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Earthquake Vs. Moonquake: A Review

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ABSTRACT

The earthquake has most horrific and devastating effects on earth as it causes building collapse, destruction of the communication transportation infrastructure system. It further creates the natural disaster like the landslide, soil liquefaction, tsunamis; sometimes can cause enormous fire incident. There are advanced studies and new technologies are being developed to fully understand the phenomenon of the earthquake and its effect, mitigation process, and early prediction. Other bodies in planet, moon or star also experience quake. The seismometer reading from Apollo mission is still being studied to know more about lunar seismology. This study will review earthquake and moonquake as the general introduction, effects, terminology, characterization and shows the relation between these on the bases of some excellent studies done by researchers.

***Keywords*:** Earthquake, moonquake, seismometer and lunar seismology

1. INTRODUCTION

An earthquake is one phenomenon that the scientists are most concerned about nowadays and is defined as the shaking of the earth’s surface which results from the release of energy which is stored in the earth's crust and causes a wave that is called a seismic wave. Earthquake seeks attention for various reasons, including its devastating effects like tsunamis, building collapse, land sliding and many others. Typical Civil engineering structures like building structures, nonbuilding structures like the bridge, towers, dam, retaining wall, embankment, and buried structures must need to consider seismic effects in their design [1].

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So EQRD, Earthquake Resistant Design is one of the most important factors of these important structures. The proper practice of earthquake resistant design should be needed in such sophisticated structures. Advanced research should be needed in this field [2]. The new device should be used in civil engineering structures to predict and mitigate the effect of cyclic loading in soil-structure interaction [3]. The Seismic Resilience framework consists of Reducing failure probabilities, Reducing failure consequences in terms of loss of lives, property damage, harmful economic and social consequences and Reducing time to recovery [4]. Earthquake becomes one of the great interests in the field of research and scientists where they are trying to understand earth seismology. Even several studies are being made on moon seismology nowadays. An attempt is being made to relate between earthquake and moonquake where the moonquake is the shaking of the moon's surface due to reason like tidal force, temperature difference and meteoric reasons [5]. The data collected by Apollo mission were studied and tried to identify this. Studies are being carried on seismic behavior of earth surface and other planetary surfaces. This paper reviews both the earthquake and moonquake phenomenon and tried to show their comparative relations.

2. EARTHQUAKE

2. 1. Introduction and Terminology

An earthquake is a natural phenomenon caused when tectonic plates get stuck and create vibrations on the earth's surface. It can also be felt due to other reason like volcanoes, man-made explosion etc. The Hypocenter or focus is the location surface where an earthquake rupture begins and the pressure releases [6]. Vertically above the hypocenter of the point on the earth's surface undergoes the most shaking and known as an epicenter. The angle between the fault and the horizontal surface is the dip. The device which is used to detect or record the ground motion of the earth is called a seismometer or seismograph [7]. The output of seismograph result is represented as a graph, plotting time vs. intensity of motion called a seismogram. Seismic waves transmitted radially outward from the focus of the earthquake and the point where the earthquake begins [8]. Primary or P (push-pull) waves are the first waves to reach seismograph followed by Secondary or S waves (shake-waves / shear waves) and surface waves. Among these surface waves are the main culprit to do the most damage and further classified as:

- **a.** Rayleigh Waves = rolling ground vibration which similar to the waves of the surface of the water.
- **b.** Love Waves = horizontally polarized shear waves which are perpendicular to travel.

Scientists tried hard to characterize earthquake in a proper way. But it was not an easy job, in fact before the 18th century the scientist only characterized the earthquake based on the destruction [10]. In 1935, Charles F. Richter invented a scale which measured the seismic wave and known as Richter scale. It is also called "Richter magnitude scale" because of measuring the strength of earthquakes [11]. The sign ML is designated as "Local magnitude scale" and Mw is identified as "Moment magnitude scale". The Richter scale is one kind of logarithmic scale where the wave amplitude is recorded by seismographs. The popular earthquake measuring scales are Surface-wave magnitude scales, Moment magnitude and energy magnitude scales, Energy class (K-class) scale, Macro seismic magnitude scales, Tsunami magnitude scales etc. The main features of the Richter scale are to measure between small to medium size earthquake (3 to 7). And it can be measured the quake within 400 miles and it has been widely used since 1979. On the other hand on the Richter scale, data is collected from different stations and comparing different seismic waves which help to estimate the earthquake. The Scale which records the damage of an earthquake is called Mercalli intensity scale. So, the proper investigation should carry to talk with many eyewitnesses to find out the important information during the earthquake [12].

