Journal of Advances in Biological and Basic Research 01[01] 2015
www.asdpub.com/index.php/jabbr

Review Article

Earthquake: A terrifying of all natural phenomena

T.A. Adagunodo[1,2]* and L.A. Sunmonu[1,2]

[1]Department of Pure and Applied Physics, Ladoke Akintola University of Technology, P.M.B. 4000, Ogbomoso, Nigeria.
[2]Geophysics/Physics of the Solid Earth Section, P/A Physics, LAUTECH, Ogbomoso, Nigeria.

***Corresponding Author**
T.A. Adagunodo
Department of Pure and Applied Physics,
Ladoke Akintola University of Technology,
P.M.B. 4000, Ogbomoso, Nigeria.
E-mail: taadagunodo@yahoo.com

Keywords:
Earthquake, Faults, Seismic Reflection, Seismic Refraction, Seismology, Stress, Volcanoes

Abstract

Earthquake is the passage of vibrations (seismic wave) that spread out in all directions from the source of the disturbance when rocks are suddenly disturbed. An earthquake is caused by sudden slip on a fault which itself described by epicenter, focus, focal depth, after shock, fore shock, magnitude of earthquake, intensity of an earthquake and intensity. Elastic rebound model is a useful guide to how an earthquake may occur. This manuscript reviews the rock responses to stress and the relationship between faults and earthquake. It also reviews the types of earthquake, earthquake seismology, differences between seismic refraction and reflection as well as basic Physics behind an earthquake phenomenon.

1. Introduction

An earthquake is caused by a sudden slip on a fault. Stresses in the earth's outer layer push the sides of the fault together. Stress builds up and the rocks slips suddenly, releasing energy in waves that travel through the earth's crust and cause the shaking that is felt during an earthquake. An earthquake occurs when plates grind and scrape against each other and it always occurs at plate margins. In another words, earthquake is a violent release of elastic energy due to sudden displacement on a fault plane. Other causes of earthquake includes those induced by human activity such as injection of fluids into deep wells for waste disposal and secondary recovery of oil and the use of reservoirs for water supplies. Nuclear detonations can trigger an earthquake [1].

Plate tectonics is the continual slow movement of the tectonic plate, the outermost part of the earth. This motion is what causes earthquake and volcanoes and has created most of the spectacular scenery around the world [2].

Earthquakes are one of the most destructive of natural hazards. Earthquake occurs due to sudden transient motion of the ground as a result of release of elastic energy in a matter of few seconds. An earthquake can also be the violent shaking of the earth caused by a sudden movement of rock beneath its surface [3].

Great earthquakes rank with volcanic eruptions as being the most terrifying of all natural phenomena usually coming with no recognized, warning, often happening in the night, extremely indefinite as to source, extent and duration. They fill the mind of the human observer with the horror of utter helplessness. They have been far more destructive to human life and property, than volcanic eruptions [3].

Earthquakes mostly of volcanic origin have visited many of the islands of the South Seas. The major portions of Africa and South America remain blank upon such a map, probably because little is known about their seismicity [3].

2. Rock Response

Rock response to stress (squeezed or pulled) near the earth surface by breaking, and when rock moves along either side of a fracture, it is called fault. Fault is a fracture or zone of fracture between two rocks. Fault allows the block to move relatively to each other [3]. This movement may occur rapidly, in form of earthquake, or may occur slowly in form of creep. Fault may range in length from few millimeters to thousands of kilometers. Most faults produced repeated displacements over geologic time. During an earthquake, the rock on one side of the fault suddenly slips with respect to the other. The fault surface can be horizontal or vertical or some arbitrary angle in between [3]. There are three (3) types of fault such as: normal fault, reversed fault, and strike fault.

i. Normal Fault

Fault caused by block of crust pulling apart under the forces of tension are called normal faults. In a normal fault, the hanging walls moves down relative to the rocks below the fault plane on the footwall. The footwall is underlying surface of an inclined fault plane. The hanging wall is the overlying surface of an inclined fault plane [3].

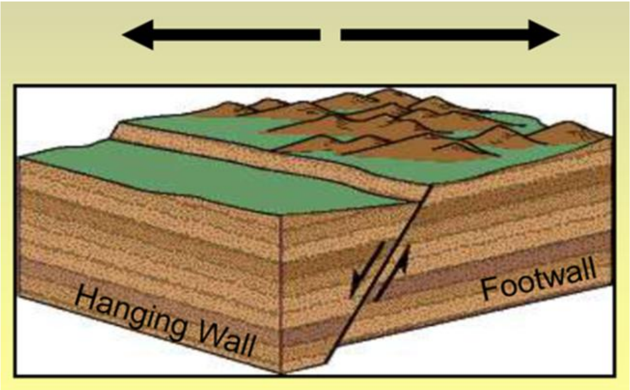

Figure 1: Relative movement of two blocks indicating a normal fault [4].

ii. Reversed Fault

Fault caused by block of crust colliding under the forces of compression are called reverse fault. Reverse faults are a prevalent feature in continent-continent collisions. Usually, there is also accompanying folding of rocks. During reverse faulting, the hanging wall block moves upward (and over) relative to the footwall block [3].

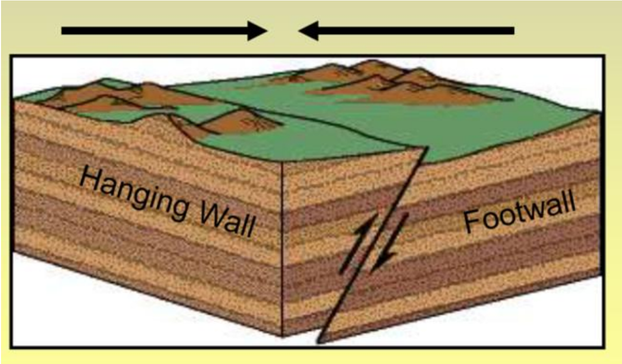

Figure 2: Relative movement of two blocks indicating a reverse fault [4].

iii. Strike-Slip

Strike-slip faults occur when two blocks move in horizontal but opposite directions of each other. Depending on the direction of offset, it can be a "right-lateral offset" or a "left-lateral offset" [3].

