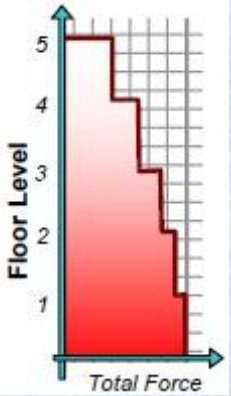
केवल कार्यालयीन उपयोग हेतु
For official use only

भारत सरकार – Government of India
रेल मंत्रालय – Ministry of Railways

भूकंपरोधी भवन निर्माण

CONSTRUCTION OF EARTHQUAKE RESISTANT BUILDING





केमटेक/2016/सि/ईआरबी/1.0
CAMTECH/2016/C/ERB/1.0
मार्च - 2016
March – 2016

अअमासंRDS
रेल अग्रदूत Transforming Railways
www.rdso.gov.in

An ISO 9001:2000 Certified Organisation
उच्च अनुरक्षण प्रौद्योगिकी केन्द्र
Excellence In Maintenance

Indian Railways
Centre for Advanced Maintenance Technology

महाराजपुर, ग्वालियर - 474005
Maharajpur, Gwalior – 474005
✆ : 0751 - 2470869 & Fax : 0751 - 2470841

भूकंपरोधी भवन निर्माण

CONSTRUCTION OF EARTHQUAKE RESISTANT BUILDING

प्राक्कथन

दुनिया के कई हिस्सों में हाल ही में आए भूकंपों ने इमारतों और जीवन को काफी नुकसान पहुंचाया है। भूकंप की दृष्टि से देखा जाए तो सबसे खतरनाक भवन निर्माण, unreinforced ईंट या concrete ब्लॉक का होता है। चार मंजिलों तक के अधिकांश घरों को प्रबलित कंक्रीट स्लैब के साथ burnt clay ईंट चिनाई से निर्मित किया जा रहा है। इसी तरह, कई नए चार या पांच मंजिला घर जो कि छोटे और बड़े शहरों में प्रबलित कंक्रीट फ्रेम से बनाए गए हैं, में एक उचित फ्रेम प्रणाली की कमी रहती है।

हाल ही में आए भूकंपों के कारण, भारत में इमारतों और घरों को कैसे सुरक्षित रखा जाये, इस पर प्रमुखता से चर्चा हुई है। भूकंपीय देशों में इंजीनियर्स को यह महत्वपूर्ण जिम्मेदारी सुनिश्चित करना है कि नए निर्माण भूकंपरोधी हों और यह भी कि उन्हें मौजूदा कमजोर संरचनाओं द्वारा उत्पन्न समस्या का समाधान भी निकालना है।

यह आशा की जाती है कि कैमटेक द्वारा तैयार पुस्तिका सिविल संरचनाओं के निर्माण एवं रखरखाव की गतिविधियों में लगे भारतीय रेलवे के इंजीनियरिंग कर्मियों के लिए काफी मददगार होगी।

केमटेक, ग्वालियर ***(ए. आर. तुपे)***

30 मार्च, 2016 ***कार्यकारी निदेशक***

FOREWORD

The recent earthquakes occurred in many parts of world has caused considerable damage to the buildings and lives. The most dangerous building construction, from an earthquake point of view, is unreinforced brick or concrete block. Most houses of upto four storeys are built of burnt clay brick masonry with reinforced concrete slabs. Similarly, many new four or five storey reinforced concrete frame building being constructed in small and large towns lack a proper frame system.

With the recent earthquakes, the discussion on how safe buildings and houses are in India has gained prominence. Engineers in seismic countries have the important responsibility to ensure that the new construction is earthquake resistant and also, they must solve the problem posed by existing weak structures.

It is expected that the handbook prepared by CAMTECH will be quite helpful to the engineering personnel of Indian Railways engaged in construction and maintenance activities of civil structures.

CAMTECH/Gwalior ***(A.R. Tupe)***
30 March, 2016 ***Executive Director***

भूमिका

योजना, डिजाइन, निर्माण और प्रबंधन के स्तर पर विभिन्न नई तकनीक में प्रगति के उपयोग से यह संभव हुआ है कि गंभीर परिणामों वाली बडी भूकंपीय आपदाओं से बचा जा सके।

*"**भूकंपरोधी भवन का निर्माण**"* पर यह पुस्तिका इस उद्देश्य से तैयार की गई है कि -

- नागरिक संरचनाओं के निर्माण और रखरखाव गतिविधियों में लगे भारतीय रेलवे के इंजीनियरों के लिए ज्ञान का प्रसार करने।
- उन्हें ऐसी संरचनाओं के व्यवहार से परिचित करवाना जो उच्च भूकंपीय जोन में load bearing तथा framed संरचनाओं के रूप में नियोजित तथा निर्मित की गई हैं।

यह पुस्तिका वैधानिक नहीं है तथा इसमें दी गई जानकारी का उद्देश्य केवल मार्गदर्शन है। किसी न किसी रूप में अधिकांश डेटा एवं जानकारी, उपलब्ध साहित्य तथा इंटरनेट खोज पर आधारित है। अधिक गहराई से जानकारी / ज्ञान के लिए, विषय पर उपलब्ध प्रासंगिक विस्तृत साहित्य, भारतीय मानक ब्यूरो संहिताओं, आदि को संदर्भ रूप में देखा जा सकता है।

इस पुस्तिका के आगे सुधार हेतु हमारे पाठकों से किसी भी सुझाव का हम स्वागत करते हैं।

केमटेक, ग्वालियर ***(डी. के. गुप्ता)***

23 मार्च, 2016 ***उप निदेशक/सिविल***

PREFACE

The use of various new technological advancements in planning, designing, and construction and management level has made it possible to avoid a great earthquake disaster with its severe consequences.

This handbook on ***'Construction of Earthquake Resistant Building'*** is prepared with the objective

- to disseminate the knowledge to the engineers of Indian Railways engaged in the construction and maintenance activities of civil structures.
- to get them familiar with the behavior of structure planned and constructed as load bearing and framed structure in high seismic zones.

This handbook is not statutory and contents are only for the purpose of knowledge dissemination. Most of the data & information in some form or the other are based on literature available and internet search. For more in-depth information / knowledge, the relevant detailed literature, BIS Codes, etc. available on the subject may be referred to.

We welcome any suggestions from our readers for further improvement of this handbook.

CAMTECH/Gwalior ***(D.K. Gupta)***
23 March, 2016 ***Dy. Director/Civil***

विषय-सूची / CONTENT

अध्याय/ CHAPTER	विवरण/ DESCRIPTION	पृष्ठ सं./ PAGE NO.
	प्राक्कथन / *PREFACE*	*(i)*
	भूमिका / *PREFACE*	*(ii)*
	विषय-सूची / *CONTENT*	*(iii)*
	संशोधन पर्चियां / *CORRECTION SLIPS*	*(iv)*
1	परिचय / Introduction	1
2	भूकंप के बारे में / About Earthquake	2
2.1	भूकंप / Earthquake	2
2.2	किन कारणों से होता है भूकंप / What causes Earthquake	2
2.3	भूकंप और दोष के प्रकार / Types of Earthquakes and Faults	4
2.4	जमीन कैसे हिलती है / How the Ground shakes	4
2.5	भूकंप का मापन / Measurement of Earthquake	5
3	भूकंप इंजीनियरिंग के लिए शब्दावली / Terminology for Earthquake Engineering	7
4	भूकंपी जोन और भूकंपी गुणांकों / Seismic Zone and Seismic Coefficients	10
5	भवन में भूकंप प्रतिरोध में सुधार के लिए सामान्य सिद्धांत / General Principle for improving Earthquake Resistance in Building	14
5.1	हल्कापन / Lightness	14
5.2	निर्माण की निरंतरता / Continuity of Construction	14
5.3	प्रोजेक्टिंग एवं सस्पेंडेड पार्ट्स / Projecting and Suspended Parts	14
5.4	भवन की आकृति / Shape of Building	14
5.5	विभिन्न दिशाओं में शक्ति / Strength in Various Directions	15
5.6	नींव / Foundations	15
5.7	छतें एवं मंजिलें / Roofs and Floors	15
5.8	सीढ़ियां / Staircases	16
5.9	बॉक्स प्रकार निर्माण / Box Type Construction	17
5.10	अग्नि सुरक्षा / Fire Safety	17
6	अल्प सामर्थ्य चिनाई संरचनाओं के निर्माण / Construction of Low Strength Masonry Structures	18
6.1	भूकंप के दौरान ईंट चिनाई की दीवारों का व्यवहार / Behaviour of Brick Masonry Walls during Earthquakes	18
6.2	भूकंपरोधी ईंट चिनाई भवन के निर्माण हेतु सामान्य सिद्धांत / General Principles for Construction of Earthquake Resistant	20

	Brick Masonry Building	
6.3	**भूकंपी सुदृढ़ीकरण व्यवस्था/ Seismic Strengthening Arrangements**	**24**
6.4	**क्षैतिज बैंड की भूमिका / Role of Horizontal Bands**	**27**
6.5	**अधोलंब सुदृढीकरण / Vertical Reinforcement**	**28**
6.6	**भूकंप के दौरान स्टोन चिनाई की दीवारों का व्यवहार / Behaviour of Stone Masonry Walls during Earthquakes**	**30**
6.7	**भूकंपरोधी स्टोन चिनाई भवन के निर्माण हेतु सामान्य सिद्धांत / General Principles for Construction of Earthquake Resistant Stone Masonry Building**	**31**
7	**ढाँचागत संरचना का निर्माण / Construction of Framed Structure**	**33**
7.1	**प्रबलित कंक्रीट इमारतों पर क्षैतिज भूकंप का प्रभाव / Effect of Horizontal Earthquakes on Reinforced Concrete Buildings**	**33**
7.2	**बीम जिन्हें आर सी इमारतों में भूकंप बलों का विरोध करने के लिए डाला जाता है / Beams that are required to resist Earthquake Forces in RC Buildings**	**35**
7.3	**कॉलम जिन्हें आरसी इमारतों में भूकंप बलों का विरोध करने के लिए डाला जाता है / Columns that are required to resist Earthquake Forces in RC Buildings**	**36**
7.4	**बीम-कॉलम जोड़ जो आरसी इमारतों में भूकंप बलों का विरोध करते हैं / Beam-Column Joints that resist Earthquakes Forces in RC Buildings**	**37**
7.5	**ओपन-ग्राउंड मंजिला इमारत जो कि भूकंप में कमजोर होती है / Open-Ground Storey Building that is vulnerable in Earthquake**	**39**
7.6	**भूकंप के दौरान लघु कॉलम वाली इमारतों का व्यवहार / Behavior of Buildings with Short Columns during Earthquakes**	**41**
7.7	**विशेषतः भूकंपीय क्षेत्र में कतरनी दीवारों वाली इमारतों का निर्माण / Construction of Buildings with Shear Walls preferably in Seismic Regions**	**42**
7.8	**हानिकारक भूकंप प्रभाव से इमारतों का संरक्षण / Protection of Buildings from Damaging Earthquake Effects**	**43**
7.9	**भूकंपरोधी इमारतों की लचीलापन आवश्यकताएँ / Ductility Requirements of Earthquake Resistant Buildings**	**44**
7.10	**झुकने एवं अक्षीय भार के अधीन कॉलम और फ्रेम मेम्बर / Columns and Frame Members subjected to Bending and Axial Load**	**45**
7.11	**अनुप्रस्थ सुदृढीकरण / Transverse Reinforcement**	**46**
7.12	**विशेष सीमित सुदृढीकरण / Special Confining Reinforcement**	**46**
7.13	**फ्लेक्स्चरल मेम्बर्स / Flexural Members**	**47**
7.14	**अनुदैर्ध्य सुदृढीकरण / Longitudinal Reinforcement**	**48**
7.15	**अनुदैर्ध्य सुदृढीकरण की स्प्लाइसिंग / Splicing of Longitudinal Reinforcement**	**48**

7.16	**वेब सुदृढीकरण / Web Reinforcement**	**49**
8	**भारतीय भूकंपी संहिताएँ / Indian Seismic Codes**	**50**
8.1	**भूकंपी डिजाइन कोड का महत्व / Importance of Seismic Design Codes**	**50**
8.2	**भारतीय भूकंपी संहिताएँ / Indian Seismic Codes**	**50**
	संदर्भ / REFERENCES	**53**
	टिप्पणी / NOTES	**54**
	गुणवत्ता नीति एवं डिस्क्लेमर / QUALITY POLICY AND DISCLAIMER	**55**

***

संशोधन पर्चियों का प्रकाशन
ISSUE OF CORRECTION SLIPS

इस हस्तपुस्तिका के लिए भविष्य में प्रकाशित होने वाली संशोधन पर्चियों को निम्नानुसार संख्यांकित किया जाएगा :

The correction slips to be issued in future for this handbook will be numbered as follows:

केमटेक/2016/सि/ईआरबी/1.0/सीएस#XX दिनांक_____

CAMTECH/2016/C/ERB/1.0/CS # XX date_____

जहाँ xx संबन्धित संशोधन पर्ची की क्रम संख्या है (01 से प्रारम्भ होकर आगे की ओर)

Where "XX" is the serial number of the concerned correction slip (starting from 01 onwards).

प्रकाशित संशोधन पर्चियाँ
CORRECTION SLIPS ISSUED

क्र.सं./ Sr. No.	**प्रकाशन दिनांक/ Date of issue**	**संशोधित पृष्ठ संख्या तथा मद संख्या/ Page no. and Item No. modified**	**टिप्पणी/ Remarks**

अध्याय / Chapter – 1

परिचय / Introduction

To avoid a great earthquake disaster with its severe consequences, special consideration must be given. Engineers in seismic countries have the important responsibility to ensure that the new construction is earthquake resistant and also, they must solve the problem posed by existing weak structures.

Most of the loss of life in past earthquakes has occurred due to the collapse of buildings, constructed with traditional materials like stone, brick, adobe (kachcha house) and wood, which were not particularly engineered to be earthquake resistant. In view of the continued use of such buildings, it is essential to introduce earthquake resistance features in their construction.

The problem of earthquake engineering can be divided into two parts, first to design new structures to perform satisfactorily during an earthquake and second to retrofit existing structures so as to reduce the loss of life during an earthquake. Every city in the world has a significant proportion of existing unsafe buildings which will produce a disaster in the event of a strong ground shaking. Engineers have the responsibility to develop appropriate methods of retrofit which can be applied when the occasion arises.

The design of new building to withstand ground shaking is prime responsibility of engineers and much progress has been made during the past 40 years. Many advances have been made such as the design of ductile reinforced concrete members. Methods of base isolation and methods of increasing the damping in structures are now being utilized for important buildings, both new and existing. Improvements in seismic design are continuing to be made such as permitting safe inelastic deformations in the event of very strong ground shaking.

A problem that the engineer must share with the seismologist/geologist is that of the future occurrence of earthquake; when, where, and how big.

Earthquake resistant construction requires seismic considerations at all stages; from architectural planning to structural design to actual constructions and quality control.

Problems pertaining to Earthquake engineering in a seismic country cannot be solved in a short time, so engineers must be prepared to continue working to improve public safety during earthquake. In time, they must control the performance of structures so that an earthquake is a nuisance rather than a danger.

To ensure seismic resistant construction, earthquake engineering knowledge needs to spread to a broad spectrum of professional engineers within the country, rather than confining it to a few organizations or individuals as if it were a super-speciality.

***

अध्याय / Chapter – 2

भूकंप के बारे में / About Earthquake

2.1 भूकंप / Earthquake

- Vibrations of earth's surface caused by waves coming from a source of disturbance inside the earth are described as earthquakes.
- Earthquake is a natural phenomenon occurring with all uncertainties.
- During the earthquake, ground motions occur in a random fashion, both horizontally and vertically, in all directions radiating from epicentre.
- These cause structures to vibrate and induce inertia forces on them.

2.2 किन कारणों से होता है भूकंप / What causes Earthquake

Earthquakes may be caused by

- Tectonic activity
- Volcanic activity
- Land-slides and rock-falls
- Rock bursting in a mine
- Nuclear explosions

As engineers we are interested in earthquakes that are large enough and close enough (to the structure) to cause concern for structural safety- such earthquakes are usually caused by tectonic activity i.e. activity pertaining to geological formation of the bedrock in the earth's crust characterized by structural features, such as dislocation, distortion, faults, folding, thrusts, volcanoes directly involved in the earth movement.

Earth (Fig. 1) consists of following segments –

- solid inner core (radius ~1290*km*) that consists of heavy metals (*e.g.*, nickel and iron)
- liquid outer core (thickness ~2200*km*)
- stiffer mantle (thickness ~2900*km*) that has ability to flow and
- crust (thickness ~5 to 40*km*) that consists of light materials (*e.g.*, basalts and granites)

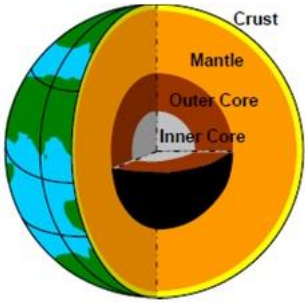
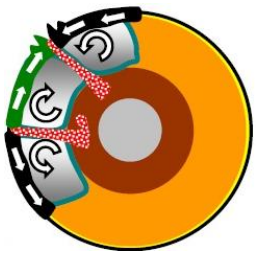


Fig. 1 Inside the Earth

At the Core, the temperature is estimated to be ~2500°*C*, the pressure ~4 million *atmospheres* and density ~13.5 *gm/cc*; this is in contrast to ~25°*C*, 1 *atmosphere* and 1.5 *gm/cc* on the surface of the Earth.

Due to prevailing high temperature and pressure gradients between the Crust and the Core, the local convective currents in mantle (Fig. 2) are developed. These convection currents result in a *circulation*


Fig. 2 Local Convective Currents in Mantle

of the earth's mass; hot molten lava comes out and the cold rock mass goes into the Earth. The mass absorbed eventually melts under high temperature and pressure and becomes a part of the Mantle, only to come out again from another location.

Tectonic Plates: The convective flows of Mantle material cause the Crust and some portion of the Mantle, to slide on the hot molten outer core. This sliding of Earth's mass takes place in pieces called *Tectonic Plates*.

Convergent boundary: Sometimes, the plate in the front is slower. Then, the plate behind it comes and collides (and *mountains* are formed). This type of inter-plate interaction is the *convergent* boundary (Fig. 3).

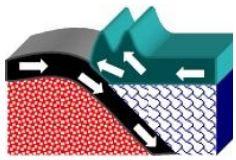


Fig. 3 Convergent Boundarv

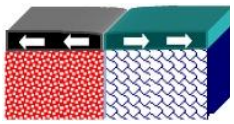


Fig. 4 Divergent Boundary

Divergent boundary: Sometimes, two plates move away from one another (and *rifts* are created). This type of inter-plate interaction is the divergent boundary (Fig. 4).

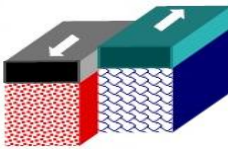


Fig. 5 Transform Boundary

Transform boundary: Sometimes, two plates move side-by-side, along the same direction or in opposite directions. This type of inter-plate interaction is the transform boundary (Fig. 5).

Fault and Slip:

- When the rocky material along the interface of the plates in the Earth's Crust reaches its strength, it fractures and a sudden movement takes place there.
- The interface between the plates where the movement has taken place (called the *fault*) suddenly *slips* and releases the large elastic strain energy stored in the rocks at the interface (Fig. 6).
- **The sudden slip at the fault causes the earthquake**. A violent shaking of the Earth during which large elastic strain energy released spreads out in the form of seismic waves that travel through the body and along the surface of the Earth.
- After the earthquake is over, the process of strain build-up at this modified interface between the tectonic plates starts all over again. This theory is known as the *Elastic Rebound Theorym* (Fig. 7).

