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CSMIP STRONG-MOTION INSTRUMENTATION AND RECORDS FROM TRANSPORTATION STRUCTURES - BRIDGES

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ABSTRACT

Seven transportation structures have been instrumented by the California Strong Motion Instrumentation Program (CSMIP), including four bridges. The instrumentation configurations are presented for these bridges, with a discussion of the planning guidelines used in selecting and instrumenting the structures. Significant records (in excess of 0.25 g maximum acceleration) have been obtained from three highway bridges. At one bridge, a freeway overpass on Hwy 101 in Rio Dell (near Eureka in northern California), strong shaking has been recorded from three separate earthquakes. Preliminary analyses of a subset of these records indicate that the vertical response of the bridge superstructure was much greater than the horizontal response.

INTRODUCTION

The damage that occurred to highway bridges during the San Fernando earthquake of February 9, 1971 demonstrated that the response of these structures during earthquake shaking was poorly understood. The behaviour of these bridges led to the initiation of an effort within the California Strong Motion Instrumentation Program (CSMIP) to instrument bridges and other transportation structures in the mid-1970s. Several goals were considered in planning the instrumentation in place today. Early analyses of bridge response data by Raggett and Rojahn (6) and the general planning concepts introduced by Rojahn and Raggett (8) were major contributors to present instrumentation concepts. There are two principal factors in the planning of strong motion instrumentation - the selection of the facility to be instrumented, and the location of sensors on the facility.

SELECTION AND INSTRUMENTATION OF STRUCTURES

Selection of Structure

The selection of a structure to be instrumented is typically made on the basis of the type of the structure and its location. In the selection of buildings for instrumentation, a basic assumption has been that the most desirable strong motion records would be those obtained

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from structures which undergo damage from an earthquake. This approach leads directly to implications on location: the most desirable locations are those near enough to a fault of sufficient potential that severe shaking may be expected at the site in the lifetime of the structure.

The type of structures selected for instrumentation depends on at least two factors. The structure should be simple, and it should be typical in design. The value of a simple structure is that fewer assumptions are needed in interpreting or modelling the recovered data. A structure which is typical of many others is of value because the lessons learned from the interpretation of data from one structure are transferable to other similar structures.

Locating Sensors on a Structure

Rojahn and Raggett (8) list three approaches which can be used to guide the planning of instrumentation for a selected structure. These include: force level determination, mathematical model identification, and mathematical model verification. Each of these approaches require differing amounts of instrumentation and provide differing levels of detail about the motion of the structure. The first, force-level determination, requires an extensive amount of instrumentation if accurate force levels are to be determined from the recorded data without resort to mathematical models of the structure. The second, model identification, also requires extensive instrumentation because the objective is to actually develop a mathematical model of the structure from the recorded data. The last approach, model verification, requires the least instrumentation because only selected measurements are desired to verify particular aspects of an existing mathematical model for the structure.

Transportation structures instrumented by CSMIP have mostly been planned with either force-level determination or model verification in mind. Perhaps after detailed analysis of the response of several transportation structures the more limited model-verification instrumentation approach will see wider application.

INSTRUMENTED TRANSPORTATION STRUCTURES

Seven transportation structures have been instrumented in basic accordance with the considerations and guidelines discussed above. These seven structures, listed in Table 1, include a tunnel, a wharf and an airport tower in addtion to four bridges. The tunnel, Caldecott Tunnel in the east-Oakland area, is a part of a major surface traffic artery. The instrumentation of this structure was completed in 1979 and is described by Ragsdale and McJunkin (7), and in general by Brekke (1). Surface and downhole (275 feet) triaxial accelerometers measure input earthquake ground motion at a site 390 feet northwest of the tunnel center. Thirteen sensors are located within the tunnel to record its response. They were mounted at three locations within the tunnel: three sensors were located near the east portal, seven were located 1,040 feet in from the east portal, and three were located about 1,600 feet in from the east portal, near the center of the tunnel.

TABLE 1

TRANSPORTATION FACILITIES INSTRUMENTED BY CSMIP

Structure	Description	N.Lat. W.Long.	No. Chns	Date Installed	No.Records, Max.Accel.
San Juan Bautista Overpass	Hwy 101/156 Separation Bridge	36.86N 121.58W	12	5/77	1, 0.33g
Rio Dell Overpass	Hwy 101/Painter St Overpass	40.50N 124.10W	20	9/77	3, 0.66g
Meloland Overpass	Hwy Interstate 8 Overpass	32.77N 115.45W	26	4/78	1, 0.50g
Caldecott Tunnel	Hwy 24 Tunnel, east of Oakland	37.86N 122.21W	19	12/79	2, 0.03g
Vincent Thomas Bridge	Suspension bridge, Long Beach	33.75N 118.27W	26	10/81	0
Oakland Wharf	14th St. Wharf, Port of Oakland	37.82N 122.31W	12	1/84	0
Lancaster Air Control Tower	Fox Field Tower, Lancaster	37.74N 118.21W	9	3/84	0

The Oakland Wharf is a long (1,620 feet) concrete, pile-supported, deck structure 65 feet wide. Two triaxial sensors are located on the ground, approximately forty feet from the deck to measure input motion. Six horizontal sensors have been placed along the deck to measure its transverse and longitudinal response.

