International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Mechanism of Earthquake and Damages of Structures

C. Selin Ravikumar[Ȧ*], V. Ramasamy[Ḃ] and T.S. Thandavamoorthy[Ḃ]

[Ȧ]M.G.R. Educational and Research Institute University, Maduravoyal, Chennai 60095, India
[Ḃ]Adhiparasakthi Engineering College, Melmaruvathur 603319, India

Accepted 05 March 2014, Available online 10 April 2014, **Vol.4, No.2 (April 2014)**

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

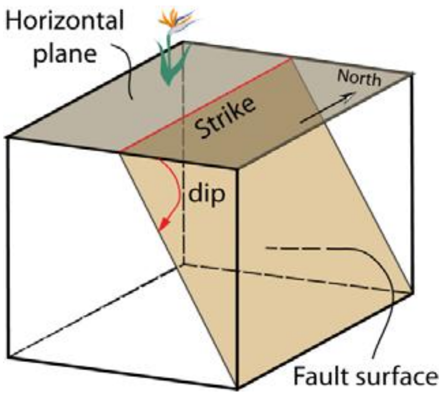


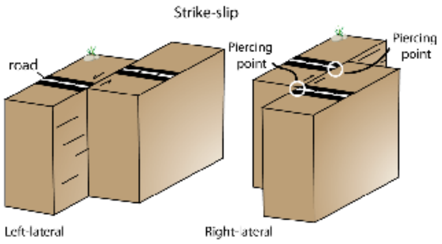
Figure 2 Fault, Strike, and Dip **(**Girty, 2009)

If the dip is 90^o, then the fault has a vertical dip. At the other end of the spectrum, if the dip is 0^o, then the dip is

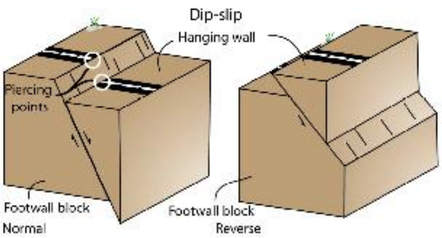
*Corresponding author's **Ph-+91-9840202071**

horizontal. 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).

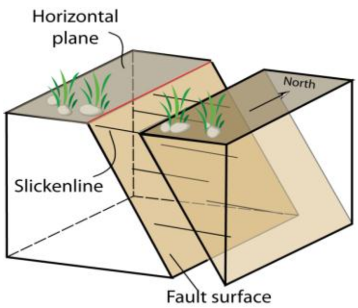
The phenomenon of accumulation of strain in the rock, the increase in stress and the consequential rupture on exceeding the inherent strength of rock is known as *elastic rebound*. The theory that explains this occurrence is called *elastic rebound theory*. The place at which rupture takes place is called 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).



(a) Strike slip



(b) Dip slip



(c) Oblique slip

Figure 3 Different types of faults **(**Girty, 2009)

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 are energy waves that move 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).

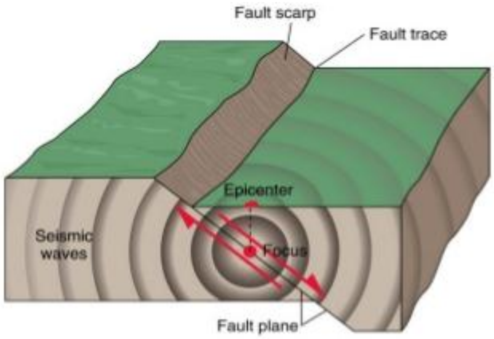


Figure 4 Features of Earthquake (courtesy Mc Graw Hill, Inc.)

1.2 Category of Seismic Waves

Three types of seismic waves are generated due to rupture of plates and propagate as shown in Figure 5. They are: P-wave, S-wave and R or L-wave (Braile, 2005). The P-wave is called a primary or compressional wave or dilatational wave (Figure 6a). The S-wave is known as a secondary or shear wave (Figure 6b). The R-wave is a Rayleigh wave (Figure 7a) and L-wave is a Love wave (Figure 7b). The speeds of these seismic waves vary depending on the density and the elastic properties of the material they pass through, and they are amplified as they reach the surface. The motion is detected at far places by sensitive seismographs.

