EARTHQUAKES INDUCED BY STRESS

Harjit Singh

Stress is one of the most destructive forces in nature. We all know the negative impacts that stress can have on humans. But what happens when rocks on continents and oceans become stressed? The result is an earthquake.

Stress is one of the most destructive forces in nature. We all know the negative impacts that stress can have on humans. But what happens when rocks on continents and oceans become stressed? The result is an earthquake. Large magnitude earthquakes with great destructive potential are unleashed due to the release of stress and strain in rocks near tectonic plate boundaries.

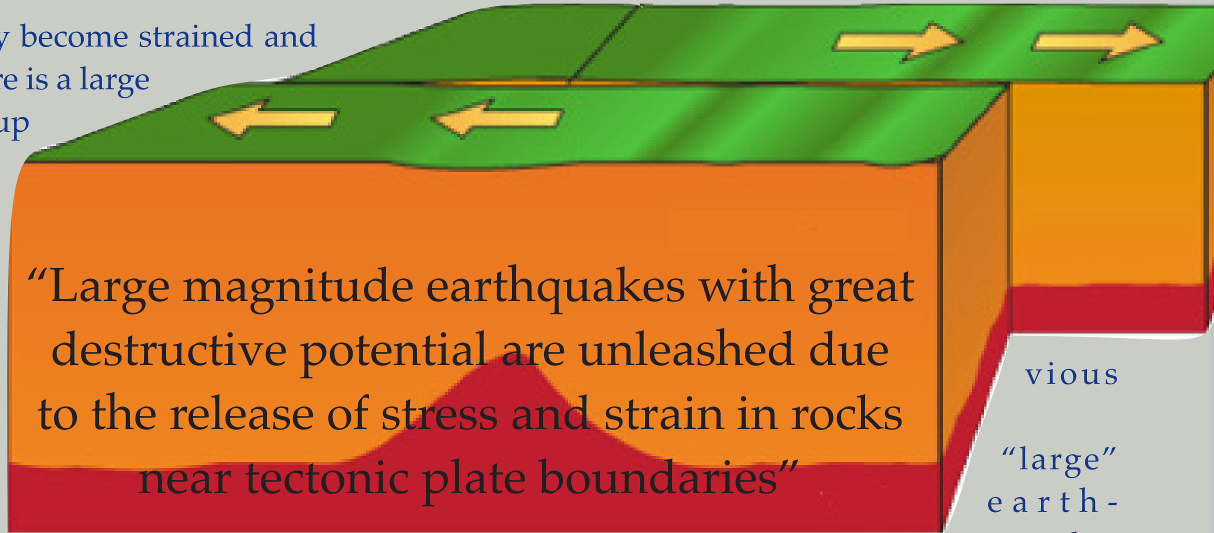
The theory of plate tectonics explains the world's earthquakes, volcanoes, and mountains. The rigid surface of the earth (its lithosphere) is broken into many pieces called tectonic plates, shown in Figure 1. These tectonic plates move around the surface of the Earth and are driven by the underlying mantle convection. This is analogous to dropping a handful of pasta shells into boiling water and seeing them move around, where the shells are tectonic plates and the boiling water represents mantle convection. The surfaces of these plates interact in three different ways at their boundaries.

The three plate boundaries are convergent, divergent, and transform. At convergent boundaries, plates move towards one another. This type of boundary is typically associated with mountain and volcano-building. Most earthquakes occur at convergent boundaries. At divergent boundaries, plates move away from one another. Magma from Earth's interior rises up and solidifies into new crust at these boundaries, as is seen in the mid-ocean ridges of the Atlantic Ocean. Few earthquakes occur at divergent boundaries. Lastly, tectonic plates slide past one another at transform boundaries. The San Andreas Fault is a prime example of a transform plate boundary. Strike-slip earthquakes occur at these boundaries.

