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PRINCIPAL FEATURES OF THE STRONG-MOTION DATA FROM THE 1984 MORGAN HILL EARTHQUAKE

by

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ABSTRACT

A strong directional dependence that can be correlated with the geometry of the earthquake fault rupture is exhibited by the strong motion data from the Morgan Hill earthquake. Higher accelerations were recorded at stations to the southeast of the earthquake than to the northwest. One of the southeast stations, Coyote Lake Dam, recorded a peak horizontal acceleration of 1.3 g. This acceleration exceeds that of the Pacoima Dam record from the 1971 San Fernando earthquake, the previous largest horizontal acceleration recorded. However, the peak velocity and displacement, as well as the duration, of the Coyote Dam record are less than those of the Pacoima Dam record. The records from the Gilroy strong motion array, also to the southeast of the earthquake, exhibit unusual high vertical accelerations. They also show alluvial amplification effects similar to those observed in corresponding records from the 1979 Coyote Lake earthquake. In addition to the ground motion data, many recordings of structural response to the ground shaking were obtained during this earthquake. These records provide unprecedented data for analysis of the rocking and torsional motion of structures as well as structural amplification.

INTRODUCTION

The Morgan Hill earthquake was a moderate (6.2 M_L BRK) strike-slip earthquake which occurred on the Calaveras fault southeast of San Jose on April 24, 1984. It triggered the largest number of strong motion instruments since the San Fernando earthquake of 1971. Accelerograms were recovered from a total of nearly 70 stations, including 48 of the California Strong Motion Instrumentation Program (CSMIP) of the Division of Mines and Geology and 19 of the Seismic Engineering Branch of the U.S. Gelogical Survey (USGS). The CSMIP stations which recorded the Morgan Hill earthquake are indicated in Figure 1 (from Shakal et al., 1984). These stations are complemented by those maintained by the USGS and discussed by Brady et al. (1984), the closest of which is the station at Anderson Lake Dam. The greatest damage, and possibly the highest acceleration, occurred in an area near the southern end of Anderson Lake, where no accelerograph stations were located. Temporary accelerographs were installed in that area by both the CSMIP and USGS following the mainshock. Unlike the Coalinga earthquake of May 1983, the Morgan Hill event was followed by

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very few aftershocks over magnitude 4.0, and as a result few accelerograms were obtained from aftershocks.

DIRECTIONAL DEPENDENCE

The Morgan Hill earthquake was recorded by a relatively complete azimuthal distribution of accelerograph stations, as indicated in Figure 1. When the peak acceleration data are considered as a function of distance, a significant difference becomes apparent between the acceleration data from stations to the southeast of the earthquake as compared with data from stations to the northwest. Figure 2 shows the peak acceleration data plotted against the distance of the stations from a point on the fault at the approximate center of the aftershock zone. The data plotted in Figure 2 include the peak acceleration data listed in Table 3 of Shakal et al. (1984) and in Table 1 of Brady et al. (1984). Figure 2 shows that for stations at the same distance, peak accelerations from the southeastern stations are higher than for the northwestern stations.

The earthquake origin has been estimated (Cockerham et al., this volume) to be located at 37.317N, 121.680W, about 4 km southeast of the Halls Valley accelerograph station. The timing on the records from the near-in accelerographs indicates that the rupture propagated from the origin toward the southeast, toward Morgan Hill and Coyote Lake (Bakun et al., 1984). The southern stations in Figure 2 are thus in the direction of rupture propagation, and the northern stations are opposite the direction of rupture propagation. Earthquake source theory indicates that a propagating rupture would cause a directivity in the close-in radiated energy, with increased amplitudes occurring at points ahead of the rupture. Studies of this effect, called directivity focusing, have been mostly limited to analytical modelling (e.g., Boore and Joyner, 1978) because of the paucity of empirical observations. The Morgan Hill data represent the first strong-motion data set in which this effect may be clearly observed, possibly because of the relatively complete azimuthal distribution of accelerograph stations. If directivity did in fact contribute to high accelerations which occurred in this event, then the question of whether similar high accelerations may be expectable from future strike-slip earthquakes is pertinent.The high acceleration record from the Coyote Lake Dam station, in particular, warrants careful analysis.

COYOTE LAKE DAM ACCELEROGRAM

The accelerogram recorded at the Coyote Lake Dam accelerograph station, shown in Figure 3, had a horizontal peak acceleration value of 1.3 g; the previous highest horizontal acceleration was recorded during the 1971 San Fernando earthquake at the Pacoima Dam accelerograph station (1.25 g). It is important to place the Coyote Lake Dam record in perspective relative to that record as well as consider the possibility of any anomalous aspects of the instrument or the site conditions.

Verification Investigations

The Coyote Lake Dam accelerograph station is located near the left (northwest) abutment of the Coyote Lake Dam, an earthen dam at the northern end of the lake. The station itself is sited near a rock promontory against which the dam embankment is located. The accelerograph site and a topographic map of the surrounding area are shown in Fig. 4. Photographs taken during construction of the dam in 1935 (R. Tepel, personal communication, 1984) indicate that the promontory is the exposed top of a rock mass that extends downward to at least the bottom of the excavation for the dam (approximately 40 m, or 120 ft). The accelerograph station was installed at its present location in 1975.

As the initial step in an investigation of the recording conditions, the recording accelerograph was removed from the station for laboratory testing shortly after the earthquake. The instrument is an SMA-1 (Kinemetrics) strong-motion accelerograph, manufactured in 1976. Static (tilt) tests of the instrument sensitivity and standard calibrations of natural frequency and damping indicated normal instrument behavior. Comparison tests of the dynamic response were performed by attaching the Coyote instrument and others to a common platform and comparing the records obtained when the platform was (manually) shaken; no significant differences were observed.

