EARTHQUAKES

25th MARCH 2010

By Rajiv Thakrar

The first earthquakes were recorded as early as 464BC, when an earthquake was reported to have destroyed Sparta, collapsing houses from their foundations and killing thousands of the people in the city. At the time, the Spartans believed that Poseidon, the Earth-shaking god, caused the earthquake because he had taken offence to some Helots (a slave population was made up of Laconians and the people of Messenia) being dragged away and executed.

Feeling that Poseidon was on their side, the Helots revolted with the encouragement of Sparta's nearby rivals, taking advantage of the vast amount of deaths caused by this natural disaster. Many at the time believed that because Poseidon controlled the Earth shaking, there was no stopping it and resistance was futile. The political impact of this earthquake was astonishing, and many see this as the initial cause of the Third Messenian War.

In the late 18th century, the city of Lisbon was totally destroyed by an earthquake. Though the earthquake originated in the Atlantic Ocean, Lisbon, some 200km away, was stuck by a deadly quake. The city did not just suffer from the earthquake; it was also followed by a tsunami, and widespread fires. A merchant at the time gave an account of the situation, saying "all of Portugal, and most, if not all, of the Kingdom of Spain felt it… It was felt, we hear, at Corke in Ireland… Infinite were the numbers of poor broken-limbed persons, who were forced to be deserted even by those who loved them best, and left to the miserable torture of being burnt alive." The magnitude of destruction of this earthquake places it as one of the worst ever recorded. The total death toll in Lisbon alone, not taking into account the surrounding areas, was placed between 10,000 and 100,000 people.

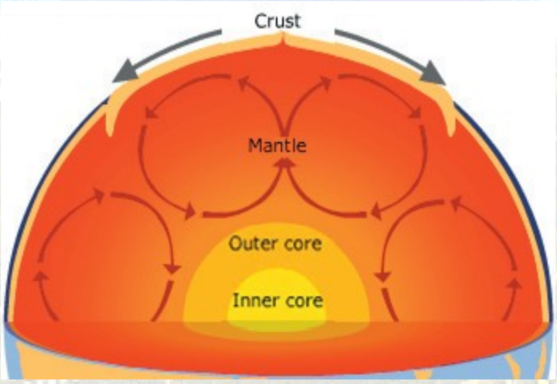
Today, earthquakes around the world still take many news headlines, and cause widespread destruction around the globe. As well as the loss of life, an earthquake can have a devastating impact on a countries economy, leaving behind it a crippled workforce and thousands homeless in need of desperate aid. Many charities have been set up to support countries in the aftermath of earthquakes, such as the Disasters Emergency Committee (DEC), who are an umbrella organisation for 13 UK organisations. The DEC "brings together a unique alliance of the UK's aid, corporate, public and broadcasting sectors to rally the nation's compassion, and ensure that funds raised go to DEC agencies best placed to deliver effective and timely relief to people most in need."

Charities such as these are beneficial to the people who have suffered at the hands of an earthquake, but there are still no current ways to effectively predict when or exactly where one may happen. It seems like even though earthquakes have been around as long as humans, we are still in a similar situation to the ancient Greeks…

Contents:

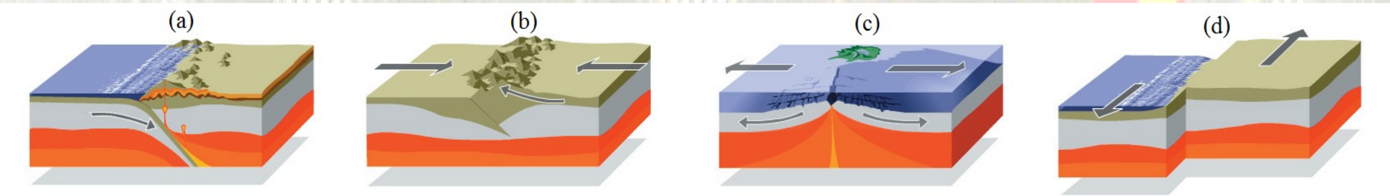
BEAR PHOTO S.F. 397

How Earthquakes Are Formed.



