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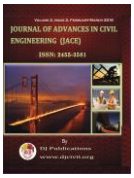

REVIEW ARTICLE

A Review of Construction Techniques in Earthquake Engineering

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ABSTRACT

In the recent decades, developing countries around the world face various disasters by way of volcanic eruptions and manmade explosions with increasing frequency and effect. These effects have resulted in death of a lot of people and damage to their properties. These impacts are more prominent in developing countries. Due to these reasons, there is requirement of some effective measures for the management of disasters. These measures are underway in many countries. This article mainly deals with the effects of earthquake affecting the buildings due to the improper construction techniques employed. These earthquake effects span a wide range and it causes damage to the buildings, resulting in total collapse. It is important to improve the construction industry in order to protect the buildings from disasters. This paper also reviews certain construction methods that are used for minimizing the effect of earthquakes on buildings. The role of building construction in building management system for resisting earthquake disaster is considered. It is concluded that building earthquake resistant features during the construction and design process is possible by applying the techniques of earthquake engineering which would extremely raise the chances of survival of buildings and their occupants in a disaster scenario.

Keywords: Building construction works, Earthquake resistant design, Construction method, Disasters, Earthquake engineering.

1. INTRODUCTION

In this world, disasters occur naturally and it is an unpredictable event which harmfully affects human beings and environment. Attempts are being carried out to protect the environment from these dangerous impacts. The results of these attempts are encouraged a lot in the developed countries but unfortunately not in the developing countries. Among all natural calamities, earthquake is one of the most dangerous disasters that can occur in the earth's surface and cause serious hazards. According to [1], earthquake is an unexpected vibrating movement which takes place on the earth's surface. Sometimes earthquakes start with slight shakes but slowly start to form one or more powerful shocks and finally end with large vibrations over the earth. Hence it is named as aftershocks. The underground point at which the earthquakes start is called focus. The magnitude and intensity of an earthquake is determined using the meter scale. [2] highlights that severe shakes from an earthquake can destroy bridges, buildings, topple utility poles, water mains etc. The earthquake produces seismic waves that can put stress on buildings to destroy them apart which also triggers landslide.

From the recent earthquakes, people have observed that the moderate earthquakes can lead to a wide range of hazards in the earth's surface. These hazards not only kill people but also lead to huge losses in their life and properties due to building collapse. Finally it leads to natural calamities and due to this, people are forced to move under the line of poverty. [3] presents that many highways and buildings are destroyed, despite the strict building regulations and around 5000 are killed in a recent earthquake. Fires spread as a result

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of broken gas mains. More than 250,000 people are left homeless. In recent years, earthquakes occurred and resulted in various hazards due to an improper way of building construction. Hence, construction engineers are forced to think about a new construction design for the management of an earthquake disaster. It is essential to think from the planning stage to the final stage of design structure in order to minimize the loss of property. Currently there are several new technologies becoming more predominant in the earthquake structures of building design. All these technologies include the use of particular devices to control the dynamic behaviour of buildings. [4] During earthquake, the dynamic behaviour of a building depends on its overall size, geometry and shape. Moreover, the forces of the earthquake are carried out in the underground. Therefore, both the civil/structural engineer and architect must work together to improve the way of choosing good building configurations and to avoid the unfavourable features at the planning stage itself. Civil/structural engineers are responsible for constructing the building in the form of earthquake resistant structures and keeping the society in a safe environment. [5] states that, an earthquake resistant construction is a structure that doesn't collapse during the time of slight earthquakes. It also serves in preventing disastrous failure of the structure and gives sufficient warning during time of earthquakes, thereby saving human lives and reducing damage during the earthquakes. Figure 1 shows the structure of building collapse during earthquake.

Adapted from [5]

Figure 1.Building collapse during earthquake

2. OVERVIEW OF EARTHQUAKE EFFECTS ON BUILDING STRUCTURE

[6] discusses that, there are various building models being constructed by civil engineers. It includes both tall and small buildings. These kinds of buildings are getting damaged during earthquakes because of the improper way of construction design and work. Both small and big buildings that do not have good foundation can't sustain the vibration and finally collapse. During the earthquake, the ground portion of the building would be in motion but the top portion of the building tends to be in rest. Hence earthquakes results in torque and building collapse.

Foundation failures, faulty construction, poor design, combination of causes, extraordinary loads are some of the reasons for building collapse during earthquakes. [7] discusses about the foundation failure of the buildings. Good design and proper construction structure provides strength to the buildings. The foundation failure occurred due to construction equipment failure, insufficient temporary support and unnecessary construction loads. Steel frame construction structures and precast concrete are the two processes which often results in failure, when temporary bracing is insufficient. Improper method of construction sequencing is also a source of failure [8].

