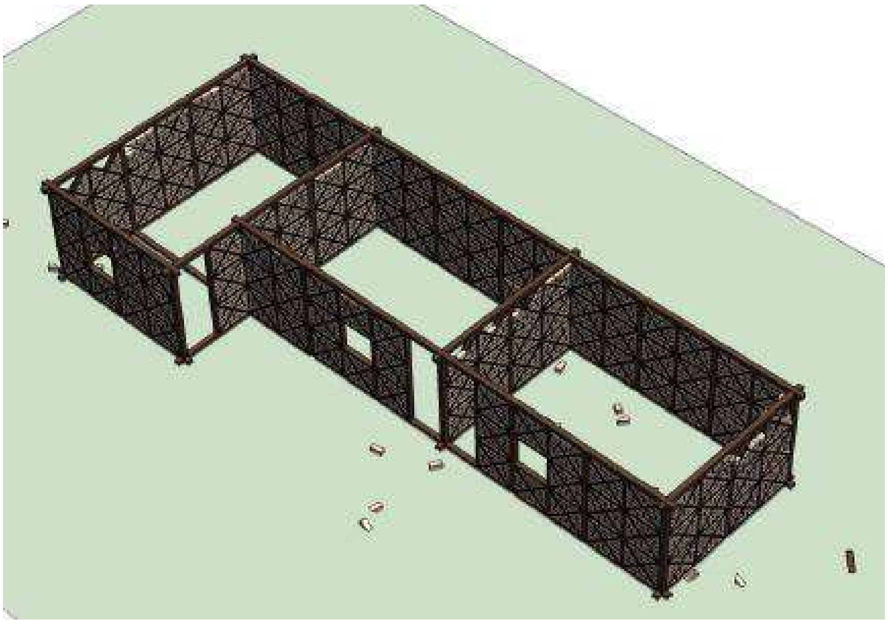
Jointing plays a major role in Dhajji Dewari construction system. Traditional joints are a part of this construction which are used as wall joints, corner joints and plinth beam joints. All the joints must be executed with great care. The quality of joints will keep the building safe and the types of joints used in Dhajji dewari are Lap joint, scarf joint, Tenon and mortise joint.



**Dhajji Dewari - Traditional Earthquake Resistant Construction of Kashmir.**

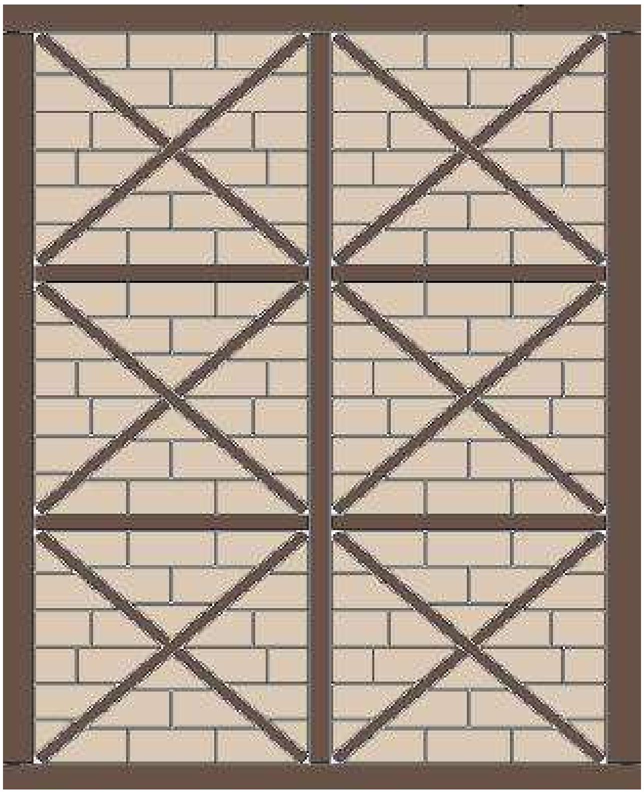
'Earthquake don't kill people-buildings do' but Dhajji Dewari emerged surprisingly earthquake resistant in the disastrous earthquake in Kashmir region in 2005. Different components in Dhajji Dewari plays different role in order to save a building collapsing in case of sever earthquake, same has been explained in detail below:





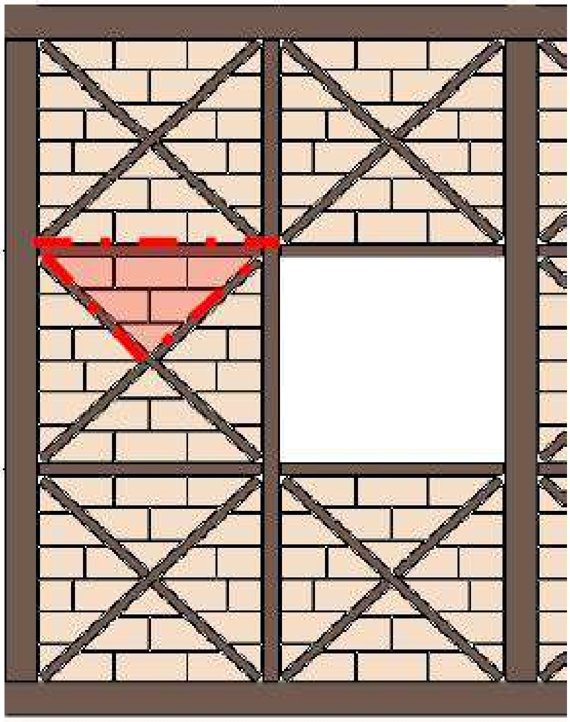
**Role of Timber studs:**

- Timer studs plays a major role as it divides the infill which prevents the loss of other numerous masonry panels which helps in gradual deterioration of rest of the wall.
- Furthermore, the tightly spaced studs prevent diagonal shear cracks from propagating inside a single panel and limit the risk of out-of-plane collapse of masonry of thin half-brick walls, even in the upper stories and gable portion of the walls.
- The vertical loads are carried to the ground via the frame made of timber studs and also provide the required elasticity in the structure.



**Role of Infill masonry:**

- The infill masonry plays a primary role in case of earthquake loads as it is an important part of the structural system.
- The mortar, masonry infill panels break quickly in-plane, absorbing seismic energy through friction with the timber framing and between cracks in the fill material. As a result, the earthquake energy is distributed uniformly.



- The masonry walls are maintained as thin as possible. This reduces the building's bulk and as a result the inertial forces that must be resisted during an earthquake.
- Pine needles and straw can be added to the mortar in order to make it more elastic and resistant to earthquake.

**Role of openings:**

- Avoid placing the too many openings on the same walls of the structure.
- Windows must be place 2 feet away from the each other and from corners as well.

**Dhajji Dewari, Eco-Friendly and Sustainable construction:**

- Apart from the natural fungus and insect resistant compounds in the timber itself, these constructions are environmentally safe and traditionally would not have included any hazardous products in their construction.
- During an earthquake, houses built with Dhajji technique proved to be more durable and sustained less damage than modern reinforced concrete buildings.
- This traditional construction is a skillful process which provides employment to the local artisans.

**Research and analysis:**

The following points summarise the key findings from the research and analysis conducted till date:

1. Dhajji dewari can safely resist earthquakes in high seismic regions of the world when built properly and maintained adequately. This makes dhajji dewari a valid form of construction in seismic areas.

2. The timber framing provides stable confinement to the infill masonry as long as it remains together. Therefore it is critical that the timber connections are detailed to have sufficient strength and ductility. Strategic use of nails and /or metal straps improves the building performance.

3. Seismic energy is dissipated through friction between the masonry panels and the timber frame and within the yielding of the connections.

4. Increased levels of overburden acting on the masonry increases the energy absorption capacity of the assembly, which provides evidence that the use of the system for two or even more storey structures may be satisfactory. This is consistent with some observations of resilience of multi-storey buildings in Turkey, India and Haiti after recent earthquakes. Further research is merited to establish design criteria for multi storey dhajji dewari buildings.

5. Shortening the braces so that they are disengaged from the timber frame leads to nominally improved seismic energy absorption of the system. No adverse effects were observed from shortening the braces. Consequently brace removal may offer acceptable performance with simpler construction (as the bricks do not have to be cut or placed at angles) and reduced timber volume, which is helpful to preserve natural resources.

Broadly, dhajji dewari is similar conceptually to 'confined masonry' construction which has concrete ring beams and columns confining the unreinforced masonry infill. The main difference is that in a 'confined masonry' system the sand cement mortar used to bond the masonry pieces together is brittle and stiff while traditional dhajji dewari has mud mortar which is very weak which allows it to start yielding even under relatively small lateral loads. Also, in dhajji dewari construction the masonry panel sizes are typically much smaller than in typical confined masonry construction, which can be advantageous. The energy in the dhajji dewari system is dissipated mainly in friction between the infill and the frame, and in the mortar joints of the infill itself, and not through the non-linear material deformations of the frame members as would be the case in modern steel or reinforced concrete construction. Therefore if key connections can be prevented from falling apart, then the integrity of the timber frame is secured and the infill dissipates the seismic energy through friction which is mobilised as the masonry pieces slide across each other and against the framing members. It is possible to imagine that after an earthquake that there will only be limited and repairable damage to a dhajji dewari building due to the unique energy absorbing properties of the system. This is a significant benefit over many modern engineering concepts as are now used for structures of similar size and use, particularly in rapidly developing cities, as well as rural areas.

**Innovations for future constructions:**

Dhajji Dewari is no doubt one of the most innovative construction systems already, but every Vernacular Architecture needs some improvements as per the present and future requirements so as to increase the life shell of the building which makes it sustainable also.

- Walls can be subdivided using different patterns as the strength of the wall depends upon the quality of connections and number of bracing boards.
- Hipped roofs (roof with four slopes) are recommended instead of gable roofs (roof with only two slopes). Gable roof needs extra bracing and also the risk of falling during an earthquake is high.

- For infill always use flat stones or bricks instead of using round ones as they fall out quickly.
- Using cement plaster for the walls should not be preferred as it do not provide the elasticity to the structure and do not allow necessary movement during earthquake.
- Instead of cement plaster it is advisable to apply thin layer of mud plaster. It provides the structure elasticity and allows necessary movement during earthquake which avoids cracks in the building.
- In order to increase the strength, galvanized wire mesh can be nailed both side of the wall as it also secure the stones against falling out.
- More the openings (doors and windows) lesser will be the strength. Doors and windows are considered as weak points during earthquake, so try to make as lesser and smaller as possible.

**Conclusion**

Dhajji Dewari is undoubtedly one of the most interesting traditional building construction techniques which need to be preserved. This is like a complete package as it is not only vernacular and eco-friendly but also earthquake resistant construction systems. Restoring and retrofitting can be easily done for Dhajji Dewari. These types of construction techniques provide employment to the local skilled labors or artisans.

If we are to create communities that are both sustainable and resilient, it is necessary to adopt construction technologies that make best use of available resources and are safe. Dhajji dewari offers hope to this cause by using durable renewable or recycled materials that are likely to be locally available. The research shows that it is a form of construction that can offer significant seismic resistance. If damaged dhajji dewari can be repaired relatively easily because the materials are readily available. However, proper engineering building standard and construction guidelines are required for construction and repair / retro-fitting of existing dhajji dewari buildings besides training of self-builders, contractors, university students, architects and engineers thus providing a credible alternative to the expensive and technologically complicated modern construction methods, such as reinforced concrete or steel framed construction.

# 9. BUILDING MAINTENANCE& AUDITING

## 9.1 General

Building maintenance is the work undertaken to keep, restore or improve every facility, that is, every part of the building, its services and surrounds to a currently acceptable standard and to sustain the utility and value of the property.

There are many types of damages in the building such as the electric system, water supply, floor, roof, the drainage system and the wall.

Any structure, building or service when built has certain objectives and during the total economic life of that structure or service, it has to be maintained. Maintenance is a continuous process requiring a close watch and taking immediate remedial action. It is inter-woven with good quality of housekeeping. It is largely governed by the quality of original construction. The owners, engineers, constructors, occupants and the maintenance agency are all deeply involved in this process and share a responsibility. Situation in which all these agencies merge into one is ideal and most satisfactory. There are two processes envisaged, that is, the work carried out in anticipation of failure and the work carried out after failure. The former is usually referred to as preventive maintenance and the latter as corrective maintenance.

## 9.2 Need for Maintenance

The building maintenance practice is needed in every development. It is because the building needs to be well maintained in order to retain the value of the property itself. Furthermore, the building also will continue to fulfill its function and will give the convenience to the occupant in the building.

The prime objective of maintenance is to maintain the performance of the building fabric and its services to provide an efficient and acceptable operating environment to its users.Maintenance and repair is very crucial part in every life of the building. The building management department also must develop checklist of a task of the work done, so that it will bemore efficiency to maintain the building.

## 9.3 Maintenance Categories

Maintenance, in general term, can be identified in the following broad categories:

### 9.3.1 Cleaning and servicing

This is largely of preventive type, such as checking the efficacy of rain water gutters and servicing the mechanical and electrical installations. This covers the house keeping also.

### 9.3.2 Rectification and Repairs

This is also called periodical maintenance work undertaken by, say, annual contracts and including external replastering, internal finishing, etc.

### 9.3.3 Replacements

This covers major repair or restoration such as re-roofing or re-building defective building parts.

## 9.4 Factors Affecting Maintenance

Maintenance of the buildings is influenced by the following factors:

**9.4.1 Technical factors:** These include age of building, nature of design, material specifications, past standard of maintenance and cost of postponing maintenance.

**9.4.2 Policy:** A maintenance policy ensures that value for money expended is obtained in addition to protecting both the asset value and the resource value of the buildings concerned and owners.

**9.4.3 Financial and economic factors**

**9.4.3.1 Financial Management In Building Maintenance**

The planning and control of finance is an important aspect of maintenance management not only for the control of maintenance but also to demonstrate that the owners are getting value for money and that the maintenance proposals justify the funds requested.

❖ Financial considerations start with the development of maintenance programmed and the preparation of budget proposals. They also include the preparation I of the detailed maintenance programme following the allocation of budget funds. These will involve decisions regarding optimum repair reaction items and the choice of the most appropriate method of execution ( directly employed labour or contract and the best type of contract ). This will lead to the need for budgetary control during the course of the financial year.

❖ It would be a good practice to carry out during the following financial year, a technical audit to ascertain the extent to which value for money was obtained from the funds expended in the previous year and what improvements in management might be made to improve cost benefits.

❖ **Financial Plan** The financial plan may be divided into short-term plan and long-term plan.

❖ **Short-Term Plan** Short-term plan takes care of short-term objectives and the various statutory requirements. This will be: a) Day-to-day service: This includes certain components or items which, by virtue of their extensive use or otherwise, need frequent repairs. This involves heavy deployment of human resources. b) Annual repairs: This includes periodical maintenance to keep the building stock habitable, healthy and in presentable condition.

❖ **Long-Term Plan**'s may include special repairs to prevent the structure from deterioration and undue wear and tear, and to restore the structure, fittings and fixtures to operative and acceptable standards.for details on financial and economic factors,reference shall be made to IS15183(Part2)

**9.4.4 Environmental:** All buildings are subject to the effects of a variety of external factors, such as, air, wind precipitation, temperature, etc, which influence the frequency and scope of maintenance.

The fabric of building can be adversely affected as much by the internal environment as by the external elements. Similarly,factors of humidity, temperature and pollution should be considered. Industrial buildings can be subject to many different factors, subject to processes carried out within. Swimming pool structures are vulnerable to the effects of chlorine used in water.

**9.4.5 User:** The maintenance requirements of buildings and their various parts are directly related to the type and intensity of use they receive.

## 9.5 Influence of Design

The physical characteristics, the life span and the aesthetic qualities of any building depend on the considerations given at the design stage. All buildings, however well designed and conscientiously built, will require repair and renewal as they get older.

However, for better performance of the building envelop, the following are the ways to minimize troubles at the later stage.

- ❖ Minimize defects during construction and design
- ❖ Detail and choose materials during construction so that the job of maintenance is less difficult and does not need much effort.

In addition to designing a building for structural adequacy, consideration should also be given to environmental factors, such as, moisture, natural weathering, corrosion and chemical action, user wear and tear, pollution, flooding, subsidence, earthquake, cyclones, etc.

A list of common causes for maintenance problems is given in Annex A for guidance.



# ANNEX A

( *Clause* 4.2.2.2 )

## COMMON CAUSES FOR MAINTENANCE PROBLEMS

**A-0 MAJOR CAUSES FOR MAINTENANCE PROBLEMS**

**A-1 FLOORS**

a) Poor quality of construction which includes quality of construction material and workmanship.

b) Improper slopes, mainly in kitchen, bathrooms/toilets, etc.

c) Lack of rounding at junctions of walls with floors.

d) Lack of damp-proof course treatment in walls and particularly in sunken floors.

e) Poor design of building.

**A-2 ROOFS**

a) Inadequate roof slopes.

b) Inferior quality of construction.

c) Cracks on roof surfaces.

d) Inadequate provision of rain water spouts.

e) Blockages in gratings/rain water pipes.

f) Worn out felts.

g) Bubbling up of tarfelt and separation of joints.

h) Leakage from the openings provided on the roof.

**A-3 PLUMBING**

a) Inadequate slopes in soil/waste pipes.

b) Improper lead joints.

c) Joints in walls.

d) Improper junctions of stacks.

e) Inadequate cleaning eyes at junctions.

f) Inadequate slopes in sewage pipes.

g) Throwing of solid wastes in WC's.

h) Lack of periodical checking and cleaning.

j) Lack of motivation/education to users for proper use.

k) Overflow from service tanks.

m) Inferior quality of fittings and fixtures.

n) Inadequate design.

**A-4 DRAINAGE**

a) Improper surface dressing around buildings and improper upkeep of surroundings.

b) Growth of wild grass and vegetation.

c) Inadequate drainage system around the building.

d) Inadequate slope of the drains or drainage pipes.

e) Inadequate number of inspection chambers.

f) Theft of manhole covers, etc.

g) Throwing of solid waste in the open surface drains.

**A-5 ELECTRICAL**

a) Loose connections.

b) Improper earthing and earth connections.

c) Damages to wires, cables and other installations.

d) Under rated cables/wires and other installations.

## 9.6 Maintenance Policy

The policy should cover such items as: The owner's anticipated future requirement for the building taking account of the building's physical performance and its functional suitability. This may lead to decisions regarding:

- ❖ The present use of the building anticipating any likely upgrading and their effect on the life cycles of existing components or engineering services; and
- ❖ A change of use for the building and the effect of any conversion work on the life cycles of existing components or engineering services.

## 9.7 Maintenance Work Programmes

The programming of maintenance work can affect an owner or his activities in the following ways:

**9.7.1** Maintenance work should be carried out at suchtimes as are likelyto minimize any adverse effect on output or function.

**9.7.2** Programme should be planned to obviate as far as possible any abortive work. This may arise if upgrading or conversion work is carried out after maintenance work has been completed or ifwork such asrewiring is carried out after re-decorations.

**9.7.3** Any delay in rectifying a defect should be kept to a minimum only if such delay is likely to affect output or function. The cost of maintenance increases with shortening response times.

**9.7.4** Maintenance work, completed or being carried out should comply with all statutory and other legal requirements.

An owner responsible for a large number of buildings may have established procedures for maintenance. When an owner is responsible for the maintenance of only one building or a small number of buildings, the preparation of a guide tailored to suit each particular building, can offer significant advantages. Such a guide should take into account the following:

- ❖ Type of construction and residual life of the building, and
- ❖ Environment and intensity of use.

The guide may form part of a wider manual covering operational matters.

## 9.8 Planning of Maintenance Work

Work should take account of the likely maintenance cycle of each building element and be planned logically, with inspections beingmade atregular intervals. Annual plans should take into account subsequent year's programmed to incorporate items and to prevent additional costs. It should be stressed that the design of some buildings can lead to high indirect costs in maintenance contracts and therefore, careful planning can bring financial benefits. Decisions to repair or replace should be taken after due consideration.

## 9.9 Feedback

Feedback is normally regarded as an important procedure of providing information aboutthe behaviour of materials and detailing for the benefit of the architect/ engineer designing new buildings, which will result in lesseningmaintenance costs. It is an equally valuable source of information for the persons responsible for maintenance. Every maintenance organisation should develop a simple way of communicating its know-how, firstly for benefit of others in the organization and secondly for the benefit of the building industry as a whole. There should be frank and recorded dialogue on an on-going basis between those who occupy and care for buildings and those who design and construct them.

Feedback should aim at the following:

- ❖ User satisfaction,
- ❖ Continuous improvement, and
- ❖ Participation by all.

**9.9.1 Source of Information**

The information on feedback can be obtained from the following: a) Occupants,

- ❖ Inspections,
- ❖ Records, and
- ❖ Discussions.

**9.9.2 Means of Effecting Maintenance**

**9.9.2.1 Responsibility**

Some maintenance work will be carried out by the occupier of a building or by the occupier's representative. In the case of leasehold or similar occupation, not all maintenance may be the responsibility of occupier. Responsibility of common areas may be clearly defined.

Maintenance work sub-divided into major repair, restoration, periodical and routine or day-today operations will be undertaken by one of the following:

- ❖ Directly employed labour,
- ❖ Contractors, and
- ❖ Specialist contractors under service agreement or otherwise.

The merits of each category for typical maintenance work must be considered because optimum use of resources appropriate to tasks in a given situation is an important element of policy.The success of contracting out depends on the nature of the services, conditions in which contracting is undertaken (the tendering process), how the contract is formulated and subsequent monitoring of service quality. The important consideration in the decision to contract out is whether a contractor can ensure a socially desirable quantity and quality of service provision at a reasonable cost to the consumers.

**9.9.3 Access**

All maintenance activities including any preliminary survey and inspection work require safe access and in some situations this will have to be specially designed. Maintenance policy and maintenance costs will be much influenced by ready or difficult access to the fabric and to building services. Special precautions and access provisions may also need to be taken for roof work or for entry into confined spaces, such as, ducts or voids.

**9.9.3.1 Access Facilities**

Permanent accessibility measures should be provided at the design stage only for all the areas for safe and proper maintenance. It is a matter on which those experienced in the case of the building can make an important contribution at design stage in the interest of acceptable maintenance costs.

A wide variety of temporary access equipment may appropriately be provided for maintenance work, ranging from ladders to scaffoldings or powered lift platforms. Wherever possible, it is better to provide permanent access facilities such as fixed barriers, ladders and stairways. When such permanent access facilities are provided, necessary arrangement may be included in maintenance plans for their regular inspection, maintenance and testing. All personnel employed for carrying out maintenance should be provided with the necessary protective clothing and equipment, and instructed in its use. When physical access is not possible in situations, such as, wall cavities, drains, etc, inspections may be made with the aid of closed circuit television or optical devices, such as, endoscopes.

**9.9.3.2 Access to Confined Spaces**

❖ Ventilation Special precautions need to be taken when entering a confined space. Such confined spaces should be adequately ventilated, particularly before being entered, to ensure that they are free fromharmful concentrations of gases, vapours other airborne substances and that the air is not deficient in oxygen.

❖ Lighting Good lighting is necessary in order that maintenance work can be carried out satisfactorily. This is particularly important in confined spaces. When the normal lighting is inadequate, it should be supplemented by temporary installations. These should provide general and spot illumination as appropriate.

❖ **Records**

General Good records can save owners and users/occupiers much unnecessary expense and reduce potential hazards in exploration work when faults arise.

Use of Building Records:

- ❖ All personnel involved in the maintenance of the building should be made aware of the existence of the building records.
- ❖ Known hazardous areas should be explicitly marked on the records as well as being marked on site and should be pointed out to such personnel together with any system of work adopted for use in such areas.
- ❖ Records are of value only if they are kept upto-date and arrangements for this should be included in any provision that may be made for records.
- ❖ Records should be readily accessible for use and the place of storage should take into account the form of the records and the conditions needed to keep them from damage of any kind. It is recommended that a duplicate set of records is kept in a secure place other than building itself and is kept up-to-date.
- ❖ Following should be typical contents of the maintenance records:
  - A brief history of property, names and addresses of consultants and contractors.
  - Short specifications, constructional processes, components, material finishes, hidden features, special features, etc.
  - 'As built' plans and as subsequently altered with sections, elevations and other detailed drawings.
  - Foundation and structural plans/sections such as concrete reinforcement drawings.
  - Detail specification of all materials incorporated, for example, concrete mix, species and grades of timber, etc. Potentially hazardous materials and types or methods of construction that under some circumstances become hazardous may be identified.
  - Information on house keeping and routine maintenance with details of internal and external surfaces and decorations, schedule of cleaning, inspection and maintenance.
  - Means of operating mechanical, electrical and plumbing installations.
  - Description of renovations, extensions, adaptations and repair to each elements.
  - All plant, machinery and propriety articles including manufacturer's trade literature and instructions for installation, use and maintenance.
  - Methods of work used in construction, such as, assembly of prefabricated units.
  - All information related to fire, such as:

- ✓ Location and service arrangements of all fire alarm and call points;
- ✓ Location and service arrangements of all extinguishers, hose reels and other tire fighting installations;
- ✓ Location of all fire compartment walls, doors, floors and screens;
- ✓ Location of all areas of exceptional fire hazard,
- ✓ Fire escape routes;
- ✓ Details of application of any fire protection treatment; and
- ✓ Location details and description of anyinstallationfor smoke control or protection of escape routes.

- ❖ There should be a wall chart showing at a glance the various operations which have to be undertaken. Line drawings of buildings are always useful.
- ❖ Records of security measures should be known to authorised personnel only.
- ❖ Where no records exist, information should be slowly built up as it becomes available during the course of maintenance work.
- ❖ Use of computers for storing information may be preferred.

❖ **Mechanical Records**

- ❖ **Documentation**Documentation should record the following as installed:
  - The location including level, if buried, of all public service connections (for example, fuel gas and cold water supplies") together with the points of origin and termination, size and materials of pipes, line pressure and other relevant information.
  - The layout, location and extent of all piped services showing pipe sizes, together with all valves for regulation, isolation and other purposes as well as the results of all balancing, testing and commissioning data.
  - The location, identity, size and details of all apparatus and all control equipment served by or associated with each of the various services together with copies of any test certificates for such apparatus where. appropriate. The information with respect to size and details may be presented in schedule form.
  - The layout, location and extent of all air ducts showing dampers and other equipment, acoustic silencers, grills, diffusers or other terminal components. Each duct and each terminal component should be marked with its size, the air quantity flowing and other relevant balancing data.
  - The location and identity of each room or space housing plant, machinery or apparatus.
- ❖ **Drawings** Drawings should record the following as installed:
  - Detailed general arrangements of boiler houses, machinery spaces, air handling plants, tank rooms and other plant or apparatus, including the location, identity, size and rating of each apparatus. The information with respect to the size and rating can be presented in schedule form.
  - Isometric or diagrammatic views of boiler houses, plant rooms, tank rooms and similar machinery, including valve identification charts. It is useful to frameand mount a copy of such drawings on the wall of the appropriate room.
  - Comprehensive diagrams that show power wiring and control wiring and/or pneumatic or other control piping including size, type or conductor or piping used and identifying the terminal points of each.

- **Electrical Records** Documentation should record the following including locations as installed:
  - Main and sub-main cables showing origin, route, termination, size and type of each cable; cables providing supplies to specialist equipment, for example, computers, should be identified separately.
  - Lighting conduits and final sub-circuit cables showing origin, route, termination and size of each, together with the number and size of cables within each conduit. The drawings should indicate for each conduit or cable, whether it is run on the surface or concealed, for example, in a wall chase, in a floor screed, cast in-situ, above a false ceiling, etc. These drawings should also indicate the locations of lighting fittings, distribution boards, switches, draw-in-boxes and point boxes, and should indicate circuitry.
  - Location and purpose of each emergency lighting fitting including an indication of the circuit to which it is connected.
  - Single and three phase power conduits and final sub-circuit cables showing locations of power distribution boards, motors, isolators, starters, remote control units, socket outlets and other associated equipment.
  - Other miscellaneous equipment, conduits and cables.
  - Lightening conductor, air terminals, conductors, earth electrodes and test clamps.
  - Location of earth tapes, earth electrodes and test points other than those in mentioned above; cables providing earth circuits for specialist equipment, for example, computers, should be identified separately.

## 9.10 Inspections / Audit

### 9.10.1 General

Regular inspections are actual part of the procedures for the maintenance of buildings. They are needed for a variety of purposes and each purpose requires a different approach if it is to be handled with maximum economy and efficiency. A more detailed inspection covering all parts of a building is needed to determine what work should be included in cyclic and planned maintenance programme.

### 9.10.2 Need for Inspection/Structural Audit

The purpose of a building inspection/structural audit is to verify compliance with the minimum safety standards set forth in the adopted codes.

Structural Audit is an important approach to comprehend the distress level or state of any existing building/structure. It is an initial specialized technical inspection of a building to evaluate its general health as a civil engineering structure. It is usually initiated as the first step for repair. This is akin to the periodic health checkup recommended for older people. It ensures the safety of the building and its premises. Structural audit is important for knowing the real health status of the heritage buildings or structure. It is a process which suggests appropriate repairsand retrofitting measures required for the better performance of the building.

### 9.10.3 Purpose of Structural Audit

- To understand the condition and health of the structure
- To check actual reliability of the structure.
- To highlight the critical areas of the structure that needs immediate attention.
- To abide by the Municipal or any statutory requirements.

**9.10.3.1 Methodology**

❖ **Stages in Structural Audit:**

- ❖ Study of architectural and structural drawings, design criteria, design calculations, structural stability certificate of existing structures.
- ❖ If the Architectural plans and Structural plans are not available, the same can be prepared by any Engineer.
- ❖ Inspection of the building.
- ❖ Preparation of Audit report.
- ❖ Visual Inspection The inspection report should reveal the following along with photographs and sketches:
  - Settlement of columns or foundations
  - Settlement of walls and floors
  - Deflection and cracks in Retaining wall
  - Materials used and framing system of structure Identification of the critical structural members like floating columns, transfer beams, slender members, rusting of exposed steel and its extent.
  - Status of all building elements like beams, slabs, columns, balconies, canopy, false ceiling, chajja, parapet and railings with respect to parameters deflection, cracks, leakages and spalling of concrete.
  - Status of water tank, staircase, lift and lift machine room.
  - Dampness in walls
  - Leakages in Terrace, toilets, plumbing lines, drainage lines and overhead tanks.
  - Blistering of paints and paint peel off
  - Inspection of drainage system.

❖ **Tapping observation**

Tapping sound is noted by tapping hammer on some structural elements to find out whether it is hollow or dense. Defects like cracks and bulging are also identified by tapping with light hammer.

❖ **Destructive testing** It is feasible most of the times to make a stroke through the components and inspect the exposed surfaces to substantiate the robustness of a component. The building components can be stressed and pressurized until failure to ascertain their properties of strength and toughness. Materials can also be subjected to chemical testing. These are some forms of destructive testing. Unfortunately this approach of destructive testing renders the component useless for its intended use as against non-destructive testing which can be performed on the components and machines without affecting their service performance.

❖ **Non Destructive and Destructive Testing** In addition to visual inspection, the real strength and quality of a concrete structure need to be checked with non-destructive tests. A number of non-destructive tests (NDT) for concrete members are available to determine present strength and quality of concrete. Some of these tests are very useful in assessment of damage to RCC structures subjected to corrosion, chemical attack, fire and due to other reasons. These tests have been put under four categories depending on the purpose of test as under

❖ **Concrete Strength**

- ❖ Rebound Hammer Test: To measure surface hardness of concrete
- ❖ Ultrasonic Pulse Velocity Test: To assess homogeneity of concrete, to assess strength of concrete qualitatively, to determine structural integrity

- ❖ Core Sampling and Testing: To measure strength, permeability, density of concrete.
- ❖ Chemical Attack
- ❖ Carbonation Test: To assess depth of carbonation and pH of concrete
- ❖ Chloride Test: To assess total water/acid soluble chloride contents
- ❖ Sulphate Test: To assess total water/water soluble sulphate contents of concrete.