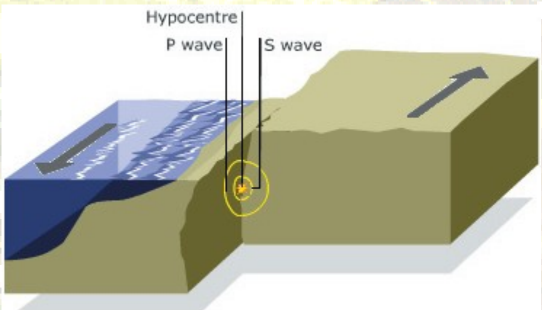
The Earth is made of many sections, including the crust (where we live), the mantle, the outer core, and the inner core. Under the crust, the other sections are made up of molten material called magma, which is seen when volcanoes erupt.
The inner sections are much hotter than the outer sections. Hence, there are convection currents across the whole of the mantle, as the outer core heats up the inner part of the mantle, and the magma cools near the crust. These currents drive crusts in various directions around the Earth.

The Earth's crust is divided by these movements into different sections called plates. These plates all move in different directions depending on the convection currents of the magma underneath them. At the plate boundaries, the plates can interact in four different ways: (a) converge (where one plate moves under the other), (b) move towards each other, (c) move away from each other, or (d) move against each other side by side. Obvious examples of plate boundary interactions can be seen by the mountainous regions of the Earth such as the Himalayas in Asia, where the Indo-Australian Plate and the Eurasian Plate collided and pushed the crust upwards.



When plates move against each other, points of pressure may build up between them. This happens due to a shearing force that the plates may have, causing cracks or *faults* along them. Parts of the plates may become locked together at faults, and the kinetic energy of the moving plates is stored as the pressure builds. Of course, the locked parts of the plate are not locked forever. Eventually, the driving force from the convection currents overcomes the force holding them back, releasing a wave of the stored energy as the fault is ruptured. The point where this release happens under the Earth's surface is known as the hypocentre.

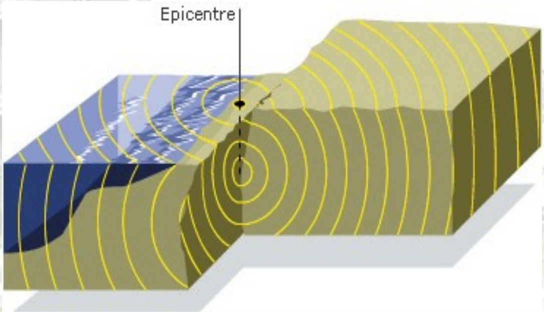
Earthquakes are formed when tectonic plates that move against each other get locked together. The tension between these plates grow until finally the fault ruptures and energy is released.



Three waves of energy are released as a result. The first is a P wave (Primary wave), which is a longitudinal wave that shakes the Earth along the line of wave propagation. These are the fastest of the three waves, averaging about 6m/s, and so are sensed first. The nature of the P wave allows them to travel through solids, liquids and gases and hence is able to travel through the Earth's crust, mantle and core.

The S wave (Secondary wave) is a transverse wave, which shakes the Earth perpendicularly to the line of wave propagation. These waves travel slower than P waves, at about 4m/s. S waves can travel through the Earth's crust and mantle, but not through the its core. This means that S waves can only be detected on specific parts of the Earth. Though S waves are slower, they are more usually the more destructive than P waves, as they shake bodies from side to side rather than up and down. This can have devastating effects on free standing structures on the Earth's surface, which can collapse if enough force is provided.