[9] states that civil engineers have designed the building structurally strong to overcome the earthquake hazards. Due to insufficient foundation design, the foundation fails and building collapses during earthquake. It is important to identify a hybrid failure mode which includes the combination of earthquake shaking and non-earthquake soil movement. These are misidentified by the civil engineers while constructing the building. The shallow foundations worsen because of weathering especially when exposed to cold climates. [10] The unsupported condition of the slab may not be stable for many years. Therefore, even very small earthquake induced forces may be sufficient to cause failure of the slab and thereby break down the whole building. Figure 2 indicates the foundation failure during the time of earthquake disaster due to the construction errors.

Adapted from [10]

Figure 2.Foundation failures during earthquake due to poor construction

[11] Poor construction designs don't mean the computation errors, but it is the failure of the structures such as inaccurate construction data, improper choice of materials and ignorance of the effects of impulsive stresses. The consequences are faced by the construction engineers as they are directly responsible for such effects. Poor designs lead to overall failure in the building construction works. [12] states that faulty construction is one of the reasons for building collapse during an earthquake. This includes poor riveting or even improper tightening torque of nuts, usage of inferior steel, excessive use of the drift pin to make holes line up, improper welding, usage of salty sand to make concrete and other practices during the construction.

[13] Extraordinary loads frequently occur in the buildings mainly due to natural calamities such as hurricane, repeated heavy snowfalls and earthquake. A flexible building structure may avoid destruction during earthquake, but a solid masonry building could be destroyed. The earthquake disasters lead to foundation problems when moist filled land become liquefied. [14] The important causes of collapse in the building during earthquake are differential foundation settlements. It leads to serious sagging of the floors, distress to the structural frame and cracking of the walls. Due to this effect, the blocks are severely affected. It is a double storey structural building framework in the masonry building. Serious cracking in the building are mainly due to differential settlement. The intensity of damage due to differential foundation settlement for various kinds of building is shown in figure 3.

[15] states that the building performance in the earthquake are varied depending on the factors such as improper construction techniques, reduction in structural walls and quality of materials used for building construction so that, most of the stone work wall structures get intensely damaged during the earthquake.

Adapted from [14]

Figure 3.Building damage due to differential settlement

Adapted from [15]

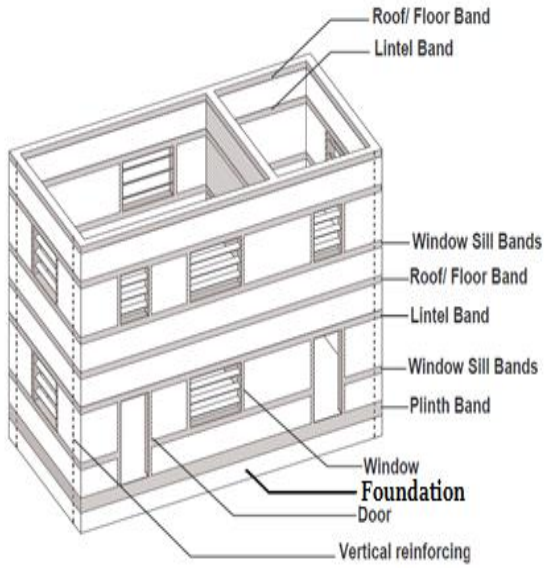
Figure 4.Representations of building collapse due to poor quality cement and mud

3. RESISTANCE OF BUILDING TO EARTHQUAKE

[16] suggests that to make an earthquake resistant building, first thing a civil engineer should do is to concentrate on the building foundation. Building foundation is needed to be constructed to resist the sideways loads. Then civil engineers could prepare a well-planned building construction design in the following manner

- The roof should be of light-weight material.
- The walls of the building must be equal in both directions.
- It should secure all directions and must be capable to handle load in the weakest direction.
- The construction of the building should be very strong and unfallen; it should remain in the same place even when the worst shock waves occur.

[17] explains that the intention of civil engineering department is to make an earthquake resistant building. Even though the building may get damaged, it could never get collapsed even during a very strong earthquake effect. The cement mortar used for the building construction could be in the ratio of one sack of cement mixed with six similar parts of sandy soil. Thus the earthquake resistant building assures the safety of the people. [18] Figure 5 shows the elements necessary for the construction of buildings in order to get protected from the hazards produced by earthquake.