The most definitive way to determine whether anomalous accelerograms are caused by local site effects is to obtain comparison records from a nearby site. Toward this end, a temporary station was installed approximately 300 m from the existing station shortly after the earthquake; unfortunately there have been no aftershocks of sufficient size to trigger either instrument. It is worth noting, however, that an accelerogram was recorded at the Coyote Dam permanent station during the 1979 Coyote Lake earthquake by the same instrument, at the same orientation, as the 1984 record. That record (shown in Fig. 5) has a peak acceleration of 0.25 g and no anomalous characteristics of the record have been proposed.

Field investigations of the geologic conditions at the site, including determinations of near-surface velocities, are described by Sherburne et al. (this volume). Some surficial cracking in the vicinity of the recording station are also described in that study. The character and orientation of these cracks are consistent with settling of the dam infill. The vertical settlement of the dam crest measured after the earthquake (a maximum of 6 cm at the center; Tepel et al., this volume) is also consistent with settlement of the dam infill during the strong shaking.

To summarize the results of investigations of recording conditions made to date, no obvious cause has been found to explain anomalous high accelerations at the site. It should be noted however, that the rock promontory near the station is a large, weathered unit, with several old faults and joints. It is possible that these could become surfaces of motion during strong shaking; motion on these surfaces could concievably lead to short-duration, high acceleration pulses.

Comparison with 1971 Pacoima Dam Accelerogram

Peak acceleration is only one parameter characterizing a strong motion record. The velocity and displacement records computed from the 1984 Coyote Lake Dam record and the 1971 Pacoima Dam record are compared in Figure 6. The comparison is between the components with the highest acceleration and velocity for each accelerogram. Peak-value comparisons (acceleration, velocity and displacement) for all three components are given in Table 1. These time-history comparisons indicate that although the 1984 record has a higher peak acceleration, the 1971 Pacoima Dam record has a greater peak velocity and significantly greater displacement. In addition, the duration of shaking in the 1984 record is significantly shorter than that of the 1971 record (approximately half that of the 1971 record, if a 0.10 g threshold is used, as indicated in Table 1).

TABLE 1

COMPARISON OF THE 1984 COYOTE DAM ACCELEROGRAM
AND THE 1971 PACOIMA DAM ACCELEROGRAM

	Maximum Acceleration (g)	Maximum Velocity (cm/sec)	Maximum Displacement (cm)	Duration (secs > 0.10g)
1984 Coyote Dam Accelerogram				
Horizontal #1 (285 deg.)	1.30	80.	10.	6.4
Horizontal #2 (195 deg.)	0.71	52.	10.	4.6
Vertical	0.40	15.	3.	5.0
1971 Pacoima Dam Accelerogram				
Horizontal #1 (S16E)	1.24	113.	38.	11.0
Horizontal #2 (S74W)	1.25	58.	11.	11.1
Vertical	0.72	58.	19.	9.6

* Note: Peak accelerations are the Volume 1 values (e.g., Hudson, 1976).

The response spectra for the two records are compared in Fig. 7 for all three components. It is particularly interesting to compare the response spectra for the first horizontal component, corresponding to the records shown in Fig. 6. The response spectra for these two components are quite similar for frequencies above about 1.0 hz (i.e., for short periods, 1.0 second and less).

However, at longer periods, over 1.0 second, the 1984 Coyote Lake Dam spectrum is significantly lower than the Pacoima spectrum (approximately a factor of three difference at 4.0 second period). The smaller spectrum at long periods is reflected in the smaller displacements in the Coyote Dam time history (Fig. 6).

The response spectra for the second horizontal components are more similar at the longer periods, and this is reflected in the more similar values of peak velocity and peak displacement (Table 1). The vertical component spectra, as well as the time-history values in Table 1, indicate that the vertical motion was significantly stronger in the 1971 Pacoima record, regardless of how the motion is parameterized.

STRONG MOTION DATA FROM THE GILROY ARRAY

An alignment of strong-motion accelerographs was installed across the Santa Clara Valley near Gilroy in the mid 1970s. The array extends from high-velocity Franciscan materials at the western edge of the valley, across the alluvial valley floor, and onto high velocity materials on the eastern edge of the valley. This array is a cooperative effort of the California Strong Motion Instrumentation Program (CSMIP) and the USGS Seismic Engineering Branch, and is currently instrumented and maintained by CSMIP. Prior to the Morgan Hill event, the array recorded the 5.9 M_L Coyote Lake earthquake of August 6, 1979 (Porcella et al., 1979) so the array has provided two suites of records in only the ten years since it was installed.

The Gilroy array records from the Morgan Hill earthquake show horizontal accelerations of 0.20 - 0.40 g in the central part of the alluvial valley, with reduced amplitudes at the margins of the valley. Peak accelerations, horizontal and vertical, are listed in Table 2 for the Gilroy array stations for both the 1984 and 1979 earthquakes. It is particularly interesting to compare the records from the two stations on the west edge of the valley which were considered by Joyner et al. (1981) in an analysis of data from the 1979 earthquake. In that event, the horizontal amplitudes at Station #2, on the valley floor, were approximately twice those at Station #1, on Franciscan. That ratio is explained by Joyner et al. (1981) as being due to the conservation of energy in the wavefront (dependent on the S-wave impedances of the soil and rock). As indicated in Figure 8, the 1984 records show nearly the same ratio (2.2) of the horizontal amplitudes. (For both earthquakes, the distance between stations (2 km) is small compared to the distance to the source - approximately 20 km in 1984, 10 km in 1979).

The vertical amplitudes are unusually high in the Gilroy array accelerograms from the Morgan Hill earthquake. The peak vertical acceleration is generally observed to be one-third to two-thirds of the peak horizontal in strong motion records (e.g., Housner, 1970). In contrast, in the 1984 Gilroy array records the vertical peak acceleration is as large or larger than the horizontal; in the Station #2 record the vertical peak is nearly three times the horizontal. The high amplitude vertical phase in the Station #2 record (see Fig. 8) is similar to that on the other Gilroy array records: a high-frequency, high-amplitude phase arriving 1-2 seconds after triggering and several seconds before the high amplitude phase (S?) on the horizontals. In the 1979 records, Station 4 also had high-frequency, high-amplitude vertical motion (0.44 g), with lower amplitudes on the horizontals (0.26 g). The other array stations did not record a similar high amplitude vertical phase, however. Thus, the high-frequency, high-amplitude vertical motion is not as clearly a source-independent characteristic as is the increased horizontal shaking in the alluvial valley.