Here, P and S waves are classified as body waves whereas R and L waves are categorized as surface waves. Body waves propagate through the interior of the Earth. Their propagation is faster than surface waves. Surface waves decay more slowly with distance when compared to body waves, which travel in three dimensions. Because the particle motion of surface waves is larger than that of body waves they tend to inflict more damage to structures (Zhao et al, 2004).

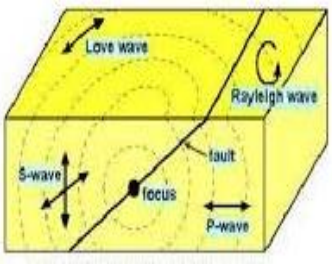
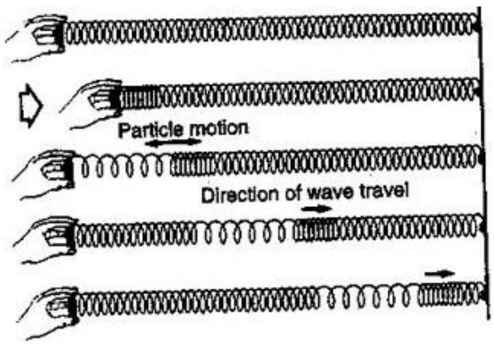
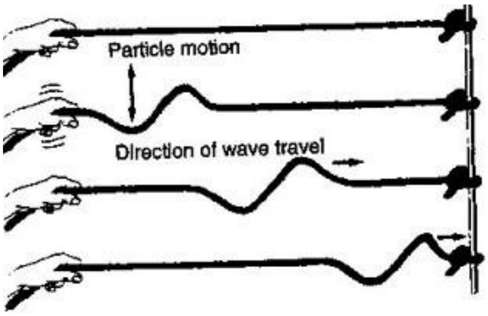


Figure 5 Direction of propagation of seismic waves

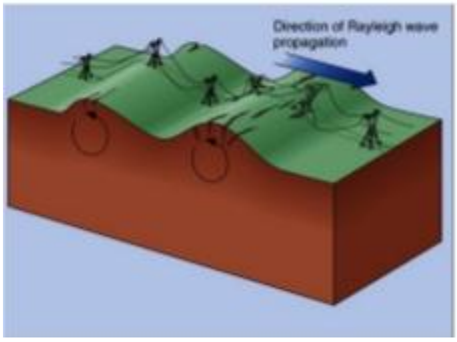


(a) P-wave

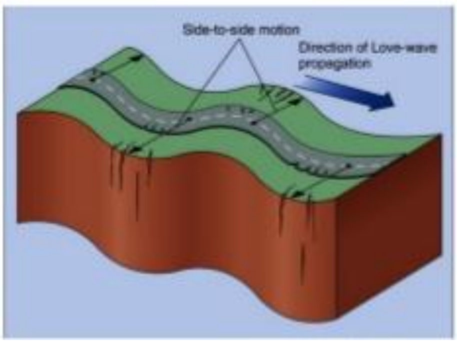


(b) S-wave

Figure 6 Body waves



(a) Raleigh wave



(b) Love wave

Figure 7 Surface waves (courtesy McGraw Hill, Inc.)

The P-wave travels in the longitudinal direction with particle motion in the vertical plane. It has high frequency, short wave, and it can reflected and refracted at boundaries and travels through the liquid and solid media of Earth. The S-wave moves sideward in plan and motion of the particle lies in the same plane. Hence, it is transverse wave. It has high frequency, short wave length.

It can be reflected and refracted at boundaries. It can travel through solid medium of earth only with varying velocity. From the focus it propagates in all directions.

The R and L waves have long wave length with low frequency. These waves vibrate in a transverse direction. The particle motion of R-wave is in vertical direction whereas in the case of L-wave it is lateral motion. They are mainly concentrated on the outer skin of the crest and hence are active at the surface of the Earth. These waves carry 65 per cent of the total energy and hence destructive in nature. They are responsible for the collapse of many structures.

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).