Adapted from [18]

Figure 5.Essential elements for resistance of buildings from earthquake

3.1. Construction design of buildings against earthquake

[19] states that the prime consideration for the design of building safe structures is to make the highest roof and the foundation strength. The slope of the roof lies between 3 and 15 degrees. Then slab can be placed over the roof with no propping. The building slab can be of 100mm diameter, 5½ inches and weight of 190kg/sqm. This slab is totally bonded to the frame and would not collapse when a shake occurs.

[20] The earth quake proof building structure design consists of good building structures with stiffness in elastic deformation capacity and strength so that these type of buildings have enough strength to withstand the level of force caused by earthquake. This can be accomplished through an appropriate selection of structural configuration and careful detailing of structural members. [21] highlights that a rectangular or a square shaped building design have better performance against earthquake when compared to many other building design projections. In the case of narrow rectangular section, torsional effects due to the differences in motions of ground are marked. Hence it is desirable to limit the length of a part.

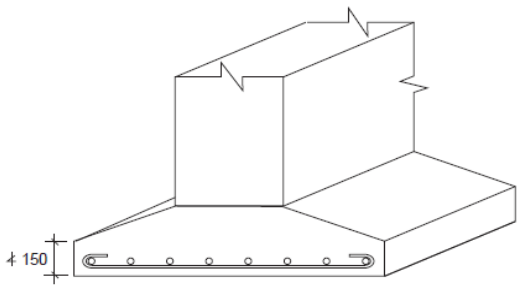
Due to the requirement of longer lengths, the building structures are divided into separate parts. Thus the separation of a large building into separate parts is better to be independent from heavy loads and to avoid building collapse due to earthquake. [22] The stiffness and building height should be uniform. Over height of the buildings should be avoided. The RC pillars should not be available in upper storeys, but this could be vertical and aligned in a line. The schematic representation of overall construction structure of a building against earthquake disasters are shown in figure B1.

In order to satisfy performance of building structures, its walls must be uniform in both the orthogonal directions and it should possess enough strength to resist earthquake loads (figure B1(b)). The connection of walls must be confined to the roof and floor. [23] explains that the walls of the building could carry its weight with the horizontal and vertical loads in the direction of the building. The structural walls for stone masonry building should be 0.38m of minimum thickness stone, 0.36m of brick and mud mortar and 0.23m of brick and cement mortar.

The representation of three dimensional view of T-type wall junctions are indicated in figure B1(c). The walls cover a minimum thickness of 2/3. The inner dimensions of the band and the reinforcement depend on the length of the walls and it is perpendicular between the cross walls [24]. Table A1 represents internal size and inner dimension reinforcement of the building construction design against seismic disaster. The walls are constructed by using a proper mortar filling and bonding elements along with the usage of big stones in the corner. The T-junction of the walls has proper connection between the perpendicular walls.

[25] states that foundation is the important portion of every building. It transfers the building weight to the earth or ground. Each building has it separate foundations and it is commonly named as footing. Normally each building column has its individual footing. Thus the civil engineer should survey the type of soil before constructing the foundation of the building. It is essential for every engineer to determine the safety bearing capacity of the soil. The safe bearing capacity required for the construction of building could be tonnes per square metre. [26] The engineers designing the building structure can decide the soil type to provide depth of the building foundation and size of the foundation in order to get resistance from earthquakes. It is important to survey the

properties and the behaviour of the soil type before laying down the foundation. The foundation structure of earthquake resist building is shown in figure 7. The width of the foundation is 10-15 cm and depth of the foundation is 750 to 900nm below the ground level. The height of the building foundation is approximately 150mm [27]. Figure B2 shows the design of the building foundation for earthquake resistant type. [28] states that the foundation of the buildings could be firm on cement concrete with a minimum thickness of 150mm. Moreover the footing stem is kept half unit wider than the superstructure wall.