❖ **Corrosion Potential Assessment**

- ❖ Cover Meter: To measure cover of reinforcement, diameter of reinforcement and spacing of reinforcement
- ❖ Half Cell Method: To assess probability of corrosion in the embedded steel
- ❖ Permeability Test: To assess permeability of concrete due to water and air Structural Audit of Buildings Homogeneity and integrity Assessment
- ❖ Ultrasonic pulse velocity for determination of cracks and discontinuities

❖ **Core Testing** This is direct method of assessing strength of concrete. In this method cylindrical core samples are taken from existing structures. The cores are visually inspected and tested in laboratory to check its compressive strength

❖ **Pushover Analysis** Generally Push over analysis is used to understand the existing capacity of structure for seismic and gravity loading which will show different occupancy levels like immediate occupancy, life safety and collapse prevention. The seismic evaluation of existing buildings compares their capacity against earthquake demand at specific site and concerns the potential earthquake-caused risk to building systems and elements that are closely related to human life safety.

Identification of critical areas in building Based on the above inspection, analysis and test results, the report should conclude the critical areas that need immediate repairs and retrofitting. For example: number of columns requiring immediate repair and strengthening, repair of critical slab and beams, water proofing of terrace, toilet blocks, cracks in walls or structural elements Non Destructive testing Non-destructive testing (NDT) is a wide group of analysis techniques used in science and technology industry to evaluate the properties of a material, component or system without causing damage. Common NDT methods include ultrasonic, magnetic particle, liquid penetrate, radiography, remote visual inspection (RVI), eddy current testing. These types of tests are of great importance in determining the damage to structures subjected to corrosion, chemical attack, fire attack, etc.

**9.10.4 Audit Report**

An Audit Report is prepared on the basis of the inspection carried out. General Format of the Structural Auditis given below.

**General observations**

| *S.NO* | DESCRIPTION | REMARKS |
|---|---|---|
| 1 | Type of building structure | |
| 2 | Age of building | |
| 3 | Date of inspection | |
| 4 | Site address | |
| 5 | Whether building is in use(fully/partially) | |
| 6 | User Departments(if it’s a government building) | |
| 7 | No. of stories | |
| 8 | Architectural plan available | |

**Structural Observations**

| Sr. No. | Description | Component | Grade |
|---|---|---|---|
| 1 | Cracks | Beam | |
| | | Column | |
| | | Slab | |
| | | Plaster | |
| | | Wall | |
| 2 | Settlement | Foundation | |
| | | Joint at plinth | |
| | | Column | |
| | | Wall | |
| 3 | Leakage &Dampness | External wall | |
| | | Toilet | |
| | | Terrace | |
| | | Slab | |
| | | Water tank | |
| | | Drainage line/Pumping line | |
| 4 | Deflection | Beam | |
| | | Slab | |
| | | Balcony | |
| 5 | | Condition of staircase, balcony, flooring and duct | |

RCC framed structures are rated by grades as follows:

- Very Bad (VB)
- Bad (B)
- Fair (F)
- Good (G)
- Very Good (VG)

**9.10.5 Post Structural Audit**

**9.10.5.1 Repairs**

Based on the audit findings and recommendations different measures of repairs and strengthening are carried out. According to ACI 546R-04, to repair is to replace or correct deteriorated, damaged, or faulty materials, components, or elements of a structural system. From this point of view, repair may be divided into structural repair and serviceability repair. The former refers to the restoration of lost sectional or monolithic properties of damaged members, while the later refers to the restoration of structural surfaces to a satisfactory operational standard. Obviously, poor design, poor construction, poor maintenance, incorrect usage, new environmental influences or an intended increase of the loading or extension of the structure's lifespan can make repair and/or strengthening necessary. Excluding technical considerations, the ultimate choice of method of repair and strengthening of a concrete structure may also be influenced by factors like overall quality of repairs and the size of individual repairs, access for repair, relative cost, ease of application, available labor skills and equipment and client requirements including future maintenance and economic consideration

**9.10.5.2 Strengthening and Retrofitting**

Strengthening is the process of restoring the capacity of damaged components of structural concrete to its original design capacity, or increasing the strength of structural concrete. Strengthening of a concrete structure may be required due to several reasons:

- Change of usage which may cause over-stress in the structural member.
- Serious materials and structural deteriorations which cause structural members to be no longer able to carry the imposed loads with an adequate factor of safety
- To increase the capacity for seismic resistance if the building is not designed for it or the structure does not fulfill current design requirement corresponding to seismic zones, R factor or so. Strengthening of structural members can be achieved by replacing poor quality or defective material with better quality material, by attaching additional load-bearing material, such as high quality concrete, additional steel, thin steel plates, various types of fiber reinforced polymer sheets, and so on, and by the redistribution of the load such as by adding a steel supporting system. The purpose of strengthening is to increase the load-carrying capacity or stability of a structure with respect to its previous condition.

**9.10.6 Conclusion**

The structural diagnosis is vast, important and highly responsible job which is connected with lives of human beings. It is mandatory and advisable to carry out the periodical structural audit of the buildings by professional experts and act immediately through recommendations provided in audit report. The success of repairs and restoration is always based on thorough knowledge, correct diagnosis and in-depth studies of problems in building, proper repair practices and finally socio-economic considerations. The effective implementation of auditing enhances the life span of structure, prevents deterioration of building leading to sustainability.

# 10. STRUCTURAL HEALTH MONITORING (SHM) OF BUILDINGS

## 10.1 Introduction

Structural health monitoring (SHM) is a process in which certain strategies areimplemented for determining the presence, location and severity of damages and theremaining life of structure after the occurrence of damage. This term is usually referred toaerospace, civil and mechanical engineering infrastructure. It is the continuousmeasurement of the loading environment and the critical responses of a structural systemor its components. Health monitoring is typically used to track and evaluate theperformance, symptoms of operational incidents and anomalies due to deterioration ordamage as well as health during and after extreme events. Damageidentification is the basic objective of SHM.There are mainly four levels in damage identification):

- **Level 1: Detection-** Damage detection when identifies that damage has occurred
- **Level 2: Localization-**Damage location, when identifies that damage has occurred and determines the location of damage
- **Level 3: Assessment -**Damage typification, where identifies that damage has occurred, location of damage, and estimates the type of damage
- **Level4: Prognosis -**Damage extent, where identifies that damage has occurred, location of damage, estimates the type of damage and evaluates the severity of damage
- **Level5: Remediation -**Damage extent, where identifies that damage has occurred, location of damage, the type of damage, the severity of damage, and evaluates the remaining useful life of the structure or viability state

SHM involves the observation of a system over time using periodically sampled dynamicresponse measurements from an array of sensors, the extraction of damage-sensitivefeatures from these measurements, and the statistical analysis of these features todetermine the current state of the system health. For long term SHM, the output of thisprocess is periodically updated to provide information regarding the ability of thestructure to perform its intended function in light of the inevitable aging and degradation resulting from operational environments. After extreme events, such as earthquakes orblast loading, SHM is used for quick condition screening and aims to provide, in near realtime, reliable information regarding the integrity of the structure.

Health monitoring has gained considerable attention in the civil engineering communityover the last two decades. Although health monitoring is a maturing concept in themanufacturing, automotive and aerospace industries, there are a number of challenges foreffective applications of the concept on civil infrastructure systems. While successful real-life studies on new or existing structures are necessary for transforming healthmonitoring from research to practice, laboratory benchmark studies are also essential foraddressing issues related to the main needs and challenges of SHM. Although it is stillmainly a research area in civil infrastructures, it would be possible to develop successfulreal-life health monitoring systems if all components of a complete health design arerecognized and integrated. Hence, SHM offers great promise for civil infrastructureimplementations.

## 10.2 Need of SHM

Appropriate maintenance prolongs the life span of a structure and can be used to preventcatastrophic failure. Higher operational loads, complexity of design and longer life timeperiods imposed to civil structure make it increasingly important to monitor the health ofthese structures. Economy of a country depends on the transportation infrastructures likebridges, railways, roads etc.

Any structural failure of these causes severe damage to the life and economy of the nation. Every nation is spending millions of Dollars every yearfor the rehabilitation and maintenance of civil engineering structures. Failure of civilinfrastructure to perform at optimum level may affect the gross domestic production ofthe country. Strength of structures decreases due to continuous loading and impact ofenvironment. Hence, it should be evaluated if the performance of the structure issatisfactorily or not after such deterioration. If structural strength falls down below acertain threshold level, sudden failure is possible which might result in accident andaffect the serviceability of the structure. Early detection of damage is of special concernfor civil structures. If not identified in time, damage may have serious consequences forsafety of occupants. There are several natural events which may affect the strength ofstructure. It should be ensured that the structure is safe after such natural events. Ifstructures are monitored periodically or continuously, better understanding will beachieved about the behaviour of the structure. It will be very useful for designimprovement. By proper SHM, the number of catastrophic events can be decreased,which will be helpful for economy of the country and also for psychology of human beings. If damage/cracks developed before failure, are detected at an early stage, propermeasures can be taken. Collapse of bridges, tall buildings and other important structureshamper the economic growth of the country and also results in the loss of humanresources. Structures are designed for a certain life span, and it is assumed that during thisperiod the structure is maintained properly. By proper monitoring, it may be possible thatthe life of the structure be increased and serviceability enhanced, resulting in hugesavings. Fatigue assessment can be determined, if continuous monitoring is done. It maypossible that a new constructed structure may not be performing well with respect todesign parameters, either due to inferior material or faulty construction. This can beensured by proper health monitoring.

A successful health monitoring design requires the recognition and integration of severalcomponents. Identification of health and performance is the first component whichis a fundamental knowledge need and should dictate the technology involved. These factsunderline the importance of an automated health monitoring system, which can not onlyprevent an incipient damage included collapse, but also make the assessment of structuralhealth, as and when desired, at a short notice. These automated systems hold the promisefor improving the performance of the structure with an excellent benefit/ cost ratio,keeping in view the long term benefits.

## 10.3 SHM Techniques

Until very recently and to great extent even today, visual inspection by trained personnelhad been the most common tool to identify the external signs of damage in buildings,bridge and industrial structures. Once gross assessment of the damage location is made,localized techniques such as acoustic, ultrasonic, radiography, eddy currents, magnetic field or electro-magnetic impedance can be used for a more refined assessmentof the damage location and severity. If necessary, test samples may be extracted from thestructure and examined in the laboratory. One essential requirement of this approach is the accessibility of the location to be inspected. In several cases, critical parts of thestructure may not be accessible or may need removal of finishes. This procedure of healthmonitoring can therefore be very tedious and expensive. Also, the reliability of the visualinspection is dependent, to large extent, on the experience of the inspector.

Over the last three decades, a number of studies have been reported which strive toreplace the visual inspection by some sort of automated method, which enable morereliable and quicker assessment of the health of the structure. The idea of smart structureswas thought to be an alternative to the visual inspection methods. Because of theirinherent ‘smartness’, the smart materials (such as piezoelectric material, shape memory alloys, fibre optic materials) exhibit high sensitivity to any change in environment.

**10.3.1 SHM by Global Dynamic Techniques**

In these techniques, the test-structure is subjected to low-frequency excitations, eitherharmonic or impulse, and the resulting vibration responses such as displacements,velocities or accelerations are picked up. First few mode shapes and the correspondingnatural frequencies of the structure are determined, which, when compared with thecorresponding data of healthy state, yield information pertaining to the locations and theseverity of the damage. Damage in a structure alters its modal parameters, such as modalfrequencies, modal damping, and mode shape. Changes also occur in structuralparameters, namely the stiffness and the damping matrices. Health of structure is judgedafter comparing the current structural parameters with the base line parameters. However,the basic drawback of this technique is low sensitivity to incipient damage.

**10.3.2 SHM by Electro-mechanical Impedance (EMI) Technique**

In the EMI technique, a piezo-electric ceramic (PZT) sensor patch is bonded/ embeddedin the structure (whose health is to be monitored) using high strength epoxy adhesive.The conductance signature of the patch is acquired over a high frequency range (30-400kHz). This signature forms the benchmark for assessing the structural health. At anyfuture point of time, when it is desired to assess the health of the structure, the signatureis acquired again and compared with the benchmark signature. The signature of thebonded PZT patch is usually acquired by means of commercially available impedance analyzers/LCR meters. The impedance analyzer/LCR meter imposes an alternatingvoltage signal of 1 volts R.M.S. (root mean square) to the bonded/ embedded PZTtransducer over the user specified preset frequency range. The magnitude and the phaseof the steady state current are directly recorded in form of the conductance and thesusceptance of signatures in the frequency domain, thereby eliminating the requirementsof domain transforms.

## 10.4 Methods Used in SHM

There are various approaches for addressing the problem of health monitoring anddamage detection in structures. The basic principle utilized is that any flaw/damagechanges some characteristic and hence the response of the structure. There are several techniques based on different kinds of structural characteristics orresponses. The various methods can be broadly classified intothe following categories:

- ❖ Global techniques
- ❖ Local techniques

**10.4.1 Global Techniques**

Global technique can be classified into two categories:

- ❖ Global static response based techniques
- ❖ Global dynamic response based techniques

**10.4.1.1 Global Static Response Based Technique**

A technique based on static displacement response was formulated by Banan et al.(1994). The technique involves applying static forces on the structure and measuring thecorresponding displacements. It is not necessary to select entire set of force anddisplacements. Any convenient subset may be selected. However, several load casesmight be necessary to obtain sufficient information. The resulting equations are solvedrecursively to arrive at a set of member constitutive properties or the structuralparameters. Any change in parameters from the baseline healthy state gives the indicationof the presence of damage.

The technique has a number of shortcomings, especially in the way of practicalimplementation. Measurement of displacements on a large real-life structure is not aneasy task. As a first step, one needs to establish a frame of reference which requires theconstruction of a secondary structure on an independent foundation. In addition,employing a number of load cases and computational approach can be very timeconsuming.

Sanayai and Saletnic (1996) proposed a similar technique based on static strainmeasurement. The advantage of this technique over the previous one is that strainmeasurement can be made with a much higher degree of precision. In addition, theestablishment of an independent frame of reference is also circumvented. Strain on astructure's surface is caused by both bending and axial deformations, and is thereforeable to capture the element behaviour well. However, like the displacement approach, thistechnique is also based on the least squared minimization of strain error function.

Therefore, the approach faces similar computational problems. In addition, its applicationon real life structures is bound to be very tedious.The application of large loads to cause measurable deflections (or strain) may necessitatehuge machinery and power input. As such, these methods are too tedious and expensiveto enable a timely and cost effective assessment of the health of real life structures.

**10.4.1.2 Global Dynamic Response Based Techniques**

The main principle of these techniques is that the modal parameters like the frequencies,the mode shapes and the modal damping are functions of the physical properties of thestructure like mass, damping and stiffness. Hence, any change in the physical propertiesresulting from damage will cause detectable change in the modal parameter. Dependingupon the modal parameter employed, these technique can be divided into four types:

- ❖ Based on frequency changes
- ❖ Based on mode shape change
- ❖ Based on modal damping change
- ❖ Based on updating structural model parameter

❖ **Frequency Change**

Considering frequency change as a parameter for damage detection, Salawu (1997) presented a comprehensive review. Since modal frequency is a global parameter, its valuedepends upon the sum total of properties at each point of the structure. On the other hand,damage is a local phenomenon, limited only to specific region of the structure. In case ofincipient damage, only very small area is affected and resultant overall change in thenatural frequency therefore become negligible. Hence, this method fails to detect theincipient damage. Another drawback of the technique is, for the same level of damage,change in the frequency could be different depending upon damaged region. Also, alone the frequency changes cannot provide spatial information about damage.

Cawley and Adams (1979) were the first researchers to apply frequency shift method todetect the damage in a composite material. They considered a parameter based on ratio offrequency shifts of two different modes. Further, Stubbs and Osegueda (1990) extendedthis work and developed a damage detection method using the sensitivity of modalfrequency change.

It is found that for same level of damage in congruent structures, changes in frequenciesare different. This is one of the major drawback of the techniques based on frequencychanges. Reason of this phenomenon is that for same level of damage at a point, the typeof damage may be different. It may be possible that existence of damage at that placemay affect several other parts, so that change of frequency might depend upon the loss ofstiffness of others points. If the damage becomes very severe, others points are alsoaffected substantially, hence change in frequencies will be significant. Surely, for samelevel of damage, damage created artificially and other created by application of load, willlead to different frequency changes.

❖ **Mode Shape Change**

The techniques relying on mode shape changes can be divided into two categories:

- ❖ Displacement mode shape change
- ❖ Curvature/ strain mode shape change

❖ **Displacement Mode Shape Change**

West (1984) was the first researcher to use the mode shape information for detection andlocation of structural damage using the modal assurance criteria (MAC). The modeshapes were partitioned using various schemes, and the change in MAC across thedifferent partitioning techniques was used to localize the structural damage. Mayes(1992) presented a method to detect damage based on mode shape changes known asstructural translational and rotational error checking (STRECH). In this method, ratios ofrelative modal displacements was determined, STRECH assesses the accuracy of thestructural stiffness between two different structural degrees of freedom (DOF). STRECH can be applied to compare the results of a test with an original FEM or to compare theresults of two tests. Fox (1992) created artificial cut in a beam and measured the MAC.He reported that MAC is relatively insensitive to damage. “Node line MAC”, a MACbased on measurement points close to a nodal point for a particular mode, was found tobe a more sensitive indicator of changes in the mode shape caused by damage. Graphicalcomparisons of relative changes in mode shapes proved to be the best way of detectingthe damage location when only resonant frequencies and mode shapes were examined (Doebling et al. 1998).

❖ **Curvature /Strain Mode Shape**

An alternative to the displacement mode shape is the curvature mode shape for damagedetection. Basic principle of this approach is based on the relationship between curvatureand the flexural stiffness of a beam. If the flexural stiffness of the beam decreases, thecurvature increases. In case of a PZT patch surface bonded on structure, curvature modeshape is directly obtained since the voltage response across the patch is directlyproportional to strain, and hence curvature. Several publications discussed the practicalissue related to event of measure strain directly or computing it from displacements oraccelerations.

❖ **Modal Damping Change**

Damping exists in all vibratory systems whenever there is energy dissipation. This is truefor each civil structure even though most are inherently lightly damped. For freevibration, the loss of energy from damping in the system results in the decay of theamplitude of motion. In forced vibration, loss of energy is balanced by the energysupplied by excitation. Modal damping increases with damage; hence it can be used asindicator of damages, but it is very difficult to measure accurately. The use of dampingratio for damage detection is rarely in used, but it can be used as supplementparameter for damage detection with the other major variables like frequencies, modeshapes, strain energy etc.

❖ **Updating Structural Model Parameters**

The fundamental principle of model updating method is based on the perturbation ofthe mass, the stiffness, and the damping matrices (estimated ones) such that the responseof resulting model resembles the measured data of real structure. Hence, the damage canbe detected by comparing the updated structural properties of model and the original one.The finite element model updating is a very wide term, and it has no universal rule forupdating. It has certain specific objectives for updating and updated model resembles only that specific objective. It can be explain in terms of following aspect. Suppose a model of a structure is updated for damage detection. If the structure is damaged, itsstructural properties like mass, stiffness, and damping change. Hence, these parametersare perturbed in model such that measured parameters like displacement, velocity andacceleration from original structure is close to test of the model. It is possible that otherparameters may be differing. There are generally three method of updating structuralparameters, namely:

- ❖ Optimum matrix update method
- ❖ Sensitivity based updating method
- ❖ Eigen structure assignment method

**10.4.2 Local Techniques**

Another category of damage detection methods are the so called ‘local technique’ due totheir limited influence range, as opposed to the global techniques. They rely on localizedstructural interrogation for detecting damages and response the health of structure. Localtechniques can be classified into two categories**:**

- ❖ Conventional techniques
- ❖ Technique using smart materials

**10.4.2.1 Conventional Techniques**

Some of the methods in conventional techniques category are the ultrasonic techniques, acoustic emission, eddy currents, impact echo testing, magnetic field analysis, penetrantdye testing, and X-ray analysis, which are discussed here briefly.

❖ **Ultrasonic Technique**

The ultrasonic techniques are based on elastic wave propagation and reflection within thematerial for non-destructive strength and characterization. A piezo-electric probe isemployed to transmit high frequency waves into the material. These waves reflect backon encountering any crack, whose location is estimated from the time difference betweenthe applied and reflected waves. These techniques exhibit higher damage sensitivity ascompared to the global techniques. However, they share few limitations, such as:

- ❖ They typically employ large transducers and render the structure unavailable for service throughout the length of the test.
- ❖ The measurement data is collected in time domain that requires complex processing.
- ❖ Since ultrasonic waves cannot be induced at right angles to the surface, they cannot detect transverse surface cracks.
- ❖ They do not lend themselves to autonomous use since experienced technicians are required to interpret the data.
- ❖ Technique is very costly compare to other technique.

❖ **Acoustic Emission Technique**

In acoustic emission technique, elastic waves generated by plastic deformations, movingdislocations and disbands are utilized for analysis and detection of structural defects. Itrequires stress or chemical activity to generate elastic waves, thereby facilitating continuous surveillance. However, the main problem to damage identification is posed byexistence of multiple travel paths from the source to the sensors. Also, contamination byelectrical interference and mechanical ambient noise degrades the quality of the emission signals.

- ❖ **Eddy Currents Technique**

The eddy currents perform a steady state harmonic interrogation of structures fordetecting surface cracks. A coil is employed to induce eddy currents in the component.The interrogated component, turn induces a current in the main coil and this inductioncurrent undergoes variations on the development of damage, which serves an indication of damage. The key advantage of the technique is that it does not warrant any expensivehardware and is simple to apply. However, a major drawback is that its application isrestricted to conductive materials only, since it relies on electric and magnetic fields. Amore sophisticated version of the method is magneto-optic imaging, which combineseddy currents with magnetic field and optical technology to capture an image of the defects.

- ❖ **Impact Echo Technique**

In impact echo testing, a stress pulse is introduced into the interrogated component usingan impact source. As the wave propagates through the structure, it is reflected by cracksand disbands. The reflected waves are measured and analyzed to yield the location ofcracks or disbands. Though the technique is very good for detecting large voids anddelimitations, it is insensitive to small sized cracks

- ❖ **Magnetic field technique**

In the magnetic field technique, a liquid containing iron powder is applied on thecomponent to be interrogated, subjected to magnetic field, and then observed under ultravioletlight, which makes the cracks are directly visible. The technique is howeverrestricted to magnetic materials only. Also, the component must be dismounted andinspected inside a special cabin. Hence, the technique is not very suitable for in situapplication.

- ❖ **Penetrant dye test**

In the penetrant dye test, a colored liquid is brushed on to the surface of the componentunder inspection, allowed to penetrate into the cracks, and then washed off the surface. Aquick drying suspension of chalk is thereafter applied, which acts as a developer andcauses colored line to appear along the cracks. The main limitation of this method is thatit can only be applied on accessible location of structure since it warrants active humanintervention.

- ❖ **X-ray technique**

In X-raymethod, the test structure is exposed to X-rays, which are then re-caught on film, where the cracks are delineated as black lines. Although the technique can detectmoderate sized cracks, very small surface cracks (incipient damages) are difficult to becaptured. A more recent version of the X-ray technique is computer tomography,whereby a cross-sectional image of solid objects can be obtained. Although originallyused for medical diagnosis, the technique is recently finding its use for structural non-destructive evaluation (NDE) also. By this method, defectsexhibiting different density and/or contrast to the surroundings can be identified.

**10.4.2.2 Techniques Based on 'Smart Materials and Smart System'**

Smart materials are those materials which have the ability to change their physicalproperties such as the shape, stiffness, viscosity, etc. in a specific manner under specificstimulus input. Smart materials are one of the components of smart structures. Thepiezoelectric materials and optical fibers are examples of smart material. Smart structureshave ability to sense change in their environment, optimally adjust themselves, and takeappropriate action.

According to Ahmad (1988), a system is termed as 'smart' if it is capable of recognizingan external stimulus and responding to it within a given time in predetermined manner.In addition, it is supposed to have the capability of identifying its status and mayoptimally adapt its function to external stimuli or give appropriate signal to the user.Smart structures can monitor their own condition, detect impending failure, control, orheal damage and adapt to changing environment. A smart system typically comprises ofthe following components:

❖ **Sensors:**

A smart system must gather information about its surroundings before taking theappropriate action. This work is done by sensors. Sensors recognize and measure theintensity of the stimulus (stress or strain) or its effect on the structure. They gather theinformation about the happenings of the surrounding and finally transfer information tothe actuators for appropriate action. There are several smart sensors like optical fibersensors, piezo film and pizoceramic patches.

❖ **Actuators:**

A smart system may additionally have embedded or bonded actuators, which respond tostimulus in predetermined manner.

❖ **Control Mechanism:**

A smart structure must have a mechanism from intersection of sensor and actuator. Bothsensors and actuators integrated in feedback architecture for the purpose of controllingthe system states

## 10.5 Components of SHM

SHM deals with continuous monitoring, assessment and then control algorithm to be in place for establishing a satisfactory performance level of a given structural system or any infrastructure. Considering this as one of the important objectives of SHM, let us look at the components involved in SHM. The components of the SHM process consist of different stages:

- ❖ Operational evaluation;
- ❖ Data acquisition (DAQ), fusion and cleansing;
- ❖ Feature extraction and information condensation; and
- ❖ Statistics-based model development for feature identification.
- ❖ Operational evaluation is focussed on a few vital points:
  - ▪ Damage definition, i.e., under what condition, it is said to be damaged;
  - ▪ Economic issues;
  - ▪ Data management; and
  - ▪ Environmental or operational constraints, if any.

Data acquisition, fusion and cleansing stages deal with the sensing and data acquisition issues.It is focused on determining the method of measurements, such as strain, displacement, acceleration, temperature, wind speed, sensor placement and other related issues. It also deals with various possible excitation methods that can be deployed, such as ambient excitation, forced vibration or local excitation, and the type of data transmission, such as wired or wireless. Various parameters and methods are used in feature extraction and information condensation, including resonant frequencies, frequency-response function, mode shapes and mode-shape curvatures, modal strain energy, dynamic flexibility, damping, Ritz vectors, extracting nonlinear features, empirical mode composition, wave propagation, Hilbert transform, evaluation of auto-correlation function and other related features. Statistical model development involves two methods: supervised learning and unsupervised learning. Supervised learning includes response surface analysis, Fisher's discriminant, neural networks, genetic algorithms and support vector machines. Unsupervised learning includes control chart analysis, outlier detection and hypothesis testing. Figure 10.1 shows various components of the SHM.

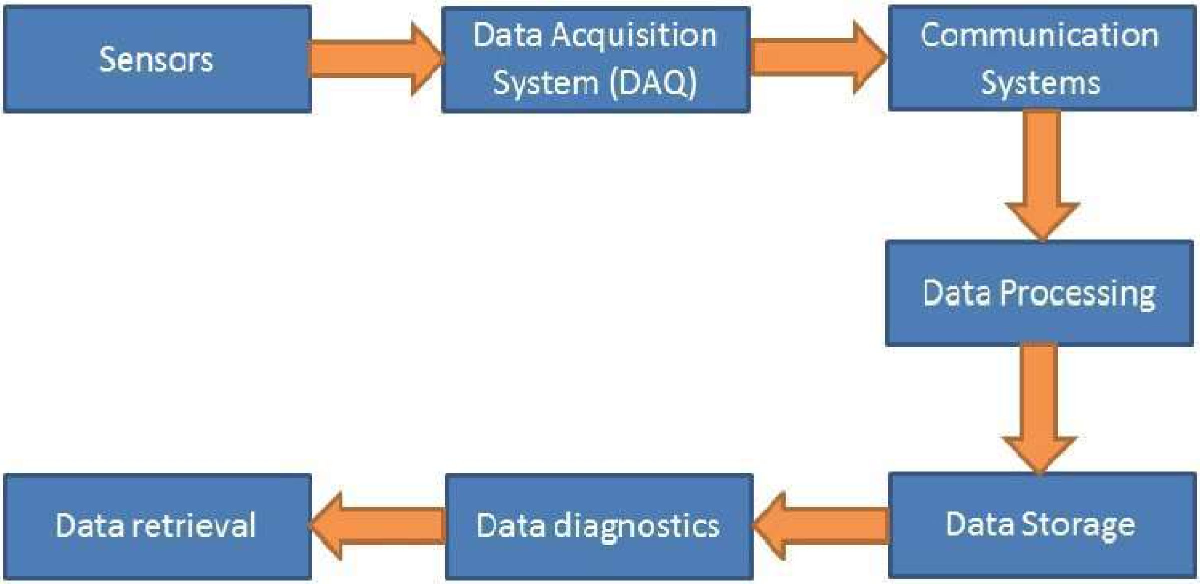



Figure 10.1 Components of SHM.

The vital components of SHM are as follows:

- **Sensors:** There are different types of sensors based on layout of topography, scalability, etc.
- **Data acquisition:** It depends upon the type of DAQ used, whether it is going to handle wireless or wired sensors, etc.
- **Communication system:** It can be done using either R/F frequency or Intranet.
- **Data processing:** It deals with the statistical analysis of the collected data.
- **Data storage:** It also requires data diagnosis and data retrieval.

## 10.6 Sensors Used in Health Monitoring

### 10.6.1 Fibre Bragg diffraction grating sensors

These are embedded in structures, which are laser marked with optical interference parameter. They measure the local strain caused by the deformation, which results in sensor measurement. These sensors will transmit a different wavelength, based on which the measured deformation can be detected.

### 10.6.2 Acoustic emission sensors

These work on the basis of acoustic signals, which are generated by the presence of cracks or local faults. These sensors are useful to measure delamination of fibres or breakage.

### 10.6.3 Smart sensors or sensor coatings

These are paints or coatings, which are applied on the surface. They remain integrated with the piezoelectric or ferroelectric elements to measure thestrain variation. Sometimes, carbon nanotubes are also used to detect such variations. A detailed spectroscopic analysis is required to process the strain variation caused by the damages in the local scale.

### 10.6.4 Microwave sensors

These are actually useful to indicate moisture ingression when embedded in structures. They are useful and efficient in composite structures.

### 10.6.5 Imaging ultrasonic sensors

These contain an ultrasonic wave transducer, which generates a signal that passes through the material. Change in reflection indicates the flaws, presence of cracks or any other local damage.

## 10.7 Review of Case Studies of SHM of Buildings

### 10.7.1 India-Monitoring of Heritage Temple

Bhand Deval Temple in Arang tehsil Raipur district, Chhattisgarh. It is a heritage temple which was built in 9th century AD under the ruler of Haihaya dynasty. The monitoring technique adopted is Rapid visual screening in which damageability grading system is used.

- **Purpose**
  - Identity the primary structural lateral load resisting system.
  - Identity building attribute that modify the seismic performance expected for this lateral load resisting system along with non structural component.
- **Results**
  - Ensure adequate maintenance at regular interval throughout the year various NDT techniques.
  - Retrofitting should be done for severe vertical irregularities observed in the structure.

### 10.7.2 Japan - Monitoring OF Tall Building

It is a 147m 33floors tall building in Toyosu, Tokyo, Japan. Toyosu area is a land reclaimed from sea. Long gage length fibre optic sensor system (SOFO) was adopted. The construction period was 2004-2006 and the monitoring started from May 2005 to October 2010. SOFO sensors were installed on the second floor which had 33 steel columns. From that 5 columns were inspected and each column was monitored by 1 sensor at centre. Length of sensor was 1m. Axial load was the dominant load.

- **Purpose**:- Evaluate the post earthquake, strong wind and ground sinking.

### 10.7.3 China- Monitoring of Tall Tower

Shanghai Tower (632m):- The construction period was from 2008 to 2015 and the monitoring was done in 2011 to 2012. There are 400 sensors of 11 types at 11 substations in 9 different zones that are 1m, 33.45m, 49m, 173.7m, 239.4m, 314.1m, 393.3m, 465.4m and 542m. Strain sensors were installed inside the RC shear walls of inner tube and on embedded steel columns.

- **Results**
  - Vertical deformation at representative location on external frame and core tube.
  - Stress at fifth floor of a super column with and without temperature compensation.