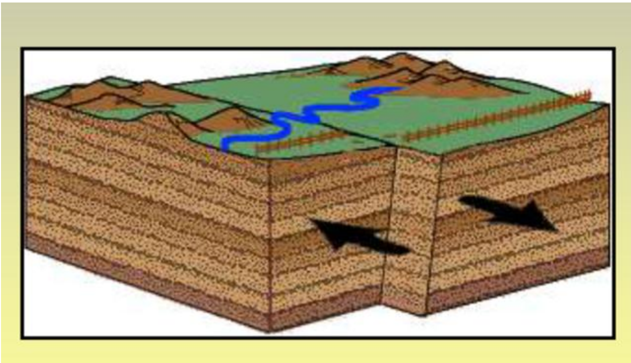

Figure 3: Relative movement of the fence that has been offset to the right; therefore it is called a right lateral strike-slip fault [4].

2.1 Relationship between Faults and Earthquake

Earthquakes do occur on faults. Strike – slip earthquake occur on strike – slip faults, normal earthquake occur on normal faults, thrust earthquake occur on thrust or reversed faults. When an earthquake occurs on one of these faults, the rock on one side of the fault slips with respect to the other [3].

2.2 Types of Earthquake

2.2.1 Tectonic Earthquakes

A tectonic earthquake is by far the most common of earthquakes. These are produced when rocks break suddenly in response to the various global forces. Tectonic earthquakes are scientifically important to the study of the earth's interior because of its greatest significance as they pose the greatest hazard [5].

2.2.2 Volcanic Earthquake

The second well known type of earthquake is the one which accompanies volcanic eruptions. A volcanic earthquake is defined as one that occurs in conjunction with volcanic activity, but it is believed that eruptions and earthquakes both result from tectonic forces in the rocks and need not occur together [5].

2.2.3 Collapse Earthquakes

Collapse earthquakes are small earthquakes occurring in regions of underground caverns and mines. The immediate cause of ground shaking is the collapse of the roof of the mine or cavern. An often- observed variation of this phenomenon is the so called "mine burst". This happens when the induced stress around the mine working cause large masses of rock to fly off the mine face explosively, producing seismic waves. Collapse earthquakes are also produced by massive land sliding [5].

2.2.4 Explosion Earthquakes

Explosion earthquakes are produced by the detonation of chemicals or nuclear devices. Some underground nuclear explosions fired since the 1950s have produced substantial earthquakes [5].

When a nuclear device is detonated in a borehole underground, enormous nuclear energy is released. In millionths of a second, the pressure jumps thousands of times the pressure of the Earth's atmosphere and the temperature increases by millions of degrees [5].

2.3 Causes of an Earthquake

The shaking motion of an earthquake is the result of a sudden release of energy. Earthquakes are caused when stress, building up within rocks of the earth's crust, is released in a sudden jolt. Rocks crack and slip past each other causing the ground to vibrate [6].

Cracks along which rocks slip are called faults. They may break through the ground surface, or be deep within the earth. The location on a fault where slip first occurs is called the focus, whereas the position directly above it on the ground surface is called the epicenter [6].

2.4 Earthquake and Human

Earthquake induced by human activity have been documented in a few location in the United State, Japan, and Canada. The cause was injection of fluids into deep wells for waste disposal and secondary recovery of oil, and the use of reservoir for water supplies. Most of these earthquakes were minor. The largest and the most widely known resulted from fluid injection at the Rocky Mountain Arsenal near Denver, Colorado [7].

In 1967, an earthquake of magnitude 5.5 followed a series of smaller earthquake. Injection had been discontinued at the site in the previous year once the link between the fluid injection and the earlier series of earthquakes was established [7]. Earthquakes cannot be prevented, but there effect can be mitigating by identifying hazards, building safer structures, and providing education on earthquake safety.

2.5 Earthquake Foreshock and Aftershock

Foreshocks are earthquake which precede larger earthquake in the same location. Aftershocks are smaller earthquake which occur in the same general area during the days to years, following a larger event or "mainshock". Aftershocks represent minor readjustments along the portion of a fault that slipped at the time of the main shock. The frequency of these aftershock decreases with time [3].

Generally, during an earthquake there will first be a feeling of a swaying or jerking motion then slight pause, followed by a more intense rolling or jerking motion. The duration of the shaking felt depends on earthquake magnitudes, the distance from the epicenter, and the geology of the ground under the feet [3].

For minor earthquakes, ground shaking usually lasts only few seconds. Strong shaking from a major earthquake usually lasts less than one minute. For example, the shaking in 1989 magnitude 7.1 Loma Prieta (San Francisco) earthquake lasted 15 seconds, for 1906 magnitude 8.3 San Francisco earthquake lasted about 40 seconds [3].

2.6 Earthquake Seismology

Seismology is the study of earthquakes and seismic waves that move through and around the earth. Seismology is also the study of the passage of elastic waves through the earth. Earthquake seismology is the best tool to study the interior of the earth. A seismologist is a scientist who studies earthquakes and seismic waves [8].

Seismometers are sensors that sense and record the motion of the Earth arising from elastic waves. Seismometers may be deployed at Earth's surface, in shallow vaults, in boreholes, or underwater. A complete instrument package that records seismic signals is called a seismograph. Networks of seismographs continuously record ground motions around the world to facilitate the monitoring and analysis of global earthquakes and other seismic sources [8].

Rapid location of earthquakes makes tsunami warnings possible because seismic waves travel considerably faster than tsunami waves. Seismometers also record signals from non-earthquake sources ranging from explosions (nuclear and chemical), to local noise from wind or anthropogenic activities, to incessant signals generated at the ocean floor and coasts induced by ocean waves (the global microseism), to cryospheric events associated with large icebergs and glaciers [3].