The Lancaster Airport Tower is a sixty foot high braced steel structure typical of the design used by the Federal Aviation Admin. (FAA) at many small airports in California. A triaxial sensor package was placed at the base of the structure to measure the input at ground level. Horizontal and torsional response of the structure is measured by three sensors below the control cab and three sensors on the roof of the cab.

Future plans for CSMIP include the instrumentation of 40 transportation structures of various types in California. Bridges are the most common type of transportation structure instrumented to date. The bridges instrumented by CSMIP are described in the following sections, in addition to the strong motion data recorded to date.

INSTRUMENTED BRIDGES: OBJECTIVES AND SENSOR CONFIGURATIONS

Table 1 indicates that a total of four bridges have been instrumented by CSMIP in the last seven years. The most recent is also the most complex - the Vincent Thomas Bridge, a three-span suspension bridge in Long Beach. The schematic illustration of the location of the 26 sensors on the structure is shown in Figure 1. This bridge is the only suspension bridge instrumented by CSMIP. The instrumentation was a cooperative effort between the CSMIP and the USGS. A report by C. Rojahn is in preparation on this project, which is not further discussed here.

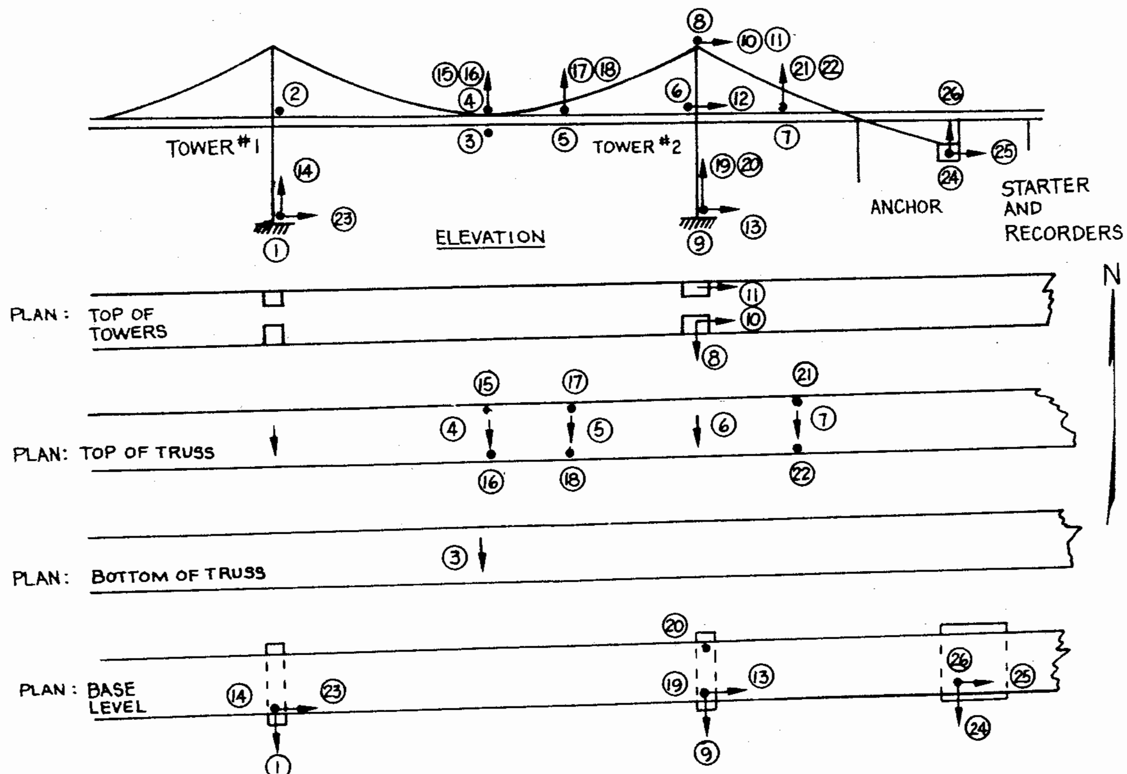

Figure 1. Schematic of strong-motion instrumentation on the Vincent Thomas Bridge in Long Beach. The locations and orientations of the 26 accelerometers are indicated by arrows and dots, which represent arrows normal to the plane of the figure.

Three freeway overpasses are presently instrumented by the CSMIP. The Meloland Overpass, shown in Figure 2, is a good example of a simple freeway overpass. The bridge is a continuous two-span cast-in-place reinforced-concrete box girder with spans approximately 105 feet in length. Figure 2 shows a total of 26 sensors (force-balance accelerometers); these are recorded on two 13-channel analog film recorders. This heavily instrumented structure is a good example for considering in some detail the factors involved in choosing appropriate sensor locations on the structure.

The three principle approaches in strong-motion instrumentation, as discussed above, are force-level determination, model identification, and model verification. Force-level determination and model identification both require relatively extensive instrumentation. For either of these approaches, Rojahn and Ragget (8) note that the number, location and orientation of sensors required on the structure depend on 1) the anticipated modes of structural response; 2) the extent of symmetry in the structure; 3) the number of locations needed to adequately characterize the input motion, and 4) the potential failure mechanisms.