TABLE 2

GILROY ARRAY PEAK ACCELERATIONS FROM THE 1979 AND 1984 EARTHQUAKES

	Morgan Hill Earthquake of April 24, 1984			Coyote Lake Earthquake of August 6, 1979		
STATION	Horiz.	Vert.	V/H	Horiz.	Vert.	V/H
Gilroy #7 Mantelli Rnch.	0.19	0.46	2.4	--	--	--
Gilroy #6 San Ysidro Micro.	0.34	0.43	1.3	0.42	0.17	0.4
Gilroy #4 San Ysidro Schl.	0.37	0.40	1.1	0.26	0.44	1.7
Gilroy #3 Sewage Plant	0.20	0.40	2.0	0.27	0.15	0.6
Gilroy #2 M.T. Motel	0.22	0.61	2.8	0.26	0.18	0.7
Gilroy #1 Gavilan H20 Tank	0.10	0.10	1.0	0.13	0.08	0.6

STRUCTURAL RESPONSE DATA

In addition to the free-field strong motion data which have been discussed, the data set from the Morgan Hill earthquake is also noteworthy for the large proportion of records obtained from structures. More structural response records were obtained from this event than from any since the 1971 San Fernando earthquake. Also, in contrast with the three independent accelerographs located in buildings at that time, the structural data from this event involve simultaneous recordings of the motion occurring at many points throughout a building. These records will allow the detailed analysis of structural amplification of the motion as well as any rotation or torsional response of the structures. Detailed information describing the instrumentation and the Morgan Hill accelerograms is available in Shakal et al. (1984) and Brady et al. (1984). However, to provide an overview of the structural response data, Table 3 provides a listing of selected structures recorded by common-timed accelerograph systems and the amplitude of the motion at the base and the roof (or top) of each structure. The number of sensors and the height of each structure are also indicated.

TABLE 3

SELECTED STRUCTURAL RESPONSE RECORDS
FROM MORGAN HILL EARTHQUAKE

Structure	No. Stories	No. Sensors	Peak Acceleration Base	Peak Acceleration Top	Agency
San Jose - Santa Clara County Office Bldg.	13	22	0.04H, 0.02V	0.18H	1
San Jose - Town Park Towers Apt. Bldg.	10	13	0.06H, 0.05V	0.22H	1
San Jose - Great Western S&L Bldg.	10	13	0.06H, 0.04V	0.22H	1
Saratoga - West Valley College Gymnasium	1	11	0.10H, 0.03V	0.42H	1
Watsonville - Phone Co. Office Bldg.	4	13	0.11H, 0.09V	0.33H	1
Hollister - Glorietta (Tilt-Up) Warehouse	1	13	0.11H, 0.31V	0.25H	1
San Bruno - Postal Services Bldg.	9	16	0.03H, 0.02V	0.11H	1
So. San Francisco - Kaiser Med. Bldg.	4	11	0.03H, 0.02V	0.26H	1
San Francisco - Transamerica Bldg.	58	12	0.02H, 0.01V	0.10H	2
Morgan Hill - Anderson Dam (Earthen)	--	6	0.41H, 0.20V	0.63H	2
San Jose - 101/680/280 Freeway Interchange	--	12	0.12H, 0.08V	---	2
San Justo - Dam	--	6	0.07H, 0.03V	0.08H	2
Los Gatos - Lexington Dam (Earthen)	--	9	0.02H, 0.01V	0.04H	1
Oakland - 14th St. Wharf	--	12	0.04H, 0.02V	---	1
Oakland - Caldecott Tunnel	--	19	0.01H, 0.01V	---	1

Agency: 1 - CSMIP, Ca. Div. Mines & Geol. 2 - SEB, U.S. Geol Surv.