# 11. DEMOLITION OR DISMANTLING OF BUILDINGS

## 11.1 General

Demolition of any structure is, inherently, more hazardous than the construction or erection of the same. From the point of view of safety, the conditions usually encountered while dismantling a structure, whatever its magnitude, do not lend themselves to the degree of control possible in the construction operations, where more stable conditions are generally obtainable. It is all the more imperative therefore, that adequate attention is paid to planning and execution of demolition work, in its various stages, so as to minimize the risk of accidents and injuries to the personnel engaged in demolition operations. It has therefore become necessary to lay down certain safety procedures which along with a planned program could ensure adequate safety, particularly with the involvement of management, supervisors and workers. The demolition work shall be preceded in such a way that, it causes least damage and nuisance to the adjoining building and the members of the public and it satisfy all safety requirements to avoid accidents.

## 11.2 Planning

Before beginning the actual work of demolition, a careful study shall be made of the structure which is to be pulled down and also of its surroundings. This shall include the following:

- ❖ The manner in which the various parts of buildings are supported and how far the stage by stage demolition would affect the safety of the adjoining structure.
- ❖ A definite plan and procedure of demolition work shall be prepared, taking into account the loads on various structural parts and their supports.
- ❖ Before commencementof each stage of demolition, the supervisor shall brief the workmen in detail regarding the safety aspects to be kept in view.
- ❖ Ensure that the demolition conditions do not, at any stage, enhance the nuisance value of demolition work on the use of adjacent buildings.
- ❖ No structure or part of the structure or any floor or temporary support or scaffold, side wall or any device for equipment shall be loaded in excess of the safe load bearing capacity, in its then existing condition, and
- ❖ Stairs and stair railings, passage ways and ladders shall be left in place as long as possible. These should be maintained in a safe condition.

## 11.3 Precautions and Protective Measures before Starting Demolition Work

The following precautions and protective measures shall be taken before commencement of demolition work:

- ❖ On every demolition job, danger signals shall be conspicuously posted all around the structure and all doors, openings giving access to structures shall be kept barricaded or manned except during the actual passage of workmen or equipment. However provision shall be made for at least two independent exits for escape of workmen during any emergency.
- ❖ Walkways and passageways shall be provided for the use of the workmen who shall be instructed to use them and all such walkways and passageways shall be kept adequately lighted, free from all debris and other materials.
- ❖ Where in any work of demolition it is imperative, because of existing danger, to ensure that no unauthorized person shall enter the site of demolition outside working hours, a watchman shall be employed. In addition to watching the site he shall also be responsible for maintaining all signs, notices, lights, barricades, etc. During nights, red lights shall be placed on or about the barricades.

- ❖ The power on all electrical service lines shall be shutoff and all such lines cut nor disconnected at or outside the property line. The only exception would be any power lines required for the demolition work itself. Prior to cutting of such lines, the necessary approval of the Authority shall be obtained.
- ❖ All mains and meters of the building shall be removed or protected from damage.
- ❖ All gas, water, steam and other service lines shall be shutoff and capped or otherwise controlled at or outside the property line.
- ❖ If a structure to be demolished has been partially wrecked by fire, explosion or other catastrophe, the walls and damaged roofs shall be shored and braced suitably.
- ❖ Construction sheds and tool boxes should be so located as to protect workers from injuries of fatling objects, wall, etc.
- ❖ A warning device should be installed in the area to be used to warn the workers, in case of danger.
- ❖ Screens shall be placed, where necessary, to prevent the lying pieces from injuring the fellow workmen.
- ❖ No demolition work shall be carried out during storm or heavy rain.
- ❖ No demolition work shall be carried out at night specially when the building or structure to be demolished in an inhabited area.
- ❖ All necessary safety appliances shall be issued to the workmen and their use explained. It shall be ensured that the workers are using all the safety appliances while at work. The safety appliances should be as follows:
  - Safety helmets as per IS 2925 : 1984
  - Goggles made of celluloid lens to be worn at the time of demolition of floors, walls, tearing of plaster, etc, especially when equipment like jack hammers are used for demolition work, to protect the eyes from flying pieces, dust, dirt, etc, that may be blown up by wind.
  - Leather or rubber gloves worn during demolition of RCC work or removing steel work, where the hands of workers are likely to be injured.
  - Safety belts while working at higher level to-prevent falling from the structure.
- ❖ First-aid equipment shall be available at all demolition works of any magnitude. Also, by prior arrangement, a qualified doctor be available at call.
- ❖ When there is a possibility of fire breaking out, appropriate portable first-aid fire appliances (see IS 2190: 1992) shall be kept at hand.
- ❖ The removal of a member may weaken the side wall of an adjoining structure and to prevent possible damage, these walls shall be sup-ported until such time as permanent protection is provided. In case of any danger is anticipated to the adjoining structure, the same shall be got vacated to avoid any danger to human life.
- ❖ Ladders, when used, shall conform to IS 3696 (Part 2): 1991. Ladders or their side rails shall extend not less than 1.0 m above the floor or platform to which the ladder gives access. All ladders shall be secured against slipping out at the bottom and against movement in any direction at the top.
- ❖ All exterior wall openings which extend down to the floor level shall be barricaded to a height not less than 1 m above the floor level. All floor openings and shafts not meant as material chutes shall be floored over and endorsed with ground rails and toe boards.
- ❖ All existing fixtures/services required during demolition operations shall be well protected with substantial covering to the satisfaction of the Authority.
- ❖ When demolition is to be done by mechanical means such as weight ball and power shovels, the following additional precautions are necessary:
  - The area shall be barricaded for a minimum distance of 1.50 times the height of the wall;
  - While the mechanical device is in operation no workmen shall be allowed to enter the building being demolished;

- The device shall be so located as to avoid falling debris; and
- The device when being used shall not cause any damage to adjacent structure, power line, other services, etc.

## 11.4 Protection of the Public

Protection of the public before and during demolition is important and the following points should be kept in mind:

- Every sidewalk or road adjacent to the work shall be closed or protected. All main roads, which are open to the public, shall be kept open to the public clear and unobstructed at all times.
- Children and public shall be kept out of the building and the adjoining yards.
- If the structure to be demolished is more than two storeyed or 7.5 m high measured from the sidewalk or street which cannot be closed or safely diverted, and the horizontal distance from the inside edge of the side walk to the structure is 4.5 m or less, a substantial side walk shall be constructed over the entire length of thesidewalk adjacent to the structure of sufficientwidth with a view to accommodating the pedestrian traffic without causing congestion. The sidewalk shall be lighted sufficiently to ensure safety at all times.
- A toe board at least 1.0 m high above the roof of the shed shall be provided on the outside edge and ends of the sidewalk shed. Such boards may be vertical or inclined outward at not more than $45^o$.
- Except where the roof of a sidewalk shed solidly abuts the structure, the face of the sidewalk shed towards the building shall be completely closed by providing sheeting/planking to prevent the falling material penetrating into the shed.
- The roof of the sidewalk shed shall be capable of sustaining a load of 730 $kg/m^2$. Only in exceptional cases, say due to lack of other space, the storing of the material on a sidewalk shed may be permitted in which case the shed shall be designed for a load of 1 460 $kg/m^2$. Roof of sidewalk shed shall be designed taking into account the impact of the falling debris. By frequent removal of loads it shall be ensured that the maximum load, at any time, on the roof of the shed is not more than 600 $kg/m^2$. The height of the sidewalk shed shah be such as to give minimum clearance of 2.4 m.
- Sidewalk shed openings, for loading purposes, shall be kept closed at all times except during actual loading operations.
- The deck flooring of the sidewalk shed shall consist of plank of not less than 50 mm thickness closely laid and deck made watertight.
- All members of the shed shall be adequately braced and connected to resist displacement of members or distortion of framework.
- When the horizontal distance from the inside edge of the sidewalk to the structure is more than 4.5 m and less than 7.5 m, a sidewalk shed or fence may be built or in their place a substantial railing shall be constructed on the inside of the sidewalk or roadway along the entire length of demolition side of the property with movable bars as may be necessary for the proper prosecution of the work.
- Where workers entrances to the building being demolished are not completely protected by sidewalk sheds, all such entrances shall be protected by canopies extending from the face of the building to a point not less than 2.5 m from it. In such a case, overhead projection shall be at least 0.6 m wider than the building entrance or opening and every canopy shall be as strong as the sidewalk shed.

## 11.5 Sequence of Demolition Operations

The sequence of demolition shall generally be as given below:

- The demolition shall always proceed systematically storey by storey in descending order and the demolition of upper floors shall be completely over before any of the supporting members or other important portion on the lower floor is disturbed. No unnecessary work shall go on below when the demolition is in progress above. When some work is to be done at the lower level, adequate protection shall be provided for all the workmen so engaged.
- The requirements of (a) shall not prohibit the demolition of structures by sections, if means are taken to prevent injuries to persons or damage to property.
- Roofs (or floors), generally, be demolished first before demolishing the supporting walls structural elements.
- All glazed sash, glazed doors and windows etc, shall be removed before the demolition of roofs and walls starts. All fragile and loose fixtures shall be removed. Lath and loose plaster be stripped off throughout the entire structure. This is advantageous because it reduces glass breakage and also eliminates a large amount of dust producing material before more substantial parts of the building are removed.

### 11.5.1 Demolition of Floors

For demolition of floors the following procedure may be followed:

- A slit in width not exceeding 300 mm shall be cut at the first stage for the entire length of the slab along which it spans. The opening shall thereafter be increased to the desired width by suitable installments.
- Planks of sufficient strength not less than 50 mm thick and 250 mm wide shall be provided at a spacing not greater than 0.4 m. These planks shall be so placed as to give workmen firm support to guard against any unexpected collapse.
- Stringers of ample strength shall be installed to support the planks where necessary and the ends of stringers shall be supported by floor beams, girders and not by floor slab alone.
- When floors are being removed, no workmen shall be allowed to work in the area, directly underneath and such area shall be barricaded to prevent access to it.
- The demolition of the floor in question shall be started only after the surrounding area for a distance of 6.0 m have been entirely cleared of persons, and the debris and other unnecessary material removed.
- Planks used for temporary protection shall be sound and at least 50 mm thick. They shall be laid close together with ends overlapping at least 100 mm over solid bearing to prevent tipping under load.

### 11.5.2 Demolition of Walls

The following procedure should be followed when demolishing walls:

- While walls or sections of masonry are being demolished it shall be ensured that they are not allowed to fall as a single mass on the floors of the building so as not to exceed the safe carrying capacity of the floors, wherever practicable, they may fall away from the floors on to catch platforms. Overloading of floors shall be prevented by removing the accumulating debris through chutes or by other means immediately. The floor shall be inspected by the Authority before undertaking demolition work and if the same is found incapable of carrying the load of debris, necessary precautions shall be taken to prevent any unexpected collapse of the floor.
- Walls shall be removed part by part. Stages shall be provided for the men to work on, if the walls are very thin and dangerous to work by standing over them.
- No section of the wall whose height, is more than 15 times the thickness, shall be permitted to stand without lateral bracing unless such a wall is in good condition and was originally designed to stand without such lateral bracing or support.

- ❖ Structural or load supporting members on any floor shall not be removed or cut until all the storeyes above that floor have been demolished and removed.
- ❖ Before demolishing any interior or exterior wall within 3.0 m of the opening in the floor immediately below, such opening shall be substantially planked over, unless access is denied to workmen to that portion of the floor immediately below the opening, in the floor of the storey being demolished, where any debris passing through the opening may fall.
- ❖ In framed structures, the frame may be left in position during demolition of masonry work. Where this is done all beams, girders, etc, shall be cleared of all loose materials as the demolition of masonry work progresses downward provided it is still strong enough to stand as an independent structure.
- ❖ Walkways shall be provided to enable workmen to reach or leave their work on any scaffold or wall. Such walkways shall neither be less than 3 planks wide, nor less than 0.8 m in width.
- ❖ After completion of each day's work, all walls shall be left stable to avoid any danger of getting overturned.
- ❖ Foundation walls which serve as retaining walls to support the earth or adjoining structure, shall not be demolished until such an adjoining structure has been underpinned or braced and the earth removed by sheet piling or sheathing.

## 11.6 Catch Platforms

Catch platforms shall be provided in case of demolition of exterior wall in multistory buildings. The following details may be considered:

- ❖ Catch platforms shall generally be provided for multistoried buildings more than 20 m high to prevent injuries to the worker and to the public when exterior walls are being demolished.
- ❖ Such platforms shall be constructed and maintained not more than three storeyes below the storey from which the exterior wall is being demolished. When demolition has progressed to within three storeyes of ground level, catch platforms will not be considered necessary.
- ❖ Catch platforms shall not be less than 1.5 m in width measured in a horizontal direction from the face of the structure and shall consist of outriggers supported not more than 3.0 m apart. Planks shall be laid tight together, without openings between them and the walls.
- ❖ Catch platforms shall be provided with a continuous solid parapet along its outer edge of at least 1 m height. The parapet may be constructed with the same material as the platform.
- ❖ Catch platform shall be capable of sustaining a live load of not less than 610 kg/m$^2$.Catch platforms shall neither be used for storing of materials nor dumping of materials.

## 11.7 Recommendations for Demolition of Different Types of Structures and Element

Structures may be dealt with as masonry, concrete, steel and timber. The structures or their elements shall be dealt with as below, in addition to other requirements as applicable.

### 11.7.1 Masonry Structures

**11.7.1.1 Jack Arches -** Where tie rods are present between main supporting beams, these should not be cut until after the arch or series of arches in the floor have been removed. Particular care should be exercised and full examination of structure be made before the demolition is commenced. The floor should be demolished in strips parallel to the span of arch rings (at right angles to the main floor beam).

**11.7.1.2 Brick Arches**

- ❖ As much dead load as possible may be removed provided it does not interfere with stability of main arch rings, it should be noted that the load carrying capacity of many old arches relies on the filling between the spandrels. On no account should the restraining influence of the abutments be removed before the dead load of the spandrel fill and the arch rings are removed. The normal sequence of demolition includes the following: Remove the spandrel filling down to the springing line,remove the arch rings,and remove the abutments.Special temporary support shall be provided in the case of skew bridges.

- A single span arch can be demolished, byhand, by cutting narrow segments progressively from each springing parallel to the span of the arch, until the width of the arch has been reduced to a minimum which can then collapse. Where it is impossible to allow debris to fall to the ground below, centering designed to carry the load should be erected and the arch demolished progressively. The design of the centering should make appropriate allowance for impact.
- Where deliberate collapse is feasible the crown may be broken by the demolition ball method working progressively from the edges to the centre.
- Collapse of structure can be affected in one action by the use of explosives. Charges should be inserted into boreholes drilled in both arch and abutments. This method is the most effective for demolition of tall viaducts.
- In multi spanarches, before individual spans are removed, lateral restraint shouldbe provided at the springing level. Demolition may be preceded as for a single span care being taken to demolish the spandrels down to the springing line as the work proceeds. Where explosives are used it is preferable to ensure the collapse of the whole structure in one operation to obviate the chance of leaving unstable portions standing.

**11.7.2 Reinforced Concrete**

**11.7.2.1** Before commencing demolition, the condition and position of reinforcement and possibility of lack of its continuity should be ascertained. Demolition should be commenced by removing partitions, non-load bearing cladding etc and similar non-structural elements.

**11.7.2.2** Where hand demolition methods are used, the following procedures should be used:

- **Beams -** For beams supporting rope should be attached to the beam. Then the concrete should be removed from both ends by pneumatic drill and the reinforcement exposed. The reinforcement should then be cut in such a way as to allow the beam to be lowered under control to the floor.
- **Columns -** For columns reinforcement should be exposed at the base after restraining wire guy ropes have been placed around the member at the top. The reinforcement should then be cut in such a way as to allow the column be pulled down to the floor under control.
- **Walls** - Reinforced concrete walls should be cut into strips and demolished as for columns.
- **Suspended Floors and Roofs** -Solid slabs should be demolished as described in demolition of floors, where ribbed construction is used, the principle of design and method of construction should be ascertained before demolition. Care should be taken not to cut the ribs inadvertently.

**11.7.3 Precast Reinforced Concrete**

Precast reinforced concrete units in a structure are normally held in position by the strength of the joints in-situ or on supporting walls, etc. As such before starting on demolition the joint structures or the supporting mechanisms shall be studied and understood.

- In devising and following demolition sequences, due precaution shall be taken to avoid toppling over of the prefabricated units or anyother part of the structure and wherever necessary temporary supports shall be provided.

**11.7.4 Pre-stressed Concrete**

Before commencing of the demolition work involving such structures advice of an expert engineer should be obtained

**11.7.5 Demolition of steel structures**

- No beams shall be cut until precautions have been taken to prevent it from swinging freely and possibly striking any worker or equipment or any part of the structure being demolished.

- ❖ All structural steel members shall be lowered from the building and shall not be allowed to drop.
- ❖ Tag lines shall be used on all materials being lowered or hoisted up and a standard signal system shall be used and workmen instructed on the signals. No person shall be permitted to ride the load line.
- ❖ When a derrick or hoisting equipment is used care shall be taken to see that the floor on which it is supported shall be strong enough for the loading. If necessary heavy planking shall be used to distribute the load to floor beams andgirders. Overloading/overturning of the equipment shall be avoided.

**11.7.6 Roof Trusses**

*Roof* trusses shall be removed to wall plate level by hand methods. Sufficient purlins and bracing should be retained to ensure stability of the remaining roof trusses while each individual truss is removed. Temporary bracing should be added, where necessary, to minimize instability. The end frame opposite to the end, where dismantling is commenced, or a convenient intermediate frame should be independently and securely guyed in both directions before work starts. On no account should the bottom tie of a truss be cut until the principal rafters are prevented from making outward movement.

**11.7.7 Cantilevers**

A cantilever type of construction depends on the balancing superimposed structure for its stability. Canopies, cornices, staircases and balconies should be demolished or supported before the balancing load is removed.

**11.7.8 Heavy Floor Beams**

Heavy baulks of timber should be supported before cutting at the extremities and should then be lowered to a safe working place.

**11.7.9 Chimney and Spires**

Before commencing of the demolition work, involving such structures, advice of an engineer expert in such demolition shall be obtained and followed.

## 11.8 Mechanical Demolition

When demolition is to be performed by mechanical devices, such as weight ball and power shovels, the following additional precautions may be observed:

- ❖ The area shall be barricaded for a minimum distance of lb times the height of the wall;
- ❖ While the mechanical device is in operation, no workmen shall be allowed to enter the building being demolished;
- ❖ The device shall be so located as to avoid falling debris; and
- ❖ The mechanical device when being used shall not cause any damage to adjacent structure, power line, etc.

## 11.9 Removal of Materials

Dismantled materials may be thrown to the ground only after taking adequate precautions. The material shall preferably be dumped inside the building. Normally such materials shall be lowered to the ground or to the top of the sidewalk shed where provided by means of ropes or suitable tackles.

**11.9.1 Through Chutes**

- ❖ Wooden or metal chutes may be provided for removal of materials the chutes shall preferably be provided at the centre of the building for efficient disposal of debris.
- ❖ Chutes,if provided at an angle of more than 45” from the horizontal, shall be entirely enclosed on all the four sides, except for opening at or about the floor level for receiving the materials.

- ❖ Opening for the chutes (see 7.3) shall not exceed 1.20 m in height measured along the wall of the chute and in all storeyes below the top floor such opening shall be kept closed when not in use.
- ❖ To prevent the descending material attaining a dangerous speed, chute shall not extend in an unbroken line for more than two storeyes. A gate or stop shall be provided with suitable means for closing at the bottom of each chute to stop the flow of materials.
- ❖ Chutes at an angle of less than 45" to the horizontal may be left open on the upper side provided that at the point where such a chute discharges into a chute steeper than 45" to the horizontal, the top of the steeper chute shall be boarded over to prevent the escape of materials.
- ❖ Any opening into which workmen dump debris at the top of chute shall be guarded by substantial guard rail extending at least one meter above the level of the floor or other surface on which men stand to dump the materials into the chute.
- ❖ A toe board or bumper, not less than 50 mm thick and 150 mm high shall be provided at each chute opening, if the material is dumped from the wheel barrows. Any space between the chute and the edge of the opening in the floor through which it passes shall be solidly planked over.

**11.9.2 Through Holes in the Floor**

- ❖ Debris may also be dropped through holes in the floor without the use of chutes. In such a case the total area of the hole cut in any intermediate floor, one which lies between floor that is being demolished and the storage floor shall not exceed 25 percent of such floor area. It shall be ensured that the storage floor is of adequate strength to withstand the impact of the falling material.
- ❖ Openings in all the floors below the floor from which materials are being removed, shall be protected by standard railings and toe boards or preferably planked over if the holes are not being used for dumping materials.
- ❖ All intermediate floor openings for passage of materials shall be completely closed with barricades or guard rails not less than one meter high and at a distance of not less than one meter from the edge of general opening. No barricades or guard rails shall be removed until the storey immediately above has been demolished down to the floor line and all debris cleared from the floor.
- ❖ When the cutting of a hole in an inter-mediate floor between the storage floor and the floor which is being demolished makes the intermediate floor or any portion of it unsafe, then such intermediate floor shall be properly shored. It shall also be ensured that the sup-porting walls are not kept without adequate lateral restraints.

## 11.10 Removal of Debris/Mulba

- ❖ As demolition work proceeds, the released serviceable materials of different types shall be separated from the unserviceable lot (hereafter called*'Mulba')* at suitable time intervals and properly stocked clear of the spots where demolition work is being done.
- ❖ The *Malba* obtained during demolition shall be collected in well-formed heaps at properly selected places, keeping in view safe conditions for workmen in the area. The height of each*Malba* heap shall be limited to ensure it is not toppling over or otherwise endangering the safety of workmen or passersby.
- ❖ The*Malba* shall be removed from the demolition site to a location as required by the local civil authority. Depending on the space available at the demolition site, this operation of conveying*Mulba* to its final disposal location may have to be carried out a number of times during the demolition work. In any case, the demolition work shall not be considered as completed and the area declared fit for further occupation till all the*Mulba* has been carried to its final disposal location and the demolition area tidied up.

- Materials which are likely to cause dust nuisance or undue environmental pollution in any other way, shall be removed from the site at the earliest and till then they shall be suitably covered. Such materials shall be covered during transportation also.
- Unauthorizeduse of the debris or *Mulba* in any work shall not be permitted. The released materials classed as 'serviceable' shall be inspected by a competent person before being used.

## 11.11 Stairs, Passageways and Ladders

- Stairs and stair railings, passageways and ladders shall be left in place as long as possible.
- For the use of ladders, provisions laid down in IS 3696 (Part 2):1991 shall be followed.
- All stairs, passageways and ladders to be used by workmen during the process of demolition shall be maintained in a safe condition.
- Ladders or their side rail extend not less than 1.0 m above the floor or platform to which such ladder gives access.
- All ladders shall be secured against, slipping out at the bottom and against movement in any direction at the top.

# 12. STEEL BUILDINGS AND COMPOSITE CONSTRUCTIONS

## 12.1. STEEL BUILDINGS:

### 12.1.1. Introduction:

Steel construction means using steel as the building's main framing material. Steel is also common in the building envelope (walls, roofing), fasteners, building services, substructures and concrete reinforcement. Compared to today's average construction practice, modern steel construction can offer:

- Material efficiency - resulting in e.g. less natural resource usage, less transports, less emissions and less energy usage,
- Ultra-high recyclability - resulting in e.g. less natural resource usage, less waste, less energy and less emissions,
- Quality and durability – resulting in sustainability favors,
- Dry construction – resulting in less health hazards, less waste, less energy usage and less emissions.

### 12.1.2. Sustainability and construction

Sustainability includes environmental, economic and social concerns for achieving a long- lasting development of the society. Sustainability of Construction here comprises the major health and environmental aspects related to the life cycles of all types of buildings. A building's life cycle includes production, use and deconstruction, and the underlying activities and material and energy flows which generate inevitable influence on the planet – good and bad. The choice of building material as to framing has been considered as of minor interest as to the social aspect of sustainability.

The construction sector is a core economy in many countries. Construction means welfare, security for individuals and businesses, growth and investments for the future.

The use of the buildings and all construction related activities generate more than 40% of all CO2 (carbon dioxide) emissions, use about 40% of the produced energy and consume more than 40% of the material resources used in the society. The global governmental intention, except the US, is to reduce the CO2 emissions by an average 5% over the next 5 years and some experts claim that the reduction must be 50% over 50 years in order to avoid large-scale climate changes.

The usage of energy during the building's service state, called operational energy, is one of the most important sustainability issues for the construction sector. Energy primarily affects the environment due to the production and distribution of electricity and water for heating and cooling. The thermal performance and overall energy efficiency have an effect on the economical and environmental performance of the building, and thereby it's competitiveness. Some frames of thermal performance are set in national Building Regulations.

Construction needs much material input: as natural resources and as recycled material. Materials primarily affect the environment through the refining processes from raw materials to building components, and also by transports. Natural resources are not infinite, and recycling leads in most cases to improved environmental performance. The construction sector generates an enormous amount of waste (estimated 500 kg/capita,), and the demands for improved recycling are increasing. Therefore, in many countries the sustainability focus is on recyclability.

Sustainable construction does not have to mean new big investments or inventing new materials, just to use "the right materials in the right combinations in the right place". Sustainability improvements will often generate economical benefits, e.g. lower costs for heating and maintenance, goodwill and market advantages, and also a future world where we can live. The World Business Council for Sustainable Development stated that "Business can benefit from pursuing sustainability in two ways: By generating top line growth through innovation and new markets, and by driving cost efficiencies". The benefit for man and environment is high quality survival.

### 12.1.3. Specification of key issues

The disturbing influences on the exterior environment can be divided into embracing environmental effects, that all are regarded significant for ecological balances, for human life- quality and on the long term for human survival. Here six main environmental effects under surveillance are:

- Global warming,
- Acidification,
- Eutrophication,
- Ozone layer depletion,
- Toxicity,
- Resource depletion.

Many different kinds of industrial, human and natural activities contribute to these effects, positively or negatively, which means that we are all able to affect the environmental future today. The major steel construction - and most industry - issues of environmental concern are:

- Energy use in production (embodied energy)
- Energy use in service (operational energy)
- Transportation
- Use of raw materials and water
- Emission of harmful substances
- $CO_2$ Emissions
- Recycling and reuse
- Waste treatment and land use
- Indoor environment

The differences in sustainability focus can be significant between various types of buildings, and the following relationships between these issues and the building's life-cycle are to be distinguished for residential, commercial and industrial steel buildings.

### 12.1.4. Embodied energy

The production of 1 kg of finished steel product for constructional usage demands about 18.6 MJ/kg of energy in average, including all processes and energy types (Worldwide average). Compared to a 50-year life cycle of a multi-storey steel building, the production of all embedded steel components contributes to less than 2% of the total energy usage.

As only 10-30% of the steel building is steel, the origin of the building's embodied energy is mainly in the cement production, the lime refining for gypsum boards, iron reduction by coke and electric arc processes for scrap melting.

While making new steel, about 70% of the constructional steel's embodied energy can be saved. About half of the embodied energy in combustible products will be reused for heating and other purposes.

### 12.1.5. Transports

Combustion of fossil fuels is the activity having most influence on the mentioned environmental effects. All heavy transports, except for electrified trains supported by electricity from 'carbon free' power plants, emit CO2, NOX, SOX, HC and other pollutants, and use finite fossil resources. Construction transports are today dominated by trucks, and the increasing international trade causes more and longer transports.

Steel structures are light and material efficient, and in most cases fabricated off-site. Therefore there is less weight to transport, a minimum of waste to move to recycling or deposit, and the instant erection and low degree of in-situ production makes the logistics very efficient. The accurate design and shape stability of steel profiles also result in a minimum of constructional waste. Though, the disadvantage of a high degree of prefabrication may be additional transports between production site and construction site.

### 12.1.6. Raw materials and water

All new construction needs material, much material. Virgin materials from nature are needed when recycled material not exist in necessary amounts or quality. The virgin materials needed for steel construction are mainly metal ores, limestone, oil, coal, natural gas and some other minerals. The recycled material input is mainly steel, other metals, plaster, glass and water. Steel construction is unique because of its high degree of recycled content and recyclability, and therefore the need for limited virgin resources is relatively small.

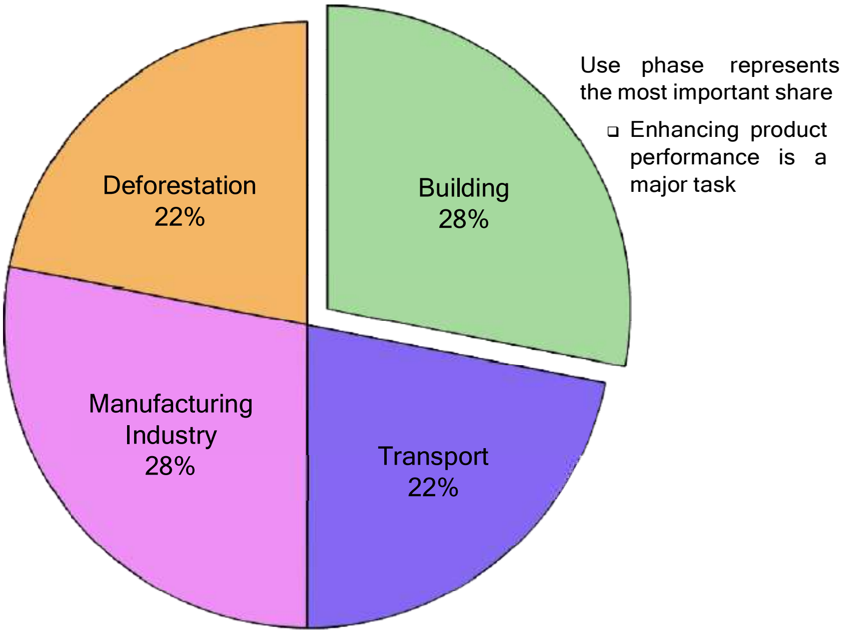
Producing 1 kg steel from ore demands about 2.5 kg of material input. The other 1.5 kg is also being used as by-products or being vaporized. In a modern production plant only about 60 g out of the 2.5 kg are sent to deposit as non-usable waste, which prove another type of excellent material efficiency.

Water is used as cooling media for producing one kg of steel for constructional purposes. Much of this is recycled and cleaned within closed systems. Moreover, in the case of steel construction, the water is used on the production site and not on the construction site. As the steel is mainly fabricated in countries and areas where the water supply is not a major problem, the use of steel profiles for construction, in countries where water reserved are small, is a key issue.

### 12.1.7. Emissions

The emissions to air and water related to steel construction are in level with other building systems with same functions and size in a life cycle perspective. Most emissions originate in combustion of organic matter, i.e. process for material production, heating, conversion to usable energy, and also transports. Main airborne emissions are CO2, NOX, SOX and dust, which cause most of the environmental effects. By amount CO2 stands for about 98% of the airborne emissions.

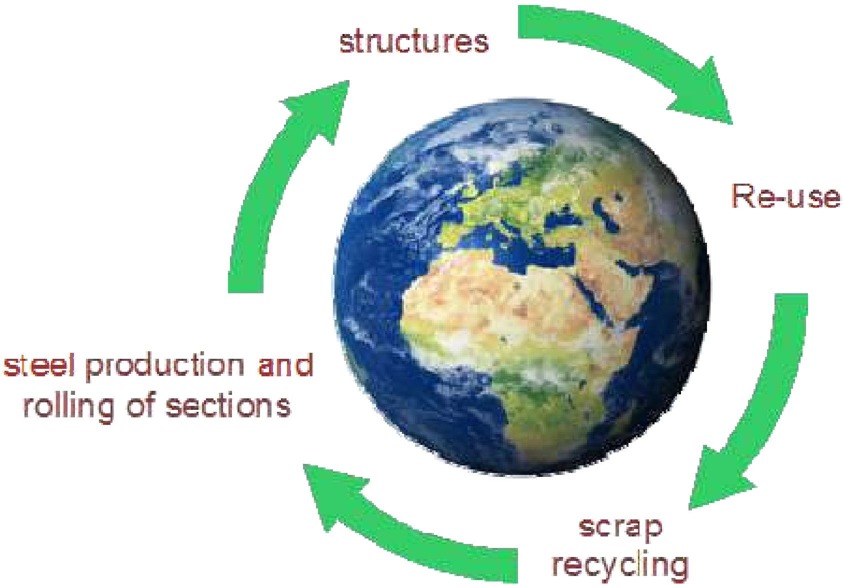
Specifying steel also means that the built in elements not will be released as emissions in the future, as the steel and some other important steel construction materials are fully material recyclable and will not be combusted or deteriorated at a deposit.




