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A BUILDING THAT CAN WITHSTAND EARTHQUAKE

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ABSTRACT

Earthquake is a natural calamity that causes loss to life and property. Earthquakes are the indication of transformation in the earth's internal structure. Seismic activity is common in most parts of the world, though the frequency of its occurrence is a function of local tectonic arrangement. Though it is not possible to avoid a quake, the least that can be attained in reducing the harm is to make the structures earthquake resistant. With the progression in our understanding of the earthquakes, most of the nations have directed the integration of seismic provisions in construction design and architecture planning.

In the occurrence of an earthquake, the seismic waves originating from the concentration is spread in all the probable directions. These shock waves circulate in the form of body waves and surface waves through the earth's internal. They are extremely random in nature. These ground motions cause buildings to vibrate and induce inertia forces in the structural foundations. In the absence of seismic design plan, the building may fail, leading to a disaster. The seismic design aims to mainly safeguard and secure the functionality of the structure. In combination with the design viewpoint, it is vital to implement earthquake-safe construction practices for the effective seismic performance of a building.

No zone in the whole of India can be assumed as earthquake free due to the ongoing subduction of the Indian Plate under the Eurasian plate. The paper aims to create an awareness on the earthquake-safe buildings in various seismic zones. The most common building structures built in the recent years are the moment resisting frame (RC frame), moment resisting frames with brick infill, and masonry buildings. This study explores the construction practices implemented for these common building typologies. Approvals are made for the local construction practices wherever found necessary with relevance to the codal provisions. In addition, the possible future trend in the earthquake resistant technology has also been discussed.

INTRODUCTION

Earthquakes are known to have great potential in causing a devastating impact on the built location and human life. India has seen over 9 severe earthquakes in the last two decades between 1990 and 2010 and reports claim the death rate to be around 30000. Although certain parts of the country are more prone to earthquakes (seismic zone V of IS 1893(Part 1)- 2016) than the rest, no region can be considered as free from earthquakes. In the Indian scenario, multiple microearthquakes are reported near the subduction zone (Himalayan belt) on a daily basis, whereas in the intraplate region (Deccan plateau) few major earthquakes have been witnessed over the years. The performance of the built environment during the past earthquakes has verified its fragile nature and has created a need among the engineers and architects to move towards seismically efficient buildings.

The majority of the Indian landmass (about 60%), is susceptible to moderate to very severe earthquakes. A excessive earthquake in an unoccupied area may produce nominal damage when compared to a moderate earthquake in a densely populated area. All the field survey studies conducted after a major earthquake shows that the maximum casualties reported were caused by building collapses. The lack of earthquake knowledge and its combination in the building design and execution leads to failure of buildings. A large part of the rural and urban dwellings are low rise non engineered buildings and these suffer maximum damage.

During an earthquake, the seismic waves propagate in all directions. However, among the various components, the horizontal vibration is considered to be the major cause of structural failure. The seismic waves tend to move the foundation of a building making inertial forces in various structural elements. The seismic activity of a structure during an earthquake rest on its overall shape, size, geometry and the nature of the load path.

The seismic design aims to safeguard the structural mechanisms and human life. It states that the load-bearing structural elements must avoid damage in an event of (frequent) minor shaking, withstand reparable damage in the event of (rare) moderate shaking and sustain severe damage without collapse under (rare) strong quake.

The present paper outlines the building typologies seen in the Indian subcontinent and their performance during earlier earthquakes. A look through the current earthquake proof construction practices has been attempted. Further, a brief report of the future trends in constructing building more resilient to earthquakes has been provided. Overall, in addition to effective and efficient seismic design, it is necessary to ensure strict code- compliant structural design and construction practices.

2. NECESSITY F OR THE EARTHQUAKE RESISTANT CONSTRUCTION

According to the 2011 census of India, there are over 330 million housing units in the country, (GOI,2011) with two-thirds of these being rural houses. The Geological Survey of India has classified the country into four seismic zones with fluctuating seismic potential.

