SEISMICITY AND SEISMIC INTENSITY STUDY

PARDEE AND CAMANCHE   DAMS

for

East Bay Municipal Utility District

by

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and

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REPORT ON SEISMICITY AND SEISMIC INTENSITY IN THE VICINITY OF PARDEE

AND CAMANCHE DAMS, AMADOR, CALAVERAS AND SAN JOAQUIN COUNTIES

1. Introduction

The objective of this analysis is to estimate the likely future

seismicity and intensity of ground shaking in the vicinity of Pardee

and Camanche dams. These dams are located in the western foothills of

the Sierra Nevada in northern California. The analysis leads to recom-

mended seismic parameters to be used in the engineering evaulation of

earthquake loadings on these structures.

The positions of the dams are shown in Figure 1. Pardee dam is

located on the Mokelumne River in the foothills of the Sierra Nevada

mountains near Valley Springs, California. It is a concrete gravity

curved-in-plan dam completed in 1929, standing 105 meters above the

river bed. Pardee reservoir has a capacity of 259 million cubic meters

at spillway elevation. Situated about 10 kms downstream from Pardee is

Camanche dam, which consists of a main structure and a number of auxiliary

dikes. The main dam consists of zoned sand and gravel with an impervious

core, completed in 1964. It stands 52 meters above the river bed. There

are 6 kms of dikes. The lake created by Camanche dam has a capacity of

531 million cubic meters at spillway elevation.

The present investigation concentrated on five features.

1. Geological information on the regional structure was consulted.

Not only were geological maps studied, but also very recent geological

work associated with the tectonics of the west side of the Sierra

Nevada.

2. Special attention was given to the evidence for activity of the Foothill Fault system based on the recent field investigations, particularly those associated with the Oroville earthquakes of 1975 (situated about 150 kms NNW) and those made in connection with the proposed Auburn dam (situated about 70 kms NNW of the Pardee reservoir).

3. Catalogs of historical and instrumentally-measured earthquakes in this part of California were scrutinized and lists of all earthquakes of relevance were made. The catalogs included the Townley-Allen catalog of felt reports and the catalogs of the Seismographic Station of the University of California. The earthquake occurrence was used (a) to delineate areas of earthquake activity, (b) to define the earthquakes that would control the largest expected ground shaking at the dams, and (c) to make an estimate of the statistics of occurrence of the more intense earthquakes near the sites.

4. The intensities characteristic of the strongest ground shaking to be expected at the dams were then estimated, based on the preceding information. At this stage, some attention was also given to geological conditions at the site.

5. A comparison was made between the assessed site intensities and published observations of intensities measured in recent earthquakes. Recommendations were then made on likely accelerograms which are suitable for engineering analyses of the structures.

It is important to note that the basic information available for the assessment of intensities at these dams has changed greatly in the last few years. Until recently, the general position of field geologists was that the Foothill Fault system (which is mapped to the east of the dams,

and consists of the Bear Mountain and Melones fault zones) was inactive, with no significant displacement for millions of years. For example, the State "Faults and Geologic Map" (Jennings, 1973) shows these fault systems as pre-Quaternary (older than 2 million years) with no recognized Quaternary movement. Recent detailed geologic field work, however, as well as the occurrence of the 1975 Oroville earthquakes, located on the Foothills Fault system about 150 kms north of Pardee dam, has brought evidence to light that portions of the Foothills Fault system are presently active. In preparing this report I have read all the available published material on these recent studies. I have benefited by extensive discussions of the Board of Earthquake Analysis of the Department of Water Resources, both in relation to the Oroville dam facilities and the proposed Auburn dam site.

For the purpose of this report, the essential background material is summarized only; the main emphasis is given to available lines of argument for setting probable levels of strong ground motion at the Pardee and Camanche dams, given present knowledge. There are, of course, uncertainties in such site evaluations. Because of the lack of strong-motion measurements on appropriate geological and soil conditions, there are no formulae that yield hard and fast numerical values for the seismic parameters. For this reason, the estimates have to be both cautious and realistic. The best modern scientific practice has been followed in approaching the assessment in a probabilistic framework. In other words, the decisions made take into account the odds of occurrence of the estimated parameters and the estimated life of the structures involved.