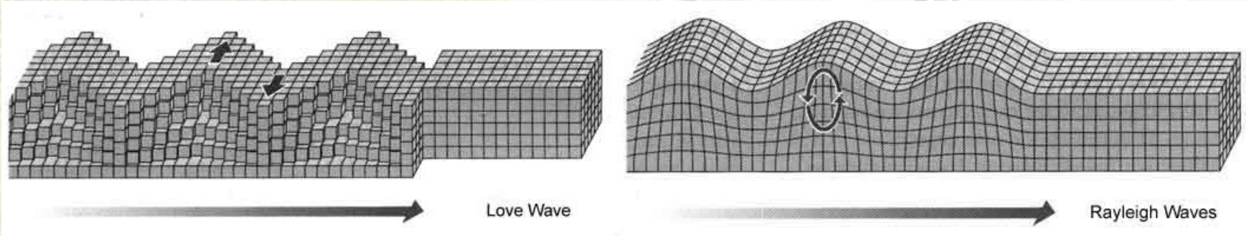
P and S waves are known as body waves, as they travel through bodies as opposed to across them. When a wave has emerged onto the Earth's face, it is known as a surface wave. This wave is propagated along the surface of the Earth. The point directly above the hypocentre of the earthquake, on the Earth's surface, is known as the epicentre of the earthquake. It is from this point where surface waves radiate.



Surface waves are the most destructive of the three types of waves, because of their long duration, and low frequency, as well as their large amplitude. They are also the slowest of the three, and so they are felt after S and P waves.

It was thought that animals could predict earthquakes before they happened. In fact, animals like dogs and cats are able to pick up the more sensitive vibrations of P and S waves, and so react before the surface waves arise.

Surface waves occur in two types: Love waves and Rayleigh waves.



Love waves (left) shake the ground surface from side to side, much like an S wave without any vertical displacement.

Rayleigh waves (right) have a rolling effect which is similar to an ocean wave. They have both vertical and horizontal displacement, with their horizontal displacement along the line of wave propagation.

Effects of Earthquakes

Though the main effects of earthquakes are ground shaking and rupture, there are many other ways that they can affect the world. These include:

Avalanches and Landslides:

In areas with loose soil or snow, sufficient shaking due to earthquakes can trigger landslides or avalanches, which can be devastating to nearby populated areas.

Destruction of Urban areas:

Urban areas may suffer from:

Destruction of buildings; Fires; Disease spreading due to scarce resources and death.

Tsunamis:

If the fault ruptures at sea, there can be a large displacement of water. Tsunamis are caused by such sudden movements, producing large waves with a long wavelengths. These waves can reach extremely high speeds, depending on the depth of the water. When there is an earthquake near a coastal region, tsunamis are very likely to occur.

Measuring Earthquakes.

The study of earthquakes and their effects is known as *seismology*. Seismologists felt that earthquakes should be categorised in terms of magnitude. However, earthquakes range broadly in size; they can range from leading to a one meter crack in a rock, to over 650km. For this reason, scientists have created scales to measure the size of earthquakes based on many factors.

"The study of earthquakes and their effects is known as *seismology*."

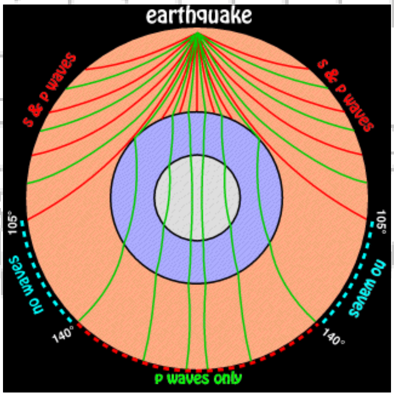
The Mercalli Scale.

The Mercalli intensity scale built upon the Rossi-Forel, which gave a qualitative measurement of earthquakes by taking the detections of ground shaking from seismographs, and the reflections of the local people in the vicinity of the quake. The Mercalli scale quantifies the effect of an earthquake on the Earth's surface, natural structures, humans, and man-made structures. The scale has been extended between I and X to XII, to include more devastating types of quake.