Figure 1 shows the details of earthquake terminology.

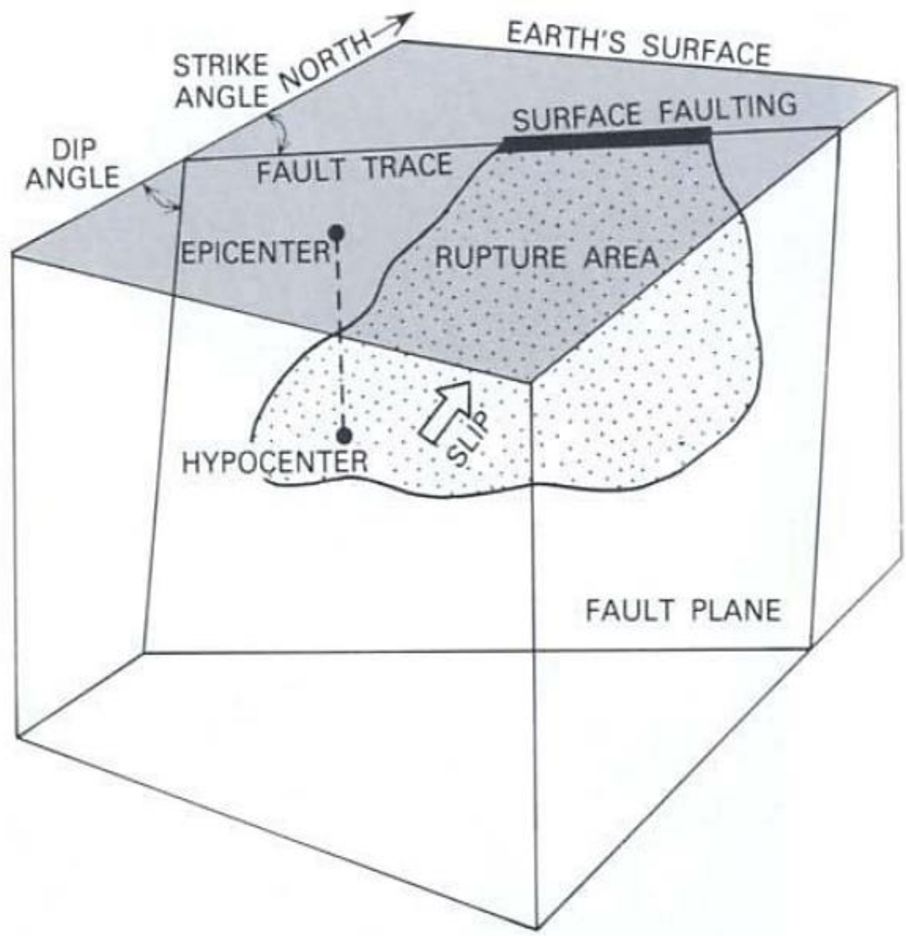

Figure 1. Earthquake terminology [9].

To reduce earthquake risk, new projects or techniques should be needed. The Current new project has taken on the mitigation of earthquake risk in the U.S.A. (2018-2019) and the cost is estimated at 7 million dollars [13]. A large-scale earthquake can damage any sophisticated structures. That's why in the design of these structures, earthquake consideration is a must. There are standards for the design included in the codes used for design guideline. The common earthquake-related experiment is shaking table experiment and this type of experiment has been widely used since 1930 [14]. So, more investigations should be needed to reduce the earthquake resistivity in building structures. Some devastating effects of earthquakes are described below.

2. 2. Tsunami

At the moment of the seismic wave under sea water, huge energy is released in the fault of tectonic plates which can create the huge displacement of seawater and this incident is called tsunamis. Many people were killed by the tsunami and greatest loss can occur. The earthquake and tsunami struck on 26 December 2004 and hit the Indonesia, Sri Lanka, India and Thailand. The Maldives and Somalia were the deadliest in recent history. In this case, water arose 12m above the sea water level and many people have died in this incident. It is regarded as mega thrust earthquake because of its high magnitude (9.1 to 9.3) and it gained the third position around the world to its intensity [15].

