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A REVIEW ON THE EXISTING SEISMIC RESISTANT CONSTRUCTION TECHNIQUES

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ABSTRACT

Earthquakes are one of the main reasons of the collapse of the structures every year. Many research studies have been focusing on decreasing the impact of seismic waves on the structures. For this, initially there were many passive techniques introduced to decrease the damage caused due to earthquakes. But since the late twentieth century, the focus has shifted to introduce active techniques which are meant to absorb the seismic waves or do not let the waves propagate through the building. Passive techniques are based on decreasing the lateral loads on a structure while the others alter the seismic waves that propagate through the structure. This study is primarily a review of most of the construction techniques designed to resist the earthquakes in masonry and reinforced concrete framed structures. Moreover, some common methods for these structures have also been highlighted. In all these methods, various aspects pertaining to the seismic behaviour of that particular method have been discussed based on the previous research work. Finally, the main conclusion drawn is that whatever method is being chosen based on the location and material availability, it should be properly designed and detailed.

KEYWORDS: Seismic Resistant, Construction Techniques

INTRODUCTION

Every year earthquakes cause tremendous damage to life and property all around the world. The collapse of structures during earthquakes is the main reason for this damage. This is evident from the fact that in the past 25 years, over 25,000 people died in major earthquakes in India alone and 95% of them were killed due to building collapse. 59% of India falls in regions that are liable to seismic damage but still less importance is given to earthquake resistant structures [29]. Building earthquake resistant structures will help save thousands of lives and property worth millions.

During earthquakes, seismic waves are produced from the ground and propagate in all directions through the earth's layers. Since the forces occurring in the structures due to these seismic waves are very random and complex in nature, there is always an uncertainty about whether the structure is able to sustain the seismic forces induced, even after doing an approximate seismic analysis. The structures can be resisted to some extent but not completely. Hence, the term "earthquake resistant" is used instead of "earthquake proof".

Seismic waves result in ground shaking. This ground shaking can destroy buildings. It may also destroy the foundation and isolate it from the superstructure. In some cases, earthquake may also cause landslides and avalanches (in hilly regions) or tsunamis (if the epicenter is in sea or ocean).

During earthquakes, the ground on which any building rests gets displaced. Hence, the base of the building moves with it. But due to the inertia of the building, the building will try to resist this motion. This causes the building to suffer a distortion and this distortion travels along the height of the building. And due to the continuous ground shaking, building undergoes a complex series of oscillations [7].

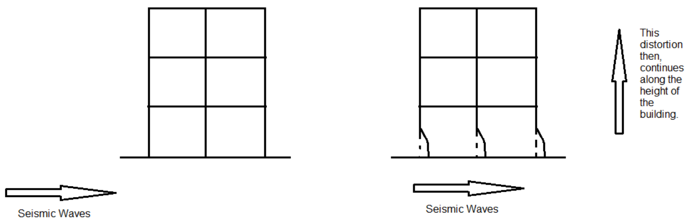

Figure 1: Propagation of Seismic Waves in a Building

There has been extensive research on the techniques to construct earthquake resistant structures. This paper is a review of the various techniques to build earthquake resistant structures as proposed by researchers. It deals with both masonry and framed structures, including high rise buildings. Recent advancements in this field have also been discussed.

The main objective of this paper is to highlight the issue of earthquake resistant structures and to review various techniques developed by researchers to achieve seismic resistance. The following sections will talk about these techniques in detail.

MASONRY BUILDINGS

Due to the brittle nature and high self weight (leading to high inertia forces), masonry structures are more prone to damage during earthquakes. Moreover, most of the masonry buildings are non-engineered, hence, adding to the problem.

Unreinforced masonry (URM) buildings generally experience two kinds of failures during an earthquake, namely out of plane bending failure and in plane failure. Out-of-plane bending occurs when a horizontal load applied at the top of a wall causes it to topple in a direction perpendicular to its plane. But if the wall gets pushed along its length (in the plane of the wall), it is in-plane bending [7].

In the case of reinforced masonry, both flexural and shear failure can take place. Flexural failure takes place when the ratio of height to the length of wall is large and vertical reinforcement is small. Shear failure may occur when the ratio of height to length ratio is small. Diagonal cracks are an indication of shear failure. [26].

To secure the buildings against any structural damage to masonry walls due to earthquakes, there are some general thumb rules. Firstly, the building should be symmetric and not too slender in plan. Secondly, high strength masonry bricks should be used in earthquake prone areas. Thirdly, the doors and windows openings should be small as they tend to decrease the lateral load resistance. Also, more the ductility of the structure, the less damage will occur to the structure. [7]

Some of the methods which can be used to improve the seismic resistance of masonry buildings are:

- **BANDS IN MASONRY**: Horizontal bands are provided in normally unreinforced masonry structures, normally at the lintel, roof or gable of the building [5]. They are provided continuously on all the edges so as to hold the masonry together. Research [16] has shown that the buildings which had lintel bands survived the earthquakes whereas ordinary masonry buildings could not. These bands are generally made up of reinforced concrete and their thickness depends on the length of the wall.