Above-ocean meteor strikes with energies as high as 4.2×10^{13} J (equivalent to that released by an explosion of ten kilotons of TNT) have been recorded by seismographs, as have a number of industrial accidents and terrorist bombs and events (a field of study referred to as forensic seismology). A major long-term motivation for the global seismographic monitoring has been for the detection and study of nuclear testing. Because seismic waves commonly propagate efficiently and interact with internal structure, they provide high-resolution noninvasive methods for studying Earth's interior [9].

One of the earliest important discoveries (suggested by Richard, [9]) was that the outer core of the earth is liquid. Since S-waves do not pass through liquids, the liquid core causes a "shadow" on the side of the planet opposite of the earthquake where no direct S-waves are observed. In addition, P-waves travel much slower through the outer core than the mantle.

Processing readings from many seismometers using seismic tomography, seismologists have mapped the mantle of the earth to a resolution of several hundred kilometers. This has enabled scientists to identify convection cells and other large-scale features such as Ultra Low Velocity Zones near the core–mantle boundary [9].

3. Basic Physics

There is some basic terminology and physics that describe the various aspects of wave form and motion [10].

i. The wavelength (λ) is the distance between two adjacent points on the wave that have similar displacements, one wavelength is the distance between successive crest.
ii. Amplitude (A) of the wave is the maximum displacement of the particle motions, or the height of the ripple crest.
iii. Period (T) is the time it takes for two successive waves to pass a reference point or the motion to complete one cycle. The cycle of seismic waves or repetitions in a given unit of time is called frequency (f). Frequency and period are related by this relationship:

$$f = \frac{1}{T} \text{ where f as unit hertz Hz or } \frac{1}{s}$$

iv. The speed in which the wavefront (or ripple crest) travel can be detected if the time the wavefront takes to reach a known distance is recorded:

V = distance / time [unit: m/s] $V = \frac{DISTANCE}{TIME} = \frac{D}{T}$

Or if wavelength and frequency are known:

$$V = f\lambda$$

Table 1: Advantage and Disadvantage of Seismic Methods [11].

SEISMIC METHODS	
Advantages	**Disadvantages**
1. Can detect both lateral and depth variation in a physical relevant parameter: seismic velocity	1. Amount of data collected in a survey can rapidly become overwhelming
2. Can produce detailed images of the structural features present in the subsurface	2. Data is expensive to acquire and the logistics of data acquisition are more intense than other geophysical methods
3. Can be used to delineate stratigraphic and in some instance depositional features	3. Data reduction and processing can be time consuming, require sophisticated computer hardware and demand considerable expertise
4. Response to seismic wave propagation is dependent on rock density and a variety of physical (elastic) constants. Thus, any mechanisms for changing these constants (porosity changes, permeability changes, compaction, etc.) can , in principle be delineated via the seismic methods	4. Equipment for the acquisition of seismic observation is in general more expensive than equipment required for other surveys
5. Direct detection of hydrocarbons in some instances is possible	5. Direct detection of common contaminants present at levels commonly seen in hazardous waste spills is not possible

3.1 Seismic Refraction and Reflection

3.1.1 Seismic Refraction

The seismic refraction technique is based on the refraction of seismic energy at the interfaces between subsurface/geological layers of different velocity. The seismic refraction method uses very similar equipment to seismic reflection, typically utilizing geophones in an array, and a seismic source (shot) [11].

Figure 4 illustrates the path of seismic waves propagating from a source at the surface. Some of the seismic energy travels along the surface in the form of a direct wave. However, when a seismic wave encounters an interface between two different soil and rock layers a portion of the energy is reflected and the remainder will propagate through the layer boundary at a refracted angle [11].

At a critical angle of incidence the wave is critically refracted and will travel parallel to the interface at the speed of the underlying layer. Energy from this critically refracted wave returns to the surface in the form of a head wave, which may arrive at the more distant geophones before the direct wave. By picking the time of the first arrival of seismic energy at each geophone, a plot of travel-time against distance along the survey line can be generated. This type of graph is shown at figure 5. The gradients of the lines in this type of plot are related to the seismic velocity of the subsurface layers. The final output is a velocity/depth profile for the refractors [11].

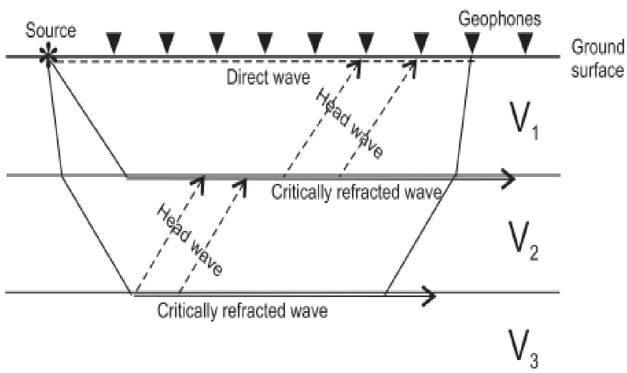

Figure 4: the seismic refraction path ray [12].

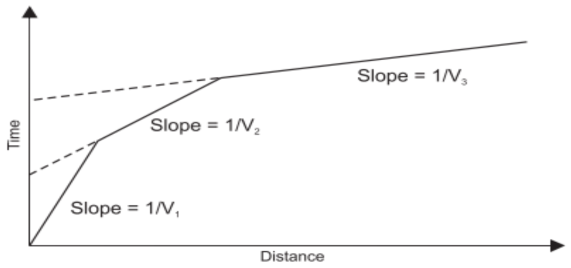

Figure 5: travel-time against distance [12]

3.1.2 Seismic Reflection

Seismic reflection can identify variations in material type with depth and horizontal position. The technique images the interfaces between materials with contrasting acoustic/seismic velocities. This translates to differences in the elastic properties and/or density of the material. Mapping these contrasts across an area can identify the extent and depth to specific layers or interfaces of interest [13].