II. Tectonic Environment

The broad tectonic features of central California are well known and it is unnecessary here to give any detail. About 180 kms to the west of the dams is the San Andreas fault system including the subsidiary major faults in the hills east of San Francisco Bay. These faults may be the sources of large to moderate earthquakes which could shake the dams. On the west side of the San Joaquin valley there are a series of marginal faults, of both dip-slip and some of strike-slip type. Some of the thrust faults separate Jurassic and Cretaceous geosyncline rock types and were probably involved in tectonic movements that are now complete. Small to moderate earthquakes may be generated by movement on some of these faults during the life of the dams.

The nearest major tectonic features to the dam sites are an en echelon system of faults along the western foothills of the Sierra Nevada. This Foothills Fault system is shown on the geological map (Figure 1) and is made up of two zones, the Bear Mountain fault zone and the Melones fault zone. These zones occur in the metamorphic belt of late-Palezoic to mid-Mesozoic sedimentary and volcanic rocks, which have been intruded by basic and ultrabasic rocks. The metamorphic belt is folded in a complex way.

In his summary of the geology of the Pardee dam site Professor G.D. Louderback stated that, "The rocks of the gorge of the Mokelumne River on which the dam is located were originally a series of volcanic breccias, ash beds, lava flows and terrigenous and mixed sediments which have been subjected to strong compression that has deformed them so that they now

dip at high angles to the northeast. The sediments show the development
of a slaty character and the volcanic members have suffered, to a greater
or less degree, changes in mineral composition, sometimes called the
greenstone type."

As Figure 1 shows, the Pardee reservoir is situated just to the
west of the Bear Mountain fault zone and one of the branches of this
fault zone is mapped passing through the reservoir. Until recently, the
general geological position was that the Foothills Fault system was
inactive and is so classified in the State fault map (Jennings, 1973).
The main arguments for the inactivity were the lack of continuity along
the faults and the interruption of many branches by plutons and gabbroic
sills. According to this view, much of the shearing seen in the Foothills
system was associated with the intrusive activity, occurring in late
Jurassic and early Cretaceous times. The main deformation along the
fault system culminated in the Nevadan orogeny about 150 million years
ago. The minimum age of the intrusive plutons is about 130 million years.

New evidence suggests, however, that some elastic strain continues to
be accumulated along this fault system and is relieved from time to time
in the form of small to moderate earthquakes. The seismological evidence
is that in both the last century and during this century scattered earth-
quakes have been centered in this area, more particularly, however, to
the north of the dam sites. Detailed field studies made following the
Oroville earthquakes of 1975, involving trenching along the line of cracks
south of the Oroville reservoir, indicated that some branches of the
Foothills Fault system have had slip on them during Quaternary time. Off-
sets in strata exposed in trench walls confirm the dominant normal faulting

mechanism inferred for the Foothills Fault system. Multiple fault displacements were observed with overall vertical motions of forty-five cms in surficial layers. On the basis of probable age of the soil overburden, there was some suggestion that the dip-slip had occurred in several episodes of faulting during the last 5,000 to 100,000 years. This work has been confirmed in a general way by most extensive trenching carried out in the vicinity of the Auburn dam site. At the present time, the evidence is that, in the vicinity of the Mokelumne River, no extensive Holocene fault rupture has occurred on the Foothills Fault system. To the contrary, from the lack of extensive recent surface morphological features and from the intermittent and mechanically disjointed nature of the shear zones, it is most probable that ruptures in contemporary earthquakes, if any, will be limited in linear and vertical extent (similar to the Oroville offsets).

A detailed geologic report on the condition of the foundation area of the Pardee dam, the nearer of the dams to the Foothills Fault system, was made by Louderback (June, 1928). The report states that the rock which makes up the foundation of the dam provides an excellent foundation. It is hard, dense, rather massive greenstone (metaandesite). In Louderback's judgment, the ground cleared for the dam presents an unusually satisfactory foundation, "probably rarely excelled. The rock between the natural joints is tight, the joints are narrow, discrete and fairly widely spaced."

It only remains to mention the active system of faults that lie on the east side of the Sierra Nevada north of Lake Tahoe and in Nevada. The nearest of these faults that are marked as active on the State fault map is at a distance of 120 kms from Pardee dam. Therefore, while a large to

moderate earthquake generated by movement along these faults would be felt at the site, the motion would be significantly smaller than that generated by the earthquakes on the Foothills Fault system. There is, therefore, no need to consider the eastern system of faults further.