Estimation of global $CO_2$ emissions by end user

### 12.1.8. Recycling and reuse

Recycling means using the material again as input for producing new material or as an energy source. Reuse means using the demounted product in another location with or without refurbishment. Steel is unique as construction material because it can be fully recycled over and over again without quality loss. Other construction materials often used in combination with steel with a high degree of material recyclability are plaster, other metals and mineral wool.




The recovery rate of structural steel construction products is today about 95% and increasing, which is maybe the strongest sustainability argument for steel construction and the structures are durable. More than two billion tonnes of steel in buildings out there is waiting to be recycled in the future. The recycled content can

be up to 100% dependent on scrap availability and the demand level; in practice about 15 to 100% is recycled content.Recycling of steel in electric arc furnaces

Reuse normally offers even greater environmental advantages than recycling. Reuse is not yet that common, but up to 10% of the steel construction products are reused on certain markets. Reused products are e.g. steel frames, cladding

components, pedestrian bridges, sheet piling, wall elements, temporary structures and modules.Steel sheet piles are reused after excavation

### 12.1.9. Waste and land-use

The waste issue is primarily directly related to the issues of recycling and raw materials. The large amount of constructional waste is a big problem in some regions where controlled disposal areas are small or non-existing. In severely exploited areas, and in close-urban areas with difficult topography or other unpleasant nature conditions, green land is very attractive for man as well as for nature.

Steel construction handles questions concerning waste and land-use in many ways:

- The high degrees of recyclability, reusability and prefabrication means less waste generation,
- Off-site production means small construction sites,
- Light structures, short construction time and material strength means possible vertical extension of existing buildings, use of developed land and construction on bad soil or in tectonic areas,
- Sites for iron ore extraction are commonly situated under ground and refilled with generated mineral waste,
- By-products from steel production are used in many other applications such as road construction.

### 12.1.10. Indoor environment

The building physics is very important for health and well-being. The relationships between indoor environment and human health are very complex. Main issues are moisture, thermal comfort, sound and air quality, and the size of each issue vary between different countries.The Sick Building Syndrome is a modern “disease” usually caused by water in organic building components in the construction. Steel is not hygroscopic, nor organic, which minimizes the risks of SBS, direct airborne emissions and structural deterioration. The common off-site prefabrication of steel buildings keeps the dry materials also dry assembled. Steel systems for walls and floorings also fulfil high Building Regulation levels on thermal comfort and sound insulation.

### 12.1.11. Regulations on Sustainability

#### 12.1.11.1. National Regulations on Sustainability

. The different governments have environmental targets, both for outdoor and indoor environment, which can have an effect on the construction industry. However, these targets are often generally expressed and there are few specific environmental regulations. Environmental issues are integrated in all aspects of the building process and sustainability issues are often dealt with in combination with other topics.

An exception is the explicit regulations on energy performance. An increase of the use of a lifetime perspective can be noted. Efforts, as to national regulations and standards, in the sustainability area concerning building constructions and related activities that might have an effect on the use of steel are:

- Energy conservation: focus on in-use consumption, often expressed as thermal performance of building envelope or CO2 emissions
- Building’s health affection: Focus on health in general and emissions of building materials
- Questions concerning life performance: focus on performance and costs where maintenance is a key issue.
- Waste reduction: focus on minimum recycled content and reduction of waste to deposits
- Land use: focus on limiting over development

Documentation of sustainability issues: focus on assessment/declaration ofconstruction materials and assessment methods for new and existing buildings

### 12.1.12. Opportunities for steel

Taken the summary of national regulations on sustainability and the trends in sustainability work, several opportunities for steel can be identified. There are also challenges to be embraced in order to secure a prosperous development as to sustainability issues for steel.

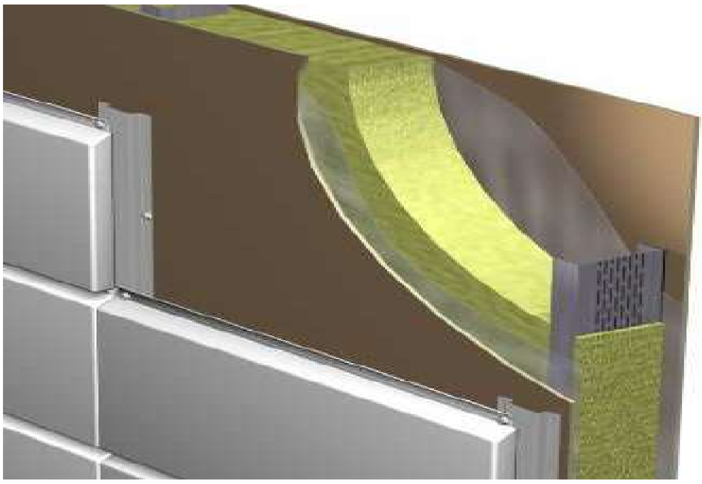
It is also noticed that some of the work in the sustainability area concerning constructions are based on voluntary undertakings or related to financial questions e.g. better insurance conditions and conditions for funding. As well as in regulations as in voluntary undertakings, opportunities and challenges can be identified.

Corresponding to important issues in the sustainability area, as stated in preceding chapter, there are opportunities for steel construction.

### 12.1.13. Energy conservation

#### 12.1.13.1. Opportunities:

- Expose the possibilities of good thermal insulation using steel systems. Using slotted steel studs and/or external insulation or other efficient techniques a building envelope with excellent thermal performance can be achieved. This must be communicated to the actors in the building industry.



Lightweight Steel-framed Construction

- It is also of great importance to communicate the good performance of steel systems as to thermal bridging.

- Prefabricated units, 3D or 2D, can provide a high quality building envelope with excellent performance as to thermal performance and provide good quality, reducing risk of thermal bridging and lack of air tightness.

- The use a photovoltaic cells can reduce drastically the total energy consumption of the building. One square meter of Arsolar roof cladding (6kg) bears photovoltaic cells that can generates 120 kWh per year. Thus each kilogram of steel helps produce 70MJ of solar electricity each year

Arsolar system from Arval ArcelorMittal Construction

- Thanks to innovative solutions like Cellular beam or Angelina™ beam, it's possible toreduce the storey height by integrating services within the height of the beam in orderto have a building with 8 levels where only 7 levels would be possible with classical solutions. An optimisation of the surface can be done by reducing of about 15% the ratio Volume of the building / net

Integration of all the services in the height of the beam using Angelina™

- Surface of floor and so reduce the global energy consumption.
- Reducing the eight between two storeys, we reduce the surface of the façade and thethermal exchanges between interior and exterior. The direct consequence is a reduction of the energy consumption for heating and cooling.

**12.1.13.2. Challenges:**

- There is a challenge to communicate the excellent performance of steel systems today. A lot of problems like thermal performance and thermal bridging are now resolved but the a efforts must be done to promote theses new solutions
- One challenge could be the use of transports on an increasing global market. This should be an issue not only for steel, but for all materials. As to steel it could be a benefit as steel is a lighter material, thus transports have less impact and there is less waste.

## 12.1.14. Occupational wellbeing and safety

**12.1.14.1. Opportunities:**

- Using steel systems, building components with low risk of acquiring problems relatedto moisture.
- The European procedure for providing structural safety in case of fire. This procedure is quite realistic as it takes account of real fire characteristics and of existing active fire fighting measures. It consists in estimating the real behaviour of a structure subjected to the natural fire which may arise under those real fire conditions. The consideration of real actions leads to real safety and also to optimized economy Thanks to this Natural Fire Safety Concept, it’s possible to design unprotected steel structures able to ensure the stability of building in case of fire. Using this king of design, the Unprotected and visible steels structure and protected structure that must be hidden protection of the structure by spray material or gypsum board can be avoided.
- Using steel systems, building components with low risk of problems with emissions from materials are achieved.
- Good opportunities of off-site production create building systems with high quality reducing risks of health affection during construction process.

**12.1.14.2. Challenges:**

- To communicate the good performance of steel systems as to health and to disseminate the use of the Natural Fire Safety Concept
- To provide industry with information on material as to documentation for buildings and as basis for decision-making.

### 12.1.15. Life performance

#### 12.1.15.1. Opportunities:

- An increased lifecycle perspective is advantageous for steel as steel constructions have long life with high quality and flexible solutions. The anticorrosion solutions are really effective (coating, galvanisation, stainless steel)
- To emphasise the low maintenance of different steel constructions.
- Steel enables the use of modular buildings for temporary locations.


Transport


Module


Small office building

- Steel structures have long design life and the high quality remains
- Steel constructions can give flexibility to the use of the building providing long spans. The use of very large span offer free open spaces that can be adapted for a future use.

Very large open space with integration of all the services

#### 12.1.15.2. Challenges:

- Composite structures are a challenge as to recyclability. Therefore efforts to designcomposite systems that can be dismantled in a cost-effective way.
- To provide systems with an architecture and function with no “best before date”.
- Further improvement of coatings.
- To provide industry with information on material as to documentation for buildings andas basis for decision-making.

### 12.1.16. Waste reduction

#### 12.1.16.1. Opportunities:

Prefabricated steel elements for multi-storey buildings

- Prefabrication can significantly reduce waste at building site
- Prefabrication can significantly increase the ability to handle waste in a good way,increasing the possibility to recycle.
- Steel is a very good material as to recycling. There should not be material fordeposition.
- Steel products for construction purposes always contain recycled material.
- Larger prefabricated units, i.e. modules, might be reused in other constructions.Especially as to temporary constructions this is a great benefit.

#### 12.1.16.2. Challenges:

- To increase the use of prefabricated units will enhance the benefits for steel as towaste reduction, thus increase the market for steel.
- To facilitate separation of composite constructions in order to increase therecyclability of these constructions.

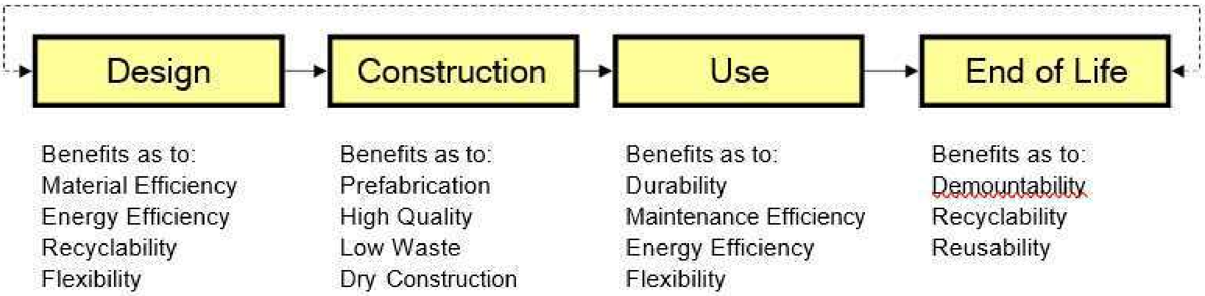
### 12.1.17. Land Use

#### 12.1.17.1. . Opportunities:

- Prefabrication reduces need for space at the building site.
- Waste reduction as waste is reduced by an increased prefabrication. Also a wellfunctioning system for recycling significantly reduces the need for deposits.
- Vertical extension reduces the need for land for e.g. new dwellings.
- Steel is an excellent material to use as to high-rise buildings.
- Low weight constructions enable the use of poor grounds to new buildings.

### 12.1.18. Summary of sustainability issues in different steps of the building process

Important considerations for steel constructions at different steps of the building process canbe displayed in a figure. Examples of possible benefits at the different steps are listed.




## 12.2. COMPOSITE CONSTRUCTIONS

### 12.2.1. OBJECTIVE/SCOPE

To introduce steel-concrete composite members and construction; to explain the composite action of the two different materials and to show how the structural members are used, particularly in building construction.

### 12.2.2. INTRODUCTION

The most important and most frequently encountered combination of construction materials is that of steel and concrete, with applications in multi-storey commercial buildings and factories, as well as in bridges. These materials can be used in mixed structural systems, for example concrete cores encircled by steel tubes, as well as in composite structures where members consisting of steel and concrete act together compositely.

These essentially different materials are completely compatible and complementary to each other; they have almost the same thermal expansion; they have an ideal combination of strengths with the concrete efficient in compression and the steel in tension; concrete also gives corrosion protection and thermal insulation to the steel at elevated temperatures and additionally can restrain slender steel sections from local or lateral- torsional buckling.

In multi-storey buildings, structural steelwork is typically used together with concrete; for example, steel beams with concrete floor slabs. The same applies to road bridges, where concrete decks are normally preferred. The extent to which the components or parts of a building structure should embody all steel construction, be constructed entirely in reinforced concrete, or be of composite construction depends on the circumstances. It is a fact, however, that engineers are increasingly designing composite and mixed building systems of structural steel and reinforced concrete to produce more efficient structures when compared to designs using either material alone. The first two pictures give an impression of how and to what extent composite construction is used for multi-storey buildings: Picture 1 shows a construction site for a commercial building in London; Picture 2 shows a factory building for the car industry in Germany.

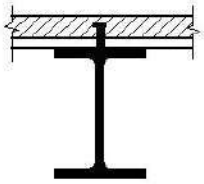
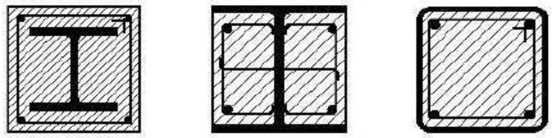
Picture 1 : Typical composite multi-storey steel-framed building during construction - a commercial building in London.

Picture 2 : Typical composite multi-storey steel-framed building during execution - a factory building for the car industry in Germany.

It should be added that the combination of concrete cores, steel frame and composite floor construction has become the standard construction method for multi-storey commercial buildings in several countries. Much progress has been made, for example in Japan, where the structural steel/reinforced concrete frame is the standard system for tall buildings. The main reason for this preference is that the sections and members shown in Picture 3 are best suited to resist repeated earthquake loadings, which require a high amount of resistance and ductility.

Picture 3 : The combination of concrete cores, steel frame and composite floor construction has become the standard method for multi-storey construction in several countries.

Figure 1 – Composite Structural
Elements in Buildings

| | | |
|---|---|---|
| Composite girder |  | Steel-beam composite slab or RC-slab |
| Composite column |  | Steel profiles embedded in or filled with concrete |
| Composite slab |  | Holorib ® sheeting + concrete |

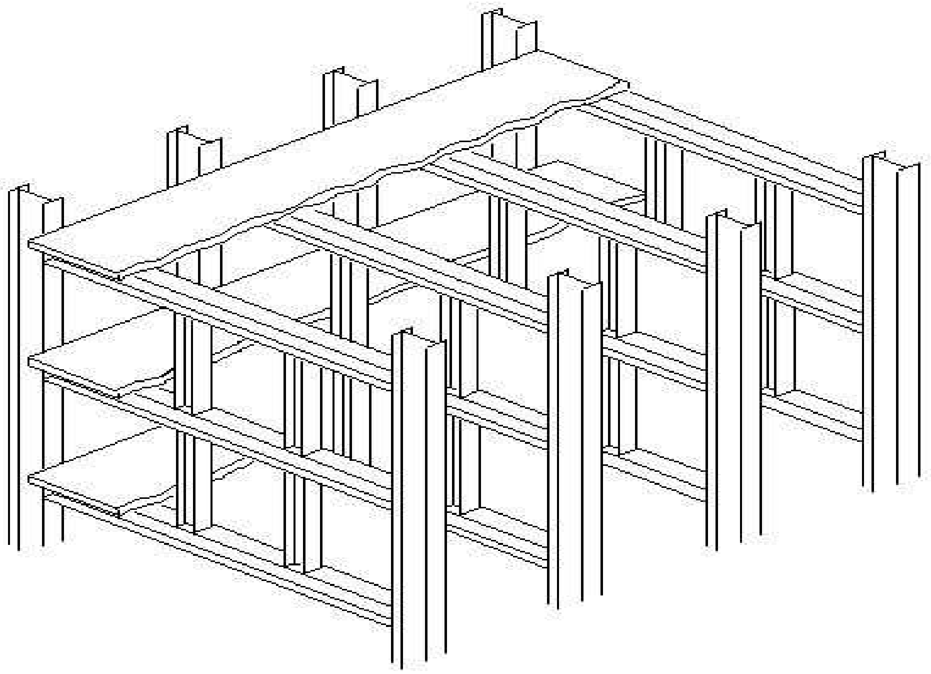


Figure 2a – Composite Construction in Buildings

A further important consideration is that the use of rolled steel sections, profiled metal decking and/or prefabricated composite members speeds up execution. For maximum efficiency and economy the joints should be cheap to fabricate and straightforward to erect on site.

Many experts feel that the further development of steel framed buildings depends largely on the use of composite construction. Unfortunately these two important building materials, steel and concrete, are promoted by two different industries. Since these industries are in direct competition with each other, it is sometimes difficult to promote the best use of the two materials.

Figure 2b - Composite Construction in Buildings

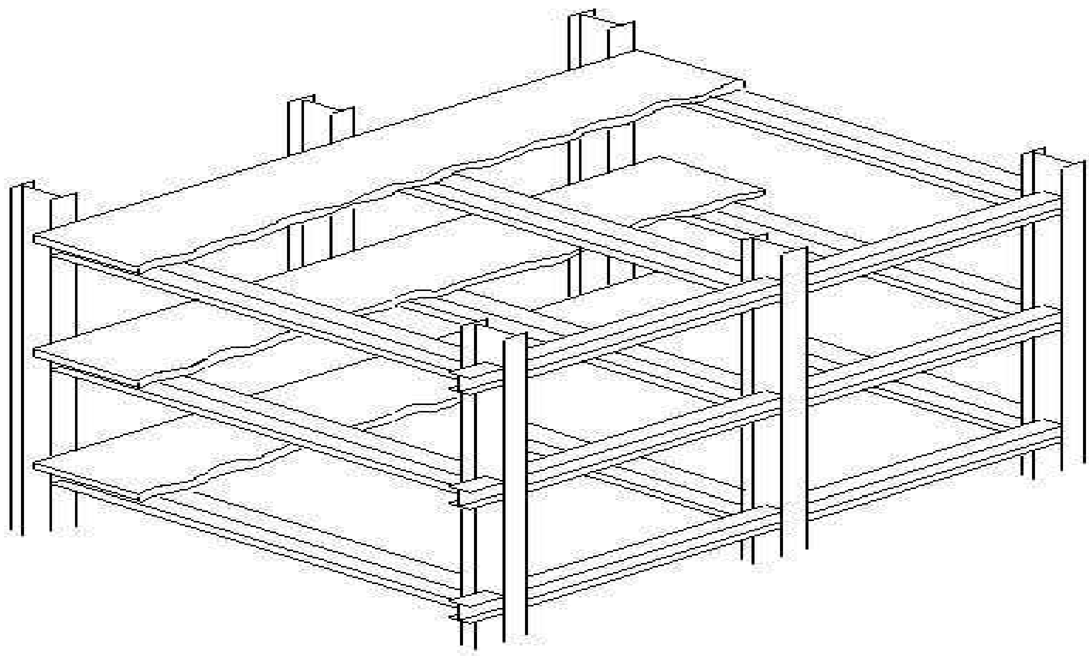


Figure 2c - Composite Construction in Buildings

### 12.2.3. COMPOSITE ACTION IN BEAMS

Composite beams, subject mainly to bending, consist of a steel section acting compositely with one (or two) flanges of reinforced concrete. The two materials are interconnected by means of mechanical shear connectors. It is current European practice to achieve this connection by means of headed studs, semi-automatically welded to the steel flange, see Picture 4.


Picture 4 : Composite beams, subject mainly to bending, consist of a steel section acting compositely with one (or two) flanges of reinforced concrete.

Figure 3 shows several composite beam cross-sections in which the wet concrete has been cast in situ on timber shuttering. For single span beams, sagging bending moments, due to applied vertical loads, cause tensile forces in the steel section and compression in the concrete deck thereby making optimum use of each material. Therefore, composite beams, even with small steel sections, have high stiffness and can carry heavy loads on long spans.

If slip is free to occur at the interface between the steel section and the concrete slab, each component will act independently, as shown in Figure 4. If slip at the interface is eliminated, or at least reduced, the slab and the steel member will act together as a composite unit. The resulting increase in resistance will depend on the extent to which slip is prevented. It should be noted that Figure 4 refers to the use of headed stud shear connectors. The degree of interaction depends mainly on the degree of shear connection used.

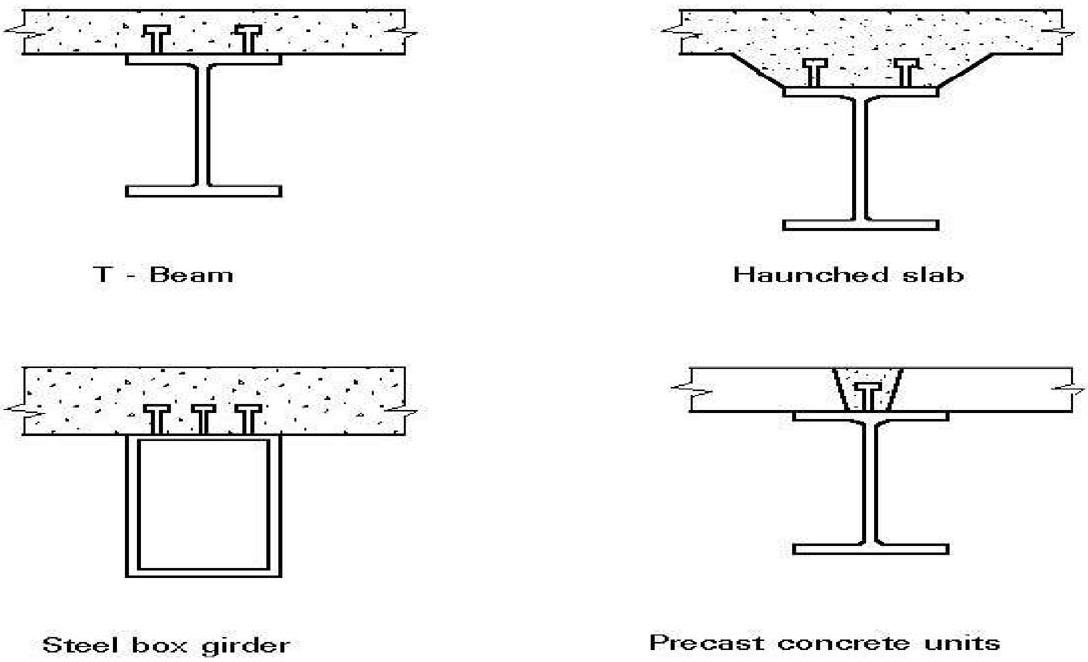



Figure 3 – Typical Beam Cross Sections

The following definitions are used to make clear the differences between resistance (strength) and stiffness properties:

- With regard to resistance, distinction is made between complete and partial shear connection. The connection is considered to be complete if the resistance of the composite beam is decided by the bending resistance, not the horizontal shear resistance.
- Complete or incomplete interaction between the concrete slab and the steel section results in a more or less stiff composite beam. Such incomplete interaction arises when flexible connectors such as headed studs are used and slip (relative displacement) occurs at the steel-concrete interface.
- The use of composite action has certain advantages. In particular, a composite beam has greater stiffness and usually a higher load resistance than its non- composite counterpart, see Figure 5. Consequently, a smaller steel section is usually required. The result is a saving of material and depth of construction. In turn, the latter leads to lower storey heights in buildings and lower embankments for bridges.

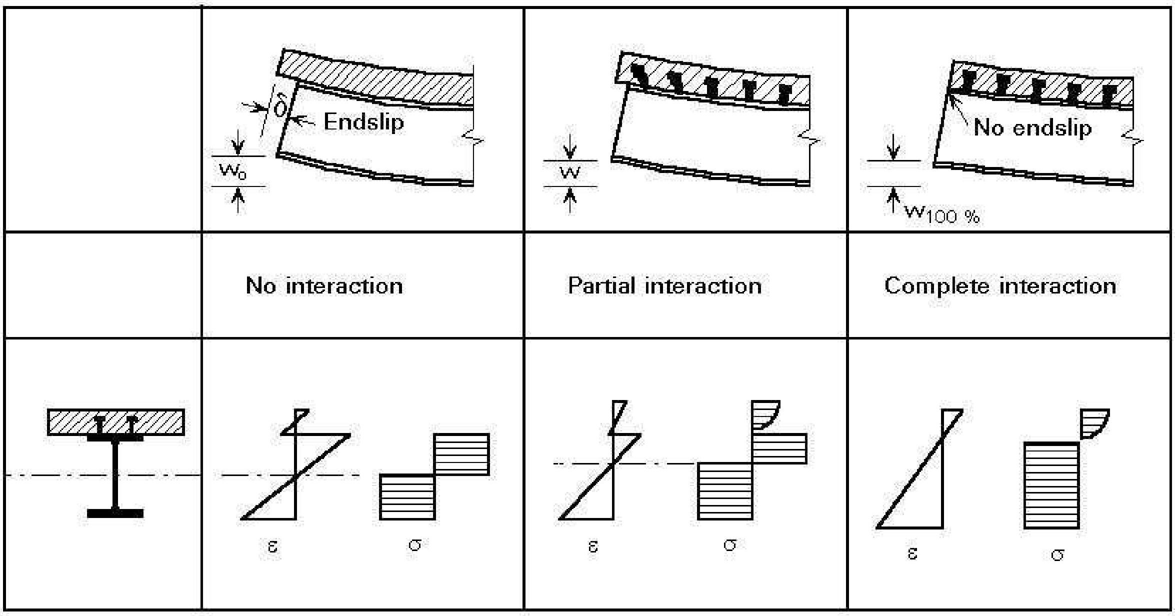
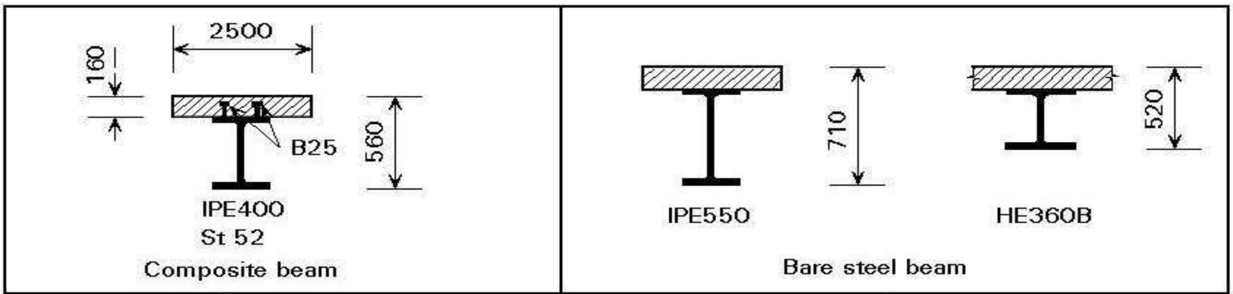



Figure 4 – Composite Steel Bea-Concrete Slab Interaction




| | Composite beam | Bare steel beam IPE550 | Bare steel beam HE360B |
|---|---|---|---|
| Load resistances | 100 % | 100 % | 100 % |
| Steel weight | 100 % | 160 % | 215 % |
| Overall height | 100 % | 130 % | 95 % |
| Stiffness | $t_o$ - 100 %<br>$t_{\infty}$ - 70 % | 70 % | 45 % |

Figure 5 – Importance of Composite Construction

### 12.2.4. COMPOSITE MEMBERS

#### 12.2.4.1. Composite Beams

Figure 3 shows the use of different shapes and types of steel beam (rolled or welded sections) together with in situ concrete.

Instead of an in situ concrete slab, precast concrete floor or deck units can be used, see Figure 5. Careful detailing and construction practice are needed to ensure adequate containment for the connectors. Figure 6a shows a system using large prefabricated deck elements with longitudinal joints. The gaps between the units would be filled with mortar in the final structure, thereby giving composite action with the beams. Such structural systems were introduced during the early 1960's. In Germany more than 100 car parks, university, school and office buildings (see Picture 4) have been built in this way. The use of precast deck units reduces on-site construction operations and avoids wet trades. The units themselves are cast on steel formwork in a shop to ensure high quality and small (strict) tolerances.

Picture 4 : Instead of an in situ concrete slab, precast concrete floor or deck units can be used.

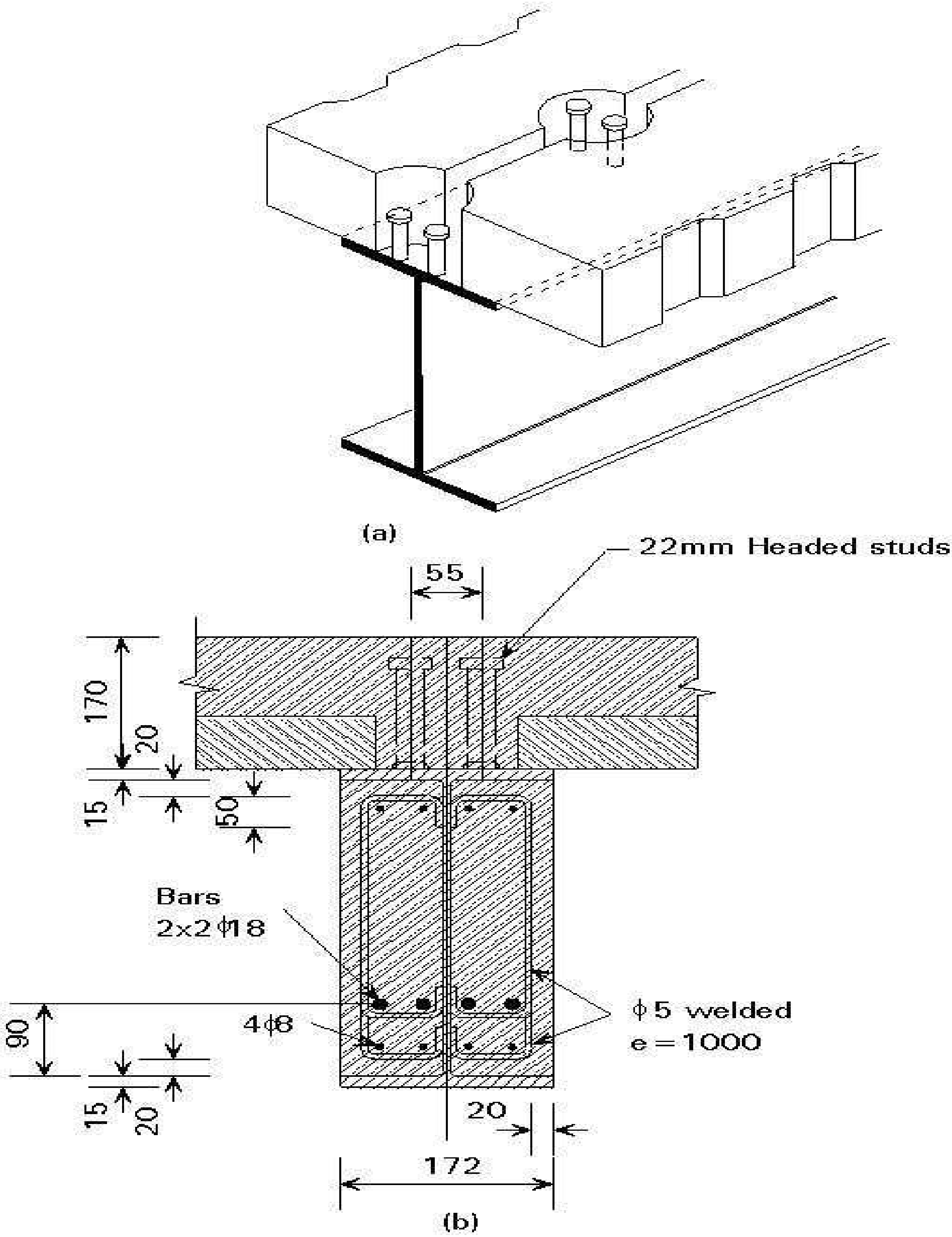



Figure 5 – Use of Precast Concrete Floor Units

Figure 5b shows thin prefabricated concrete elements, supported by the steel beam flange. These elements act as permanent formwork when casting the in situ concrete. The transverse distances between the stud shanks and the edge of the prefabricated concrete element may be small however, making it difficult to ensure adequate containment for the connectors. The main reason for the use of these thin plate elements (usually 4-5cm thick) is that they are easy to handle, and almost as convenient to handle as metal decking.