The seismic reflection method is based on the propagation of seismic waves through the subsurface, and their reflection at interfaces across which there is a sufficient contrast in velocity. This is illustrated by figure 6a. The seismic energy is generated at the surface by an impact or an explosion [13].

Seismic waves arriving at positions along the survey line are recorded by geophones. Modern geophones consist of a coil wound on a magnetic core, spring suspended in the field of a permanent magnet. If the coils move relative to the magnet, a voltage is induced in an external circuit. The strength of this voltage is related to the strength of the oscillation. Each geophone is connected to the seismometer which records the arrival time and magnitude of the induced voltages (oscillations) at each geophone [13].

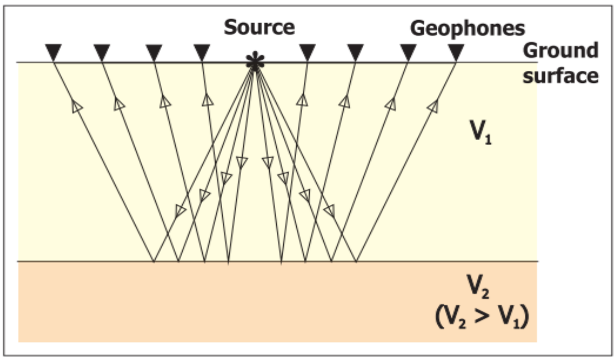

Figure 6: seismic reflection path ray [12]

Research from seismic reflection and refraction has led to many important discoveries [13], such as:

1) There are three main layers of the Earth: The crust, mantle, and core.
2) The continental crust is thicker than oceanic crust and seismic waves travel slower in the continental crust meaning that they are made up of different kinds of rock (granite/basalt).
3) There is a distinct boundary between the crust and the mantle called the Mohorovicic discontinuity, or, simply, the Moho. At this boundary, seismic waves are refracted.
4) There is a layer within the mantle up to 70 km thick beneath the ocean and up to 250 km thick beneath the continents where waves travel slower than in more shallow layers. This layer is called the low-velocity zone, and scientists have concluded that this zone is at least partially liquid. In plate-tectonic theory, it is called the asthenosphere, which is the semi-molten region of the earth's" interior just below the earth's rigid crust that allows for tectonic plate movement.
5) P-waves can pass through the outer core but S-waves cannot.
6) The outer core is a molten liquid.

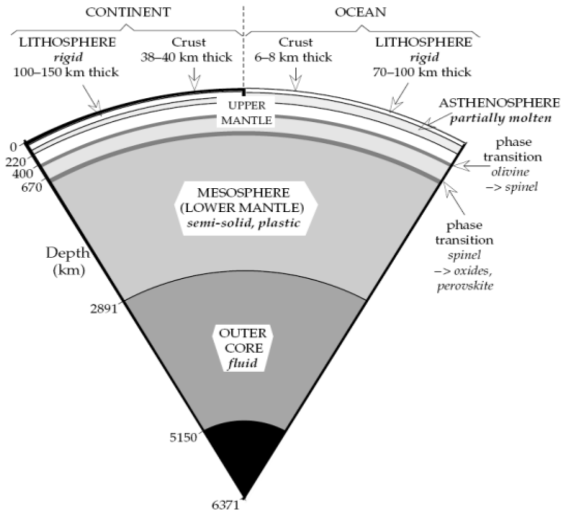

Figure 6b: simplified layered structure of the Earth's interior showing the depths of the most important seismic discontinuities [1].

Table 2: Differences between Seismic Refraction and Reflection [11].

	SEISMIC METHOD COMPARISON	
	REFRACTION	**REFLECTION**
Typical targets	Near – horizontal density Contrasts at depth less than 100 feet	Horizontal to dipping density Contrasts, and laterally restricted targets such as cavities or tunnels at greater than 50 feet
Require site condition	Accessible dimensions greater than 5x the depth of interest; unpaved greatly preferred	None
Vertical resolution	10 to 20 percent of depth	5 to 10 percent of depth
Lateral resolution	½ the geophone spacing	½ the geophone space
Effective practical survey depth	1/5 to ¼ the maximum shot-geophone separation	➢ 50 feet
Relative cost	$N	$3 xN to $5 xN

In situations where both could be applied, seismic reflection generally has better resolution, but is considerably more expensive. In those situations, the choice between seismic reflection and refraction becomes an economic decision.

In other cases (e.g. very deep/small targets) only reflection can be expected to work. In still other cases, where boreholes or wells are accessible, neither refraction, nor reflection may be recommended in favor of seismic tomography.

3.2 Earthquake (Seismic) Waves

The shaking during an earthquake is caused by seismic waves. Seismic waves are generated when rock within the crust breaks, producing a tremendous amount of energy. The energy released moves out in all directions as waves, much like ripples radiating outward when you drop a pebble in a pond [5].

The Earth's crusts near tectonic plate edges are forced to bend, compress, and stretch due to the internal forces within the earth, causing earthquakes. Nearly all earthquakes occur at plate boundaries [5].

3.3 Seismic Waves

Seismic waves are generated by the release of energy during an earthquake. They travel through the earth like waves travel through water. The location within the Earth where the rock actually breaks is called the focus of the earthquake. Most foci are located within 65 km of the Earth's surface; however, some have been recorded at depths of 700 km. The location on the Earth's surface directly above the focus is called the epicenter. The study of seismic waves and earthquakes is called seismology, which is a branch of geophysics [5].

3.3.1 Two Types of Seismic Waves are generated from Earthquake

The two types of seismic wave generated from earthquakes are: body wave, and surface wave.

1) Body wave
2) Surface wave

i. Body Waves

Body wave spread outward from the focus in all directions. There are two types of Body Waves such as Primary wave and Secondary wave

A. **Primary Wave: (P wave):** also called Compressional wave: travels in the same direction the waves move. Example: A slinky.

Characteristic of a primary wave

1) Very fast (4-7 km/second).
2) Can pass through a fluid (gas or liquid).
3) Arrives at recording station first.