Table 1

Sources and Estimated Seismic Intensities

Source	M_L+	Recurrence Frequency (per Century)	Distance to Pardee (km)	Site Intensity MM*	Peak Ground Acceleration ($1 \leqslant f \leqslant 8$ Hz)	Bracketed Duration ($1 \leqslant f \leqslant 8$ Hz)
San Andreas	8.25	1	150	V	0.05g	5
Hayward–Calaveras	7.5	1	120	VI	0.08g	5
West Valley	6.0	2	80	VI+	0.10g	5
Pleasant Valley (south of Mono Lake)	6.0	2	100	VI	0.08g	5
Foothills	6.25	1	10	VIII–IX	0.40g	15
			25 (Camanche)		0.30g	10

+"Maximum likely" earthquakes (see text).

*Modified Mercalli intensities.

III. Seismicity of the Region

A complete earthquake listing since the historical record began for
a circular area with a 100-km radius centered on the dams was obtained
using the computer program RETRIEVE at the Seismographic Station,
Berkeley. The list contains all relevant historical information in
the Townley-Allen Catalog (1939) and instrumental locations of earth-
quakes given in the Bulletin of the Seismographic Stations up to 1976
(see Bulletin, 1976). These data are attached to this report as
Appendix A. (Single copy only)

The list begins with an earthquake in December 1851 and shows that
this region along the foothills of the Sierra Nevada has had rather
scattered earthquakes in historical time. Both reported intensities
(Greek letters) and instrumental epicenters (full circles) are plotted
in Figure 2 for the events within the area of the map. It should be
understood that many of the intensities (Modified Mercalli) assigned to
earthquakes with sources well away from the vicinity of this site are
merely felt or damage reports from the town or village within the immed-
iate geographical region. The recorded seismicity that emerges from the
earthquake catalogs is quite minor in the vicinity of the dams. Typical
of the events is a small earthquake on July 5, 1956 at 38.35° N, 120.75°
W, reported felt near Jackson but with low intensity (about II).

Few or no earthquakes have been detected in the last decade along
adjacent segments of the Melones and Bear Mountain fault zones by the
sensitive seismographic stations at Oroville and Jamestown. Certain add-
tional stations have been run for short periods in connection with special

studies in this vicinity and the results of these special seismographic networks indicates that only quite small earthquakes have occurred spasmodically in the region in recent times.

Of more definite interest is the largest shock to be centered along the Foothill Fault system since instrumental recording was started in northern California about 70 years ago. This is the August 1, 1975 Oroville earthquake (magnitude 5.7) about 150 kms north of the EBMUD dams. For reasons given in the previous section, a repetition of this earthquake can now be considered mechanically feasible at many positions along the Foothill Fault system and, so far as this study is concerned, near to the dams here considered. It should be noted that the 1975 Oroville main shock had a focal depth of 8 kms and a normal dip-slip mechanism, with the west side downwards.

No special analysis is necessary here of the seismicity of the other active fault systems in central California listed in Table 1. It is generally accepted that the largest earthquake that might be produced by slippage along the San Andreas fault would have a magnitude of 8.2. Similarly, the Calaveras-Hayward fault systems may be the source of earthquakes of magnitude up to about 7.5. In the companion report on the seismicity and seismic intensity for the Mokelumne aqueducts (Report to East Bay MUD, Bolt, 1977), detailed study was given to the seismicity on the west side of the San Joaquin Valley. The inference arrived at in that report was that these faults may be the site of an earthquake as large as magnitude 6. The distance to Pardee Dam of the fault rupture in these cases would be about 80 kms and the estimates of intensity from this source are clearly less consequential than those from the seismicity

produced by dislocation on the Foothills Fault system, which are much nearer to the dam sites.

IV. Likely Intensity Parameters

From the studies of tectonics and seismicity outlined in the previous sections estimates can now be made of appropriate ground motion intensities likely at the dam sites.

Any assessment of this kind involves, whether explicitly or not, some basis of probability of occurrence. For dams of this kind, prudent but realistic values in terms of risk and design life should be adopted. I have chosen an intensity value so that the odds are better than 99 per cent that neither dam will be shaken more strongly in 100 years. In other words, in the sense of risk at practical probability decision levels, the intensity levels chosen approximate what are referred to as "maximum credible events".

Let us now consider the earthquakes generated by the nearby Foothills Fault system. There are three independent lines of argument.