Figure 5b also shows a partly encased composite beam, the voids of which are filled with concrete. This type of composite section is often used in parts of Europe today, in order to enhance the fire resistance rating without additional protection measures. The lower steel flange remains unprotected.

The usual practice however, in the case of commercial and industrial buildings (see Picture 6), is to construct the floors using metal decking which incorporates additional embossments or indentations to provide composite action. This is a very economical way to speed up construction, and is an important part of modern structural systems. The deck supports the loads developed before and during concreting and later acts compositely with the in situ concrete. Steel decking with re-entrant and trapezoidal profiles are typically used, see Figures 6 and 7.

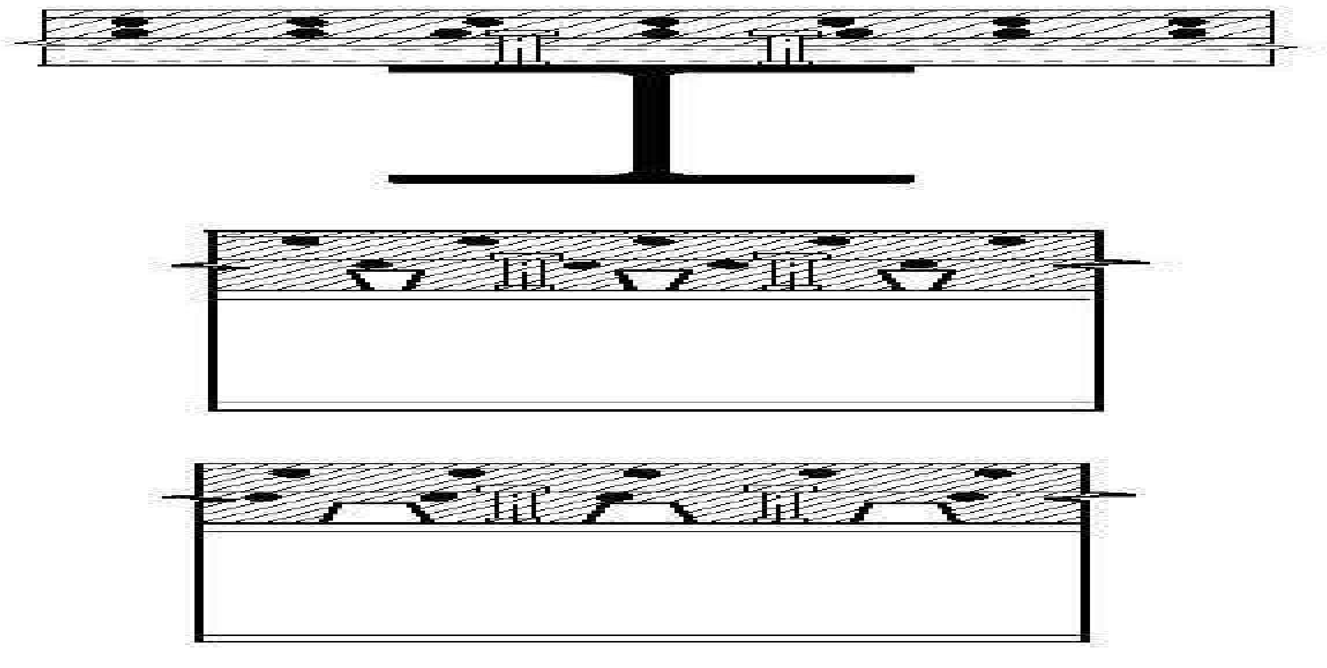


Figure 6 – The Use of Metal Decking of Different Shapes

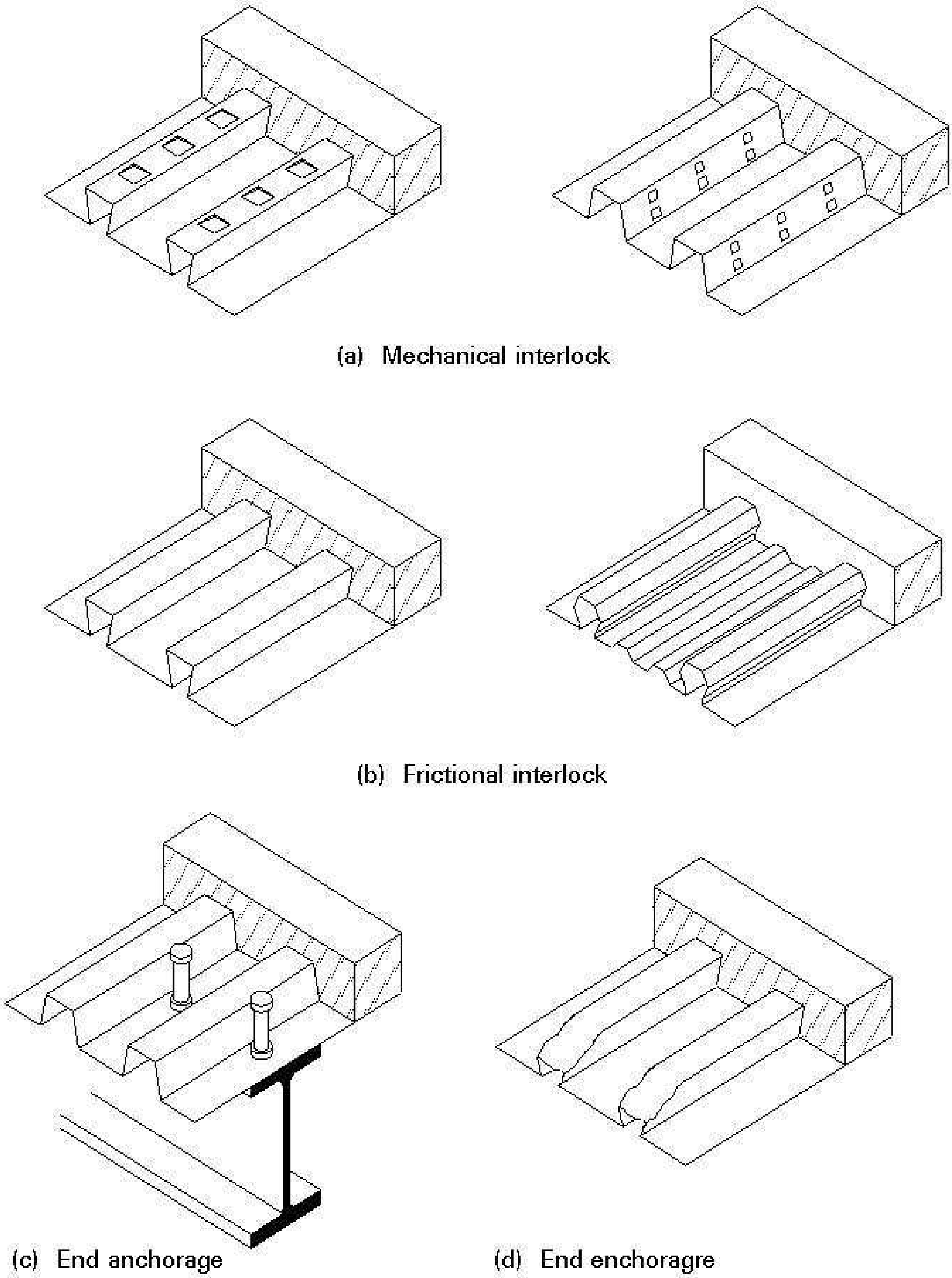
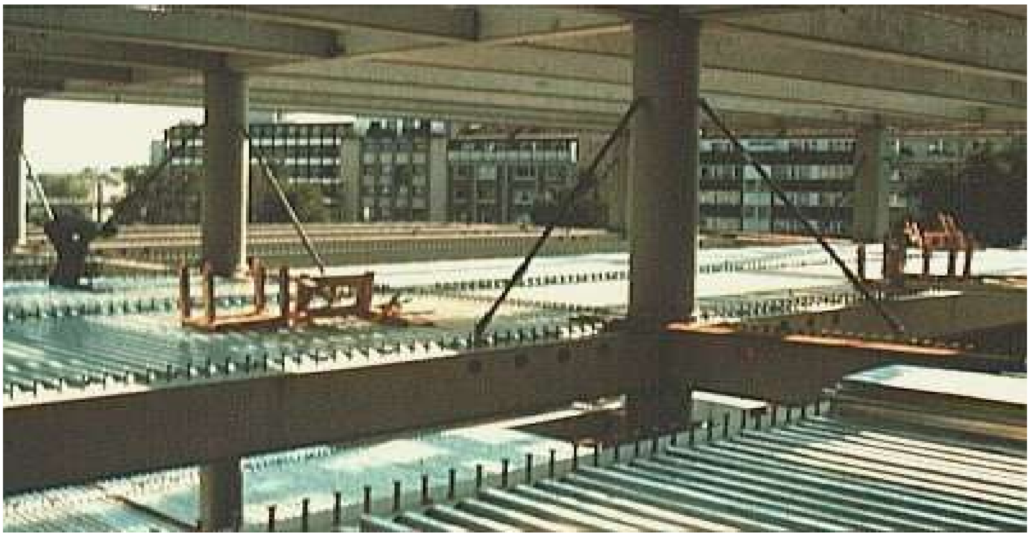



Figure 7 – Typical Forms of Interlock in Composite Slabs



Picture 5 : The usual practice for commercial and industrial buildings is to construct the floors using metal decking which is embossed to provide composite action.

Composite beams do not need any falsework or timber shuttering. This advantage is considered in the following section together with two different construction methods, "propped" and "unpropped".

### 12.2.5. Propped construction

The efficiency in structural performance will be greatest if it is possible to ensure that the concrete slab and steel member act compositely at all times. For this purpose, all loads, including the dead weight of the structure, should be resisted by the composite section. This requirement can be met by supporting the steel beam until the concrete has hardened. Such support is known as "propping". The number of temporary supports need not be high; propping at the quarter-span points and mid-span is generally sufficient. The props are left in place until the concrete slab has developed adequate resistance.

Different construction methods lead to different stress states, force distributions and deflections under service conditions. However, composite beams loaded up to failure fail at the same bending moment (assuming local instability is prevented) irrespective of whether propped or unpropped construction has been used. Their bending resistance can be easily calculated by means of rectangular stress blocks as outlined below.

### 12.2.6. Resistance of section

A typical form of composite construction consists of a slab connected to a series of parallel steel members. The structural system is therefore essentially a series of interconnected T-beams with wide, thin concrete flanges as shown in Figure 2. In such a system, the flange width may not be fully effective in resisting compression due to "shear lag". This phenomenon, which is taken into account by the well known "effective width" approach, is explained later.

No account needs usually to be taken of local buckling in the steel section in simply supported composite beams, since the compression flange is attached to the concrete slab by shear connectors, and the depth of the web in compression is usually small. In the case of partial interaction however, the depth of the compressed part of the web is greater. In this case, therefore, there remains at least theoretically the possibility that local buckling could occur in the web of a deep plate girder or in a flange with a wide outstand beyond the shear connectors.

The dimensions of most steel beam sections in buildings are such that plastic analysis can be applied to the cross-section of the composite beam. The calculation of the ultimate moment of resistance is, therefore, an application of the rectangular stress block diagram on the assumption that the steel sections belong to Class 1 or 2.

### 12.2.7. Continuous beams and slabs

Many composite beams in buildings are - from the point of view of the static calculation - continuous beams over simple supports. The concrete slabs are also usually continuous since they are cast without joints. Continuous beams in comparison with single span beams, therefore, have the following advantages:

- greater load resistance due to the redistribution of bending moments
- greater stiffness
- smaller steel section to withstand the same loading.

On the other hand, the continuity can complicate the design, particularly in regard to lateral-torsional and local buckling in negative moment regions. Local buckling of steel can reduce the bending resistance of the section below the plastic moment, unless certain limitations to the breadth/thickness ratios of the elements making up the section are met. Based on these ratios steel sections are grouped in Classes 1 to 4: Class 1 sections allow for global plastic analysis, using moment redistribution, which gives a very economic design; Class 2 sections allow for plastic calculation of the moment of resistance but do not permit redistribution. Hot rolled sections conform to Class 1 or 2 in most cases and when they are used local buckling is not, therefore, a problem.

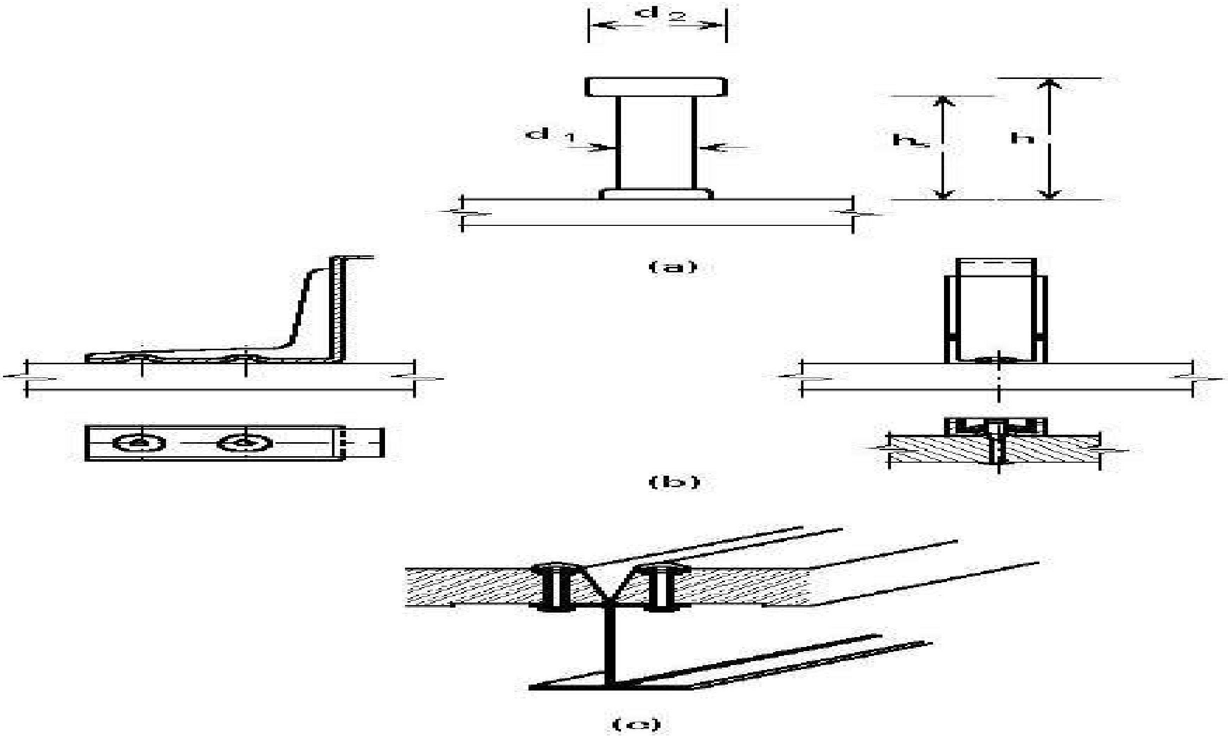
Adequately proportioned anti-crack reinforcement should be provided in the concrete slab over interior supports where joints are not present. If the reinforcing bars have enough ductility they will increase the bending resistance substantially in these hogging moment regions.

### 12.2.8. Shear Connection

Mechanical connectors are used to develop the composite action between steel beams and concrete. This connection is provided mainly to resist longitudinal shear, and is referred to as the "shear connection". Figure 9 shows several types of shear connectors. They have to fulfil a number of requirements, as follows:

- they must transfer direct shear at their base.
- they must create a tensile link into the concrete.
- they must be economic to manufacture and fix.

Figure 9 – Shear Connectors




In the industrialised countries the most common connector is the headed stud. It can be welded semi-automatically (see Picture 4) to the upper flange either directly in the shop or through thin galvanised steel sheeting on site (see Figure 9a).

Shot fired connectors, as shown in Figure 9b, have been used as an alternative in cases where metal decking is used and sufficient electrical power is not available on site. These connectors have the advantage that modified cartridge guns can be used instead of the special equipment required for complex through-deck welding.

In the case of prefabricated concrete deck units preloaded high strength bolts have sometimes been used to connect them to the beams, see Figure 9c. This type of connection has been used, for example, in temporary car parks because the connection can be removed (although all such existing car parks are in permanent use at the present time).

The behaviour and resistance of headed studs and other connectors are examined by means of "shear" or "push out" tests. These tests yield load-slip curves such as is shown in Figure 10 for headed studs. The behaviour is characterised by great stiffness at low loading (under service conditions) and large deformations at high loadings up to failure. Such ductile behaviour makes shear force redistribution at the steel-concrete interface possible and allows for partial shear connection. In addition, headed studs may be spaced uniformly along the beam length between critical cross-sections.

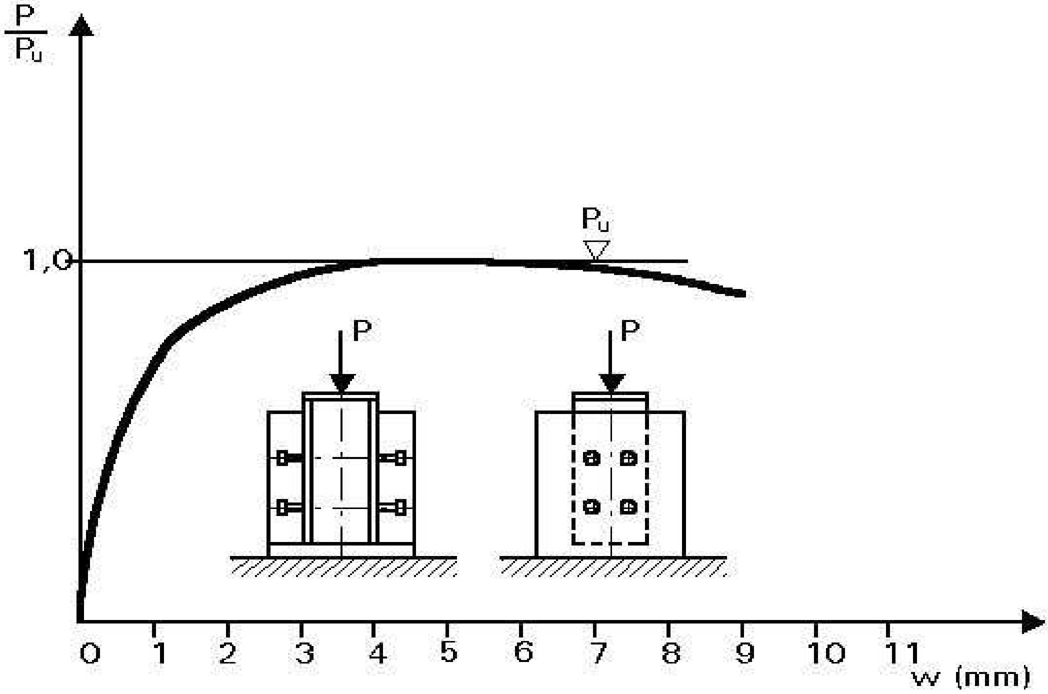



Figure 10 – Shear Tests for Headed Studs

Composite beams are often designed under the assumption that the unpropped steel beam supports the weight of the structural steel and wet concrete plus construction loads. It may, therefore, be decided for reasons of economy to provide only sufficient connectors to develop enough composite action to support the loads applied afterwards. This approach results in many less connectors than are required to enable the maximum bending resistance of the composite beam to be reached. The use of such partial shear connection results in reduced resistance and stiffness.

Partial shear connection may be unavoidable when a slab is constructed with metal decking. The number of shear connectors attached to the steel beam may then be limited by the restriction of being able to place them only in the troughs of the profiled steel sheeting.

### 12.2.9. Beam-to-Column Connection

Highly developed connection techniques can be used for connecting together structural steel members. Economy requires, however, that the joints are economic to fabricate and straightforward to install on site. Studies have indicated that the cost effectiveness of composite structures may be improved, if the actual degree of continuity provided by nominally simple joints is recognised in design.

In composite steel-concrete structures, however, significant additional stiffness and resistance can be provided simply by placing continuous reinforcing bars in the slab around the columns, since the single major factor governing the behaviour of joints is the slab action.

This effect can be augmented by a special sequence of construction and concreting, as follows: during concreting the steel section acts as a single span beam; the beam should be connected to the steel column by means of double web angles or flange cleats with or without web angles; after the concrete has hardened (assuming it is without joints as shown in Figure 11c) it is considered as a continuous beam supporting the additional applied loads. By following this construction sequence, the required bending moment redistribution is not extensive and plastic rotation can be significantly reduced. In addition the designer can take the decision whether or not to use shims between the steel compression flange and the column mainly depending upon the plastic end moment of the joint.

Figure 11 compares simple, rigid and semi-rigid composite joints. The construction detail without shims, shown in Figure 11c, is consistent with the growing interest in flexibly connected (semi-rigid) steel frames with simple construction details which speed up construction. It is proposed that the following performance criteria should be met:

- joints should behave much like a hinge before concreting.
- joints should be stiff and behave elastically up to a predetermined moment value.
- joints must be able to resist the governing plastic moment with adequate plastic rotation.

Beam-to-column connections in tall buildings demand somewhat different solutions. Until recently such structural systems employed only simple shear connections between structural steel and reinforced concrete elements. However, mixed structures should also be considered which are built by first erecting a frame of light steel columns and deep spandrel beams. The steel columns are later encased by reinforced concrete.

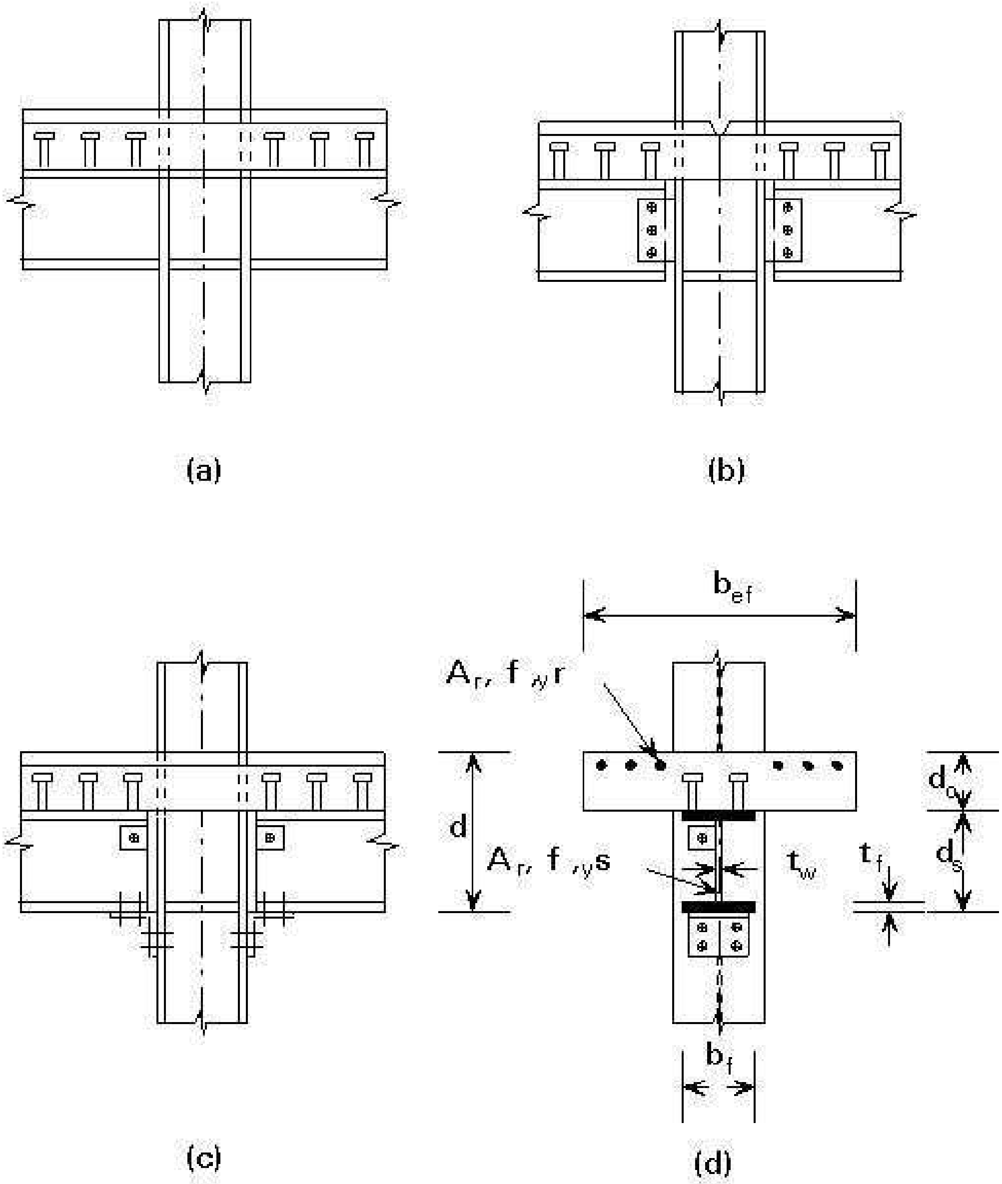



Figure 11 – Composite Joints

### 12.2.10. Composite Columns

Three different types of composite columns are principally in use, see Figure 12:

- concrete encased steel columns (a)
- concrete filled steel tubes and (c and d)
- rolled section columns partly encased in concrete (b).

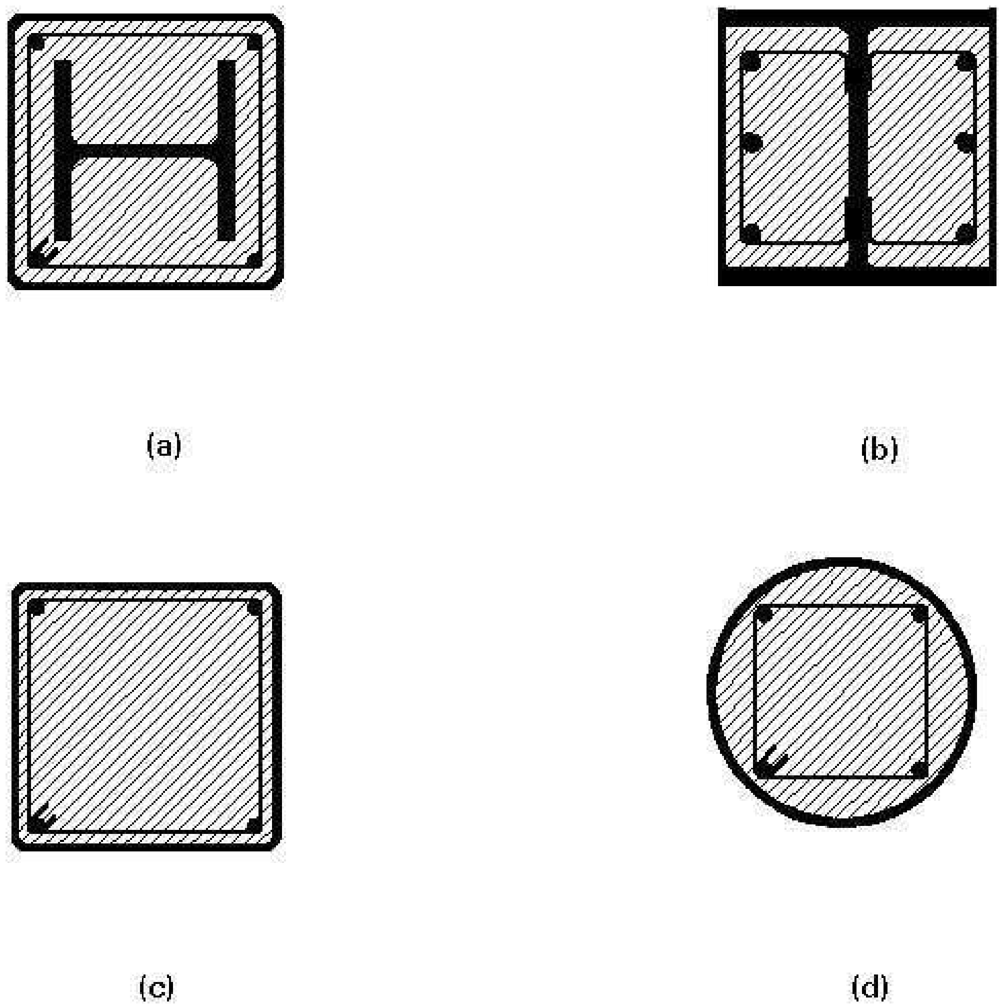



Figure 12 – Typical Cross Sections of Composite Columns

In calculating the strength of such columns, full composite interaction without any slip at the steel-concrete-interface is assumed. Strictly speaking all geometrical and physical non-linearities of the different materials should be observed. It is only possible, however, to meet these requirements by using comprehensive numerical methods of analysis and computer software. The assumed complete interaction enables definition of section properties, and stiffness and slenderness ratios, for the whole inhomogeneous cross- section. This information is necessary to determine the load carrying resistance, including slenderness or P-□-effects. Eurocode 4 gives simplified design methods for practical use. Instead of more precise buckling curves, Eurocode 4 [1] has adopted the European buckling curves a,b and c which were originally established for bare steel columns.

The complete interaction must be ensured by means of mechanical connections. The connections have to be provided at least at the column ends and where loads or forces are acting. They should be distributed over the whole cross-section. Such connectors can be headed studs, top and bottom plates, suitable brackets, vertical gusset plates, shear heads or other structural means.

Concrete encased columns have the advantage that they meet fire resistance requirements without any other protection. In addition, they can be easily strengthened by reinforcing bars in the concrete cover. They do not, however, present an accessible structural steel surface for later fastenings and attractive surface treatment. In the case of prefabricated encased columns, the structural steel sections are fabricated in a workshop and include all welds, connection plates and other necessary attachments. These steel columns (the longest have been up to 30 m long) can then be transported to another workshop, where concreting takes place. After the concrete encasement has cured the completed columns can be brought to the construction site.

Concrete filled steel tubes are also in use. The tubes are generally filled with high strength concrete, with a minimum cube strength of 45 to 55N/mm$^2$. These strengths, however, are far below those which have been developed recently in North America.

If the bearing forces from the floor beams are transferred by means of vertical connection plates, these plates run through the tube and are welded on both sides. This welding ensures both parts, the steel tube as well as the concrete core, are loaded directly without excessive slip at the steel-concrete interface. In order to meet the required fire resistance rating, the concrete core must be longitudinally reinforced. It is impossible, however, to take advantage of the full column resistance in many cases.

### 12.2.11. Partially Encased Steel Sections

Partially encased steel sections, for both beams and columns, are an interesting development of the last 10 years. The most important feature of such a partially encased section is its inherent high fire resistance. The fire resistance is due to the fact that the concrete part prevents the inner steel parts - structural steel as well as reinforcing bars - from heating up too fast. Figure 13 shows two partly encased composite beams (on the right hand side) compared with conventional fire protection by means of boards.

Picture 7 shows a typical composite floor construction, where partly encased sections are used; no further fire protection for beams and slabs is necessary.

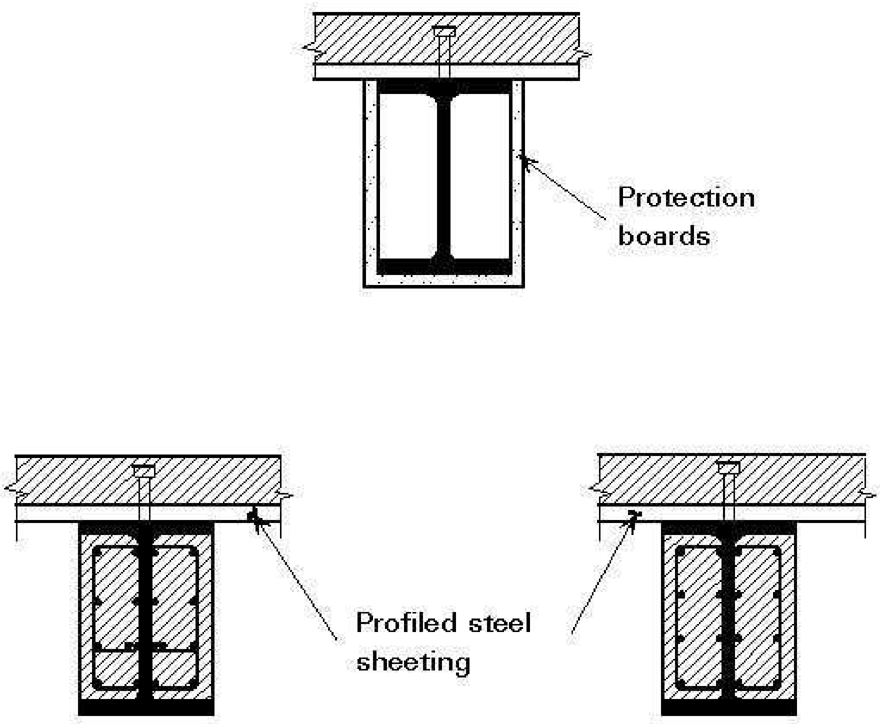



Figure 13 – Fire Resistant Composite Beams

Picture 7 : Partially encased steel sections, for both beams and columns, are an interesting development of he last ten years.

