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Review Article

A REVIEW ON BEHAVIOR AND DAMAGES OF BUILDINGS DURING EARTHQUAKE

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The Earth beneath our feet usually feels solid and firm, even though a million times each year (an average of once every 30 s) somewhere around the world, the ground shakes and sways. This is called an earthquake. Most Earthquakes are too small to be noticed by people; only sensitive scientific instruments record their passage. But hundreds of earthquakes every year are strong enough to change the face of the land and are capable of causing injuries, deaths and property damage. Seismic hazards are those associated with earthquakes. The earthquake engineering involves the identification and mitigation of seismic hazards. This paper describes behavior and damages of buildings due to earthquakes, so that several precautions in terms of earthquake resisting systems like base isolation, other energy absorbing or dissipating devices, bracings, shear walls, etc., can be developed and implemented.

Keywords: Earthquake, Seismic Hazards, Earthquake resisting systems

INTRODUCTION

Murty *et al.* (2012) reported that all buildings are vertical cantilevers projecting out from the earth's surface. Hence, when the earth shakes, these cantilevers experience whiplash effects, especially when the shaking is violent. Hence, special care is required to protect them from this jerky movement. Buildings intended to be earthquake-resistant have competing demands. Firstly, buildings become expensive, if designed not to sustain any damage during strong earthquake shaking. Secondly, they should be strong enough to not sustain any damage during weak earthquake shaking. Thirdly, they should be stiff enough to not swing too much, even during weak earthquakes. And, fourthly, they should not collapse during the expected strong earthquake shaking to be sustained by them even with significant structural damage. These competing demands are accommodated in buildings intended to be earthquake resistant by incorporating four desirable characteristics in them. These characteristics, called the four virtues of earthquake-resistant buildings, are:

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1. Good seismic configuration, with no choices of architectural form of the building that is detrimental to good earthquake performance and that does not introduce newer complexities in the building behavior than what the earthquake is already imposing;
2. At least a minimum lateral stiffness in each of its plan directions (uniformly distributed in both plan directions of the building), so that there is no discomfort to occupants of the building and no damage to contents of the building;
3. At least a minimum lateral strength in each of its plan directions (uniformly distributed in both plan directions of the building), to resist low intensity ground shaking with no damage, and not too strong to keep the cost of construction in check, along with a minimum vertical strength to be able to continue to support the gravity load and thereby prevent collapse under strong earthquake shaking; and
4. Good overall ductility in it to accommodate the imposed lateral deformation between the base and the roof of the building, along with the desired mechanism of behavior at ultimate stage.

Behavior of buildings during earthquakes depends critically on these four virtues.

BEHAVIOR OF BUILDINGS

A majority of building structures can be divided into the following two broad categories: (i) load bearing masonry; and (ii) reinforced concrete frames with unreinforced masonry infill walls.

Load Bearing Masonry

A large number of buildings are built in unreinforced load bearing masonry units which include (i) random rubble stones, (ii) rough dressed stones, (iii) clay bricks, and (iv) solid or hollow concrete blocks. The units are assembled with mud mortar, lime mortar, or cement mortar. When the building has more than one storey, the floors and roofs are generally reinforced concrete slabs.

Reinforced Concrete Frames

In most cases buildings taller than three storeys have a structure that consists of reinforced concrete frames with unreinforced masonry infill. The masonry infill may consist of stone blocks, clay brick, or solid or hollow concrete blocks, generally set in cement mortar. Jag Mohan Humar *et al.* (2001) noted that during bhuj earthquake in India Load bearing masonry buildings in Ahmedabad performed quite well, but for minor damage in some cases. As noted earlier, Ahmedabad is about 300 km away from the epicenter and the ground shaking in the area was not very intense. The performance of masonry buildings in the Kachchh region was very poor. No reinforcement had been provided in any of the buildings. The walls were not tied to each other or to the floors and roofs. Most buildings used large size, heavy stone blocks, either undressed or rough dressed. The roof construction of wooden logs and Mangalore tiles was very heavy. All of these factors made the buildings very vulnerable to damage during earthquake, leading to widespread destruction. Figures 1 and 2 shows collapse of some masonry buildings during earthquake.

Figure 1: Stone Masonry with Tile Roof

Figure 2: Heavy Stone Masonry Walls That Had No Reinforcement

A large number of reinforced concrete frame buildings located in Ahmedabad suffered serious damage or collapsed eventhough they were such a distance that the intensity of ground motion would not be expected to be large. Important factor contributing to the damage was the use of open first storey combined with poor detailing and indifferent quality of construction. Figures 3 and 4 shows collapse of some RCC framed Buildings. Bokey *et al.* (2004) reported that Important reasons for the failure of RC Frame Buildings are (1) Short column effect; (2) Flexible ground floor (Soft storey); (3) Lack of proper detailing; (4) poor workmanship; (5) Ponding effect; and (6) Appendage effect.

