Creepmeter mini-proposal

John Langbein, Evelyn Roeloffs, Mick Gladwin, Ross Gwyther

The Proposal

We propose to install creepmeters in the creeping section of the San Andreas Fault system adjacent to borehole strainmeter arrays. For this section, creepmeters provide a bridge between borehole strain data and GPS displacements. We estimate that 15 to 20 new installations will be required. The creepmeters that we propose to install will be built upon the lessons that we have acquired in the past 30 years. Specifically, the largest problem with the existing instruments is their susceptibility to localized displacements of their monuments that are not necessarily due to fault slip. In addition, other transducer designs need to be considered which have similar resolution and temporal stability as the displacement transducers that are currently being used, but can provide better reliability and less maintenance.

To improve long-term stability, these new creepmeters should use braced monuments that are currently used for most GPS installations. As Langbein *et. al* (1995) demonstrated, the braced monuments are superior to the surface monuments that are used with the 2-color EDM installation at Parkfield. The EDM surface monuments are exactly like those installed at many of the creepmeters at Parkfield. Along with using braced monuments, a geotechnical evaluation of each new creep site should be performed. This would include soil testing for shear strength, measurement of clay content, and evaluation of susceptibility to downslope movement (landslides).

Various transducer designs need to be considered. This list includes differential GPS, fiber optical cable, and laser-ranging. With some designs, it might be possible to measure slip for a wider portion of the fault zone; perhaps 100-meters rather than the 30-meters that are typically measured. We estimate the typical installation will cost $25k to $30k per site.

Background

Over the past 30 to 40 years, the USGS has been measuring surface slip along the creeping section of the San Andreas faults system. This includes the Hayward and Calaveras faults from Berkeley to Hollister in the San Francisco Bay area and along the San Andreas fault from San Juan Bautista to Parkfield. In a good portion of this region, particularly from south of San Juan Bautista to north of Parkfield, the creep rate averages 25 mm/yr which is roughly 50% of the plate motion between the North American and Pacific Plates. Along the creeping section, this right lateral motion is confined to an approximately 30-meter wide zone. In addition, creepmeter measurements indicate that surface slip is composed of two parts: 1) steady-state motion and 2) discrete events of 0.5 to 2 mm amplitude that occur over periods of less than 1 hour.

Many discrete creep events are often detected by borehole strainmeters and/or water wells if they are located within a few kilometers of the creepmeter. Many investigators (Johnston, Gladwin, Linde, Roeloffs) have described these events and have, in general, concluded that they represent shallow fault slip, less than 1 km in depth. However, as Johnston, Gladwin, Linde *et al.* have reported, the surface creep events may be part of a larger, near-surface slip event that they term a "slow earthquake", which occurs over a few hours to days and are well-recorded on strainmeters. Analysis suggests that these slow earthquakes may extend to a few kilometers in depth and can be coincident with small to moderate sized (M4) earthquakes located adjacent to the patch that appeared to have slipped during the slow earthquake.

However, some of the creep events are clearly correlated with rainfall since these events occur either during periods of significant rainfall or soon thereafter (Roeloffs and Mavko). In addition, these events are not detected on nearby strainmeters, which suggests, that the apparent creep is localized to the creepmeter installation.

Along with short-duration events, there is a steady state, secular slip that is recorded by the creepmeters. Comparison of slip rate recorded by creepmeters and longer baseline alignment arrays (Burford and Harsh), and small EDM quadrilaterals (Prescott and Lisowski) suggests that the creepmeters may miss 10 to 25% of the total slip because of their short aperture (30 meters or less).

In addition, numerous investigators have reported variations in the rate of creep over periods of months to years and have often tried to correlate these rate changes with the occurrence or absence of nearby earthquakes. Without a doubt many of these motions are due to random motions of the creepmeter monuments since these monuments are shallow, (less than 2-meters deep). The monument motions are a random-walk that are probably due to swelling and contraction of the soils which has a significant component of clay. On the other hand, there have been creep-rate changes that are coherent over several 10s of kilometers of fault length that can be modeled by static stress changes from nearby, large earthquakes. The most notable examples are from Coalinga (Simpson, Stein) and Loma Prieta (Simpson and Leinkaemper).

Currently, the USGS maintains a set of 21 creepmeters along the San Andreas fault system. Many of these instruments are near the end of their expected lifetime. These instruments measure several times per hour the displacement between two monuments located on either side of the fault. These measurements are telemetered to Menlo Park and are available within the hour of the actual measurement. In addition, there are approximately 10 other sites that have had telemetry but are now only measured mechanically once or twice per year. Finally, in the SF Bay area, small aperture geodetic measurements made a few time annually by Jon Galehouse (SFSU) complement the creepmeter records.