1. <u>Historical seismicity.</u> In 150 years, the greatest earthquakes reported along the Foothills Fault system had intensities of VII+ or less, with two recorded since 1930 with magnitude about 5.7. Until 1975, no clear association between known faults and the earthquake sources was made and no surface ruptures were observed. If a procedure, used in siting studies for nuclear reactors, is used, the greatest magnitude earthquake to have occurred along the major active tectonic structure is considered to be repeatable near to the site. This conservative procedure would bring the source of a magnitude 5.7 earthquake a few kms upstream from Pardee dam and 5 to 10 kms deep.

2. <u>Observed displacements in trenches along the Foothill Fault system.</u>
Observations in trenches placed across various branches of the Foothill
Fault system in recent years indicate about 50 cm as the maximum total
vertical displacement since the formation of the surficial soil (5,000 to
100,000 years old). There is some evidence (e.g., Woodward-Clyde and
Assoc., 1976) that displacements of this amount have occurred in several
(perhaps three) separate offsets of normal faulting. The inference is that
small Quaternary fault movements of up to 20 cm vertical displacement (which
would be associated with moderate earthquakes) have occurred in the Foothill's
shear zone at mean intervals of 1,000 years or more. The case is similar
to the faulting in the Fort Sage earthquake in California in 1950 (M = 5.6;
maximum offset 15 to 16 cm).

There is some theoretical and empirical evidence that the highest
intensities of ground shaking are correlated more closely with the fault
offset, D, than with fault rupture length. As a test of source size, if
we adopt the largest displacement formula (D in feet) given by Bonilla (1970)

$$\log D = 0.57\ M - 2.67,$$

we get

$$M_L = 5.2 \text{ for } D = 2 \text{ feet.}$$

3. <u>Linear extent of faulting.</u> As the geological maps in Figures 1
and 2 indicate, the Foothill Fault system is made up of parallel branches,
a few of which have lengths which reach 50 kms. The geometry of the com-
plex, mainly en echelon, system of surface fault features is against an
extended fault rupture in Holocene time. The inference from the geologi-
cal data is that the magnitudes of any earthquakes involving fault ruptures
are likely to be small to moderate. Suppose, to obtain a rough estimate,

that magnitude is related to offset D and length L (Bonilla, 1970) as

$$M_L = 3.68 + 0.41 \log LD,$$

where L and D are in cms. Then for L = 25 kms and D = 30 cms, the magnitude is 6.1. There is much uncertainty in such formulae because various types of faulting are lumped together. (The scatter in the field measurements suggests a standard error of about $\pm$ 0.3 magnitude units.) There is also a bias on the high side because both the values for M and D are towards the upper bounds according to the available studies of geological deformation along the Foothill Fault system.

In summary, the three arguments given above all lead to earthquake sources in the shear zone in the vicinity of the dam sites as between 5.2 and 6.1 $\pm$ 0.3 in magnitude. For design purposes, an upper bound of M_L = 6.25 seems appropriate. Such sources would be likely to be predominantly normal dip-slip with focal depths between 5 and 10 kms.

Only the first argument from seismicity is really subject to statistical treatment, but the earthquake population is small and uneven so formal calculation is not available. The second and third arguments may inflate the estimates of size so far as site intensity is concerned because they are spacial point estimates, whereas interval estimation should be used. In other words, the probability of a focus occurring exactly at some point (for example, just adjacent to Pardee Dam) in this tectonic region within a finite time (say, 100 years) is close to zero. Interval estimates lead to foci at various distances from the site, thus requiring attenuation of the ground motions and thus reduction of the expected peak intensity in a finite time. In order to meet this point, and also take account of focal depth, a source distance of 10 kms should be taken for the nearer of the two

dams, Pardee, and 25 kms for the further of the two, Camanche . I estimate,
therefore, that the maximum size earthquake that is likely to affect Pardee
in its lifetime would have a magnitude of M_L = 6.25 and the waves would
radiate from a source at a distance of at least about 10 kms from Pardee
dam. This information is listed in Table 1.

Table 1 also gives the summarized information on magnitude and source
to site distance for the other earthquakes that are likely to shake the
dams. The intensities given in Table 1 for the San Andreas, Hayward,
Calaveras and West Valley sources are taken from observations in the
literature of historical earthquakes. The Pleasant Valley site intensity
is an estimate based on analogous situations in California. The intensity
in Table 1 for the magnitude 6.25 earthquake located near to the dams in
the Foothill Fault system is given as intensity VIII to IX. Such intensi-
ties have never been reported from the dam sites in historical time and
are based merely on extrapolations from similar situations elsewhere in
California.