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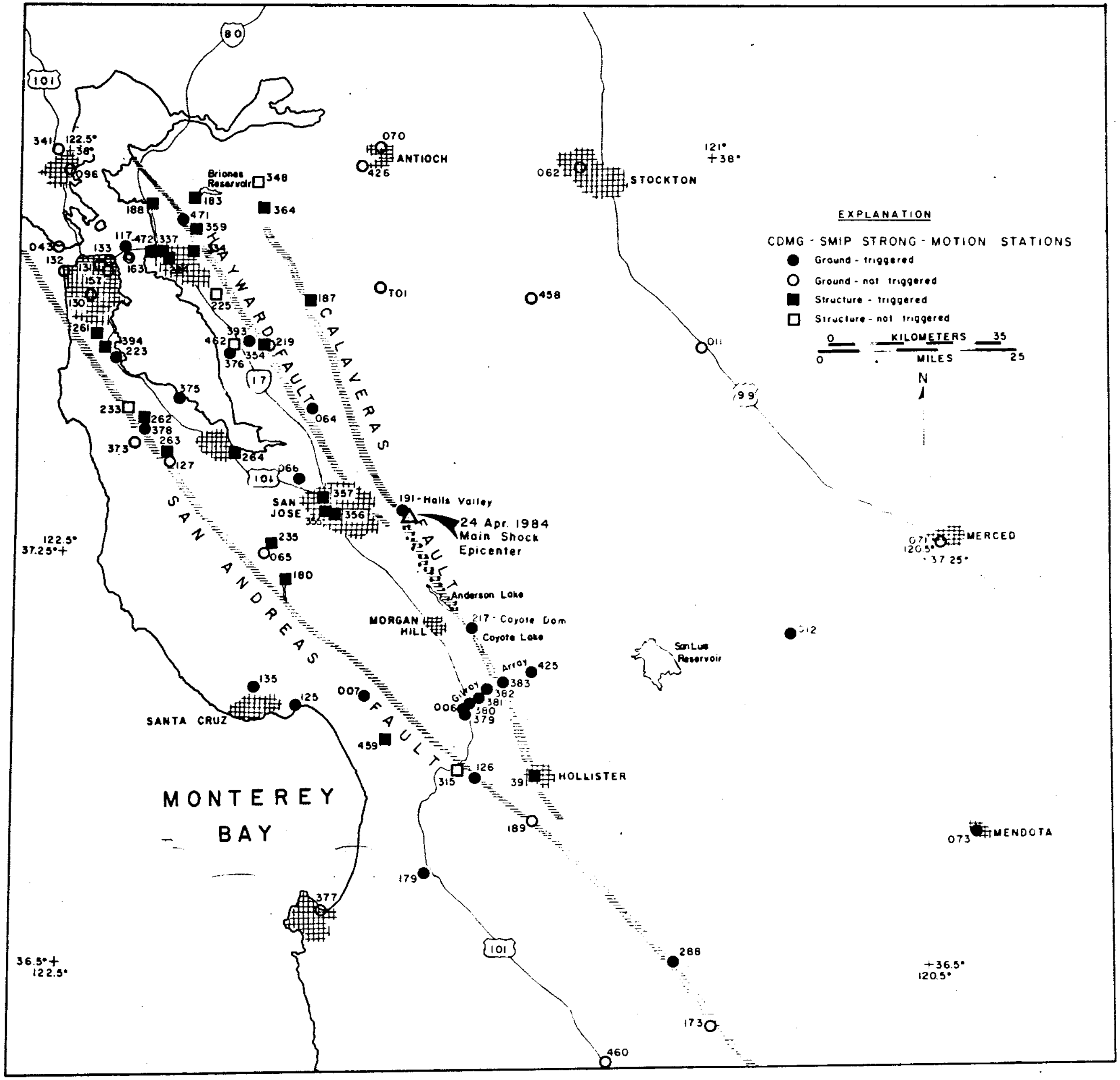

Fig. 1 CDMG strong-motion stations, the Morgan Hill epicenter, and aftershock zone (stipled). Stations are identified by 3-digit code listed in Shakal et al. (1984).

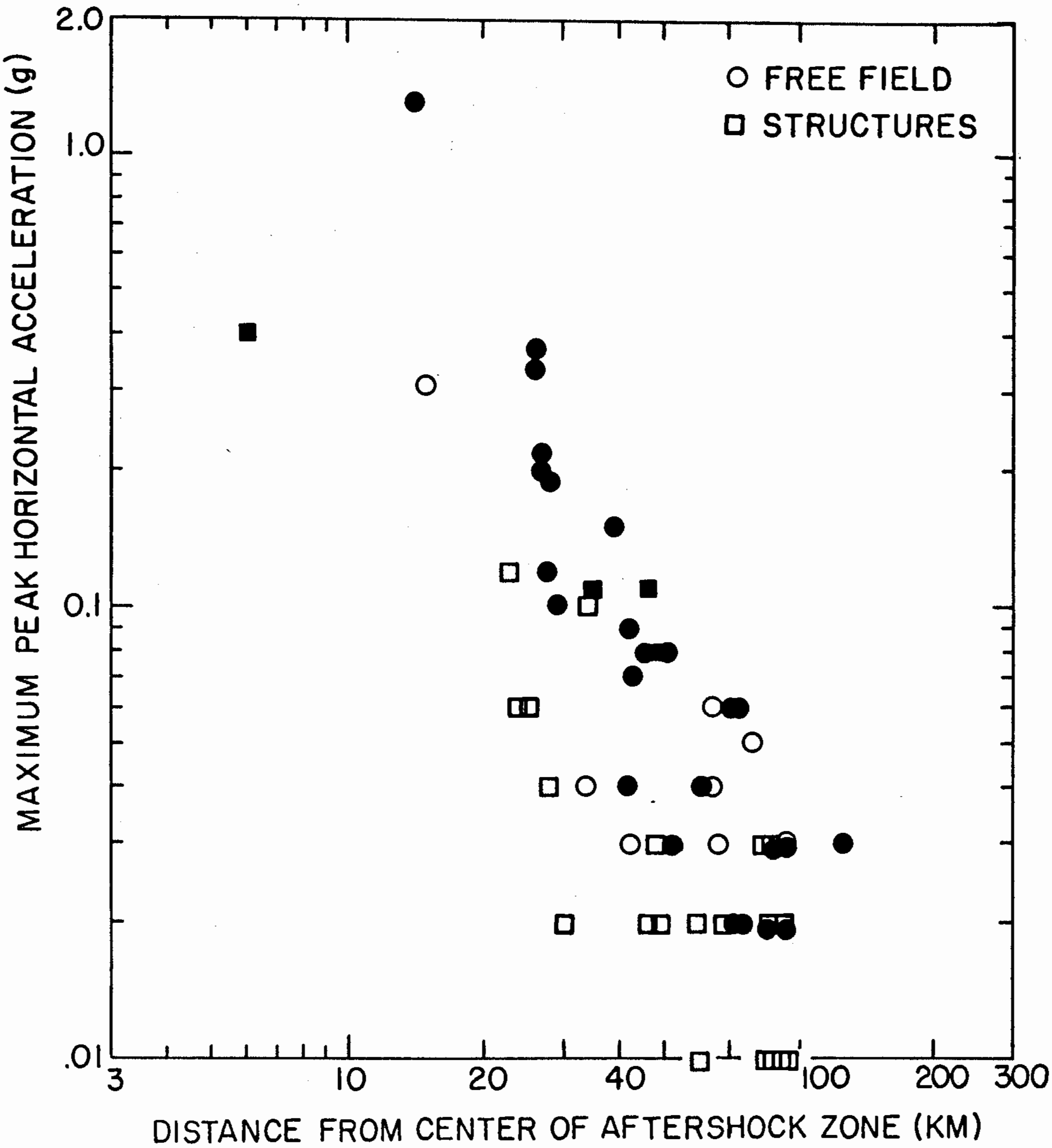

Fig. 2. Peak horizontal acceleration from the Morgan Hill earthquake. Distance is measured from a point (37.217N, 121.640W) on the fault at the approximate center of the aftershock zone. Solid symbols correspond to stations southeast of that point, open symbols to northwest stations.