Seismic zones IV and V constitute about 30% of the housing units. These rural building are mainly constructed using locally available resources such as mud and unburnt bricks, stone walls or walls made of burnt bricks, all of which are vulnerable due to poor construction and maintenance (BMTPC,2006). In addition to the larger part of housing stock in the rural area, a rapid growth in the urban population has been observed over the last decade. The census of India shows a 32% increase in growth of urban population from 286 million in 2001 to 377 million in 2011. The urban population by the end of 2030 is projected to be nearly 590 million. As per the statistics, 50% of the demand for construction activity in India comes from the infrastructure sector, others come from industrial activities, residential and commercial development etc.,(Make India, 2015). Due to rapid urbanization, there is an increased demand for infrastructure, essential basic amenities, residential layouts and municipal development.

The past earthquake knowledge has demonstrated the lack of seismic design in the modern residential buildings. At the same time, the significance of incorporation of seismic principles in structural design for a building to perform as a single unit in an earthquake has become clearer. It is necessary to empower rural communities to ensure the seismic safety of the building standard by creating awareness about earthquakes and importance of earthquake-resistant buildings.

The constructed environment in urban sectors has to be planned and calculated carefully in the initial stages so that the building configuration is favourable for good seismic performance.

The building models classified on the basis materials used for their construction are further classified based on the vertical or lateral load resisting systems. For example, buildings under structural concrete may be moment resisting frames or shear wall buildings based on the load resisting system unified into the buildings. The buildings that are built with bamboo as a material have mostly thatched roof system.

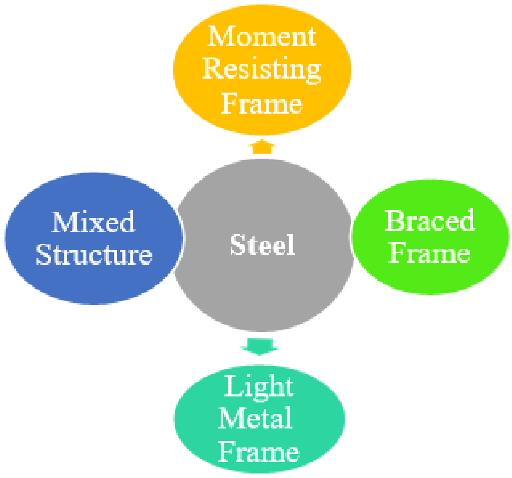

Figure 6: Classification of various load-bearing units of Steel.

In addition, various factors influence the Seismic performance of a building and are listed below.

•The height of the building – the seismic response of a building to a ground vibration is a function of its natural frequency - in other words, its inherent mass and stiffness. These factors vary with the height of the building and hence, its vulnerability. As a result, in severe seismic zones, the building height is restricted in accordance with the seismic hazard valuation that are specific to a region.

•Irregularities – The obstruction to the load in transferring the forces from rooftop to the foundation is caused by the horizontal and vertical irregularities present in the building. A more detailed description about the irregularities is given in IS 1893.

•Quality of Construction – The quality imparted by the local construction practices in terms of compliance with codal provisions and the Status of maintenance or visual appearance is a major factor.

•Ground Slope - In several parts of the country such as in the Himalayas, along with the Eastern and Western Ghats and in North-Eastern states, the sloping terrain is often encountered, as a result of which, a large number of buildings are located on hill slopes. Depending on the sloping angle, the slopes are classified as the gentle slope (≤ 20°) and steep slope (> 20°).

When buildings are constructed on moderate slopes, the ground is naturally levelled before construction. For a building constructed on a steep slope, the foundation varies in terms of elevation along the plan of the building. This leads to vertical members with varying mass and stiffness resulting in vertical irregularity. The stability of the ground is also one of the major parameters that influence the seismic performance of a building.