	Name	Description
I	Instrumental	Felt by some in a good environment
II	Feeble	Felt more considerably on the upper floors of buildings. Delicately suspended objects may swing.
III	Slight	Felt distinctly indoors; Not recognised much outside. Vehicles may rock.
IV	Moderate	Felt indoors by many people; Felt outdoors by a few in the day time; Dishes, windows, doors rattle; Standing vehicles noticeably move from side to side.
V	Rather Strong	Felt by most; Dishes and windows may break and large bells will ring.
VI	Strong	Felt by all; Many become frightened; People walk unsteadily; Books can fall off shelves; heavy furniture may shifted; Slight structural damage.
VII	Very Strong	Difficult to stand or walk; Furniture breaks and there is badly made structures may damage. Well built structures should have negligible damage.
VIII	Destructive	Slight damage in well built structures; Ordinary and badly built structures may collapse; Chimneys fall, large furniture moves about.
IX	Ruinous	The public are in a state of panic; Considerable damage to all structures; Partial collapse or shifting of large buildings.
X	Disastrous	Some wooden structures destroyed.; Many masonry and frame structures are destroyed; Rails are bent.
XI	Very Disastrous	Very few masonry structures still stand; Bridges are destroyed; Rails are bent greatly.
XII	Catastrophic	Total destruction; Lines of sight and level distorted. Objects are projected into the air; The ground moves in waves or ripples; Large amounts of rock displace

It can be noted that the lower levels of the Mercalli scale are based more on the effects felt by people on a small and large scale. The middle and higher levels of the scale consider damage to household objects, and later structural damage and the effect on the Earth's surface.

The Richter Scale.



Earthquakes can be detected at specific points around the world through the waves dispersing outwards.

Using technology, seismologists can measure the magnitude of ground motion as a function of time. Though these devices have been around since the late 19th century, it was not until the 20th century when Charles F. Richter produced a scale based on ground vibrations. As ground vibrations vary to a very large extent, Richter decided that earthquakes should be categorised on a logarithmic scale.

His scale measured ground motion in terms of amplitude; the period of vibrations; and a correction factor which is a function of distance to the epicentre and focal depth. From this, corrections were able to be made for both body waves and surface waves. The waves are calculated as follows:

For body waves:

$$m_b = \log_{10}\left(\frac{A}{T}\right) + Q(D,h)$$

Where: A is the amplitude of ground motion; T is the period of vibrations; Q is a correction factor in terms of D, the distance between the detector and the epicentre (degrees), and h, the focal depth.

The Richter scale gives a quantified result for the magnitude of an earthquake, and so can be used more widely in terms of comparison. Both the Richter and Mercalli scales can be used in conjunction with each other to describe earthquakes based on the magnitude of the quake itself, and the scale of damage caused.

For surface waves:

$$M_s = \log_{10}\left(\frac{A}{T}\right) + 1.66\log_{10}(D) + 3.30$$

These two formulas may vary depending on the geographical location so that they are more accurate.

It is also relevant to measure an earthquake in terms of a *seismic moment*, as seismologists can use this to work out the energy released by the earthquake as a whole. The seismic moment is constrained by the rigidity of the Earth, the average amount of slip on the fault, and the amount that the area slipped by. It is defined by:

$$M_0 = \mu A D$$

Where μ is the rigidity of the Earth (or Shear Modulus); A is the area that has ruptured; D is the displacement of the rupture.

The moment magnitude scale is based on this, value, and is defined as:

$$M_W = \left(\frac{2}{3}\right)\log_{10} M_0 - 10.7$$

Magnitude	Depiction	Effects
<2.0	Micro	Not Felt
2.0-3.9	Minor	Felt by very few; do not cause damage usually
4.0-4.9	Light	Indoor items shake, damage to items is not likely.
5.0-5.9	Moderate	Felt by most. Poorly built buildings may have major damage.
6.0-6.9	Strong	Felt by all. General panic; it becomes hard to walk; Can be destructive to about 160km across. Damage to buildings.
7.0-7.9	Major	Larger areas may suffer from destruction.
8.0-9.9	Great	Can cause widespread destruction from several hundred, to thousands of miles across.
>10.0	Epic	Has never been recorded.

Case Study: Haiti, 12 January 2010

It is not surprising to know that most earthquakes occur at plate boundaries. Lucky for us, most plate boundaries lie along the ocean floors, away from major land masses. However, the few that lie across or close to land can be potentially devastating to all inhabitants of these areas.