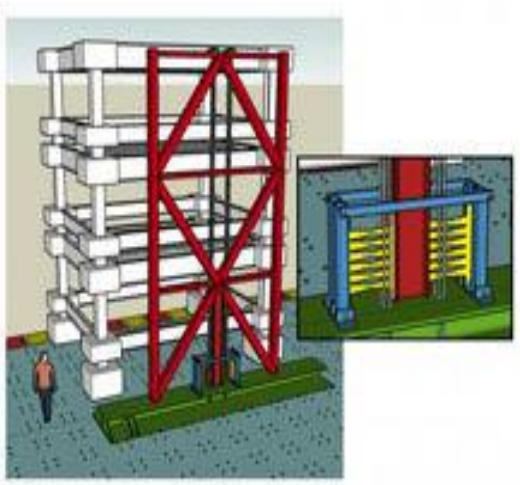


Adapted from [29]
Figure 6. Earthquake resistant strip foundation

[29] describes the RC strip for building foundation against earthquake (figure 6). The foundation could be laid down more effectively for seismic earthquakes. The foundation includes an RC strip which is laid on stone soling and bricks. The minimum thickness of this RC strip could be less than 160mm. Over this, masonry foundation is built in order to improve the strength of the building foundation. [30] states that the integrity between different components of building is the main critical feature for survey of a building during the earthquake. The building construction requires improvement by way of the following features which are discussed in [31].

- Strengthen the junction of the walls by improving the possible weak point.
- Bands should be reinforced with RC band at various levels in order to avoid damage in the walls.
- The walls must be capable of transferring the inertial force from floor structure to the top of the walls.
- The floor structure can be improved by attaching with different types of components.
- The walls must have horizontal and vertical reinforcements.
- The quality of the materials such as cement, mortar, bricks, etc. must be increased during the construction of the building.
- The materials which are used for the construction should be regularly tested in the qualified laboratories.
- Shear walls should be constructed in the buildings in order to provide more strength and stiffness to the buildings.
- Substandard materials, improper construction design and inadequate skills in construction etc., must be avoided.

These are the certain techniques that civil engineers must apply during building construction in order to escape from earth quake disasters [32]. [33] states a new technique called keeping building upright (figure 7) established by civil engineers. When the earthquake strikes the structural system, it holds the building together with a magnitude. When the earthquake stops, this system pulls the building back to its upright position over the foundation. [34] It contains steels and frames that dissipates energy in the building's core and the exterior part during earthquakes. The steel tendon pulls the frame back down and returns the building to its upright position. These ways of constructing the building provides good strength and capacity to overcome the collapse of the building.



Adapted from [33]
Figure 7.Keeping building upright structural system during earthquakes

4. CONCULSION

In this review article, it is concluded that earthquakes are unpredictable natural hazards. Earthquakes mainly affect buildings and they collapse each other. This is due to improper construction design of the building. In order to overcome this impact, the civil engineers must follow a proper design method of construction. In this review, analyses of the techniques of designing earthquake resistant buildings are carried out. Adequate building codes with balanced methods provide safe building for owners and occupants. The building codes state the structures of earthquake resistant designs. Its intention is to strengthen the building in-order to overcome the drastic earthquakes. The construction techniques of civil engineers should prevent the building damage and collapse during an unpredictable earthquake. The structural and architecture engineering have its own historical growth and its interaction lead to several fascinating and delightful current structures. There is still a need to simulate the original design of architectural structures. The structural/civil engineers further require to co-operate in the construction process. Every civil engineer must establish a new way of construction design technique in order to resist building collapse from earthquake disaster and thereby make a safe living of people all over the world.

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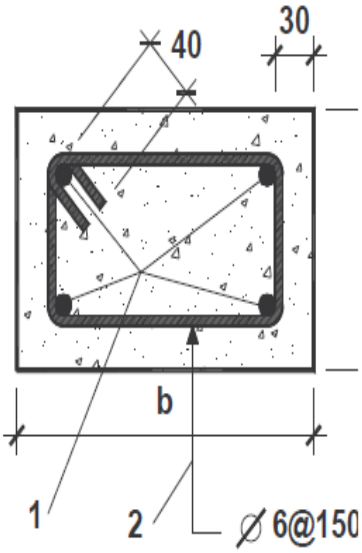
APPENDIX A

Adapted from [18]

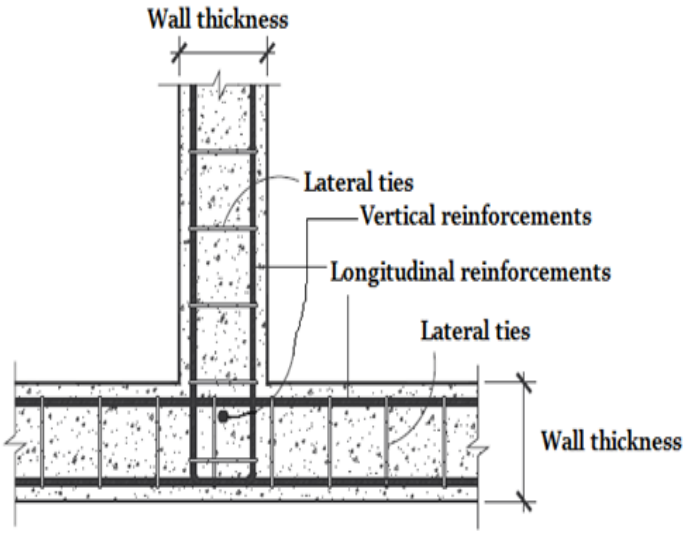
Table A1.Building construction design against earthquake