Figure 3: A Damaged Reinforced Concrete Frame Buildings With Open First Storey And Brick Masonry Infills

Figure 4: Failure of Column Through Plastic Hinge

During an earthquake buildings oscillate, but not all buildings respond to an earthquake equally. If the frequency of oscillation of the ground is close to the natural frequency of the building, resonance (high amplitude continued oscillation) may cause severe damage. Small building are more affected, or shaken, by high frequency waves (short and frequent). For example, a small boat sailing in the ocean will not be greatly affected by a low-frequency swell where the waves are far apart. On the other hand several small waves in quick succession can overturn, or capsize, the boat. In same way, a small building experiences more shaking by high frequency earthquake waves. Large structures or high rise buildings are more affected by low-frequency, or slow shaking. For instance, an ocean liner will experience little disturbance by short waves in quick succession. However, a low-frequency swell will significantly affect the ship. Similarly, a skyscraper will sustain greater shaking by long-period earthquake waves than by the shorter waves.

Quake Scenarios and Damages

Oisler (2008) suggested that Vertical acceleration being so close to the horizontal acceleration indicates that the acceleration has been recorded from exactly the epicenter of the earthquake. On the other hand, in the area where such figures are measured, it can be said that a horizontal load approximately half of their weights has affected. This has particularly caused the damage to result heavily in the region. Local ground conditions have been substantially influential on heavy damage and high loss of casualties. The two scenarios below are Seattle-area earthquake scenarios show the possible effects on buildings of different structural integrity of a shallow, magnitude 7 (M7) earthquakes and a M9 subduction-zone earthquake. These scenarios could apply to any cities on the coast or inland valley. The details are shown in Figure 5 and 6. Pratima R Bose *et al.* (2004) noted that the type and extent of damage to the structure during an earthquake depends on the strength of the materials, used for construction, the structural system, joint details, quality of construction, the foundation stability and strength, maintenance, besides the intensity of earthquake shock. Bose *et al*. (2003) reported the following different types of damages:

Non-Structural Damages

The non-structural damages do not impair the strength or stability of a structure but may sometimes be the sources of falling hazards.

- Cracking and overturning of parapets;
- Falling of plaster;
- Cracking and overturning of partition walls;
- Cracking and falling of ceilings; and
- Falling of loosely placed objects.

Damages in Roofs and Floors

- Dislodging of roofing material;
- Separation and fall of roof truss from supports;
- Complete roof collapse due to the collapse of supporting structure;
- Failure of the joints connecting columns and girders in wooden trusses; **and**
- Failure of wooden gable frames due to the rupture of bottom chords.

Damages in Bearing Walls

- Failure due to longitudinal shear;
- Failure due to bending in the transverse plane;
- Failure of gable end masonry walls;
- Failure of spandrel beams
- Failure due to torsion;
- Failure of masonry arches;

