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A BROAD-BAND, WIDE-DYNAMIC RANGE, STRONG-MOTION ARRAY NEAR PARKFIELD, CALIFORNIA, USA FOR MEASUREMENT OF ACCELERATION AND VOLUMETRIC STRAIN

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SUMMARY

Installation of a 14-station array was completed July, 1987, to provide on-scale, broad-band, high resolution measurements of earthquakes occurring near the segment of the San Andreas fault zone that is expected to rupture before 1993 with a moderate earthquake similar to the 1966 Parkfield, California event. The array is designed to provide on-scale measurement of volumetric strain, ground acceleration, and ground velocity to permit the observation of co-seismic strain offsets, seismic strain radiation, and strong ground motions of engineering interest. Data sets are presented to illustrate array bandwidth (0-100 Hz), dynamic range (145 dB), and detection levels for strain (10^{-11} at 1 Hz) and acceleration ($6x10^{-6}$g). Use of volumetric strain meters as strong-motion sensors allows the bandwidth for observation of near-source motions to be extended to periods longer than that of conventional accelerometers and permits the inference of seismic wave field characteristics not permitted by either sensor alone.

INTRODUCTION

Scientific evidence suggests an occurrence probability of 0.95 for a moderate earthquake (M~6) before 1993 along the Parkfield segment of the San Andreas fault (Refs. 1, 2, 3). This event has afforded the scientific and engineering communities the opportunity to establish experiments to study earthquake related phenomena (Ref. 4). This report is concerned with an experiment designed to obtain high-fidelity measurements near the rupture zone.

The experiment includes an array of fourteen stations equipped with accelerometers, velocity transducers, and volumetric strain sensors (Fig. 1). Eight stations are equipped with accelerometers and velocity transducers (see Fig. 1) to provide on-scale recordings of ground motions ranging in amplitude from near seismic background noise to 2g in acceleration. Six sites are equipped with volumetric strain sensors and accelerometers to provide on-scale recordings for events larger than magnitude 2.5.

The use of dilatational strain sensors (Sacks-Evertson dilatometers, Ref. 5) extends the bandwidth for observation of near-source motions to periods longer than those detectable by conventional accelerometers. The bandwidth allows observation of pre- and post-seismic strain changes and co-seismic strain offsets. Dynamic range of the dilatometers allows the sensors to be used as both near-source strong-motion sensors as well as sensors to detect strain variations including changes in DC level at levels of seismic background noise near 10^{-11}. In addition, because the dilatometers respond to dilatational strain but not shear strain, they respond to P and Rayleigh energy but not shear or Love wave energy. As a result when dilatometers are colocated with conventional three-component seismometers and accelerometers, they can be used to resolve superimposed wavefields and infer characteristics of seismic wavefields not permitted by either sensor alone (Refs. 6, 7).

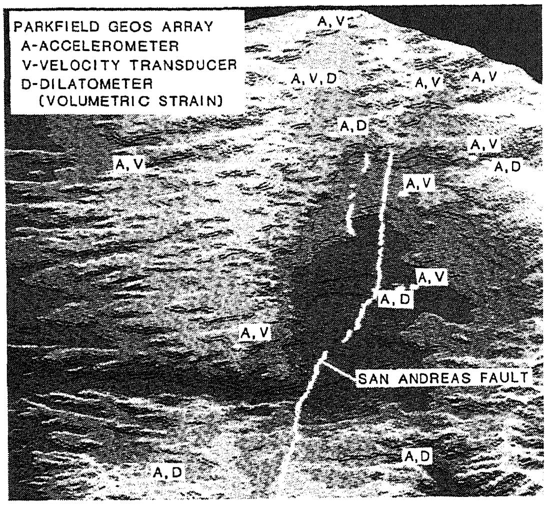

Fig. 1. Location map for GEOS array near Parkfield, California.

This report describes instrumentation, expected data sets, and theoretical results pertinent to interpretation of seismic radiation fields recorded on colocated sensors.