- **INTERLOCKING AT THE CORNERS:** The corners of a masonry building should be interlocked so that the transfer of loads between the walls can take place more efficiently. To obtain this, a stepped joint or a toothed joint can be made at the corners. To obtain full bond between the perpendicular walls, a sloping (stepped) joined is preferred. The details of these joints have been mentioned in the Indian Standards code, IS 4326:1993.

- **CONFINED MASONRY:** In confined masonry arrangement, vertical reinforced concrete elements (or tie columns) are used at the intersection of masonry walls or corners to confine the masonry walls along their vertical edges. The seismic forces are resisted by the composite action of tie columns and the masonry walls [20]. In the construction of masonry wall buildings, masonry walls are constructed first, one story at a time, and then the RC tie-columns are constructed. Finally, RC tie-beams are constructed on top of the walls often simultaneously with the floor/roof slab construction. In the research done by Tomaževič and Klemenc [20], various models of a three storeyed structure were tested and was found that the buildings made of confined masonry will not collapse when subjected to repeated shaking with peak ground acceleration (PGA) of more than 1.3g. The general failure mode is diagonal shear. The tensile stresses are resisted by the longitudinal reinforcement in tie-columns as concrete is weak in tension and the compression stresses are resisted by concrete, masonry, and longitudinal reinforcement in tie-columns.

- **REINFORCEMENTS IN MASONRY:** Since steel is ductile, providing steel reinforcements in masonry will improve the ductility of the system. A hollow cavity is made between two layers of bricks and steel rebars, in both horizontal and vertical reinforcements, are inserted into this cavity and then grout is poured into the cavity to fill the space. Through this arrangement, steel is sandwiched between the layers of masonry, thereby helping in resisting the horizontal seismic forces. The reinforcements should generally be provided at corners, junctions and around large openings [12]. Adequately placed reinforcements are expected to improve the seismic behaviour of a building significantly. Horizontal reinforcements prevents the walls from failing in shear [19]. Many experiments have been performed which compare the seismic capacity and damage of reinforced and unreinforced masonry buildings.

- **AERATED CONCRETE:** Aerated or foamed concrete is made by aerating the concrete mix while casting so as to make it fluffy and lightweight [27]. Using foamed concrete as a substitute for the mortar used in masonry structures may help to decrease the high self weight of masonry and hence decrease its seismic vulnerability. This is due to the fact that the earthquake forces depend on the inertia forces which in turn depend on the mass of the structure; hence, using aerated concrete instead of mortar decreases the magnitude of earthquake forces. The specifications on how to use aerated concrete in masonry have been provided by the Masonry Standards Joint

Committee (MSJC)- MSJC 2008, administered by The Masonry Society (TMS). Reinforcements can also be used along with aerated concrete to make the structure more earthquake resistant.

- **FRP LAMINATES IN MASONRY:** Using Carbon fiber reinforced polymer (CFRP) and Glass fiber reinforced polymer (GFRP) laminates in the masonry can help increase the seismic load carrying capacity and shear capacity also [21]. FRPs are generally preferred over other materials because they are lightweight yet strong (Young's modulus of elasticity up to 600 GPa can be achieved).

- **NSM FRPs in Masonry:** Using NSM (Near Surface mounted) FRPs in the masonry, where FRP bars were mounted vertically or horizontally into embedding materials can also increase seismic capacity of the structure. The research done by V. Turco et. al. used two different embedding materials: a latex modified cementitious paste and an epoxy-based paste [33]. The specimens were tested for both flexure and shear. The experiments were conducted by using both CFRPs and GFRPs and using two different sections, circular and rectangular. Through these experiments, it was found that often GFRPs gave better results than CFRPs, though both had increased seismic capacity. Moreover, it was also observed that Smooth circular FRP bars are appropriate for shear strengthening, while rectangular FRP bars have good performances in the case of flexural strengthening.

- **MASONRY SHEAR WALL:** Shear walls are vertical walls constructed to resist lateral forces through in-plane bending. These walls generally start at the foundation level and are continuous throughout the building height, or at least 85% of the building height. Masonry shear walls are the shear walls made of hollow concrete blocks with filled mortar and reinforcement on site to resist the lateral forces caused by the earthquakes. The design of masonry shear walls has been specified in many codes. Masonry shear walls are generally built for small structures.