The layout of sensors for the Meloland Overpass in Figure 2 is a good example of the application of these guidelines. The free-field motion is recorded by three sensors (14,15,24) approximately 200 feet from the bridge. Input motion, as well as the response of the embankments, are recorded by the triaxial sensors at the south (10-12) and north (23,25,26) embankments. Input motion is also measured at the base of the central support column (1,2,4). The remainder of the sensors, on the bridge itself, are primarily oriented vertically or horizontally (transverse to the bridge). The verticals along the east edge of the deck (19,16,17,20,6) provide the vertical motion along that edge of the bridge, and coupled with the corresponding sensors on the west edge of the deck (18,21,22) provide for a complete picture of the first-mode vertical motion of the spans and the torsional motion of the deck. The transverse horizontal response of the deck is provided by the transverse sensors along the east edge of the deck (3,5,7,9,13). Finally, the sensors at the foot of the central support column (1,2,4) provide a reference for relative motion of the bridge superstructure relative to the base of the column. Some longitudinal response information is provided by sensors 4 and 25.

This structure was instrumented by CSMIP during 1978, with sensor layout planned by C. Rojahn and J. D. Raggett of the U.S. Geological Survey and J. H. Gates of the Califonia Department of Transportation. Fortunately, during the following year the Imperial Valley earthquake occurred (15 Oct 1979) and resulted in an extensive set of data from the bridge. These data (4) have been used in several research projects (e.g., Lisiecki (3), Rojahn and others (9)).

In contrast with the Meloland Overpass, instrumented well enough for model identification studies, the San Juan Bautista Overpass has relatively limited instrumentation. This bridge, shown in Figure 3, is a long five-span structure, with instrumentation most appropriately described as model verification since only two of the five bents are instrumented. Good records were recovered from this bridge during the

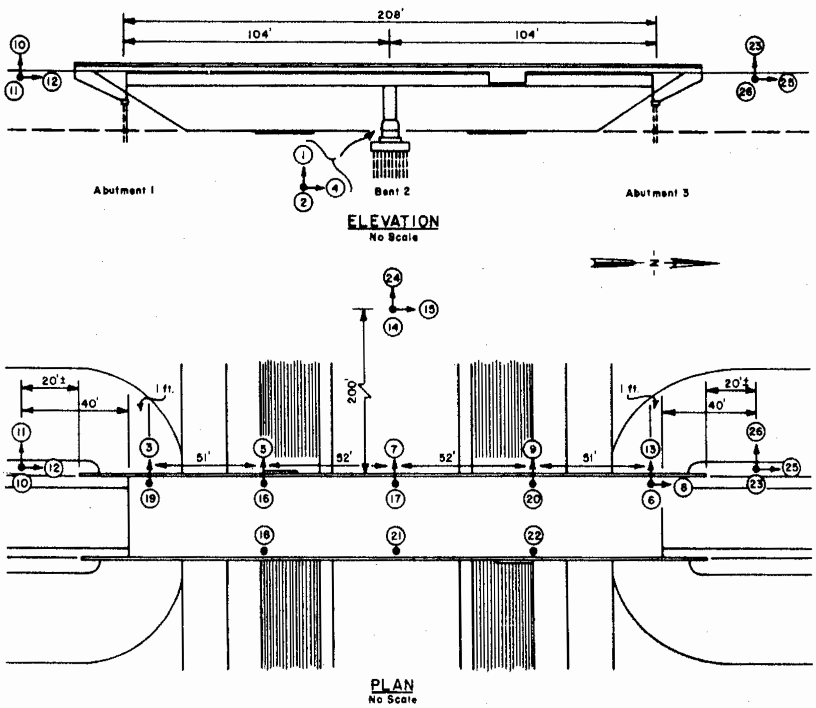

Figure 2. Schematic of strong-motion instrumentation installed on the Meloland Overpass over Hwy 8 near El Centro in southern California. Faulting associated with the 15 Oct 1979 Imperial Valley earthquake passed within 0.5 km of this overpass.