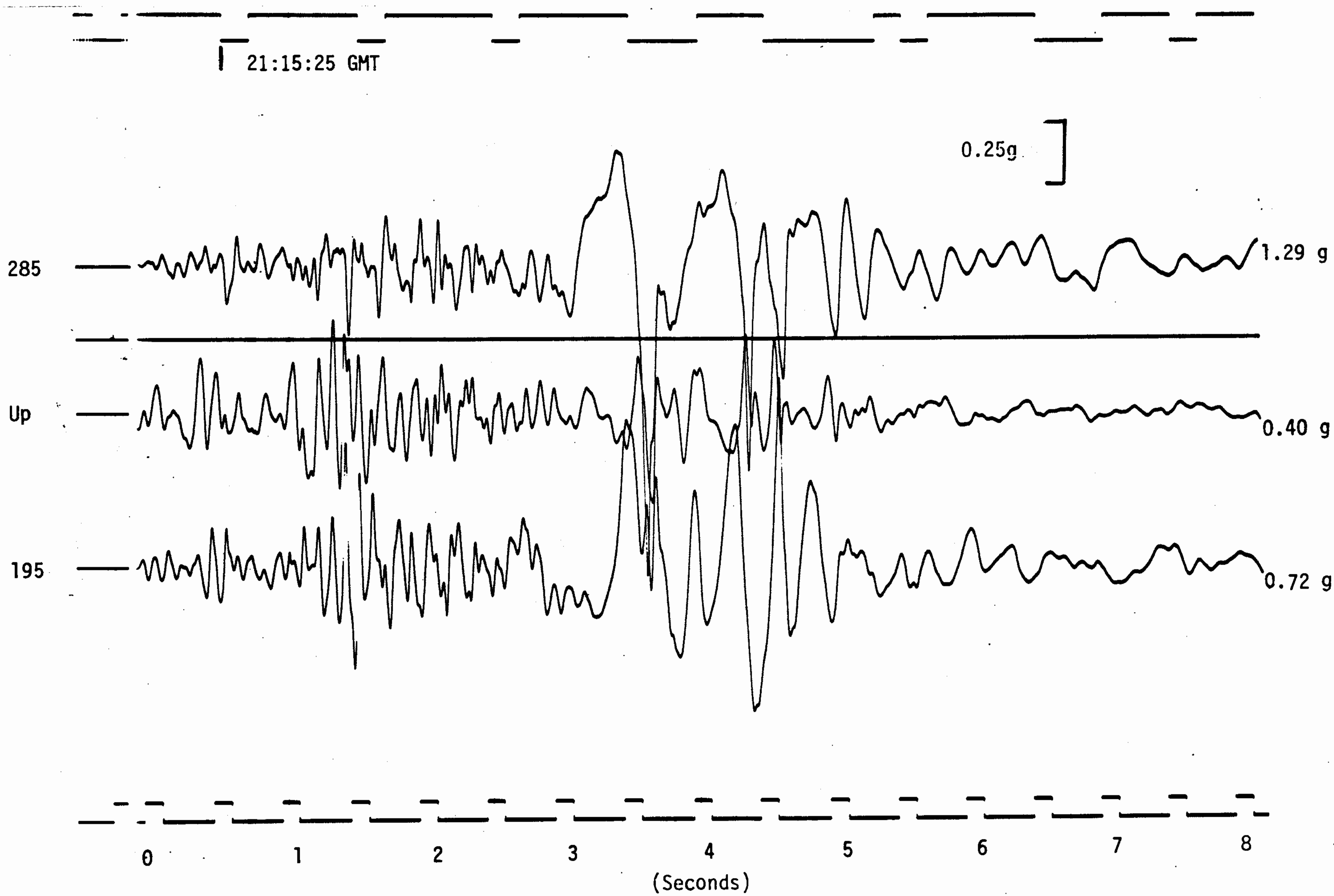

Fig. 3. The accelerogram recorded at the Coyote Lake Dam during the Morgan Hill earthquake of April 24, 1984.

