Submitted to ATC Seminar on Base Isolation and Passive Energy -
Dissipation Devices, March 12-13, 1986, San Francisco

OSMS 86-02

RECORDED MOTION OF A BASE-ISOLATED BUILDING DURING THE 1985 REDLANDS EARTHQUAKE

M.J. Huang, A.F. Shakal and J.T. Ragsdale

Office of Strong Motion Studies, California
Department of Conservation, Division of Mines and Geology

ABSTRACT

Low-level acceleration records were obtained in a recently-instrumented base-isolated building. The San Bernardino County Law and Justice Center in Rancho Cucamonga is a 4-story braced steel-frame structure isolated on elastomeric bearings located between the basement and foundation levels. The structure is approximately 414 by 110 feet in plan and 74 feet from the basement to the roof. The building is instrumented with a total of 16 accelerometers which are located at the foundation, basement, 2nd floor and roof levels. An additional triaxial set of accelerometers is deployed in the free-field approximately 330 feet from the building. An earthquake of magnitude 4.8 (ML) occurred on October 2, 1985 near Redlands, at a distance of about 30 kilometers from the building. The records obtained at the building during that earthquake have been digitized and processed. The purpose of this paper is to highlight aspects of these data and present some preliminary interpretation of the structural response indicated by these low level records.

The peak horizontal acceleration was 0.036 g at the foundation level (below the isolators), 0.016 g at the basement level (above the isolators), and 0.029 g at the roof level. The peak vertical acceleration was approximately 0.02 g below and above the isolators. The computed peak horizontal dynamic displacement is 0.07 cm below the isolators, 0.08 cm above the isolators, and 0.19 cm at the roof.

Preliminary analysis of the data indicates that for this low-level motion the structure exhibited a fundamental mode period of about 0.6 second in both the transverse and longitudinal directions and that the modal damping is about 4 percent of critical. The building underwent both torsional motion, roof relative to the basement, as well as rigid body rotation of the entire structure above the isolators. In terms of translational motion, lateral structural deformation dominated over rigid body translation and rocking. The structure above the isolators behaved as a 0.6 sec period conventional structure. The data indicate that the period of the entire structural system did not shift to longer period for this low-level input motion.

INTRODUCTION

The Law and Justice building has 4 stories and a full basement. The lateral force-resisting system consists of braced steel frames in the upper four stories and concrete shear walls at the basement. The structure is isolated on elastomeric bearings placed on the foundation under each of the 98 columns. More detailed information on the base isolation system used in this building is given by Tarics et al. (1984).

The Law and Justice building is instrumented with a total of 19 accelerometers by the California Strong Motion Instrumentation Program (CSMIP). The locations of the accelerometers are shown schematically in Fig. 1. Sensors 1 through 4 are mounted vertically to record the vertical motion at the basement level (above the isolators) and at the foundation level (below the isolators). Located on each edge of the building, the pairs allow measurement of any overturning motions in the transverse direction, whether in the input ground motion or the structural response. Sensors 5 through 13 record the translational motion in the transverse direction at the roof, 2nd floor, basement and foundation. These sensors also allow determination of the torsional or rotational motion of the structure at these levels. Sensors 14 through 16 record the translational motion in the longitudinal direction. Sensors 17 through 19 are a triaxial set deployed about 330 feet from the building to record free-field ground motion unaffected by soil-structure interaction. The signals from each of the sensors are recorded on two multichannel recorders located in the center of the building. Sensors 1-13 are connected to one recorder and 14-19 are connected to a second recorder synchronized with the first.

RECORDED MOTION

The accelerograms recorded in this building and other structures during the October 2, 1985 Redlands earthquake are available in a report (OSMS 85-02, 1985). The acceleration records from the base-isolated Law and Justice building have been digitized and processed although they are of low amplitude. The acceleration records from the transverse sensors are shown with a sectional view of the structure in Fig. 2. The entire set of acceleration records obtained from the 19 sensors is shown in Fig. 3. The displacement records obtained from these acceleration records after digitization are shown in Fig. 4. Although the motions are of low amplitude, the records provide valuable information about the response of this building to earthquakes and the effects of the bearings on the structural response at low levels of shaking.

