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EARTHQUAKE RESISTANT DESIGN OF BUILDINGS: A GUIDELINE

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ABSTRACT

Earthquake tremors have shook India time and again. Due to unsafe construction practices these earthquake waves have left with damages to life and property. As maximum part of India lies in earthquake prone zone the earthquake resistant building is the need of the hour. Earthquake resistant design features can minimize these loss and damages. But people are found to be unaware and reluctant of this methodology. Earthquake resistant design features might be expensive for shorter span but prove beneficial for longer span.This paper covers all the features of earthquake resistant design and the highlights some of the low cost ones. It aims at brining awareness among the people, prevention of damages and safeguarding the country's wealth.

Keywords: Building, damages, earthquake, earthquake resistant design,low cost features

I. INTRODUCTION

Building is a shelter which people occupy for their living or pursue their living functions. It is essential that a building whether, it is office building, a shopping complex, a residential area or any playhouse, must be able to withstand all the forces which could be applies on it. The building must be able to protect the occupants from natural phenomenon such as rain, snow, heat and cold and hazards such as strong winds and earthquakes. The intensity of the hazards differ from place to place. It has different intensities in different regions across the world [1].

An Earthquake (also known as a quake, tremor and temblor) is the result of a sudden release of energy in the earth's crust that creates seismic waves. Earthquakes are measured using observations from seismometers. An earthquakes point of initial rupture is called its focus or hypocentre. The epicentre is the point at ground level directly above the hypocentre.

Earthquakes are caused due to due to the movement of the tectonic plates and rupture of the rock zones called faults. The tectonic plates move relative to one another building strain energy along theplates boundaries. When this energy exceeds the capacity of the rock materials along the fault line surface, the fault ruptures and seismic waves are produced. These waves then travel to the earth surface through hard bedrock layers. Most of the earthquakes occur along the plate boundaries.

India is quite vulnerable to the hazards caused by Earthquakes. The entire Himalayan Range and several tracts of Peninsular India are prone to Earthquake hazards. The Himalayan range and the Tibetan is formed by the collision of Indian plate and Eurasian plate. The rest of India is formed by the Indo-Australian plate. Recent studies suggests that India and Australia have separate plates. The Earthquakes in the country results due to the

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movement of these plates. Himalayan range which is also known as the young-fold mountain range is so called because the mountain range is increasing in height every year. Due to this reason the Himalayan Range is found to be one of the most vulnerable part of the country for Earthquakes. The Indian region which is divided into 4 zones as per IS 1893:2002 [2]. The most part of the country falls in the crucial zones III, IV and V.

The country has faced major losses in the past due to the damages caused by Earthquakes to life and property. According to Indian National Heritage Trust for Arts and Cultural Heritage (INTACH), the Bhuj earthquake (2001) resulted the collapse or serious damage to about 40% of the buildings while 10% remained undamaged [3]. The Killari Earthquake (1993) resulted in the collapse of 71% of the dwellings [4].

It is a very sad fact that the earthquakes are very unpredictable and thus can't be prevented. But damages and loss of both life and property can be prevented by proper precautionary measures. One of the precautions comes on the form of Earthquake Resistant design of the Buildings.

Structures are often found to lack the basic features of Earthquake Resistant design. People are often found to be unaware of the features that shall be adopted for making a structure aseismic. Labour is often found to redundant to use these features due to the lack ofknowledge. Thus, there is a need of spreading awareness among the people to adopt this methodology to prevent the loss of life and property.

II. HISTORICAL DEVELOPMENT

The Earthquake engineering has been developed through the experiences gained from the past earthquakes and their consequences. The building structures have been evolved from using timber to masonry structures and then to the RCC structures. The buildings are damaged when the inertial forces associated with earthquakes exceeds the structural resistance offered by the structure. As inertia is all related to mass, greater the mass more is the inertial forces, the heavy construction material or the heavy structures attract large inertia force whereas resistance is low.

John Milne at University of Tokyo studied the damage caused in 1891 Nohbi Earthquake, Japan and recommended that "we must construct, not only to resist vertically applied stress, but carefully consider the effects due to movement applied more or less in horizontal directions".