3.EARTHQUAKE RESISTANT CONSTRUCTION PRACTICES FOR MASONRY BUILDINGS

Masonry is the most commonly used structural material from times immemorial. Many of the greatest structures such as The Taj Mahal (Agra), Pyramids (Cairo, Egypt), Colosseum (Rome, Italy) and many other structures are live examples of masonry construction from the earlier civilization. In general, masonry buildings are brittle in nature and are most vulnerable to ground motions.

Previous earthquake experiences have seen a disastrous failure of masonry buildings in rural areas. These masonry buildings need to be engineered in order to make them sustain earthquakes. Over the years several researchers have been working relentlessly in finding an effective solution for improving the seismic resistance of masonry structures. These researches have led to the development of new seismic resistant technology, skills and construction systems.

To ensure good seismic performance, the following conditions must be applied.

a. Walls are the weaker components and when loaded in its weaker direction can lead to failure. In order to prevent this type of failure, it is necessary to ensure that a good bond exists between adjacent walls so that loaded in their weak direction can gain good lateral resistance accessible by walls loaded in their strong direction. In addition, the tendency of a wall to collapse when pushed in the weak direction can be reduced by limiting its length-to-thickness and height to- thickness ratios.

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b. The window and door openings serve as a weak spot in masonry walls and hence, the size of the openings must be restricted to a minimum value. Steel bars must be provided in the wall all around the openings to restrict the initiation and propagation of cracks.

c. The vulnerability of the junction can be improved by ensuring good interlocking of the masonry courses.

d. Low porosity bricks must be used and they have to be pre-soaked before use to minimize the amount of water drawn from the mortar.

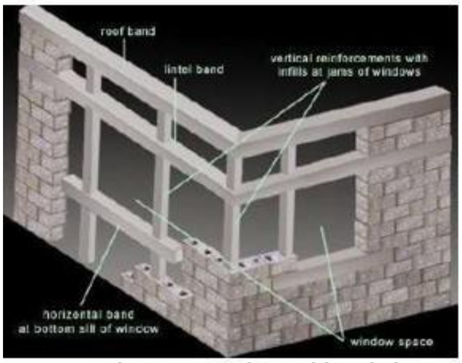


Figure 8: Horizontal bands in a masonry building

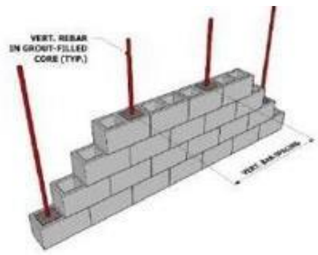


Figure 9: Vertical reinforcement in masonry walls

4. EARTHQUAKERESISTANT CONSTRUCTION PRACTICES FOR RC BUILDINGS:

The modern construction has been replacing the traditional masonry building units with RC buildings. Concrete can be poured into any mould of desirable shape and the steel imparts the necessary tensile strength to the structure. As a result, RC buildings find wide applications and are commonly adopted in towns and cities. The RC frame is the major lateral load resisting unit in a structure. The inertial forces induced by earthquakes are proportional to the mass and these forces are transferred from one building component to another and get accumulated near the base of the building. Hence, the columns and walls at lower storeys experience higher earthquake-induced forces. The amount and location of steel in an RC member should be such that the failure of the member is by steel reaching its strength in tension before concrete reaches its strength in compression. This type of failure is a ductile failure and hence is preferred over a failure where concrete fails first in compression. The structures require additional ductile detailing in order to ensure good seismic performance. These provisions are put together in the form of a special seismic design code, IS13920- 1993 for RC structures. There are various types of RC structures as follows.

- Designed with seismic features
- Frame with unreinforced masonry infill walls
- Flat slab structure
- Frame with concrete shear walls (dual system)
- With a load-bearing masonry, with timber, bamboo or others, with composite steel

In order to ensure the good seismic performance of the RC structures during an earthquake, the following structural criteria must be satisfied.

