TEGAM's Connection to the EarthScope Project

Introduction

The EarthScope Project is an undertaking funded by the National Science Foundation in partnership with the United States Geological Survey and NASA to characterize the geology of North America.

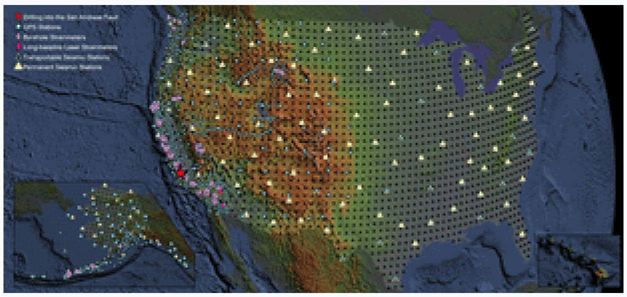

Figure 1 *- To meet the project's scientific goals, EarthScope will install thousands of stations across the country and drill a 3.2km borehole into the San Andreas Fault over the next five years. In addition, EarthScope will purchase 2,500 campaign GPS and seismic instruments, which will be available for temporary deployments and individual research experiments. Most of the stations will transmit data in real-time to data collection centers for an additional 15 years. All of the data from EarthScope will be freely and openly available to the scientific community, the educational community, and the public. Photo Credit: EarthScope*

Background and Theory

Continental drift, the precursor to understanding plate tectonics, was first theorized by German meteorologist Alfred Lothar Wegener in 1912. Since that time plate tectonics has provided a basic understanding of what is happening on the earth's crust as various plates, or large piles of solid rock, grind away at each other as they float on earth's molten mantle.

The intersection of tectonic plates is a subduction zone – an area where one plate slides under, or across, another plate. Earthquakes are most frequent in faults at or near subduction zones. The most famous of these zones is the "ring of fire" around the pacific basin.

Except during an earthquake, plate movement is very slow. To imagine what is happening kilometers under the earth's surface, think of a tire on pavement. The tire, accelerated slowly, offers friction which will grip and move a vehicle forward. Imagine, however, the car's bumper is against a wall and the same slow acceleration begins. Initially, friction between the tire and pavement will prevent any movement at the interface between the tire and pavement. But as the wheel continues to try to turn, deformation of the side wall of the tire begins, storing energy. Eventually the friction between tire and pavement is overcome and the tire breaks loose, bouncing then spinning – until the built up energy is released and the friction between the tire and pavement stabilize and the obvious motion stops.

Laboratory studies by Das and Scholtz led to the development of a stress triggering theory of earthquakes, and this work has expanded by many others, both in further laboratory studies and in active fault zones. Collecting strain data for analysis to compare to laboratory results can lead to improved theories or mathematical models of the relationship between stress and the resulting release as an earthquake.

Now imagine you are challenged with collecting and evaluating data that would increase the possibility of an accurate prediction of when energy would be released from a fault a few days or weeks in advance. A multidisciplinary team of earth scientists, engineers, physicists and others is assembled to gather and share data for analysis. What data would be helpful to gather?

Data Collection

Capturing the slow movement (which in some areas happens over centuries) can be done by measuring strain – defined as the relative change in distance divided by the distance over which the change occurs, would provide information to analyze stored energy, a key element in understanding the impact of stress and energy release. Because rock does not show much deformation under stress, measurements need to be precise. Distances can be great as faults run for tens or hundreds of kilometers. Capturing strain (the deformation caused by stress) also can highlight areas that are moving faster along a fault relative to other areas. Like the tire example above, when one area slips less, or not at all, relative to another area, strain builds. The "locked" region will eventually fail, releasing the stored energy. The catastrophic failure is an earthquake.

As previously mentioned, rock deformation caused by stress is tiny. Dr. Michael Gladwin of GTSM Technologies in Brisbane, Australia has developed a tensor strainmeter to measure stress in this application. The GTSM strainmeter has a resolution of 0.02 nanostrain – the equivalent of 0.02 mm of motion per 1000 km of distance, or 0.02 parts per billion (ppb). It also includes a TEGAM Ratio Transformer as one of its main components.

Figure 2 *– The TEGAM Part Number 1949-0001 is used in the GTSM Tensor Strainmeter.*

Each GTSM sensor has three strain gauges oriented 120 degrees apart, providing detailed three axis information on the strain that results from earth movement. Figure 3 shows a mechanical representation of the element that measures the strain. In a resting state before installation, the electrical output of the strainmeter is adjusted to zero the output (Figure 4) using the TEGAM ratio divider.

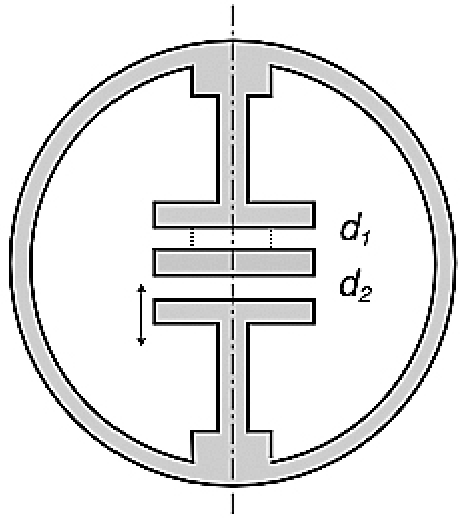

Figure 3 – Mechanical representation of one axis of the of the strain element. As distances d_1 and d_2 vary with rock deformation, the capacitive output will also vary.