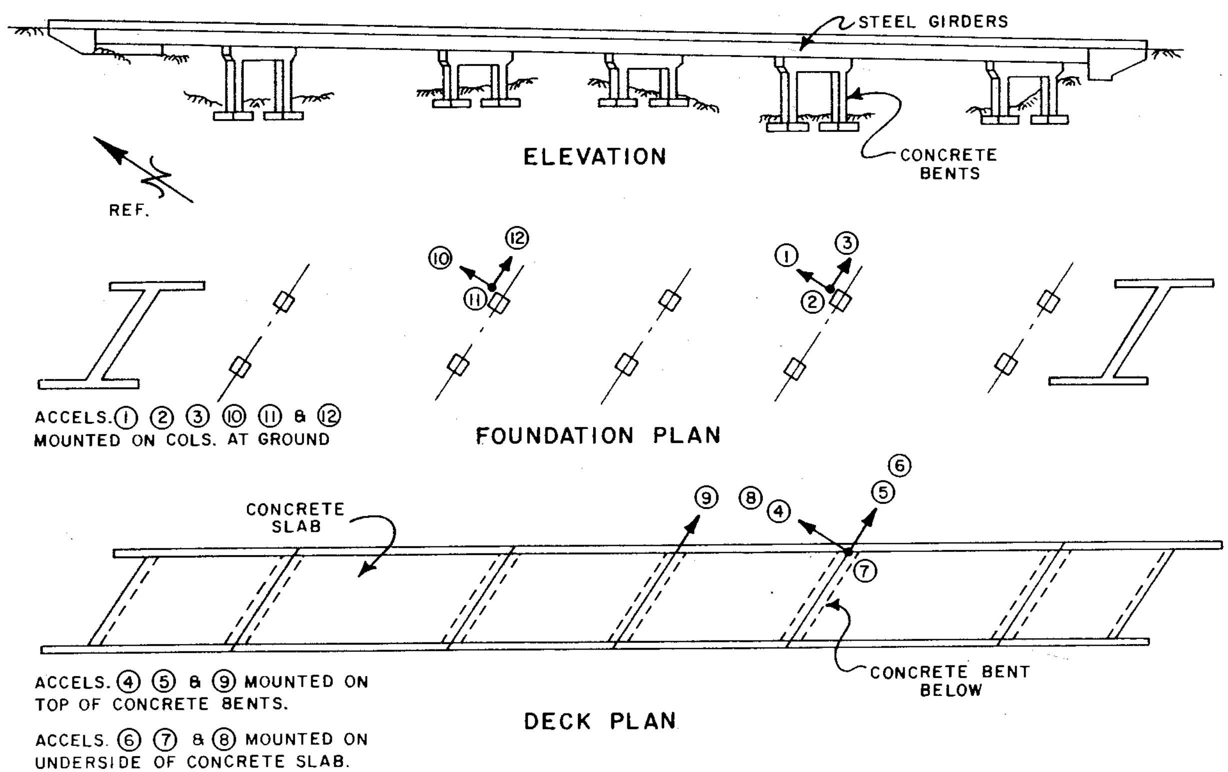

Figure 3. Schematic of strong-motion instrumentation installed on the San Juan Bautista Overpass, a highway 101/156 separation bridge near Gilroy.

1979 Coyote Lake earthquake and have been digitized (Porter and others, (5)) and subsequently analyzed by several investigators.

The third freeway overpass instrumented by CSMIP is located in Rio Dell (near Eureka) on Hwy 101 (see Figure 5). This structure, shown schematically in Figure 4, is relatively simple like the Meloland Overpass, except that the longitudinal axis of the bridge is skewed relative to the highway passing underneath. The instrumentation layout is similar in many respects to that of the Meloland Overpass. One difference is that only one edge of the bridge deck is instrumented, so that twisting or torsion of the deck cannot be measured. At the east end of the bridge triaxial sets of sensors are located both on the embankment and end of the bridge deck so relative motion between the deck and the embankment can be measured.

These three overpass bridges, Meloland, San Juan Bautista and Rio Dell, have each recorded strong shaking since they were instrumented in the late 1970s. The Rio Dell overpass has recorded strong shaking three times since it was instrumented, making it of particular interest.

STRONG MOTION RECORDS FROM THE RIO DELL OVERPASS

The Rio Dell Overpass was shaken by the large (6.9ML) Trinidad-Offshore earthquake of November 8, 1980 and by two additional events since then. The locations and magnitudes of the earthquakes are indicated on the map of Figure 5 and listed in Table 2. The maximum accelerations recorded at the bridge was over 0.25g for each event, as indicated in Table 2. The earthquake magnitudes and distances vary from the local Rio Dell 4.4ML event of 16 Dec 82, at a distance of 15 km, to the 6.9ML Trinidad-Offshore event of 8 Nov 1980 at a distance of 70 km. Records from the most recent event, the 5.5ML Cape Mendocino-Offshore event of 24 Aug 1983, have been digitized recently and are discussed in the following.

TABLE 2

EARTHQUAKES RECORDED BY THE RIO DELL OVERPASS INSTRUMENTATION

Earthquake	Date, Time (GMT)	Location	Depth (km)	Mag. (ML)	Epicentral Distance	Max. Accel.
Trinidad-Offshore	8 Nov 1980, 10:27	41.00N 124.64W	9	6.9	72.	0.34g
Rio Dell	16 Dec 1982, 06:53	40.37N 124.06W	5	4.4	15.	0.60g
Cape Mendocino-Offshore	24 Aug 1983, 13:36	40.31N 124.77W	30	5.5	61.	0.27g

Cape Mendocino-Offshore Earthquake

The instrumentation schematic in Figure 4 indicates that the Rio Dell overpass has a series of vertical sensors along the south edge of the bridge deck, as discussed above. The vertical accelerations recorded at the middle of each span and at the end of the abutments