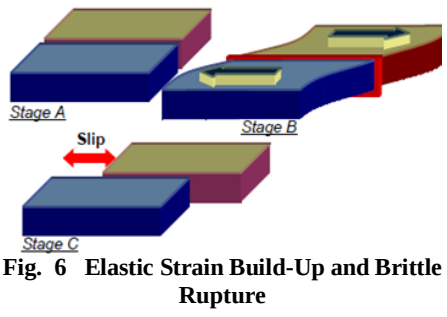


Fig. 6 Elastic Strain Build-Up and Brittle Rupture

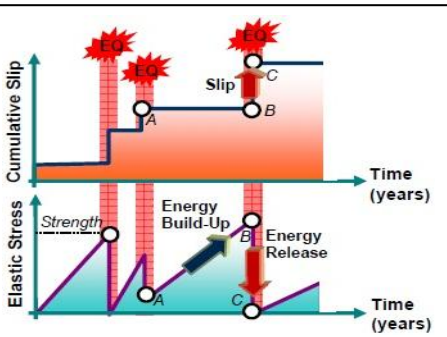


Fig. 7 Elastic Rebound Theory

2.3 भूकंप और दोष के प्रकार / Types of Earthquakes and Faults

Inter-plate Earthquakes: Most earthquakes occurring along the boundaries of the tectonic plates are called Inter-plate Earthquakes, (*e.g.*, 1897 Assam (India) earthquake).

Intra-plate Earthquakes: Numbers of earthquakes occurring within the plate itself but away from the plate boundaries are called Intra-plate Earthquakes, (*e.g.*, 1993 Latur (India) earthquake).

Note: *In both types of earthquakes, the slip generated at the fault during earthquakes is along both vertical and horizontal directions (called Dip Slip) and lateral directions (called Strike Slip), with one of them dominating sometimes* (Fig. 8).

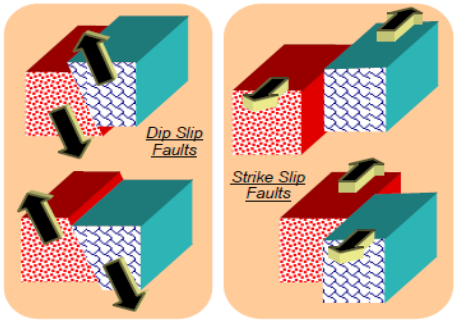


Fig. 8 Type of Faults

2.4 जमीन कैसे हिलती है / How the Ground shakes

Seismic waves: Large strain energy released during an earthquake travels as seismic waves in all directions through the Earth's layers, reflecting and refracting at each interface (Fig. 9). There are of two types of waves (Fig. 10) –

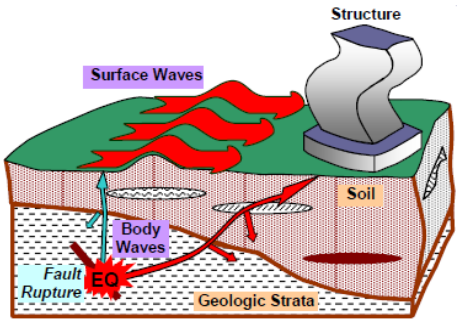


Fig. 9 Arrival of Seismic Waves at a Site

1) Body Waves
2) Surface Waves

Body Waves: They consist of

- *Primary Waves (P-waves):* Under P-waves, material particles undergo extensional and compressional strains along direction of energy transmission.

- *Secondary Waves (S-waves):* Under S-waves, material particles oscillate at right angles to direction of energy transmission.

Surface Waves: They consist of

- *Love Waves:* To the direction of energy transmission, these waves cause surface motions similar to that by S-waves, but with no vertical component

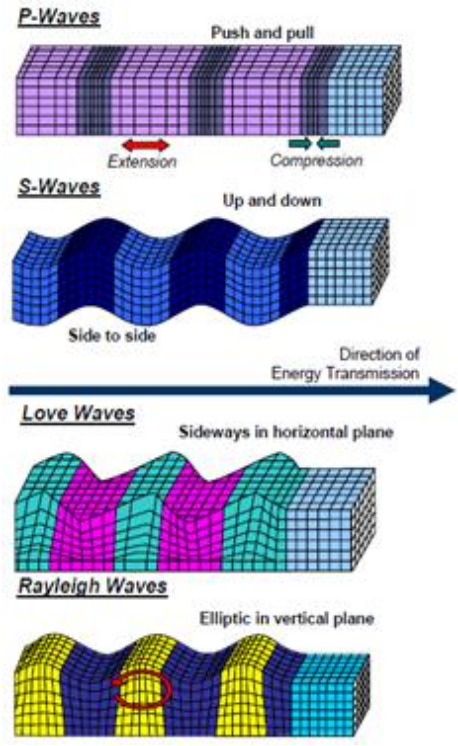


Fig. 10 Motions caused by Body and Surface Waves

- *Rayleigh Waves:* These waves make a material particle oscillate in an elliptic path in the vertical plane with horizontal motion along direction of energy transmission.

Note: *P-waves are fastest, followed in sequence by S-, Love and Rayleigh waves.*

2.5 भूकंप का मापन / Measurement of Earthquake

2.5.1 मापन उपकरण / Measuring instruments

- **Seismograph:** The instrument that measures earthquake shaking is known as a seismograph (Fig. 11). It has three components –
  - **Sensor –** It consists of pendulum mass, string, magnet and support.
  - **Recorder –** It consists of drum, pen and chart paper.
  - **Timer –** It consists of the motor that rotates the drum at constant speed.

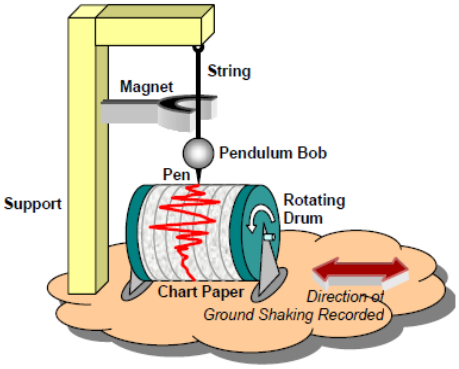


Fig. 11 Schematic of Early Seismograph

- **Seismoscopes:** Some instruments that do not have a timer device provide only the maximum extent (or scope) of motion during the earthquake.

- **Digital instruments:** The digital instruments using modern computer technology records the ground motion on the memory of the microprocessor that is in-built in the instrument.

Note: *The analogue instruments have evolved over time, but today, digital instruments are more commonly used.*

2.5.2 मापन के स्केल / Scale of Measurement

The Richter Magnitude Scale (also called Richter scale) assigns a magnitude number to quantify the energy released by an earthquake. Richter scale is a base 10 logarithmic scale, which defines magnitude as the logarithm of the ratio of the amplitude of the seismic wave to an arbitrary minor amplitude.

The magnitude M of an Earthquake is defined as

$$M = \log_{10} A - \log_{10} A_0$$

Where,

A = Recorded trace amplitude for that earthquake at a given distance as written by a standard type of instrument (say Wood Anderson instrument).

A_0 = Same as A, but for a particular earthquake selected as standard.

This number M is thus independent of distance between the epicentre and the station and is a characterstic of the earthquake. The standard shock has been defined such that it is low enough to make the magnitude of most of the recorded earthquakes positive and is assigned a magnitude of zero. Thus, if $A = A_0$,

$$M = \log_{10} A_0 - \log_{10} A_0 = 0$$

Zero magnitude does not mean that there is no earthquake. In fact, magnitude of an earthquake can be a negative number also. A standard shock of magnitude zero is defined as one that records peak amplitude of one thousandths of a millimetre at a distance of 100 km from the epicentre. Thus, an earthquake that records peak amplitude of 1 mm on a standard seismograph at 100 km will have its magnitude as

$$M = \log_{10} (1) - \log_{10} (10^{-3}) = 0 - (-3) = 3$$

Thus, magnitude of a local earthquake is defined as the logarithm to base 10 of the maximum seismic wave amplitude (in thousandths of a mm) recorded on Wood Anderson seismograph at a distance of 100 kms from the earthquake epicentre.

***

अध्याय / Chapter – 3

भूकंप इंजीनियरिंग के लिए शब्दावली / Terminology for Earthquake Engineering

3.1 फोकस या हाइपोसेंटर / Focus or Hypocenter

In an earthquake the waves emanate from a finite area of rocks. However, the point from which the waves first emanate or where the fault movement starts is called the earthquake focus or hypocenter.

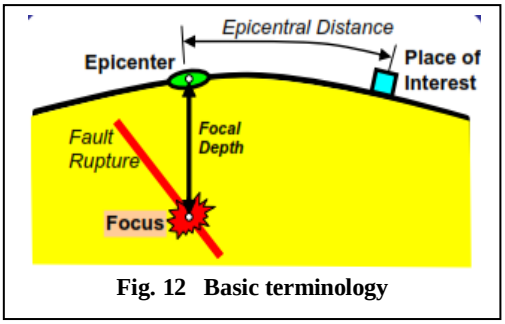


Fig. 12 Basic terminology

3.2 इपीसेंटर / Epicentre

The point on the ground surface just above the focus is called the epicentre.

3.3 सतही फोकस भूकंप / Shallow Focus Earthquake

Shallow focus earthquake occurs where the focus is less than 70 km deep from ground surface.

3.4 इंटरमीडिएट फोकस भूकंप / Intermediate Focus Earthquake

Intermediate focus earthquake occurs where the focus is between 70 km to 300 km deep.

3.5 गहरा फोकस भूकंप / Deep Focus Earthquake

Deep focus earthquake occurs where the depth of focus is more than 300 km.

3.6 इपीसेंटर दूरी / Epicentre Distance

Distance between epicentre and recording station in km or in degrees is called epicentre distance.

3.7 पूर्व के झटके / Foreshocks

Fore shocks are smaller earthquakes that precede the main earthquake.

3.8 बाद के झटके / Aftershocks

Aftershocks are smaller earthquakes that follow the main earthquake.

3.9 परिमाण / Magnitude

The magnitude of earthquake is a number, which is a measure of energy released in an earthquake. It is defined as logarithm to the base 10 of the maximum trace amplitude, expressed in microns, which the standard short-period torsion seismometer (with a period of 0.8s,

magnification 2800 and damping nearly critical) would register due to the earthquake at an epicentral distance of 100 km.

3.10 तीव्रता / Intensity

The intensity of an earthquake at a place is a measure of the strength of shaking during the earthquake, and is indicated by a number according to the modified Mercalli Scale or M.S.K. Scale of seismic intensities.

3.11 परिमाण और तीव्रता के बीच बुनियादी फर्क / Basic difference between Magnitude and Intensity

Magnitude of an earthquake is a measure of its size, whereas intensity is an indicator of the severity of shaking generated at a given location. Clearly, the severity of shaking is much higher near the epicenter than farther away.

This can be elaborated by considering the analogy of an electric bulb. Here, the size of the bulb (*100-Watt*) is like the magnitude of an earthquake (M), and the illumination (measured in *lumens*) at a location like the intensity of shaking at that location (Fig. 13).

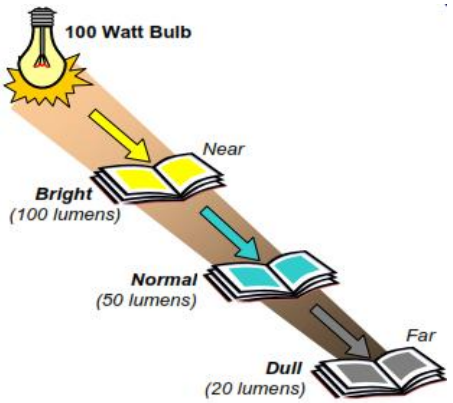


Fig. 13 Reducing illumination with distance from an electric bulb

3.12 द्रवण / Liquefaction

Liquefaction is a state in saturated cohesion-less soil wherein the effective shear strength is reduced to negligible value for all engineering purpose due to pore pressure caused by vibrations during an earthquake when they approach the total confining pressure. In this condition, the soil tends to behave like a fluid mass.

3.13 विवर्तनिक लक्षण / Tectonic Feature

The nature of geological formation of the bedrock in the earth's crust revealing regions characterized by structural features, such as dislocation, distortion, faults, folding, thrusts, volcanoes with their age of formation, which are directly involved in the earth movement or quake resulting in the above consequences.

3.14 भूकंपी द्रव्यमान / Seismic Mass

It is the seismic weight divided by acceleration due to gravity.

3.15 भूकंपी भार / Seismic Weight

It is the total dead load plus appropriate amounts of specified imposed load.

3.16 आधार / Base

It is the level at which inertia forces generated in the structure are transferred to the foundation, which then transfers these forces to the ground.

3.17 द्रव्यमान केंद्र / Centre of Mass

The point, through which the resultant of the masses of a system acts, is called Centre of Mass. This point corresponds to the centre of gravity of masses of system.

3.18 कठोरता का केंद्र / Centre of Stiffness

The point, through which the resultant of the restoring forces of a system acts, is called Centre of stiffness.

3.19 बॉक्स प्रणाली / Box System

Box is a bearing wall structure without a space frame, where the horizontal forces are resisted by the walls acting as shear walls.

3.20 पट्टा / Band

A reinforced concrete, reinforced brick or wooden runner provided horizontally in the walls to tie them together, and to impart horizontal bending strength in them.

3.21 लचीलापन / Ductility

Ductility of a structure, or its members, is the capacity to undergo large inelastic deformations without significant loss of strength or stiffness.

3.22 कतरनी दीवार / Shear Wall

Shear wall is a wall that is primarily designed to resist lateral forces in its own plane.

***

अध्याय / Chapter – 4

भूकंपी जोन और भूकंपी गुणांकों / Seismic Zone and Seismic Coefficients

Due to convective flow of mantle material, crust of Earth and some portion of mantle slide on hot molten outer core. This sliding of Earth's mass takes place in pieces called Tectonic Plates. The surface of the Earth consists of seven major tectonic plates (Fig. 14).

They are

1. Eurasian Plate
2. Indo-Australian Plate
3. Pacific Plate
4. North American Plate
5. South American Plate
6. African Plate
7. Antarctic Plate

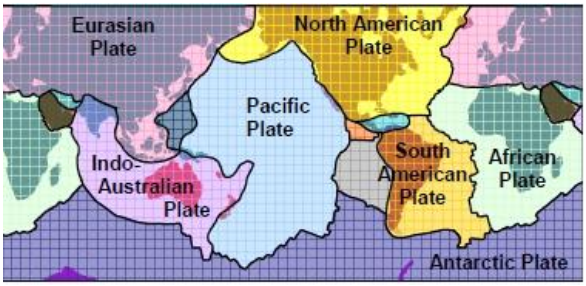


Fig. 14 Reducing illumination with distance from an electric bulb

India lies at the northwestern end of the Indo Australian Plate (Fig. 15). This Plate is colliding against the huge Eurasian Plate and going under the Eurasian Plate.

Three chief tectonic sub-regions of India are

- the mighty Himalayas along the north,
- the plains of the Ganges and other rivers, and
- the peninsula

Most earthquakes occur along the Himalayan plate boundary (these are inter-plate earthquakes), but a number of earthquakes have also occurred in the peninsular region (these are intra-plate earthquakes).

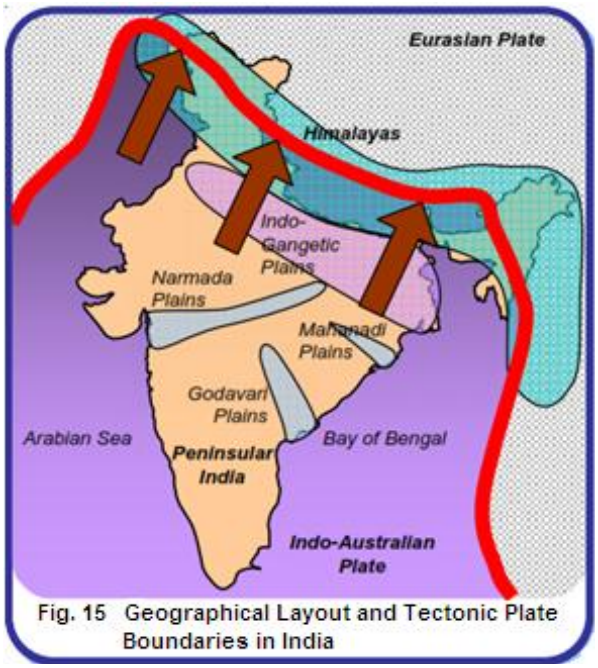


Fig. 15 Geographical Layout and Tectonic Plate Boundaries in India

For the purpose of determining seismic forces, the country is classified into four seismic zones as shown in Fig. 16.

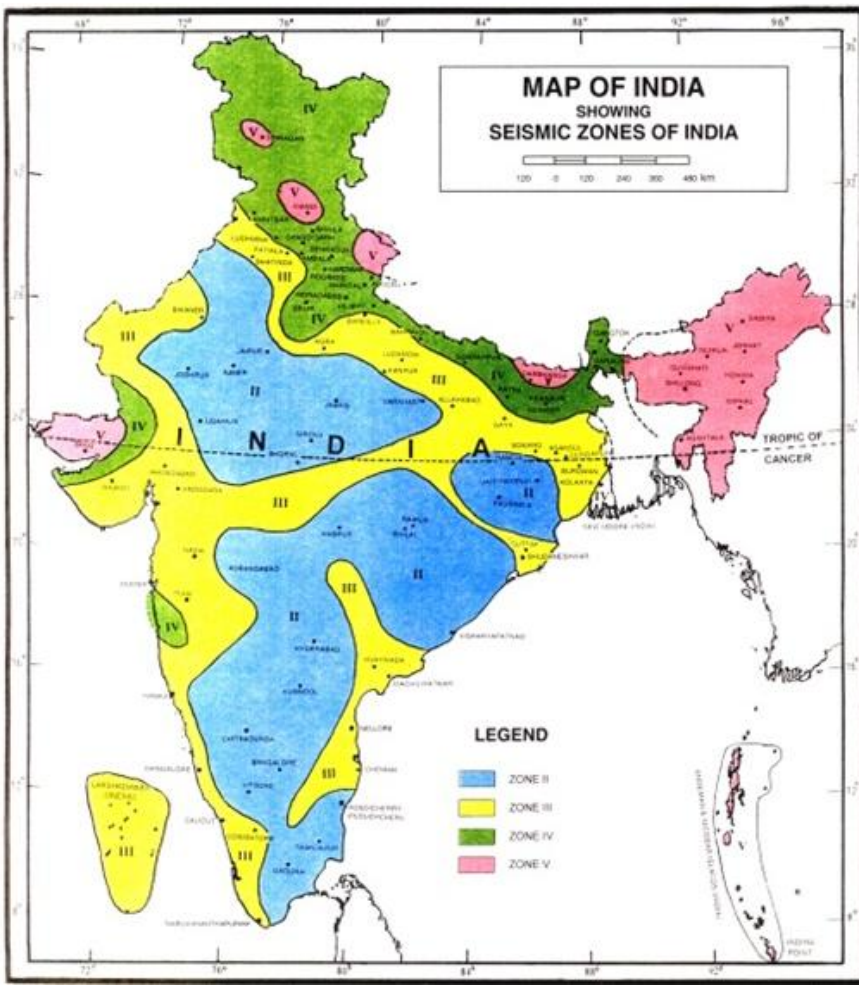


Fig. 16 Map showing Seismic Zones of India [IS 1893 (Part 1): 2002]

The random earthquake ground motions, which cause the structure to vibrate, can be resolved in any three mutually perpendicular directions. The predominant direction of ground vibration is usually horizontal.

The design horizontal seismic coefficient A_h for a structure shall be determined by the following expression:

$$A_h = ZIS_a / 2Rg$$

Where,

Z = **Zone factor** as given in Table -1, is for the Maximum Considered Earthquake (MCE) and service life of structure in a zone. The factor 2 in the denominator of Z is used so as to reduce the Maximum Considered Earthquake (MCE) zone factor to the factor for Design Basis Earthquake (DBE).

Table – 1 Zone Factor, Z [IS 1893 (Part 1): 2002]

Seismic Zone	**II**	**III**	**IV**	**V**
Seismic Intensity	Low	Moderate	Severe	Very Severe
Zone Factor, Z	0.10	0.16	0.24	0.36

I = **Importance factor**, depending upon the functional use of the structures, characterized by hazardous consequences of its failure, post-earthquake functional needs, historical value, or economic importance (as given in Table - 2).