2. 3. Landslides and Rockfall

Cliffs and steep slopes get destabilized at the time of Ground shaking due to earthquakes causing landslides and rock falls. The destructive landslide has occurred in the Calabria region of Italy after the earthquake in 1783 [16]. So, to stable the stiff slope, some measures may be taken. To plant small grasses can stable the stiff slope by the natural way because of having root cohesion to the sloppy soil. Anchoring or nailing small steel piles and using cemented sand paste in the sloppy soil can stable the stiff soil [17]. The Kumamoto earthquake, that occurred in Japan generated significant numbers of landslides and did remarkable destruction throughout the entire area [18].

2. 4. Liquefaction

In case of the earthquake, waterlogged ground more specifically saturated unconsolidated soil undergoes failure due to loss of strength. While Seismic shaking separates the grains from each other, the soil loses its bearing capacity and ultimately solid soil behaves temporarily as a viscous liquid. This incident was known as Liquefaction. Liquefaction has devastating effects on buildings, bridges, pipelines, and roads, as it undermines the foundations and ultimately causing them to sink into the ground, collapses or dissolves. Although liquefaction was known for its destructive effect for centuries but the phenomenon was observed in Japan (1964) and Alaska (1964). Earthquake resistive building code should be maintained in case of building design [19].

2. 5. Fire

When electrical power lines or gas supply lines get broken at the time of the Earthquake, it increases the possibility of incidents of fires. The earthquake of San Francisco in 1906, proves the effect of fire caused by the earthquake can be as costly as it causes more deaths happened because of fire as compared to the earthquake itself [20].

Education, training, publications, mass media actions need to Increase public awareness about earthquakes. Proper assessment and research work on ground motion, soil effects, forecast the probable damage to buildings and other structures should be needed. Testing facilities for research need to be improved by developing laboratory [21]. Disaster management plan should be made for the resultant incident of earthquakes like tsunamis, liquefaction, landslide etc. Table 1 shows the statistics of some devastating earthquakes.

Table 1. The statistics of some devastating earthquakes.

Place	Date	Magnitude	Number of people killed
Haiti	Jan. 12, 2010	7-magnitude	316,000 people killed [22]
Tangshan, China:	July 27, 1976;	7.5-magnitude	255,000 people killed [23]
Sumatra, Indonesia	Dec. 26, 2004	9.1-magnitude	227,898 people killed [24]
Eastern Sichuan, China	May 12, 2008;	7.9-magnitude	87,587 people killed [25]
Pakistan	Oct. 8, 2005	7.6-magnitude	80,361 people killed [26]

3. MOONQUAKE

3. 1. Structure of Moon

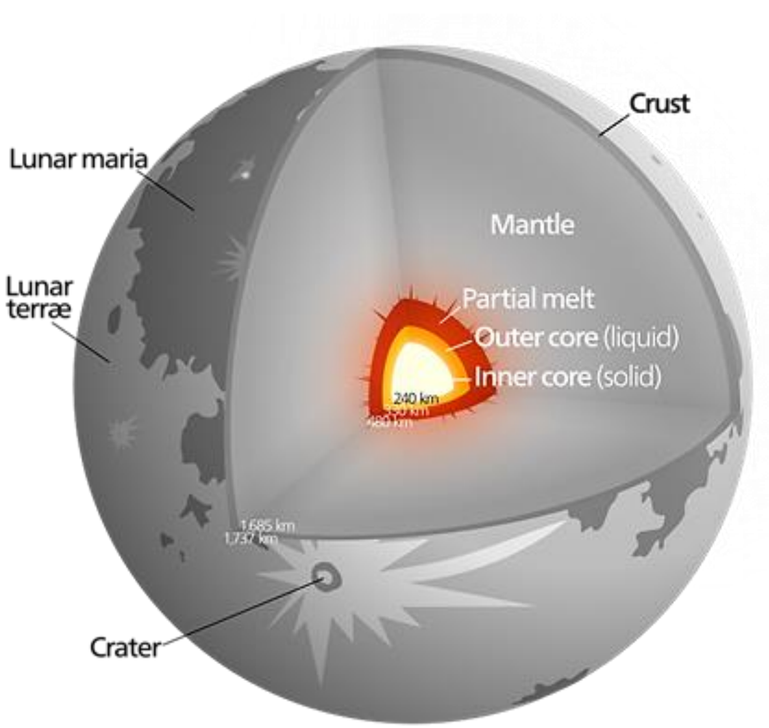

Figure 2. The details of the physical aspects of the moon [30].

