EARTHQUAKE ENGINEERING ASPECTS OF STRONG MOTION DATA FROM RECENT CALIFORNIA EARTHQUAKES

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Abstract

Six magnitude 6 and greater earthquakes, with important earthquake engineering results, occurred in California in 1992. The Cape Mendocino earthquake sequence in northern California includes a magnitude 7.0 mainshock and aftershocks with magnitudes of 6.2 and 6.3. The Landers sequence in southern California includes the Joshua Tree, Landers and Big Bear earthquakes of magnitude 6.1, 7.4 and 6.4, respectively. We present three significant results obtained from the California Strong Motion Instrumentation Program (CSMIP) data for these earthquakes. First, the strong motion record from the Cape Mendocino station has one of the highest accelerations ever recorded, near 2 g. Second, recordings from the Cape Mendocino and Landers mainshocks have more long period energy in the ground motion than seen in previous strong motion recordings. Third, the Landers earthquake records are of long duration compared to most records that have been obtained in California. The duration of strong shaking for Landers was 2-3 times longer than for the magnitude 7 Loma Prieta earthquake.

Important data for geotechnical engineering was recorded at the new NSF/CSMIP Treasure Island Geotechnical Array near San Francisco from a magnitude 5.3 earthquake 120 km away. In this site-response array accelerometers are installed in 5 boreholes and at the surface. The borehole accelerometers are located below the bedrock surface and at 4 intermediate locations in the soil profile. Peak accelerations ranged from 0.0032 g in the bedrock to 0.0143 g at the surface with an amplification of peak acceleration of greater than 4. Spectral amplification of the horizontal bedrock motion at the surface is greater than 10 near 0.8 Hz (1.2 second).

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CSMIP Strong Motion Data and Earthquake Engineering Results

This paper highlights three important earthquake engineering results from the extensive Cape Mendocino and Landers strong-motion data sets. These results include high recorded peak accelerations, significant response spectra content at long and short periods, and significantly longer duration of strong shaking than most recent California earthquakes. In addition, site-response results from the recently installed NSF/CSMIP Treasure Island Geotechnical Array (de Alba and others, 1993) are presented. Additional aspects of the earthquake sequences and the strong-motion data from these events are discussed in CSMIP (1992a); Darragh and others (1993a); Huang and others (1992); Shakal and others (1992a); and Shakal and others (1992b).

Cape Mendocino Sequence

Strong-motion records were recovered from 14 CSMIP stations after the Cape Mendocino earthquakes of April 25-26, 1992 which included a moment magnitude 7 mainshock and two large aftershocks (Shakal and others, 1992a). These 14 stations include 10 ground-response stations and 4 extensively-instrumented structures. The records recovered from the mainshock have some of the highest accelerations ever recorded. Peak accelerations near 2 g were recorded at the Cape Mendocino station, approximately 4 km southwest of the epicenter, on hard sandstone. Figure 1 shows the acceleration, velocity and displacement waveforms in the north-south direction (Darragh and others, 1992). The usable data bandwidth for this corrected data is from 0.064 to 23.6 Hz (0.04 to 15 seconds period). A peak velocity of 126 cm/sec and a peak displacement near 70 cm (on the vertical component) are calculated. The duration of strong shaking was about 7 seconds at this station. Significant long-period energy was recorded at this site as shown by these waveforms. Figure 2 shows the response spectrum calculated from the Cape Mendocino record compared to the spectra calculated from the Taft (1952 Kern County earthquake) and El Centro (1940 Imperial Valley earthquake) records. The Cape Mendocino spectrum is larger than the other spectra for all periods shown.

Landers Sequence

Strong-motion records were recovered from a total of 144 CSMIP stations after the magnitude 7.4 Landers earthquake of June 28, 1992 (Shakal and others, 1992b). These 144 stations include 88 ground-response stations and 56 extensively-instrumented structures. The closest CSMIP station, located 14 km southeast of the epicenter at Joshua Tree, recorded a peak acceleration of 0.28 g. The peak values of velocity and displacement at this station are 43 cm/sec and 16 cm (CSMIP, 1992b). A station at Yermo, 84 km north of the epicenter, recorded a peak acceleration of 0.25 g and the largest peak velocity and displacement calculated at CSMIP stations. The peak velocity is 50 cm/sec and the peak displacement is larger than 40 cm (15 inches). Many of the response spectra calculated from Landers earthquake recordings are comparable to the Taft (1952 Kern County earthquake) and El Centro (1940 Imperial Valley earthquake) spectra, especially at long periods (Darragh and others, 1993a).

