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Earthquake Early Detection Systems: Strategies for Hazard Minimization

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Abstract: ***Earthquakes are disastrous to mankind. It affects human life, buildings and economy. Overcoming the after effects of earthquakes & diseases all imposes challenges to human life. All these can be minimised if early detection & warning of an earthquake is sent to areas where possibility of occurrence of earthquake is most predominant.***

Keywords: Seismograph, Accelerometers, Ritcher scale, Artificial Intelligence

1. Introduction

Earthquake is the sudden shaking of ground due to the release of energy from Earth's crust. The Earth's crust is broken into tectonic plates, which are in constant motion. The plates move in different directions, colliding, sliding past, or moving apart. When the stress on the edge overcomes the friction, the plates release energy in waves, causing an earthquake.

Earthquakes occur along fault lines in Earth's crust where tectonic plates meet. Faults are cracks in the earth's crust along which there is movement. They occur where plates are subducting, spreading, slipping or colliding. Faults are of four types - normal, reverse, strike - slip & oblique.

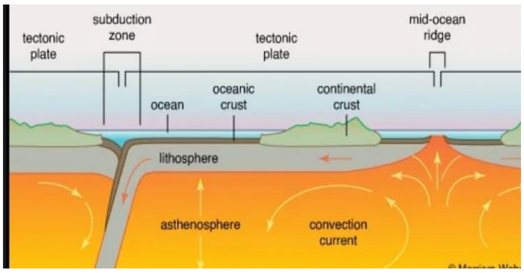

Figure 1: Earth’s crust

Seismic waves are produced when energy is released. There are two types of seismic waves – primary waves and secondary waves. Primary waves also known as P wave or pressure waves are longitudinal compression waves. Secondary wave or S waves are slower than P waves. P waves can travel through liquid and solids and gases, while S waves only travel through solids. P waves travel fastest and are the first to arrive from the earthquake. In S or shear waves, rock oscillates perpendicular to the direction of wave propagation

Earth’s Structure

The Earth’s crust is the outer layer of the planet. It is made up of several pieces called tectonic plates. The plates under the oceans are called oceanic plates. Other plates are continental plates. The mantle is the largest and thickest layer. The solid crust and top, stiff layer of the mantle make up a region called the lithosphere. The upper mantle is also known as asthenosphere. It is hot and can flow. Lithosphere is brittle and rigid solid.

India has a history of major earthquakes, including some of the world's largest. The Indian plate is moving towards the Eurasian plate, which is the main cause of earthquakes in the country. The Rann of Kutch earthquake on June 16, 1819 a 8.3 magnitude earthquake that struck the west coast of India. The earthquake was one of the largest intra - plate earthquakes in the world.

Figure 2: Plates across the world.

Major earthquakes in India include:

Most of the large earthquakes occur around the edges of the Pacific Ocean, an area known as the 'Ring of Fire' , where the Pacific plate is being subducted beneath the surrounding plates. The Ring of Fire is the most seismically and volcanically active zone in the world.

In California there are two plates - the Pacific Plate and the North American Plate. The Pacific Plate consists of most of the Pacific Ocean floor and the California Coast line. The North American Plate comprises most the North American Continent and parts of the Atlantic Ocean floor. The primary boundary between these two plates is the San Andreas Fault. Smaller faults like the Hayward (Northern California) and the San Jacinto (Southern California) branch from and join the San Andreas Fault Zone.

Trenches - Trenches are formed by subduction, a geophysical process in which two or more of Earth's tectonic plates converge and the older, denser plate is pushed beneath the lighter plate and deep into the mantle, causing the seafloor and outermost crust (the lithosphere) to bend and form a steep, V - shaped depression.

Table 1: List of Earthquake prone areas according to USGS

Earthquake zones	Tectonic Plates	Locations
Ring of Fire	Pacific, North American, Philippine, Juan de Fuca Cocos, Nazca	Rim of the Pacific Ocean
Alpide Belt	Eurasian African Arabian, Indian	Java to Sumatra, through the Himalayas, west to the Mediterranean and out into the Atlantic.

Seismometer

Seismometer measurements are used to measure earthquakes. The modern seismograph is credited to the British scientist **John Milne** in 1880. It detected earthquakes with a stylus attached to a long pendulum. When the ground moved, the stylus would move over a carbon - coated paper. The resulting pattern can indicate the direction and intensity of the quake.

- **Seismometers**: Convert seismic wave vibrations into electrical signals.
- **Seismographs**: Combine the seismometer & recording device.
- **Accelerometers**: Detect vibrations in smartphones that indicate an earthquake.