Moon consists of a core, mantle and crust. Comparing with other terrestrial body's core, moon core's is smaller and its radius is 24 kilometers [27]. The major component of solid moon's core is iron. It is surrounded by a liquid iron shell of 56 miles thick which is followed by a partially molten layer with a thickness of 93 miles [28]. The mantle is the layer exists between the top of the partially molten layer to the bottom of the moon's crust. Aluminum, calcium, iron, magnesium, silicon and oxygen are the primary components of the crust of the moon and having small amounts of hydrogen, potassium, thorium, titanium and uranium [29]. In previous, many volcanoes were presented on the moon's surface but now at present they are totally situated in lethargic condition and lose their eruption capability for millions of years. Figure 2 shows the details of the physical aspects of the moon.

Figure 3 shows the details of the chemical aspects of the moon.

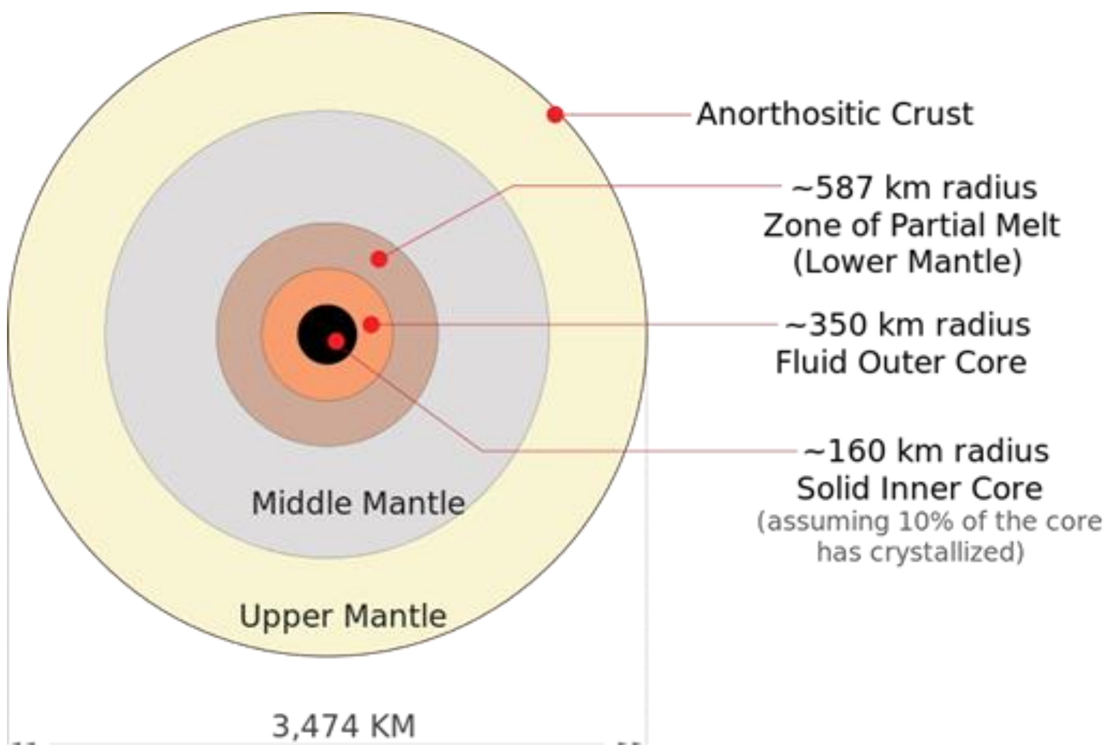

Figure 3. The details of the chemical aspects of the moon [30].