In addition to these stations, a peak acceleration of 0.88 g was recorded during the Landers earthquake at a Southern California Edison (SCE) station at Lucerne located 2 km from the fault. The six other SCE stations that recorded this earthquake were located between 31 and 152 km from the fault (Hawkins and others, 1993).

The most significant aspect of the records from the Landers earthquake is their long duration, compared to most recent records obtained in California. For example, Figure 3 compares records from 4 California earthquakes (Landers, Loma Prieta, Big Bear and Whittier) recorded at similar distances of 10 to 20 km with magnitude ranging from 6 to 7.4. The record from the Landers earthquake has duration of strong shaking of about 30 seconds. This duration is 2 to 4 times longer than the duration of the other records including those from the magnitude 7 Loma Prieta earthquake.

Another significant earthquake engineering aspect of the Landers earthquake is that several CSMIP stations located in the Los Angeles basin, at an epicentral distance of approximately 165 km (102 mi), have large peak displacements near 20 cm (8 inches). The peak accelerations at these stations are quite small (7% g or less), however. Large displacements despite low levels of ground acceleration may have contributed to the damage sustained by structures in the basin.

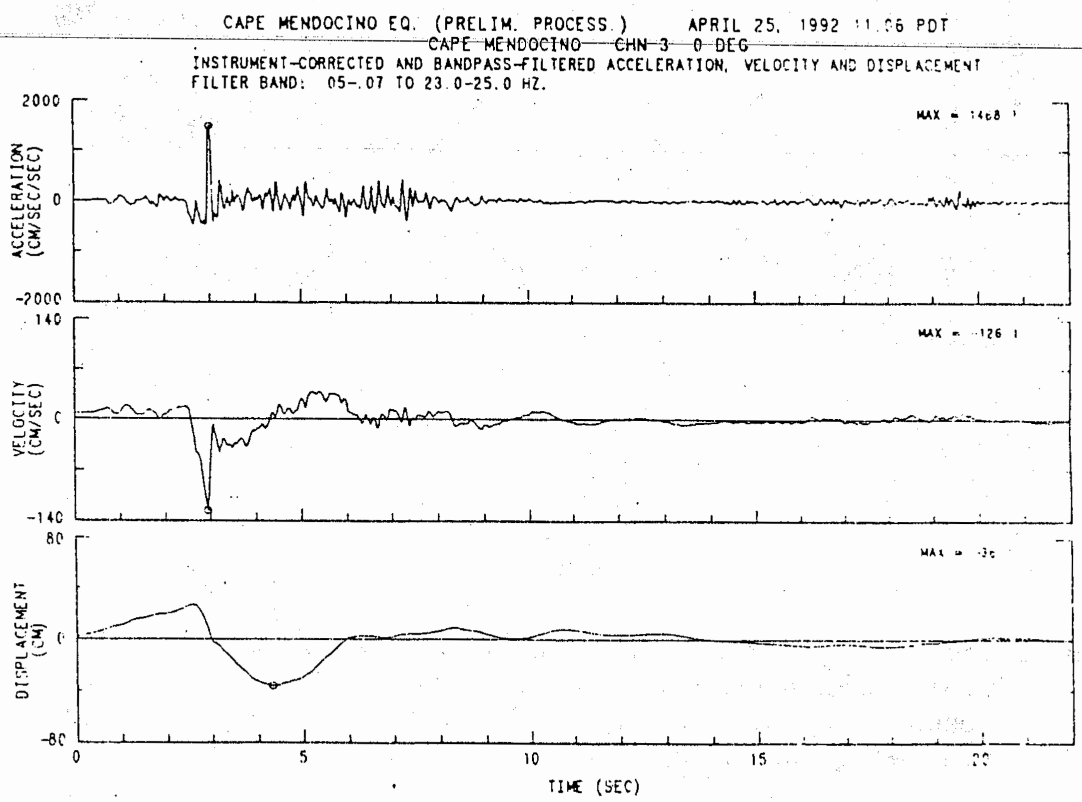

Figure 1. Acceleration, velocity and displacement time-histories (instrument-corrected and band-pass filtered) for the north-south component at the Cape Mendocino station (figure from Darragh and others, 1993a).