Stress is the cause of all earthquakes but it is easiest to imagine at transform boundaries. Stress is the same as pressure; it occurs when a force is applied over an area (Ormand & Baer, 2012). Strain is the deformation of rocks that results from stress. Imagine taking your hands and pressing them together tightly. You are exerting a force over the area of your hands and this leads to a buildup of stress. Now if you try to slide your hands past one another they will not

Figure 1. Diagram of Earth's tetonic plates

move. But slowly they become strained and start slipping until there is a large slip and all the built up stress has been released. This is precisely what happens during a strike-slip earthquake. The comparison is that your hands are two distinct plates and as those plates try to slide past one another stress is built up in the fault until an eventual release. Note that the limits of this simple model do not explain that two plates actually create an array of faults rather than just one large fault.



"Large magnitude earthquakes with great destructive potential are unleashed due to the release of stress and strain in rocks near tectonic plate boundaries"

As Berkeley students, we do not need to look far to see an example of a transform boundary. The sliding motions of the North American and Pacific plates create a network of faults throughout California. In the Bay Area, the principle fault as a result of the transform boundary is the San Andreas Fault. The Hayward Fault lies parallel to the San Andreas Fault, shown if Figure 2. The Hayward Fault is 74 miles long, running from Richmond to San Jose, and it runs just under the famous California Memorial Stadium (CA Department of Conservation, 2008). Due to previous earthquakes and decades of creep (the slow shifting of tectonic plates) Memorial Stadium has essentially split into two parts. If an earthquake were to happen, Memorial Stadium would collapse due to surface rupture that occurs from ground motion. The engineering task of seismically retrofitting Memorial Stadium was completed by breaking the stadium into fault rupture blocks where the fault crossed, so that these portions of the building could move in response to possible surface rupture without affecting the rest of the structure (Forell / Elsesser Engineers). Now that we have a retrofitted stadium, how soon will its engineering be tested, or in other words "when will we experience a large earthquake in Berkeley?" The previous "large" earthquake (where large is relatively defined as greater than magnitude 5.5) struck the Hayward fault in 1889; it was a magnitude 5.6 earthquake (CA Department of Conservation, 2008). That was 124 years ago. This hiatus is troubling because there is a common scientific notion about earthquakes: the longer an active tectonic boundary goes without an earthquake, the greater the chance for there to be an upcoming large earthquake. This makes sense in terms of stress. The longer a boundary goes without an earthquake, more stress builds up and the built up stress holds more destructive power. Since earthquakes are a relevant natural disaster, it is important to think about how to predict earthquakes.

There are arguments both for and against the feasibility of earthquake predictions. Critics of earthquake prediction say that tectonic boundaries are a complicated system. Thus, it is difficult to say with good certainty when an earthquake may occur. For example, in Parkfield, CA, between 1857 and 1966, earthquakes of magnitude 5.5 or larger would occur nearly every 22 years. Based on this trend, a prediction was made that there is a 95% chance that an earthquake greater than magnitude 5.5 will occur between 1985 and 1993 (Kanamori, 2003). However, an earthquake of that magnitude did not occur in Parkfield until 2004. This is an example of how short-term predictions are not possible. The National Research Council has deduced that "based on the relative timescales, predicting the size, location, and time of an earth-

Figure 2: Hayward Fault and the adjacent San Andreas Fault

quake to within a week corresponds to predicting the size, location, and time of a lightning bolt to within a millisecond." The closest we can come to "predicting" an earthquake in the short term is saying that "large shallow earthquakes are immediately followed by aftershocks that are triggered by the main shock. Large earthquakes sometimes trigger other large earthquakes" (DePaolo, 2008). An example of the latter is when a series of large earthquakes ruptured most of the North Anatolian fault during the 20th century. In addition, by monitoring the stress and strain in small areas, for example, the San Andreas Fault, in great detail we can hope to predict when renewed activity in that area is likely to take place (U.S. Geological Survey, 2012). This methodology may not seem very satisfying, but it is all we have right now as there is active but unfinished research in improving short-term forecasting for earthquakes. The next best option is early warning forecasting.