- The failure of a column leads to the overall failure of the structure (global failure) whereas the failure of a beam tends to have localized damage. Therefore, it is preferred to make the beams weaker than the columns so that the failure of beams precedes column failure providing sufficient warning for evacuation of the building. Similarly, repair and retrofitting of beams is much easier than columns. The beam column joint is one of the potential weak zones causing immense damage to the entire structure. Hence, an effective ductile reinforcement detailing is required for this region. Diagonal cracking & crushing of concrete in the joints should be prevented. Providing large column dimensions is effective in achieving good seismic performance. 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 (Murty CVR (2005). IS:13920- 1993 recommends continuing the transverse loops around the column bars through the joint region.

- The building plan must be simple and regular in shape. Any form of horizontal and vertical irregularity as illustrated in IS 1893 (2016) must be avoided.
- The grade of concrete and steel as specified in the code must be adopted for construction.
- Strict adherence to prescribed standards of construction materials and construction processes is essential in assuring an earthquake-resistant building.

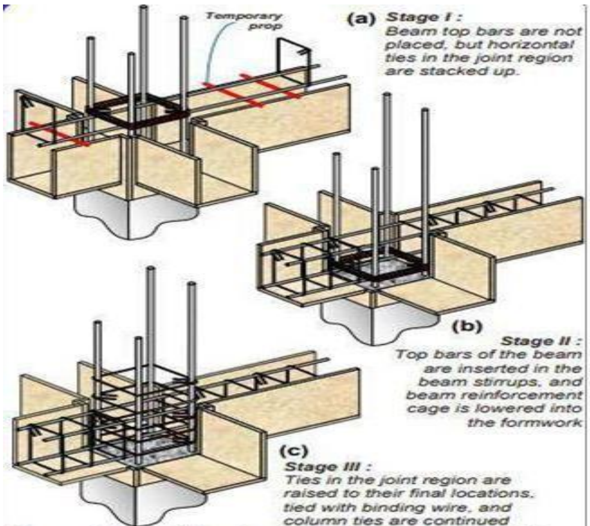
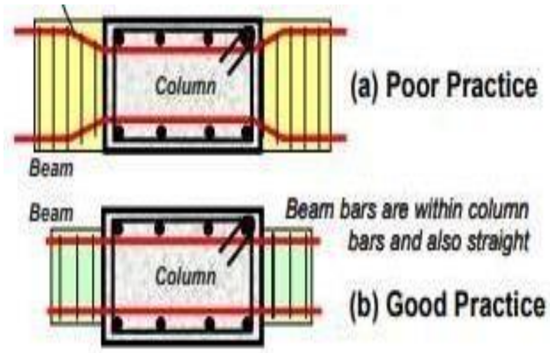


Figure 4: Providing horizontal ties in the joints – three-stage procedure is required.



5. MODERN CONSTRUCTION TECHNIQUES FOR EARTHQUAKE RESISTANT BUILDINGS:

- *Prestressed concrete members in earthquake-resistant construction* - this ensures proper connection between various components of a structure. Further, this technology has been widely adopted in New Zealand.
- *Shape-memory alloys* - exhibit unique characteristics desirable in an earthquake- resistant building. They have the ability to dissipate substantial energy without significant degradation or lasting deformation. The most common shape- memory alloys are made of metal mixtures containing copper-zinc-aluminum-nickel, copper-aluminum-nickel or nickel- titanium. This specific smart material is being widely researched to explore its extensive applications.

The important structures such as hospitals, fire stations, and other public buildings need to remain functional after an earthquake. In order to make this possible, the response of the building to seismic load must be controlled using suitable control devices such as:

- *Base isolation* is one of the widely accepted and adopted approaches for protecting the building from seismic forces. It is a collection of structural elements responsible for decoupling superstructure from the substructure. When the ground supporting the foundation of the building shakes, this component undergoes lateral displacement while keeping the structure intact. There is considerable interest now in base-isolated systems among earthquake engineers – especially in countries like Japan, USA, and New Zealand – with an eye towards developing cheaper systems with broader applications.