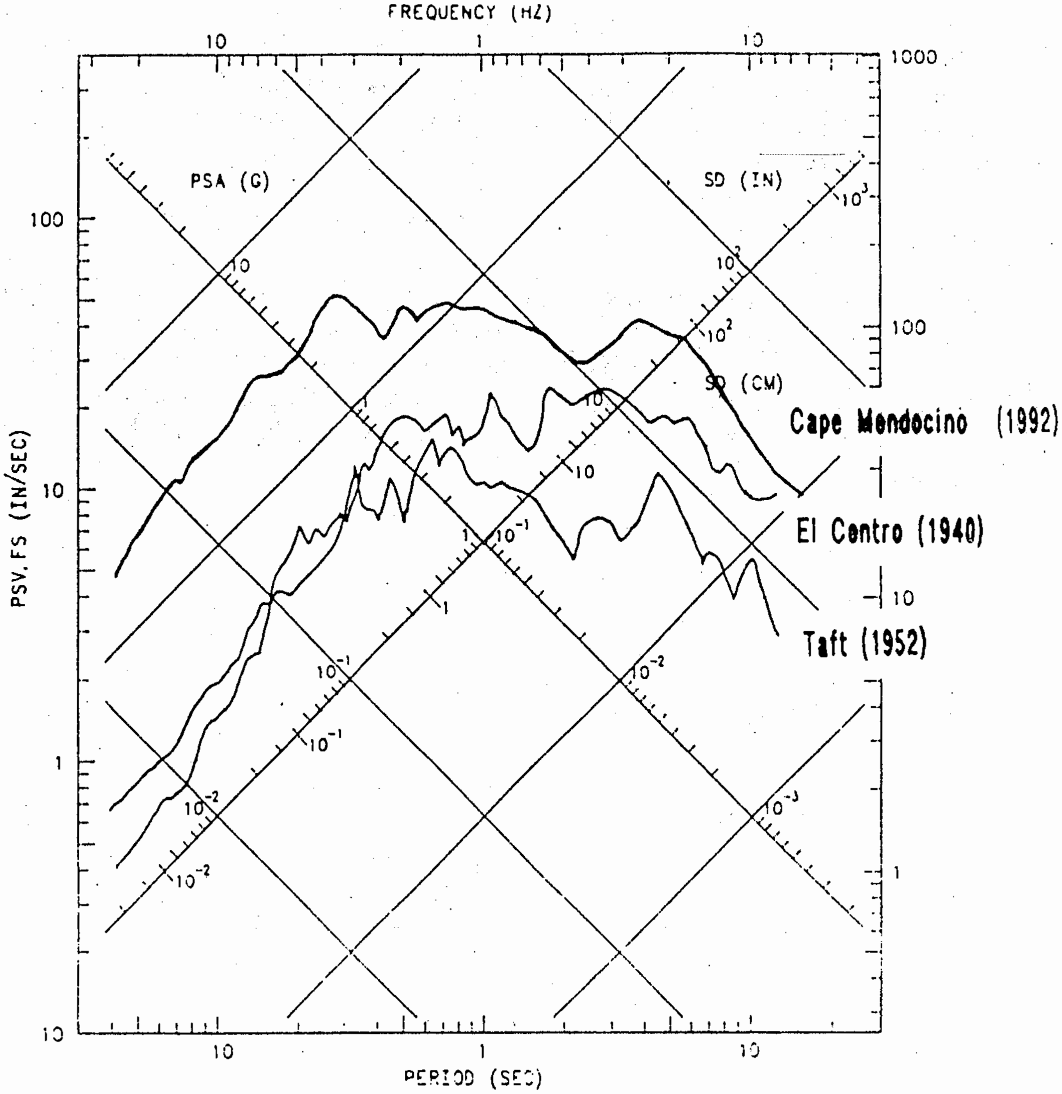

Figure 2. The 5% damped response spectra from the Cape Mendocino station (1992 Cape Mendocino mainshock), and for comparison, from Taft (1952 Kern County earthquake) and El Centro (1940 Imperial Valley earthquake) (figure from Darragh and others, 1993a).