3. 2. Moonquake

A moonquake is one kind of vibration on the surface of the moon. On July 20, 1969 human first touched the moon's surface [31]. Neil Amstrong and Buzz Aldrin were the first astronauts whose set a seismometer in moon surface and observed quake there. Apollo 11 was the name of their space flight [32]. The figure 4 shows the details of a seismometer which was set up in moon's surface.

The seismometer had a sensor and it recorded the first moonquake minutes after the seismometer had settled down, and transmitted the 1st ever seismic data from the moon back to Earth [34]. After the installation of the seismometer on the surface of the moon, the data are recorded in Apollo 11. And this data is sent to earth after three weeks [35]. Apollo 12, 14, 15, and 16 also set up instruments with more advanced technology near their respective landing sites. These sensors transmitted their recordings down to until September 1977 [36]. The intensity of the moonquake is smaller than the earthquake but the occurrence time (up to an hour) is larger than earthquake because of the lacking of the presence of water in moon's surface which cannot absorb that kind of vibration [37]. The moonquakes are categorized into four types.

Figure 4. The details of a seismometer which was set up in moon's surface [33].

3. 3. Deep Moonquakes

It is located at the 700 Km below of the moon's surface. The deep moonquakes are described as the process of storage and release of tidal energy but it doesn't release any tectonic energy as the earthquake does. There is not any tectonic seismicity observed in the moon. It is the tidal force between the earth and moon and sun causes moonquake [37]. There is regularity in the time of occurrence of deep moonquake. It finds the relation with the tidal periodicity of the moon and confirms tidal forces as the reason. Deep moonquakes are the most frequently observed seismic events on the Moon, and Apollo seismic experiment detected more than 7000 events during the July 1969 to September 1977 [38]. In recent analyses, it has found that Deep moonquake source regions are located between depths of 750 and 1200 km. A study is being done to find out new constraints on the source of the mechanism including mechanical and thermal conditions at the depth of the deep moonquakes by revisiting the Apollo seismic data.

3. 4. Meteorite impact vibrations

At least 1700 more than other moonquakes were recorded due to the impact of a meteorite on the moon's surface [39]. The moon has no atmosphere. So, there is no hindrance to burn up such meteorite where earth's atmosphere can do this. So, the direct hit of meteorite in the moon's crust can occur the medium scale vibration [40].

3. 5. Thermal moonquakes

When the sunlight returns after the two-week lunar night then the frigid lunar crust expands and at the consequences, quake has happened. This quake is termed as thermal moonquakes. It is mainly occurred because of occurring the temperature differences between the night and day of the lunar surface. This temperature difference is recorded as 400 degrees Fahrenheit [41].

3. 6. Shallow moonquakes

Table 2. The comparison between earthquake and moonquake.

Point of basis	Earthquake	Moonquake
Prediction	There are significant works are being done on earthquake forecasting. Although there is some success of the earthquake prediction incident like The M 7.3, 1975 Haicheng earthquake, 1985–1993: Parkfield, U.S. (Bakun-Lindh), but reliable and skillful deterministic earthquake prediction is not yet possible [44].	Most moonquake is predictable as it is regular in time occurrence and related to tidal stresses and position on the moon and earth effect (Except surface moonquake).

Effects on building or destructive effects	The earthquake has an enormous destructive effect on earth including collapsing of building and non-building structure, damaging transportation, communication system causing the disaster like the landslide, tsunamis, liquefaction etc, and causing a great harm to life and property.	Although moonquake doesn't have any destructive effects on earth, but Apollo astronauts measured shallow moonquake of up to magnitude 5.5, where the magnitude of 4.5 can cause damage to a rigid structure on the earth. Moonquake is also longer than the earthquake, which indicates future lunar settlers should take this into their consideration and build structures which is strong enough to withstand these shallow moonquakes.
Code for earthquake	In building Code, there is the consideration for earthquakes, and these are strictly followed.	Specific research-based structural code should be needed for in case of moonquake to install any kind of structure on the moon's surface.
Influence on each other	One of the main reasons of the moonquake is the tidal force, so the earth can cause moonquake with its gravitational force.	As the moon is 27% total size of earth, so far no direct evidence of moon's responsibility in an earthquake is proved. Tidal Ocean waves generated by moon and sun's gravitational pull can create seismic waves billions of times weaker than the seismic waves produced by earthquakes. Together, these waves are known as the ambient wave and more seismic field investigations are needed to be done on this topic.
Causes	Tectonic plates collide, volcanoes, man-made explosion etc.	Tidal forces, Meteorite impact, thermal impact etc.