Comparison of the motions across the isolators shows a dramatic difference in the horizontal motion. High-frequency horizontal motions of around 12 to 16 Hz in the records from sensors 11-13 and 16 at the foundation level (below the isolators) were filtered out by the isolators and are not present in the corresponding records from sensors 8-10 and 15 at the basement level (above the isolators). In contrast with these differences in the horizontal motion, the vertical motions below the isolators (sensors 1 and 2) differ only slightly from those above (sensors 3 and 4).

Spectral Comparisons

To clarify the differences in the horizontal motions at different levels in the structure, response spectra (5 percent damping) from the roof, 2nd floor, and basement are compared in Fig. 5. Spectra from the foundation (below the isolators) and from the free-field site for the same transverse direction are also shown. The free-field and foundation spectra show that much of the input motion was at high frequency, above 10 Hz. This high frequency energy is almost entirely missing above the isolators. The fundamental mode of structural response indicated by the peak near 0.6 sec (1.7 Hz) is obvious in the roof, 2nd floor and basement spectra.

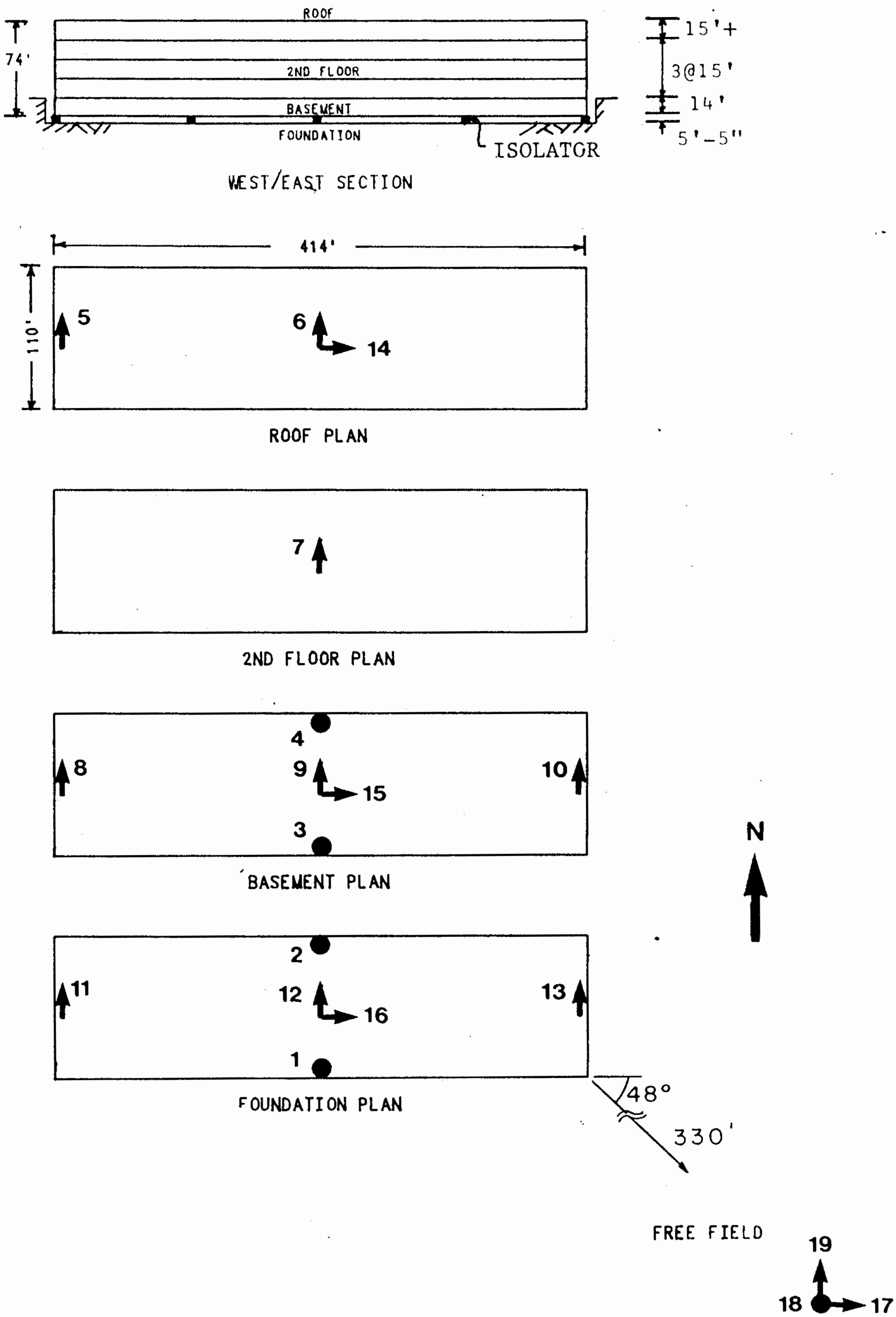

Fig. 1. Locations of acceleration sensors in the Rancho Cucamonga Law and Justice building. Arrows show the location and positive direction of the accelerometers. Dots indicate positive direction out of the plane of the figure.

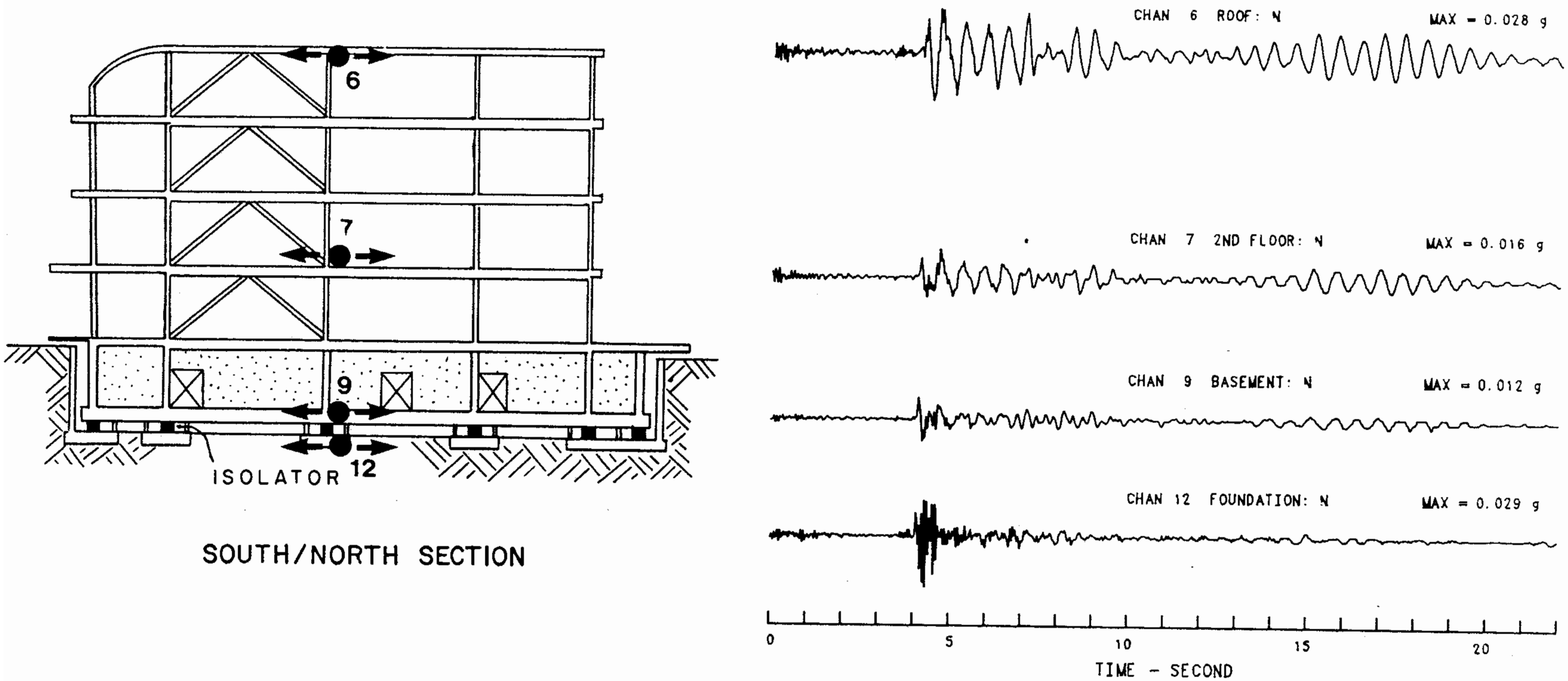

Fig. 2. Cross-section of the Rancho Cucamonga Law and Justice building and accelerograms obtained at the roof, 2nd floor, basement (above the isolators) and foundation (below the isolators) during the Redlands earthquake of October 2, 1985.