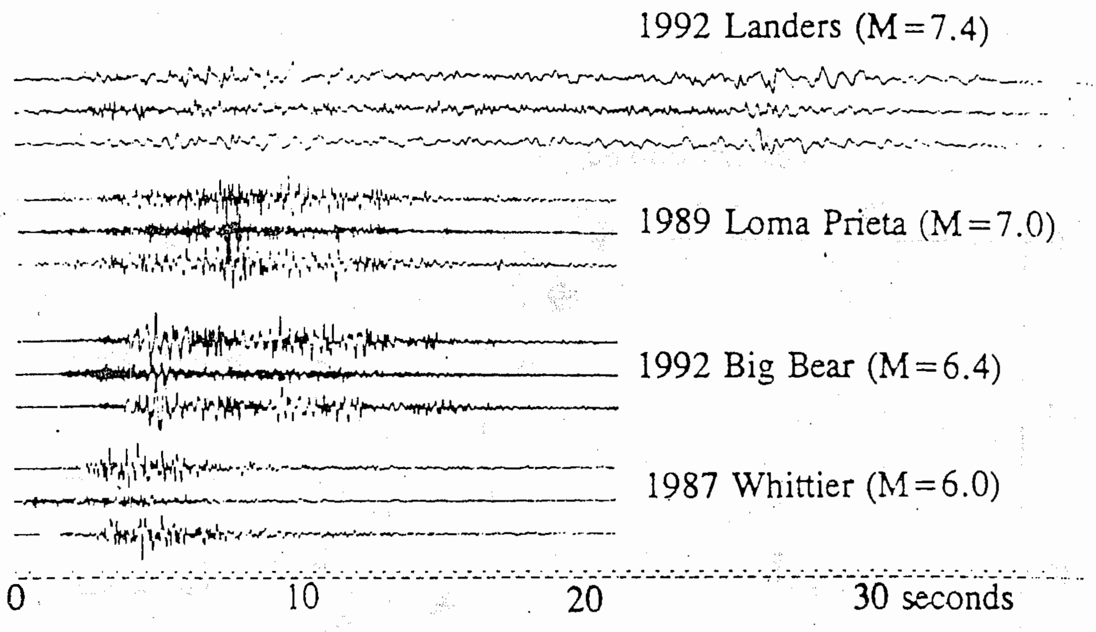

Figure 3. Accelerograms recorded for 4 different magnitude earthquakes at stations with similar distances (10 - 20 km). The waveforms demonstrate the long duration of the Landers earthquake (figure from Darragh and others, 1993a).

Treasure Island Geotechnical Array

The Treasure Island Geotechnical Array is a newly installed joint project of CSMIP and NSF (de Alba and others, 1993). The array includes triaxial accelerometers that have been installed at the surface and in boreholes. The borehole accelerometers are at depths of 7, 16, 33 and 44 m in the soil column, and below the bedrock interface at 104 m. The accelerometers are secured in the borehole using the CSMIP orientation and locking system (Shakal and Petersen, 1992).

Figure 4 shows the location of the instrumentation in the soil profile beneath the array, along with the shear-wave velocity and lithology (after Gibbs and others, 1992). Beneath the array there is approximately 12 m of hydraulic fill and sand overlying about 15 m of medium-stiff Holocene Bay Mud (soft silt and clay sediments) over dense sand and stiff Pleistocene Bay Mud. Franciscan sandstone and shale is encountered at 91 m beneath the site. Site characterization studies at Treasure Island are described in detail by Gibbs and others (1992), de Alba and others (1993), and EPRI (1993).

One of the goals of the installation of the Treasure Island Geotechnical Array is to explain the amplification of rock motion by soil deposits during the magnitude 7 Loma Prieta earthquake. For example, Darragh and Shakal (1991) found that at Treasure Island the site amplification near 1 Hz ranged from 4 for the Loma Prieta mainshock to