M. Panetti, Professor of Applied Mechanics in Turin gave the first quantitative seismic design recommendations after the Messina Earthquake 1908. He suggested that the first storey must be designed for horizontal forces equal to 1/12 the weight above and second and third storey to be designed for 1/8 of the weight above.

The introduction of moment distribution method in 1930 gave a method of structural analysis to estimate the distribution of internal forces under design lateral forces. The US Seismological Field Survey was established in 1932 and installed the first strong motion Seismographs in California. The response of highly idealized simple design was calculated when subjected to observed ground motions using a simple mechanical analyser in 1941. These calculations of response of buildings to earthquake were sensitive to period of a system. The 1943 City of Los Angeles Building Code introduced design seismic coefficients as a function of number of stories, which influenced the period if oscillation of a building.

The relation between the maximum response if linearly elastic and elasto-plastic systems was reported in 1960. Linearly elastic response spectra have been used in the seismic design to determine the required load resistance of a structure for estimated ductility capacity.

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With the development of digital computer technology, realistic nonlinear response of building structures was calculated under earthquake motions. This made possible the construction of high-rise buildings in seismically active zones. Recent application of base isolation and vibrational controls can further reduce the damage to the building construction during an intense earthquake [1].

III.SEISMIC DESIGN PHILOSOPHY AS PER IS 1893:2002 Part 1

1. The philosophy of seismic design can be summarized as:

The design philosophy adopted in the code is to ensure that structure possess at least a minimum strength to:

a. Resist minor earthquake (< DBE), which may occur frequently, without damage.

b. Resist moderate earthquake (DBE) without significant structural damage through some non-structural damage.

c. Resist major earthquake (MCE) without collapse.

“Design Basis Earthquake is defined as the maximum earthquake that reasonably can be expected to experience at the site once during lifetime of the structure. The earthquake corresponding to the ultimate safety requirements is often called as Maximum Considered Earthquake (MCE). Generally DBE is half of MCE.

2. Actual forces that appear on the structures during earthquakes are much higher than the design forces specified in the code. It is recognised that the complete protection against earthquakes of all sizes is not economically feasible and design based alone on strength criteria is not justified. The basic criteria of earthquake resistant design should be based on lateral strength as well as deformability and ductility capacity of the structure with limited damage, but no collapse. Ductility in the structures will arise from inelastic material, behaviour and detailing of the reinforcement in such a manner that brittle failure is avoided and ductile behaviour is induced by allowing steel to yield in controlled manner. Therefore, the gap between the actual and design lateral forces is narrowed down by providing ductility in the structure and additional reserve strength in the structures over and above the design strength.

3. The design lateral forces specified in the code shall be considered in each of the two orthogonal directions of the structure. For structures, which have lateral force resisting elements in the two orthogonal directions only, the design lateral force shall be considered along one direction at a time, and not in both directions simultaneously. Structures, having lateral force resisting elements in direction other than the two orthogonal directions, shall be analysed considering the load combinations as specified in the code.

4. The response of a structure to ground vibrations is a function of nature of foundation soil; material, form, size and mode of construction of structures; and the duration and characteristics of ground motion. This code specifies design forces for the structures standing on rock or firm soils, which do not liquefy or slide due to loss of strength during ground vibrations [5].

IV. REASONS FOR BUILDING FAILURE DURING EARTHQUAKE

1. The Soil Fails: The horizontal and vertical forces of the earthquake move the ground sideways and up & down simultaneously. These forces are powerful enough to turn the soft soil into quicksand, which reduces the bearing capacity of the soil. Buildings constructed on the soil having low bearing capacity are therefore under special risk. These may be found sinking after the tremors stop.

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2. The Foundation Fails: Every building has a capability of resisting some lateral forces due to its weight like the normal wind load. Even the poorly constructed ones a capable of doing so. But building are not necessarily designed for earthquake loads as they are irregular, multidirectional and intense side-to-side loads. In case if the earthquake loads there is a high possibility of failure of the foundation connection. As the lateral forces of earthquakes increases with increase in height of the structure, taller buildings are more prone to these kinds of failures. The building slides off its foundation due to the lateral forces. Use of anchor bolts or reinforcement to the foundation wall also help to protect against the concentration of shear forces at grade.

3. A soft Floor fails: Floors with minimum interior shear walls, additional floor-to-floor height or large open space with concentration of building mass above are known as soft floors. These floors often crumble due to the large inertial force acting above them during an earthquake. Soft floors are less rigid which makes them susceptible to failure due to earthquake [6].