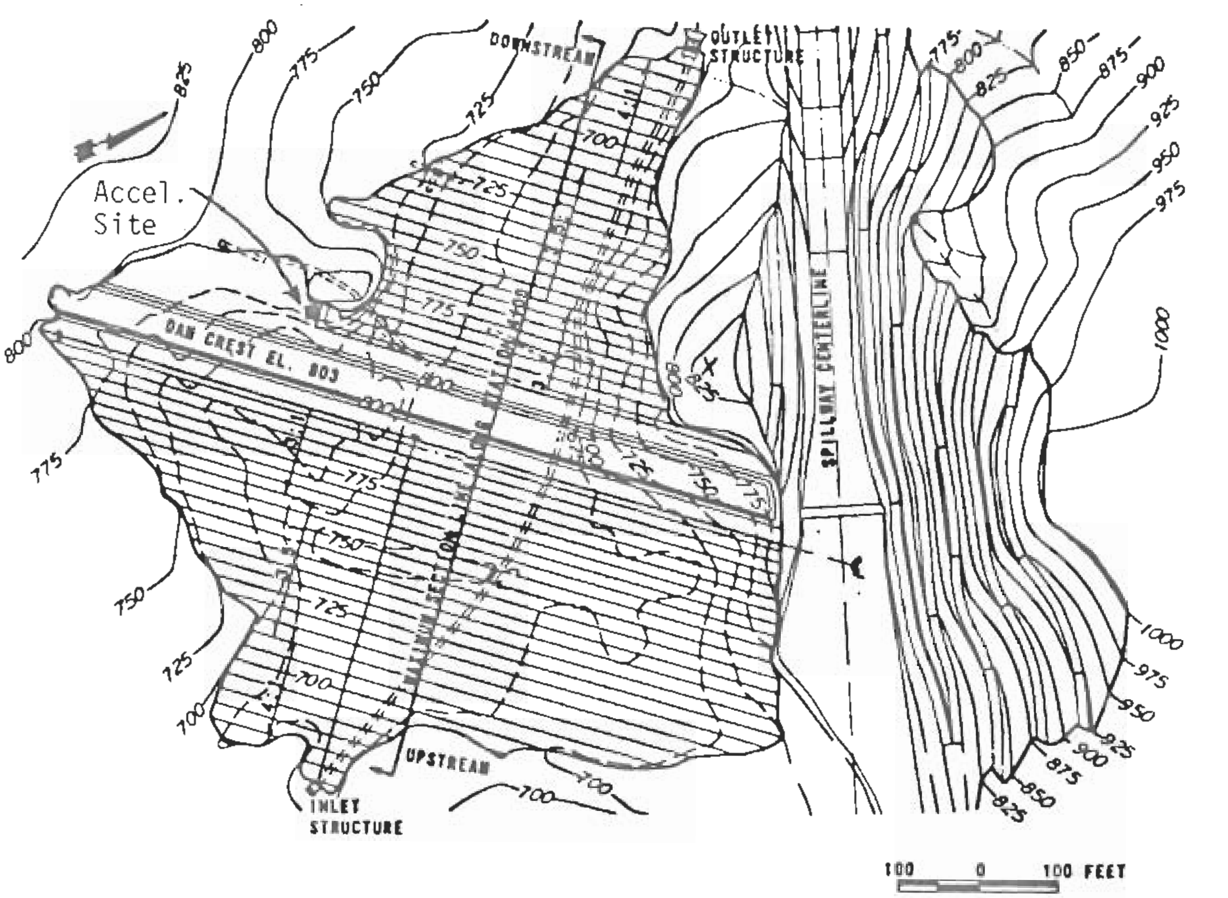

Fig. 4. (Upper) Photograph of accelerograph site at Coyote Lake Dam showing the strong-motion instrument shelter (arrow) near the rock promontory, with the rock riprap on the downstream face in the foreground. (Lower) Topography in the vicinity of Coyote Lake Dam, based on 1937 as-built drawings (from Buangan and Wahler, 1980; 25 foot contour interval). The approximate location of the instrument shelter is indicated. The upper photo was taken from the right abutment (near the 'x'), across the dam toward the rock promontory.

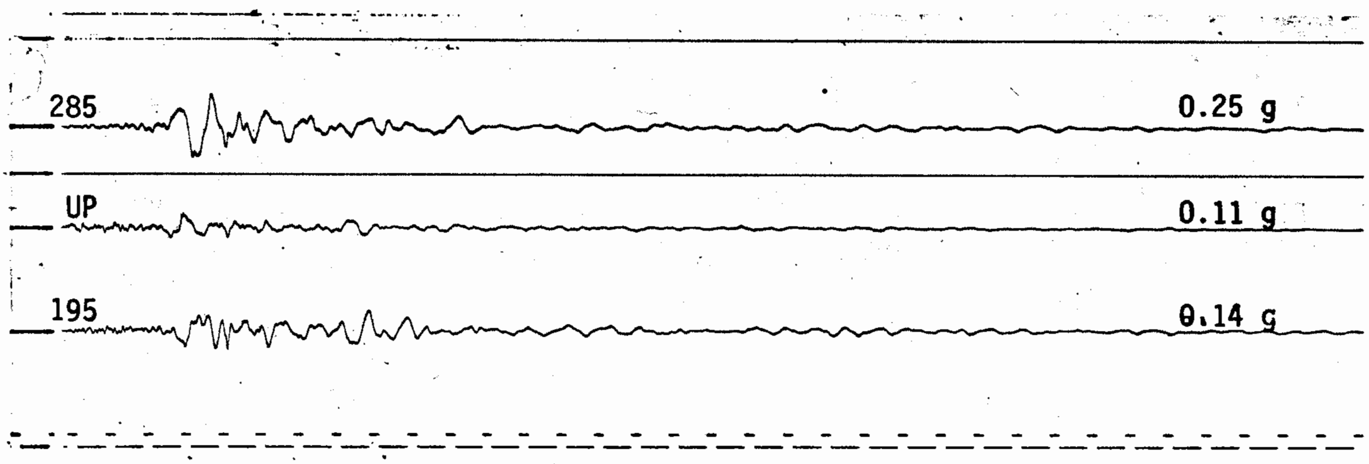

Fig. 5. Accelerogram recorded at the Coyote Lake Dam during the 1979 Coyote Lake earthquake. This accelerogram was recorded at the same site, with the same instrument at the same orientation, as the 1984 accelerogram shown in Fig. 3. The epicenter of the 1979 event (August 6, 5.9 ML) was approximately 2 km distant from this station. (Note that the instrument orientation given here for the 1979 record corrects that listed in Porcella et al. (1979))