Table – 2 Importance Factors, I [IS 1893 (Part 1): 2002]

S. No.	Structure	Importance Factor
1	Important service and community buildings, such as hospitals; schools; monumental structures; emergency buildings like telephone exchange, television stations, radio stations, railway stations, fire station buildings; large community halls like cinemas, assembly halls and subway stations, power stations	1.5
2	AU other buildings	1.0

Note:
1 The design engineer may choose values of importance factor I greater than those mentioned above.
2 Buildings not covered in S. No. (i) and (ii) above may be designed for higher value of I, depending on economy, strategy considerations like multi-storey buildings having several residential units.
3 This does not apply to temporary structures like excavations, scaffolding etc of short duration.

R = **Response reduction factor**, depending on the perceived seismic damage performance of the structure, by ductile or brittle deformations. However, the ratio (I/R***)*** shall not be greater than 1.0. The values of R[1)] for buildings are given in Table below.

Table – 3 Response Reduction Factor[1)], R, for Building Systems [IS 1893 (Part 1): 2002]

S. No.	Lateral Load Resisting System	R
Building Frame Systems		
(i)	Ordinary RC moment-resisting frame (OMRF)[2)]	3.0
(ii)	Special RC moment-resisting frame (SMRF)[3)]	5.0
(iii)	Steel frame with	
	a) Concentric braces	4.0
	b) Eccentric braces	5.0
(iv)	Steel moment resisting frame designed as per SP 6 (6)	5.0
Building with Shear Walls[4)]		
(v)	Load bearing masonry wall buildings[5)]	
	a) Unreinforced	1.5
	b) Reinforced with horizontal RC bands	2.5
	c) Reinforced with horizontal RC bands and vertical bars at corners of rooms and jambs of openings	3.0
(vi)	Ordinary reinforced concrete shear walls[6)]	3.0
(vii)	Ductile shear walls[7)]	4.0
Buildings with Dual Systems[8)]		

(viii)	Ordinary shear wall with OMRF	3.0
(ix)	Ordinary shear wall with SMRF	4.0
(x)	Ductile shear wall with OMRF	4.5
(xi)	Ductile shear wall with SMRF	5.0

1) The values of response reduction factor are to be used for buildings with lateral load resisting elements, and not just for the lateral load resisting elements built in isolation.
2) OMRF (Ordinary Moment-Resisting Frame) are those designed and detailed as per IS 456 or IS 800 but not meeting ductile detailing requirement as per IS 13920 or SP 6 (6) respectively.
3) SMRF (Special Moment-Resisting Frame) defined in 4.15.2.
   As per 4.15.2, SMRF is a moment-resisting frame specially detailed to provide ductile behaviour and comply with the requirements given in IS 4326 or IS 13920 or SP 6 (6).
4) Buildings with shear walls also include buildings having shear walls and frames, but where:
   a) frames are not designed to carry lateral loads, or
   b) frames are designed to carry lateral loads but do not fulfil the requirements of 'dual systems'
5) Reinforcement should be as per IS 4326.
6) Prohibited in zones IV and V.
7) Ductile shear walls are those designed and detailed as per IS 13920.
8) Buildings with dual systems consist of shear walls (or braced frames) and moment resisting frames such that:
   a) the two systems are designed to resist the total design force in proportion to their lateral stiffness considering the interaction of the dual system at all floor levels, and
   b) the moment resisting frames are designed to independently resist at least 25 percent of the design seismic base shear

Sa/g= Average response acceleration coefficient for rock or soil sites (as given by Fig. 17 and Table - 4) based on appropriate natural periods and damping of the structure. These curves represent free field ground motion.

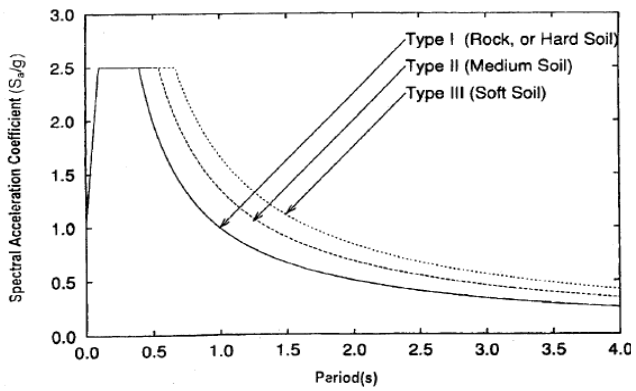


Fig. 17 Response Spectra for Rock and Soil Sites for 5 % Damping [IS 1893 (Part 1): 2002]

Table – 4 Multiplying Factors for Obtaining Values for Other Damping [IS 1893 (Part 1): 2002]

Damping, (%)	0	2	5	7	10	15	20	25	30
Factors	3.20	1.40	1.00	0.90	0.80	0.70	0.60	0.55	0.50

***

अध्याय / Chapter – 5

भवन में भूकंप प्रतिरोध में सुधार के लिए सामान्य सिद्धांत / General Principle for improving Earthquake Resistance in Building

5.1 हल्कापन / Lightness

Since the earthquake force is a function of mass, the building should be as light as possible consistent with structural safety and functional requirements. Roofs and upper storeys of buildings in particular should be designed as light as possible.

5.2 निर्माण की निरंतरता / Continuity of Construction

- As far as possible, all parts of the building should be tied together in such a manner that the building acts as one unit.
- For integral action of building, roof and floor slabs should be continuous throughout as far as possible.
- Additions and alterations to the structures should be accompanied by the provision of positive measures to establish continuity between the existing and the new construction.

5.3 प्रोजेक्टिंग एवं सस्पेंडेड पार्ट्स / Projecting and Suspended Parts

- Projecting parts should be avoided as far as possible. If the projecting parts cannot be avoided, they should be properly reinforced and firmly tied to the main structure.
- Ceiling plaster should preferably be avoided. When it is unavoidable, the plaster should be as thin as possible.
- Suspended ceiling should be avoided as far as possible. Where provided, they should be light and adequately framed and secured.

5.4 भवन की आकृति / Shape of Building

- In order to minimize torsion, the building should have a simple rectangular plan.
- It should be symmetrical both with respect to mass and rigidity so that the centre of mass and rigidity of the building coincide with each other.
- It will be desirable to use separate blocks of rectangular shape particularly in seismic zones V and IV.
- Buildings having plans with shapes like, L, T, E and Y shall preferably be separated into rectangular parts by providing separation sections at appropriate places.

Typical examples are shown in Fig. 18.

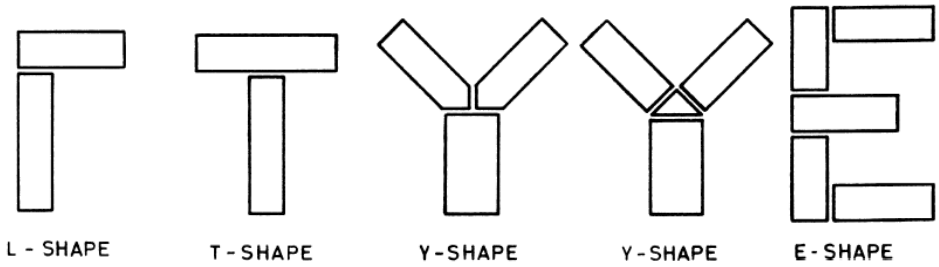


Fig. 18 Typical Shapes of Building with Separation Sections [IS 4326: 1993]

5.5 विभिन्न दिशाओं में शक्ति / Strength in Various Directions

The structure shall have adequate strength against earthquake effects along both the horizontal axes considering the reversible nature of earthquake forces.

5.6 नींव / Foundations

- For the design of foundations, the provisions of IS 1904: 1986 in conjunctions with IS 1893: 1984 shall generally be followed.
- The sub-grade below the entire area of the building shall preferably be of the same type of the soil. Wherever this is not possible, a suitably located separation or crumple section shall be provided.
- Loose fine sand, soft silt and expansive clays should be avoided. If unavoidable, the building shall rest either on a rigid raft foundation or on piles taken to a firm stratum. However, for light constructions the following measures may be taken to improve the soil on which the foundation of the building may rest:

  a) Sand piling, and
  b) Soil stabilization.

- Structure shall not be founded on loose soil, which will subside or liquefy during an earthquake resulting in large differential settlement.

5.7 छतें एवं मंजिलें / Roofs and Floors

5.7.1 सपाट छत या फर्श / Flat roof or floor –

Flat roof or floor shall not preferably be made of terrace of ordinary bricks supported on steel, timber or reinforced concrete joists, nor they shall be of a type which in the event of an earthquake is likely to be loosened and parts of all of which may fall. If this type of construction cannot be avoided, the joists should be blocked at ends and bridged at intervals such that their spacing is not altered during an earthquake.

5.7.2 ढलान वाली छतें / Pitched Roofs –

- For pitched roofs, corrugated iron or asbestos sheets should be used in preference to country, Allahabad or Mangalore tiles or other loose roofing units.
- All roofing materials shall be properly tied to the supporting members.
- Heavy roofing materials should generally be avoided.

5.7.3 संवृत छतें / Pent Roofs –

All roof trusses should be supported on and fixed to timber band reinforced concrete band or reinforced brick band. The holding down bolts should have adequate length as required for earthquake and wind forces.

Where a trussed roof adjoins a masonry gable, the ends of the purlins should be carried on and secured to a plate or bearer which should be adequately bolted to timber reinforced concrete or reinforced brick band at the top of gable end masonry.

- At tie level, all the trusses and the gable end should be provided with diagonal braces in plan so as to transmit the lateral shear due to earthquake force to the gable walls acting as shear walls at the ends.

NOTE — Hipped roof in general have shown better structural behaviour during earthquakes than gable ended roofs.

5.7.4 जैक मेहराब / Jack Arches –

Jack arched roofs or floors where used should be provided with mild steel ties in all spans along with diagonal braces in plan to ensure diaphragm actions.

5.8 सीढ़ियां / Staircases

- The interconnection of the stairs with the adjacent floors should be appropriately treated by providing sliding joints at the stairs to eliminate their bracing effect on the floors. Ladders may be made fixed at one end and freely resting at the other.

- Large stair halls shall preferably be separated from rest of the building by means of separation or crumple section.

Three types of stair construction may be adopted as described below:

i) **Separated Staircases –**

One end of the staircase rests on a wall and the other end is carried by columns and beams which have no connection with the floors. The opening at the

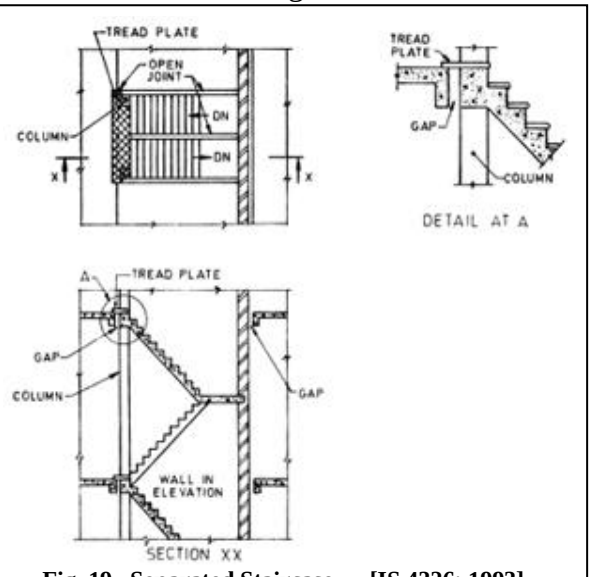


Fig. 19 Separated Staircase [IS 4326: 1993]

vertical joints between the floor and the staircase may be covered either with a tread plate attached to one side of the joint and sliding on the other side, or covered with some appropriate material which could crumple or fracture during an earthquake without causing structural damage. The supporting members, columns or walls, are isolated from the surrounding floors by means of separation or crumple sections. A typical example is shown in Fig. 19.

ii) **Built-in Staircase –**

When stairs are built monolithically with floors, they can be protected against damage by providing rigid walls at the stair opening. An arrangement, in which the staircase is enclosed by two walls, is given in Fig. 20. In such cases, the joints, as mentioned in respect of separated staircases, will not be necessary.

The two walls mentioned above, enclosing the staircase, shall extend through the entire height of the stairs and to the building foundations.

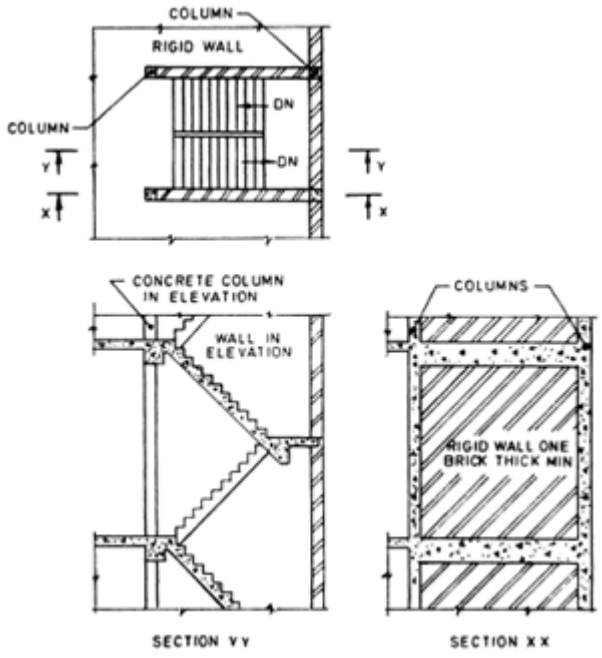


Fig. 20 Rigidly Built-In Staircase [IS 4326: 1993]

iii) **Staircases with Sliding Joints –**

In case it is not possible to provide rigid walls around stair openings for built-in staircase or to adopt the separated staircases, the staircases shall have sliding joints so that they will not act as diagonal bracing.

5.9 बॉक्स प्रकार निर्माण / Box Type Construction

This type of construction consists of prefabricated or in-situ masonry wall along with both the axes of the building. The walls support vertical loads and also act as shear walls for horizontal loads acting in any direction. All traditional masonry construction falls under this category. In prefabricated wall construction, attention should be paid to the connections between wall panels so that transfer of shear between them is ensured.

5.10 अग्नि सुरक्षा / Fire Safety

Fire frequently follows an earthquake and therefore buildings should be constructed to make them fire resistant in accordance with the provisions of relevant Indian Standards for fire safety. The relevant Indian Standards are IS 1641 : 1988, IS 1642 : 1989, IS 1643 : 1988, IS 1644 : 1988 and IS 1646 : 1986.

***

अध्याय / Chapter – 6

अल्प सामर्थ्य चिनाई संरचनाओं के निर्माण / Construction of Low Strength Masonry Structures

Two types of construction are included herein, namely

a) Brick construction using weak mortar, and
b) Random rubble and half-dressed stone masonry construction using different mortars such as clay mud lime-sand and cement sand.

6.1 भूकंप के दौरान ईंट चिनाई की दीवारों का व्यवहार / Behaviour of Brick Masonry Walls during Earthquakes

Ground vibrations during earthquakes cause inertia forces at locations of mass in the building (Fig. 22). 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.

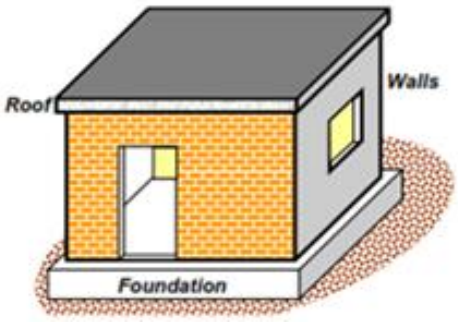


Fig. 21 Basic components of Masonry Building

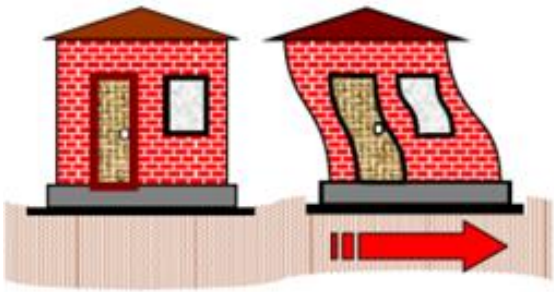


Fig. 22 Effect of Inertia in a building when shaken at its base

Of the three components of a masonry building (*roof*, *wall* and *foundation* as illustrated in Fig. 21), 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*) (Fig. 23 & 24).

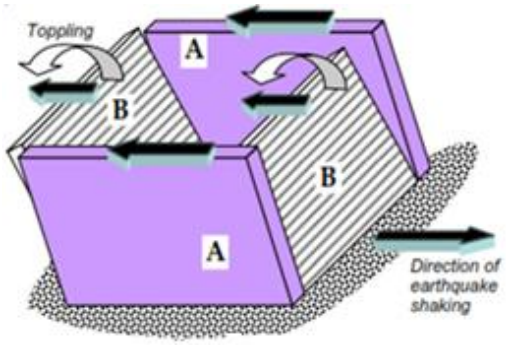


Fig. 23 For the direction of Earthquake shaking shown, wall B tends to fail

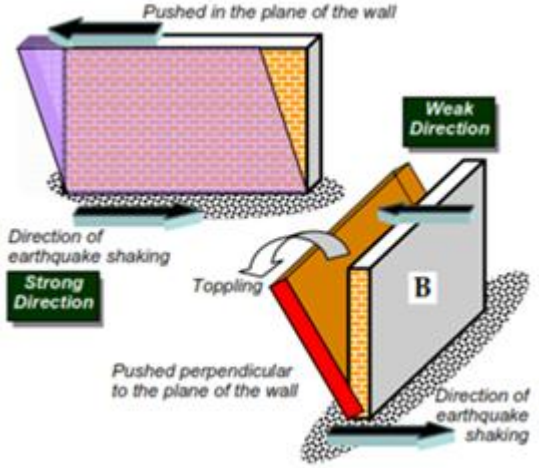


Fig. 24 Direction of force on a wall critically determines its earthquake performance

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.

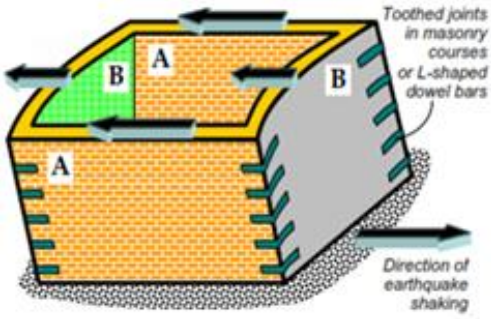


Fig. 25 Wall B properly connected to Wall A (Note: roof is not shown): Walls A (loaded in strong direction) support Walls B (loaded in weak direction)

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 (Fig. 25). Further, walls also need to be tied to the roof and foundation to preserve their overall integrity.

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.

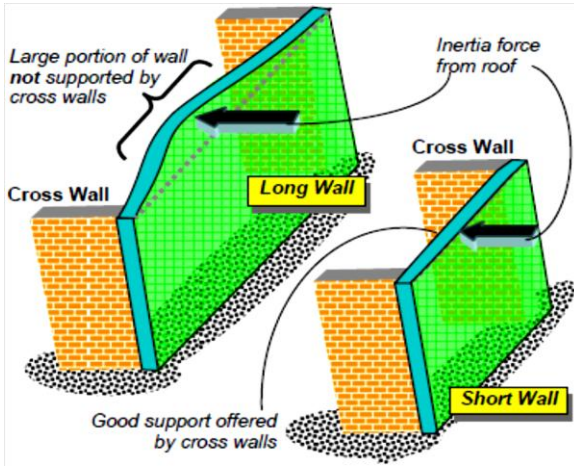


Fig. 26 Slender walls are vulnerable

- 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 opening, 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. 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 (Fig. 26).

6.1.1 चिनाई वाली इमारतों में बॉक्स एक्शन / 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 un-symmetric 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 (Fig. 27). For example, a horizontal band introduced at the lintel level ties the walls together and helps to make them behave as a single unit.