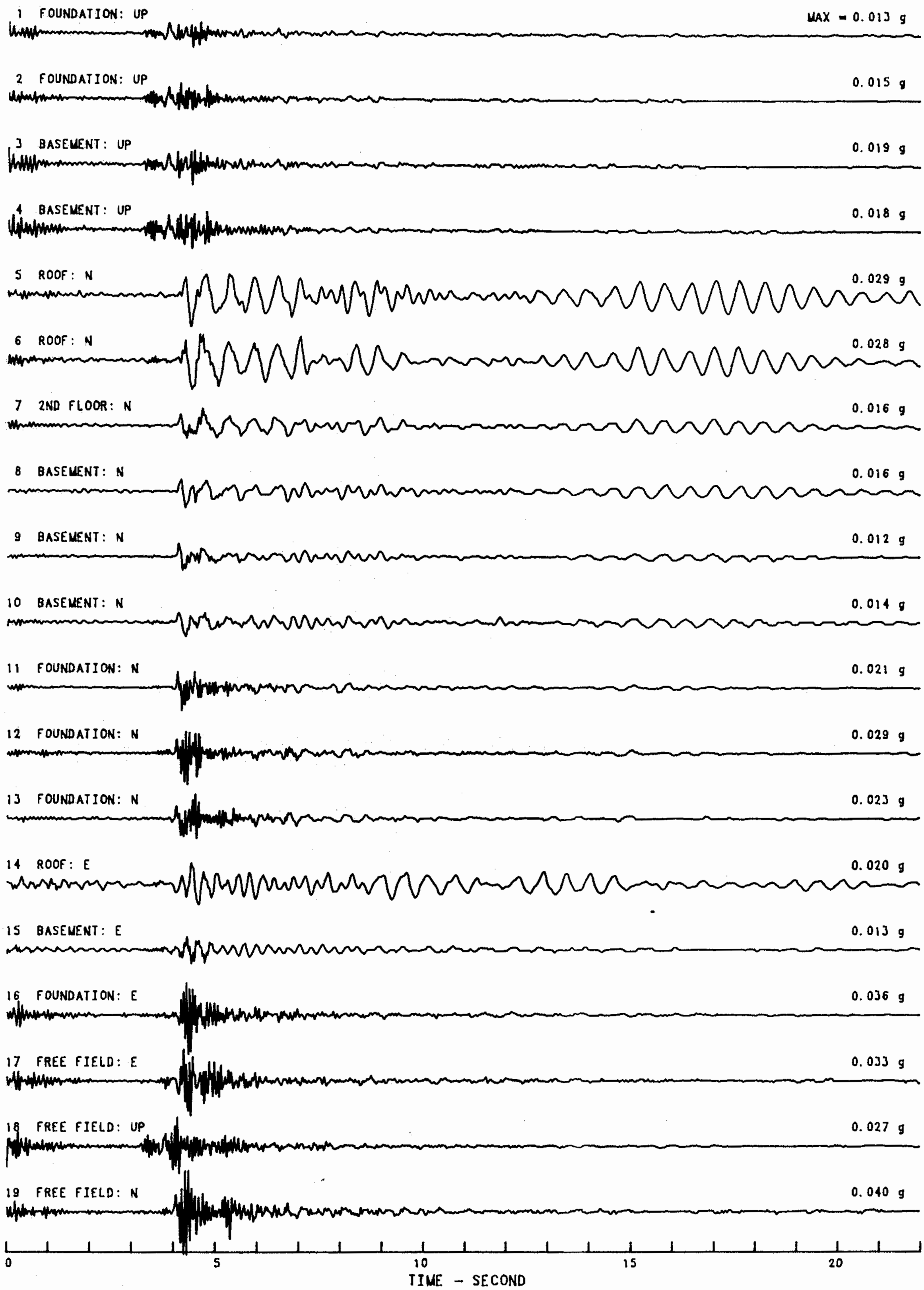

Fig. 3. Acceleration records obtained at the Rancho Cucamonga Law and Justice building during the Redlands earthquake of October 2, 1985.