V. Discussion

Three measurements of seismic intensity are listed in Table 1: the
Modified Mercalli seismic intensity, the mean (expected) peak ground
acceleration near the dams, and the bracketed duration of ground shaking
(accelerations greater than 0.05g) near the dams.

The estimated peak ground accelerations have been based upon a num-
ber of recent studies (Page, et al., 1972; Schnabel and Seed, 1973; Bolt,
et al., 1975; Trifunac and Brady, 1975) which correlate observations of
acceleration measured by accelerometers with the size of the earthquake.
The most severe intensity that emerges is the case of the near-earthquake

on the Foothill Fault system. On the side of caution, I have inferred for engineering purposes a source size (magnitude 6.25) which is an upper bound to the arguments given in the last section. It should be stressed, however, that a shallow-focus earthquake, having a magnitude of M = 6.25 and centered 10 kms from the Pardee Dam, exceeds the inferences discussed here and is an unlikely event. The estimated mean peak acceleration at Pardee dam that corresponds to this event is estimated to be 0.40g and a value of 0.30g is the corresponding amplitude scaling factor for the more distant structure, the Camanche dam. Several measured occurrences confirm these values. For example, in the Long Beach 1933 earthquake (M = 6.3) the Vernon accelerometer gave a peak horizontal acceleration of 0.15g at a distance of 16 kms. In the 1973 Managua earthquake (M = 6.2), the peak acceleration was 0.39g at a distance of 5 kms from the fault. In the May 1940 Imperial Valley, California earthquake, the horizontal acceleration measured at El Centro at a distance of about 6 kms from the fault reached 0.32g on the N-S component (M=7.1).

We might also note that in the main shock of the 1975 Oroville earthquake (M_L = 5.7) accelerometers on Oroville dam (6 kms from the faulting) measured less than 0.15g maximum horizontal acceleration.

Camanche dam is situated further from the Foothill Fault system than Pardee dam. If a minimum value of 25 kms is taken for the nearest distance of the seismic source from Camanche dam, then the average attenuation values obtained in earthquakes elsewhere (Boore, et al., 1972; Bolt, et al., 1975) would suggest that the corresponding peak acceleration to be used to study the response to earthquake shaking of the Camanche structures would be about 0.30g.

Next, the likely duration of strong shaking from an earthquake in the Foothill Fault system must be determined. We use the notion of bracketed duration which is now being widely used in seismic site assessments. This is the total time of shaking at the site between the first and last acceleration excursions greater than 0.05g. A number of studies (Boore, _et al._, 1972; Bolt, _et al._, 1975, p.33) indicate that for a magnitude 6.2 earthquake, generated 10 kms from the site, the duration of significant ground motion would be about 15 seconds. At Camanche , the corresponding duration is 10 seconds.

Finally, an accelerogram (time history) and its associated frequency spectrum is needed that fits the estimated source conditions and strong-motion site parameters determined in the previous discussion. With allowance for the uncertainties in the various geological and seismological parameters, a strong-motion record obtained from an earthquake centered 10 to 20 kms away from the site with peak horizontal accelerations of about 0.4g and a bracketed duration of about 15 seconds should meet the seismological and geological requirements. From the list of world-wide strong-motion records several cases fit these specifications, although none duplicate them exactly.

It is suggested that the N21°E component recorded on the abutment of Castaic dam in the 1971 San Fernando earthquake (M_L = 6.5) be used as a model of ground motion. The maximum acceleration on the N21°E record was about 0.40g and it was obtained on rock about 20 kms from the observed faulting. Another pair of strong-motion records that might be used come from the Managua earthquake (M_L = 6.2) of December 23, 1973. These records, obtained about 5 kms from the fault, had an E-W component peak acceleration of 0.39g, and a N-S component peak acceleration of 0.34g.

VI. Summary of Conclusions and Recommendations

A value of 0.40 g (forty per cent of gravity) is an appropriate maximum acceleration of ground shaking to be used for testing the dynamic response of Pardee Dam. The corresponding duration (as defined) of strong motion is about 15 seconds. Corresponding values for Camanche Dam are 0.30g and 10 sec. It is highly improbable that these accelerations will be attained or exceeded more than once in 100 years.

If it should ever occur, the source of such strong acceleration is likely to be a rupture along one of the fault planes of the Foothills Fault system, one trace of which is mapped passing through Pardee reservoir.