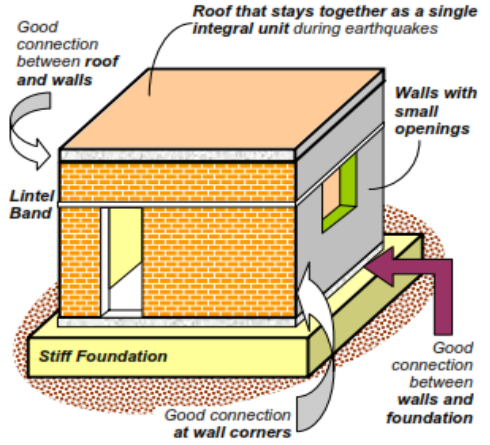


Fig. 27 Essential requirements to ensure box action in a masonry building

6.1.2 ओपनिंग का प्रभाव / Influence of Openings

Openings are functional necessities in buildings. 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. To be more specific, wall B1 pulls walls A1 and A2, while wall B2 pushes against them.

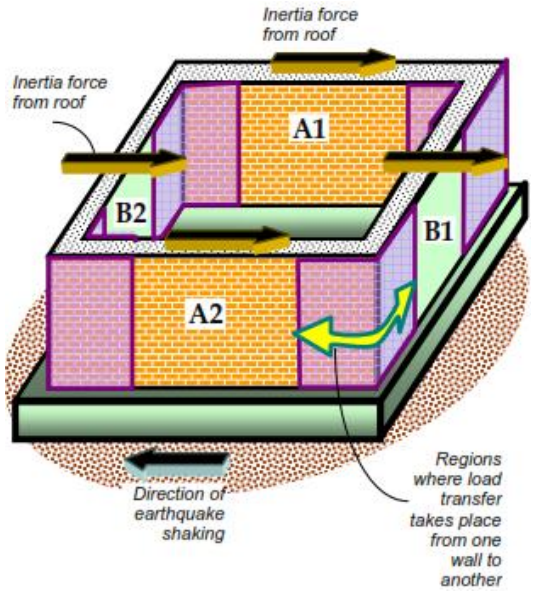


Fig. 28 Regions of force transfer from weak walls to strong walls in a masonry building – *wall B1 pulls walls A1 and A2, while wall B2 pushes walls A1 and A2*

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 (Fig. 28). 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. 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.

6.2 भूकंपरोधी ईंट चिनाई भवन के निर्माण हेतु सामान्य सिद्धांत / General Principles for Construction of Earthquake Resistant Brick Masonry Building

- Low Strength Masonry constructions should not be permitted for important buildings.

- It will be useful to provide damp-proof course at plinth level to stop the rise of pore water into the superstructure.
- Precautions should be taken to keep the rain water away from soaking into the wall so that the mortar is not softened due to wetness. An effective way is to take out roof projections beyond the walls by about 500 mm.
- Use of a water-proof plaster on outside face of walls will enhance the life of the building and maintain its strength at the time of earthquake as well.
- Ignoring tensile strength, free standing walls should be checked against overturning under the action of design seismic coefficient, ah, allowing for a factor of safety of 1.5.

6.2.1 ईमारतों की श्रेणियाँ / Categories of Buildings

For the purpose of specifying the earthquake resisting features, the buildings, have been categorized in five categories A to E, as given in Table 5, based on the value of α_h, given by:

$$\alpha_h = \alpha_0 I \beta$$

where,

α_h = design seismic coefficient for the building,
α_0 = basic seismic coefficient for the seismic zone in which the building is located
I = importance factor applicable to the building
β = soil foundation factor

Building Categories	Range of α_h
A	Less than 0.05
B	0.05 to 0.06 (both inclusive)
C	More than 0.06 and less than 0.08
D	0.08 to less than 0.12
E	Equal to or more than 0.12

Note - Low-strength masonry shall not be used for category E

Table - 5 Building Categories for Earthquake Resisting Features (IS 4326: 1993)

6.2.2 कमजोर गारे में ईंट चिनाई कार्य / Brickwork in Weak Mortars

- The fired bricks should have a compressive strength not less than 3.5 MPa. Strength of bricks and wall thickness should he selected for the total building height.

- The mortar should be lime-sand (1:3) or clay mud of good quality. Where horizontal steel is used between courses, cement-sand mortar (1:3) should be used with thickness so as to cover the steel with 6 mm mortar above and below it. Where vertical steel is used, the surrounding brickwork of 1 X 1 or l½ X 1½ brick size depending on wall thickness should preferably be built using 1:6 cement-sand mortar.

- The minimum wall thickness shall be one brick in one storey construction and one brick in top storey and 1½ brick in bottom storeys of up to three storey constructions. It should also not be less than l/16 of the length of wall between two consecutive perpendicular walls.

- The height of the building shall be restricted to the following, where each storey height shall not exceed 3.0 m.

  For Categories A, B and C **-** three storeys with flat roof; and two storeys plus attic pitched roof.
  For Category D **-** two storeys with flat roof; and one storey plus attic for pitched roof.

- ***Special Bond in Brick Walls*** **–** For achieving full strength of masonry, the usual bonds specified for masonry should be followed so that the vertical joints are broken properly from course to course. To obtain full bond between perpendicular walls, it is necessary to make a sloping (stepped) joint by making the corners first to a height of 600 mm and then building the wall in between them. Otherwise the toothed joint should be made in both the walls, alternately in lifts of about 450 mm.

6.2.3 आयताकार चिनाई इकाइयों वाला चिनाई निर्माण / Masonry Construction with Rectangular Masonry Units

General requirements for construction of masonry walls using rectangular masonry units are:

6.2.3.1 *चिनाई इकाइयां / Masonry Units*

- Well burnt bricks conforming to IS 1077: 1992 or solid concrete blocks conforming to IS 2185 (Part 1): 1979 and having a crushing strength not less than 3.5 MPa shall be used. The strength of masonry unit required shall depend on the number of storeys and thickness of walls.
- Squared stone masonry, stone block masonry or hollow concrete block masonry, as specified in IS 1597 (Part 2): 1992 of adequate strength, may also be used.

6.2.3.2 *गारा / Mortar*

- Mortars, such as those given in Table-6 or of equivalent specification, shall preferably be used for masonry construction for various categories of buildings.

- Where steel reinforcing bars are provided in masonry the bars shall be embedded with adequate cover in cement sand mortar not leaner than 1:3 (minimum clear cover 10 mm) or in cement concrete of grade M15 (minimum clear cover 15 mm or bar diameter whichever more), so as to achieve good bond and corrosion resistance.

*Category of Construction	Proportion of Cement-Lime-Sand†
A	M_2 (Cement-sand 1 : 6) or M_3 (Lime-cinder‡ 1 : 3) or richer
B, C	M_2 (Cement-lime-sand 1 : 2 : 9 or Cement-Sand 1 : 6) or richer
D, E	H_2 (Cement-sand 1 : 4) or M_1 (Cement-lime-Sand 1 : 1 : 6) or richer

NOTE — Though the equivalent mortar with lime will have less strength at 28 days, their strength after one year will be comparable to that of cement mortar.

*Category of construction is defined in Table 2.

†Mortar grades and specification for types of limes etc, are given in IS 1905 : 1987.

‡In this case some other pozzolanic material like Surkhi (burnt brick fine powder) may be used in place of cinder.

Table - 6 Recommended Mortar Mixes (IS 4326: 1993)

6.2.4 दीवारें / Walls

- Masonry bearing walls built in mortar, as specified in 6.2.2.2 above, unless rationally designed as reinforced masonry shall not be built of greater height than 15 m subject to a maximum of four storeys when measured from the mean ground level to the roof slab or ridge level.

- The bearing walls in both directions shall be straight and symmetrical in plan as far as possible.
- The wall panels formed between cross walls and floors or roof shall be checked for their strength in bending as a plate or as a vertical strip subjected to the earthquake force acting on its own mass.

Note — For panel walls of 200 mm or larger thickness having a storey height not more than 3.5 metres and laterally supported at the top, this check need not be exercised.

6.2.5 चिनाई बॉण्ड / Masonry Bond

For achieving full strength of masonry, the usual bonds specified for masonry should be followed so that the vertical joints are broken properly from course to course. To obtain full bond between perpendicular walls, it is necessary to make a slopping (stepped) joint by making the corners first to a height of 600 mm and then building the wall in between them. Otherwise, the toothed joint (as shown in Fig. 29) should be made in both the walls alternatively in lifts of about 450 mm.

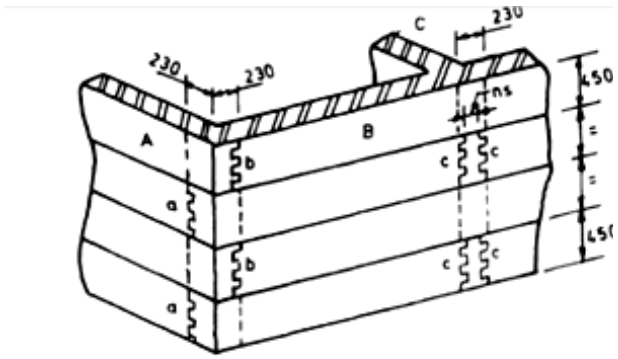


Fig. 29 Alternating Toothed Joints in Walls at Corner and T- Junction (IS 4326: 1993)

- Panel or filler walls in framed buildings shall be properly bonded to surrounding framing members by means of suitable mortar (as given in 6.2.2.2 above) or connected through dowels.

6.2.6 धारक दीवारों में ओपनिंग / Openings in Bearing Walls

- Door and window openings in walls reduce their lateral load resistance and hence, should preferably be small and more centrally located. The guidelines on the size and position of opening are given in Table – 7 and in Fig. 30.

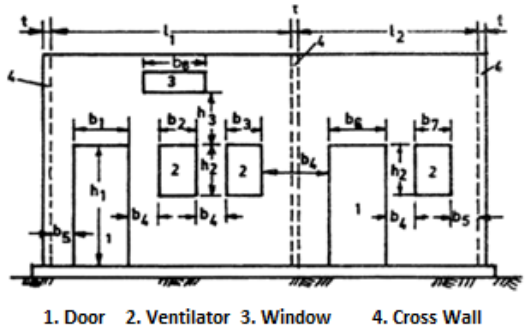


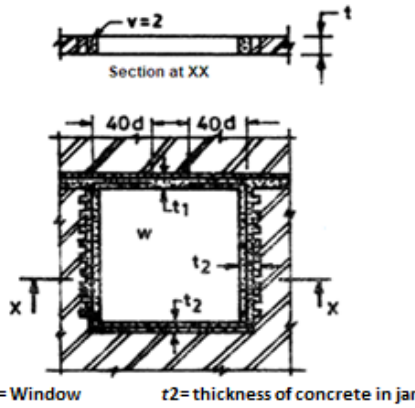
Fig. 30 Dimensions of Openings and Piers for Recommendations in Table 3 (IS 4326: 1993)

Table – 7 Size and Position of Openings in Bearing Walls

S. No.	Position of opening	Details of Opening for Building Category		
		A and B	C	D and E
1	Distance b_5 from the inside corner of outside wall, *Min*	Zero mm	230 mm	450 mm
2	For total length of openings, the ratio $(b_1+b_2+b_3)/l_1$ or $(b_6+b_7)/l_2$ shall not exceed			
	a) one-storeyed building	0.60	0.55	0.50
	b) two-storeyed building	0.50	0.46	0.42

	c) 3 or 4-storeyed building	0.42	0.37	0.33
3	Pier width between consecutive openings b_4, *Min*	340 mm	450 mm	560 mm
4	Vertical distance between two openings one above the other h_3, *Min*	600 mm	600 mm	600 mm
5	Width of opening of ventilator b_8, *Max*	900 mm	900 mm	900 mm

- Openings in any storey shall preferably have their top at the same level so that a continuous band could be provided over them, including the lintels throughout the building.
- Where openings do not comply with the guidelines as given in Table - 7, they should be strengthened by providing reinforced concrete or reinforcing the brickwork, as shown in Fig. 31 with high strength deformed (H.S.D.) bars of 8 mm dia but the quantity of steel shall be increased at the jambs.
- If a window or ventilator is to be projected out, the projection shall be in reinforced masonry or concrete and well anchored.
- If an opening is tall from bottom to almost top of a storey, thus dividing the wall into two portions, these portions shall be reinforced with horizontal reinforcement of 6 mm diameter bars at not more than 450 mm intervals, one on inner and one on outer face, properly tied to vertical steel at jambs, corners or junction of walls, where used.
- The use of arches to span over the openings is a source of weakness and shall be avoided. Otherwise, steel ties should be provided.



W= Window *t2*= thickness of concrete in jamb
t= Wall thickness *v*= Vertical bar
t1= Lintel thickness *d*= Diameter of reinforcing bar

Fig. 31 Strengthening Masonry Around Opening (IS 4326: 1993)

6.3 भूकंपी सुदृढ़ीकरण व्यवस्था / Seismic Strengthening Arrangements

All masonry buildings shall be strengthened as specified for various categories of buildings, as listed in Table 8.

Table - 8 Strengthening Arrangements Recommended for Masonry Buildings (Rectangular Masonry Units) (IS 4326: 1993)

Building Category	Number of Storeyes	Strengthening to be Provided in all Storeys
A	i) 1 to 3 ii) 4	a a, b, c
B	i) 1 to 3 ii) 4	a, b, c, f, g a, b, c, d, f, g
C	i) 1 and 2 ii) 3 and 4	a, b, c, f, g a to g
D	i) 1 and 2 ii) 3 and 4	a to g a to h
E	1 to 3*	a to h

Where,
a — Masonry mortar
b — Lintel band
c — Roof band and gable band where necessary

d — Vertical steel at corners and junctions of walls
e — Vertical steel at jambs of openings
f — Bracing in plan at tie level of roofs
g — Plinth band where necessary, and
h — Dowel bars
*4th storey not allowed in category E.

NOTE — *In case of four storey buildings of category B, the requirements of vertical steel may be checked through a seismic analysis using a design seismic coefficient equal to four times the one given in (a)* ***3.4.2.3*** *of IS 1893: 1984. (This is because the brittle behaviour of masonry in the absence of vertical steel results in much higher effective seismic force than that envisaged in the seismic coefficient provided in the code). If this analysis shows that vertical steel is not required the designer may take the decision accordingly.*

The overall strengthening arrangements to be adopted for category D and E buildings which consist of horizontal bands of reinforcement at critical levels, vertical reinforcing bars at corners, junctions of walls and jambs of opening are shown in Fig. 32 & 33.

Lintel band: Lintel band is a band provided at lintel level on all load bearing internal, external longitudinal and cross walls.

Roof band: Roof band is a band provided immediately below the roof or floors. Such a band need not be provided underneath reinforced concrete or brick-work slabs resting on bearing walls, provided that the slabs are continuous over the intermediate wall up to the crumple sections, if any, and cover the width of end walls, fully or at least 3/4 of the wall thickness.

Gable band: Gable band is a band provided at the top of gable masonry below the purlins. This band shall be made continuous with the roof band at the eaves level.

Plinth band: Plinth band is a band provided at plinth level of walls on top of the foundation wall. This is to be provided where strip footings of masonry (other than reinforced concrete or reinforced masonry) are used and the soil is either soft or uneven in its properties, as frequently happens in hill tracts. This band will serve as damp proof course as well.

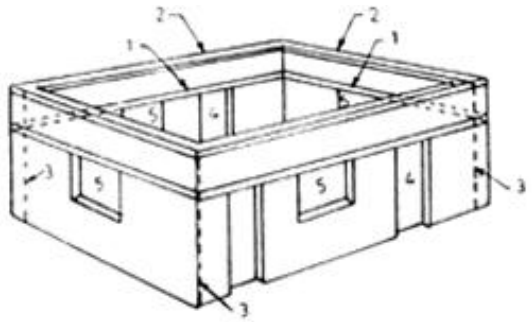


Fig. 32 Overall Arrangement of Reinforcing Masonry Buildings (IS 4326: 1993)

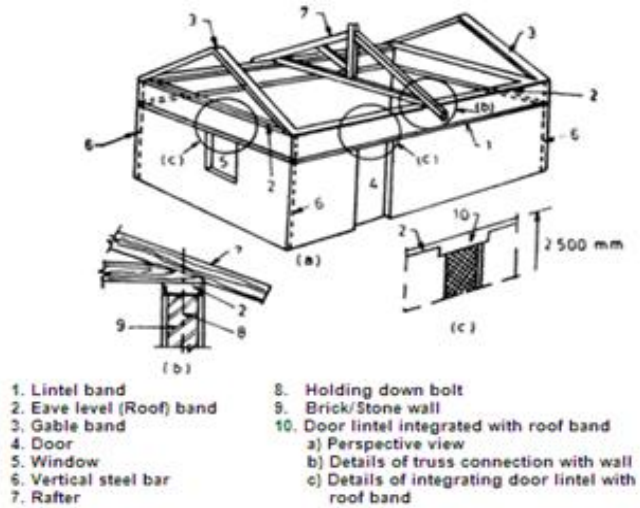


Fig. 33 Overall Arrangement of Reinforcing Masonry Building having Pitched Roof (IS 4326: 1993)

6.3.1 पट्टे का अनुभाग एवं सुदृढीकरण / Section and Reinforcement of Band

The band shall be made of reinforced concrete of grade not leaner than M15 or reinforced brick work in cement mortar not leaner than 1:3. The bands shall be of the full width of the wall, not less than 75 mm in depth and reinforced with steel, as indicated in Table 9.

Table – 9 Recommended Longitudinal Steel in Reinforced Concrete Bands (IS 4326: 1993)

Span	Building Category B		Building Category C		Building Category D		Building Category E	
	No. of Bars	Dia.	No. of Bars	Dia.	No. of Bars	Dia.	No. of Bars	Dia.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
m		mm		mm		mm		mm
5 or less	2	8	2	8	2	8	2	10
6	2	8	2	8	2	10	2	12
7	2	8	2	10	2	12	4	10
8	2	10	2	12	4	10	4	12

Notes -

1 Span of wall will be the distance between centre lines of its cross walls or buttresses. For spans greater than 8 m it will be desirable to insert pillasters or buttresses to reduce the span or special calculations shall be made to determine the strength of wall and section of band.

2 The number and diameter of bars given above pertain to high strength deformed bars. If plain mild-steel bars are used keeping the same number, the following diameters may be used:

High Strength Def. Bar dia.	8	10	12	16	20
Mild Steel Plain bar dia.	10	12	16	20	25

3 Width of R.C. band is assumed same as the thickness of the wall. Wall thickness shall be 200 mm minimum. A clear cover of 20 mm from face of wall will be maintained.

4 The vertical thickness of RC band be kept 75 mm minimum, where two longitudinal bars are specified, one on each face; and 150 mm, where four bars are specified.

5 Concrete mix shall be of grade M15 of IS 456: 1978 or 1: 2: 4 by volume.

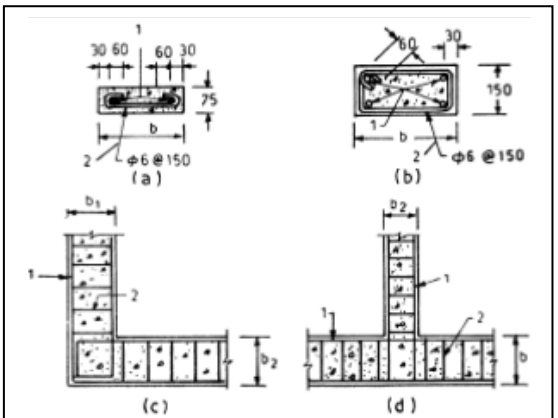
6 The longitudinal steel bars shall be held in position by steel links or stirrups 6 mm dia. spaced at 150 mm apart.

NOTE — In coastal areas, the concrete grade shall be M20 concrete and the filling mortar of 1:3(cement-sand with water proofing admixture).

As illustrated in Fig. 34 –

- In case of reinforced brickwork, the thickness of joints containing steel bars shall be increased so as to have a minimum mortar cover of 10 mm around the bar. In bands of reinforced brickwork the area of steel provided should be equal to that specified above for reinforced concrete bands.