INSTRUMENTATION

Signals from the two types of sensors at each station location are recorded on-site in event-detect mode with broad-band, 16-bit (96dB) digital, six-channel recorders (General Earthquake Observation System, GEOS, Ref. 9) at sampling rates of 200 sps per channel. A detailed account of the recording system characteristics is provided by Borcherdt *et al.* (Ref. 9). Signals from the dilatometers at six of the sites are recorded in both AC and DC coupled modes at high and low gain levels. In addition, the dilatometer signals are recorded continuously in Menlo Park, California via 16 bit satellite telemetry at a low sampling rate (1 sample per 10 minutes) for purposes of earthquake prediction (Ref. 8).

For those sites equipped with accelerometers, velocity transducers, and GEOS recorders, the effective dynamic range exceeds 130 dB over a bandwidth for signal resolution of about 15 to 0.01 seconds. For those sites equipped with accelerometers and dilatometers, the lower limit for resolution of acceleration is 6×10^{-6}g. The period band for detection of volumetric strain at earth-strain noise levels is greater than 10^{8} to 0.05 secs. (Ref. 8).

An average estimate of earth strain noise is shown in Fig. 2. The spectrum, obtained for a site in the eastern Mojave desert, California, reveals peaks due to microseisms near 4 and 8 seconds, peaks due to earth tides near 12 and 24 hours, and a decrease in noise with period of about 10 dB per decade. The spectrum shows a detection bandwidth of more than 8 orders of magnitude at earth noise levels. Maximum strain detection limits of 10^{-6} strain for the dilatometers located at depths of 150-200 m suggests a dynamic range for strain detection of 145-150 dB.

In the time interval 7/87 through 12/87, 36 of the earthquakes in the Parkfield region had been recorded on one or more stations in the array (Ref. 10). These events ranged in magnitude from less than 1 to 2.5. As no event larger than 2.5 for which the array was designed has occurred since completion of the array, examples of data sets from similar installations in other locations of California are used for illustration purposes.

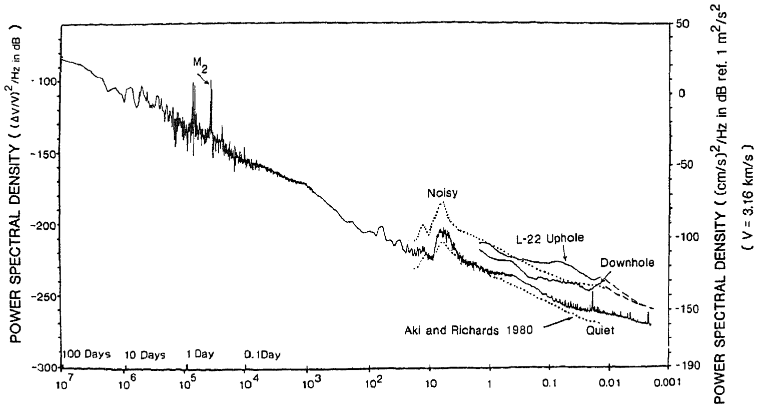

Fig. 2. Earth strain noise observed with dilatometer and seismometers illustrates array detection levels for periods ranging over more than 8 orders of magnitude.

ANTICIPATED NEAR-SOURCE MEASUREMENTS

Recordings of a moderate earthquake near North Palm Springs, California, obtained at a distance of 130 km illustrate the types of signals expected on the array (Fig. 3). The first trace shows the continuous volumetric strain time history as recorded at 1 sample per 10 minutes for a 48-hour time interval. This trace shows strain variations due to earth tides, atmospheric pressure changes, and the strain offset of 17 nanostrain associated with the earthquake. This offset, when interpreted with respect to a dislocation model, yields an estimate of moment magnitude for the event of 6.0 (Ref. 11).