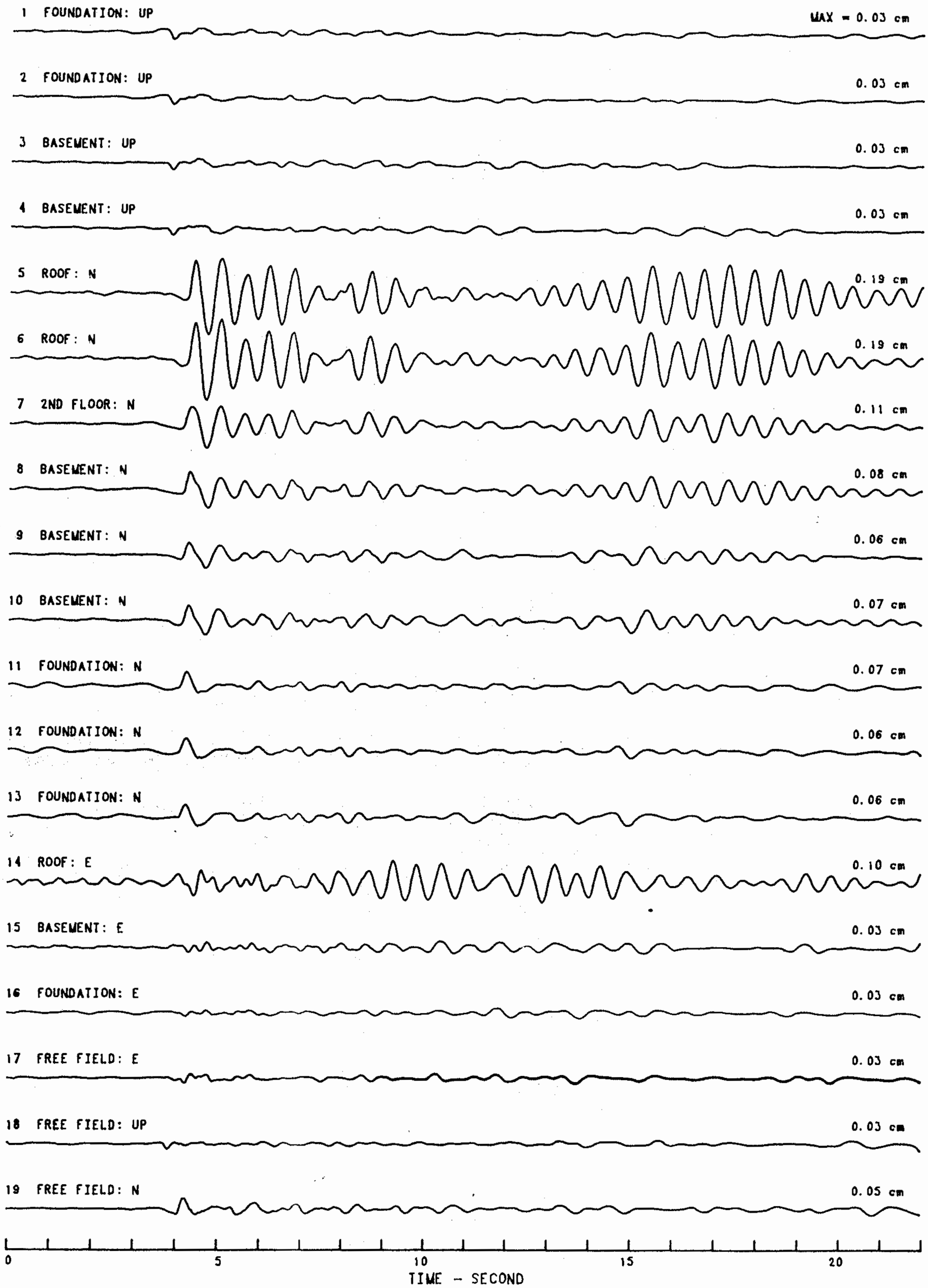

Fig. 4. Displacements computed from the acceleration records in Fig. 3. In processing these records a filter was applied to remove motions of period longer than 1.25 sec (predominantly digitization noise) from each trace.