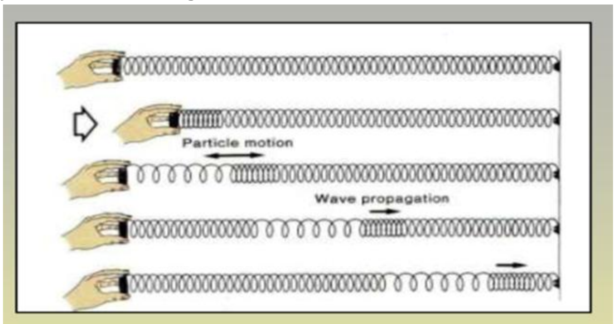

Figure 7: the movement of a primary wave [4].

B. **Secondary Wave:** also known as S wave or Transverse wave: travels perpendicular to the wave movement. Example: Shaking a rope.

Characteristic of a secondary wave

1) Slower moving (2-5 km/second).
2) Caused by a shearing motion.
3) Cannot pass through a fluid (gas or liquid).

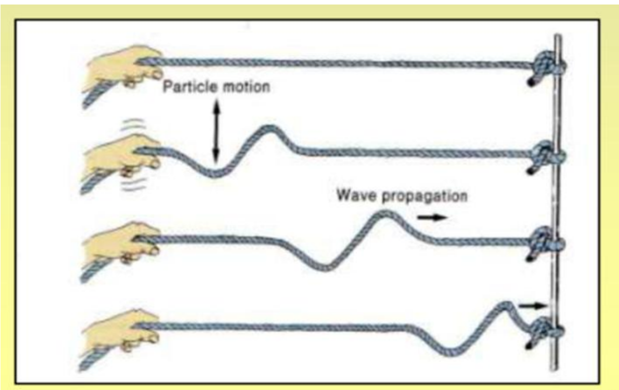

Figure 8: the movement of a secondary wave [4]

ii. Surface waves

Surface waves spread outward from the epicenter to the Earth's surface, similar to ripples on a pond. These waves can move rock particles in a rolling swaying motion so that the earth moves in different directions that very few structures can withstand.

Characteristic of a surface wave

1) These are the slowest moving waves.
2) These are most destructive wave for structures on earth.

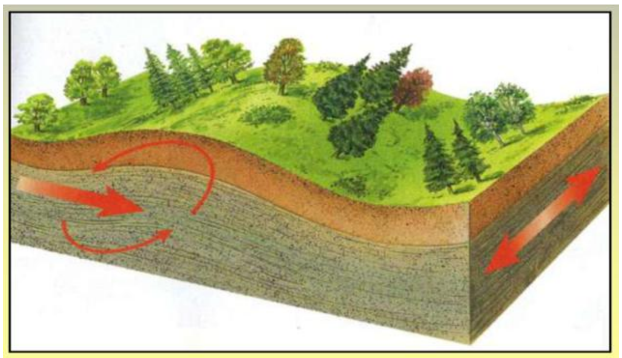

Figure 9: the movement of a surface wave [4]

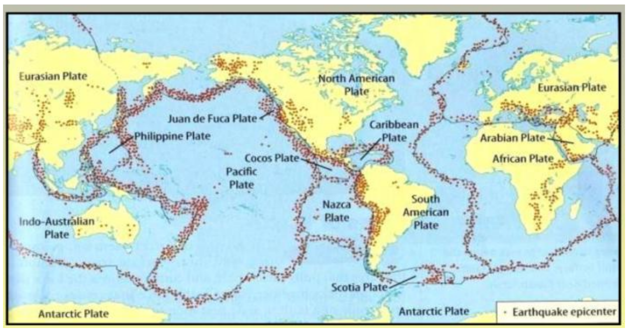

Figure 9: Earthquake locations around the world and their correlation to plate boundaries. Plate boundaries are outlined by red circles, which indicate past earthquake epicenters [14].

3.4 The Relationship of Earthquakes and Volcanoes

As discussed earlier, great earthquakes rank with volcanic eruptions as being the most terrifying of all natural phenomena. Earthquakes are related to volcanoes because most earthquakes are along the edges of tectonic plates and this is where most volcanoes are too. However, most earthquakes are caused by the interaction of the plates not the movement of magma [5].

Most earthquakes directly beneath a volcano are caused by the movement of magma. The magma exerts pressure on the rocks until it cracks the rock. Then the magma squirts into the crack and starts building pressure again. Every time the rock cracks it makes a small earthquake. These earthquakes are usually too weak to be felt but can be detected and recorded by sensitive instruments. The distribution of earthquakes provides information about magma pathways and the structure of volcanoes [5].

3.5 General Characteristics

3.5.1 Earthquake Vibrations

Earthquake vibrations occur in a variety of frequencies and velocities. The actual rupture process may last from a few seconds to as long as one minute for a major earthquake. Seismic waves generated by the rupture can last from several seconds to a few minutes [8].

Ground shaking is caused by body waves and surface waves. Body waves (P and S waves) penetrate the body of the earth, vibrating fast. P waves traveling at about 6 km per hour provide the initial jolt and cause buildings to vibrate in an up and down motion. S waves, traveling about 4 km per second in a movement similar to a rope snapped like a whip, because a typically sharper jolt that vibrates structures from side to side and typically causes even greater damage. S waves are usually the most destructive [8].

.Surface waves vibrate the ground horizontally and vertically. These long-period waves because swaying of tall buildings and slight wave motion in bodies of water even at great distances from the epicenter [2].

3.5.2 Depth of Earthquakes

Earthquake focus depth is an important factor in shaping the characteristics of the waves and the damage they inflict. The focal depth can be deep (from 300 to 700 km), intermediate (60 to 300 km) or shallow (less than 60 km). Deep focus earthquakes are rarely destructive because the wave amplitude is greatly attenuated by the time it reaches the surface. Shallow focus earthquakes are more common and are extremely damaging because of their close proximity to the surface [2].