In order to meet these ground motion specifications I recommend the use of the N21° E component accelerogram recorded at Castaic dam in the 1971 San Fernando earthquake. A copy of this accelerogram is attached as Figure 3. Alternative ground motions suitable for engineering studies have been recorded, however, and at the time of analysis further attention should be given to selection of ground motions with suitable spectral contents. I recommend that one or two standard strong motion accelerographs be maintained near the dam so that crucial observations will be obtained from any future local earthquakes.

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APPENDIX A

Historical seismicity within 100 kms of the dams (January 1769-
January 1975). Hypocenter quality ranges from A (Excellent) to D
(Poor) and after 1967 the quality is based partly on the number of
stations recording the earthquake. The intensity scale is Modified
Mercalli after 1932; Rossi-Forel before.

The list is in the form of a computer printout from a master
file kept on magnetic tape at the Seismographic Stations, University
of California, Berkeley. (Single copy only--filed in Materials
Engineering Section Files.)

APPENDIX B

Historical seismicity within 100 kms of the dams (1769-1927).

This list is an edited abstract of the Townley-Allen catalog, revised where necessary using more modern data. In this list all intensities are specified on the Modified Mercalli scale.

The list is in the form of a computer printout from a magnetic tape prepared by D. Seeburger, 1976. (Single copy only--filed in Materials Engineering Section Files.)
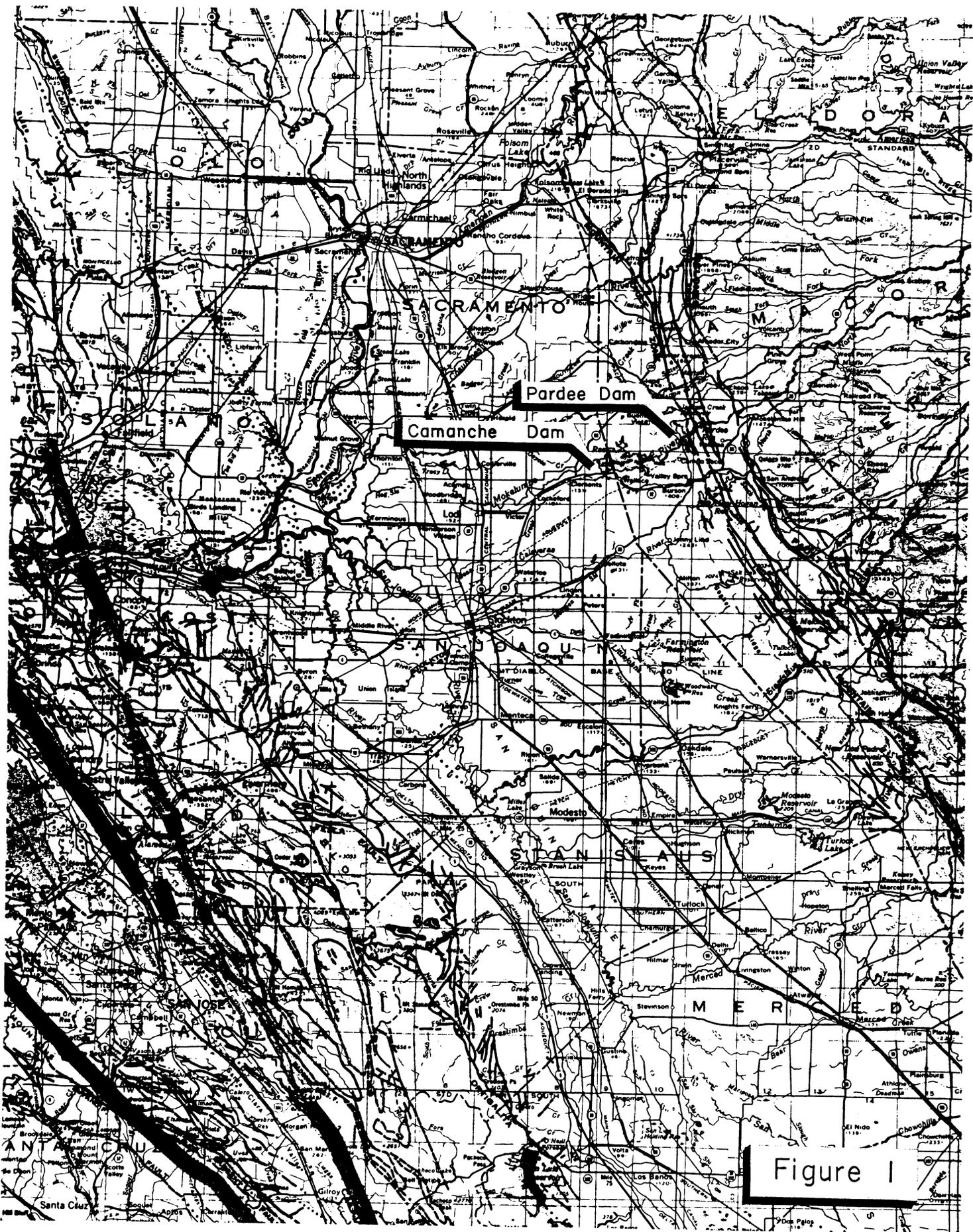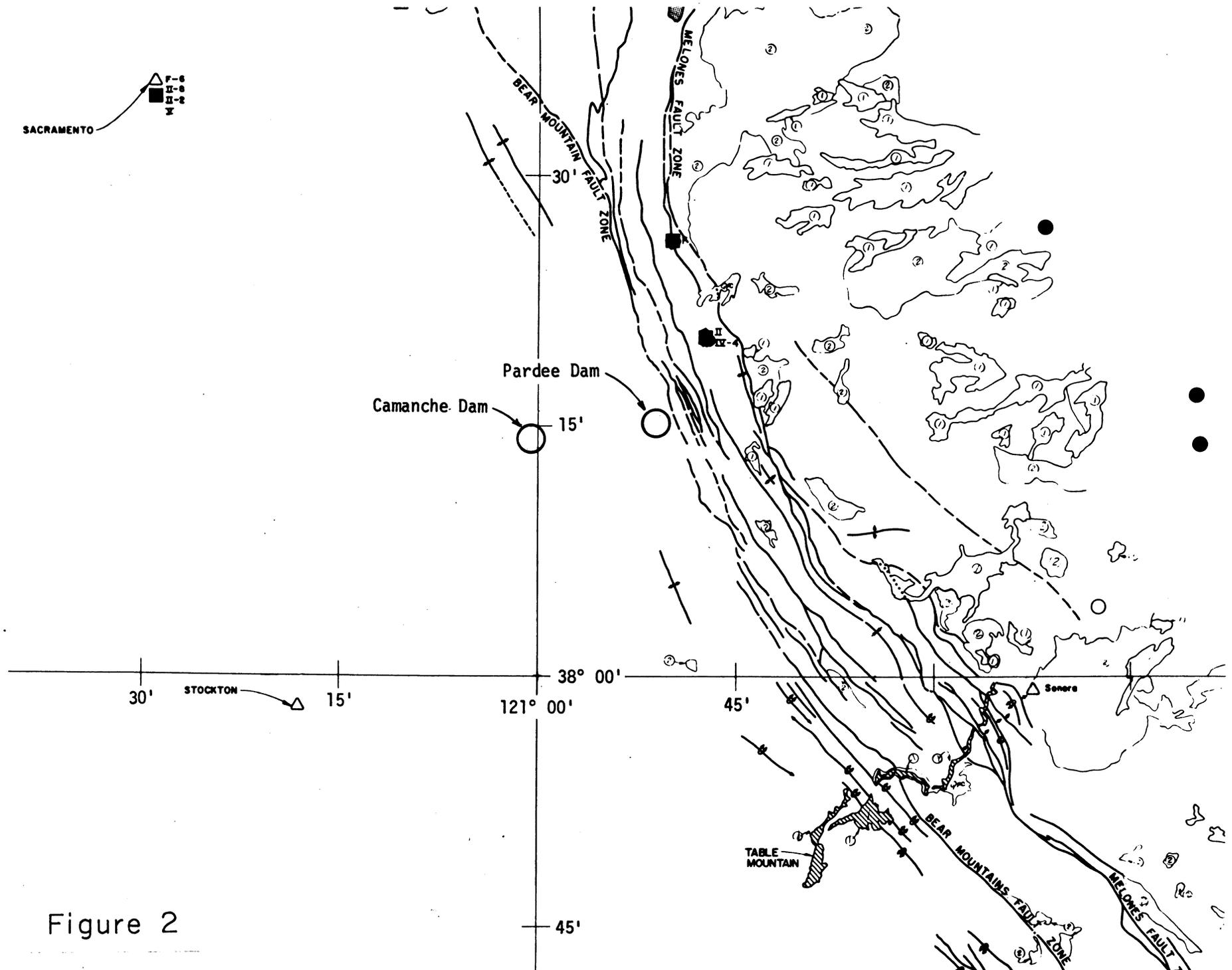
Figure 1