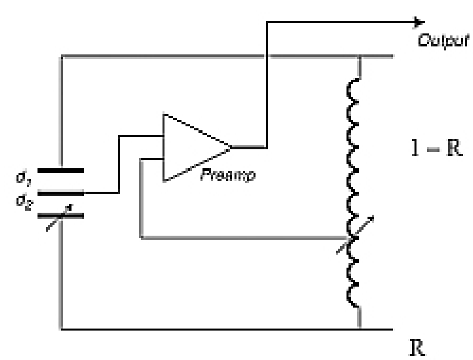

Figure 4 – Electrical representation of the strainmeter. The TEGAM ratio transformer is shown as "R" in the schematic. The initial output of the device is set at zero.

The strainmeter is put into service by drilling a borehole into the earth (Figure 5). Although initial accuracy of the ratio transformer is important, it is critical that the ratio transformer have extremely low drift. Once the GTSM device is embedded in the rock, it is there for the life of the device. Component drift would produce unacceptable results, and the TEGAM ratio transformer assures there will be insignificant drift for that component over the life of the project.

Figure 5 *– The GTSM Tensor Strainmeter as installed in the borehole.*

Field Results

According to Dr. Gladwin (Figure 6), stress triggering theories focus on what happens immediately before the final failure of the fault. A complement to stress triggering theories are stress transfer theories. Stress transfer studies focus more on the dynamics of how stress is redistributed during and after events, over very long time scales. The earliest strainmeters have been in service for more than twenty years.

Figure 6 *– Dr. Michael Gladwin of GTSM Technologies, the inventor of the tensor strainmeter.*

Combined with GPS data which measures the overall motion of the earth surface, the equipment can distinguish regions of energy accumulations (strain accumulation at constant or varying stress) from regions of simple deformations (e.g. deformation at constant stress which is often called creep).

Initial failures along a fault, which some believe can be in a region less than 100 meters, precipitate shifts in local stress fields. This shift, together with the dynamic stress changes associated with rock movement, change the stress load on nearby zones. Critical to the advancement of both stress triggering and stress transfer studies is the precision measurement available with the GTSM unit – which is .001 PPM over short periods, a precision unavailable without the accuracy and very long term stability of the ratio transformers supplied by TEGAM. Theories can be tested by analyzing the data provided by the strainmeter, and mathematical models can be improved as more sites and data become available.

Importance

Why is the stress/strain relationship of faults important? Current scientific literature shows a growing body of evidence and acceptance by seismologists that the release of energy in an earthquake transfers stress to either a different region of the same fault, or to a different fault altogether. The transfers can increase or decrease the probability of an earthquake along the same fault or in a neighboring fault, depending on how the stress is transferred. An improved capability of understanding the stresses involved will likely lead to a better determination of the timing of an earthquake, which can save lives. For example, even with as little as one to two minutes warning, natural gas pipelines could be sealed at critical points, minimizing damage from fires that happen when gas lines rupture during an earthquake. Details are hazy, in part due to the politics of the time, but some estimates are that in the San Francisco 1906 earthquake more people died in the firestorm after the earthquake than in the earthquake itself (casualty numbers, for example, range from 567 to nearly 3,000, depending on the source).

EarthScope Project

The EarthScope project (www.earthscope.org) has funded a significant increase in the number of strainmeter sites. As the density of strain measurements grows, changes in earthquake models are likely as a result of better information, particularly over long time frames. Other countries are also expanding their network of sites to collect information. As the data analysis expands, risk assessment will improve and prediction with reasonable accuracy may become a reality in the future.

Acknowledgements

Michael Gladwin *has a Ph.D. in Physics and a broad range of scientific, technical and academic experience involving creation of innovative programs in teaching and geophysical research. Over the last twenty years, he has been responsible for a significant paradigm shift in the observation and analysis of fault processes on the San Andreas Fault in California by development of a new deformation sensing system (the so called "Gladwin Tensor Strain Meter").*

For Further Reading

The following resources were used in the preparation of this paper and provide additional detail for those that wish to explore further.

EarthScope website - www.earthscope.org

Plate Boundary Observatory website - http://pboweb.unavco.org/

GTSM Technologies website - http://www.gtsmtechnologies.com/

Earthshaking Science by Susan Elizabeth Hough

Stress Test by Simon LeVay, Scientific American December 1999

Earthquake Conversations, by Ross S. Stein, Scientific American, January 2003

San Andreas Fault on the move at Parkfield, California – http://www.cyberwest.com/cw16/16scwst6.html

Earthquakes: Predicting the Unpredictable by Susan Hough – http://www.geotimes.org/mar05/feature_eqprediction.html

US Geological Survey, Earthquake Hazards Program - http://earthquake.usgs.gov/

Wikipedia - http://en.wikipedia.org/wiki/Earthquake, http://en.wikipedia.org/wiki/Continental_drift, http://en.wikipedia.org/wiki/San_Francisco_Earthquake

After the Earth Quakes, by Susan Elizabeth Hough and Roger G. Bilham

1906 San Francisco Earthquake - http://www.sfmuseum.org/1906/06.html, http://earthquake.usgs.gov/regional/nca/1906/18april/index.php