3.5.3 Measurement Scales

Earthquakes can be described by use of two distinctly different scales of measurement demonstrating magnitude and intensity. Earthquake magnitude or amount of energy released is determined by use of a seismograph, and instrument that continuously records ground vibrations. A scale developed by a seismologist named Charles Richter mathematically adjusts the readings for the distance of the instrument from the epicenter [15].

The Richter scale is logarithmic. An increase of one magnitude signifies a 10-fold increase in ground motion or roughly an increase of 30 times the energy (figure 10). Thus, an earthquake with a magnitude of 7.5 releases 30 times more energy than one with a 6.5 magnitude, and approximately 900 times that of a 5.5 magnitude earthquake. A quake of magnitude 3 is the smallest normally felt by humans. The largest earthquakes that have been recorded under this system are 9.25 in 1969 which occurred in Alaska while 9.5 in 1960 occurred in Chile.

3.5.4 Earthquake Hazards

The primary hazards associated with earthquakes are fault displacement and ground shaking. Secondary hazards include ground failure, liquefaction, landslides and avalanches, and tsunamis and stiches [2].

3.5.5. Fault Displacement and Ground Shaking

Fault displacement, either rapid or gradual, may damage foundations of buildings on or near the fault area, or may displace the land, creating troughs and ridges. Ground shaking causes more widespread damage, particularly to the built environment [15].

The extent of the damage is related to the size of the earthquake, the closeness of the focus to the surface, the buffering power of the location's rocks and soils, and the type of buildings being shaken. Secondary tremors that follow the main shock of an earthquake, called aftershocks, may cause further damage. Such tremors may recur for weeks or even years after the initial event [15].

3.5.6 Landslides and Avalanches

Slope instability may cause landslides and snow avalanches during an earthquake. Steepness, weak soils and presence of water may contribute to vulnerability from landslides. Liquefaction of soils on slopes may lead to disastrous slides. The most abundant types of earthquake-induced landslides are rock falls and rock slides usually originating on steep slopes [10].

3.5.7 Ground Failure

Seismic vibrations may cause settlement beneath buildings when soils consolidate or compact. Certain types of soils, such as alluvial or sandy silts are more likely to fail during an earthquake [2].

3.5.8 Liquefaction

Liquefaction is a type of ground failure which occurs when saturated soil loses its strength and collapses or becomes liquefied. During the 1964 earthquake in Niigata, Japan, ground beneath buildings that were earthquake resistant became liquefied, causing the buildings to lean or topple down sideways. Another type of ground failure that may result from earthquakes is subsidence or vertically downward earth movement caused by reduction in soil water pressure [2].

3.5.9 Tsunami

Tsunami is a Japanese word meaning "harbor wave". Tsunamis are popularly called tidal waves but they actually have nothing to do with the tides. These waves, which often affect distant shores, originate from undersea or coastal seismic activity, landslides, and volcanic eruptions. Whatever the cause, sea water is displaced with a violent motion and swells up, ultimately surging over land with great destructive power [10].

In 1883, the violent explosion of the famous volcano, Krakatoa in Indonesia, produced tsunamis measuring 40 meters which crashed upon Java and Sumatra. Over 36,000 people lost their lives as a result of tsunami waves from Krakatoa.

3.5.10 Typical Effects

Physical Damage – Damage occurs to human settlements, buildings, structures and infrastructure, especially bridges, elevated roads, railways, water towers, water treatment facilities, utility lines, pipelines, electrical generating facilities and transformer stations. Aftershocks can do much damage to already weakened structures. Significant secondary effects include fires, dam failures, and landslides, which may block waterways and also cause flooding.

Damage may occur to facilities using or manufacturing dangerous materials resulting in possible chemical spills. There may be a breakdown of communications facilities. Destruction of property may have a serious impact on shelter needs, economic production and living standards of local populations. Depending on the vulnerability of the affected community, large numbers of people may be homeless in the aftermath of an earthquake [3].

3.5.11 Frequency of Occurrence of Earthquakes

The United States Geological Survey (USGS) estimates that several million earthquakes occur in the world each year.

Table 3: Frequency of Occurrence of Earthquakes [4].

Descriptor	Magnitude	Average Annually
Great	8 and higher	1 [1]
Major	7 - 7.9	17 [2]
Strong	6 - 6.9	134 [2]
Moderate	5 - 5.9	1319 [2]
Light	4 - 4.9	13,000 (estimated)
Minor	3 - 3.9	130,000 (estimated)
Very Minor	2 - 2.9	1,300,000 (estimated)

[1] Based on observations since 1900.
[2] Based on observations since 1990.

Table 4: 10 Most Powerful Earthquake Recorded [16]

S/N	YEAR	MAGNITUDE	LOCATION
1	May 22, 1960	9.5	Chile
2	March 28, 1964	9.2	Alaska
3	December 26, 2004	9.1	Off the west coast of northern Sumatra
4	November 4, 1952	9	Kamchatka
5	August 13, 1868	9	Arica, Peru (now part of Chile)
6	January 26, 1700	9 (est)	North Pacific coast of America
7	February 27, 2010	8.8	Bio – Bio Chile
8	January 13, 1906	8.8	Coast of Ecuador
9	November 1, 1755	8.7	Lisbon
10	August 15, 1950	8.6	Assam - Tibet

Table 5: Ten (10) Most Expensive Earthquake Disasters in History [17]

S/N	YEAR	NAME	LOCATION	COST
1	2011	Earthquake and Tsunami	Japan	$235BN
2	1995	Kobe Earthquake	Japan	$100BN
3	2008	Sichuan Earthquake	China	$29BN
4	2011	Sichuan Earthquake	China	$75BN
5	2010	Chile Earthquake	Chile	$20BN
6	1994	Northridge Earthquake	California	$42BN
7	2012	Emilia Earthquakes,	Italy	$13.2BN
8	1989	Loma Prieta Earthquake,	United States	$11BN
9	1999	921 Earthquake,	Taiwan	$10BN
10	1906	San Francisco Earthquake,	United States	$9.5BN

3.6 Factors Contributing to Vulnerability and Elements of Risk

Several key factors contribute to vulnerability of human populations:

1) Location of settlements in seismic areas, especially on poorly consolidated soils, on ground prone to landslides or along fault lines.
2) Building structures, such as homes, bridges, dams, which are not resistant to ground motion.
3) Unreinforced masonry buildings with heavy roofs are more vulnerable than lightweight wood framed structures.
4) Dense groupings of buildings with high occupancy.
5) Lack of access to information about earthquake risks.