Figure 5: M7 Shallow Earthquake

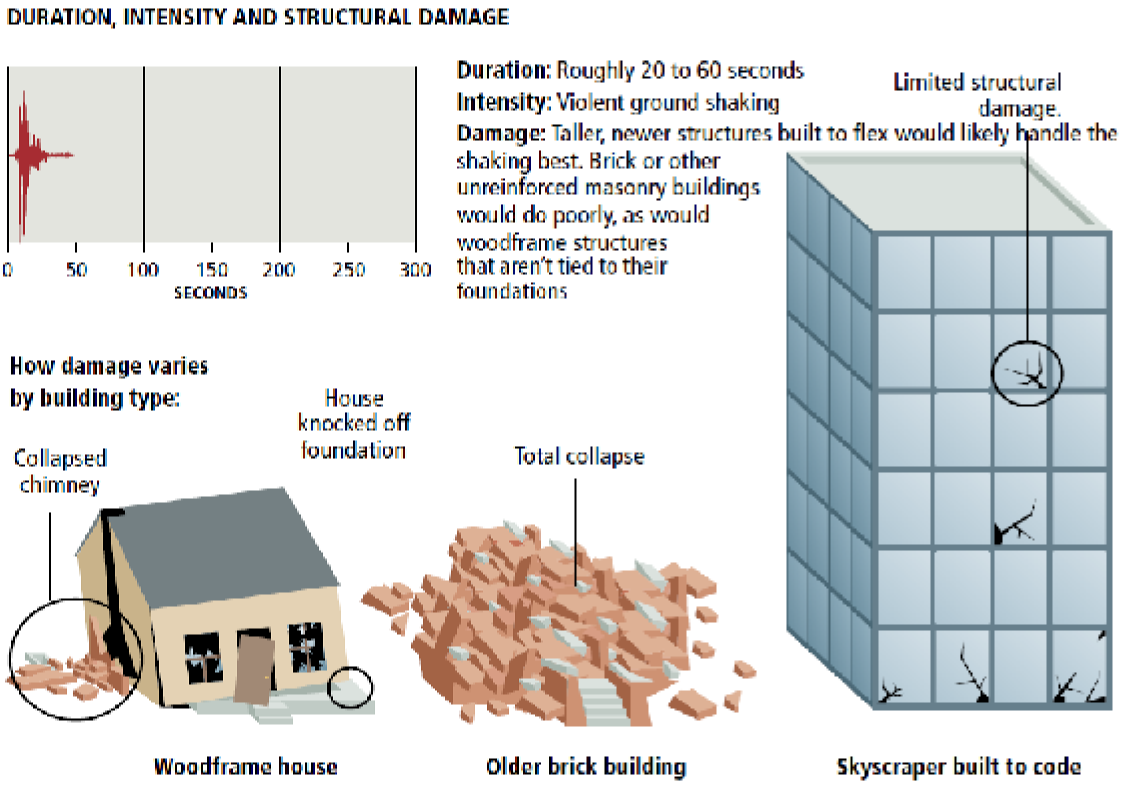

Figure 6: M9 Subduction Earthquake

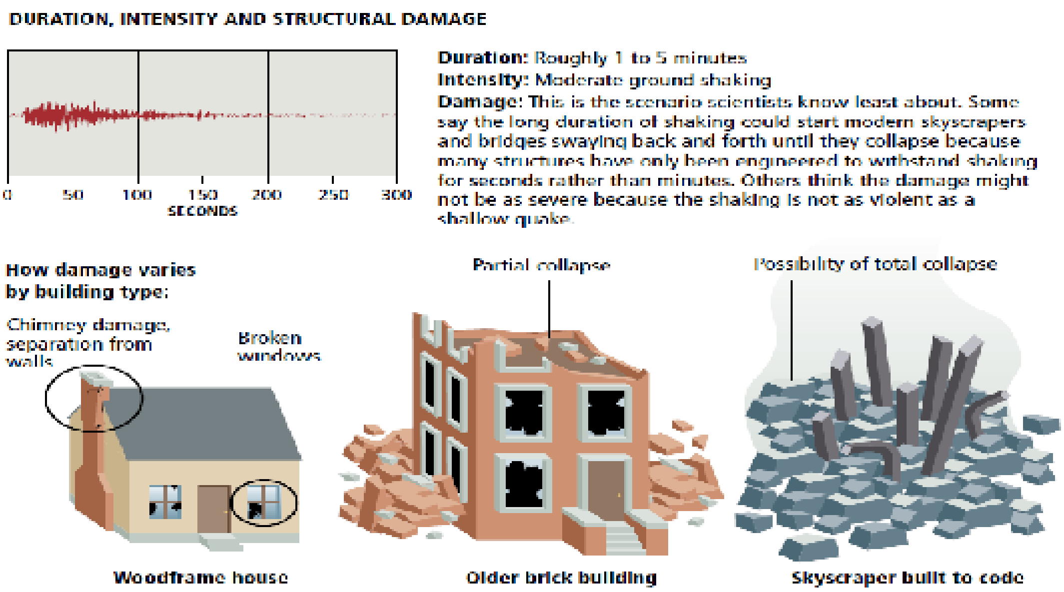

Table 1: Geotechnical Damages During Earthquake

Landslides and Mudslides 	Extremely high occurrence of landslides is attributed to the geology of the region and intense rainfall. High intensity of rainfall contributes to rapid erosion and weathering of rock mass. The increase of water level causes instability in natural slopes. Earthquake provide just a triggering action to already unstable or marginally stable slopes.
Failure of Retaining Walls 	In hilly areas, normally toe line of multi-storey buildings are founded on loose soil which is supported by a flexible retaining wall. Due to earthquake, many of these retaining walls damaged which led to failure of supporting foundations.
Failure and Damage to Roads 	Wide cracks with a gap of about 20 cm were observed on the road which can be attributed to the failure of backfill on riverside.
Foundation Failures 	As the ground floor of the building is completely collapsed, perhaps this is due to foundation failure which may be due to excessive settlement caused by shaking.

- Separation of walls at corners and T-junctions;
- Delamination and bulging of walls leading to their collapse in stone walls; and
- Outward overturning of walls.

Damages in Foundations

- Failure of foundation due to inadequate depth;
- Differential settlement; and
- Sliding of foundation at slopes.

Sharma *et al.* (2011) reported some of the geotechnical damages as shown in Table 1 like landslides, slope failures, ground failures, settlement of soils, failure of retaining walls, failure of foundations, damage to roads.

Pathak (2008) suggested that attempt has been made to prepare seismic risk map with engineering, seismological inputs on vulnerability of engineered and non engineered structures including parameters of population living in dwelling susceptible to damage and other exposure factors.

CONCLUSION

There may be many unattended factors and features which may intensify the damage at the time of the earthquake. Special care should be needed at the time of analysis, design and construction of building to incorporate these at the time of execution of construction. There are certain Gaps in theoretical knowledge and practical implementation. People or Agencies involved in disaster mitigation should be able to identify the weaknesses introduced in the buildings by the people themselves and they are to be made aware of the implications involved with the decisions they are taking at the time of planning, designing or at the time of construction.

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