Traces 2 through 5 of Fig. 3 show the corresponding volumetric strain and three-component seismometer signals recorded at the site at 200 samples per second in the intervening ten minute time interval between samples recorded continuously *via* satellite telemetry (see trace 1, Fig. 3). The traces recorded at high sampling rates illustrate the capability of the array to observe seismic radiation fields from both types of sensors in an overlapping period band of engineering interest, while at the same time suggesting the capability to observe characteristics of the seismic radiation field at periods longer than those permitted by conventional accelerometers. Analysis of the colocated signals has been shown by Borcherdt *et al.* (Ref. 10) to yield estimates at the site of local material velocity (2.9 km/s), attenuation ($Q_{MS}^{-1} \approx 0.1$), and the vertical free surface reflection coefficient for SP (0.8).

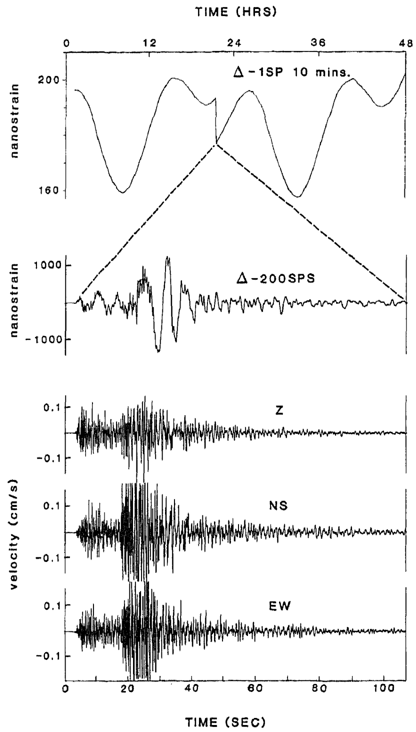

Fig. 3. Volumetric strain (Δ) and ground velocity for North Palm Springs earthquake (M6.0) shows tidal variations and co-seismic strain offset observed at 10 minute intervals (trace 1), seismic strain radiation at 200 sps (trace 2), and absence of long period energy detected by 1 Hz seismometers (traces 4, 5, 6).

Recordings of small events (M<2.0) near the source (<8 km) serve to illustrate the capability of the volumetric strain meter to respond to dilatational energy but not shear energy (Fig. 4). For comparison purposes, the volumetric strain signal (bold) recorded for this event is superimposed on that of the vertical seismometer. The traces have been filtered in a pass band (2 to 6 Hz) common to the two sensor types. Comparison of the straingram and vertical seismogram shows a small phase shift due to vertical spatial separation of the sensors and considerable similarity in wave form during arrival of the initial P-wave energy. Comparison of the signals during the arrival of the S energy, evident on the radial and transverse components of the horizontal seismometers, suggests the dilatometer is showing a relatively small response to the incident S energy.

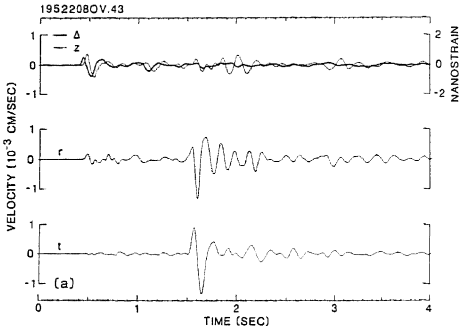

Fig. 4. Volumetric strain (Δ) and ground velocity (z, r t) recorded near (<8km) small earthquake (M<2.0) suggests that dilatometer responds to P energy but not incident S energy.

Theoretical descriptions of the response of a volumetric strain meter to incident P-, S-, and Rayleigh-type waves on a viscoelastic half-space are provided by Borcherdt (Ref. 7). They show that the effect of the free surface must be considered in order to account for the response of a dilatometer to incident S energy. The free surface, volumetric-strain reflection coefficient for a homogeneous S wave incident on the free surface of a viscoelastic half-space is shown (Fig. 5) for Pierre Shale (Ref. 8). The computed reflection coefficient suggests that the response of the volumetric strain sensor near the time of incident S energy vanishes for angles of incidence near vertical and 45 degrees and reaches a maximum for angles (28°) beyond the elastic critical angle (22°). For angles of incidence corresponding to maximum response, velocity Q^{-1} and particle motion ellipticity for the reflected dilatational disturbance are 25 percent less, 300 percent greater, and 60 percent greater respectively than those for corresponding homogeneous P wave (Figs. 5b-5d).