4. A building joint fails: Many times it is found that there are new expansion to the buildings which are connected with the older buildings. The expansion usually do not match the height of the rest of the structure and it is being found to be pounded by the older structure during an earthquake. It is therefore necessary to provide sufficient clearance between the structures or the provision of effective expansion joints must be there.

5. The Building Fails: Sometimes it is found that the roof or façade fall from the building during or after an earthquake. These failures occur because several diverse building elements have been treated like a single system when, in fact they must be tied separately back to the structure, with space between them to provide differential movements of the dissimilar elements [7].

6. Cheap Concrete: The failure is also associated with quality of the material used. People are usually found to use sub-standard material during construction to cut down the cost, without considering the long term consequences. Also, it is a well-known fact that the strength of the concrete decreases when huge amount of water is added to it. People are found to ignore this fact to save cost on material. Building codes are also not followed properly. The buildings so constructed do not meet up to the requirements of the load conditions and are subjected to failure.

7. Resonance: It is usually found that the buildings having lesser height are ignored from the consideration under the earthquake resistant design. But the failure of the building due to earthquake is majorly dependent on the resonance. During an earthquake not all buildings respond to an earthquake equally. If the frequency of oscillations meet the natural frequency of the building, then resonance can cause severe damage. Small buildings are more affected by the high-frequency waves while the tall buildings are affected by low frequency waves [8].

V. COMMON UNSAFE PRACTICES IN EARTHQUAKE PRONE ZONES

During an earthquake, a wave propagates from the rock to the soil and then into the structure. The key to the designing an Earthquake resistant structure is to build a ductile structure rather than a stiff structure. The extent

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of damage caused by the earthquake depends on the distance of epicentre from the structure horizontally and vertically below the ground. If the epicentre is close to the surface the damage tends to be greater. Also, as discussed earlier soft soil can lead to liquefaction or quick sand resulting into damage of the structures. Some areas in Delhi are prone to the occurrence of Liquefaction during an earthquake.

Load bearing structures are brittle and have low resistance toearthquake. In recent earthquake in Nepal most of the structures that were damaged were load bearing structures. One way to protect these kinds of failures is to separate the superstructure from the foundation using base isolation, which shall be discussed later.

In RCC framed structures usually parking is built on the ground floor with greater height and no walls are provided in the parking area. These are regarded as soft or weak storey. This increase the flexibility of the ground floor and the floors above sway more than the ground floor. These parking greatly reduces the earthquake resistance of the structures and lead to failure during an earthquake event [9].

Common unsafe practices are:

1. Plan and mass irregularity.
2. Buildings with vertical setbacks or excessive overhangs.
3. Cantilever staircase.
4. Floating Columns.
5. Columns of parking not designed for ductile loading.
6. Design of buildings in seismic zones without considering the relevant code.
7. Improper anchorage of the structure to the ground.
8. Providing soft storey.
9. Torsional irregularity in the structure.
10. Diaphragm Discontinuity or difference in the stiffness of the diaphragm or provision of more than 50% openings in the diaphragm.
11. Pounding effect.
12. Vertical Discontinuity in Load.
13. Poor Hillside Practices [10].

VI. CONSIDERATIONS FOR MAKING RC BUILDINGS EARTHQUAKE RESISTANT

1. Stronger Columns: Stronger columns weak beam theory must be adopted in buildings as when dispatching the forces toward the footing from the structure, columns play a vital role than that of the beams *(See Fig 1.1)*[11].

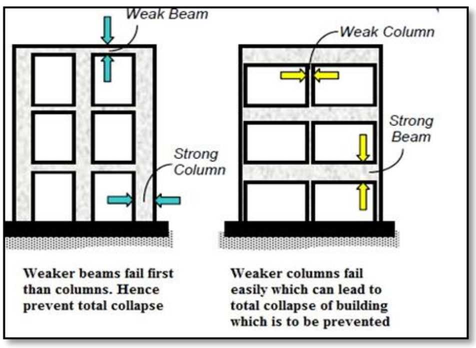

Fig. 1.1: Strong Column Weak Beam

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2. Symmetrical dimensions: Structure should not be too long or too high (both cases make the structure irregular and easily susceptible to seismic forces) *(See Fig. 1.2)*