- In category D and E buildings, to further iterate the box action of walls steel dowel bars may be used at corners and T-junctions of walls at the sill level of windows to length of 900 mm from the inside corner in each wall. Such dowel may be in the form of U stirrups 8 mm dia. Where used, such bars must be laid in 1:3 cement-sand-mortar with a minimum cover of 10 mm on all sides to minimize corrosion.



1.Longitudinal bar
2. Lateral ties
*b*1, *b*2 = Wall thickness

a) Section of band with two bars
b) Section of band with four bars
c) Structural plan at corner junction
d) Section plan at T- junction of Walls

All dimensions in millimeters.

Fig. 34 Reinforcement and Bending Detail in RC Band ((IS 4326: 1993)

6.4 क्षैतिज बैंड की भूमिका / 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 (Fig. 35& 36).

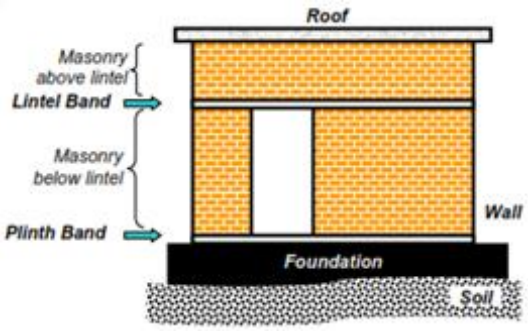


Fig. 35 Building with flat roof

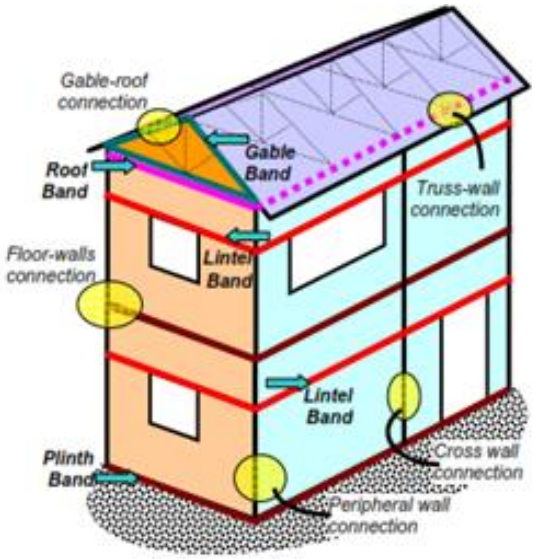


Fig. 36 Two-storey Building with pitched roof

- The lintel band undergoes bending and pulling actions during earthquake shaking (Fig.37).
- 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); the RC bands are the best (Fig. 38).
- The straight lengths of the band must be properly connected at the wall corners.
- In wooden bands, proper nailing of straight lengths with spacers is important.
- In RC bands, adequate anchoring of steel links with steel bars is necessary.
- 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 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.

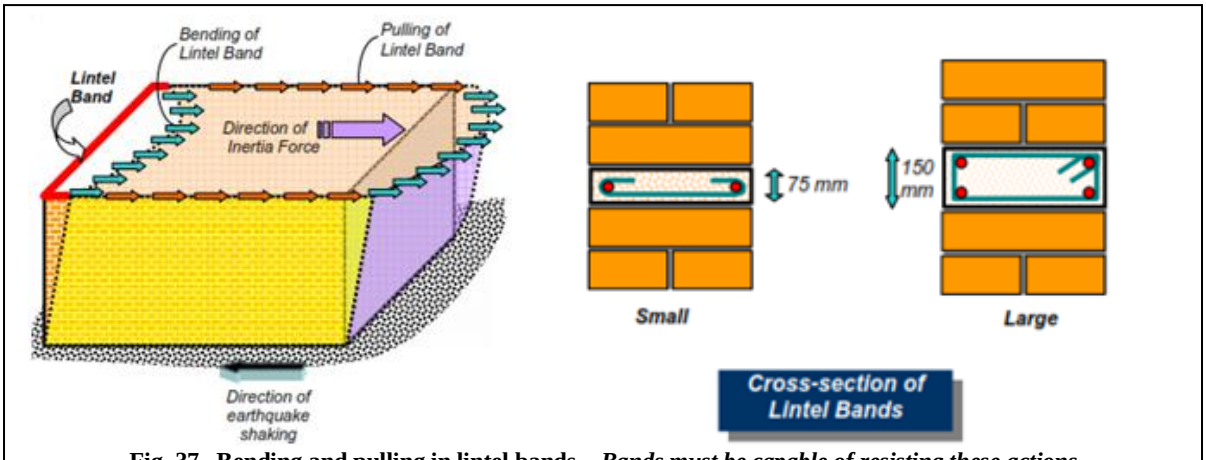


Fig. 37 Bending and pulling in lintel bands – ***Bands must be capable of resisting these actions***

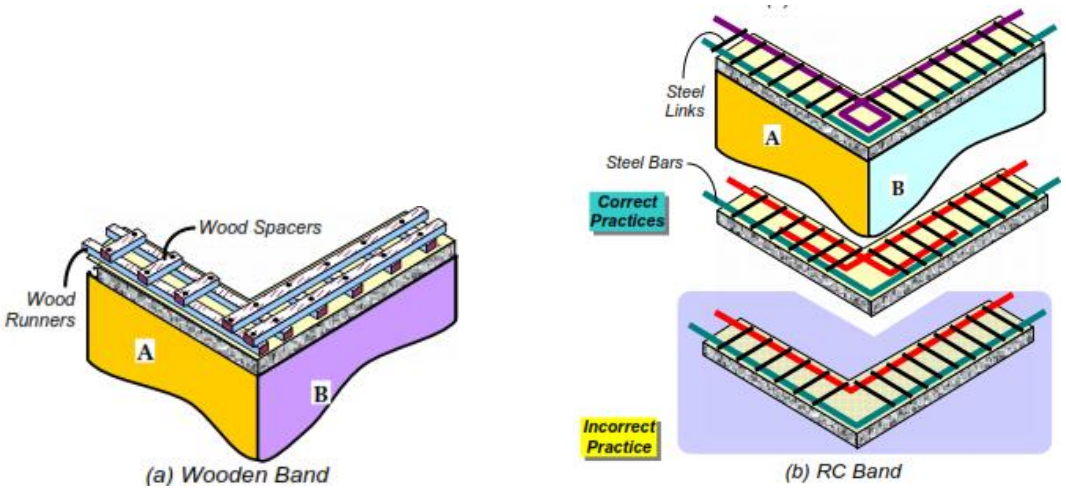


Fig. 38 Horizontal Bands in masonry buildings – *RC bands are the best*

6.5 अधोलंब सुदृढीकरण / Vertical Reinforcement

Vertical steel at corners and junctions of walls, which are up to 340 mm (1½ brick) thick, shall be provided as specified in Table 10. For walls thicker than 340 mm the area of the bars shall be proportionately increased.

No vertical steel need be provided in category A building. The vertical reinforcement shall be properly embedded in the plinth masonry of foundations and roof slab or roof band so as to develop its tensile strength in bond. It shall be passing through the lintel bands and floor slabs or floor level bands in all storeys.

Table – 10 Vertical Steel Reinforcement in Masonry Walls with Rectangular Masonry Units (IS 4326: 1993)

No. of Storeys	Storey	Diameter of HSD Single Bar in mm at Each Critical Section			
		Category B	Category C	Category D	Category E
One	—	Nil	Nil	10	12
Two	Top	Nil	Nil	10	12
	Bottom	Nil	Nil	12	16
Three	Top	Nil	10	10	12
	Middle	Nil	10	12	16
	Bottom	Nil	12	12	16
Four	Top	10	10	10	Four storeyed building not permitted
	Third	10	10	12	
	Second	10	12	16	
	Bottom	12	12	20	

NOTES

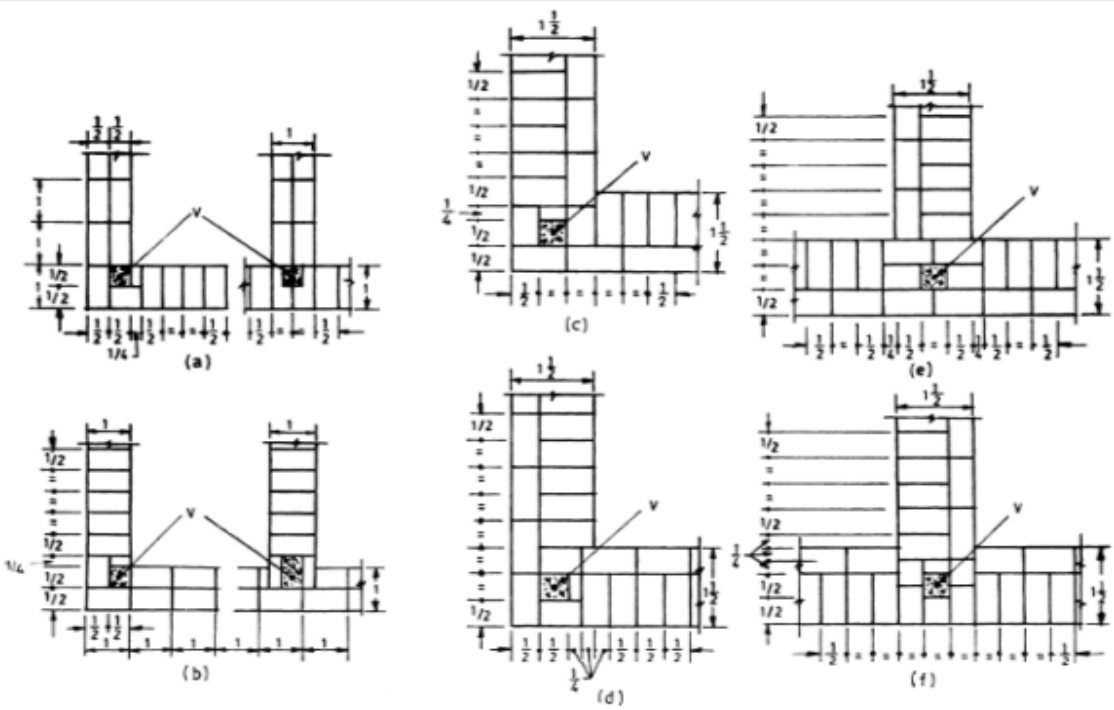
1 **The diameters given above are for H.S.D. bars. For mild-steel plain bars, use equivalent diameters as given under Table 9 Note 2.**

2 **The vertical bars will be covered with concrete M15 or mortar 1: 3 grade in suitably created pockets around the bars. This will ensure their safety from corrosion and good bond with masonry.**

3 **In case of floors/roofs with small precast components, also refer 9.2.3 of IS 4326: 1993 for floor/roof band details.**

- Bars in different storeys may be welded (IS 2751: 1979 and IS 9417: 1989, as relevant) or suitably lapped.
- Vertical reinforcement at jambs of window and door openings shall be provided as per Table - 10. It may start from foundation of floor and terminate in lintel band (as shown in Fig. 31).

- Typical details of providing vertical steel in brickwork masonry with rectangular solid units at corners and T-junctions are shown in Fig. 39.



1 - One brick length, ½ - half brick length, V - Vertical steel bar with mortar/ concrete filling in pocket
a) and b) - Alternate courses in obe brick wall
c) and d) - Alternate courses at corner junction of 1½ - brick wall
e) and f) - Alternate courses at T- junction of 1½ - brick wall

Fig. 39 Typical Details of Providing Vertical Steel Bars in Brick Masonry (IS 4326: 1993)

6.5.1 अधोलंब सुदृढीकरण प्रदान करके दीवारों में सूराखों का संरक्षण / Protection of Openings in Walls by providing Vertical Reinforcement

Horizontal bands including *plinth band*, *lintel band* and *roof band* are provided in masonry buildings to improve their earthquake performance. Even if horizontal bands are provided, masonry buildings are weakened by the openings in their walls.

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, 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.

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. 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. In summary, lintel and sill bands above and below openings, and vertical reinforcement adjacent to vertical edges, provide protection against this type of damage (Fig. 40).

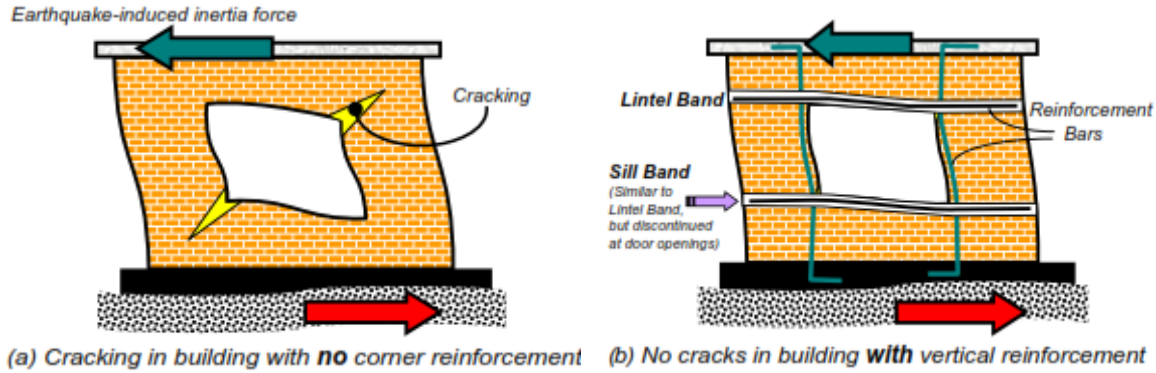


Fig. 40 Cracks at corners of openings in a masonry building – *reinforcement around them helps*

6.6 भूकंप के दौरान स्टोन चिनाई की दीवारों का व्यवहार / Behaviour of Stone Masonry Walls during Earthquakes

Stone has been used in building construction in India since ancient times since it is durable and locally available. The buildings made of thick stone masonry walls (thickness ranges from 600 to 1200 mm) 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) (Fig. 41 & 42).



Fig. 41 Separation of a thick wall into two layers

Note: *A wythe is a continuous vertical section of masonry one unit in thickness. A wythe may be independent of, or interlocked with, the adjoining wythe(s). A single wythe of brick that is not structural in nature is referred to as a veneer.* (https://en.wikipedia.org/wiki/Wythe)

The main patterns of earthquake damage include:

(a) bulging/separation of walls in the horizontal direction into two distinct *wythes*,

(b) separation of walls at corners and T-junctions,

(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.



Fig. 42 Separation of unconnected adjacent walls at junction

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.

6.7 भूकंपरोधी स्टोन चिनाई भवन के निर्माण हेतु सामान्य सिद्धांत / General principle for construction of Earthquake Resistant stone masonry building

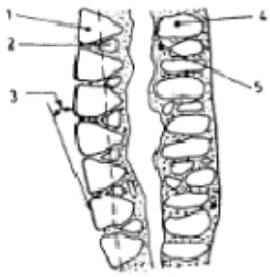
6.7.1 भूकंपरोधी लक्षण / Earthquake Resistant Features

1. Low strength stone masonry buildings are weak against earthquakes, and should be avoided in high seismic zones. Inclusion of special earthquake-resistant features may enhance the earthquake resistance of these buildings and reduce the loss of life. These features include:

(a) Ensure proper wall construction:
(b) Ensure proper bond in masonry courses:
(c) Provide horizontal reinforcing elements:
(d) Control on overall dimensions and heights:

2. The mortar should be cement-sand (1: 6), lime-sand (1: 3) or clay mud of good quality.

3. The wall thickness should not be larger than 450 mm. Preferably it should be about 350 mm, and the stones on the inner and outer *wythes* should be interlocked with each other.



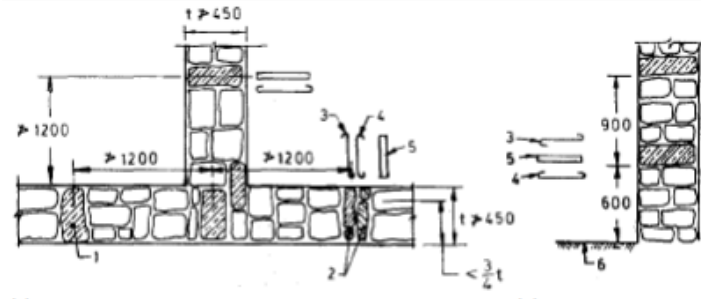
1. Half-dressed conical stone, 2. Small alignment stone
3. Rotation of Wythe, 4. Random rubble,
5. Mud or weak lime mortar.

Fig. 43 Wall delaminated with buckled withes (IS 13828: 1993)

NOTE - If the two wythes are not interlocked, they tend to delaminate during ground shaking bulge apart (as shown in Fig. 43) and buckle separately under vertical load leading to complete collapse of the wall and the building.

4. The masonry should preferably be brought to courses at not more than 600 mm lift.

5. **'Through' stones** at full length equal to wall thickness should be used in every 600 mm lift at not more than 1.2 m apart horizontally. If full length stones are not available, stones in pairs each of about 3/4 of the wall thickness may be used in place of one full length stone so as to provide an overlap between them (as shown in Fig. 44).



(a) Sectional plan of wall (b) Cross-section of wal
1. Through stone, 2. Pair of overlapping stone, 3. S-Shape tie, 4. Hooked tie,
5. Wood plank, 6. Floor level.
All dimensions in millimetres.

Fig. 44 Through Stone and Bond Elements (IS 13828: 1993)

6. In place of 'through' stones, 'bonding elements' of steel bars 8 to 10 mm dia. bent to S-shape or as hooked links may be used with a cover of 25 mm from each face of the wall (as shown in Fig. 44). Alternatively, wood-bars of 38 mm X 38 mm cross section or concrete bars of 50 mm X 50 mm section with an 8 mm dia. rod placed centrally may be used in place of through' stones. The wood should be well treated with preservative so that it is durable against weathering and insect action.

7. Use of 'bonding' elements of adequate length should also be made at corners and junctions of walls to break the vertical joints and provide bonding between perpendicular walls.

8. Height of the stone masonry walls (random rubble or half-dressed) should be restricted as follows, with storey height to be kept 3.0 m maximum, and span of walls between cross walls to be limited to 5.0 m:

a) For categories A and B - Two storeys with flat roof or one storey plus attic, if walls are built in lime-sand or mud mortar; and -one storey higher if walls are built in cement-sand 1 : 6 mortar.

b) For categories C and D - Two storeys with flat roof or two storeys plus attic for pitched roof, if walls are built in 1 : 6 cement mortar; and one storey with flat roof or one storey plus attic, if walls are built in lime-sand or mud mortar, respectively.

9. If walls longer than 5 m are needed, buttresses may be used at intermediate points not farther apart than 4.0 m. The size of the buttress be kept of uniform thickness. Top width should be equal to the thickness of main wall, t, and the base width equal to one sixth of wall height.

10. The stone masonry dwellings must have horizontal bands (*plinth*, *lintel*, *roof* and *gable 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.

Note: *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 in seismic zones III and higher. Also, the use of seismic bands is highly recommended.*

***

अध्याय / Chapter – 7

ढाँचागत संरचना का निर्माण / Construction of Framed Structure

7.1 प्रबलित कंक्रीट इमारतों पर क्षैतिज भूकंप का प्रभाव / Effect of Horizontal Earthquakes on Reinforced Concrete Buildings

In recent times, *reinforced concrete* buildings have become common in India, particularly in towns and cities. A typical RC building consists of horizontal members (*beams* and *slabs*) and vertical members (*columns* and *walls*). The system is supported by *foundations* that rest on ground. The RC frame participates in resisting the earthquake forces.

Earthquake shaking generates inertia forces in the building, which are proportional to the building mass. Since most of the building mass is present at floor levels, earthquake-induced inertia forces primarily develop at the floor levels. These forces travel downwards - through *slab and beams* to *columns and walls*, and then to the foundations from where they are dispersed to the ground (Fig. 45).