FRAMED RCC STRUCTURES

Generally, an RCC framed building is made of horizontal components like beams and slabs and vertical components like columns and walls. The earthquake forces travel through slabs and beams to the columns and then to the ground through the foundations. These forces tend to accumulate at the lower storeys. Therefore the lower storeys should be designed stronger than the top storeys. Since the nature of earthquake forces is different from the gravity forces, there can be tension even at the top face of the beam. Hence it is recommended to provide reinforcements at both top and bottom faces of the beams as concrete alone is weak in tension. [7]

Moreover, the design should be based on "strong column weak beam" theory, which means that beams should fail before the columns. This is so because during strong earthquakes, it is required that the columns remain elastic so that they can provide stability and strength of the stories above. It is also required that the beam column joint should be stronger than the column.

The seismic resistance of framed structures can be improved by using any of the following methods:

- **MASONRY INFILLS:** Introducing masonry infill walls between the columns can significantly increase both the in-plane horizontal stiffness and the strength of the frame. [34]. But due to lack of knowledge of the composite behavior of the frame and the infill, their effect on the behaviour of the composite structure cannot be theoretically explained. Therefore, several experiments have been performed by adding masonry infills with and without openings. For new buildings, infill wall is modeled and designed to provide high rigidity. Infill panels decrease the storey drift demands and increase the storey lateral force resistance respectively, while their contribution to the global energy dissipation capacity is significant, provided they are effectively confined by the surrounding frame. Moreover, due to infill walls in the building, the top storey displacement is reduced.

- **RC SHEAR WALLS AND SHEAR CORE**: Shear walls are vertical reinforced concrete walls constructed to resist lateral forces through in-plane bending. Buildings with properly designed and detailed shear walls have shown good performance in the past earthquakes. Shear walls are easy to construct and efficient, both in terms of cost and reduction of damage due to earthquakes. Shear walls should be provided along the length and the width of the building and they should be symmetrically located in the building so that there are no torsion effects on the building [7, 22]. The structure formed by shear walls at the center of the building is known as a shear core. Generally, the shear core is provided around the elevators or staircases. The thickness of the shear walls should not be less than 100mm [18].

- **STEEL PLATE SHEAR WALLS**: There has been much research [3,4,9] on the behaviour and modeling of steel plate shear walls. Steel plate shear walls have been used in buildings in the USA, Canada and Japan for more than the past three decades. On one side, they help in reducing the wall thickness, speeding up the construction process and improving the ductility of the structure, but on the other, they decrease the flexural stiffness of the system and these shear walls require a proper construction sequence to avoid excessive compression in the panel [13].

- **BRACED FRAMES:** Braced frames are generally used to refer frames that utilize trussing as the primary bracing technique. The trussing, or triangulation, is usually formed by the insertion of diagonal members in the rectangular bays of the frame. If single diagonals are used, they must serve dual functions: acting in tension for lateral loads in one direction and in compression when the load direction is reversed. To eliminate the need of compression members, frames are often braced with criss-crossed set of diagonals (X-bracing).

- The various advantages of using braced frames are that firstly, the trussing causes the lateral loads to induce only axial forces in the members of the frame as compared to the behaviour of rigid frames. Moreover, the trussing results in a frame which is stiffer and has lesser deformations than the rigid frame. But the disadvantage with the trusses is that they lack the potential for resiliency and energy absorption that exists with more flexible structures.

- **MOMENT RESISTING FRAMES:** These are the frames in which interactions between members of the frame include the transfer of moments through the connections. These are also called rigid frames, since the joints or connections are fixed. Design of these frames should consider both gravity and lateral load conditions. Most moment resistive frames are made up of either steel or concrete. Though the frame becomes indeterminate, but there are various approximate methods to find out the moments, reactions and/or deflections for both gravity and lateral load conditions.

- **BOX SYSTEMS:** Box systems are used to describe a building consisting of a connected set of horizontal and vertical elements (consisting of stiffened planar construction). The horizontal diaphragms consist essentially of the continuous structural deck of a roof or floor. The vertical diaphragms consist of walls etc. If the element themselves, plus their connections are capable of developing resistance to lateral forces, the result is typically a relatively stiff bracing system.