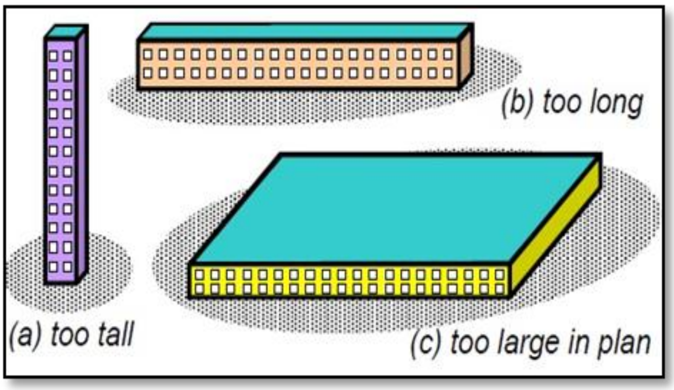
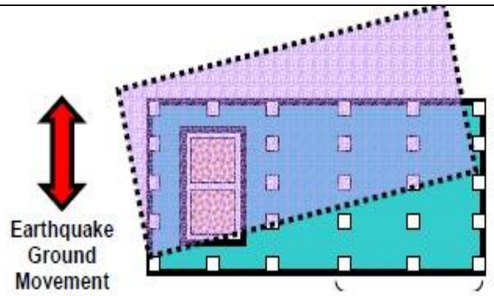
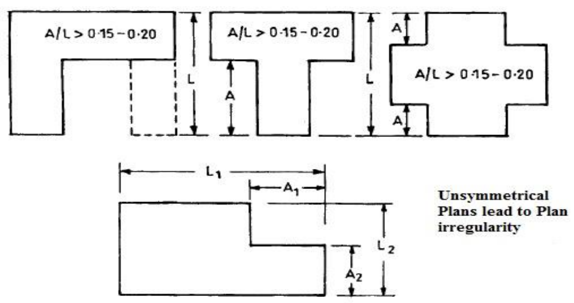
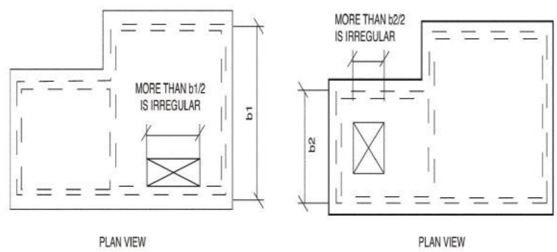


Fig. 1.2: Improper dimensions of building attract more seismic forces

3. Horizontal Irregularities should be avoided: Structure might be of various shapes but for earthquake-resistant design, a simple and regular shape such as rectangular can be beneficial *(See Table 1.1)*

Table 1.1: Plan Irregularities

Torsional Irregularity It is to be considered to exist when the maximum storey drift, computed with design eccentricity, at one end of the structures transverse to an axis is more than 1.2 times the average of the storey drifts at the two ends of the structure	
Re-entrant Corners Plan configurations of a structure and its lateral force resisting system contain re-entrant corners, where both projections of the structure beyond the re-entrant corner are greater than 15 percent of its plan dimension in the given direction	
Diaphragm Discontinuity Diaphragms with abrupt discontinuities or variations in stiffness, including those having cut-out or open areas greater than 50 percent of the gross enclosed diaphragm area, or changes in effective diaphragm stiffness of more than 50 percent from one storey to the next	