The earliest that people can be undeniably warned of a coming earthquake are a mere seconds before it hits. With the use of high-quality instruments in seismology, reliable estimates on the location and size of earthquakes can be collected within minutes of the initiation of rupture if the earthquake is far away. For nearby earthquakes, the ground will have begun shaking before these estimates can be made. If seismographs can quickly pick up an earthquake under way, then an earthquake early warning system can be enforced. Regions that will be subject to dangerous shaking can be warned through telecommunications before the shaking arrives because the speed of electromagnetic waves in telecommunications exceeds that of seismic waves. Within the seconds

> "In a good scenario, a 10-15 second warning can be provided before an earthquake hits a city."

of warning from an incoming earthquake, public transportation systems can be halted, people can take cover under desks, sensitive and dangerous manufacturing equipment can be paused, and dangerous chemicals in labs can be isolated. In a good scenario, a 10-15 second warning can be provided before an earthquake hits a city (DePaolo, 2008). This might not seem like much time but it is enough to save lives and money.

Professor Richard Allen, director of the Berkeley Seismological Laboratory, is a leading advocate for early warning systems. Early warning technology was tested when a magnitude 9 earthquake hit Japan in 2011. The closest large city received a 15 second warning which saved many lives and even more money from reduced damage costs. Professor Allen is calling for a US early warning system. He first proposes a West Coast system that will cost $120 million for the first five years to build and operate early warning technologies. This would include California, Oregon, and Washington because these are the states most likely to be affected by an earthquake. A partnership between the public and private sectors would manage the early warning system. The private sector would pay for "the installation and long-term operation of geophysical networks" including sensors and GPS technology that detects the earthquakes (Allen, 2013, p.30). The private sector would deliver the alerts through mobile apps. Besides the obvious benefit for human lives, with increased data from sensors and GPS, scientists can better study plate motion and have more information to further nuance our model of Earth's interior. In September 2013, Governor Jerry Brown signed into law a bill to build an earthquake early warning system in the state. Thus, the momentum for early warning technology is increasing.

Stress can come in many different forms. It is deadly at an individual scale and on a large geologic scale. Rocks being stressed from the coming together or sliding of tectonic plates are the cause of earthquakes. When the built up stress is released, the energy that is released travels through Earth's crust and creates ground motions. The intensity of these ground motions depends on the type of rock that is present in that area. Some areas are more prone to higher intensity shaking than others. Those who live in seismically unsafe buildings can be crushed in a building collapse, representing a significant risk when an earthquake strikes. Trains may be derailed from earthquakes. Also, as seen from the great 1906 earthquake in San Francisco, gas lines can burst and there may be widespread fires. However, a lot of damage can be prevented through early warning technologies. Even with just a few seconds notice, the proper adjustments can be made to save many lives. Now the only question is can we allocate the money that is required to build a nationwide early warning system. It worked for Japan. Let's make it work for us.

References

1. Ormand, C & Baer, E. (2012)."Stress and Strain." Teaching Quantitative Skills in the Geosciences. National Science Foundation. Retrieved from http://serc.carleton.edu/quantskills/methods/quantlit/stressandstrain.html
2. Hayward Fault Fact Sheet. (2008) Retrieved from California Department of Conservation Web site: http://www.conservation.ca.gov/index/Pages/HaywardFaultFactSheet.aspx
3. UC Berkeley California Memorial Stadium. (n.d.) Retrieved from Forell / Elsesser Engineers Web site: http://www.forell.com/case-studies/uc-berkeley-california-memorial-stadium/
4. DePaolo, D. J., et al. (2008). Origin and Evolution of Earth: Research Questions for a Changing Planet. The National Academies Press, Washington D.C.
5. Earthquakes and Plate Tectonics. (2012). Retrieved from U.S. Geological Survey Web site: http://earthquake.usgs.gov/learn/topics/plate_tectonics/rift_man.php
6. Allen, R. (2013). Seconds Count. Nature, 502, 29-31. Retrieved from http://seismo.berkeley.edu/~rallen/pub/2013allen/Allen-EEW-Nature-2013.pdf
7. Kanamori, H. (2003). Earthquake Prediction: An Overview. International Handbook of Earthquake and Engineering Seismology, 81B. Retrieved from http://www.gps.caltech.edu/uploads/File/People/kanamori/HKees03.pdf

Image Sources

1. http://www.learner.org/interactives/dynamicearth/images/new_map.jpg
2. http://geomaps.wr.usgs.gov/3D4Dmapping/html/images/hayward_fault_map.jpg