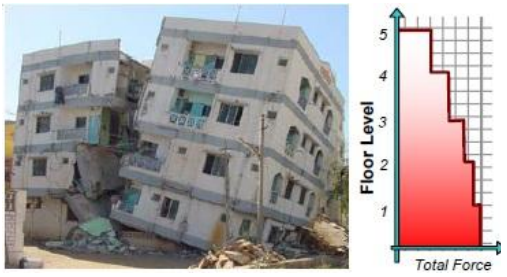


Fig. 45 Total horizontal earthquake force in a building increases downwards along its height

As inertia forces accumulate downwards from the top of the building, the columns and walls at lower storeys experience higher earthquake-induced forces and are therefore designed to be stronger than those in storeys above.

For a building to remain safe during earthquake shaking, columns (which receive forces from beams) should be stronger than beams, and foundations (which receive forces from columns) should be stronger than columns.

When this strategy is adopted in design, damage is likely to occur *first* in beams. When beams are detailed properly to have large ductility, the building as a whole can deform by large amounts despite progressive damage caused due to consequent yielding of beams.

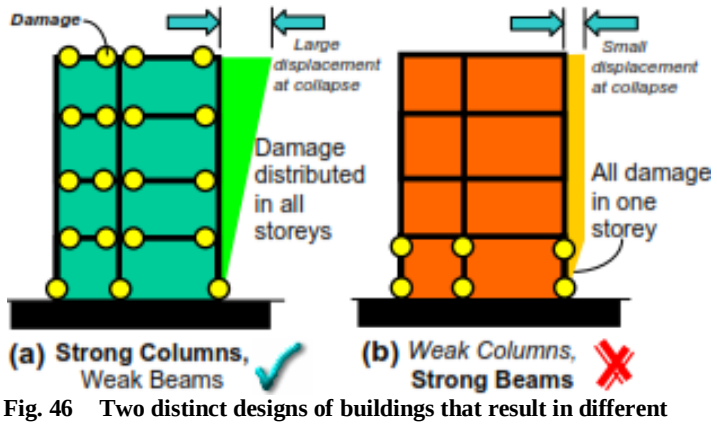


Fig. 46 Two distinct designs of buildings that result in different earthquake performances – columns should be stronger than beams

Note: If columns are made weaker, they suffer severe local damage, at the top and bottom of a particular storey. This localized damage can lead to collapse of a building, although columns at storeys above remain almost undamaged (Fig. 46).

- When beams bend in the vertical direction during earthquakes, these thin slabs bend along with them. And, when beams move with columns in the horizontal direction, the slab usually forces the beams to move together with it. In most buildings, the geometric distortion of the slab is negligible in the horizontal plane; this behaviour is known as the *rigid diaphragm action*. This aspect must be considered during design. (Fig. 47)

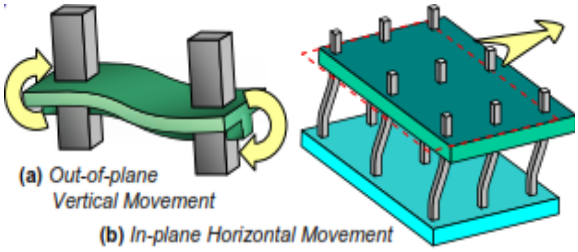


Fig. 47 Floor bends with the beam but moves all columns at that level together.

- When columns receive horizontal forces at floor levels, they try to move in the horizontal direction, but masonry walls tend to resist this movement. Due to their heavy weight and thickness, these walls attract rather large horizontal forces. However, since masonry is a brittle material, these walls develop cracks once their ability to carry horizontal load is exceeded. Thus, infill walls act like sacrificial fuses in buildings; they develop cracks under severe ground shaking but help share the load of the beams and columns until cracking. Earthquake performance of infill walls is enhanced by mortars of good strength, making proper masonry courses, and proper packing of gaps between RC frame and masonry infill walls (Fig. 48).

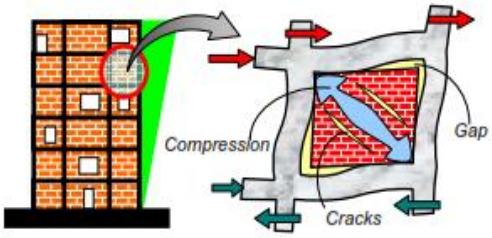


Fig. 48 Infill walls move together with the columns under earthquake shaking

7.1.1 Gravity Loading and Earthquake Loading

As illustrated in Fig. 49,

- *Gravity loading* (due to self weight and contents) on buildings causes RC frames to bend resulting in *stretching* and *shortening* at various locations. Tension is generated at surfaces that stretch and compression at those that shorten. Under gravity loads, tension in the beams is at the bottom surface of the beam in the central location and is at the top surface at the ends.

- On the other hand, *earthquake loading* causes tension on beam and column faces at locations different from those under gravity loading; the relative levels of this tension (in technical terms, *bending moment*) generated in members are shown in Figure. The level of bending

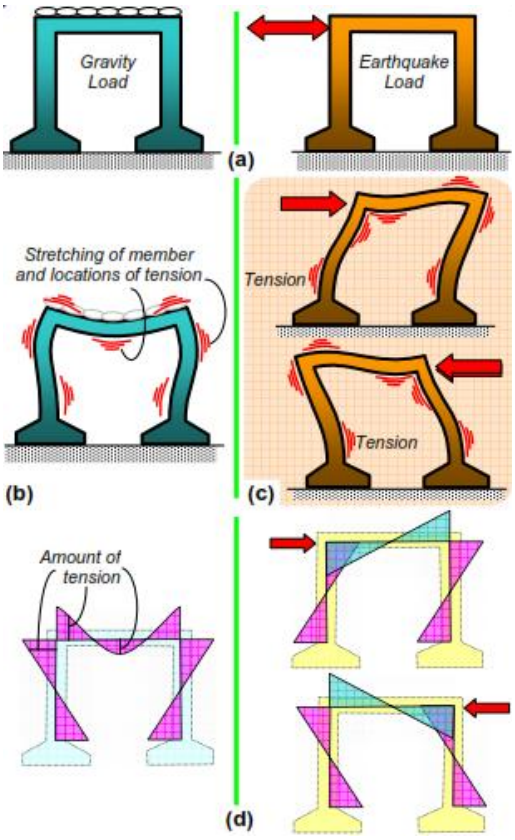


Fig. 49 Earthquake shaking reverses tension and compression in members – reinforcement is required on both faces of members

moment due to earthquake loading depends on severity of shaking and can exceed that due to gravity loading. Thus, under strong earthquake shaking, the beam ends can develop tension on either of the top and bottom faces. Since concrete cannot carry this tension, steel bars are required on both faces of beams to resist *reversals* of bending moment. Similarly, steel bars are required on all faces of columns too.

7.2 बीम जिन्हें आर सी इमारतों में भूकंप बलों का विरोध करने के लिए डाला जाता है / Beams that are required to resist Earthquake Forces in RC Buildings

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.

Beams in RC buildings have two sets of steel reinforcement (Fig. 50), 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.

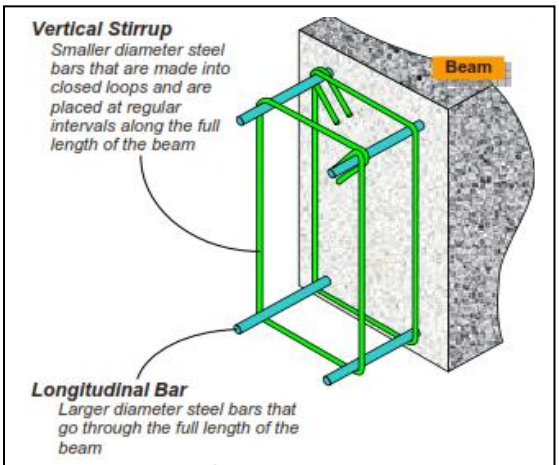


Fig. 50 Steel reinforcement in beams - stirrups prevent longitudinal bars from bending outwards

Beams sustain two basic types of failures, namely:

(i) *Flexural (or Bending) Failure*

As the beam sags under increased loading, it can fail in two possible ways (Fig. 51).

- 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 snaps and 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.

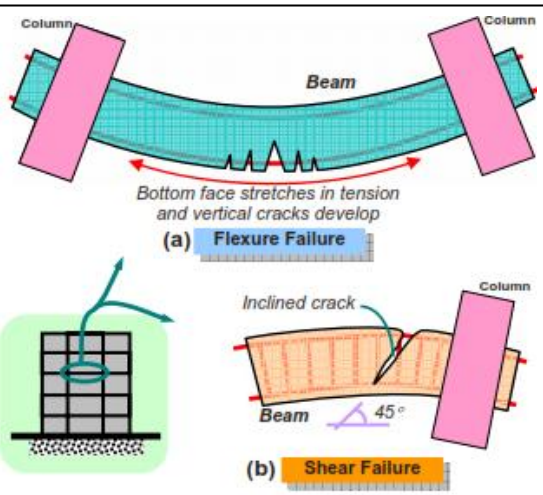


Fig. 51 Two types of damage in a beam: flexure damage is preferred. Longitudinal bars resist the tension forces due to bending while vertical stirrups resist shear forces

(ii) *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. 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.

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 (Fig. 52).

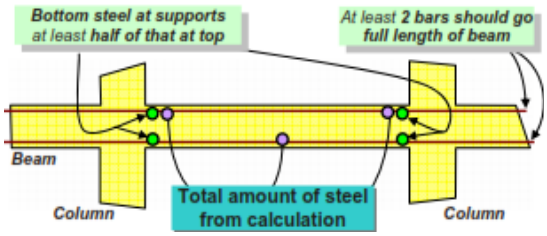


Fig. 52 Location and amount of longitudinal steel bars in beams – these resist tension due to flexure

- 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.
- 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 IS13920-1993.

7.3 कॉलम जिन्हें आरसी इमारतों में भूकंप बलों का विरोध करने के लिए डाला जाता है / Columns that are required to resist Earthquake Forces in RC Buildings

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.

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.

Closely spaced horizontal closed ties (Fig. 53) help in three ways, namely

(i) they carry the horizontal shear forces induced by earthquakes, and thereby resist diagonal shear cracks,

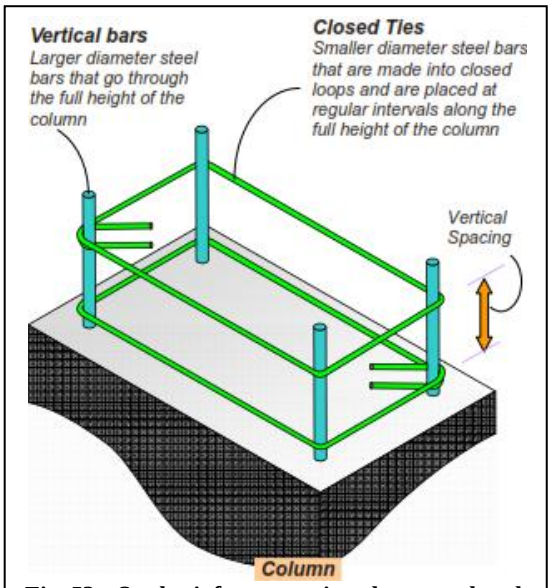


Fig. 53 Steel reinforcement in columns – closed ties at close spacing improve the performance of columns under strong earthquake shaking

(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. Such hook ends prevent opening of loops and consequently bulging of concrete and buckling of vertical bars.

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 (Fig. 54); special care is required to implement this properly at site.

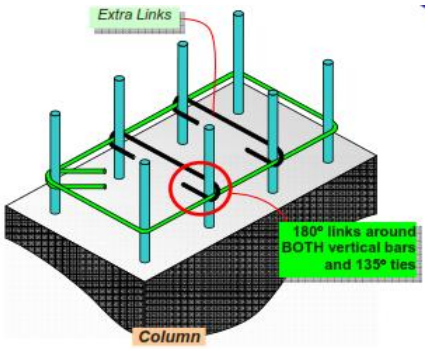


Fig. 54 Extra links are required to keep the concrete in place – 180° links are necessary to prevent the 135° tie from bulging outwards

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 IS 13920 : 1993 requires columns to be at least 300 mm wide. A column width of up to 200 mm is allowed if unsupported length is less than *4m* and beam length is less than *5m*. Columns that are required to resist earthquake forces must be designed to prevent *shear* failure by a skillful selection of reinforcement.

7.4 बीम-कॉलम जोड़ जो आरसी इमारतों में भूकंप बलों का विरोध करते हैं / Beam-Column Joints that resist Earthquakes Forces in RC Buildings

In RC buildings, portions of *columns* that are common to *beams* at their intersections are called *beam column joints* (Fig. 55). 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.

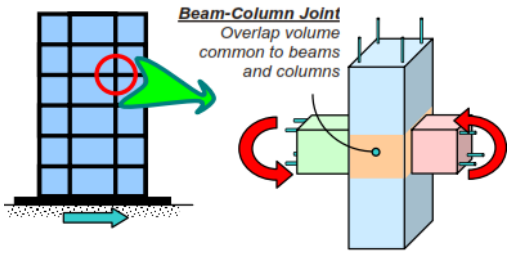


Fig. 55 Beam-Column Joints are critical parts of a building – they need to be designed

Under earthquake shaking, the beams adjoining a joint are subjected to moments in the same (clockwise or counter-clockwise) direction.

- Under these moments, the top bars in the beam-column joint are pulled in one direction and the bottom ones in the opposite direction. These forces are balanced by bond stress developed between concrete and steel in the joint region. (Fig. 56)

- 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. 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.
- If the column cross-sectional size is insufficient, the concrete in the joint develops diagonal cracks.

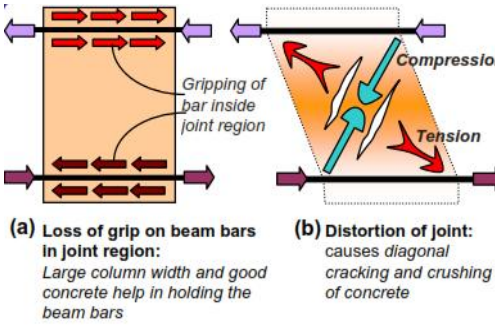


Fig. 56 Pull-push forces on joints cause two problems – these result in irreparable damage in joints under strong seismic shaking

7.4.1 Reinforcing the Beam-Column Joint

Diagonal cracking and crushing of concrete in joint region should be prevented to ensure good earthquake performance of RC frame buildings. (Fig. 57)

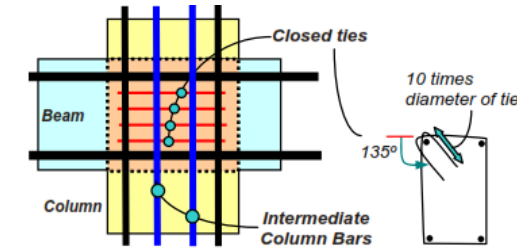


Fig. 57 Closed loop steel ties in beam-column joints – such ties with 135° hooks resist the ill effects of distortion of joints

- 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 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. Providing closed-loop ties in the joint requires some extra effort.
- IS:13920-1993 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. (Fig. 58)

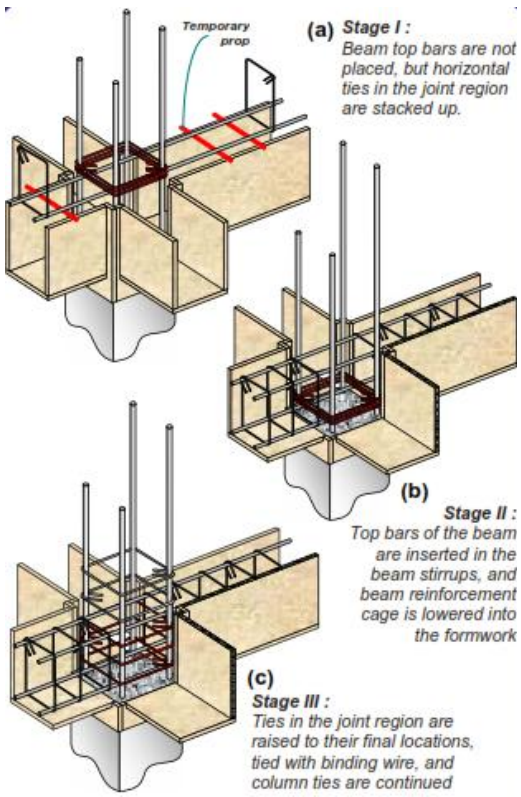


Fig. 58 Providing horizontal ties in the joints – three-stage procedure is required

However, this may not always be possible particularly when the beams are long and the entire reinforcement cage becomes heavy.

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:13920-1993 requires building columns in seismic zones III, IV and V to be at least *300mm* wide in each direction of the cross-section when they support beams that are longer than *5m* or when these columns are taller than *4m* between floors (or beams).

In exterior joints where beams terminate at columns, 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. (Fig. 59)

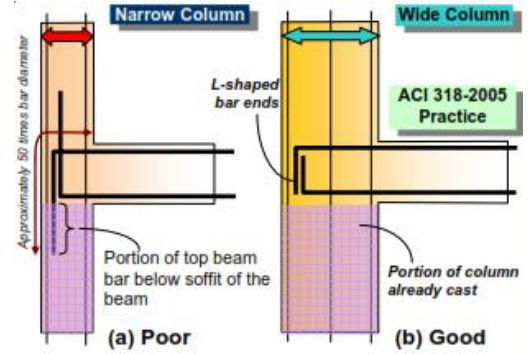


Fig. 59 Anchorage of beam bars in exterior joints – diagrams show elevation of joint region

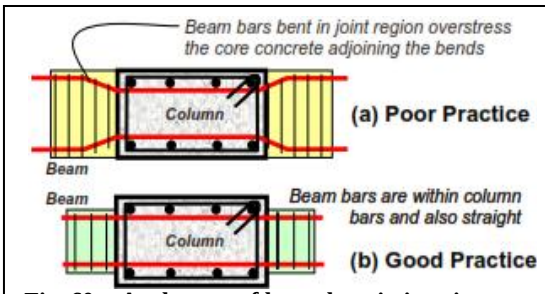


Fig. 60 Anchorage of beam bars in interior joints– diagrams (a) and (b) show cross-sectional views in plan of joint region

- In columns of small widths and when beam bars are of large diameter (Fig. 60 (a)), 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 *90°* 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 (Fig. 60(b)). Thus, it is preferable to have columns with sufficient width.
- 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.

7.5 ओपन-ग्राउंड मंजिला इमारत जो कि भूकंप में कमजोर होती है / Open-Ground Storey Building that is vulnerable in Earthquake

The buildings that have been constructed in recent times with a special feature - the ground storey is left *open* for the purpose of parking, *i.e.*, columns in the ground storey do not have any partition walls (of either masonry or RC) between them, are called *open ground storey buildings* or *buildings on stilts*.

An open ground storey building (Fig. 61), having *only columns* in the ground storey and *both partition walls and columns* in the upper storeys, have two distinct characteristics, namely:

(a) It is relatively *flexible* in the ground storey, *i.e.*, the relative horizontal displacement it undergoes in the ground storey is much larger than what each of the storeys above it does. This flexible ground storey is also called *soft storey*.

(b) It is relatively *weak* in ground storey, *i.e.*, the total horizontal earthquake force it can carry in the ground storey is significantly smaller than what each of the storeys above it can carry. Thus, the open ground storey may also be a *weak storey*.

The collapse of more than a hundred RC frame buildings with open ground storeys at Ahmedabad (~225km away from epicenter) during the 2001 Bhuj earthquake has emphasized that such buildings are *extremely* vulnerable under earthquake shaking.

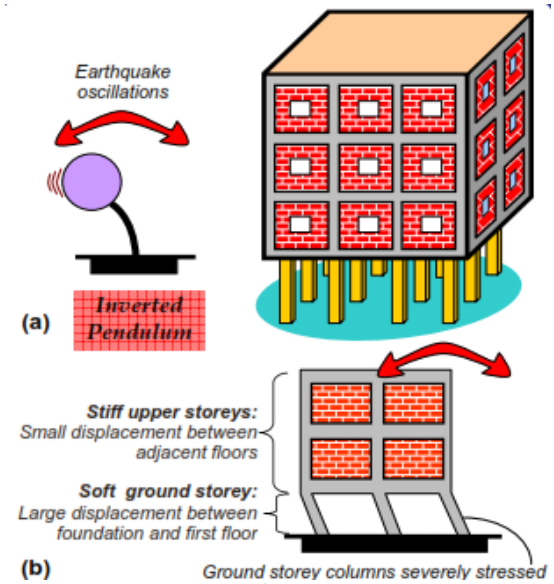


Fig. 61 Upper storeys of open ground storey buildings move together as a single block – such buildings are like inverted pendulums

7.5.1 इम्प्रूव्ड़ डिजाइन रणनीतियां / Improved design strategies

After the collapses of RC buildings in 2001 Bhuj earthquake, the Indian Seismic Code IS 1893 (Part 1): 2002 has included special design provisions related to soft storey buildings.