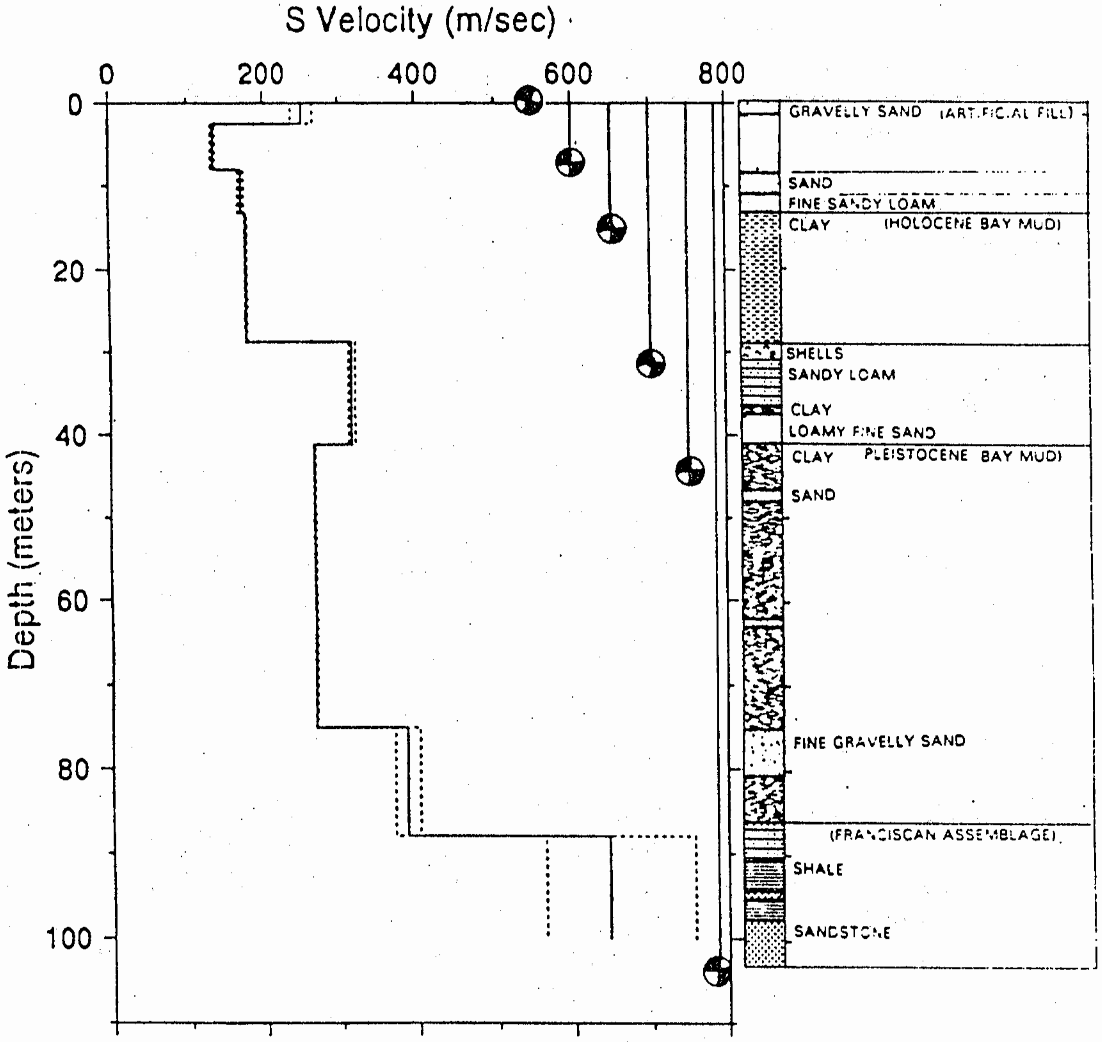

Figure 4. The NSF/CSMIP Treasure Island Geotechnical Array acceleration instrumentation. Acceleration is recorded at the surface and at depths of 7, 16, 31, 44 and 104 m (denoted by the circular symbol). The USGS shear-wave velocity and lithology log from Gibbs and others (1992) are shown (figure modified from Gibbs and others, 1992).

near 20 for several aftershocks. In that study, the surface motions recorded at Treasure Island (soft-soil) and Yerba Buena Island (rock) were compared.

The first significant ground motion recorded by the array was from the January 16, 1993 M_L 5.3 earthquake located near Gilroy. The epicenter is located approximately 120 km south-east of the array. The results of standard CSMIP processing of the array data are presented in Darragh and others (1993b). Figure 5 compares the instrument-corrected and band-pass filtered acceleration data recorded from this earthquake. The usable data bandwidth is from 0.5 to 23.6 Hz (0.04 to 2 seconds period). In the north-south direction the peak acceleration ranged from 0.0143 g at the surface to 0.0032 g at 104 m depth in bedrock. An amplification ratio of peak acceleration of greater than 4 is obtained for the horizontal components. In contrast, on the vertical component the peak acceleration ranged from 0.0044 g at the surface to 0.0021 g in bedrock with an amplification ratio of peak vertical acceleration of about 2. In addition, the acceleration waveforms recorded at the surface and in the soil profile have significantly longer duration of shaking than the bedrock record.