Haiti lies on the island of Hispaniola, next to the Dominican Republic. This area is on the edge of the Caribbean plate, and so has suffered seismic activity before. There are two known fault systems around Haiti. The first is called the *Enriquillo-Plantain* fault system, found along the south side of Hispaniola. This fault system and the *Septentrional-Orient* fault zone, which runs along the north side of Hispaniola, depend on the movements of the North American and Caribbean Plates. Together they form a *microplate* around the island, called the *Gonâve Microplate*. This microplate is in the process of both shearing off the Caribbean plate, and adding to the North American plate. The two fault systems around Haiti make it a possible hotspot for seismic activity.

In 2007, a study had been conducted by C. DeMets and M. Wiggins-Grandison, finding that the *Enriquillo-Plantain* fault system was nearing the end of its seismic cycle. They reported that the Caribbean and North American plates were fully locked together, and had not suffered any major ruptures in over 40 years. The data they collected suggested that Port-au-Prince had a major risk of suffering from seismic activity.

On top of this, Haiti has also been regarded as one of the poorest countries in the world, according to the Human Development Index, which lists Haiti at 149th out of 177 countries. Previously, the Australian government expressed concerns that the Haitian emergency services would not be able to handle a major disaster if it occurred.

At 16:53 local time, on the 12th of January 2010, a magnitude $7.0M_w$ earthquake was recorded 25km away from Haiti's capital city, Port-au-Prince. The hypocentre of the earthquake was 13km underground on the *Enriquillo-Plantain* fault system. This area was where the Caribbean tectonic plate moves into the North American plate. It was found that the *Enriquillo-Plantain* fault system had been locked for over 250 years before it finally ruptured. When it did rupture, a 65km long crack slipped 1.8m on average, producing a terrific force.

On the Mercalli scale, the earthquake was measured at IX (Ruinous) in the area, corresponding to the amount the ground shook and the amount of structural damage caused. The quake was also felt in surrounding countries, such as Cuba, at about III on the Mercalli scale.

After the initial shock, there were reported to be 8 separate aftershocks within, according to the United States Geological Survey. These aftershocks had an average magnitude of 4.0 on the Richter scale, and caused further destruction to the already brutally damaged cities. The nearby fishing town of Petit Paradis was also hit by a localised tsunami due to an underwater slip in the fault. Most structures in the city that were weakened by the initial shock collapsed. Haiti is full of densely-packed shantytowns and badly-constructed buildings, so the destruction of weak buildings was massive, leaving hundreds of thousands of people dead and homeless, with 1 in every 15 dying in Port-au-Prince. To rebuild form this disaster, the Haitian government is estimating that Haiti will need £7.5 billion to rebuild itself. This figure is over 120% of Haiti's GDP, and with Haiti's major capital in ruins, its economic and administrative centres are crippled. The quake also affected the roads and bridges, schools, hospitals, ports and airports in the region, crushing the livelihood of the area.

Though we are fully aware of the dangers earthquakes may cause, their unexpectedness and brute force will keep them as a danger to life on Earth. There is no current method of fully detecting earthquakes before they happen, humans can soften the effects of them by creating sustainable structures, using better detection methods, and more responsive aid to victims.

Earthquake Prediction

Though earthquakes cannot be detected down to the hour, day or month, sizeable efforts have gone into researching earthquake prediction. Seismologists are able to give probabilities based on factors including seismicity patterns, ground movements, weather patterns, electromagnetic fields and many more. These efforts are still ongoing, though there have been no conclusive methods of forecast for earthquakes as of yet.

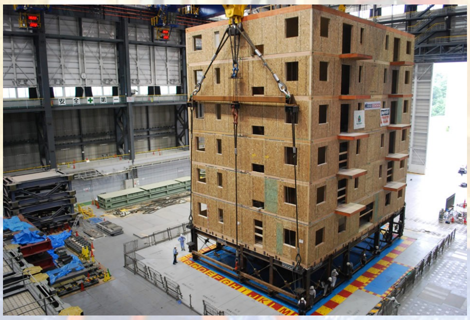
Earthquake Engineering

An alternative to predicting earthquakes is to learn to live with them.