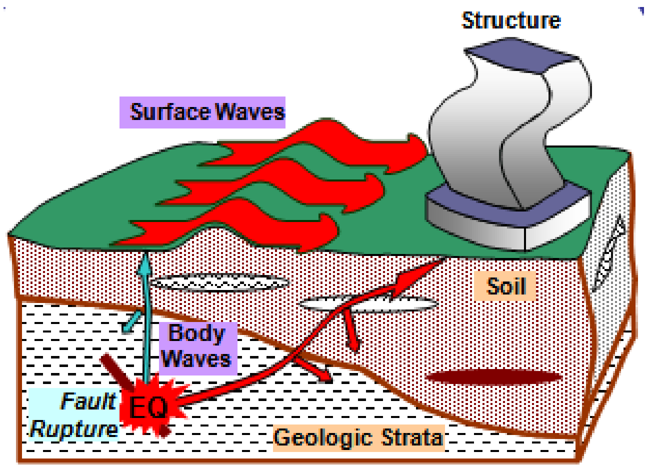


Fig. 8 Vibration of structure

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:

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.

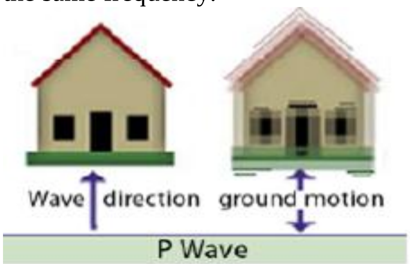


Figure 9 Vertical motion of building

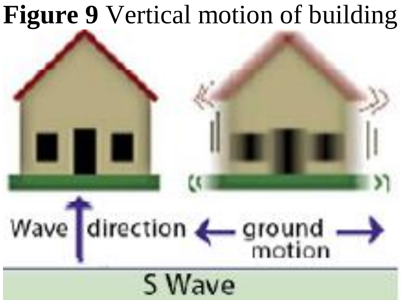


Figure 10 Lateral motion of building

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 resistant 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

Figure 12 Fractured Road (Kasmauski, 2014)

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)

(a) Shear crack in wall

(b) Separation of wall at corner

Figure 13 Damages in masonry buildings

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 is 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).

Figure 14 Collapse of concrete column

Figure 15 Collapse of expressway

(a) Extensive damage and collapse

(b) Pancake collapse in of buildings 1985 Mexico City (USGS)

Figure 16 Different Types of Damages to Buildings

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.

Figure 17 Overturning of building due to soil liquefaction

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

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 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 or 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.

References

Braile, L. (2005), Wave Properties, *National Science Foundation, USA*.

Celebi, M. and Brown, Jr., R. D. (1994), Column failure on interstate highway overpass, Northridge earthquake, *Structural Damage, Earthquakes and Volcanoes*, 25 (2), pp. 94-102.

Girty, G.H. (2009), Perilous Earth: Understanding Processes Behind Natural Disasters, *Department of Geological Sciences, San Diego State University, USA, June.*

Kasmauski, K. (2014), Photo Gallery: Earthquakes, *National Geographic, National Geographic Society, USA*

Langenbach, R. (2006), Preventing Pancake Collapses: Lessons from Earthquake-Resistant Traditional Construction for Modern Buildings of Reinforced Concrete, International Disaster Reduction Conference (IDRC), Davos, Switzerland, *ICCROM: Integrating traditional knowledge systems and cultural heritage into risk management*, pp. 1-44

Moehle, J. P. and Mahin, S. A. (1998), Observations on the Behavior of Reinforced Concrete Buildings during Earthquakes, Republished Article, Structural Engineering, Mechanics and Materials Department, University of California Berkeley, NISEE, *National Information Service for Earthquake Engineering*, January 23

Prasad, B.B. (2009), *Fundamentals of Soil Dynamics and Earthquake Engineering*, PHI Learning Private Ltd., New Delhi

Saran, S. (1999), *Soil Dynamics and Machine Foundations*, Galgotia Publications Pvt. Ltd., New Delhi

Twiss R.J. and Moores, E.M. (2007), *Structural Geology*, W.H. Freeman and Company, New York, 2nd Edition

Wu, C. L., Yang, Y. S., Hwan, S.J., and Loh, C. H. (2010), Dynamic Collapse of Reinforced Concrete Columns, Proceedings of the *9th U.S. National and 10th Canadian Conference on Earthquake Engineering*, July 25-29, Toronto, Ontario, Canada, Paper No 1172, pp. 1-6.

Zhao, Z., Xu, J., Kubota, R., Yasuhiko, W., Syozo, K. (2004), Collapse Ratios of Buildings due to the 1995 Kobe Earthquake and Interference between S-wave and the Second Surface Wave at Basin Edge, *Chinese Science Bulletin*, 49(2) 189-195.