Instrumented-corrected and band-pass filtered peak velocity and displacement for all records are less than 1 cm/sec and 0.1 cm, respectively. The amplification ratio for peak velocity and displacement from the bedrock to the surface is again greater than 4 for the horizontal components. For example, in the north-south direction peak velocity ranges from 0.15 in bedrock to 0.86 cm/sec at the surface. In contrast, the amplification ratio of peak vertical velocity and displacement is less than 2 for the soil profile. Similar to acceleration, the duration of the displacement and velocity waveforms recorded at the surface and in the soil profile is significantly longer than recorded in the bedrock.

Figure 6 shows the 5% damped response spectra computed from the 6 north-south records. The spectra computed from the surface and the soft-soil profile recordings are larger than the bedrock spectrum at all periods. The spectra generally decrease in amplitude with increasing depth. Spectral amplification in the north-south direction is greater than 10 near 0.8 Hz (1.2 second). The east-west spectra show similar trends. However, spectral amplification of the bedrock motion on the vertical component is generally 2 or less for the periods shown.

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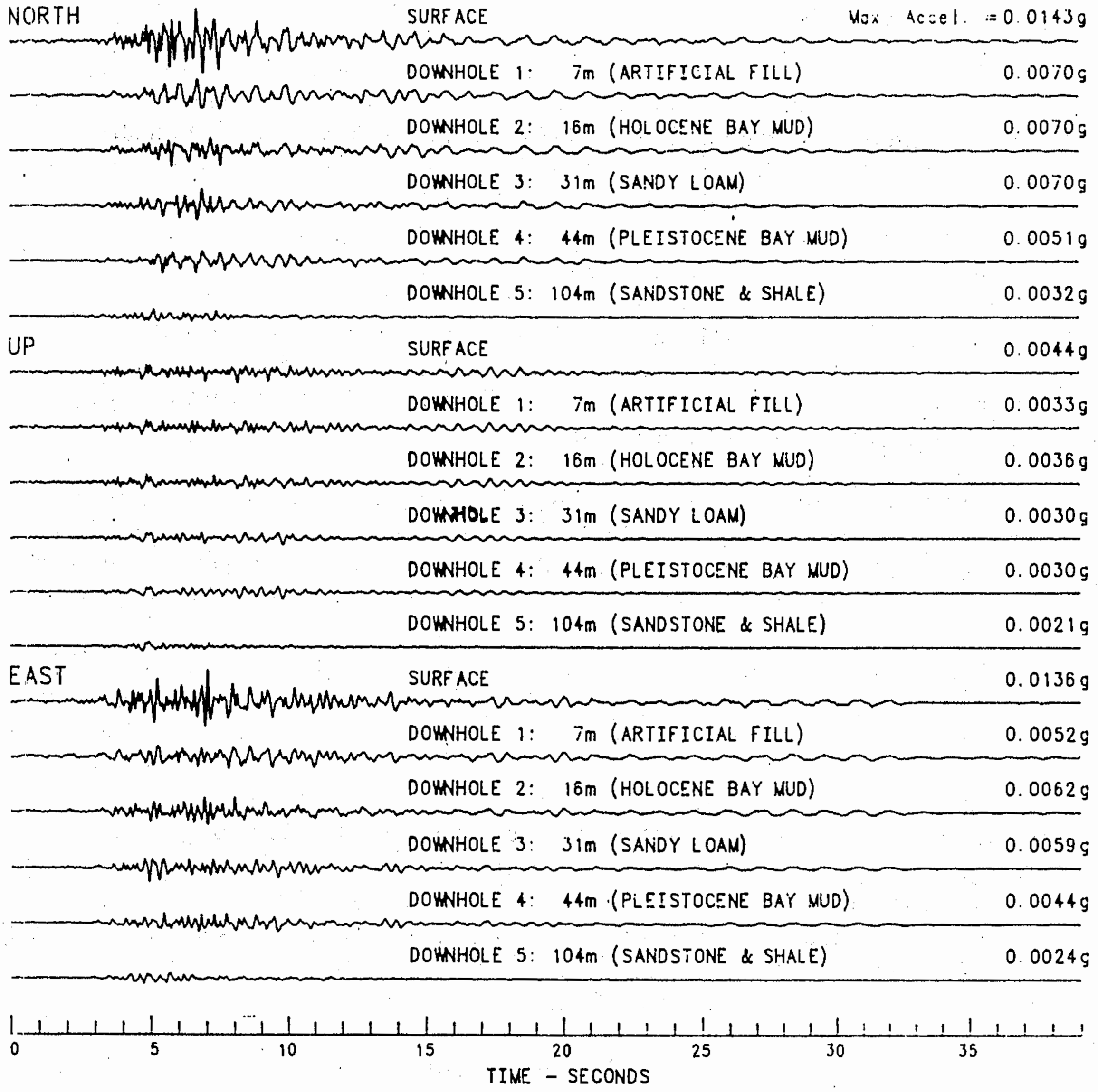