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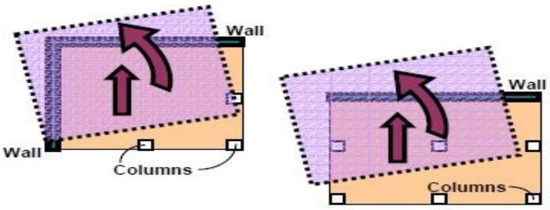
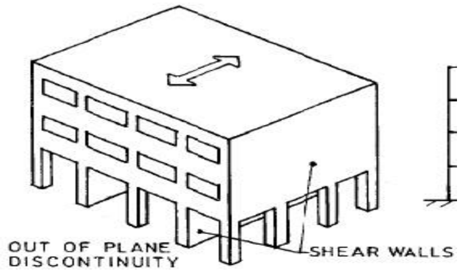
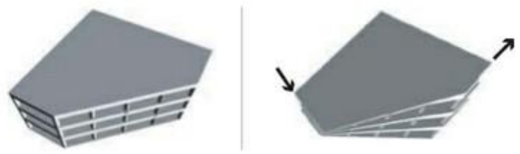
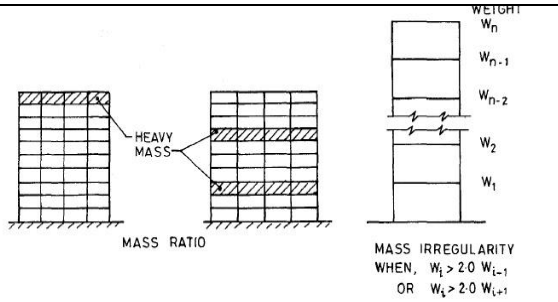
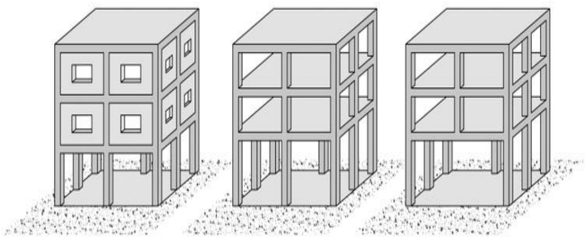
Out-of-Plane Offsets Discontinuities in a lateral force resistance path, such as out-of-plane offsets of vertical elements 	
Non-parallel Systems The vertical elements resisting the lateral force are not parallel to or symmetric about the major orthogonal axes or the lateral force resisting elements	

4. Vertical Irregularities should be avoided: Mass and stiffness of different components should be regularly distributed throughout the height of the building. Irregularities need to be avoided. The components of the structure like walls and columns should not be discontinued (See Table 1.2)

Table 1.2: Vertical Irregularities

Mass Irregularity Mass irregularity shall be considered to exist where the seismic weight of any storey is more than 200 percent of that of its adjacent storeys. The irregularity need not be considered in case of roofs	
Stiffness Irregularity —Soft Storey A soft storey is one in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of the average lateral stiffness of the three storeys above	 (a) Stiff and strong upper floors due to masonry infills (b) The columns in one storey longer than those above (c) Soft storey caused by discontinuous column

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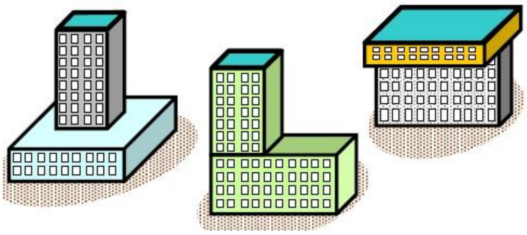
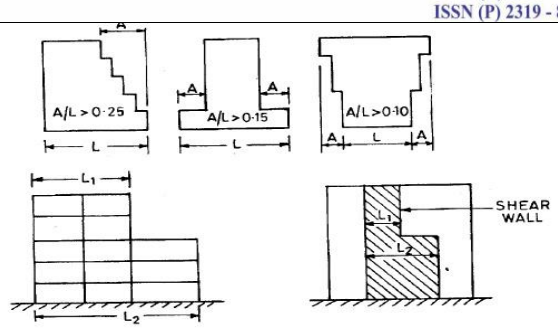
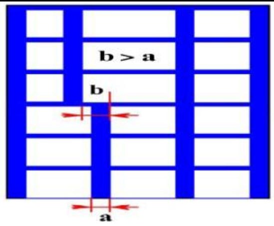
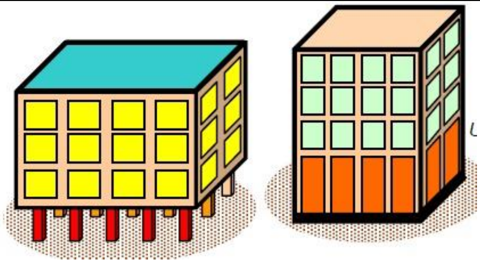
Vertical Geometric Irregularity Vertical geometric irregularity shall be considered to exist where the horizontal dimension of the lateral force resisting system in any storey is more than 150 percent of that in its adjacent storey 	 4 C Vertical Geometric Irregularity when $L_2 > 1.5\ L_1$
In-Plane Discontinuity in Vertical Elements Resisting Lateral Force A in-plane offset of the lateral force resisting elements greater than the length of those elements	
Discontinuity in Capacity— Weak Storey A weak storey is one in which the storey lateral strength is less than 80 percent of that in the storey above, The storey lateral strength is the total strength of all seismic force resisting elements sharing the storey shear in the considered direction.	