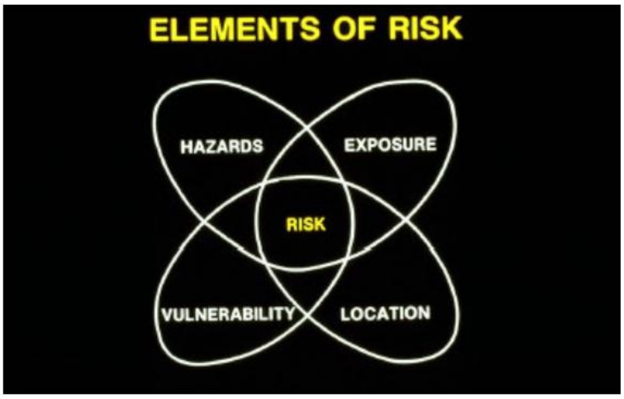

Figure 10: schematically illustrates of the four elements contributing to risk (chance of loss).

a) Hazards (physical effects generated in the naturally occurring event),
b) Location of the hazards relative to the community at risk,
c) Exposure (the value and importance of the various types of structures and lifeline systems in the community serving the populace), and
d) Vulnerability of the exposed structures and systems to the hazards expected to affect them during their useful life.

4. Necessary precautions before, during, and after earthquake strikes

4.1 Before the Earthquake Strikes

1) Develop a Family Disaster Plan. If you are at risk from earthquakes:
2) Pick "safe places" in each room of your home. A safe place could be under a sturdy table or desk or against an interior wall away from windows, bookcases, or tall furniture that could fall on you. The shorter the distance to move to safety, the less likely you will be injured. Injury statistics show that people moving as little as 10 feet during an earthquake's shaking are most likely to be injured. Also pick safe places, in your office, school and other buildings you are frequently in.
3) Practice drop, cover, and hold-on in each safe place. Drop under a sturdy desk or table and hold on to one leg of the table or desk. Protect your eyes by keeping your head down. Practice these actions so that they become an automatic response. When an earthquake or other disaster occurs, many people hesitate, trying to remember what they are supposed to do. Responding quickly and automatically may help protect you from injury.
4) Practice drop, cover, and hold-on at least twice a year. Frequent practice will help reinforce safe behavior.
5) Wait in your safe place until the shaking stops, then check to see if you are hurt. You will be better able to help others if you take care of yourself first, and then check the people around you. Move carefully and watch out for things that have fallen or broken, creating hazards. Be ready for additional earthquakes called "aftershocks."
6) Be on the lookout for fires. Fire is the most common earthquake-related hazard, due to broken gas lines, damaged electrical lines or appliances, and previously contained fires or sparks being released.
7) If you must leave a building after the shaking stops, use the stairs, not the elevator.
8) Earthquakes can cause fire alarms and fire sprinklers to go off. You will not be certain whether there is a real threat of fire. As a precaution, use the stairs.
9) If you're outside in an earthquake, stay outside. Move away from buildings, trees, streetlights, and power lines. Crouch down and cover your head. Many injuries occur within 10 feet of the entrance to buildings. Bricks, roofing, and other materials can fall from buildings, injuring persons nearby. Trees, streetlights, and power lines may also fall, causing damage or injury.
10) Inform guests, babysitters, and caregivers of your plan. Everyone in your home should know what to do if an earthquake occurs. Assure yourself that others will respond properly even if you are not at home during the earthquake.
11) Get training. Take a first aid class from your local Red Cross chapter. Get training on how to use a fire extinguisher from your local fire department. Keep your training current. Training will help you to keep calm and know what to do when an earthquake occurs.
12) Discuss earthquakes with your family. Everyone should know what to do in case all family members are not together. Discussing earthquakes ahead of time helps reduce fear and anxiety and lets everyone know how to respond.
13) Talk with your insurance agent. Different areas have different requirements for earthquake protection. Study locations of active faults, and if you are at risk, consider purchasing earthquake insurance.

4.2 During an Earthquake

1) Drop, cover, and hold on! Move only a few steps to a nearby safe place. It is very dangerous to try to leave a building during an earthquake because objects can fall on you. Many fatalities occur when people run outside of buildings, only to be killed by falling debris from collapsing walls. In U.S. buildings, you are safer to stay where you are.
2) If you are in bed, hold on and stay there, protecting your head with a pillow. You are less likely to be injured staying where you are. Broken glass on the floor has caused injury to those who have rolled to the floor or tried to get to doorways.
3) If you are outdoors, find a clear spot away from buildings, trees, streetlights, and power lines.
4) Drop to the ground and stay there until the shaking stops. Injuries can occur from falling trees, street-lights and power lines, or building debris.
5) If you are in a vehicle, pull over to a clear location, stop and stay there with your seatbelt fastened until the shaking has stopped. Trees, power lines, poles, street signs, and other overhead items may fall during earthquakes. Stopping will help reduce your risk, and a hard-topped vehicle will help protect you from flying or falling objects. Once the shaking has stopped, proceed with

caution. Avoid bridges or ramps that might have been damaged by the quake.

6) Stay indoors until the shaking stops and you're sure it's safe to exit. More injuries happen when people move during the shaking of an earthquake. After the shaking has stopped, if you go outside, move quickly away from the building to prevent injury from falling debris.
7) Stay away from windows and falling objects. Windows can shatter with such force that you can be injured several feet away.
8) In a high-rise building, expect the fire alarms and sprinklers to go off during a quake.
9) Earthquakes frequently cause fire alarm and fire sprinkler systems to go off even if there is no fire.
10) Check for and extinguish small fires, and, if exiting, use the stairs.
11) If you are in a coastal area, move to higher ground. Tsunamis are often created by earthquakes.
12) If you are in a mountainous area or near unstable slopes or cliffs, be alert for falling rocks and other debris that could be loosened by the earthquake. Landslides commonly happen after earthquakes.