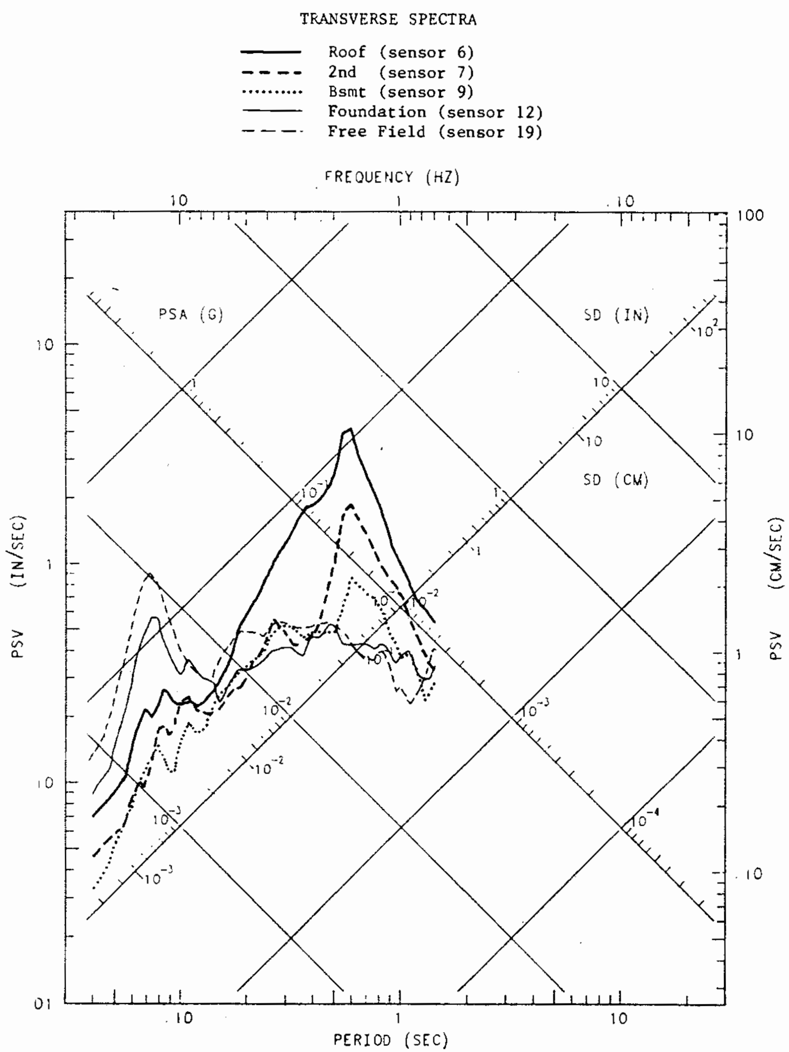

Fig. 5. Response spectra (5% damping) for motion in the transverse direction at the roof, 2nd floor, basement and foundation levels. The spectrum from the free-field site is also shown.