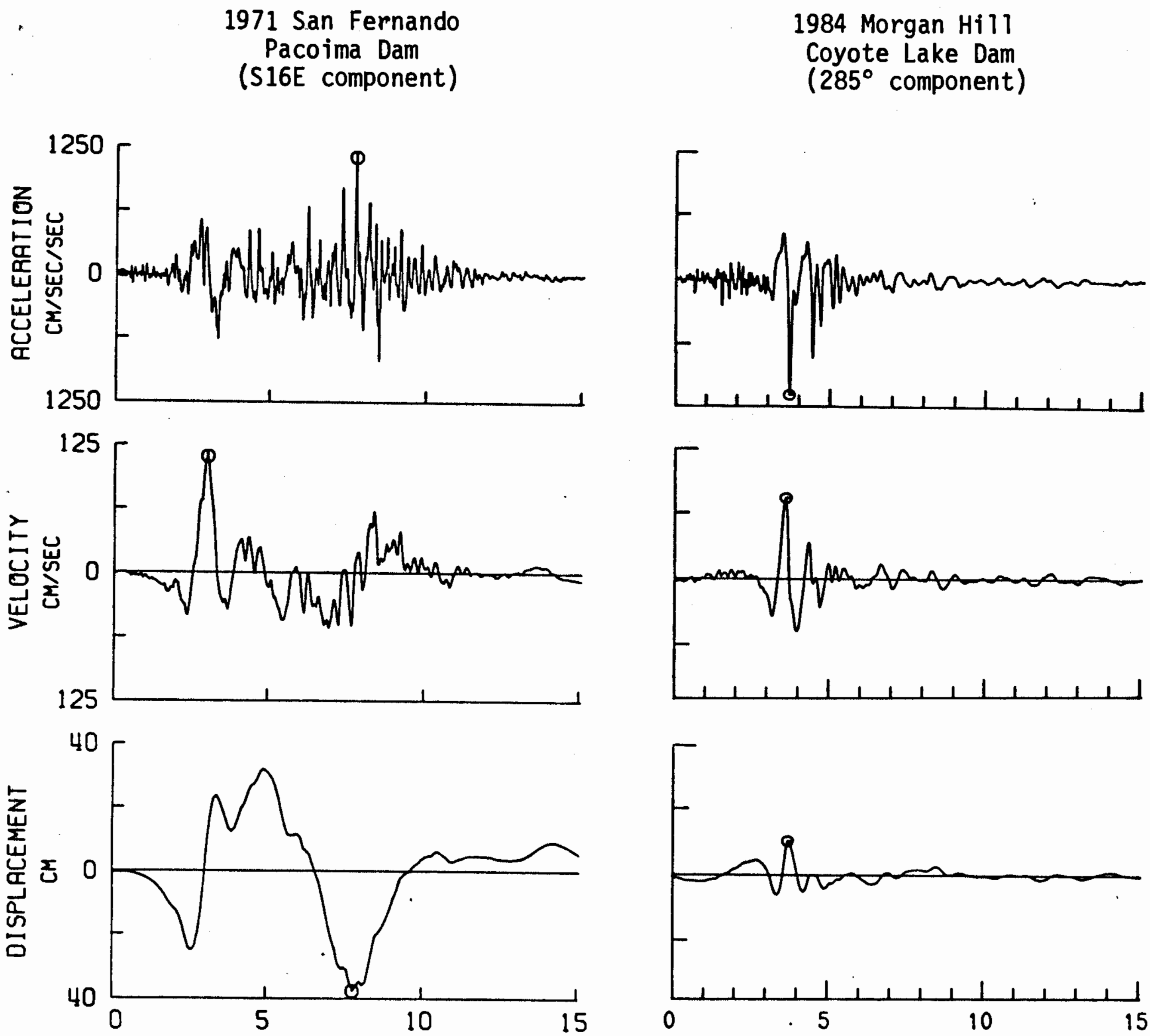

Fig. 6. Acceleration, velocity and displacement time histories computed from the 1971 San Fernando accelerogram from Pacoima Dam (S16E component, left) and the 1984 Morgan Hill accelerogram from Coyote Lake Dam (285 degree component, right).