5. **Providing lateral force resisting elements:** Shear walls and cross bracings should be provided as a part of lateral force resisting system of the frame. In some very important structures, base isolators are also provided. (See Fig. 1.3) Use of waste tyre pads as isolators and isolators made of concrete and rubber can serve for low cost features[12].

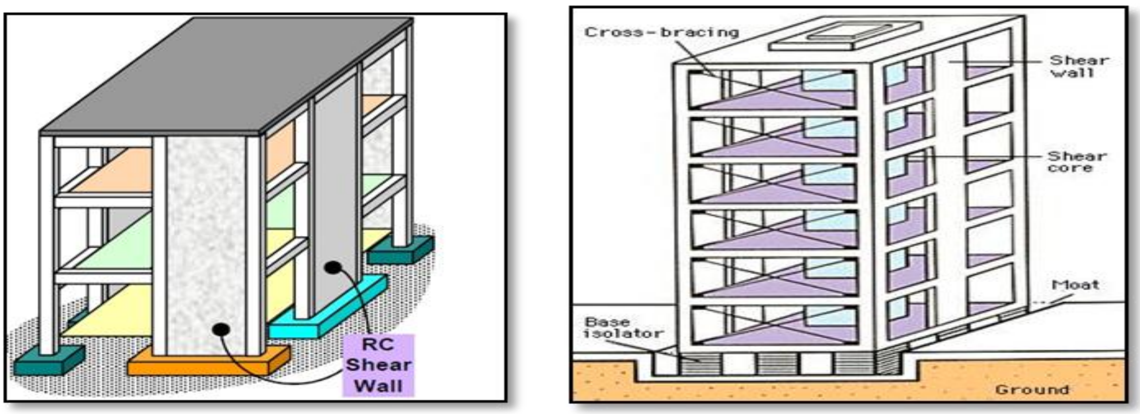


Fig. 1.3: Shear Wall, Cross Bracings, Base Isolator

6. Proper spacing: Adequate spacing must be maintained between two buildings so as to prevent pounding. *(See Fig. 1.4)*

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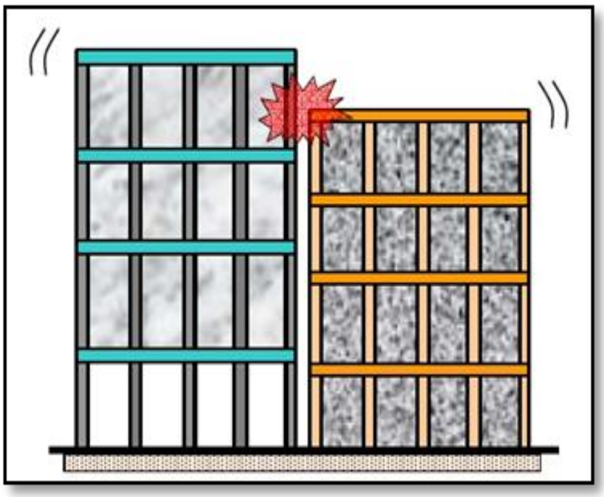

Figure 1.4: Proper Spacing between Buildings

7. Light weight: Earthquake force is a function of mass, the building shall be as light as possible. Also, as inertia forces accumulate downwards from the top of the building, the columns and walls at lower storey's experience higher earthquake-induced forces and are therefore designed to be stronger than those in storeys above. Roofs and upper storeys of buildings, in particular, should be designed as light as possible.

8. Quality of construction and materials: The different structural components: beams, columns, should be ductile so as to easily undergo allowable displacements within a limit. Stiff members can be very easily cracked being brittle. Concrete mix and reinforcement should be of proper standards.