Classification	There are different scales to characterize earthquake like Surface-wave magnitude scales, Moment magnitude and energy magnitude scales, Energy class (K-class) scale, Tsunami magnitude scales, Macro seismic magnitude scales etc.	NASA, categorizes moonquakes as deep moonquake, Meteorite impact, thermal impact and shallow moonquake.
Quake sizes	Earthquakes are larger in magnitude than moonquake, the biggest earthquake recorded in Valdivia, Chile May 22, 1960 magnitude of 9.4–9.6 [45].	Moonquakes are smaller in magnitude than earthquake but longer. Apollo astronauts measured shallow moonquake of up to magnitude 5.5.
Man-made quake	Activity like artificial lakes, Mining, Groundwater extraction, Geothermal energy, Carbon Capture and Storage, nuclear activity causes man-made earthquake. The largest man-made earthquake caused by oil-drilling in Oklahoma, 2011 had a Magnitude of 5.6 [46].	Landing spacecraft on the moon's surface can create moonquake. And it is regarded as one kind of man-made activities.
Advanced studies	Advanced studies are being done on resilience; hazard awareness, reducing the risk posed by existing structures And infrastructure; developing and implementing new materials, elements and predict the quake on the earth's surface etc.	A Study is being done to find out new constraints on the source mechanism including mechanical and thermal conditions at the depth of the deep moonquakes by revisiting the Apollo seismic data.

No regularities like deep moonquake are observed in case of shallow moonquake and it's quite random. Between 1972 and 1977, 28 shallow moonquakes have been detected and their epicenter is found randomly in the lunar surface. Shallow moonquakes are the rarest seismic event observed on the moon and also known as HFT (high-frequency teleseismic) [42]. Actually, shallow moonquake can exceed the rated 5.5 on the Richter scale. So, comparing with other moonquakes, the intensity of the shallow moonquake is larger than another. On earth, when a quake exceeds 4.5 in Richter scale then it is considered as a great threat to any kind of structures. But when shallow moonquake occurs around simultaneously around one hour or longer time than it is considered as a great threat to install any sophisticated research-based structure in such place [43]. Table 2 shows the comparison between earthquake and moonquake.

4. FUTURE SCOPE OF WORK

There are several communities' works with the earthquake to mitigate hazards, determine the exact effects of earthquakes, and to minimize after effects like loss of life, injuries, and other property losses etc. More investigations should be needed on the moon's surface to detect different seismic waves. Recently, some research projects have stopped due to the lacking of proper funding which is recognized as moonquake based research. So, many agencies may collect funds to run these kinds of projects [47]. So, many research-based sophisticated structures should be needed to install to carry the moonquake related research. Discussions took place during the January 25-26, 2010 workshop, Vision 2020: An Open Space Technology (OST) Workshop on the Future of Earthquake Engineering mentioned seven principal research directions identified where significant progress needs to be made by 2020 [48]. They are as follows:

1) Metrics to quantify resilience.
2) Hazard awareness should be created and risk communication should be maintained.
3) Reducing the risk posed by existing structures and infrastructure.
4) New techniques should be developed and implemented to reduce the earthquake hazards.
5) Monitoring activity should be properly maintained.
6) Implementation and technology transfer.

On the other hand, Studies to find out more specific information about moonquakes needs to carry on. As the magnitude of 5.5 Shallow moonquakes had already been recorded by the Apollo seismometer, research on new technology, code and consideration needs to carry on.

5. CONCLUDING REMARKS

This study represents basic aspects of earthquake and moonquake and their relations. Moonquakes and earthquakes are different in magnitude, lasting times and sources. Although moonquakes are smaller in magnitude, it is longer than the earthquake in terms of time. Recording of magnitude 5.5 moonquake is a clear indication that moon landing ships and structure must need to consider this vibration.

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