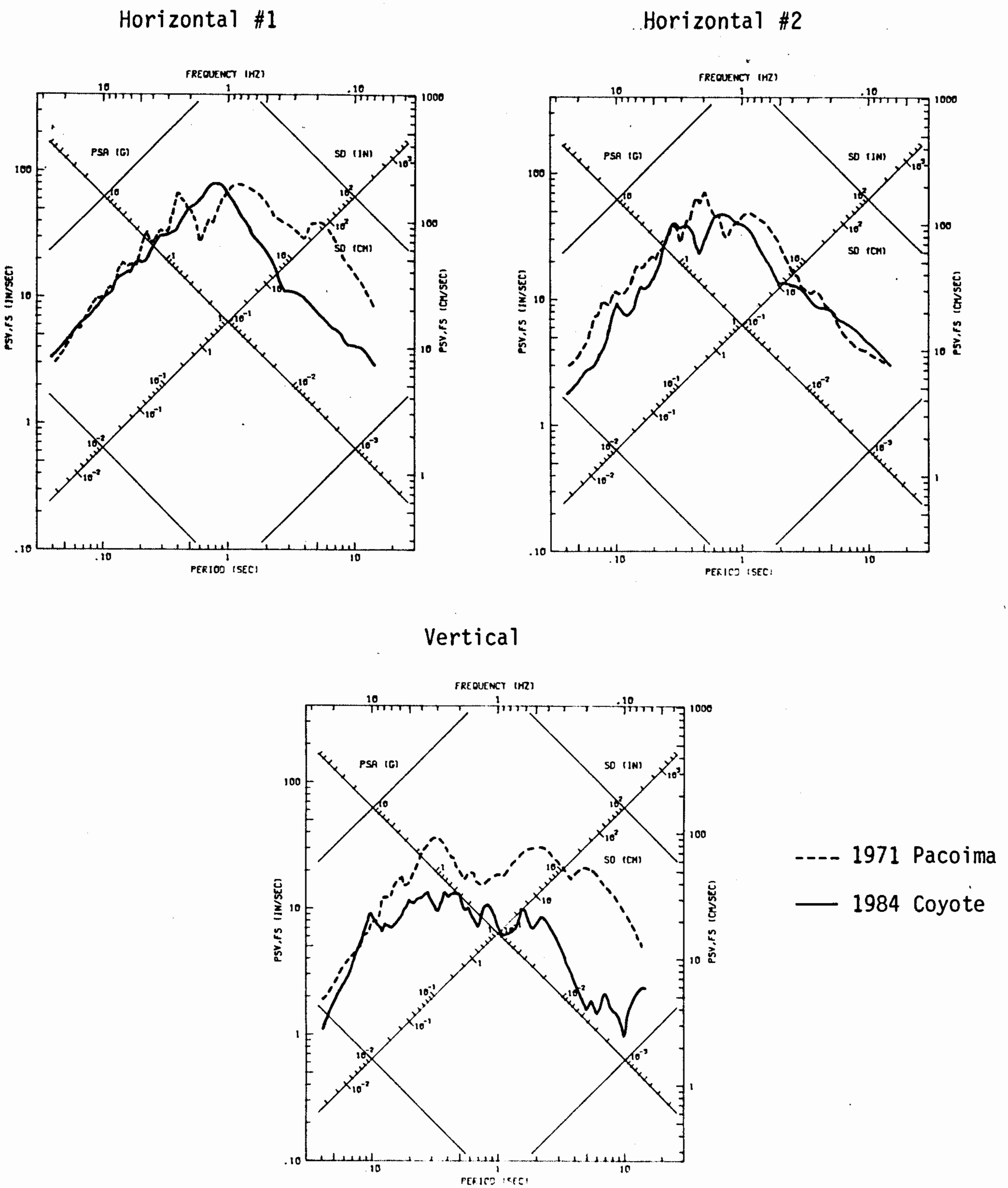

Fig. 7. Response spectra (5% damping, PSRV) for all three components of the 1984 Coyote Lake Dam accelerogram (solid) and the 1971 Pacoima accelerogram (dashed). The upper pair are the horizontal components; the leftmost corresponds to the high amplitude components (1.3g for the Coyote record) shown in Fig. 6.

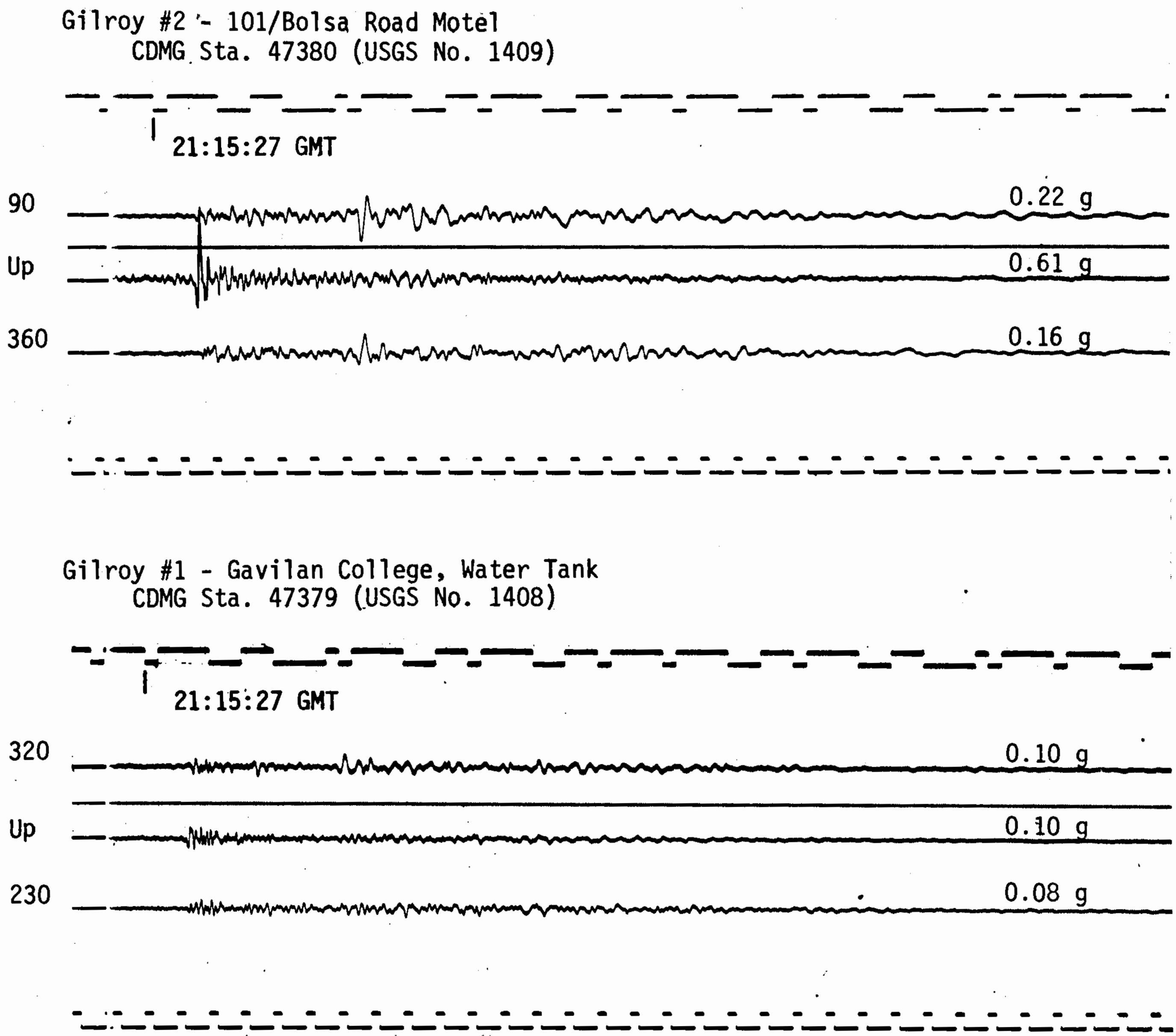

Fig. 8. Accelerograms recorded at Gilroy Array Station #2 (upper), on alluvium, and Station #1 (lower), on Franciscan, during the 1984 Morgan Hill earthquake.