The concrete parts are cast in a workshop or on site before erection. This procedure enables rapid construction with prefabricated composite members. The concrete between the flanges should be reinforced by longitudinal bars and stirrups, and should be attached to the web by stud connectors, welded bars, or bars through holes.

In addition to the enhanced fire resistance, crippling and local buckling of the steel web is prevented and the resistance of the steel beam against lateral-torsional buckling is significantly increased. These beams also have greater stiffness under bending and vertical shear which results in a reduction of final deflection. They look very massive, as can be seen from Figure 14, and are characterised by their free bottom flange, to which ducts, other services and plant can be clamped or fastened.

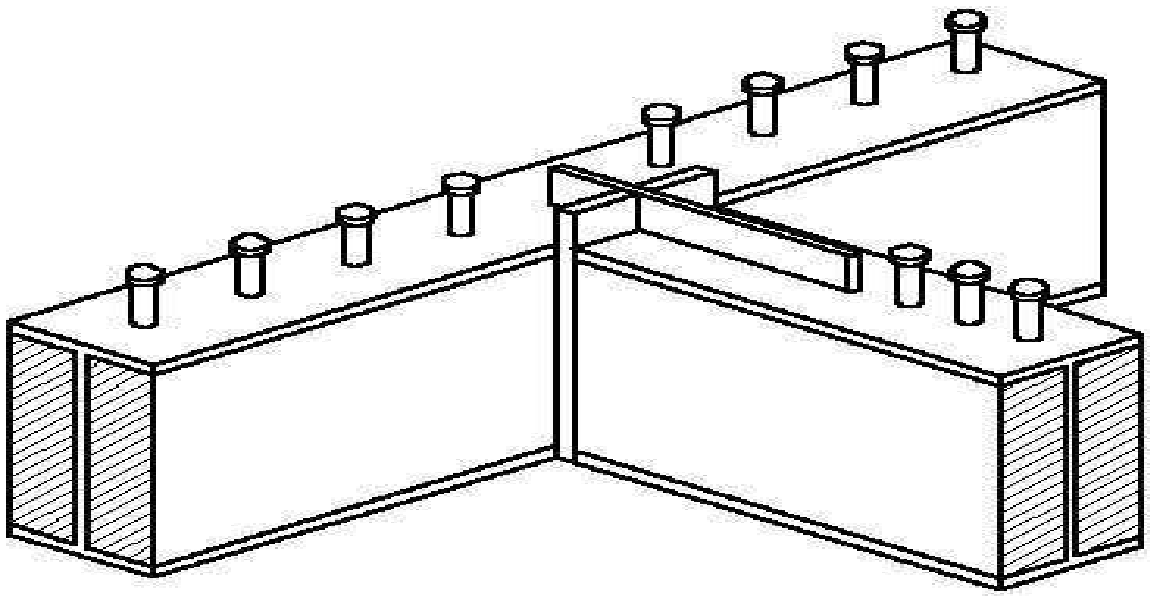


Figure 14 – Partially Encased Beams with Pinned Connections

### 12.2.12. Composite Slabs

In floor construction, the use of the solid reinforced concrete slab is being replaced more and more by metal decking, see Figure 15. Modern profiled steel sheeting with additional indentations or embossments acts as both permanent formwork during concreting and tension reinforcement after the concrete has hardened. At this final stage the composite slab consists of a profiled steel sheet and an upper concrete topping which are interconnected in such a manner that horizontal shear forces can be resisted at the steel-

concrete interface. Slip (relative displacements) at the interface must be prevented completely or partly, as should vertical separation of the steel decking from the concrete topping.

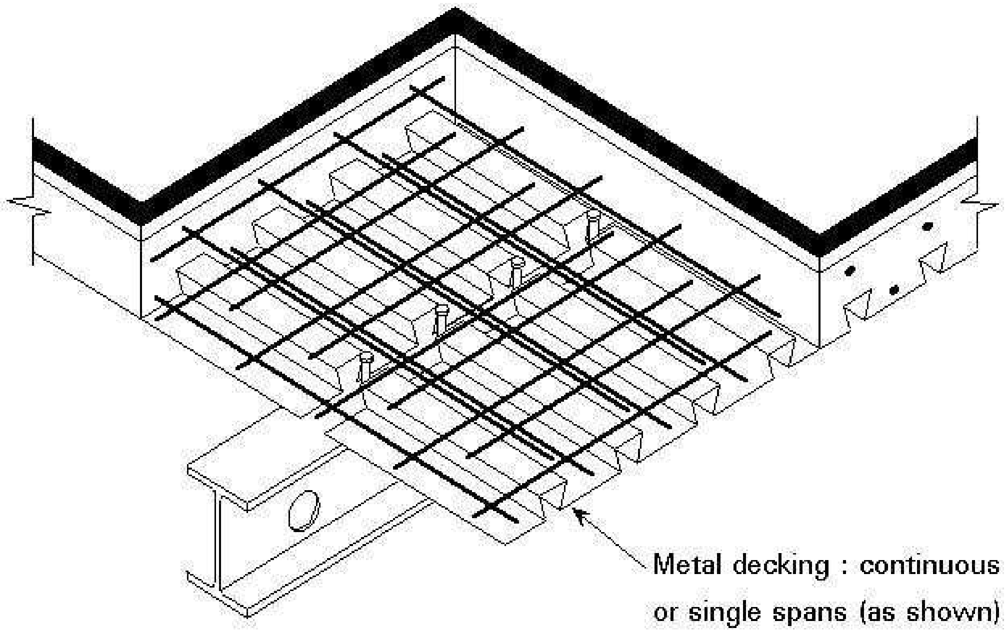



Figure 15 - The Use of Metal Decking in Composite Construction

The required composite action can be achieved by various means, see Figure 15. To allow for the large variety of current and possible future products on the market Eurocode 4 permits the following methods of achieving shear load:

a. mechanical interlock provided by deformations in the profile (indentations or embossments).

b. frictional interlock for profiles shaped in a re-entrant form.

c. end anchorage provided by welded studs or shot fired shear connectors.

d. end anchorages by deformation of the ribs at the end of the sheeting in combination with (b).

The use of profiled steel sheeting undoubtedly speeds up construction. It is also often used with lightweight concrete to reduce the dead load due to floor construction. In UK, for example, this use of lightweight concrete is common practice for commercial buildings.

The composite slabs are supported by steel beams, which normally act compositely with the concrete slab. The spacing of the beams, and therefore the slab span, depends on the method of construction, as follows:

- if the beam spacing is about 2,50 m, then no temporary propping is necessary during concreting of the slab. In this case, the construction stage controls the design of the metal decking. Due to the short slab span, the stresses in the composite slab in the final state after the concrete has hardened, are very low. For such floors, trapezoidal steel sheets with limited horizontal shear resistance and ductility are most often used. They have the lowest steel weight per square meter of floor area.

- for other floor layouts where the lateral beam spacing is much larger, props are necessary to support the metal decking during concreting. Due to the longer slab span, the final composite slab is highly stressed. As a result this final state may govern the design. In this case the steel sheeting will require good horizontal shear bond resistance. Re-entrant profiles are often used leading to greater steel weight per square meter of floor area.

## 12.2.13. COMPOSITE FLOOR CONSTRUCTION

Composite floor construction is essentially an overlay of one-way structural elements. The slabs span between the secondary or floor beams, which span transversely between the primary beams. The latter in turn span onto the columns, see Figure 16, Pictures 1 and 2. This set of load paths leads to rectangular grids, with large spans in at least one direction (up to 12, 15 or even 20 m). Up to 15 m, rolled sections are mainly used, while from 12 m upwards welded plate girders, stub girders or truss girders tend to be more economical.

During the life of a structure changes in use must be expected. Whilst many of these changes affect service requirements, others will primarily affect layout. The best way to maximize flexibility of internal planning is to minimize the number of columns. Figure 2 shows typical examples of ways in which primary beams of larger span, can reduce or eliminate internal columns. These large span beams may be so deep that services can only be accommodated by providing holes in the primary webs, see Figure 17. Stiffening around the openings may be necessary, particularly in the presence of very high vertical shear forces.

Other methods of incorporating services within the structural depth are shown in Figure 18. One additional alternative is the possibility of tapering the beams near to their ends.

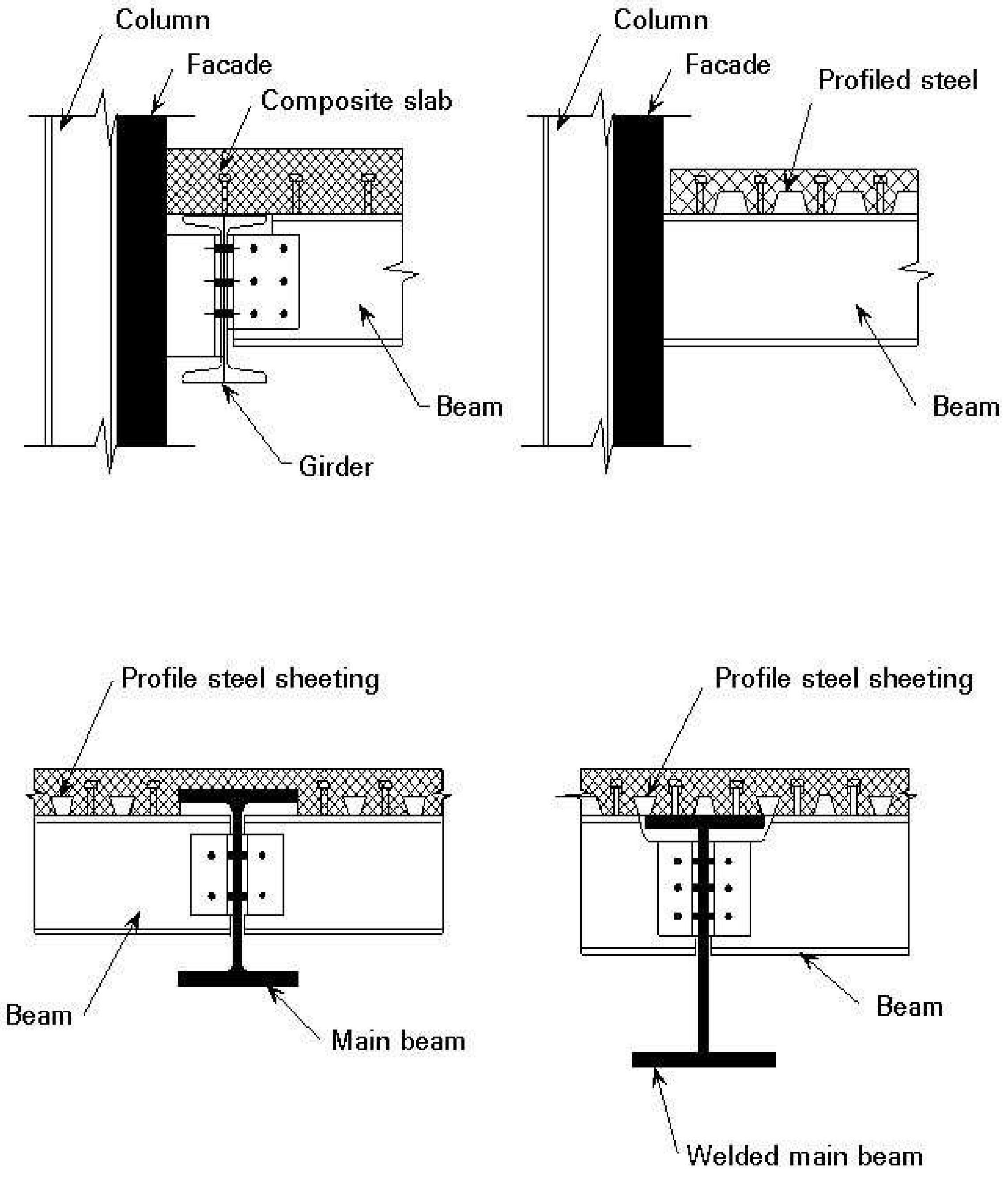



Figure 16 - Composite Floor Construction

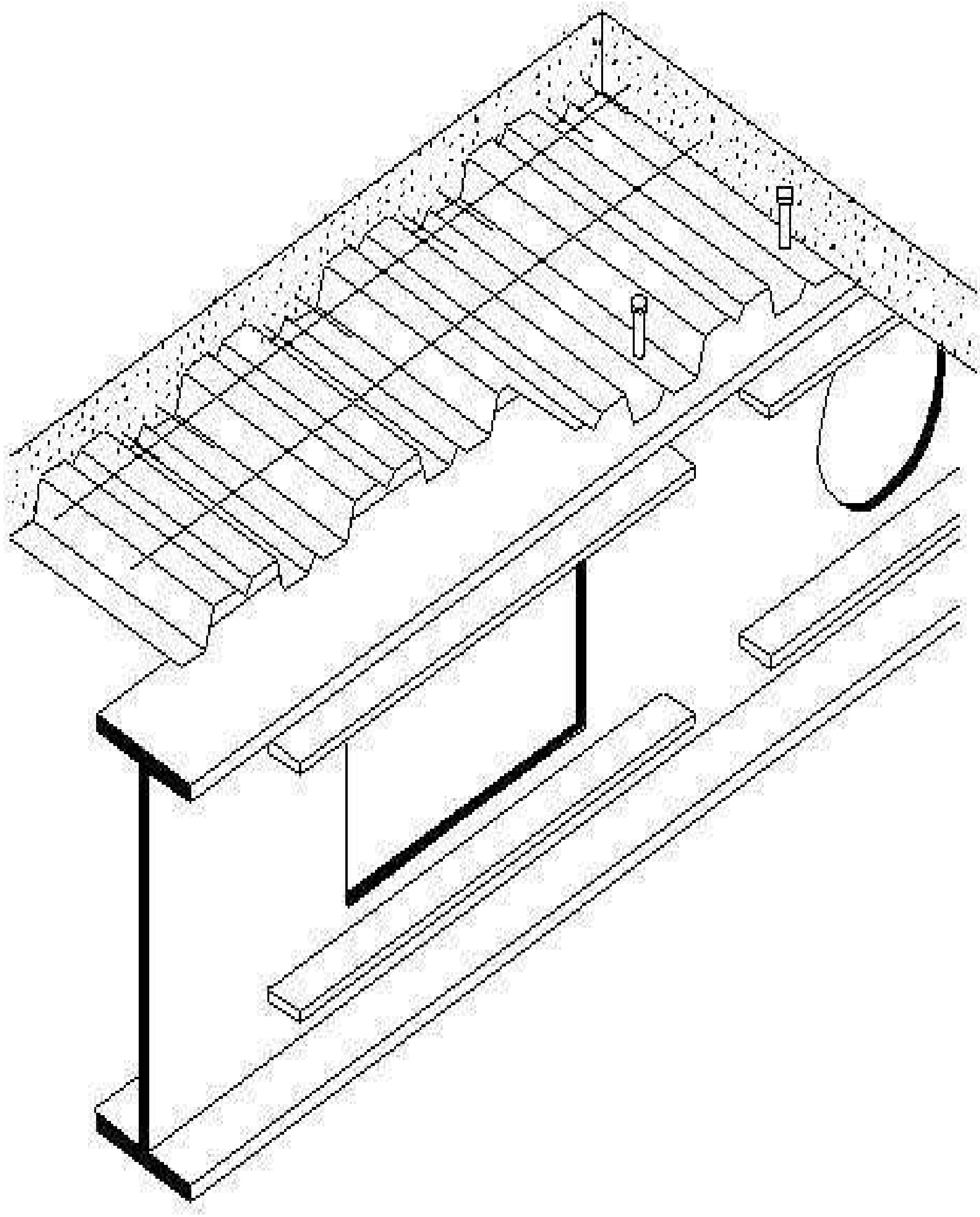
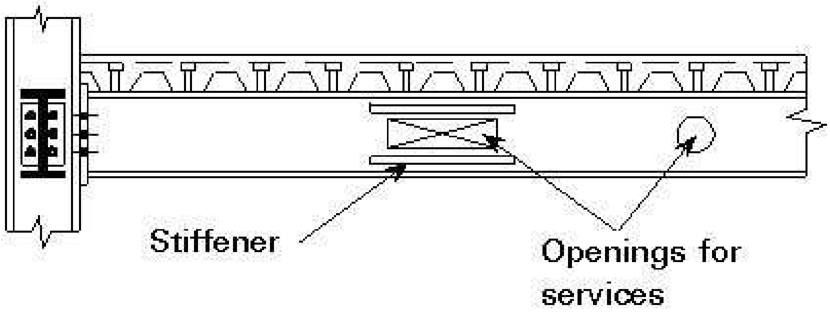
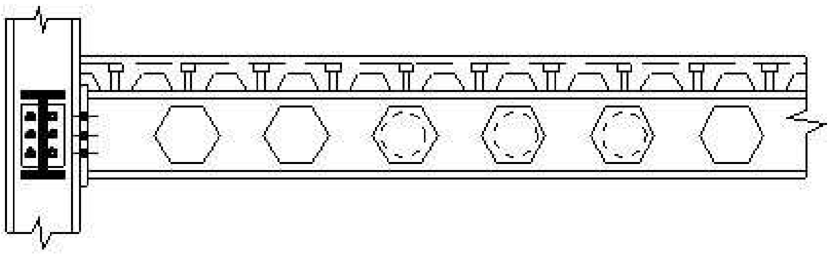


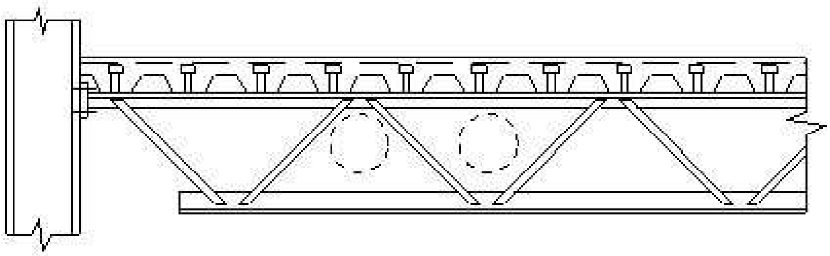
Figure 17 - Large Stiffened Web Openings




(a) Beam with web openings

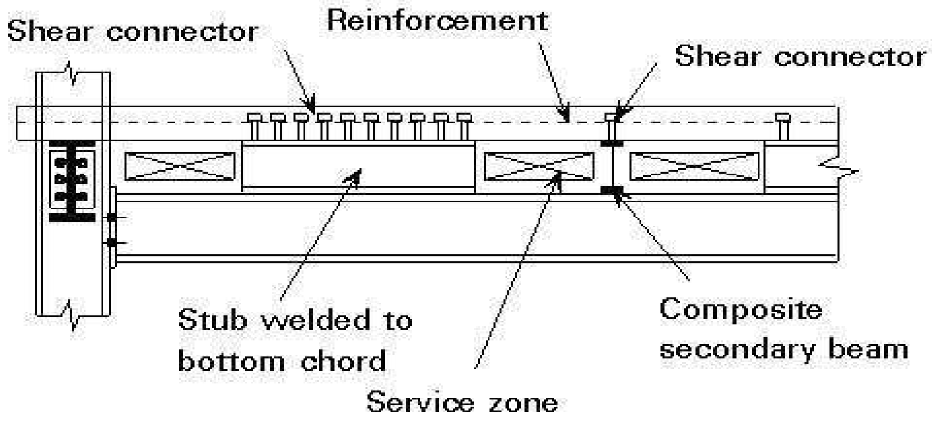


(b) Castellated beam

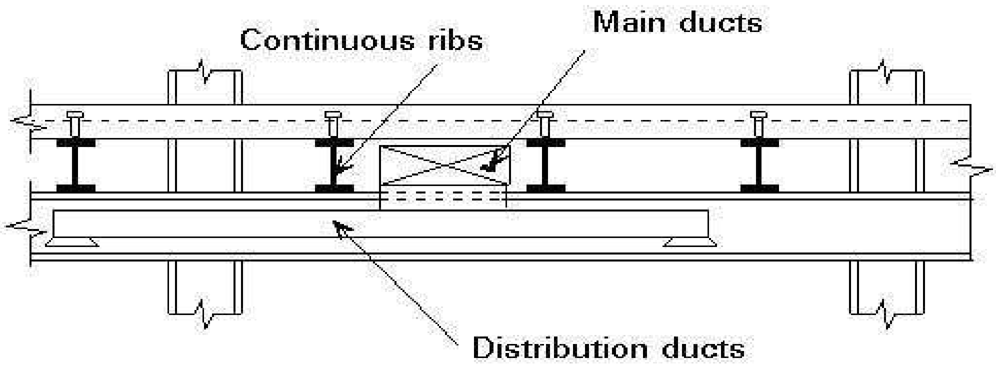


(c) Truss

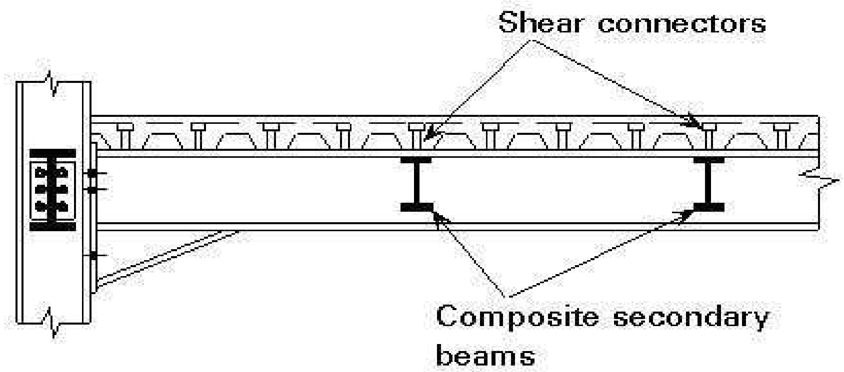
Figure 18a, b, c – Different Methods of Incorporating Services Within the Structural Depth




(d) Stub girder




(e) Parallel beam approach




(f) Haunched beams

Figure 18 d, e, f – Different Methods of Incorporating Services Within the Structural Depth

In the case of longer span floors, the designer may need to consider the susceptibility of the floor structure to vibration. The parameter commonly associated with this effect is the natural frequency of the floor: the lower the natural frequency, the more the structure may respond dynamically to occupant- induced vibration.

For this purpose floors (or beams) are normally designed to have a natural frequency not less than 3Hz, and in the case of floors that may be subject to rhythmic group activities, not less than 4Hz. An alternative more precise approach is to assess the likely vibrational behavior and, taking into account the human reaction to vibration, thereby establish acceptance criteria.

In summary, composite floor construction used for commercial and other multi-storey buildings, offers the following main advantages to the designer and client:

- speed and simplicity of construction (metal decking, simple steel connections).
- lighter construction than a traditional concrete building (structural steel and lightweight concrete, slender structural elements of small dimensions).
- less on site construction (steelwork, prefabricated structural elements).
- small (strict) tolerances achieved by using steel members manufactured under controlled factory conditions to established quality procedures.

Composite beams are designed using plastic design methods and partial interaction theory, combining steel and concrete to great effect. To obtain maximum advantage from this form of construction, planning and design should be integrated from the start. The involvement of experienced site managers at an early stage will help avoid problems later on. With this carefully planned approach, different operations such as steel erection, metal decking and stud welding, concreting, fire protection, cladding, facade work, services and finishing can be carried out at different floor levels simultaneously.

## 12.2.14. COMPOSITE BRIDGES

Medium span composite bridges are normally constructed from welded, built up, steel plate girders and a wide reinforced concrete deck, as shown in Figure 19. Box girders, see Figure 20, which look very attractive but which are more expensive, are used less frequently. For the smaller spans, from 20 up to 35m, rolled steel sections are more popular. They can be used with a concrete deck slab or embedded in concrete (upper flange and web). Picture 8 gives an illustration of rolled sections, which can be fabricated curved if required, used in this way.

Since the 1950's, several large span continuous composite highway bridges have been erected. During the years immediately after World War II, structural steel was very expensive, and advantage was taken of the light composite cross-section to save material costs. The sections of today are more compact and simpler, and do not have so many secondary beams, bracings and stiffeners. This form of structure saves labour costs in the workshop as well as on the construction site.

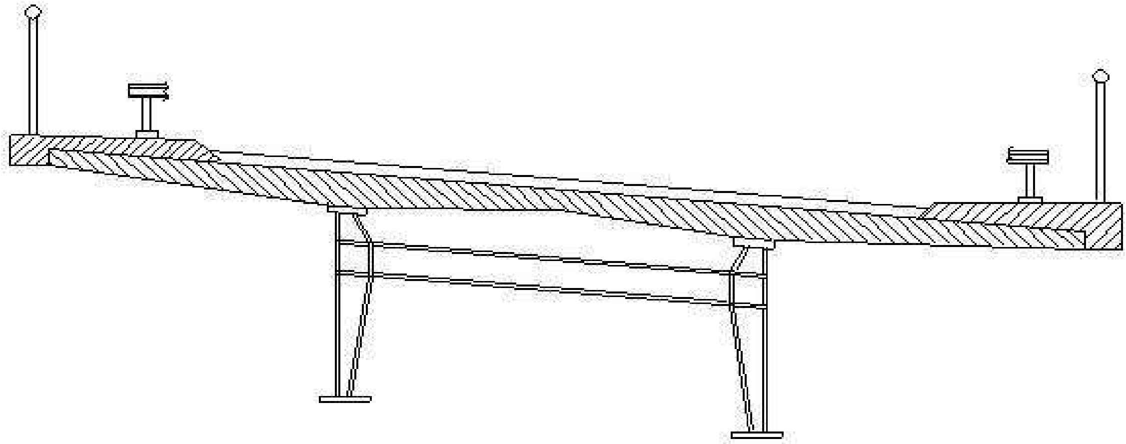


Figure 19 – Typical Cross-Section of a Composite Plate Girder Bridge for Medium Spans

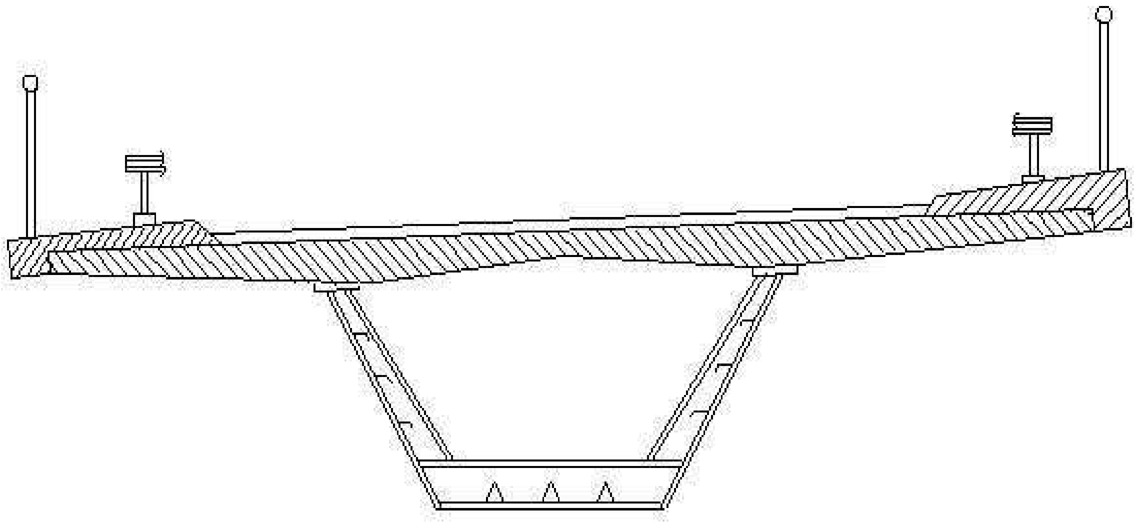
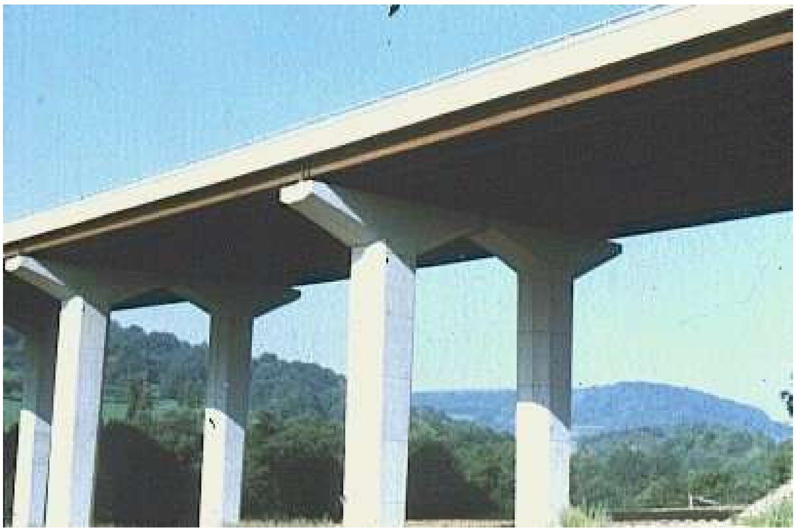


Figure 20 – Box Girder Composite Bridge



Picture 8 : Medium span composite bridges are normally constructed from welded, built up, steel plate girders and a wide reinforced concrete deck.

Due to the unsymmetrical nature of the cross-section, concrete shrinkage always causes compression and positive bending in the steel section leading to greater deflections.

In propped construction the compression in the concrete flange due to the self weight of the beam causes creep deformations. The concrete sheds compression. Stresses and forces are then redistributed from the concrete flange to the steel beam, and the steel beam, therefore, has to resist a greater part of the loading. This redistribution also results in increased deflections.

A simple way to take creep and shrinkage effects into account is to reduce the stiffness of the concrete by means of appropriate reduction coefficients "n". These n-factors depend not only on duration and time of loading after concreting, but also on the cross-section properties and the environmental conditions. It should be noted that this procedure does not apply to beams in buildings, where less precision is required.

At the ultimate limit state strains due to load are much larger than the strains due to creep and shrinkage, and the latter can therefore be neglected.

## 12.2.15. CONCLUDING SUMMARY

- Composite construction, particularly that using profiled steel sheeting, allows rapid construction.
- The weight of steelwork required in composite construction is significantly less than if the materials were used independently.
- There is no need for expensive falsework and formwork because the steel beam is able to sustain the self weight of steel and concrete, by itself or with the assistance of a few temporary props. Timber formwork can be replaced by precast concrete elements or profiled steel sheeting.
- The aforementioned advantages present a very strong argument for the use of composite beams in

buildings. They are more significant, however, for medium to long spans than for short spans.

- The main disadvantage of composite construction is the need to provide connectors at the steel-concrete interface.
- Another minor drawback is that it is somewhat more complicated than other methods to design and construct. This drawback is particularly relevant to continuous structures and bridges. However, it is far outweighed by the significant advantages that can be gained.

## 12.2.16. ADDITIONAL READING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# 13. RETROFITTING OF STRUCTURES

## 13.1. Introduction

The retrofit process is a general term that may consist of a variety of treatments, including: preservation, rehabilitation, restoration and reconstruction. Selecting the appropriate treatment strategy is a great challenge involved in the retrofit process and must be determined individually for each project. Depending on project objectives, preservation and renovation of buildings may involve an array of diverse technical considerations, such as fire life safety, geotechnical hazards and remedies, weathering and water infiltration, structural performance under earthquake and wind loads.