A modern seismograph is an instrument that records the seismic waves when the ground moves. It is made up of electromagnetic sensors that translate it into an analog or digital reading. Recently AI is used for early detection of earthquakes.

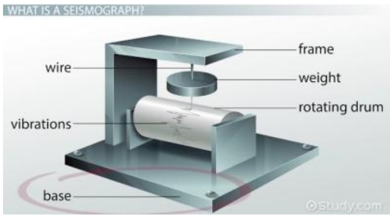

Figure 3: Seismograph

The basic structure of a seismograph consists of a weight suspended from a stationary frame via a spring. The frame itself is connected to bedrock so that it picks up on vibrations (waves) originating from the crust rather than those due to external factors. When there is a seismic wave, the ground shakes, as does the frame, while the weight and spring remain stationary due to inertia.

Earlier seismographs had a pen - like attachment to the weight which moved over a roll of paper marking wave - like patterns that conveyed the intensity of the seismic waves. The seismographs are built such that the movement between the weight and the frame produces an electrical voltage that is then recorded. The output of the seismograph is called a seismogram.

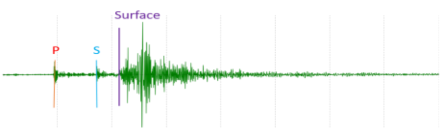

Figure 4: A seismogram shows the P, S, and surface waves.

To find the location of an earthquake epicenter, seismologists use the differences in arrival times of the P, S, and surface waves. After an earthquake, P waves will appear first on a seismogram, followed by S waves, and finally surface waves, which have the largest amplitude. The calculated distance from each seismometer to the earthquake is shown as a circle. The location where all the circles intersect is the location of the earthquake epicenter.

Different types of seismometers are used for earthquake monitoring - MEMS seismometers, DAS systems accelerometers,, array seismometers Satellite - based technologies like InSAR.

1) Earthquake magnitude

Magnitude is a measure of the amount of energy released during an earthquake and can be estimated from the amplitude of ground motions recorded by seismometers. It is independent of distance from the epicentre. A number of different magnitude scales have been developed based on the amplitude of different parts of the observed record of ground motion with specific corrections for distance. Earthquake magnitude scales are logarithmic, i. e. a one unit increase in magnitude corresponds to a tenfold increase in amplitude.

Richter scale (M_L)- The earthquake's magnitude is determined by the logarithm of the amplitude of the largest seismic wave calibrated to a scale by a seismograph It is a quantitative measure of an earthquake's magnitude introduced in 1935 by American seismologists Charles E Richter and Beno Gutenberg.

Moment magnitude- The most standard and reliable measure of earthquake size is moment magnitude (Mw), which is based on seismic 'moment'. Moment is related to the area of the earthquake fault rupture and the amount of slip on the rupture, as well as the strength of the rocks themselves.

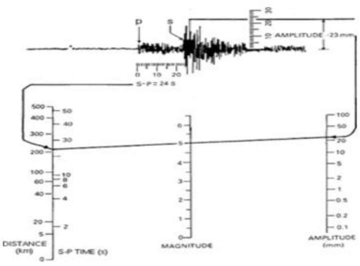

Figure 5: Measurement in Richter scale

2) Earthquake detectors

The first known earthquake detector was invented in 132 A. D. by the Chinese astronomer and mathematician Chang Heng. He called it an "earthquake weathercock. "Each of the eight dragons had a bronze ball in its mouth. Whenever there was even a slight earth tremor, a mechanism inside the seismograph would open the mouth of one dragon. The bronze ball would fall into the open mouth of one of the toads, making enough noise to alert someone that an earthquake had just happened. Imperial watchmen could tell the direction the earthquake came from by seeing which dragon's mouth was empty.

A large-scale model of Chang Heng's original earthquake weathercock.

Figure 6: Earthquake weathercock.

EWS (Early Warning System)

Seismometers, microelectromechanicalsystem (MEMS), Satellite data, GPS , interferometry synthetic aperture radar (InSAR) and distributed acoustic sensing systems canpredict earthquakes. Seismologists use the data from earthquake detectors to determine the size and location of earthquakes Earthquake detectors can be used to issue alarms and evacuation orders before major shaking occurs.
Examples of earthquake detectors
EQ guard, ShakeAlert.

EQ guard - A stand - alone device that can be connected to a local network. It detects preliminary tremors and issues an alarm.

ShakeAlert - A system that uses accelerometers in Android phones to detect earthquakes. It sends alerts to Android users in affected areas.