9. Short Columns: When a building is rested on sloped ground, during earthquake shaking all columns move horizontally by the same amount along with the floor slab at a particular level. If short and tall columns exist within the same storey level, then the short columns attract several times larger earthquake force and suffer more damage as compared to taller ones. The short column effect also occurs in columns that support mezzanine floors or loft slabs that are added in between two regular floors. *(See Figure 1.5)*

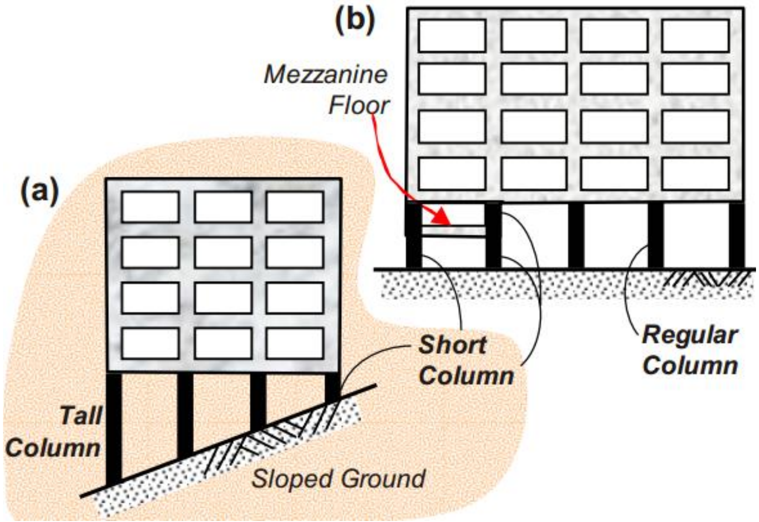

Fig. 1.5: Short Column Effect

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VII. CONSIDERATIONS FOR MASONRY BUILDINGS

1. Wall Thickness and Box Action: Masonry walls are slender because of their small thickness compared to their height and length. A simple way of making these walls behave well during earthquake shaking is by making them act together as a box along with the roof at the top and with the foundation at the bottom. *(See Fig. 1.6)*

2. Isolated Staircase and Lesser Openings: In a masonry structure staircase slab acts like a cross-brace between floors and transfers large horizontal forces at the roof and lower levels. These are areas of potential damage in masonry buildings. 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. *(See Fig. 1.7)*

3. Horizontal Bands: The bands are provided to hold a masonry building as a single unit by tying all the walls together, and are similar to a closed belt provided around cardboard boxes. There are four types of bands in a typical masonry building, namely gable band, roof band, lintel band and plinth band, named after their location in the building. *(See Fig. 1.8) These bands account for low cost feature*[13].