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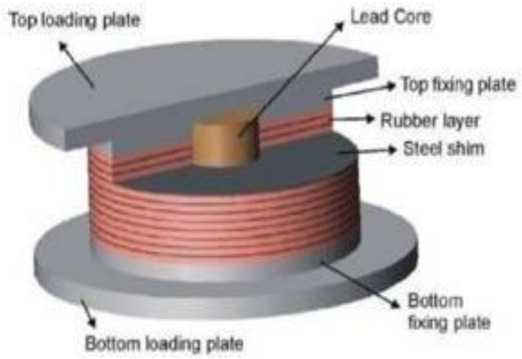

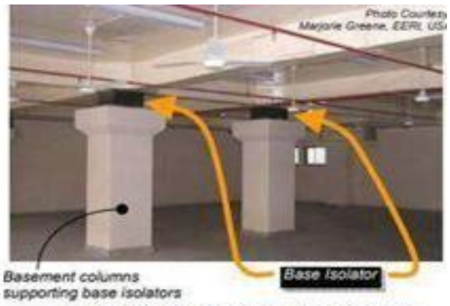

Basement columns supporting base isolators
View of Basement in Bhuj Hospital building – *built with base isolators after the original District Hospital building at Bhuj collapsed during the 2001 Bhuj earthquake.*

- *Seismic Dampers* - Diagonal braces in a moment resisting frame are used as an effective lateral load resisting system. However, recent developments in the area of structural seismic response control have led to the replacement of these bracings with seismic dampers as shown in Figure 15. 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 reduce the magnitude of the force acting on a structure. Commonly used types of seismic dampers 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), and yielding dampers (energy is absorbed by metallic components that yield).In India, friction dampers have been provided in an 18-story RC frame structure in Gurgaon.
- *Steel Plate Shear walls*–Shear walls are considered as an essential component of a lateral load resisting systems and steel is well known for its ductile behavior. These walls are designed in such a way that they bend instead of buckling under the action of lateral loads. These walls are significantly thinner and lighter, thereby reducing the building weight. Further, these walls need not be cured and hence, speeding up the construction process.

6. FUTURE TRENDS:

- Blue mussels can be found clinging to rocks and sea decks all along the coast of New England. They are anchored in place by a stringy outcrop of cabling that emerges from between their twin shells. Usually, even the most vicious of high tides can't pry them loose. To stay attached to their precarious perches, mussels secrete sticky fibers known as byssal threads. Researchers are trying to incorporate this particular feature into structures in order to make the building withstand earthquakes.

A Blue mussel found along the coast of New England.

Sensors fitted on top of the concrete blocks to monitor the seismic waves

- Seismic Invisibility Cloak – A series of the borehole is dug around the periphery of the structure that needs to be protected.
- A cardboard can become a sturdy, durable building material. Japanese architects have designed numerous structures that include cardboard tubes coated with polyurethane as the main framing elements. The Transitional Cathedral -- in Christchurch, New Zealand was constructed using 98 giant cardboard tubes reinforced with wooden beams. The cardboard-and-wood structure is

extremely light and flexible and it accomplishes much better than concrete during seismic events. And if it does collapse, it's far less likely to crush people gathered inside.

7. CONCLUSION:

The researchers all over the world are attempting to produce cost-effective and efficient construction technology by making use of the locally available materials. A school where younger generation spends most of the time should be safe and secure against earthquake. In India, engineers have successfully used bamboo to strengthen concrete. And in Indonesia, some homes now stand on easy-to-make bearings fashioned from old tires filled with sand or stone. It was also found that even the non-engineered constructions sometimes possess the required resistance to earthquake ground motions. For example, the Assam-type traditional housing in North-eastern states and the Dhajji-Diwari buildings in Kashmir have good earthquake resistance. The earthquake- safe construction technology should mainly involve usage of materials of ductile nature, earthquake resilient building configuration, lightweight structural components to reduce the seismic forces and robust architectural forms.

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