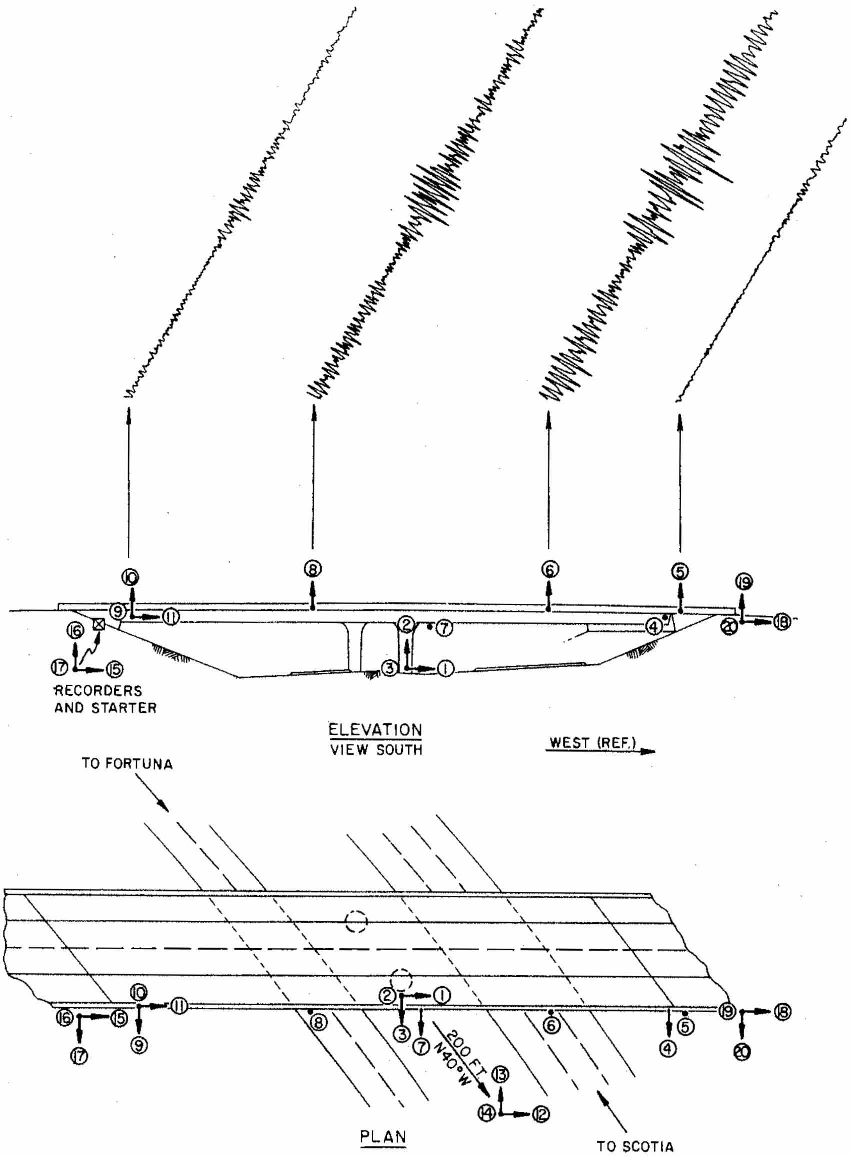

Figure 4. Strong-motion instrumentation installed on the Hwy 101 overpass in Rio Dell (near Eureka in northern California). The upper part of the figure compares the vertical accelerations recorded at the abutments and at the centers of the spans during the 24 Aug 1983 earthquake.

