The mechanism of earthquake consists of generation of seismic waves due to the rupture of the rock in the Earth and their propagation within the earth crest due to the movement of the Earth. The rupture surface is called a fault plane. There are three kinds of faults, namely, strike slip, dip slip and oblique slip. The severity of earthquake depends on the slip. The seismic waves comprises of P wave, S waves, R or Rayleigh waves and L or Love waves. The P and S waves constitute the body waves and the R and L waves constitute surface waves. The surface waves are dangerous and causes extensive damages on the Earth surface. Normally structures are founded on the Earth. So due to the motion of the Earth the ground vibrates and this sets in motion the structures. Many structures consisting of masonry, concrete, road and railway were damaged in the past earthquakes globally. The paper presents the mechanism of earthquake and the damages it can cause to structures of varied types by reviewing the available literature.

Abstract

The mechanism of earthquake consists of generation of seismic waves due to the rupture of the rock in the Earth and their propagation within the earth crest due to the movement of the Earth. The rupture surface is called a fault plane. There are three kinds of faults, namely, strike slip, dip slip and oblique slip. The severity of earthquake depends on the slip. The seismic waves comprises of P wave, S waves, R or Rayleigh waves and L or Love waves. The P and S waves constitute the body waves and the R and L waves constitute surface waves. The surface waves are dangerous and causes extensive damages on the Earth surface. Normally structures are founded on the Earth. So due to the motion of the Earth the ground vibrates and this sets in motion the structures. Many structures consisting of masonry, concrete, road and railway were damaged in the past earthquakes globally. The paper presents the mechanism of earthquake and the damages it can cause to structures of varied types by reviewing the available literature.

Keywords: earthquake, fault line, slip, seismic waves, structures, damages

1. Introduction

Earthquake is ground shaking as a result of which structures connected to the ground are set in vibration. The mechanism of generation of earthquake, ground motion, structural vibration, and the destruction of buildings (Celebi and Brown, 1994) are described below in detail. Generally, the crust of the earth is divided into smaller plates with irregular boundaries. These plates keep moving because of earth rotation and during these movement strains are developed in them due to rubbing action at their boundaries. Strains get accumulated in the plates due to their continuous movement and as a result stresses are also built up in the materials of the plates. When these stresses exceed the limiting strength of the material it ruptures (Figure 1).

This rupture in rock mass is called a fault. According to geology, a fault is a fracture in a plane or discontinuity in a volume of rock, across which there has been significant displacement along the fractures as a result of earth movement. A fault line is the surface trace of a fault, the line of intersection between the fault plane and the Earth's surface. Since faults do not usually consist of a single, clean fracture, geologists use the term fault zone when referring to the zone of complex deformation associated with the fault plane (Twiss and Moores, 2007). The attitude of a fault describes its orientation in 3D space, and consists of its strike and its dip. The strike is the direction of a line produced by the intersection of the fault surface and an imaginary horizontal plane (Figure 2). In contrast, the dip is the angle between an imaginary horizontal plane and fault surface (Figure 2).

Figure 1 Fault plane

Figure 2 Fault, Strike, and Dip (Girty, 2009)

If the dip is 90°, then the fault has a vertical dip. At the other end of the spectrum, if the dip is 0°, then the dip is
The nature of the fault is important because it is used to classify the fault as either dip or strike-slip. For example, if the displacement across the fault is parallel to strike, then the fault is a *strike-slip fault* (Figure 3a). On the other hand, if the displacement is parallel to the dip and at right angles to the strike, then the fault is a *dip-slip fault* (Figure 3b). However, sometimes the displacement is neither parallel to the strike nor to the dip, and, in such cases the fault is classified as an *oblique-slip fault* (Figure 3c).

The phenomenon of accumulation of strain in the rock, the increase in stress and the consequential rupture on exceeding the inherent strength of rock is known as *elastic rebound*. The theory that explains this occurrence is called *elastic rebound theory*. The place at which rupture takes place is called a *focus* which lies deep inside the earth, typically in terms kilometres. The point directly above focus on the surface of the earth is called *epicenter* (Figure 4).

Due to the release of energy at focus, shock waves are set up and radiate in all directions from this point (Figure 4). These waves are called seismic waves. Seismic waves travel through the earth. Seismic waves travel either through the Earth’s interior or near Earth’s surface with a characteristic speed and style of motion (Prasad, 2009).
S waves, also known as secondary waves, are the waves that follow the P waves. S waves travel in the same direction. However, instead of being a compressive wave, they oscillate with a shearing behaviour at right angles to the direction of motion. Figure 6b shows that though the wave direction is the same as the P wave, the ground motion is sideward horizontally. Their speed is about 1.7 times slower than P waves. Liquids do not sustain shear stresses and hence S waves do not travel through liquids like water, molten rock, or the Earth’s outer core. S waves are more dangerous than P waves. This is because they have greater amplitude and produce vertical and horizontal motion of the ground surface (Figure 6b).

There is the last type of wave as discussed above and the slowest is the surface wave which moves close to or on the outside surface of the ground. As seen before, there are two types of surface waves:

### 1.3 Effect of Seismic Waves

The seismic waves move the ground and hence any structure founded on it according to their wave motion (Figure 8). It depends on the proximity to the focus of the earthquake. Shaking of the ground is different depending upon the types of seismic-energy waves. Combination of different waves and their reflections and refractions by the boundaries within the earth generate many other types of seismic waves, but these are of interest to seismologists. The P wave, also called primary wave, is the fastest of all the waves and the first to be detected by seismographs. They can move through both solid rock and liquids. As stated above, these are also called compressional or longitudinal waves that oscillate the ground back and forth along the direction of wave travel, similar to sound waves which are also compressional move the air back and forth as they travel from the sound source to the receiver. Compressional waves compress and expand the particles as they move through it (Figure 6a).
i) Rayleigh waves move both horizontally and vertically in a vertical plane pointed in the direction of travel (Figure 7a).

ii) Love waves move like S waves in that they have a shearing motion in the direction of travel, but the movement is back and forth horizontally (Figure 7b).