Figure 2

SAN FERNANDO EARTHQUAKE   FEB 9, 1971 — 0600 PST
IID056 71.007.0   CASTAIC OLD RIDGE ROUTE, CAL.   COMP N21E
⊙ PEAK VALUES :   ACCEL = -309.4 CM/SEC/SEC   VELOCITY = -16.5 CM/SEC   DISPL = 4.2 CM
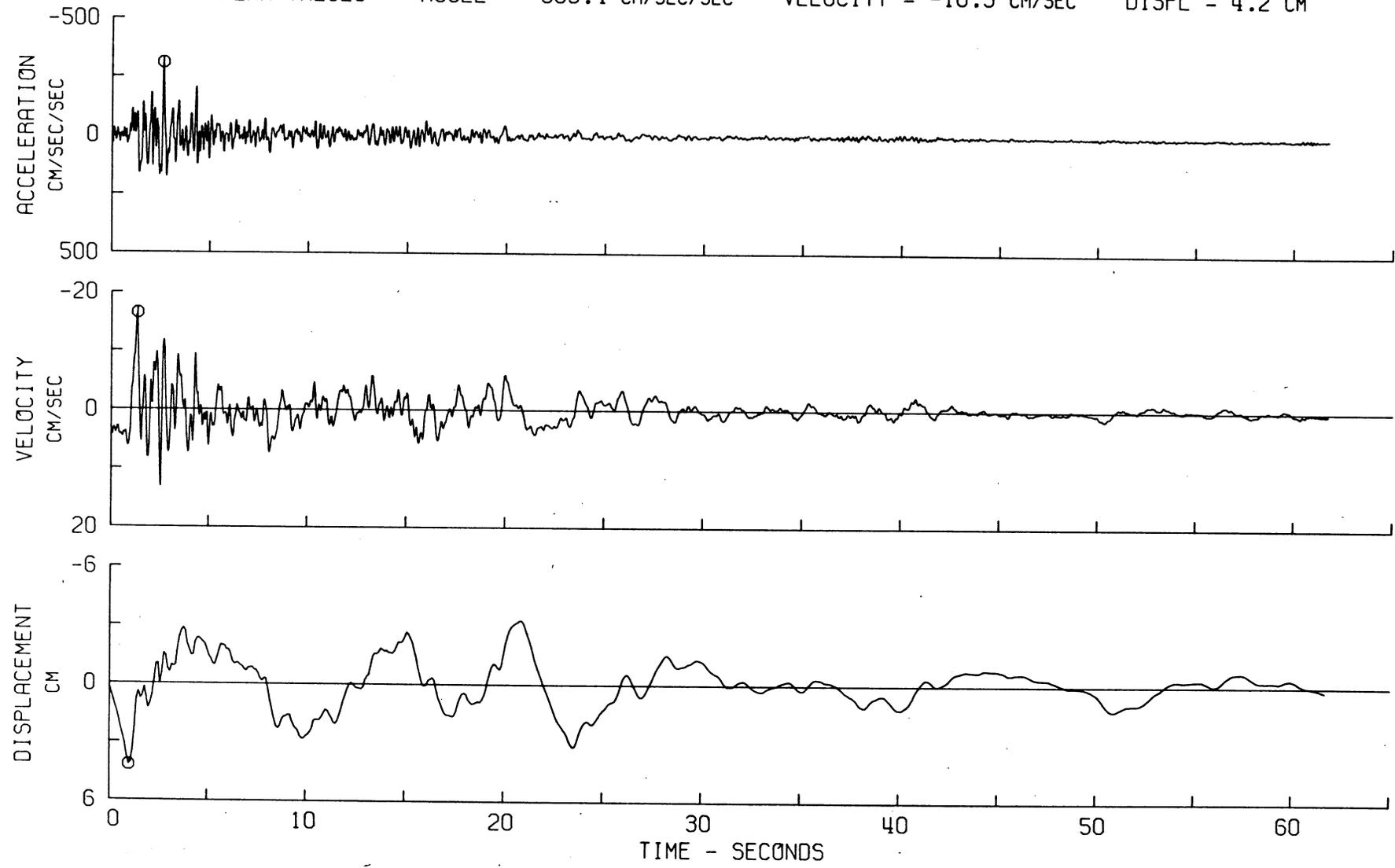
Figure 3