Figure 5. Acceleration time histories (instrument-corrected and band-pass filtered) at depths of 0, 7, 16, 31, 44 and 104 m from NSF/CSMIP Treasure Island Geotechnical Array for the January 16, 1993 earthquake are compared. The 18 accelerograms are arranged by orientation (North-south, Up-down and East-west) and by increasing depth. For each accelerogram the depth, site geology, peak acceleration and borehole number are also shown.

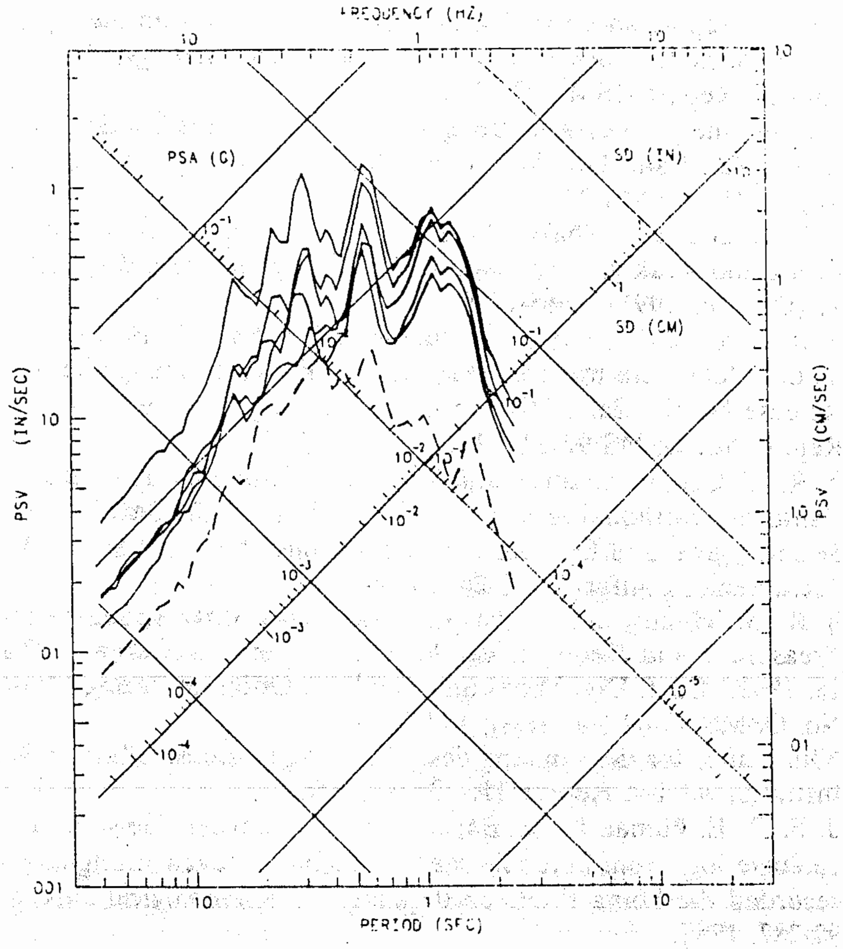

Figure 6. The 5% damped response spectrum computed for the north-south recordings from the January 16, 1993 earthquake are compared. The dashed curve is the bedrock spectrum computed from the recording at 104 m. The 5 solid curves are the spectrum computed from the recordings at the surface and at 4 depths in the soil profile. Note that the PSV scale is from 0.001 to 4 in/sec.

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