COMMON METHODS

Apart from the specific construction techniques to improve the seismic resistance of a building, there are some methods common to all the buildings. Some of them are:

- **BASE ISOLATION**: Base isolation is a technique in which the base of the superstructure is isolated from the ground in such a way that only a small portion of the seismic ground motions is transmitted up through a building. In other words, although the ground underneath may vibrate violently, the building itself would remain relatively stable. This results in significant reduction in the earthquake motion in the superstructure. Isolators are used to separate the superstructure and the substructure. Some of the common isolators being used are elastomers, spherical sliding isolators, rubber layer as foundation support and friction pendulum bearings [30]. In masonry structures, waste tire pads generally act as an elastomeric bearing. Rectangular shaped layers are cut from tread sections of used tires and then piled on top of each other, which can function as an elastomeric bearing. But base isolation for other structures is a difficult and costly process which is not suitable for low and medium rise buildings and low cost buildings. As of now, in India, the use of base isolation techniques is in its inception. Much of the research has been going on in this process.

- **SMART BASE ISOLATION TECHNIQUE**: Considering the fact that the base-isolated buildings are still vulnerable to strong impulsive ground motions if they are generated at near-source locations [15], therefore base isolation method should be modified. Hence, researchers have proposed a "smart" base isolation technique through which the base drifts can be decreased without the increase in superstructure motion as seen for passive devices. Ramallo et. al. (2002) used a smart base isolation technique which was composed of low damping elastomeric bearings and active (controllable) magnetorheological fluid dampers [15]. This was compared to the conventional (passive) lead-rubber bearing and it was found that the former had a superior performance as compared to the latter. Due to the adaptable nature of the smart isolation system, it can even sustain severe earthquakes.

- **DAMPERS:** Dampers, as the name suggests, damps the seismic vibrations of the building by partially absorbing the seismic energy which is being transmitted. Seismic dampers were introduced in 1990s though for wind resistance, they were being used since 1960s. [7]. There are various types of dampers based on how they absorb the seismic energy. There are basically three types: viscous dampers where energy is absorbed by a fluid passing between piston cylinder arrangement, friction dampers where energy is absorbed through friction and yielding dampers where energy is absorbed by metallic components that yield.

- Nowadays, tuned mass dampers (TMD) are being used in tall structures. TMD is a vibrating mass which vibrates out of phase with the structure it is installed or suspended to. It is a simple assembly of a mass, a spring and a damper. Whenever earthquakes come, the TMD displaces in the opposite direction to the structure so that the the lateral displacement and hence, damage due to earthquakes is reduced [32]. The famous Taipei-101 building encloses a huge 728 ton TMD. During the 2008 Sichuan earthquake, there was no damage to Taipei-101.

- **SEISMIC INVISIBILITY CLOAK**: In the past 10 years, there has been an increased emphasis on the use of seismic invisibility cloak to shield buildings from earthquakes. Scientists in Europe have claimed to have built and tested the first seismic invisibility cloak [17]. The technique involves modifying the ground around a structure to divert seismic waves, effectively cloaking the structure from an earthquake's destructive energy using large rings of a flexible metamaterials spaced around building foundations and tuned to the wavelength of the waves to be diverted. This concept can be used to protect high value buildings such as nuclear power plants or airports. This process is still in its developing phase as the researchers are currently characterizing polymers and other metamaterials for giant ring resonators that could be tuned to a seismic wavelength

- **ROCKING FRAME:** Rocking frame is constructed by rocking the base of an elastic braced frame. In other words, it is a modification of braced frame in which the frame is allowed to uplift from its supports prior to diagonal brace yielding and bracing. [23]. Sliding is not allowed in rocking frames. This arrangement helps in the reduction of peak base overturning moments. Many experiments have shown that rocking frames improve the seismic performance as compared to the traditional ductile systems. In the design of rocking frames, shear design must be considered whenever a gap opening mechanism is allowed [8]. Shear transfer across the base joint interface in steel rocking frames is usually provided through a steel curb or bumper at the column base. Moreover, viscous dampers can also be mounted between the foundation and the column bases in order to dissipate energy and control the lateral displacements. Several experiments have also testified the advantages of viscous dampers in these frames. [25]. There have been many modifications in the design of rocking frame in order to maximize its efficiency to resist the earthquakes like using prestressed materials and eccentric frames [8].

CONCLUSIONS

In this paper, a number of techniques have been explored and discussed which could improve the earthquake resistance of a structure. In the past century, a number of researchers and people from the industry have been proposing ways to tackle the damage caused by the earthquakes. And there is still research going on to improve the existing techniques.

On one hand, where techniques like bands in masonry, confined masonry, braced frames, shear walls and moment resisting frames are becoming very common but on the other hand, newer techniques like seismic invisibility cloak and smart base isolation techniques are rare and not fully developed.

In the 2010 earthquake of Haiti, the improper reinforcement of the walls was a bigger problem whereas after the 1970 earthquake of Peru, the walls were reinforced with a plastic mesh. Hence, different techniques are being adopted based on the location and the availability of materials. To conclude, proper design and detailing is essential to ensure proper load distribution and seismic resistance of a building.

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