Scientific Justification

New creepmeters will complement the proposed borehole strainmeter and GPS networks:

- Most significant episodic creep events have amplitudes of 1 to 5 mm, and time constants of hours to days. These events have provided significant insights into shallow fault slip processes. Events of this character are not readily measured with intended GPS arrays. The creep arrays complement the GPS by extending the domain of measurement. Further, creepmeters provide detailed measurements of the structure of these episodic events as well as the long term slip across the fault which can be directly compared with the observed GPS data. Accordingly, this requires a displacement transducer capable of measuring small, 0.1mm displacements. The LVDT used on existing instruments easily satisfy this requirement.

- The creepmeters will measure slip events that occur over the period of minutes to hours that are often detected by nearby borehole strain measurements. A recent event occurred in Parkfield and is shown in Figure 1. The signals recorded by both strain and creep instruments are well above the background noise. However, if we did not have any creepmeters, then the signal detected by the strainmeters would be ambiguous. Modeling of these strain signals may or may not able to confidently resolve whether these strain events are due to surface slip or some other event on either the San Andreas fault or another nearby fault. For this reason, we recommend that creepmeters be installed on the San Andreas (or Calaveras or Hayward) fault when strainmeters are located nearby. Then, any strain signals that are clearly due to surface fault slip can be easily identified.
- With GPS networks spanning the plate boundary, part of the secular deformation that GPS detects will be from surface fault slip. Again, without the precise measurement of surface fault-slip that a deeply anchored creepmeter could provide, it makes interpretation of the GPS data will be ambiguous. With precise creep-rate measurements and GPS data, the resolution for mapping of the slip distribution improves because the surface slip can be distinguished from slip at depth.
- Since deeply anchored monuments have less noise than the monuments that we currently use, we should have better confidence in the validity of any changes in rate that might be detected. Past examples are numerous with respect to changes in creep rate. In two cases, Loma Prieta and Coalinga, there is spatial correlation that seems to support a model of static stress change. However, in both examples, the rate changes also correspond to significant changes in seasonal rainfall; for Coalinga, the post-seismic responce followed two years of extreme rainfall and for Loma Prieta, the time corresponded to a multi-year long drought. In addition, at Parkfield, strain and EDM data suggest that the rate of slip increased over a finite region of the fault after 1993. Several creepmeters also indicate changes in slip rate but for many, these rate changes are not above their normal random-walk variations.

Description of existing creepmeters

The typical creepmeter consists of two monuments of 20-cm diameter pipes. Each pipe is installed vertically into the ground. The bottom 2 meters is cemented into the ground, an additional 0.5m is below the instrument housing but is isolated from the ground, and the remaining 0.5m extends into the instrument housing. The instrument housing, or vault, is buried from 0.5 to 1.5 meters below the surface of the ground. In one vault, an invar wire is clamped to the monument. The invar wire traverses to the second vault through a conduit and then is supported by rocker-arm assembly mounted on the second monument. The rocker-arm assembly allows for the invar wire to drape as a catenary across the fault-zone. Attached to the second monument is a linear displacement transducer for an electronic measurement and a mechanical micrometer. The electronic measurement is telemetered to Menlo Park via the GOES satellite-system.

Creepmeters made prior to the early 1980s have different installation schemes and transducers. For instance, two instruments installed in a winery along the central, creeping section of the San Andreas fault measure the shear displacement of a crack in the floor of the building using an electronic micrometer bolted across the crack.

All of these instruments have been in operation for 15 to 30 years. Most are now near the limits of their operational range. In several of the instruments, the invar wire now makes contact with the culvert that houses the wire. In some of the older, compression creepmeters, the rod has reached the end of its travel. In all of the instruments, the monuments are subject to localized soil motions that are not necessarily tectonic in origin.

More recently, Roger Bilham has installed 4 creepmeters on the Hayward fault. For these instruments, he used auger monuments that extend 5 to 10 meters deep into the ground which is primarily "bay mud". This data has not been analyzed to determined whether these new instruments have less noise than the standard USGS creepmeter.

Figure 1. Strainmeter and creepmeter measurements from a slip event in September 2000, at Parkfield, CA. The strain data are from three borehole tensor strainmeters (Gladwin *et al.*) and 3 borehole volumetric strainmeters (Johnston). The scale for the strain data is shown on the left-hand axis while the creep is shown on the right hand axis. Strain and creep data presented are from automated processing of the telemetered measurements. The main event started with creep at xmd1 on Sept 22. Then early on Sept 23, simulataneous events occurred at creepmeters xva1 and xpk1 and the FR and ED strainmeters. Then, one day later, a creep event occurred at xmm1 and much of the previous activity subsided.

Sept 2000 Parkfield event