Inside length of wall	Residential buildings			Important Public Building (Schools, Colleges, Hospitals, Shopping malls etc.)		
	Band size	No. of Bars	Diameter (mm)	Band size	No. of Bars	Diameter (mm)
5 m or less	10 cm x wall width	2	8	10 cm x wall width	2	10
6m	10 cm x wall width	2	10	10 cm x wall width	2	12
7m	15 cm x wall width	4	8	15 cm x wall width	4	10
8m	15 cm x wall width	4	10	15 cm x wall width	4	12

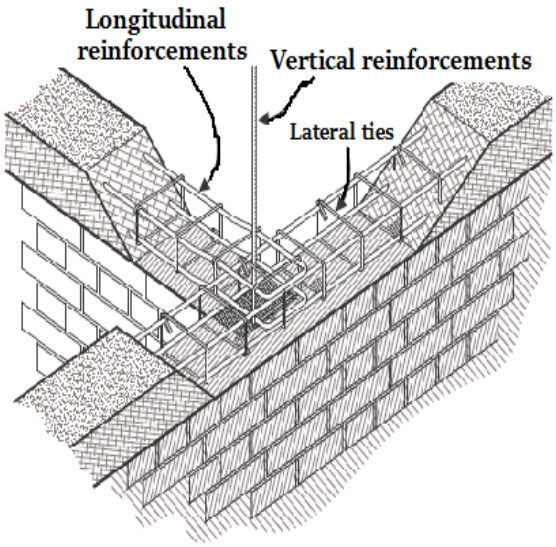
APPENDIX B



a) Four longitudinal steel bars in the band section



b) Structure of T-type wall junction



c) T- type wall junction in 3D view

Adapted from [18]

Figure B1. Overall construction structure for earthquake proof building

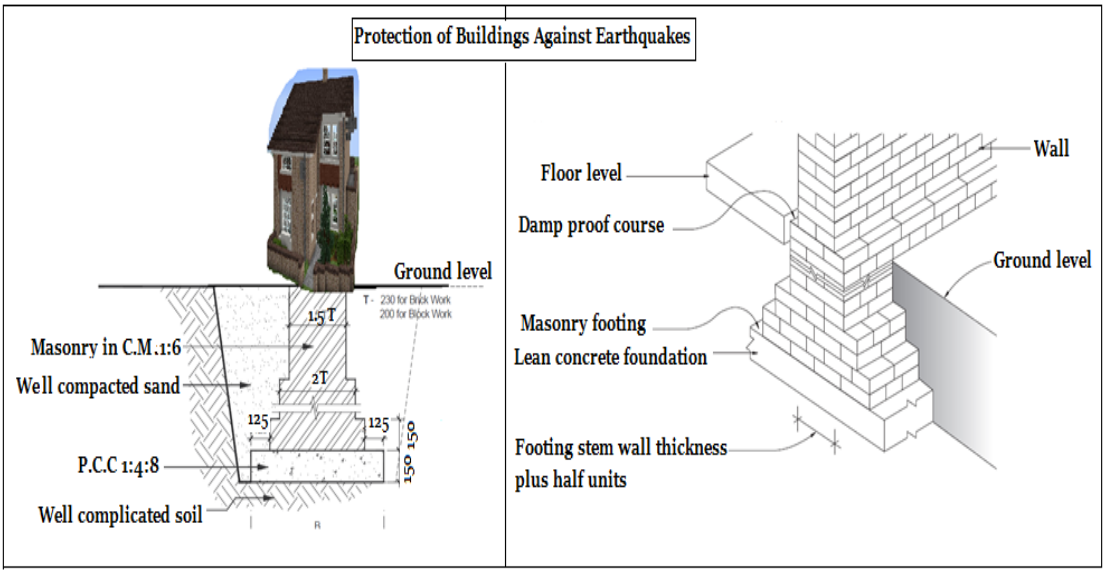


Figure B2.Foundation for building resistant earthquake