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Displacement of Surface Monuments: Horizontal Motion

FRANK WYATT

Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, California 92093

Measurements of tectonic deformation depend on both accurate instrumentation and adequate coupling of the apparatus to the earth's crust. Existing techniques, capable of resolving the signals of interest (strain rates of 10 nϵ/yr), are mainly observatory based. The limitation in the baselength of these instruments (~1 km) results in a requirement that the reference monuments be exceptionally stable (10 μm/yr). However, records from Piñon Flat Observatory, California, show that the actual horizontal displacements for massive near surface monuments, emplaced in competent, weathered granite, are of the order of 50 μm/yr. The low noise level of the strain measurements at this site indicates that this magnitude of monument displacement is abnormally small. Until high-accuracy geodetic techniques are developed, sophisticated monuments (or monument monitoring devices) will be necessary to record faithfully continuous crustal deformation.

1. INTRODUCTION

Most techniques currently used to monitor continuously the deformation of the earth's crust employ instruments which measure over a limited baselength, almost always less than 1 km. Associated with this limitation is a requirement that the reference monuments, used as the fiducial points in the measurements, be well coupled to the crustal rocks. Because crustal deformations are both small in magnitude and occur very slowly, monument instabilities are likely to be the limiting factor in many crustal dynamics studies.

Even in areas of current tectonic activity the expected deformational signals may be so small as to be masked by undesirable monument displacements. That this is the situation is indicated by the measurements made at Piñon Flat Observatory (PFO), located in southern California. A collection of instruments has been operated at PFO since 1971 (see *Wyatt and Berger* [1980], for a list), with particular emphasis on the measurement of crustal strain using three 731-m laser strainmeters described by *Berger and Lovberg* [1970]. Although the observatory is situated only 12 km from the active San Jacinto fault zone [*Thatcher et al.*, 1975; *Sharp*, 1967], the dominant low-frequency signals recorded at the site are caused by environmental changes affecting the near-surface materials.

In an attempt to understand and compensate for the nontectonic (low frequency) displacements, three experiments were conducted at PFO. (1) Tiltmeters were fabricated to mount directly on the sides of the long (3 m) granite columns used as reference monuments for the strainmeters. These sensors served to detect the tilt of the granite columns and thereby to establish the horizontal motions at the tops of the columns relative to their bottoms. (2) An array of shallow borehole tiltmeters was deployed [*Wyatt and Berger*, 1980] in an effort both to understand the limitations of the particular instrumentation and to determine the spatial coherence of the near-surface displacements. (3) An instrument was designed and constructed to measure the horizontal motion of a surface monument relative to the material below. This device, called an 'optical anchor,' has been in operation for more than 1 year.

Naturally, the implications of these investigations are limited in scope by the nature of the materials and the processes which affect the surface layers at PFO. However, the observatory is located on ground that is unusually well suited for monitoring crustal deformations. Evidence for this is provided by the records of the three strainmeters at the site. These observations show unsurpassed low strain noise [*Berger and Levine*, 1974], linear response to tidal strains [*Agnew*, 1981], and agreement with an elastic model of deformation due to earthquakes [*Wyatt*, 1980]. It is likely that the monument displacements recorded at PFO are representative of the lower range of motion for markers used in geophysical studies. If this is true, then current observatory-based instrumentation will require additional improvements in order to record crustal strains.

2. GEOLOGICAL SETTING

In selecting a site for monitoring tectonic deformation, proximity to a region of active faulting is most important. It is also desirable to choose a location that is situated on competent material. If long baselength instrumentation (1 km) is to be installed, the terrain must be sufficiently smooth. Unfortunately, in tectonically active areas the nonsedimentary surfaces are usually rugged. Gentle topography is more often associated with mature surfaces that have weathered to a stable base level without disturbance by recent crustal motions.

Pinyon Flat, which is located in southern California some 12 km northeast of the San Jacinto fault system and 25 km southwest of the San Andreas fault zone (33.609°N, 116.455°W), is an area that has the desired properties. The flat is situated on the northernmost flank of the Santa Rosa Mountains in the Peninsular Range Province. Roughly 12 km^2 in area, the flat is bounded by Asbestos Mountain to the north, Deep Canyon to the east, Santa Rosa Mountain to the south, and Palm Canyon to the west. Figure 1 shows a generalized map of the pertinent geological features and a sectional profile of the area, indicating the smooth topography of the flat between 'PFO' and 'Edge.'

There are several possible explanations as to why such an isolated flat surface is found at these elevations (1300

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