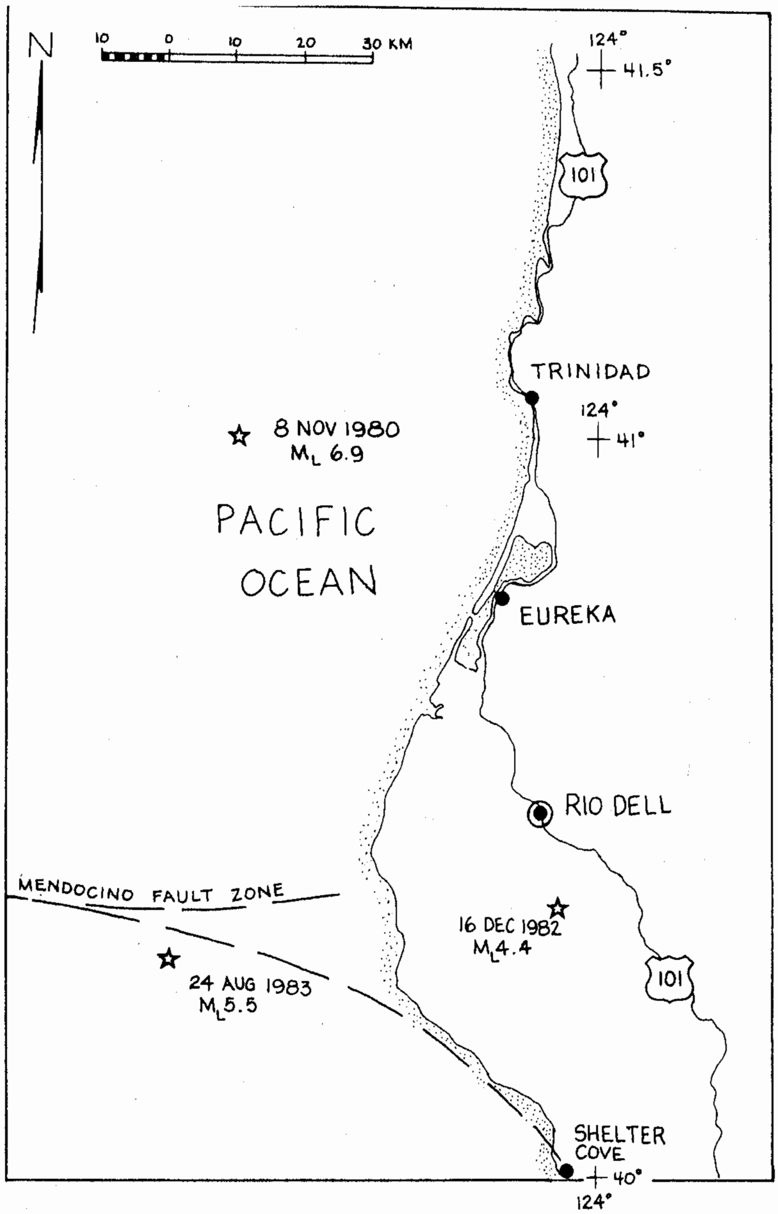

Figure 5. Map of the Eureka area in northern California showing the location of Rio Dell on Hwy 101 and the three earthquakes which generated strong shaking records (>0.25g) at the Rio Dell overpass.

(sensors 5,6,8,10) during the Cape Mendocino-Offshore event are shown in Figure 4. The peak vertical acceleration at the center of the west span (sensor 6) is larger than at the abutment (sensor 5) by nearly a factor of ten. The response spectra for these channels are shown in Figure 6, and they also show a striking difference, with the mid-span spectra higher by a factor of 6 or more at periods shorter than about 0.5 sec (frequencies higher than 2 Hz).

The instrumentation also includes a series of transversely horizontal sensors along the bridge deck. Figure 7 shows the transverse accelerations recorded on the abutments and at the middle of the bridge near the center bent (sensors 4, 7 and 9). In contrast with the dramatic difference seen for the vertical response of the bridge, the transverse accelerations show only a moderate increase in amplitude at the center of the bridge compared to the abutments. The spectra for the west abutment and center bent records are compared in Figure 8. Although the center bent spectra shows some increase over the abutment record at frequencies above 2 Hz, the difference is very much less than for the vertical response shown in Figure 6.

Trinidad-Offshore Earthquake

The largest earthquake recorded in California since the 1952 Kern County earthquake was the 6.9ML Trinidad-Offshore earthquake of 8 Nov 1980. The rarity of large earthquakes make that an important event. The nature of ground motion from large earthquakes is indicated by the displacement record from the free-field instruments of the Rio Dell instrumentation, shown in Figure 9. The long-period nature of the ground motion and its long duration are expected properties of large-earthquake records not present in the many existing records from moderate earthquakes.

That the response of the Rio Dell bridge was recorded during this earthquake makes the records very valuable. This earthquake caused the collapse of two spans of the Fields Landing Overpass on Hwy 101, about 23 km (15 mi) north of Rio Dell. As discussed by Imbsen (2), that overpass failed because of relative displacements between the abutments and deck spans. The Rio Dell instrumentation includes sensors on the embankment and the deck oriented to record the longitudinal motion of the deck relative to the embankment. The longitudinal displacements in the free-field, on the east embankment, and on the east end of the deck (sensors 12,11,15) are shown in Figure 9. It is apparent that there is little difference between the displacements at these locations for this bridge, for this earthquake.

CONCLUSION

Seven transportation structures have been instrumented by CSMIP including three freeway overpasses, a suspension bridge, a tunnel, a wharf and an airpot tower. Strong motion records in excess of 0.25g maximum acceleration have been obtained from the three highway bridges. One of the bridges has been shaken by three separate earthquakes ranging from a large, distance earthquake to a small local event. Preliminary analysis of the records indicates a strong response of the bridge spans in the vertical direction, with only moderate response in the transverse horizontal direction.