4.3 After the Earthquake

1) Check yourself for injuries. Often people tend to others without checking their own injuries. You will be better able to care for others if you are not injured or if you have received first aid for your injuries.
2) Protect yourself from further danger by putting on long pants, a long-sleeved shirt, sturdy shoes, and work gloves. This will protect your from further injury by broken objects.
3) After you have taken care of yourself, help injured or trapped persons. If you have it in your area, call 9-1-1, and then give first aid when appropriate. Don't try to move seriously injured people unless they are in immediate danger of further injury.
4) Look for and extinguish small fires. Eliminate fire hazards. Putting out small fires quickly, using available resources, will prevent them from spreading. Fire is the most common hazard following earthquakes. Fires followed the San Francisco earthquake of 1906 for three days, creating more damage than the earthquake.
5) Turn off gas on supply from the cylinder. Explosions have caused injury and death when homeowners have improperly turned their gas back on by themselves.
6) Switch off all electrical appliances.
7) Clean up spilled medicines, bleaches, gasoline, or other flammable liquids immediately and carefully. Avoid the hazard of a chemical emergency.
8) Inspect your home for damage. Get everyone out if your home is unsafe. Aftershocks following earthquakes can cause further damage to unstable buildings. If your home has experienced damage, get out before aftershocks happen.
9) Help neighbors who may require special assistance. Elderly people and people with disabilities may require additional assistance. People who care for them or who have large families may need additional assistance in emergency situations.
10) Listen to a portable, battery-operated radio (or television) for updated emergency information and instructions. If the electricity is out, this may be your main source of information. Local radio and local officials provide the most appropriate advice for your particular situation.
11) Expect aftershocks. Each time you feel one, drop, cover, and hold on! Aftershocks frequently occur minutes, days, weeks, and even months following an earthquake.
12) Watch out for fallen power lines or broken gas lines, and stay out of damaged areas. Hazards caused by earthquakes are often difficult to see, and you could be easily injured.
13) Stay out of damaged buildings. If you are away from home, return only when authorities say it is safe. Damaged buildings may be destroyed by aftershocks following the main quake.
14) Use battery-powered lanterns or flashlights to inspect your home. Kerosene lanterns, torches, candles, and matches may tip over or ignite flammables inside.
15) Inspect the entire length of chimneys carefully for damage. Unnoticed damage could lead to fire or injury from falling debris during an aftershock. Cracks in chimneys can be the cause of a fire years later.
16) Take pictures of the damage, both to the house and its contents, for insurance claims.
17) Use the telephone only to report life-threatening emergencies. Telephone lines are frequently overwhelmed in disaster situations. They need to be clear for emergency calls to get through.
18) Watch animals closely. Leash dogs and place them in a fenced yard. The behavior of pets may change dramatically after an earthquake. Normally quiet and friendly cats and dogs may become aggressive or defensive.

5. Conclusion

The manuscript has reviewed extensively on the rock response to squeeze or pull near the earth surface by breaking, and when rock moves along either side of a fracture is described as fault. Different types of earthquake, causes of earthquake, earthquake and human, earthquake control and the principle of Physics governing the phenomenon have also been reviewed. However, these controls should be noted as a means of protecting people against seismic hazard: identification of seismically active zones (active faults) or perilous areas and avoidance of these as the areas of construction, the development and enforcement of appropriate building codes, education and training of the population in emergency procedures to be followed during and in the aftermath of a shock, and injecting fluids to lubricate sections of the fault plane or by pumping out fluid to lock the fault.

References

[1] Sunmonu L.A. and Adagunodo T.A. (2015). Lecture note on Physics of the Solid Earth.
[2] Dayanthie W. (2012). Syllabus on Seismology – GEOL 595 SP/L.
[3] Shearer P.M. (2009). Introduction to Seismology 2nd edition.
[4] USGS (2005). U.S. Geological Survey Department of the Interior.
[5] Stein S. and Michael W. (2003). Introduction to Seismology and Earthquakes, and Earth Structure.
[6] Gerard T.S. (2003). Stanford Mathematical Geophysics Summer School Lectures. Basics of Exploration Seismology and Tomography. Geology and Geophysics Department. University of Utah.
[7] Nicholson C. and Wesson R.L. (1990). Earthquake Hazard Association with Deep Well Injection. A report to U.S. Environmental Protection Agency: U.S. Geological Survey Bulletin 1951. 74.
[8] Telford W.M., Geldart, L.P., Sheriff, R.E. and Keys, D.A. (1988). Applied geophysics, Oxford and IBH Publishing Co., New Delhi, 860 pp.
[9] Richard D.O. (1906). The Constitution of the Interior of the Earth as revealed by Earthquake. Quarterly Journal of the Geological Society of London. 62, 456 – 472.
[10] Dobrin M.B. (1984). Introduction to Geophysical Prospecting. McGraw-Hill Book Co., Tokyo, 630 pp.
[11] Chaubey A.K.. (2007). Seismic Reflection and Refraction Methods National Institute of Oceanography, Dona Paula, Goa-403 004.
[12] http://www.geo.mtu.edu/UPSeis/waves.html
[13] Waters K.H. (1978). Reflection Seismology, John Willey & Sons Ltd., New York, 377 pp.
[14] McGraw Hill/Glencoe, 1st ed., Pp 143.
[15] Parasnis D.S. (1979). Principles of Applied Geophysics. Chapman and Hall Ltd. London. 275.
[16] http://www.wikipedia.com/ten_most_powerful_earthquake_record.html
[17] http://www.wikipedia.com/ten_most_expensive_earthquake_disaster_in_history.html