4. Vertical Reinforcement: 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. *(See Fig. 1.9)*.

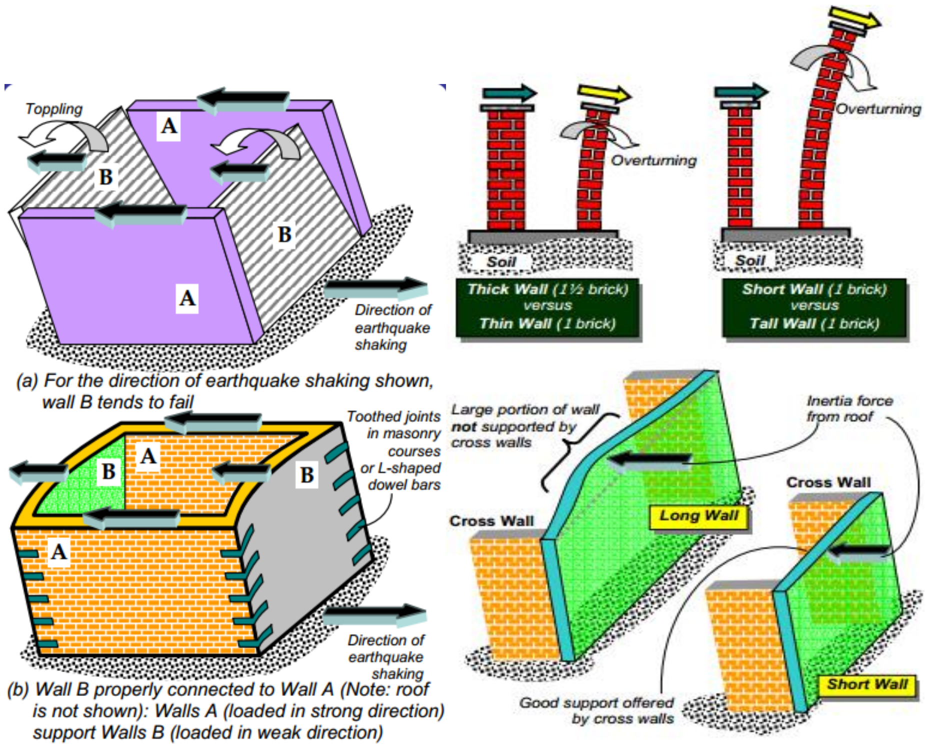

Fig. 1.6: Role of Box Action and Wall thickness

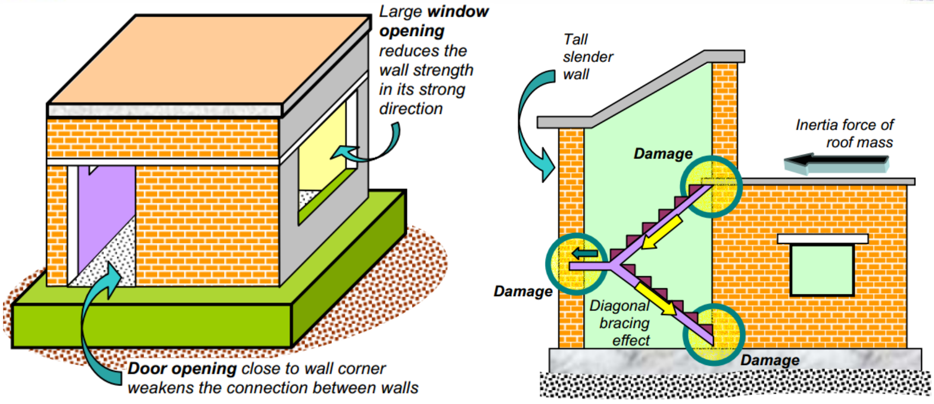

Fig. 1.7: Openings and Staircase

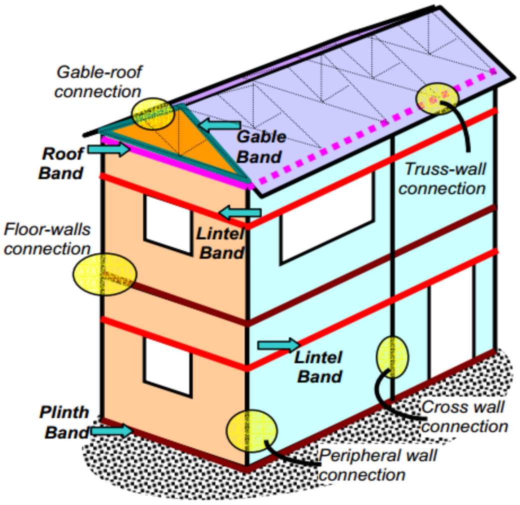

Fig. 1.8: Bands in Masonry Structure

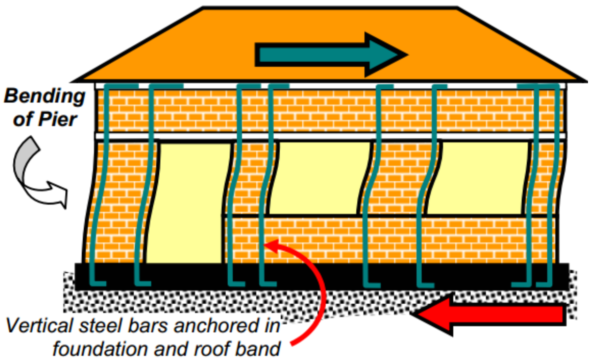

Fig. 1.9: Role of Vertical Reinforcement

VII. CONCLUSION

Before the construction of any building the zone should be checked as to in which earthquake zone does the building fall into and construction should be done judiciously. In order to construct an earthquake resistant building various design considerations need to be kept in mind. The irregularities of any sort need to be avoided. The building structure shall be ductile, brittle structures shall be avoided. Special care has to be taken while constructing a building on a hilly terrain, short columns shall be avoided.

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