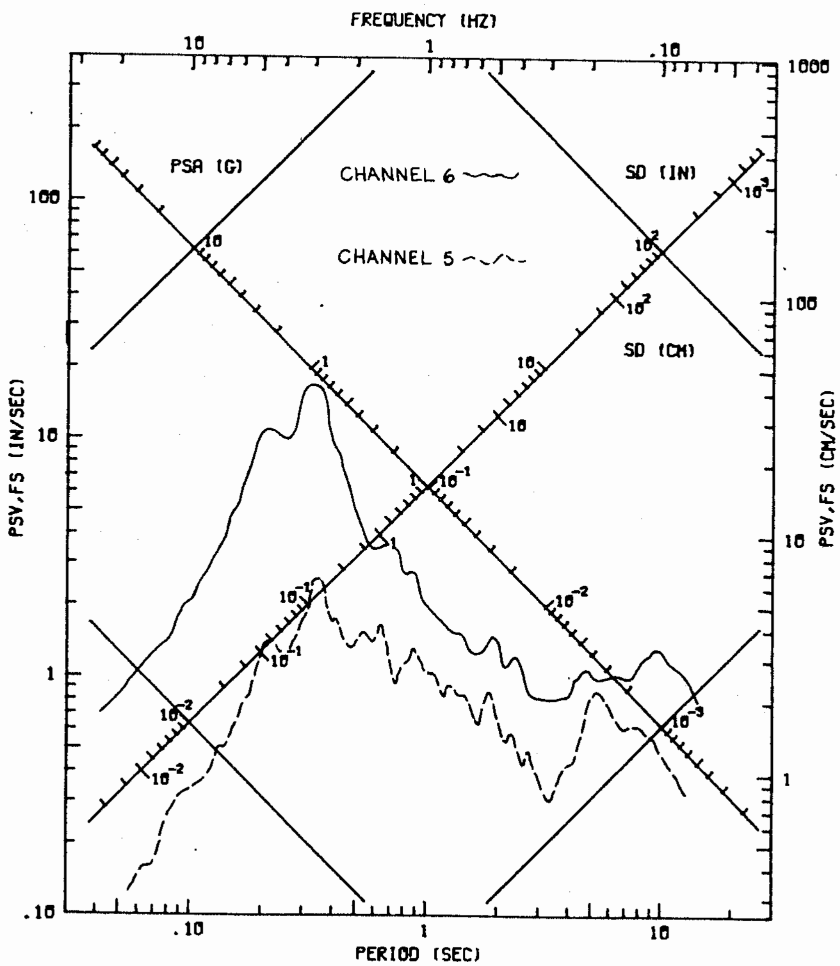

Figure 6. Response spectra (5% damping) for the mid-span (solid, sensor 6) and west abutment record (dashed, sensor 5) of the Rio Dell overpass for the 24 Aug 1983 Cape Mendocino-Offshore earthquake.

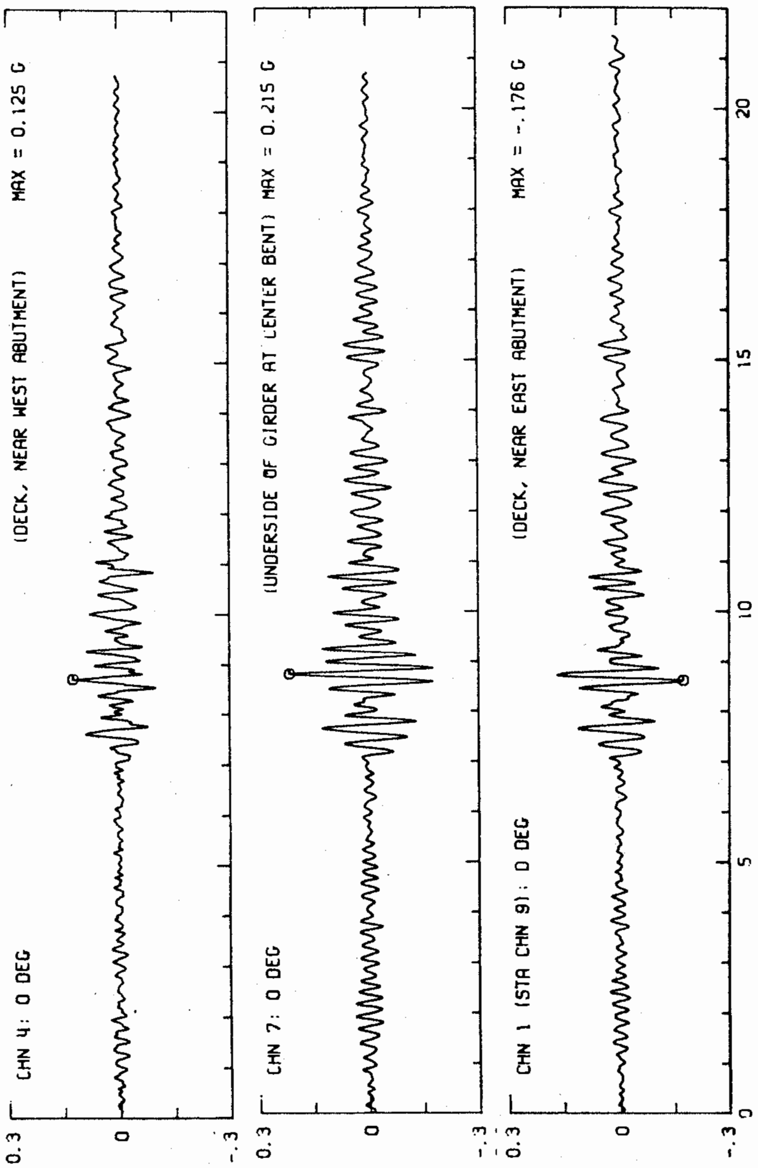

Figure 7. Horizontal transverse acceleration records from the west abutment (upper), bridge center (middle) and east abutment (lower) of the Rio Dell overpass for the 24 Aug 1983 earthquake.