Earthquake engineering involves studying the effects of seismic activity on buildings and other free standing structures. Engineers of these new age buildings have researched into a buildings ability to handle an earthquake by learning how a building interacts with the ground; how a buildings collapse effects urban areas; and how specific designing of buildings will allow them to stand after earthquakes hit.

The application of an earthquake like force on a structure is known as seismic loading. Engineers attempt to boost the resistance of a structure so that it is less likely to collapse partially or fully under an earthquake or tsunami. This requires engineers to know about the range of earthquake magnitudes a structure is likely to come across, and the properties of the earth surrounding the structures geographical location. Engineers aim for a structure to survive the most powerful earthquake that is predicted for the region.

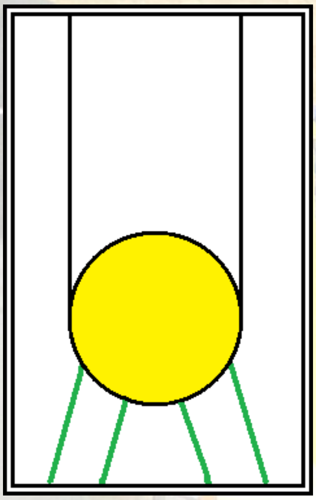
The performance of structures under seismic loading is scored by its ability to follow safety and serviceability guideline both during and after an earthquake. A *safe* structure is one which does not engender human lives or welfare through its collapse, while a serviceable structure is one which allows it to operate under seismic loading.



A Shake Table

One way engineers can test this is by putting the structure on a *shake-table*, which simulates an earthquake. By analysing the results, they can find the best possible structures for a particular location. Most modern analysis techniques involve simulation of earthquakes. When structures have undergone simulated earthquakes, analogies may be made between the outcome of the simulation and the real structure.

After analysis of structures under the shake table, engineers aim to dissipate the calculated energy earthquakes put into the real structures. There are many ways to disperse the energy in a structure. Methods include using tuned mass dampers, which are large spherical devices that are mounted to structures. The device has a large inertia, and so will absorb the energy that the structure feels and hence damp its movement.



A mass damper as used in Taipei 101.

A damper of this type is famously seen in the Taipei 101 tower in Taiwan. The bottom supports are springs which store the potential of the moving ball. This potential builds up as the tower moves, and the produces a counter force, steadying the structure.

It is structures like these and many others that will help us overcome earthquake disasters. Through our knowledge of mechanical systems, humans can adapt buildings and other structures to make earthquakes less harmful to a population. Learning to understand earthquakes still does not prevent them; what we must seek instead is damage limitation.

References:

Armijo, R., H. Lyon-Caen, and D. Papanastassiou. "A possible normal-fault rupture for the 464 B.C. Sparta earthquake." Nature 351 (1991): 137-139.

Jonathan Schonberg, Middlebury College "THE SPARTAN EARTHQUAKE OF 464-65 B.C."Brown Classical Journal (1997 Volume 11) - http://www.fsmitha.com/h1/rel-greece4.htm

An account of the late dreadful earthquake and fire, which destroyed the city of Lisbon, The Metropolis of Portugal. In a letter from a merchant resident there, to his friend in England. - London : printed: and sold by J. Payne, in Pater-Noster-Row, MDCCLV. [1755].

Disasters Emergency Committee website - http://www.dec.org.uk/who_we_are/

Table of intensities on http://en.wikipedia.org/wiki/Mercalli_intensity_scale

http://earthquake.usgs.gov/learn/topics/measure.php

Human Development Report 2009 – Produced for the United Nations Development Programme (UNDP); http://hdr.undp.org/en/media/HDR_2009_EN_Complete.pdf

http://www.smartraveller.gov.au/zw-cgi/view/Advice/Haiti

UN, EM-DAT

Agents of Chaos : Earthquakes, Volcanoes, and Other Natural Disasters by Stephen L. Harris