Organizations are formed to monitor earthquakes throughout the world. The Incorporated Research Institutions for Seismology or IRIS, provides a data center with thousands of seismic stations. The IRIS Earthquake Browser (IEB) is an interactive map for exploring millions of seismic event epicenters on a map of the world. Selections of up to 5000 events can also be viewed in 3D and freely rotated with the 3D Viewer companion tool.

IoT based earthquake detection - The basic idea of using IoT for earthquake detection is to deploy a network of sensors that can detect seismic activity and transmit the data to a central server for analysis. These sensors can be embedded in recording stations, to find the epicentre of the earthquake. The signals arrive first the closest station and last at the one furthest away. P - and S - waves at different seismometers are used to determine the location of the earthquake.

1) Accelerometer - based sensors for seismic detection: Accelerometers used in earthquake sensors can detect noises with sensitivity 20 times greater than current - based seismometers. Accelerometers detect vibrations and quantitatively measure acceleration, which is directly proportional to the force applied to an object that causes it to change speed or position.

2) Seismic Sensing: Seismic sensing is the process of measuring and analyzing seismic waves. Ground motion is characterized by three parameters: displacement, velocity, and acceleration. Displacement measures the distance traveled by the earth's surface. Position can be horizontal or vertical, ground velocity determines how far the surface of the ground has moved, and ground acceleration describes how the ground velocity changes with respect to time.

3) Strain Seismometers: A strain seismometer is an instrument capable of recording and measuring the displacement between two points in the ground. Laser interferometers operate at one point serving as a sensor, laser source, and short arm; at another point, a reflector is situated. Laser interferometers translate the change in the movement of the reflector, caused by ground displacement; strain sensors require deep underground installations as the sensitivity and accuracy of the displacement measurement is directly proportional to the measuring distance. Strain seismometers have a precision of up to one part per billion.

4) Inertial Seismometers: Inertial seismometers can characterize ground motion parameters with respect to a reference of inertia. This is typically a suspended mass, while the ground motion parameters measure other linear velocity and displacement of the suspended mass. The ground motion that results is comprised of a linear and angular component; if the ground is displaced rapidly in the direction of freedom of the pendulum when the pendulum is not moving, it will remain in place through inertia.

5) Artificial Intelligence : Artificial intelligence (AI) algorithms for earthquake prediction use pattern recognition to identify seismic activity. These algorithms are trained to recognize patterns in seismic data, such as changes in ground motion and waveforms.

Detect microquakes: AI algorithms can detect small earthquakes, which can provide information about how earthquakes evolve. AI code generation relies on machine learning and natural language processing to automatically generate source code.

Seismologists, through seismic monitoring devices called seismometers, have been able to detect, record, and analyze the seismic waves produced by earthquakes.

An Early Earthquake Warning System (EEWS) based on real - time response and integrated with IoT technology was developed by **Clements (2021) .** Arduino Cortex M4 microcontroller and MEMS accelerometers were used to build the IoT network.

6) Distributed acoustic sensing (DAS): Distributed acoustic sensing (DAS) uses short pulses of laser light and a fiber optic cable to measure acoustics. It can provide real - time measurements with high resolution. It is an optoelectronic device. It measures Rayleigh backscattering, which is produced by imperfections in the optical fiber. It samples scattered light to detect small changes in the strain of the material around the fiber. It can record seismic measurements at thousands of points, producing a very dense seismic array.

7) Android Earthquake Alert System: Android device is a mini - seismometer, making up the world's largest mobile earthquake detection network. All smartphones come with tiny accelerometers that can sense signals, it sends signals to stations for earthquake detection.

8) Earthquake Sensing & damage prevention: Sensors are placed throughout the rail infrastructure to monitor seismic activity. Seismic - resistant buildings, such as airports, hospitals, arenas, and residential buildings, are proliferating in red zones across the world.

Earthquake hazards

Earthquake causes landslides and avalanches. Earthquakes causes damage to dams or trigger landslides into lakes and rivers that in turn overflow their banks resulting in floods. Following an earthquake, damage to power and gas lines can spark fires.

Tsunamis

Undersea earthquakes and earthquake - triggered landslides into the sea, can trigger a tsunami such as the wave in 2004 that swept across the Indian Ocean and killed nearly one quarter million people.

2. Conclusion

Disruption of basic services and widespread disease is the main concern caused by earthquakes Damage to property, loss of life & time to rebuild the structures taking too long are others hazards due to the occurrence of earthquakes. By early detection of occurrence of earthquakes using Sensors, IoTs, the damages caused by earthquakes can be minimised & people can save their lives.

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