Both Love and Rayleigh waves produce ground shaking at the Earth’s surface but very little motion deep in the Earth. Because the amplitude of surface waves decays with distance not so fast as that of P or S waves, surface waves are often the most important component of ground shaking far from the earthquake source, thus can be the most destructive.

1.4 Damages to Structures

Structures are in general designed to resist their own weight and other loads applied on them vertically downward which are called gravity loads. They can usually carry a small quantity of snow and a few other floor loads and suspended loads as well, vertically; so even badly constructed structures can resist some up-and-down loads (Figure 9). But buildings and structures are not necessarily resistant to side-to-side loads which are also known as lateral loads, unless this has been taken into account during the structural engineering design and construction phase with some earthquake proof measures taken into consideration. This weakness would only be found out when the earthquake strikes (Figure 10). It is this lateral load which causes the worst damage, often collapsing poor buildings on the first shake. The side-to-side load can be worse if the shocks come in waves, and some bigger buildings can vibrate like a huge tuning fork, each new sway bigger than the last, until failure. This series of waves is more likely to happen where the building is built on deep soft ground, like Mexico City. A taller or shorter building nearby may not oscillate much at the same frequency.

Often more weight has been added to a building or structure in the form of swimming pools or heavy mass at most frequently at greater heights. A few of this sort of weight can be in the form of another floor and another over that; walls constructed around open balconies and inside partitions to make more, smaller, rooms; rocks heaped on roofs to stop them blowing away; storage inside; etc. This extra weight produces great forces called inertia forces on the structure and helps it collapse. The more weight there is, and the higher this weight is in the building, the stronger the building and its foundations must be to resist the earthquakes; many buildings have not been strengthened when the extra weight was added. Often, any resistance to the sway loading of the building is provided by walls and partitions; but these are sometimes damaged and weakened in the Main Earthquake. The building or structure is then more vulnerable, and even a weak aftershock, perhaps from a slightly different direction, or at a different frequency, can cause collapse. In a number of multi storey buildings, the floors and roofs are just resting on the walls, held there by their own weight; and if there is any structural framing it is too often inadequate. This can result in a floor or roof falling off its support and crashing down, crushing anything below. Some of the failure and collapse of structures during the past earthquakes worldwide are described below.

As stated above, during earthquake the ground moves. Therefore the first casualty is the railway track which gets distorted as shown in Figure 11. Ground motion ruptures the roads as seen in Figure 12. A crane and several construction vehicles lay toppled on a fractured road in Kobe, Japan, after a 7.2 magnitude temblor shook the quake-prone country.

![Figure 11 Distortion of railway track](image1)

![Figure 12 Fractured Road (Kasmauski, 2014)](image2)

It is mainly the lateral motion of the ground that causes shear cracking of walls as well as separation of corner of buildings (Figure 13).
In concrete buildings also extensive damage can be caused by earthquake loading (Moehle and Mahin, 1998). The concrete in the column can be crushed and fall off exposing the reinforcement as shown in Figure 14 (Wu et al, 2010). Failure of inadequate, anti-burst wrapping and lack of connection between upper and lower vertical elements led to the collapse of the Cypress Freeway viaduct (Figure 15). There has been cases of total collapse of many buildings in an area as reported by United States Geological Survey Department as shown in Figure 16 (a). Pancake type failure of multi-storeyed building as shown in Figure 16(b) is a common sight during earthquake in urban areas (Langenbach, 2006).

In 1964 Niigata earthquake in Japan, buildings overturned and fell down on one side without any damage to them as shown in Figure 17 due to soil liquefaction, a condition wherein grainy soil like sand turns out to be liquid due to the application of repeated loading during earthquake (Saran, 1999). There has been failure of fence due to ground movement as shown in Figure 18.
A 2500-car parking garage on the campus of the California State University, Northridge collapsed inward during earthquake as shown in Figure 19. Earthquake does not damage and collapse only buildings outside. It can also cause fall of stored objects inside a building as seen in Figure 20 that happened in Loma Prieta earthquake.

Figure 17 Overturning of building due to soil liquefaction

Figure 18 Bending of Fence (McGraw Hill Co. Inc.)

Figure 19 Collapse of parking garage

Figure 20 Fallen objects in a book store in Loma Prieta earthquake (Celebi and Brown, 1994)

1.5 Concluding Remarks

Earth crust is made up of disjointed plates of irregular shape and size. Due to the movement of Earth these plates rub each other building up of strain in the rock. As a result strength gets accumulated and when it reaches the limiting value the rock fractures. The plane on which fracture takes place is called a fault plane. The shape of the fault plane is of three major types, namely, strike slip, dip slip and oblique fault. When rupture takes place deep inside the earth, called focus, a lot of energy is released and transmitted in all directions in the form of energy waves. They are called seismic waves which are of two major types, namely, body waves and surface waves. The body waves consist of P wave and S wave. The surface wave consists of R wave or Rayleigh wave and L wave. The surface wave is quite active for a shallow depth and carries almost 65 per cent of energy. It is the surface wave that causes damage to structures and collapses it. Many catastrophic failures have taken place during the past earthquakes worldwide. They range from road to buildings. It is the bad design of buildings that causes more loss of life than the earthquake.

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