- Firstly, it specifies when a building should be considered as a *soft* and a *weak storey building*.
- Secondly, it specifies higher design forces for the soft storey as compared to the rest of the structure.

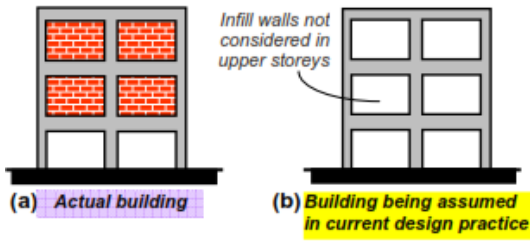


Fig. 62 Open ground storey building – assumptions made in current design practice are not consistent with the actual structure

The Code suggests that the forces in the columns, beams and shear walls (if any) under the action of seismic loads specified in the code, may be obtained by considering the *bare frame* building (without any infills). However, beams and columns *in the open ground storey* are required to be designed for 2.5 times the forces obtained from this bare frame analysis. (Fig. 62)

For all *new RC frame buildings*, the best option is to avoid such sudden and large decrease in stiffness and/or strength in any storey; it would be ideal to build walls (either masonry or RC walls) in the ground storey also. Designers can avoid dangerous effects of flexible and weak ground storeys by ensuring that too many walls are not discontinued in the ground storey, *i.e.*, the drop in stiffness and

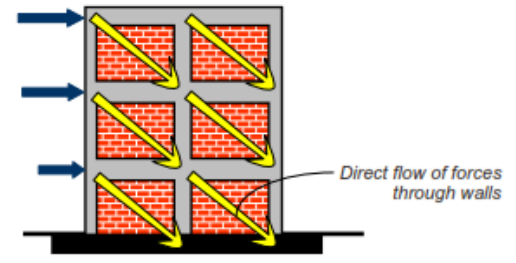


Fig. 63 Avoiding open ground storey problem – continuity of walls in ground storey is preferred

strength in the ground storey level is not abrupt due to the absence of infill walls. (Fig. 63)
The *existing open ground storey buildings* need to be strengthened suitably so as to prevent them from collapsing during strong earthquake shaking. The owners should seek the services of qualified structural engineers who are able to suggest appropriate solutions to increase seismic safety of these buildings.

7.6 भूकंप के दौरान लघु कॉलम वाली इमारतों का व्यवहार / Behavior of Buildings with Short Columns during Earthquakes

During past earthquakes, reinforced concrete (RC) frame buildings that have columns of different heights within one storey, suffered more damage in the shorter columns as compared to taller columns in the same storey.

Two examples of buildings with short columns are shown in Fig. 64 – (a) buildings on a sloping ground and (b) buildings with a mezzanine floor

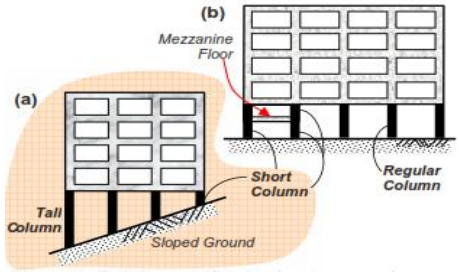


Fig. 64 Buildings with short columns – two explicit examples of common occurrences

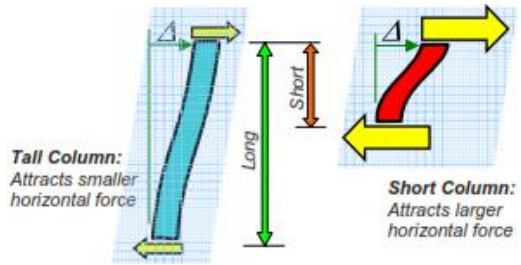


Fig. 65 Short columns are stiffer and attract larger forces during earthquakes – this must be accounted for in design

Poor behaviour of short columns is due to the fact that in an earthquake, a tall column and a short column of same cross-section move horizontally by same amount.

However, the short column is stiffer as compared to the tall column, and it attracts larger earthquake force. Stiffness of a column means resistance to deformation – the larger is the stiffness, larger is the force required to deform it. If a short column is not adequately designed for such a large force, it can suffer significant damage during an earthquake. This behaviour is called *Short Column Effect.* (Fig. 65)

In new buildings, *short column effect* should be avoided to the extent possible during *architectural design* stage itself. When it is not possible to avoid short columns, this effect must be addressed in structural design. The IS: 13920-1993 for ductile detailing of RC structures requires special confining reinforcement to be

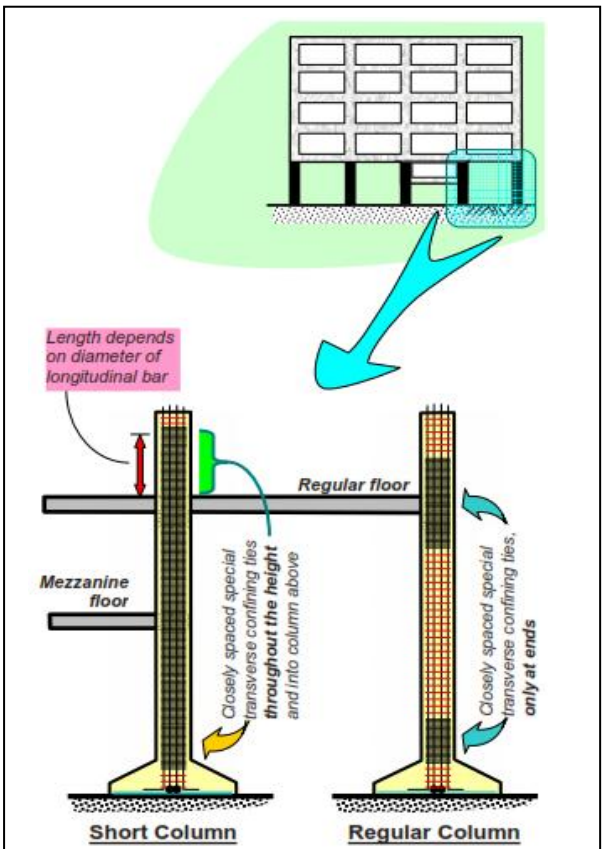


Fig. 66 Details of reinforcement in a building with short column effect in some columns – additional special requirements are given in IS:13920- 1993 for the short columns

provided over the *full height* of columns that are likely to sustain short column effect.

The special confining reinforcement (*i.e.*, closely spaced closed ties) must extend beyond the short column into the columns vertically above and below by a certain distance as shown in Fig. 66.

In existing buildings with short columns, different retrofit solutions can be employed to avoid damage in future earthquakes. Where walls of partial height are present, the simplest solution is to close the openings by building a wall of full height – this will eliminate the short column effect. If that is not possible, short columns need to be strengthened using one of the well established retrofit techniques. The retrofit solution should be designed by a qualified structural engineer with requisite background.

7.7 विशेषतः भूकंपीय क्षेत्र में कतरनी दीवारों वाली इमारतों का निर्माण / Construction of Buildings with Shear Walls preferably in Seismic Regions

Reinforced concrete (RC) buildings often have *vertical plate-like* RC walls called *Shear Walls* 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. Shear walls are like *vertically-oriented* wide *beams* that carry earthquake loads downwards to the foundation. (Fig. 67)

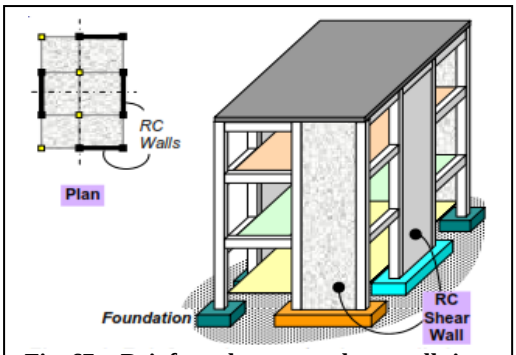


Fig. 67 Reinforced concrete shear walls in buildings – an excellent structural system for earthquake resistance

Properly designed and detailed buildings with shear walls have shown *very good* performance in past earthquakes. Shear walls in high seismic regions require special detailing. Shear walls are efficient, both in terms of construction cost and effectiveness in minimizing earthquake damage in structural and non-structural elements (like glass windows and building contents).

- 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*

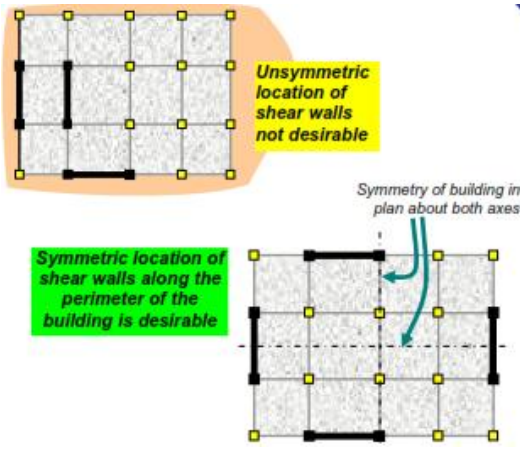


Fig. 68 Shear walls must be symmetric in plan layout – twist in buildings can be avoided

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.
- Shear walls in buildings must be symmetrically located in plan to reduce ill-effects of twist in buildings. (Fig. 68)
- Shear walls are more effective when located along exterior perimeter of the building – such a layout increases resistance of the building to twisting.

7.7.1 तन्य डिजाइन और कतरनी दीवारों की ज्यामिति / Ductile Design and Geometry of Shear 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. 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:13920-1993) provides special design guidelines for ductile detailing of shear walls.

7.8 हानिकारक भूकंप प्रभाव से इमारतों का संरक्षण /Protection of Buildings from Damaging Earthquake Effects

Conventional seismic design attempts to make buildings that do not collapse under strong earthquake shaking, but may sustain damage to non-structural elements (like glass facades) and to some structural members in the building. There are two basic technologies – *Base Isolation Devices* and *Seismic Dampers*, which are used to protect buildings from damaging earthquake effects.

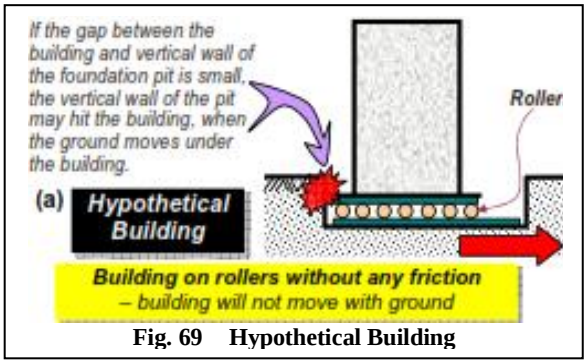


Fig. 69 Hypothetical Building

7.8.1 आधार अलगाव / Base Isolation

The idea behind *base isolation* is to detach (*isolate*) the building from the ground in such a way that earthquake motions are not transmitted up through the building, or at least greatly reduced.

- As illustrated in Fig. 69, when the ground shakes, the rollers freely roll, but the building above does not move. Thus, no force is transferred to the building due to shaking of the ground; simply, *the building does not experience the earthquake*.

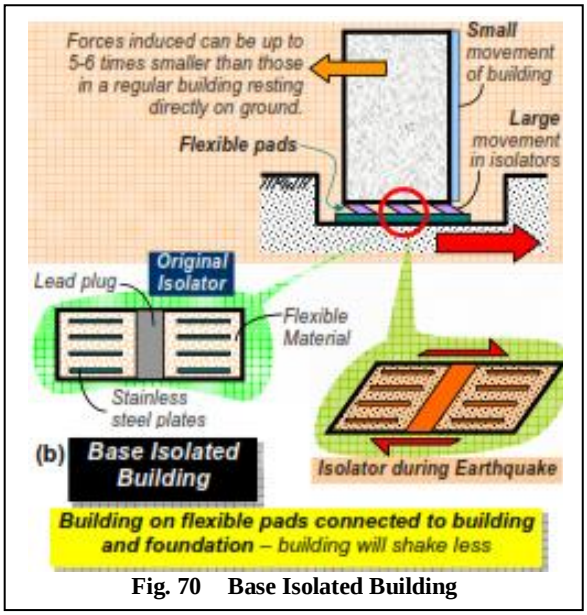


Fig. 70 Base Isolated Building

- As illustrated in Fig. 70, if the same building is rested on flexible pads that offer resistance against lateral movements, then *some* effect of the ground shaking will be transferred to the building above.

- As illustrated in Fig. 71, if the flexible pads are properly chosen, the forces induced by ground shaking can be a few times smaller than that experienced by the building built directly on ground, namely a *fixed base building*.

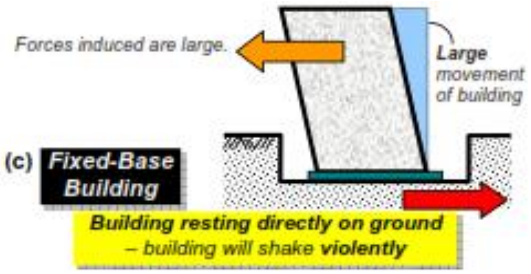


Fig. 71 Fixed-Base Building

7.8.2 भूकंपी स्पंज / Seismic Dampers

Seismic dampers are special devices introduced in the building to absorb the energy provided by the ground motion to the building. These dampers act like the hydraulic shock absorbers in cars – much of the sudden jerks are absorbed in the hydraulic fluids and only little is transmitted above to the chassis of the car.

When seismic energy is transmitted through them, dampers absorb part of it, and thus *damp* the motion of the building. Commonly used types of seismic dampers (Fig. 72) include

- *Viscous dampers* – Energy is absorbed by silicone-based fluid passing between piston-cylinder arrangement.

- *Friction dampers* – Energy is absorbed by surfaces with friction between them rubbing against each other.

- *Yielding dampers* – Energy is absorbed by metallic components that yield.

In India, friction dampers have been provided in an 18-storey RC frame structure in Gurgaon.

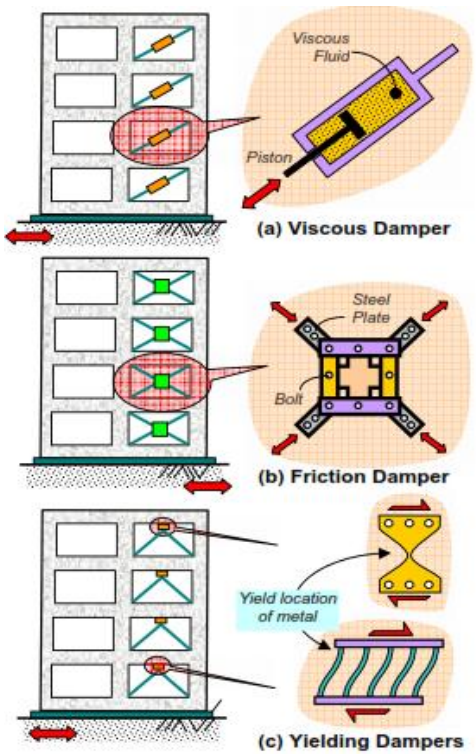


Fig. 72 Seismic Energy Dissipation Devices – each device is suitable for a certain building

7.9 भूकंपरोधी इमारतों की लचीलापन आवश्यकताएँ / Ductility requirements of Earthquake Resistant Buildings

The primary members of structure such as beams and columns are subjected to stress reversals from earthquake loads. The reinforcement provided shall cater to the needs of reversal of moments in beams and columns, and at their junctions.

Earthquake motion often induces forces large enough to cause inelastic deformations in the structure. If the structure is brittle, sudden failure could occur. But if the structure is made to behave ductile, it will be able to sustain the earthquake effects better with some deflection larger than the yield deflection by absorption of energy. Therefore, besides the design for strength of the frame, ductility is also required as an essential element for safety from sudden collapse during severe shocks.

The ductility requirements will be deemed to be satisfied if the conditions given as in the following are achieved.

1. For all buildings which are more than 3 storeys in height, the minimum grade of concrete shall be M20 (f_{ck} = 20 MPa)

2. Steel reinforcements of grade Fe 415 (IS 1786: 1985) or less only shall be used.

However, high strength deformed steel bars, produced by the thermo-mechanical treatment process, of grades Fe 500 and Fe 550, having elongation more than 14.5 percent and conforming to other requirements of IS 1786 : 1985 may also be used for the reinforcement.

7.10 झुकने एवं अक्षीय भार के अधीन कॉलम और फ्रेम मेम्बर / Columns and Frame Members subjected to Bending and Axial Load

7.10.1 सामान्य आवश्यकताएँ / General Requirements

- These requirements apply to frame members which have a factored axial stress in excess of 0.1 f_{ck} under the effect of earthquake forces.
- The minimum dimension of the member shall not be less than 200 mm. However, in frames which have beams with centre to centre span exceeding 5 m or columns of unsupported length exceeding 4 m, the shortest dimension of the column shall not be less than 300 mm.
- The ratio of the shortest cross sectional dimension to the perpendicular dimension shall preferably not be less than 0.4.

7.10.2 अनुदैर्ध्य सुदृढीकरण / Longitudinal Reinforcement

- Lap splices shall be provided only in the central half of the member length. It should be proportioned as a tension splice. Hoops shall be provided over the entire splice length at spacing not exceeding 150 mm centre to centre. Not more than 50 percent of the bars shall be spliced at one section.

- Any area of a column that extends more than 100 mm beyond the confined core due to architectural requirements shall be detailed in the following manner.

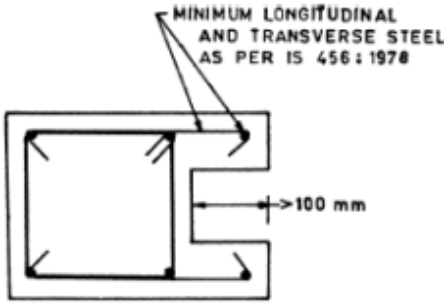


Fig. 73 Reinforcement requirement for Column with more than 100 mm projection beyond core (IS 13920: 1993)

a) In case the contribution of this area to strength has been considered, then it will have the minimum longitudinal and transverse reinforcement as per IS 13920: 1993.

b) However, if this area has been treated as non-structural, the minimum reinforcement requirements shall be governed by IS 456: 1978 provisions minimum longitudinal and transverse reinforcement, as per IS 456: 1978 (as shown in Fig. 73).

7.11 अनुप्रस्थ सुदृढीकरण / Transverse Reinforcement

- Transverse reinforcement for circular columns shall consist of spiral or circular hoops. In rectangular columns, rectangular hoops may be used. A rectangular hoop is a closed stirrup, having a 135° hook with a 10 diameter extension (but not < 75 mm) at each end, that is embedded in the confined core (as shown in Fig. 74 A).

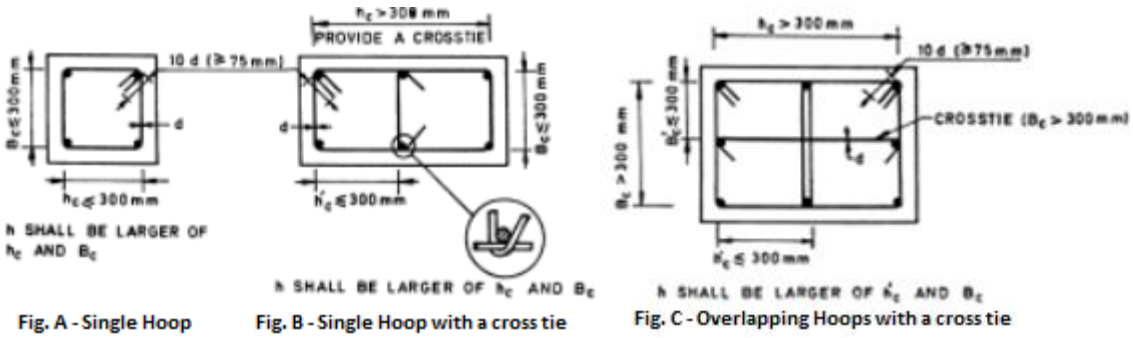


Fig. 74 Transverse Reinforcement in Column (IS 13920: 1993)

- The parallel legs of rectangular hoop shall be spaced not more than 300 mm centre to centre. If the length of any side of the hoop exceeds 300 mm, a crosstie shall be provided (as shown in Fig. 74 B). Alternatively, a pair of overlapping hoops may be provided within the column (as shown in Fig. 74 C). The hooks shall engage peripheral longitudinal bars.