Preservation is defined as the process of applying measures to sustain the existing form, integrity, and materials of a historic property. Rehabilitation refers to the process of creating new application for a property through repair, alterations and additions while preserving those features which convey it's historical, cultural, or architectural values. Restoration is the process of accurately restoring a property as it existed at a particular period of time. Reconstruction is described as the act of replicating a property at a specific period of time. Rehabilitation provisions require selecting the rehabilitation objectives and acquiring current building information prior to performing rehabilitation design. At the stage of selecting the retrofitting method, the current status of the existing structure and its performance are known, and the performance required for the structure after retrofitting. Factors that should be considered in selecting the method include the effectiveness of the various retrofitting methods with respect to the required performance improvements, the viability of execution of the retrofitting work, the impact of the retrofitting work on the surrounding environment, the ease of maintenance after retrofitting, economy and other factors.

## 13.2. Retrofitting of Concrete Members :

♣ Continuous fiber reinforced plate bonding construction method: Bonding continuous fiber reinforced plates to the surface of the existing structure to restore or improve load-carrying capacity

♣ Continuous fiber reinforced plate jacketing construction method: Jacketing with continuous fiber reinforced plates around the periphery of the existing structure to restore or improve load-carrying capacity and deformation characteristics

♣ Prestressed concrete jacketing construction method: Placing prestressing wires and prestressing stranded steel wires in place of lateral ties around the periphery of existing member sections and using mortar and concrete to bond them in order to reinforce the structure.

♣ Prestressing introduction construction method: Using internal cables for the existing concrete members to provide prestressing and restore or improve the loadcarrying capacity of the members.

♣ Repaving method: Replacing some or all of the existing concrete members with new members through the use of precast members or concreting on site to restore or improve load-carrying capacity.

## 13.3. **Retrofitting as a Structural Body**

♣ Beam addition method: Adding beams between the main girders of the existing reinforced concrete deck to reduce the deck span and restore or improve the loadcarrying capacity of the reinforced concrete deck.

♣ Seismic wall addition method: Placing new reinforced concrete walls between existing reinforced concrete rigid-frame bridge piers and bonding them to form a continuous unit in order to restore or improve the loadcarrying capacity as a structural body.

♣ Support point addition method: Supporting the intermediate sections of the beams and other existing concrete members with new members to reduce the span of the members in order to restore or improve the loadcarrying capacity as a structure.

♣ Seismic Isolation method: Using seismic isolation bearings and the like to reduce the seismic energy applied to the structure in order to improve its various performance values during an earthquake.

## 13.4. **Foundation Retrofitting**

♣ Underground wall (beam) addition method: Connecting the foundations with cast-in-site diaphragm walls and underground connecting beams to distribute stress and ensure the stability of the entire system.

♣ Pile/footing addition construction method: When pile foundations are damaged or there is residual displacement, adding piles or footings to increase the load-carrying capacity of the foundation.

♣ Foundation improvement method: Improving the ground around the foundation with cement improvement materials to improve the ground bearing capacity and horizontal foundation resistance. Also prevents excessive pore water pressure and liquefaction.

♣ Steel sheet-pile coffering construction method: Placing sheet-piles around the periphery of the footings and bonding them to the footings to improve bearing capacity and horizontal resistance.

♣ Foundation compacting method: When insufficient foundation bearing capacity is a concern due to scouring or the like, using concrete or the like to compact the ground around the foundation in order to restore bearing capacity.

♣ Ground anchor method: When bridge abutments or the like move or tilt laterally as a result of an earthquake, etc., using ground anchors to stabilize the bridge abutments.

## 13.5. **Repair of Cracks**

♣ Crack fills method: Forcing low viscosity resin and ultra-fine cement into the cracks in existing concrete members to seal the cracks.

♣ Fill method: Filling cracks, rock pockets, cavities, peeling and other small-scale missing sections in existing concrete members with resin and mortar to repair sections.

♣ Section repair method: Removing deteriorated or damaged portions of existing concrete.

### 13.6. Historical Building

Buildings with historic value are regional cultural assets worth preserving. Minimizing noise, disturbance, and damage to the surrounding buildings and providing temporary shoring and support are typical challenges involved in most retrofit projects. Depending on the extends of retrofitting, assessed risk, technical limitations, structural historic value, and economical constraints, the preferred retrofit strategies are studied to preserve the authenticity of historic fabrication and minimize removal of architectural material

### 13.7. No penetration of Building Envelope

The process does not require any destructive procedure so the historic fabrication remains untouched. This approach is only applicable to very limited cases since structural components are mostly either embedded in or covered by the finishing.

### 13.8. Penetration without Breakage

The structural component subjected to retrofitting is accessible, and the retrofit process only requires drilling holes

### 13.9. Breakage with Repair

In many cases, some destructive procedures are required to access the structural component or to perform retrofit process.

### 13.10. Replace

In cases structural components cannot be improved to meet retrofitting objectives or the damage or deterioration could not be repaired, components are replaced.

### 13.11. Rebuild

In cases a feasible retrofitting solution cannot be found, the historic building is reconstructed, partially or as a whole.

### 13.12. Innovative Technologies for Historic Preservation

Modern materials and equipment provide many retrofit options to improve the behavior of structural system, global strength, and stiffness or mitigate the seismic hazards. Some of the commonly used techniques in retrofitting are listed below:

### 13.13. Post Tensioning

Post tensioning (fig1) is considered one of the potentially efficient retrofit options for reinforced concrete or masonry buildings. Masonry has a relatively large compressive strength but only a low tensile strength. Hence, it is most effective in carrying gravity loads. Commonly, induced tensile stresses exceed the compressive stresses and reinforcing must be added to provide the necessary strength and ductility.

Figure 1

## 13.14. **Composite Wraps**

Composite wraps (fig2) or carbon fiber jackets are used to strengthen and add ductility to reinforced concrete and masonry components without requiring any penetration. Composite wraps are most effective on reinforced concrete columns by providing additional confinement.

**FIGURE 2**

## 13.15. **Micro-piles**

Micro-piles (fig3) are utilized in foundation rehabilitation and seismic retrofitting projects to enhance the foundation ultimate capacity and reduce foundation deflection.

Figure 3

## 13.16. **Epoxy**

Epoxy is one of the most versatile materials used in structural repair and retrofitting and it is used as a sealant, adhesive or mortar.

### 13.17. **SEISMIC RETROFITTING TECHNIQUE:**

There are many seismic retrofit techniques available, depending upon the various types and conditions of structures.

### 13.18. **Structure-Level Retrofit**

Structure-level retrofits are commonly used to enhance the lateral resistance of existing structures. Such retrofits for RC buildings include steel braces, post-tensioned cables, infill walls, shear walls, masonry infill's, and base isolators.

### 13.19. **Addition of RC Structural Walls**

Adding structural walls is one of the most common structure-level retrofitting methods to strengthen existing structures. In order to reduce time and cost, shotcrete or precast panels can be used. The overturning effects and base shear are concentrated at the stiffer in fill locations.

### 13.20. **Use of Steel Bracing**

Concentric or eccentric bracing (fig4) schemes can be used in the selected bays of an RC frame to increase the lateral resistance of the structure. The advantage of this method is that an intervention of the foundation may not be required because steel bracings are usually installed between existing members.

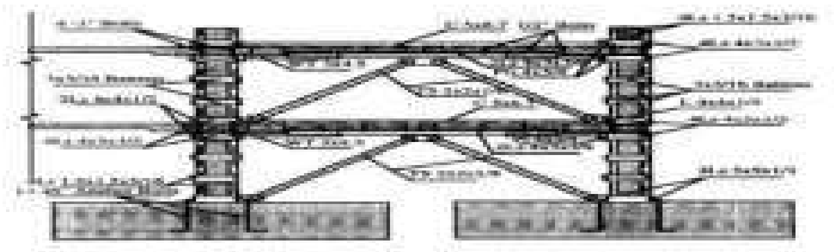


Figure 4

### 13.21. **Seismic Isolation**

The objective of this type of retrofit is to isolate the structure from the ground motion during earthquake events. The bearings are installed between the superstructure and its foundations. Because most bearings have excellent energy dissipation characteristics, this technique is most effective for relatively stiff buildings with low-rises and heavy loads.

### 13.22. **Member-Level Retrofit**

The member-level retrofit approach can provide a more cost-effective strategy than structurelevel retrofit because only those components needed to enhance the seismic performance of the existing structure are selected and upgraded. The memberlevel retrofit approaches include the addition of concrete, steel, or fiber reinforced polymer (FRP) jackets for use in confining RC columns and joints.

### 13.23. **Column Jacketing**

Column retrofitting is often critical to the seismic performance of a structure. To prevent the story mechanism during earthquakes, columns should never be the weakest components in the building structure. The response of a column in a building structure is controlled by its combined axial load, flexure, and shear. Therefore, column jacketing may be used to increase column shear and flexural strength so that columns are not damaged. Fiber reinforced polymer (FRC) material is used for jackets when retrofitting columns.

### 13.24. **Surface Treatment**

Surface treatment is a common method, which has largely developed through experience. Surface treatment incorporates different techniques such as ferrocement, reinforced plaster, and shotcrete. By nature this treatment covers the masonry exterior and affects the architectural or historical appearance of the structure.

### 13.25. **Ferrocement**

Ferrocement consists of closely spaced multiple layers of hardware mesh of fine rods with reinforcement ratio of 3-8% completely embedded in a high strength (15-30 MPa) cement mortar layer (10- 50 mm thickness). The mortar is troweled on through the mesh with covering thickness of 1-5 mm. The mechanical properties of ferrocement depend on mesh properties. However, typical mortar mix consists of 1 part cement: 1.5-3 parts sand with approximately 0.4 w/c ratio. The behavior of the mortar can be improved by adding 0.5-1% of a lowcost fiber such as polypropylene. Ferrocement is ideal for low cost housing since it is cheap and can be done with unskilled workers. The mesh helps to confine the masonry units after cracking and thus improves in-plane inelastic deformation capacity

### 13.26. **Reinforced Plaster**

A thin layer of cement plaster applied over high strength steel reinforcement can be used for retrofitting. The steel can be arranged as diagonal bars or as a vertical and horizontal mesh. The improvement Its strength depends on the strengthening layer thickness, the cement mortar strength, the reinforcement quantity and the means of its bonding with the retrofitted wall.

### 13.27. **Grout and Epoxy Injection**

Grout injection is a popular strengthening technique, as it does not alter the aesthetic and architectural features of the existing buildings. The main purpose of injections is to restore the original integrity of the retrofitted wall and to fill the voids and cracks, which are present in the masonry due to of the slab can prevent punching shear failures.

### 13.28. **FRP Strengthening**

A Fibre Reinforced Polymer (FRP) typically consists of high tensile continuous fibres oriented in a desired direction in a speciality resin matrix. These continuous fibres are bonded to the external surface of the member to be strengthened in the direction of tensile force or as confining reinforcement normal to its axis. FRP can enhance shear, flexural, compression capacity and ductility of the deficient member. Glass fibers are the most common types of fibers used in the majority of commercially available FRPs. FRP systems, commonly used for structural applications. FRP strengthening is a quick, neat, effective, and aesthetically pleasing technique to rehabilitate reinforced and pre-stressed concrete structures. Unlike steel plates, FRP systems possess high physical and chemical deterioration or mechanical actions. For injection, epoxy resin is used for relatively small cracks (less than 2 mm wide); while, cement-based grout is considered more appropriate for filling of larger cracks, voids, and empty collar joints in multi-Wythe masonry walls. Walls retrofitted with epoxy injection tend to be stiffer than the unretrofitted, but the increase in stiffness (10 - 20%) is much less dramatic than the increase in strength. The increment in lateral resistance ranged from 2-4 times the unretrofitted resistance. The use of epoxy resins can be advisable when a thorough study of the structural consequences of such an increment in strength in selected portions of the building shows that there is no danger of potential damage to other portions.

### 13.29. Slab-Column Connection Retrofits

In slab-column connections, punching shear failure due to the transfer of unbalanced moments is the most critical type of structural damage. The retrofitting of slab-column connections is beneficial for the prevention of punching shear failures and much research into retrofitting slab-column connections has been conducted and reported that adding concrete capitals or steel plates on both sides strength to self-weight ratio and do not corrode. But, it is imperative to be aware of the performance characteristics of various FRP systems under different circumstances to select a durable and suitable system for a particular application. It should be ensured that the FRP system selected for structural strengthening has undergone durability testing consistent with the application environment and structural testing in accordance with the anticipated service conditions. Suitably designed protective coatings may also be applied on an FRP system to protect it from exposure to adverse environmental conditions

### 13.30. Shotcrete:

Shotcrete (fig5) overlays are sprayed onto the surface of a masonry wall over a mesh of reinforcing bars. The thickness of the shotcrete can be adapted to the seismic demand. In general, the overlay thickness is at least 60 mm. In order to transfer the shear stress across shotcrete-masonry interface, shear dowels (6- 13 mm diameter @ 25-120 mm) are fixed using epoxy or cement grout into holes drilled into the masonry wall. Retrofitting using shotcrete significantly increases the ultimate load of the retrofitted walls. This retrofitting technique dissipates high-energy due to successive elongation and yield of reinforcement in tension.

FIGURE 5

## 13.31. **Recent Retrofitting Methods:**

There are many relatively new technologies developed for seismic Retrofitting which are based on "Response control". These techniques includes providing additional damping using dampers (Elastoplastic dampers, friction dampers, tuned mass and tuned liquid dampers, etc.) and techniques such as base isolation which are introduced to take care of seismic control. (i) Concrete Jacketing, (ii) Steel Jacketing, (iii) FRP Wrapping Reduce the demand/forces on the system (Seismic Response Control Design) (a)Elasto-Plastic Dampers, (b)Base Isolators, (c) Lead Extrusion Dampers, (d)Tuned Liquid Dampers, (e) Friction dampers.

### 13.31.1. **Elasto-Plastic Dampers**

The proposed retrofitting method achieves a high level of structural safety through dampers installed in an existing seismically vulnerable building more efficiently than conventional retrofitting methods. There are many ways of installing dampers in an existing building, including (1) installing steel-framed braces that incorporate dampers into an existing open frame and (2) installing damper-embedded studs into existing frame so that existing openings are maintained. The latter method can be used in cases where the building is to be strengthened internally. Dampers used in this retrofitting method are elasto-plastic steel dampers that have honeycomb openings. External cable method, bonding and jacketing method and overlaying and jacketing method has most often been limited to beams, columns, slabs and so on.

### 13.31.2. **Liquid Dampers (TLDs)**

TLDs are rigid walled containers filled with liquid up to certain height, to match the sloshing frequency and are placed at the rooftop of the structure.

### 13.31.3. **Base Isolators**

Base isolation (fig. 6) is generally suitable for low to medium rise buildings, usually up to 10-12 stories high, which have their fundamental frequencies in the range of expected dominant frequencies of earthquakes. Superstructure characteristics such as height, width, aspect ratio, and stiffness are important in determining the applicability and effectiveness of seismic isolation. The seismicity of the region and the underlying soil conditions should also be considered in the feasibility studies and design process. Constraint in the application of base isolation is the large relative displacements between the superstructure and the supporting ground at the isolation level. A clearance around the building must be provided and maintained through the life of the structure to accommodate the expected large displacements. Such displacements may be reduced with the incorporation of additional stiffness and energy dissipation mechanisms in the isolation system. Isolators have low horizontal stiffness and they are placed between the structure and foundation.

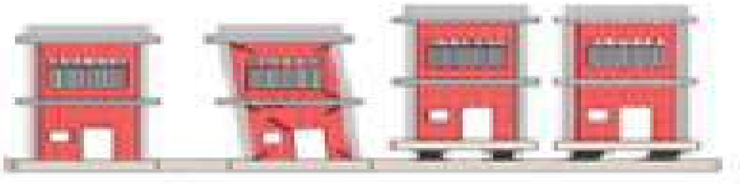


Figure 6

FIGURE SHOWING BASE ISOLATORS

## 13.32. **Non-Metallic Fiber Composites/Fibre Reinforced Composites (FRC)**

Commonly used forms of FRC viz. Pre cured CFRC (Carbon Fiber Reinforced Composite), Glass Fiber Reinforced polymer Composites (GFRC) rebar, glass fibre roll, etc. Fiber Reinforced Polymer (FRP) composites comprise fibers of high tensile strength within a polymer matrix such as vinyl ester or epoxy. FRP composites have emerged from being exotic materials used only in niche applications following the Second World War, to common engineering materials used in a diverse range of applications such as aircraft, helicopters, spacecraft, satellites, ships, submarines, automobiles, chemical processing equipment, sporting goods and civil infrastructure. The role of FRP for strengthening of existing or new reinforced concrete structures is growing at an extremely rapid pace owing mainly to the ease and speed of construction, and the possibility of application without disturbing the existing functionality of the structure. FRP composites have proved to be extremely useful for strengthening of RCC structures against both normal and seismic loads.

## 13.33.1. LIGHTENING PROTECTION SYSTEM.

Lightning is one of the common weather phenomena. At any instance the lightning strikes the earth around 100 times per second. As per the data by the Indian Institute of Tropical Meteorology (IITM), there were almost 41000 clouds to ground lightning strikes recorded all over India on 16 April -2019. Over the past decade, lightning strikes accounted for approximately 2000 deaths every year throughout India. These numbers are increasing day by day due to changes in atmospheric cycle of Earth resulted by Industrialization, Global warming etc.

The purpose of lightning protection system (LPS) is to protect buildings from direct lightning strikes and its consequence effects. For any building, special directives by National Building Code (NBC) must be implemented to protect building from direct lightning. As per IS 62305-Part 2, risk assessment study is to be done for the building and lightning protection level to be decided accordingly.

Risk assessment study considers the following criteria to decide the probability of occurrence of lightning on the building and its consequence effects:

- Type of Construction.
- Material / process vulnerable to fire.
- Degree of isolation of building from near by structures.
- Location of building (To decide lightning strike density - No. of thunderstorms /$KM^2$/ year).

IS 2309, 2010 defines acceptable limit for probable number of lightning strikes on building per year (P) is 01 in 10000. After completion of risk assessment study;

If $P>1$, LPS should be considered for building.

If $P<1$, implementation of LPS is not necessary.

For special case, if consequence effect of lightning is very negligible and slightly damage the building, it may be economical to not opt for protection and go for the risk.

During thunderstorms, high volume of energy is instantaneously released which acts not only as a potential threat to the structure but also more frequently, electronic equipments are damaged by surges caused by remote lightning discharges/caused because of lightning electromagnetic impulses (LEMPs) or switching operations in larger electrical systems. The international standard for lightning protection referred as IEC 62305 “protection against lightning” (which is also accepted by many countries as national standard) especially adopted by Bureau of India Standards as IS IEC 62305, in one of its part explains the need of planning, erection, testing and maintenance of lightning protection system for building structures without any height limit. The same is also implemented in new National Building Code-2016, part-08, Section 02 which also clearly defines the need of the measures to be taken care for planning, erection, testing and maintenance of lightning protection system (consisting of air terminal, down conductor, earthing) design is very important to ensure increased protection of building against lightning and its effect.

### 13.33.2. EFFECTIVE LIGHTNING PROTECTION MEASURES:

Proper measures are to be taken care of while designing, procuring and installing of lightning protection components for handling a strike and dissipation of current without any dangerous spark overs. For buildings surrounded by trees, or a taller metallic tower the protection measures should include not only lightning protection but also require ring earthing around the building and surge protection for the equipment since the fatality due to lighting could be more disastrous for an equipment than the structural damage. Periodic maintenance, monitoring and certification should be made mandatory for the effective functioning of the protective devices installed. For protection of electrical, wiring, electrical and electronic equipment, installation of surge protection devices should be adopted.

An effective lightning protection is achieved only if the following points are adhered to:

I. Type of protection.
II. Level of protection based on risk assessment.
III. Technically qualified product as per latest and relevant IEC standards.
IV. Sizes and dimensions of components.
V. Location of air terminal and coverage.
VI. Conductor routing and connections.
VII. Sufficient and required earthing provisions.
VIII. Proper utilization of natural components as down conductor if applicable.

### 13.33.3. STRUCTURAL AND ELECTRONIC EQUIPMENT VULNERABILITY TO LIGHTENING

South Asian Countries and many African and South American Countries are prone to lightning hazards. Global maps of lightning frequency, developed through NASA's optical transient detector (OTD) and through the lightning imaging sensor (LIS) reveal that the high lightning areas are all located in tropical land areas, especially in high elevation terrains while the polar areas have almost no lightning.

Lightning-fatality and characterization studies have highlighted the under reporting of lightning incidents in the media and have reiterated the difficulty in getting authentic figures. Lightning deaths are usually single events and only in very few cases does it affect a group of people, thus making it unattractive to the media. Lightning does not often find mention in accounts of extreme weather events in India and reporting of lightning deaths and injuries are haphazard.

The BIS as the National Standards Body of India in its code IS 2309: 1989 gives specifications to standardize the technical and engineering aspects of lightning conducting systems. The average number of thunderstorm days in a year in various places of India has been published by the BIS in its Code IS 2309:1989 (BIS 2007). The BIS data has been geographically plotted to generate lightning and thunderstorm vulnerability of major cities of India. The average number of thunder and lightning days for Srinagar is recorded as 54 which place it in high hazard areas. This makes lightning associated fatalities and losses a widespread disaster for Kashmir. Therefore, it is essential to install an effective high-tech lightning protection system that guarantees adequate protection and conducts the electrical discharge to the grounding system safely. In addition Govt. buildings and offices that have sensitive electronic devices that stores the administrative data, it is very important to use surge protectors that protect them from the over voltages caused by lightning current in the electrical network. Thus the installation of the state of the art Lightning Protection Systems are highly recommended for all Govt. structures for safety of life and Assets therein.

The gradual investment on such protection in existing buildings is worth to avoid the loss of data and economic damage caused to any Government office in case of such eventuality and should be an integral component of future buildings and infrastructure. The directions for keeping provision of Lightening Protection System in the DPRs for construction of new Government Infrastructure / Buildings as well as Installation of Lightening Protection System in existing Buildings, in terms of IS 2309:1989, National Buildings Code and other relevant Standards have also been communicated to the executing agencies in the Union Territory of Jammu & Kashmir.

## 14.0 ENERGY EFFICINECY IN BUILDINGS:

### 14.1 PREFACE:

A penny saved is a penny earned, they said. So is with joules of energy!!! With recent exponential increases in energy pricing, the formerly neglected or underestimated concept of energy conservation has swiftly assumed great significance and potential in cutting costs and promoting economic development, especially in a developing-country scenario.

Reckless and unrestrained urbanization, with its haphazard buildings, has bulldozed over the valuable natural resources of energy, water, and ground cover, thereby greatly hampering the critical process of eco-friendly habitat development. However, it is not too late to retrace the steps. The resource crunch confronting the energy supply sector can still be alleviated by designing and developing future buildings on the sound concepts of energy efficiency and sustainability.

Energy efficiency in buildings can be achieved through a multi-pronged approach involving adoption of bioclimatic architectural principles responsive to the climate of the particular location; use of materials with low embodied energy; reduction of transportation energy; incorporation of efficient structural design; implementation of energy-efficient building systems; and effective utilization of renewable energy sources to power the building.

### 14.2 INTRODUCTION:

Buildings, as they are designed and used today, contribute to serious environmental problems because of excessive consumption of energy and other natural resources. The close connection between energy use in buildings and environmental damage arises because energy-intensive solutions sought to construct a building and meet its demands for heating, cooling, ventilation, and lighting cause severe depletion of invaluable environmental resources.

However, buildings can be designed to meet the occupant's need for thermal and visual comfort at reduced levels of energy and resources consumption. Energy resource efficiency in new constructions can be affected by adopting an integrated approach to building design. The primary steps in this approach are listed below.

1. Incorporate solar passive techniques in a building design to minimize load on conventional systems (heating, cooling, ventilation, and lighting).

2. Design energy-efficient lighting and HVAC (heating, ventilation, and air-conditioning) systems.

3. Use renewable energy systems (solar photovoltaic systems or solar water heating systems) to meet a part of building load.

4. Use low energy materials and methods of construction and reduce transportation energy.

Thus, in brief, an energy-efficient building balances all aspects of energy use in a building – lighting, space-conditioning, and ventilation – by providing an optimized mix of passive solar design strategies, energy efficient equipment, and renewable sources of energy.

Use of materials with low embodied energy also forms a major component in energy efficient building designs. To function efficiently all aspects of the building design and equipment need to be matched carefully to the projected requirements. Because, in the past, the use of energy in buildings has not been particularly well regulated changes are now taking place which are beginning to specify the quality of the materials, the building orientation, the levels of insulation and efficiency of installed equipment to provide basic heating, cooling, ventilation and lighting. Similarly, the provision of both hot and cold water services must also be specified based on occupancy requirement and energy demands. Ventilation and temperature control must be such that air volumes are exchanged at certain rates to remove smell, moisture and other contaminants otherwise the atmosphere becomes foul, dangerous or condensation takes place. The absorption of moisture by internal building fabric, if the temperature falls below the certain temperature (dew point), will lead to the deposition of liquids which will promote the breakdown of internal surfaces and the growth of fungi. Such poor maintenance of the air in a building can result in the occurrence of so called 'sick building syndrome' which leads to people working within the property suffering from adverse health conditions.

## 14.3 ENERGY EFFICIENT BUILDINGS; NEED AND USEFULNESS:

A typical residence uses up to 40% more energy than it needs to operate economically. Commercial and industrial buildings also consume much more energy than they need to provide equivalent levels of comfort and functionality. Recent advances in design and cost-saving retrofits prove that existing buildings and new building design can unlock massive energy and cost savings while reducing carbon dioxide equivalent ($CO_2e$) emissions.

New buildings can be designed to use 1/3 to 1/2 less energy than they use today, with little to no increase in the cost of construction. There are also recent examples of "Net-zero" energy use in new construction. Net-zero buildings pair energy-efficient design with distributed onsite generation, such as photovoltaic panels to reduce energy use - and utility bills - to zero. The additional cost of energy-efficient design and construction is small with a payback period of less than 2 years and accompanied with a lifetime of savings.

## 14.4 THE ENVIRONMENTAL IMPACT:

Globally, buildings are responsible for between 30 and 40 percent of all primary energy use, Green house gas emissions, and waste generation. Because of these two realities— the large environmental footprint and the capability to significantly reduce emissions—buildings have emerged as a critical area for climate change mitigation and the move toward environmental sustainability.

When buildings are viewed as a whole, they are one of the world's largest users of energy and emitters of greenhouse gases. In the European Union, buildings use as much as 40–45 percent of all energy. They also use large amounts of raw materials and water and generate immense quantities of waste and pollution. The building sector consumes more electricity than any other sector worldwide. In the United States, buildings account for 39 percent of total energy use, 39 percent of $CO_2$ emissions, 68 percent of electricity use, and 12 percent of water use. These percentages include not only the energy used to operate the building, but also the stored or embodied energy it takes to produce the building materials (steel, glass, aluminum, and cement), building components (tile, glass, carpet), and the energy required to transport the materials to the building site. It is important to note that despite the intensity of building materials used in construction and the long distances traveled to the construction site, the largest percent of energy use by far, approximately 80–85 percent, occurs during the operational phase for heating, cooling, ventilation, lighting, water heating, and to run appliances.

## 14.5 DESIGN FEATURES OF ENERGY EFFICIENT BUILDINGS:

Commercial buildings are one of the major consumers of energy and are the third largest consumers of energy, after industry and agriculture. Buildings annually consume more than 20% of electricity used in India. The potential for energy savings is 40 – 50% in buildings, if energy efficiency measures are incorporated at the design stage. For existing buildings, the potential can be as high as 20-25% which can be achieved by implementing house keeping and retrofitting measures. The incremental cost incurred for achieving energy efficiency is 5-8% vis-à-vis conventional design cost and can have an attractive payback period of 2-4 years.

TYPICAL ENERGY CONSUMPTION PATTERN IN BUILDINGS:

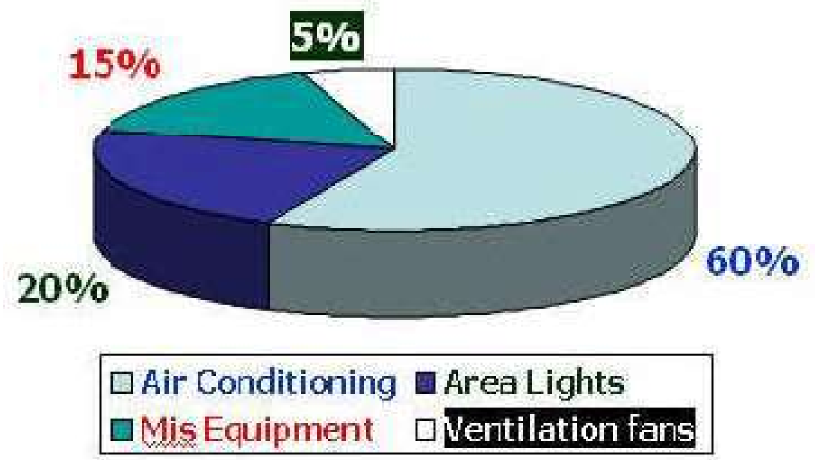



Figure: Break-up of energy consumption in a building

In a typical building, air conditioning is the highest consumer of energy followed by lighting and other miscellaneous equipment. Therefore, if the initial design considers energy efficiency measures in these areas, substantial energy savings can be realized.

## 14.6 TYPICAL ENERGY SAVING APPROACH IN BUILDINGS:

A. ORIENTATION:

This is the first step to achieve energy efficiency. The following measures can be adopted:

1. Minimize exposure on the south and west
2. Use simulation tools and techniques which can help in designing the orientation to minimize heat ingress and enhance energy efficiency.