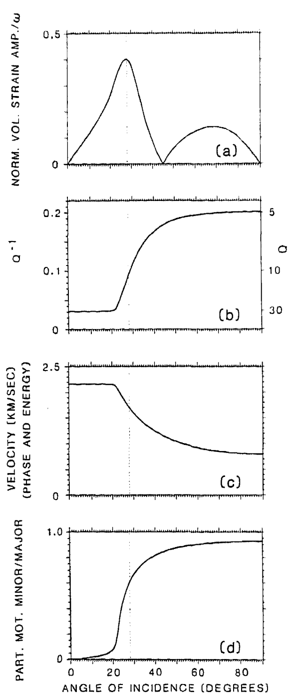

Fig. 5. Volumetric strain reflection coefficient (a) for S wave incident on free surface and Q^{-1} (b) velocity (c), and particle motion axis ratio (d) for reflected P wave.

Although no near-source recordings of a moderate earthquake have yet been obtained on a comparable array using colocated volumetric strain meters and accelerometers, the records from the 1966 Parkfield array with maximum acceleration near 0.5 g serve as a basis to determine gain settings for the corresponding sensors. Guidance regarding estimates of maximum strain levels as observed in boreholes located in sandstone and granite at depths of sensor emplacement (~150-200 m) is provided by model estimates (Fig. 6, Ref. 12). Estimates of coseismic strain offset at each of the stations is not expected to exceed 10^{-6} (Fig. 6). The estimates suggest that the maximum offsets are likely to be measured for sites near rupture initiation and termination.

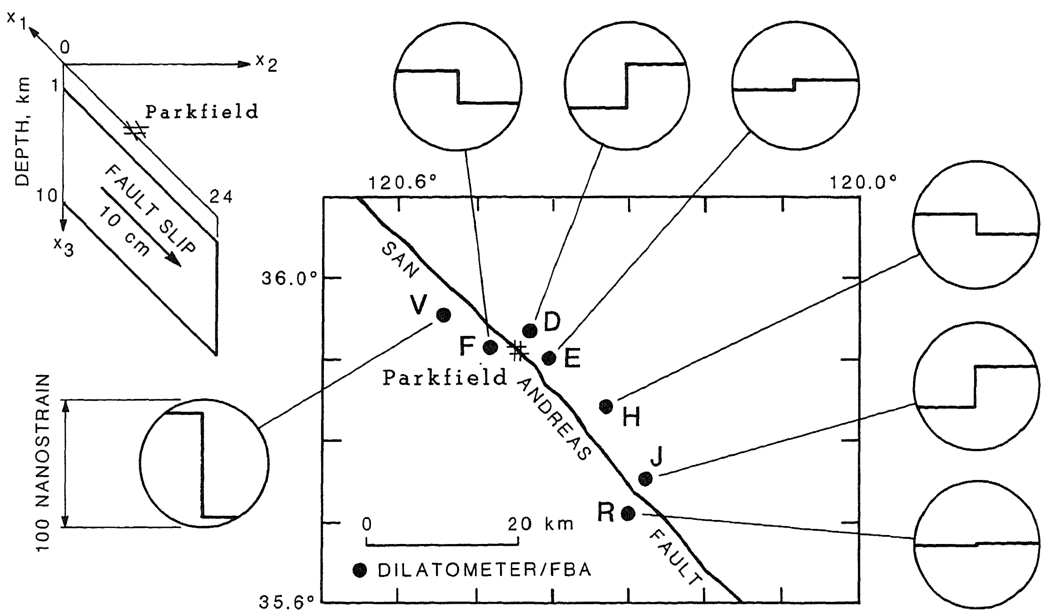

Fig. 6. Estimates of co-seismic dilatational strain offset, using the indicated dislocation model for the anticipated Parkfield earthquake.

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