- The spacing of hoops shall not exceed half the least lateral dimension of the column, except where special confining reinforcement is provided, as per Para 7.12 below.

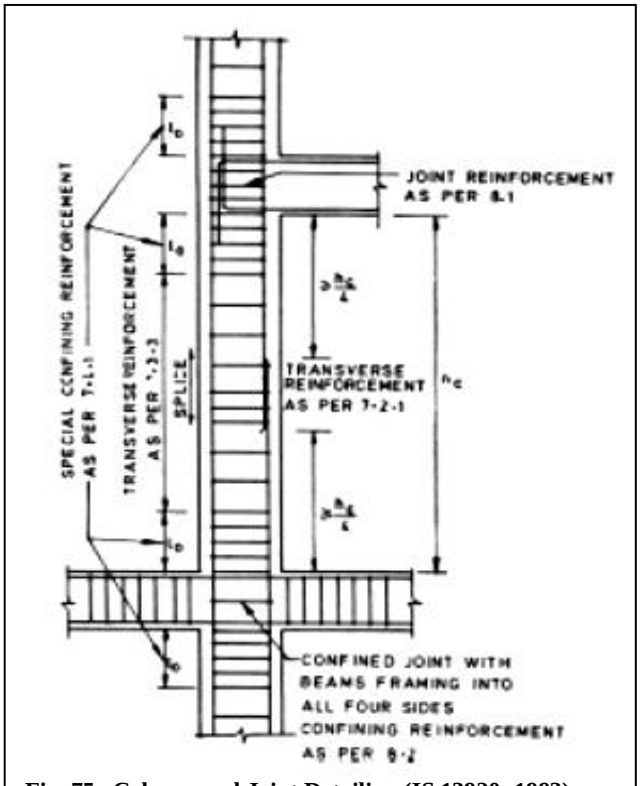


Fig. 75 Column and Joint Detailing (IS 13920: 1993)

7.12 विशेष सीमित सुदृढीकरण / Special Confining Reinforcement

This requirement shall be met with, unless a larger amount of transverse reinforcement is required from shear strength considerations.

- Special confining reinforcement shall be provided over a length '*l*o' from each joint face, towards mid span, and on either side of any section, where flexural yielding may occur under the effect of earthquake forces (as shown in Fig. 75). The length '*l*o' shall not be less than

  (a) larger lateral dimension of the member at the section where yielding occurs,

  (b) 1/6 of clear span of the member, and

  (c) 450 mm

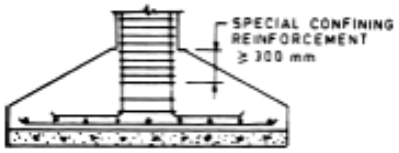


Fig. 76 Provision of Special confining reinforcement in Footings (IS 13920: 1993)

- When a column terminates into a footing or mat, special confining reinforcement shall extend at least 300 mm into the footing or mat (as shown in Fig. 76).

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

- Columns supporting reactions from discontinued stiff members, such as walls, shall be provided with special confining reinforcement over their full height (as shown in Fig. 77). 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.

- 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 the presence of bracing, a mezzanine floor or a R.C.C. wall on either side of the column that extends only over a part of the column height (as shown in Fig. 77).

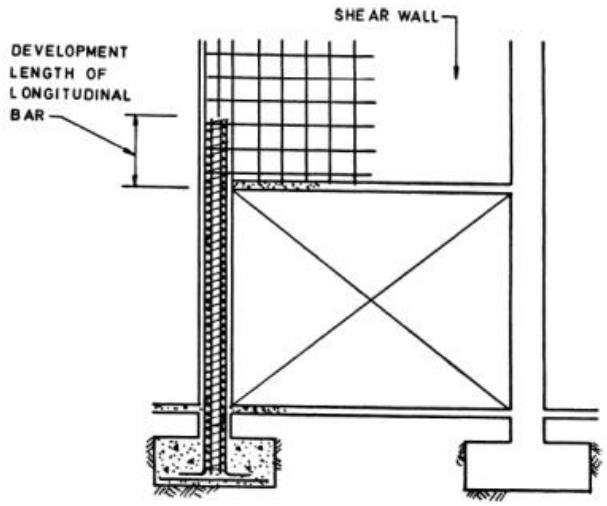


Fig. 77 Special Confining Reinforcement Requirement for Columns under Discontinued Walls (IS 13920: 1993)

7.13 फ्लेक्स्चरल मेम्बर्स / Flexural Members

These members shall satisfy the following requirements.

- The member shall preferably have a width-to-depth ratio of more than 0.3.

- The width of the member shall not be less than 200 mm.
- The depth D of the member shall preferably be not more than 1/4 of the clear span.
- The factored axial stress on the member under earthquake loading shall not exceed $0.1f_{ck}$.

7.14 अनुदैर्ध्य सुदृढीकरण / Longitudinal Reinforcement

a) The top as well as bottom reinforcement shall consist of at least two bars throughout the member length.

b) The tension steel ratio on any face, at any section, shall not be less than $\rho_{min} = 0.24$; where f_{ck} and f_y are in MPa.

The positive steel at a joint face must be at least equal to half the negative steel at that face.

- The steel provided at each of the top and bottom face of the member at any section along its length shall be at least equal to one-fourth of the maximum negative moment steel provided at the face of either joint. It may be clarified that redistribution of moments permitted in IS 456: 1978 (clause 36.1) will be used only for vertical load moments and not for lateral load moments.

- In an external joint, both the top and the bottom bars of the beam shall be provided with anchorage length, beyond the inner face of the column, equal to the development length in tension plus 10 times the bar diameter minus the allowance for 90 degree bend(s) (as shown in Fig. 78). In an internal joint, both face bars of the beam shall be taken continuously through the column.

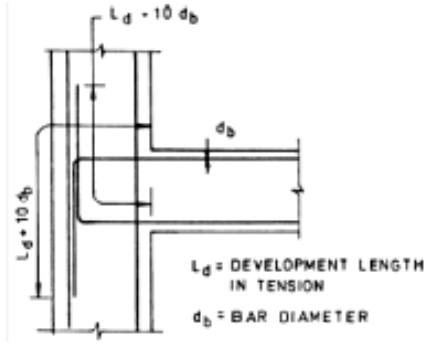
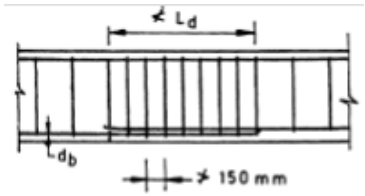


Fig. 78 Anchorage of Beam Bars in an External Joint (IS 13920: 1993)

7.15 अनुदैर्ध्य सुदृढीकरण की स्प्लाइसिंग / Splicing of longitudinal reinforcement

- The longitudinal bars shall be spliced, only if hoops are provided over the entire splice length, at a spacing not exceeding 150 mm (as shown in Fig. 79). The lap length shall not be less than the bar development length in tension. Lap splices shall not be provided (a) within a joint, (b) within a distance of 2*d* from joint face, and (c) within a quarter length of the member where flexural yielding may generally occur under the effect of earthquake forces. Not more than 50 percent of the bars shall be spliced at one section.



Ld = DEVELOPMENT LENGTH IN TENSION
db = BAR DIAMETER

Fig. 79 Lap, Splice in Beam (IS 13920: 1993)

- Use of welded splices and mechanical connections may also be made, as per 25.2.5.2 of IS 456: 1978. However, not more than half the reinforcement shall be spliced at a section where flexural yielding may take place.

7.16 वेब सुदृढीकरण / Web Reinforcement

Web reinforcement shall consist of vertical hoops. A vertical hoop is a closed stirrup having a 135° hook with a 10 diameter extension (but not < 75 mm) at each end that is embedded in the confined core (as shown in Fig. 80 (a)). In compelling circumstances, it may also be made up of two pieces of reinforcement; a U-stirrup with a 135° hook and a 10 diameter extension (but not < 75 mm) at each end, embedded in the confined core and a crosstie (as shown in Fig. 80 (b)). A crosstie is a bar having a 135° hook with a 10 diameter extension (but not < 75 mm) at each end. The hooks shall engage peripheral longitudinal bars.

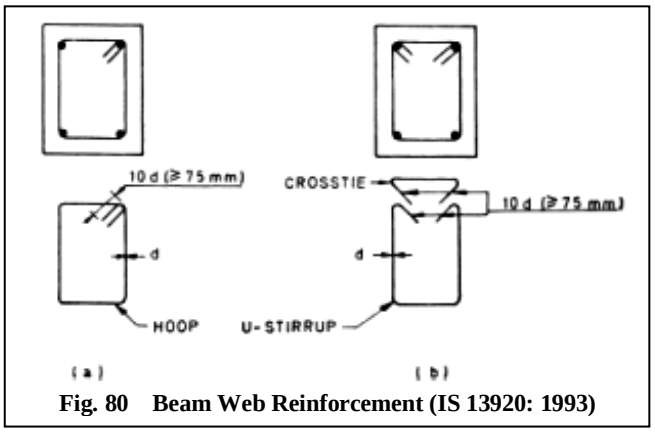


Fig. 80 Beam Web Reinforcement (IS 13920: 1993)

***

अध्याय / Chapter – 8

भारतीय भूकंपी संहिताएँ / Indian Seismic Codes

Development of building codes in India started rather early. Today, India has a fairly good range of seismic codes covering a variety of structures, ranging from mud or low strength masonry houses to modern buildings. However, the key to ensuring earthquake safety lies in having a robust mechanism that enforces and implements these design code provisions in actual constructions.

8.1 भूकंपी डिजाइन कोड का महत्व / Importance of Seismic Design Codes

Ground vibrations during earthquakes cause forces and deformations in structures. Structures need to be designed to withstand such forces and deformations. Seismic codes help to improve the behaviour of structures so that they may withstand the earthquake effects without significant loss of life and property. An earthquake-resistant building has four *virtues* in it, namely:

(a) *Good Structural Configuration*: Its size, shape and structural system carrying loads are such that they ensure a direct and smooth flow of inertia forces to the ground.
(b) *Lateral Strength*: The maximum lateral (horizontal) force that it can resist is such that the damage induced in it does not result in collapse.
(c) *Adequate Stiffness*: Its lateral load resisting system is such that the earthquake-induced deformations in it do not damage its contents under low-to moderate shaking.
(d) *Good Ductility*: Its capacity to undergo large deformations under severe earthquake shaking even after yielding, is improved by favourable design and detailing strategies.

Seismic codes cover all these aspects.

8.2 भारतीय भूकंपी संहिताएँ / Indian Seismic Codes

Seismic codes are unique to a particular region or country. They take into account the local seismology, accepted level of seismic risk, building typologies, and materials and methods used in construction. The first formal seismic code in India, namely IS 1893, was published in 1962. Today, the Bureau of Indian Standards (BIS) has the following seismic codes:

1. IS 1893 (Part I) : 2002, *Indian Standard Criteria for Earthquake Resistant Design of Structures* (5 Revision)
2. IS 4326 : 1993, *Indian Standard Code of Practice for Earthquake Resistant Design and Construction of Buildings* (2nd Revision)
3. IS 13827 : 1993, *Indian Standard Guidelines for Improving Earthquake Resistance of Earthen Buildings*
4. IS 13828 : 1993, *Indian Standard Guidelines for Improving Earthquake Resistance of Low Strength Masonry Buildings*

5. IS 13920 : 1993, *Indian Standard Code of Practice for Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces*
6. IS 13935 : 1993, *Indian Standard Guidelines for Repair and Seismic Strengthening of Buildings*

The regulations in these standards do not ensure that structures suffer *no damage* during earthquake of *all magnitudes*. But, to the extent possible, they ensure that structures are able to respond to earthquake shakings of *moderate intensities* without *structural damage* and of *heavy intensities* without *total collapse*.

8.2.1 IS 1893 (Part I) : 2002

IS 1893 is the main code that provides the seismic zone map and specifies seismic design force. This force depends on the mass and seismic coefficient of the structure; the latter in turn depends on properties like seismic zone in which structure lies, importance of the structure, its stiffness, the soil on which it rests, and its ductility. For example, a building in Bhuj will have 2.25 times the seismic design force of an identical building in Bombay. Similarly, the seismic coefficient for a single-storey building may have 2.5 times that of a 15-storey building.

The revised 2002 edition, Part 1 of IS 1893, contains provisions that are general in nature and those applicable for buildings. The other four parts of IS 1893 will cover:

a) Liquid-Retaining Tanks, both elevated and ground supported (*Part 2*)
b) Bridges and Retaining Walls (*Part 3*)
c) Industrial Structures including Stack Like Structures (*Part 4*) and
d) Dams and Embankments (P*art 5*)

These four documents are under preparation. In contrast, the 1984 edition of IS1893 had provisions for all the above structures in a single document.

Provisions for Bridges

Seismic design of bridges in India is covered in three codes, namely *IS 1893 (1984)* from the BIS, *IRC 6 (2000)* from the Indian Roads Congress, and *Bridge Rules (1964)* from the Ministry of Railways. All highway bridges are required to comply with IRC 6, and all railway bridges with Bridge Rules. These three codes are conceptually the same, even though there are some differences in their implementation. After the 2001 Bhuj earthquake, in 2002, the IRC released interim provisions that make significant improvements to the IRC6 (2000) seismic provisions.

8.2.2 IS 4326 : 1993

This code covers general principles for earthquake resistant buildings. Selection of materials and *special features* of design and construction are dealt with for the following types of buildings: timber constructions, masonry constructions using rectangular masonry units, and buildings with prefabricated reinforced concrete roofing/flooring elements.

8.2.3 IS 13827 : 1993 and IS 13828 : 1993

Guidelines in IS 13827 deal with empirical design and construction aspects for *improving* earthquake resistance of *earthen houses*, and those in IS 13828 with general principles of design and special construction features for *improving* earthquake resistance of buildings of *low-strength masonry*. This Masonry includes burnt clay brick or stone masonry in weak mortars, like clay-mud. These standards are applicable in seismic zones III, IV and V. Constructions based on them are termed non-engineered, and are not totally free from collapse under seismic shaking intensities VIII (MMI) and higher. Inclusion of features mentioned in these guidelines may only enhance the seismic resistance and reduce chances of collapse.

8.2.4 IS 13920 : 1993

In India, reinforced concrete structures are designed and detailed as per the Indian Code IS 456 (2002). However, structures located in *high seismic regions* require ductile design and detailing. Provisions for the ductile detailing of *monolithic* reinforced concrete frame and shear wall structures are specified in IS 13920 (1993). After the 2001 Bhuj earthquake, this code has been made mandatory for all structures in zones III, IV and V. Similar provisions for seismic design and ductile detailing of steel structures are not yet available in the Indian codes.

8.2.5 IS 13935 : 1993

These guidelines cover general principles of seismic strengthening, selection of materials, and techniques for repair/seismic strengthening of masonry and wooden buildings. The code provides a brief coverage for *individual reinforced concrete members* in such buildings, but does not cover *reinforced concrete frame* or *shear wall buildings* as a whole. Some guidelines are also laid down for *non-structural* and *architectural components* of buildings.

***

संदर्भ / REFERANCE

1	Guidelines for Earthquake Resistant Non-Engineered Construction, reprinted by Indian Institute of Technology Kanpur 208016, India (Source: www.nicee.org)
2	IS 1893 (Part 1): 2002 Criteria for Earthquake Resistant Design Of Structures PART- 1 GENERAL PROVISIONS AND BUILDINGS (Fifth Revision)
3	IS 4326: 1993 (Reaffirmed 1998) Edition 3.2 (2002-04) Earthquake Resistant Design and Construction of Buildings – Code of Practice (Second Revision) (Incorporating Amendment Nos. 1 & 2)
4	IS 13828: 1993 (Reaffirmed 1998) Improving Earthquake Resistance of Low Strength Masonry Buildings – Guidelines
5	IS 13920: 1993 (Reaffirmed 1998) Edition 1.2 (2002-03) Ductile Detailing of Reinforced Concrete Structures subjected to Seismic Forces – Code of Practice (Incorporating Amendment Nos. 1 & 2)
6	IS 13935 : 1993 (Reaffirmed 1998) Edition 1.1 (2002-04) Repair and Seismic Strengthening of Buildings – Guidelines (Incorporating Amendment No. 1)
7	Earthquake Tips authored by Prof. C V R Murty, IIT Kanpur and sponsored by Building Materials and Technology Promotion Council, New Delhi, India. (Source: www. www.iitk.ac.in)

***

टिप्पणी / NOTES

गुणवत्ता नीति

रेलों में यात्री और माल यातायात की बढ़ती माँग को पूरा करने के लिए गुणवत्ता प्रबंध प्रणाली में अनुसंधान, डिज़ाइनों और मानकों में उत्कृष्टता तथा सतत सुधारों के माध्यम से सांविधिक और नियामक अपेक्षाओं को पूरा करते हुए सुरक्षित, आधुनिक और किफ़ायती रेल प्रौद्योगिकी का विकास करना।

QUALITY POLICY

To develop safe, modern and cost effective Railway technology complying with Statutory and Regulatory requirements, through excellence in Research, Designs & Standards and Continual improvements in Quality Management System to cater to growing demand of passenger and freight traffic on the Railways.

डिस्क्लेमर / Disclaimer

The document prepared by CAMTECH is meant for the dissemination of the knowledge/ information mentioned herein to the field staff of Indian Railways. The contents of this handbook/booklet are only for guidance. Most of the data & information contained herein in the form of numerical values are indicative and based on codes and tests/trials conducted by various agencies generally believed to be reliable. While reasonable care and effort has been taken to ensure that information given is at the time believed to be fare and correct and opinion based thereupon are reasonable. Due to very nature of research it can not be represented that it is accurate or complete and it should not be relied upon as such. The reader/user is supposed to refer the relevant codes/ manuals available on the subject before actual implementation in the field.

हमारा उद्देश्य

अनुरक्षण प्रौद्यौगिकी और कार्यप्रणाली को उन्नयन करना तथा उत्पादकता और रेल्वे की परिसम्पत्ति एवं जनशक्ति के निष्पादन में सुधार करना जिससे अन्तर्विषयों में विश्वसनीयता, उपयोगिता और दक्षता प्राप्त की जा सके।

यदि आप इस सन्दर्भ में कोई विचार और सुझाव देना चाहते हों तो कृपया हमें इस पते पर लिखें:

सम्पर्क सूत्र	:	उप निदेशक (सिविल)
पत्राचार का पता	:	भारतीय रेल उच्च अनुरक्षण प्रौद्योगिकी केन्द्र, महाराजपुर, ग्वालियर (म.प्र.) पिनकोड - **474005**
टेलीफोन	:	0751–2470869
फैक्स	:	0751–2470841
ई–मेल	:	**dircivilcamtech@gmail.com**

Our Objective

To upgrade Maintenance Technologies and Methodologies and achieve improvement in productivity and performance of all Railway assets and manpower which inter-alia would cover Reliability, Availability, and Utilisation.

If you have any suggestion & comments, please write to us:

Contact person	**:**	**Dy. Director (Civil),**
Postal Address	**:**	**Indian Railway Centre for Advanced Maintenance Technology,** **Maharajpur, Gwalior (M.P.)** **Pin code – 474 005**
Phone	**:**	**(0751) - 2470869**
Fax	**:**	**(0751) – 2470841**
Email	**:**	**dircivilcamtech@gmail.com**