B. BUILDING ENVELOPE:

Wipro Technologies, Gurgaon

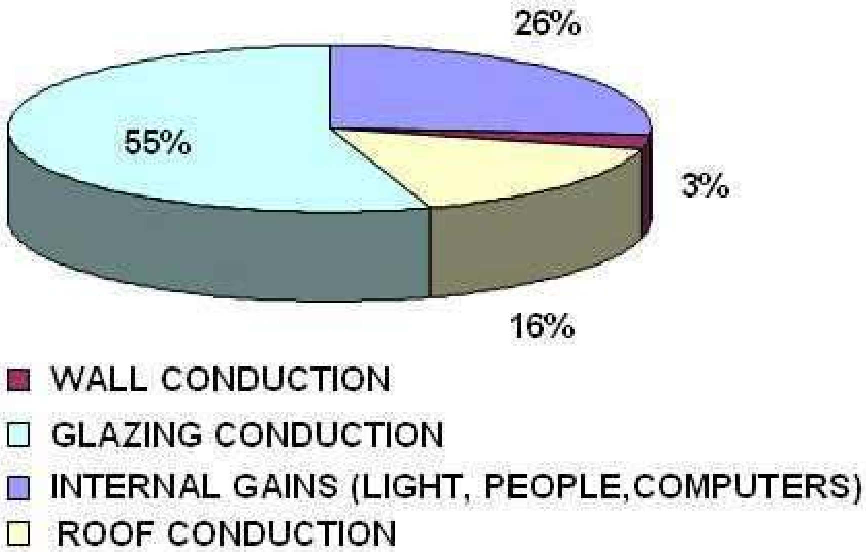
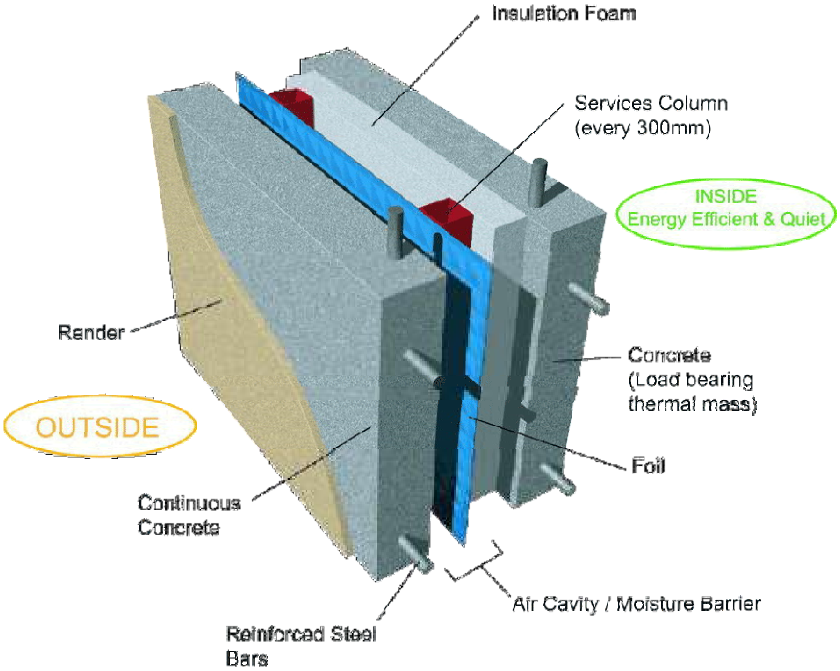



Figure: Typical break-up of heat gain in a building

The following envelope measures can be considered:

1. Select high performance glazing with low U-value, low Shading Coefficient and high VLT (Visual Light Transmittance).

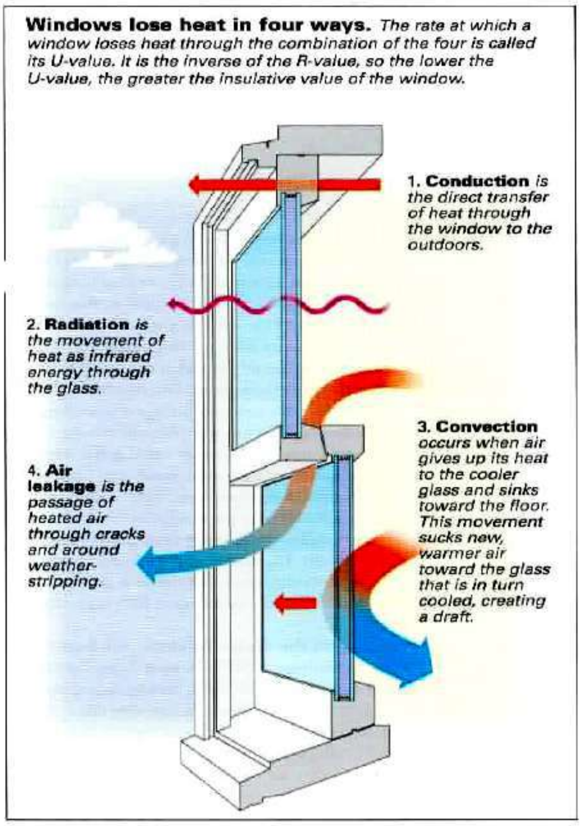
2. Insulate the wall. The options for insulation materials can be – Extruded polystyrene, Expanded polystyrene (thermocol), Glass wool etc.
3. Brick wall with air cavity can also significantly reduce the heat ingress.
4. Hollow blocks, Fly ash bricks and Autoclaved Aerated Concrete (AAC) Blocks are also good insulators.
5. The heat ingress through the roof can be as high as 12-15%. Insulating the roof can substantially reduce the heat ingress.
6. Consider shading devices for window openings.

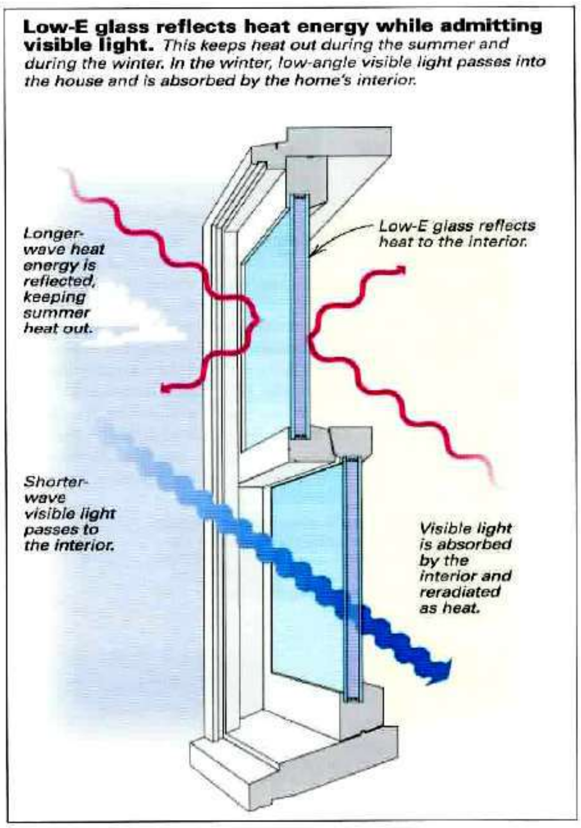



C. EQUIPMENT & SYSTEMS:
1. Select chillers with high Coefficient of Performance (CoP).
2. Install Variable Frequency Drives (VFD) for supply & return air fans and pumps.
3. Select high efficiency cooling towers.
4. Use high efficiency motors, transformers and pumps.
5. Install Heat recovery wheels and economizers
6. Consider night purging with ambient air to flush out the heat trapped within the building during the day
7. Adopt Controls & Building Management Systems for effective control
8. Engage a Commissioning Authority to ensure that savings are realized once the building becomes operational.

D. LIGHTING:
1. Design in such a way that the building gets maximum day lighting.
2. Overall lighting power density can be designed as less as 1.0 W/square feet.
3. Use daylight-cum-dimmer controls.

4. Install occupancy sensors.
5. Select energy efficient luminaires like CFL, T-5, LED, etc.

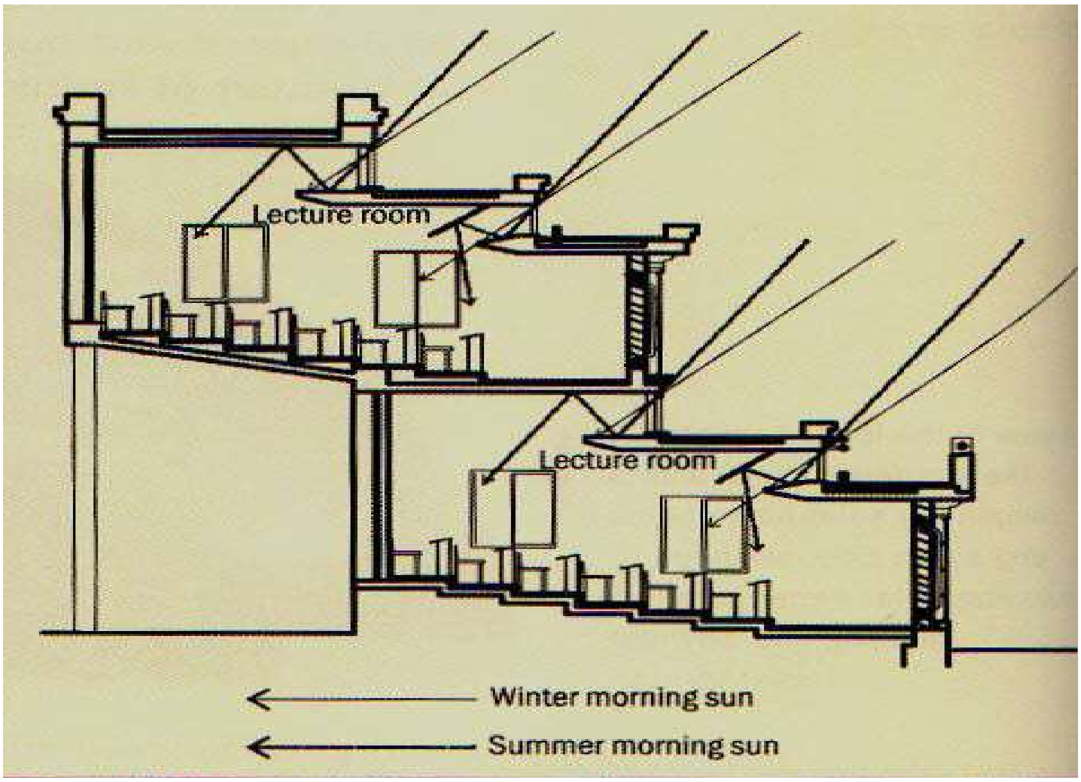



Few examples of buildings where such measures have been successfully implemented:

LEDEGS TRAINEES' HOSTEL, LEH:
PROJECT DETAILS:

Project description:
Hostel building for trainees in appropriate technology
Architect Sanjay Prakash.
Climate Cold and sunny
Consultants In-house
Project period 1994–1996
Size 300 m² covered area in a small campus
Client/Owner: LEDeG (Ladakh Ecological Development Group)
Builder/Contractor Owner-managed construction




DESIGN FEATURES:

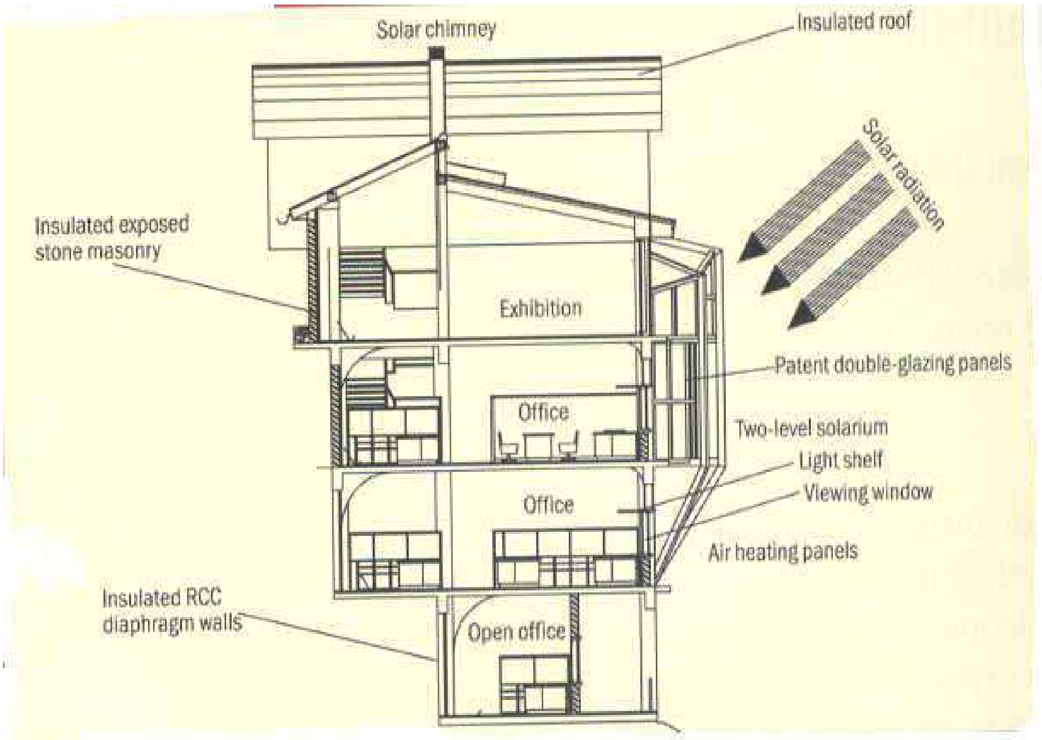
1. Traditional materials and methods of construction have been modified and adapted to achieve energy efficiency

2. Predominantly south exposure with no overhangs for maximum winter gains.
3. Entrance lobby designed as a solarium on the south side.
4. Bedrooms provided with various types of Trombe walls (half Trombe, unvented Trombe, and vented Trombe) or direct gain systems for passive heating.

HIMURJA OFFICE BUILDING, SHIMLA:

PROJECT DETAILS:
Location: Shimla, Himachal Pradesh
Building type: Office building
Climate: Cold and cloudy
Architects: Arvind Krishan and Kunal Jain
Owner/client: Himachal Pradesh Energy Development Agency (Himurja)
Year of completion :1997.
Built-up area 635 m².
Cost: The initial cost of the building was estimated at Rs 7 million (without incorporation of passive or active solar measures). Additional amount of Rs 1.3 million was incurred due to incorporation of passive and active solar measures. Thus there was an increase of 18.6% over initial cost by adoption of these measures. The high additional cost is attributed to the fact that solar systems were retrofitted onto an already constructed building.

DESIGN FEATURES:
1. Air heating panels designed as an integral part of the south wall provide effective heat gain. Distribution of heat gain in the building through a connective loop that utilizes the stairwell as a means of distributing heated air
2. Double-glazed windows with proper sealing to minimize infiltration n Insulated RCC diaphragm walls on the north to prevent heat loss
3. Solar chimney
4. Specially designed solarium on south for heat gain
5. Careful integration of windows and light shelves ensures effective daylight distribution
6. Solar water heating system and solar photovoltaic system


Solar chimney
Insulated roof
Solar radiation
Insulated exposed
stone masonry
Exhibition
Patent double-glazing panels
Office
Two-level solarium
Light shelf
Viewing window
Office
Air heating panels
Insulated RCC
diaphragm walls
Open office

## 14.7 ENERGY CONSERVATION BUILDING CODES:

To improve the energy efficiency in the new commercial buildings, the Energy Conservation Building Code (ECBC) was created. ECBC was launched by the Ministry of Power (MoP), Government of India, in May 2007, as the first step towards promoting energy efficiency in the commercial building sector. The Energy Conservation Building Code (ECBC) sets minimum energy standards for new commercial buildings having a connected load of 100 kW or contract demand of 120 kVA or more. The effective implementation of code provides comfort to occupants by adopting passive design strategies & day light Integration. It is technologically neutral, promotes renewable energy and also emphasizes on the life cycle cost of building. The updated code was launched in 2017, which had additional priorities of renewable energy integration, ease of compliance, inclusion of passive building design strategies and flexibility for the designers. The purpose of this code is to provide minimum requirements for the energy-efficient design and construction of buildings.

## 14.8 OBJECTIVE:

ECBC defines norms of energy performance for various building components, and takes into consideration the climatic region. The application of these norms lowers the building's energy requirement without affecting the function, comfort, health or productivity of the occupants.

BEE has launched a new version of code ECBC 2017 on 19th June 2017. The newly developed code is futuristic, pragmatic and easy to implement. The new version of Code is geared to encourage public and private sectors to not only meet the basic ECBC criteria, but to exceed them as well. Long-term success of the ECBC will depend heavily on the collaborative roles that various stakeholders would play towards the development, adoption and implementation of building code.

Commercial building sector in India is expanding rapidly at over 9% per year spurred largely by the strong growth in the services sector. It has been estimated that more than 50% of building stock that will exist in the year 2030 is yet to come up in the country – a situation that is fundamentally different from developed countries. Having regard to the fact that the rate of growth in the commercial building sector is amongst the highest and this sector needs to be moderated in its energy consumption, BEE introduced the Energy Conservation Building Code (ECBC) as a voluntary policy measure in 2007 to reduce the adverse impact of buildings on the environment.

ECBC 2017 is one of the first building energy codes to recognize beyond code performance. One of the major updates to the code is inclusion of incremental, voluntary energy efficiency performance levels. There are three levels of energy performance standards in the Energy Conservation Building Code (ECBC) i.e. ECBC, ECBC Plus, Super ECBC. In ascending order of efficiency, ECBC compliant building has approx. 25% savings, ECBC+ building approx. 35% savings and compliance with Super ECBC building will show energy savings by 50% or more as compared to conventional building.

## 14.9 TARGET BENEFICIARIES:

CPWD, Town and Country Planning, State PWDs, State Designated Agencies, UDD, Municipal corporations/ULBs, DISCOMs, Electrical Inspectorate, Architect, Engineers, Institutions/organizations, Builders, Developers. Accordingly, the provisions of ECBC 2017 and any amendments thereof and other relevant standards and guidelines shall be considered while framing DPRs for upcoming infrastructure like offices, hospitals, schools, etc., in the Union Territory of Jammu and Kashmir.

## ANNEXURE I: Format for Detailed Building Structural Audit

# DETAILED CHECKLIST FOR BUILDING STRUCTURAL EVALUATION PROTOCOL

[Document Format, DIQCD, Srinagar]

Note: Please make reference to Plate-No/Annexure-No, indicating a Drawing/Plate/Photo Manifestation, wherever such explicit reference has been deemed mandatory.

| | | |
|---|---|---|
| A | GENERAL | |
| 1 | Subject: | |
| 2 | Referral Reference No/Date: | |
| 3 | Type of Evaluation/Audit (Regular/Special) | |
| 4 | Date of Inspection/Evaluation | |
| 5 | Date of Reporting | |
| 6 | Validity time of Report | |
| 7 | Name of the Building Structure | |
| 8 | Site Address | |
| 9 | District | |
| 10 | Muncipal Ward/Ward Number | |
| 11 | Building Permission Competant Authority | |
| 12 | Location Coordinates (GPS) | |
| 13 | Whether Building is in use (fully/Partially) or idle | |
| 14 | Type of Building Ownership | |
| 15 | User/Proprietor Name (if owned) | |
| 16 | Name of the Building Consultant (Architectural/Structural) | |
| 17 | Name of the Building Contractor/Builder | |
| 18 | User Departments (If it's a Government Building) | |
| 19 | Any reported subjudice matter concerning the structure | |
| B | GENERAL BUILDING SITE CONDITIONS/TOPOGRAPHY/GEOLOGY/ENVIRONMENT | |
| a) | Low-lying/Lowland | |
| b) | Waterlogged/Swampy | |
| c) | Plain terrain | |
| d) | Upland location | |
| e) | River Side | |
| f) | Sub-mountainous | |
| g) | Sloping Terain | |
| h) | Lately Reported Calamity (Earthquake/Flood/Blast/Fire) | |
| i) | HFL with any history of lately flood submergence/details | |
| j) | Any Reported Seepage/Springs in proximity (In case of uplands) | |
| k) | Hazard Zone Classification/Rating of area as per BIS | |
| l) | Reported lately earthquake for magnitude Mw>6.0 in the area (Year) | |
| m) | Details of Environment of building and anticipated effects | |

| C | TECHNICAL OBSERVATION & VISUAL EVALUATION | |
|---|---|---|
| 1 | Building Statistics | |
| a) | Building Plan/Construction Approval/Project Conception (Date/year) | |
| b) | Year of Construction/ Completion (Age of Building) | |
| c) | Whether Building was completed in Stages/One-time (Reasons of Delay) | |
| d) | Functional/Occupational Classification of Building | |
| e) | Any details pertainig to previous Structural Audit (Authority Involved) | |
| f) | Overal Building Size (Length, Breadth. Height)/(Asymetrical) | |
| g) | Face Orientation (Facing North, East, West, South) | |
| h) | Availability of Architectural Plans | |
| i) | Availability of Structural Drawings/Design Calculations | |
| j) | Availability of As-Built drawings/need for preparing same | |
| k) | Availability of Site Plan/Key Plan | |
| l) | Closest Structure Proximity/Distance (Details on all sides N-E-W-S) | |
| m) | Open space around building (Details on all sides N-E-W-S) | |
| n) | Any reported failure or distress of adjoining building | |
| o) | Additional structure constructed along building and date of its construction | |
| p) | Any Extension of existing building | |
| q) | Whether drainage system of building is fully functional | |
| r) | Any rainwater harvesting being done/Location of Sump from foundation | |
| 2 | Number of Stories/Floors/Access-Exit method | |
| a) | Level Sequencing (Basment+Stilt+Gound+N-Floors+Attic/terrace) | |
| b) | No of Basment (if any) | |
| c) | No of Stilt floor (if any) | |
| d) | No of Stories/Floors | |
| e) | Type of Terrace Covering (open/roofed) | |
| f) | Whether planned/designed access provided to Roof/Terrace/Attic | |
| g) | Roofing Material (Steel Truss/Timber Truss) | |
| h) | Floor access/exit source (Stairs/Lifts/Escalators) with number | |
| i) | Any Fire/Emergency exit | |
| 3 | Building Classification (Load Bearing/Framed/Mixed) | |
| a) | Load Bearing | |
| b) | Framed | |
| c) | Mixed | |
| 4 | Mode of Construction (Structural Element Configuration) | Give Numbered Order ①②③④ etc. |
| a) | Foundation | |
| b) | Columns | |
| c) | Beams | |
| d) | Walls | |
| e) | Floors Slabs | |
| f) | Roof | |

| | | |
|---|---|---|
| 5 | History of repairs (If any) | |
| a) | Any Structural element repair/recasting | |
| b) | Any Non-Structural element repair/recasting | |
| c) | Any random tenantable repair | |
| d) | Any non-engineered addition/alteration | |
| e) | Any major plumbing repair/alteration | |
| f) | Any roof repair/alteration | |
| g) | Any major functional occupancy change | |
| h) | Any reported misuse/overloading | |
| i) | Any post flood major/minor repairs | |
| j) | Any other maintenance history | |
| 6 | INSPECTION OF MATERIAL | |
| a) | Material used in foundation | |
| b) | Material used in plinth | |
| c) | Material used in plinth-beam/Grade-beam | |
| d) | Material used within plinth, under flooring | |
| e) | Material used in walls/infills (Brick Masonary/Concrete Blocks/LWCB) | |
| f) | Material used in lintels | |
| g) | Material used Beams & Columns | |
| h) | Material used in floors/ceiling, like RCC/Steel or Timber | |
| i) | Previous material (Concrete/Steel/Timber) test reports (if any) | |
| 7 | External Condition of building (Details on all sides N-E-W-S) | |
| a) | External plaster condition (Cracks/distress/disintegeration if any) | |
| b) | External façade condition (Cracks/distress/disintegeration if any) | |
| c) | External Plumbing condition (leakage/dampnes if any) | |
| d) | Drain Line condition (leakage/dampness if any) | |
| e) | Any leakage in Washrooms/Toilets | |
| f) | Any leakage in Water Tanks/Overhead Tanks | |
| g) | Any other apparent specific material deterioration | |
| h) | Any reported or apparent post flood distress/damages (Outside) | |
| i) | Any reported or apparent post earthquake distress/damages (Outside) | |
| j) | Any compound wall failure/distress/disintegeration | |
| k) | Any damage/distress/failure of Chhajas/Parapet/Terrace-waterproofing | |
| 8 | INSPECTION OF FOUNDATION | |
| a) | Availability of Sub-Soil/Geotechnical Investigation Report | |
| b) | Conformity/Consistency of Sub-Structural drawing & detailing with respect to method of design used (Working Stress/Limit-State) | |
| c) | General idea of probable founding strata (Soft, hard, gravelly) | |
| d) | Ground Water Table (GWT) | |
| e) | Anticipated fluctuation in GWT | |
| f) | Proximate Land-use (Built-Up/Agricultural/Open) | |
| g) | Whether site/land is reclaimed (filled-up) or Natural | |
| h) | Surrounding Foundation Type of similar size structures | |

| | | |
|---|---|---|
| i) | Existing Foundation Details (If physical access has been made) | |
| j) | Type & Depth (shallow/deep) of foundation used | |
| k) | Any change made in execution with respect to drawings (if available) | |
| l) | Visual observation of exposed foundation/plinth/plinth-beam | |
| m) | Any signs of excessive foundation settlement/deflections/sagging | |
| n) | Any cracking pattern (Settlement Cracks/Surface micro-cracking) | |
| o) | Any signs of ground/silt floor sagging or uneven flooring gaps | |
| p) | Any cracks/gaps between columns-walls or joints at plinth-level | |
| q) | Any reported distress/cracks or water loss in Underground Tanks | |
| r) | Predominant distress/failure sign or pattern. | |
| 9 | INSPECTION OF SUPERSTRUCTURE | |
| a) | Conformity/Consistency of Super-Structural drawing & detailing with respect to method of design used (Working Stress/Limit-State) | |
| b) | Any remarkable cracks/distress/disintegeration during lately earthquake | |
| c) | Has building been designed for Earthquake induced forces | |
| d) | Applicable Earthquake Code Mandate of BIS, during Design/Construction | |
| e) | Present applicable Earthquake Code Mandate of BIS | |
| f) | Any change made in executing with respect to drawings (if available) | |
| g) | Any remarkable cracks/distress post floods, with HFL above Plint Level | |
| h) | Any reported unusual difficulty of Opening/Closing of Doors/Windows | |
| i) | Any exposure of Column, Beams or Slab Reinforcement. | |
| j) | Any Major Cracking/disintegeration/spalling/swelling in Column/Beams | |
| k) | Any sign of remarkable deflection in Beams | |
| l) | Condition of Staircase Area/Lift Walls | |
| m) | Any Unsual vegetative growth outside/inside building | |
| n) | Any exposed rusting/corrosion of reinforcement in any structural element | |
| o) | Any structural cracking/distress/settlement in infill-walls (External) | |
| p) | Any structural cracking/distress/settlement in infill-walls (Internal) | |
| q) | Leakages & Dampness in External Walls (Load Bearing) | |
| r) | Leakages & Dampness in Internal Walls (Load Bearing) | |
| s) | Any leakages/dampness on any floor-slab | |
| t) | Terrace water proofing condition | |
| u) | Any Electrical System induced distress/damage | |
| v) | Whether Lightening Arrestor/Protection is installed | |
| w) | Predominant distress/cracking/disintegeration/failure sign or pattern. | |
| D | DISTRESS MAPPING | |
| a) | Distress Mapping Plan Prepared (Indicate Annexure No.) | |
| b) | Photographs with Captions (Indicate Plate/Annexure No.) | |
| c) | Any Video Record/Evidence taken (Attach CD/SSD/Flash Drive) | |

| E | TESTING PROTOCOL EXECUTED FOR STRUCTURAL EVALUATION | | | |
|---|---|---|---|---|
| 1 | Non-Destructive Tests (NDT) | | | |
| a) | Rebound Hammer Test | | | |
| b) | Ultrasonic Pulse Wave Velocity Test | | | |
| c) | Carbonation Depth Test | | | |
| d) | Half Cell potential Test | | | |
| e) | Chemical Analysis (Chloride/Sulphates etc.) | | | |
| f) | Reinforcement detection/classification & Cover Meter Test | | | |
| g) | Concrete Permeability Test | | | |
| h) | Pile Integrity Test | | | |
| 2 | Destructuve or Semi-Destructive Tests | | | |
| a) | Core Extraction & Equivalent Compressive Strength Test | | | |
| b) | Cement Aggregate Ratio Test | | | |
| F | IMMEDIATE RECOMMENDED REPAIRS/RESTORATION (If Any) | | | |
| a) | Structural Repairs | | | |
| b) | Column jacketing/retrofiting | | | |
| c) | Beam jacketing/recasting/retrofiting | | | |
| d) | Slab recasting/retrofiting | | | |
| e) | RCC cover replacement/repair/retrofit | | | |
| f) | Plastering Repairs | | | |
| g) | Plumbing Repairs | | | |
| h) | Drainage Repairs | | | |
| i) | Waterproofing Repairs | | | |
| j) | Coloring Repair | | | |
| k) | Any Evacuation Protocol During Repairs (partial/full) | | | |
| l) | Any requirement of Proping during repairs. | | | |
| m) | Any Other | | | |
| n) | Recommended frequency of future audit/evaluation | | | |
| | Evaluation/Audit Team (DIQCD) | | | |
| G | Name of Evaluation Team Member with Signature | Designation | Department/Address | Contact/email-ID |
| 1 | | | | |
| 2 | | | | |
| Executing/Intending Departmental representatives (Names/Signatures) | | | | |
| 3 | | | | |
| 4 | | | | |

# REFERENCES

| S. No. | Code/ Document No. | TITLE |
|---|---|---|
| **1. IS CODES** | | |
| **1** | IS 269 : 1989 | 33 Grade Ordinary Portland Cement |
| **2** | IS: 383 | Specification for Coarse and Fine Aggregates. From Natural Sources For Concrete |
| **3** | IS:432 | Mild Steel and Medium Tensile Steel Bars and Hard-Drawn Steel Wire for Concrete Reinforcement |
| **4** | IS: 456 | Plain and Reinforced Concrete - Code of. Practice |
| **5** | IS: 516 | Method of Tests for Strength of Concrete |
| **6** | IS-1003(Part 1) | Timber Panelled and Glazed Shutters– Specification |
| **7** | IS:1077 | Common Burnt Clay Building Bricks -Specification |
| **8** | IS-1038:1983 | Specification for Steel Doors, Windows and Ventilators. |
| **9** | IS-1080:1986 | Code of Practice For Design And Construction Of Shallow Foundations |
| **10** | IS:1124 | Method of test for determination of water absorption, apparent specific gravity and porosity of natural building stones |
| **11** | IS-1597:1992 | Construction of Stone Masonry - Code of Practice |
| **12** | IS: 1786 | High strength deformed steel bars and wires for concrete reinforcement |
| **13** | IS 1893 ( Part 1):2016 | Criteria For Earthquake Resistant Design of Structures – Part 1: General Provisions and Buildings. |
| **14** | IS:1904 | Code of practice for design and construction of foundations in soils: General requirements |
| **15** | IS:2185 | Concrete masonry units |

| | | |
|---|---|---|
| **16** | IS-2191:1983 | Wooden Flush Door Shutters. |
| **17** | IS-2202 (Part 2):1983 | wooden flush door shutters (solid core type) |
| **18** | IS 2212:1991. | Code of practice for brickworks |
| **19** | IS 2250:1981 | Code of Practice for Preparation and Use of Masonry Mortars. |
| **20** | IS: 2386 | Methods of test for aggregates for concrete |
| **21** | IS:2572 | Construction of hollow and solid concrete block masonry |
| **22** | IS: 2770 | Methods of testing bond in reinforced concrete |
| **23** | IS:2911 | Code of Practice for Pile Foundation |
| **24** | IS:2950 | Code of practice for design and construction of raft foundations |
| **25** | IS:2974 | Code of practice for design and construction of machine foundations |
| **26** | IS -3696:1987, | Safety code of scaffolds and ladders |
| **27** | IS:3812 | Specification for Pulverized Fuel Ash |
| **28** | IS 4014:1967. | Code of practice for steel tubular scaffolding |
| **29** | IS-4021:1983. | Specification for Timber Doors, Windows and Ventilator Frames |
| **30** | IS:4032 | Method of chemical analysis of hydraulic cement |
| **31** | IS: 4078 | Code of practice for indexing and storage of drill cores |
| **32** | IS-4351:1976 | Indian Standard Steel Door Frames – Specification |
| **33** | IS:4464 | Code of practice for presentation of drilling information and core description in foundation investigation |

| | | |
|---|---|---|
| **34** | IS:4453 | Subsurface Exploration by Pits, Trenches, Drifts and Shafts |
| **35** | IS:4925-4926 | Concrete Batching and Mixing Plant<br>Code of Practice Ready-Mixed Concrete |
| **36** | IS-4962:1968. | Wooden side sliding doors |
| **37** | IS:5249 | Determination of dynamic properties of soil - Method of test |
| **38** | IS:5313 | Guide for Core Drilling Observations |
| **39** | IS 6198 :1992. | Ledged, braced and battened timber door shutters |
| **40** | IS:6403 | Code of practice for determination of bearing capacity of shallow foundations |
| **41** | IS: 6461 | Glossary of terms relating to cement concrete |
| **42** | IS:7292 | Code of practice for in-situ determination of rock properties by flat jack |
| **43** | IS: 7317 | Code of practice for uniaxial jacking test for deformation modulus of rock |
| **44** | IS:7764 | Code of practice for in-situ shear test on rock |
| **45** | IS:8009 | Code of practice for calculation of settlements of shallow & deep foundations |
| **46** | IS:8112 | Specification for 43 grade ordinary Portland cement |
| **47** | IS:9716 | Guide for lateral dynamic load test on piles |
| **48** | IS:10108 | Code of practice for sampling of soils by thin wall sampler with stationary piston |
| **49** | IS:10262 | Guidelines for concrete mix design proportioning |
| **50** | IS:12089 | Specification for granulated slag for the manufacture of Portland slag cement |
| **51** | IS:13094 | Selection of ground improvement techniques for foundation in weak soils -Guidelines |

| | | |
|---|---|---|
| **52** | IS 13311;1992 (part 1) | NDT Methods of test ultrasonic pulse velocity |
| **53** | IS 13311;1992 (part 2) | NDT Methods of test rebound hammer |
| **54** | IS 13920: 2016 | Ductile Design and Detailing of Reinforced Concrete Structures Subjected to Seismic Forces |
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