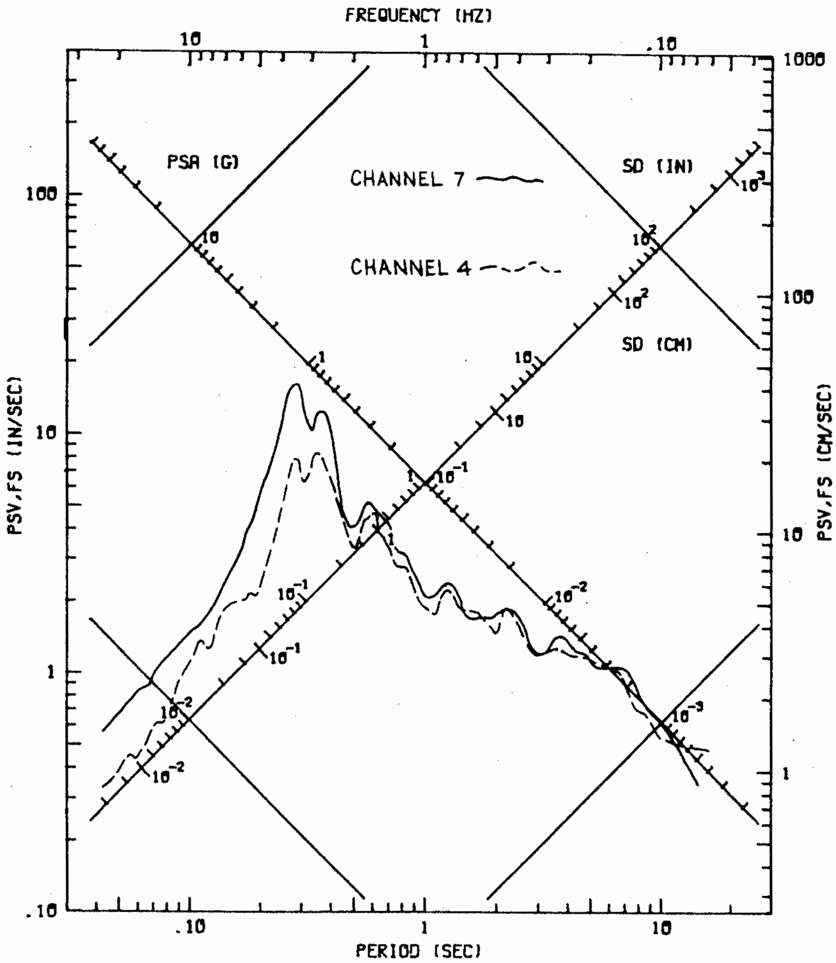

Figure 8. Response spectra (5% damping) for the transverse acceleration records from the bridge center (solid, sensor 7) and the west end of the bridge deck (dashed, sensor 4) of the Rio Dell overpass.

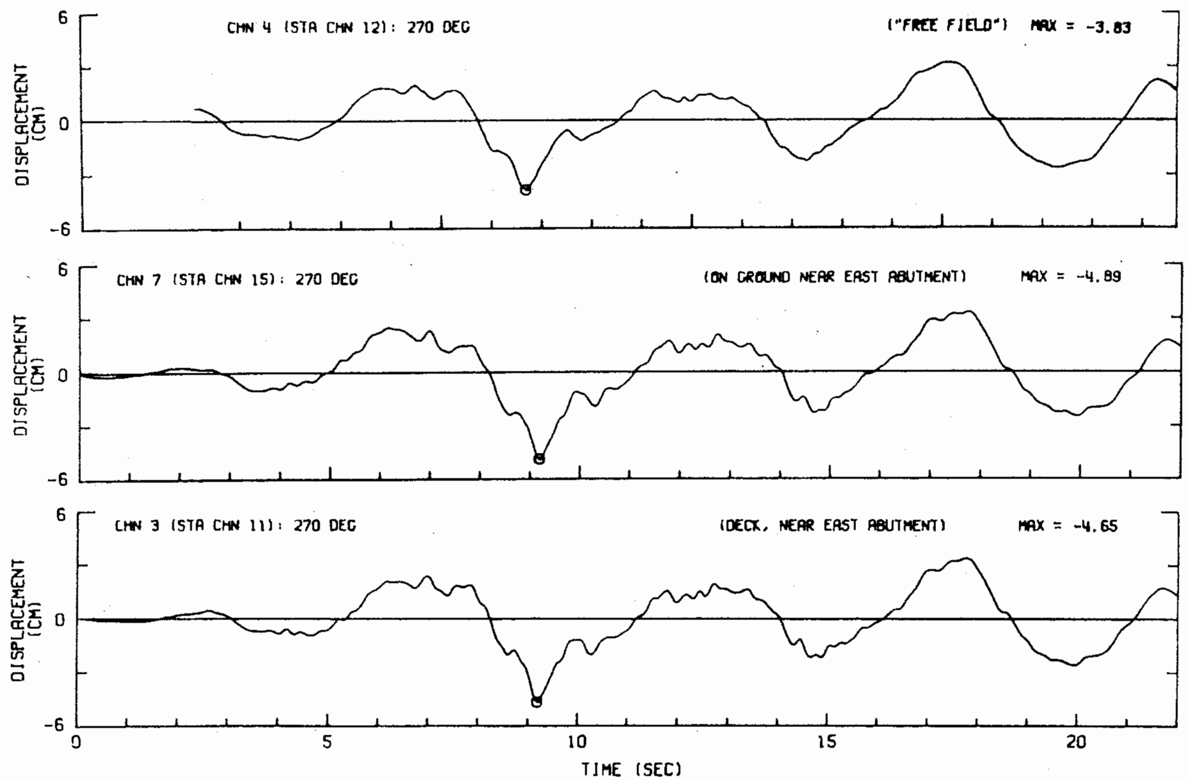

Figure 9. Longitudinal displacements computed from the accelerations recorded at the free-field sensor, at the east embankment, and at the east end of the Rio Dell bridge deck during the 6.9ML Trinidad-Offshore earthquake of 8 Nov 1980.

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