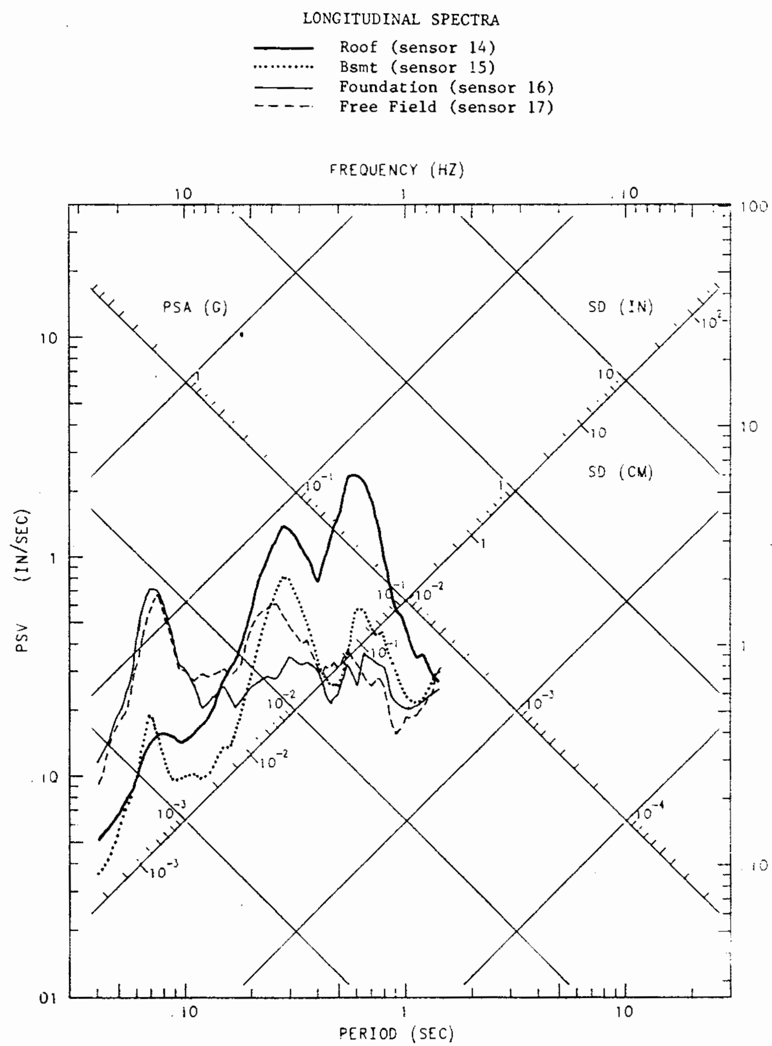

Fig. 6. Response spectra (5% damping) for motion in the longitudinal direction at the roof, basement and foundation levels. The spectrum from the free-field site is also shown.

Response spectra for the longitudinal direction are compared in Fig. 6. High frequency energy (above 10 Hz) again dominates in the free-field and foundation records. The roof spectrum shows a response peak near 0.6 sec (1.7 Hz), similar to that for the transverse direction. An additional peak near 0.3 secs (3.5 Hz) may reflect the second longitudinal translation mode.

The low-level accelerogram recorded at Rancho Cucamonga is near the minimum at which the CSMIP digitization system is reliable. However, noise analyses indicate that the results for this record are accurate for periods shorter than about 1 second (frequencies above 1 Hz).

Relative Displacements

To show the deformation of the structural frame, the displacement of the roof relative to the basement and the second floor relative to the basement are plotted in Fig. 7. The deformation of the isolators is shown by the displacement of the basement relative to the foundation, also plotted in Fig. 7. The relative displacements in the longitudinal directions are also shown in the last two traces in Fig. 7.

For a base-isolated building, the motion of the roof can differ from that below the isolators due to 1) rigid body translation of the structure above the isolators, 2) rocking of the structure, and 3) structural deformation. The motion of the basement relative to the foundation (the third trace in Fig. 7) shows that the rigid body translation is a small part of the total motion. The vertical sensors (numbers 1-4 in Fig. 3) indicate that rocking motion of the structure above the isolators is also quite small. Thus the roof-to-basement displacement shown in the top trace of Fig. 7 is predominately due to structural deformation as seen in a conventional structure.

Differencing the records from the parallel horizontal sensors on the roof, basement, and foundation levels allows estimation of the rotation and torsional motion at these levels. Fig. 8 shows the result of this estimation for the roof and basement levels. These records indicate that between 5 and 10 seconds in the record the data show torsional motion of the structure, roof relative to basement. Between 15 and 20 seconds, the data indicates rigid body rotation of the entire structure above the isolators. The rotational period is near 0.6 second, similar to the translation modal periods.

SUMMARY

The records obtained at the base-isolated building during the 1985 Redlands earthquake provide valuable information on the response of the base-isolated structural system to earthquakes. Although the motions are of low amplitude, the recorded data can be used to check the design assumptions and numerical modelling. It will be of interest to compare the results from these data with those from ambient vibration tests and future large earthquake records. The complete results of processing the records from this building during the 1985 Redlands earthquake are available on magnetic tape and in a report (Huang et al., 1986). Copies of the structural drawings and details on the location of each sensor are available upon request to this office.

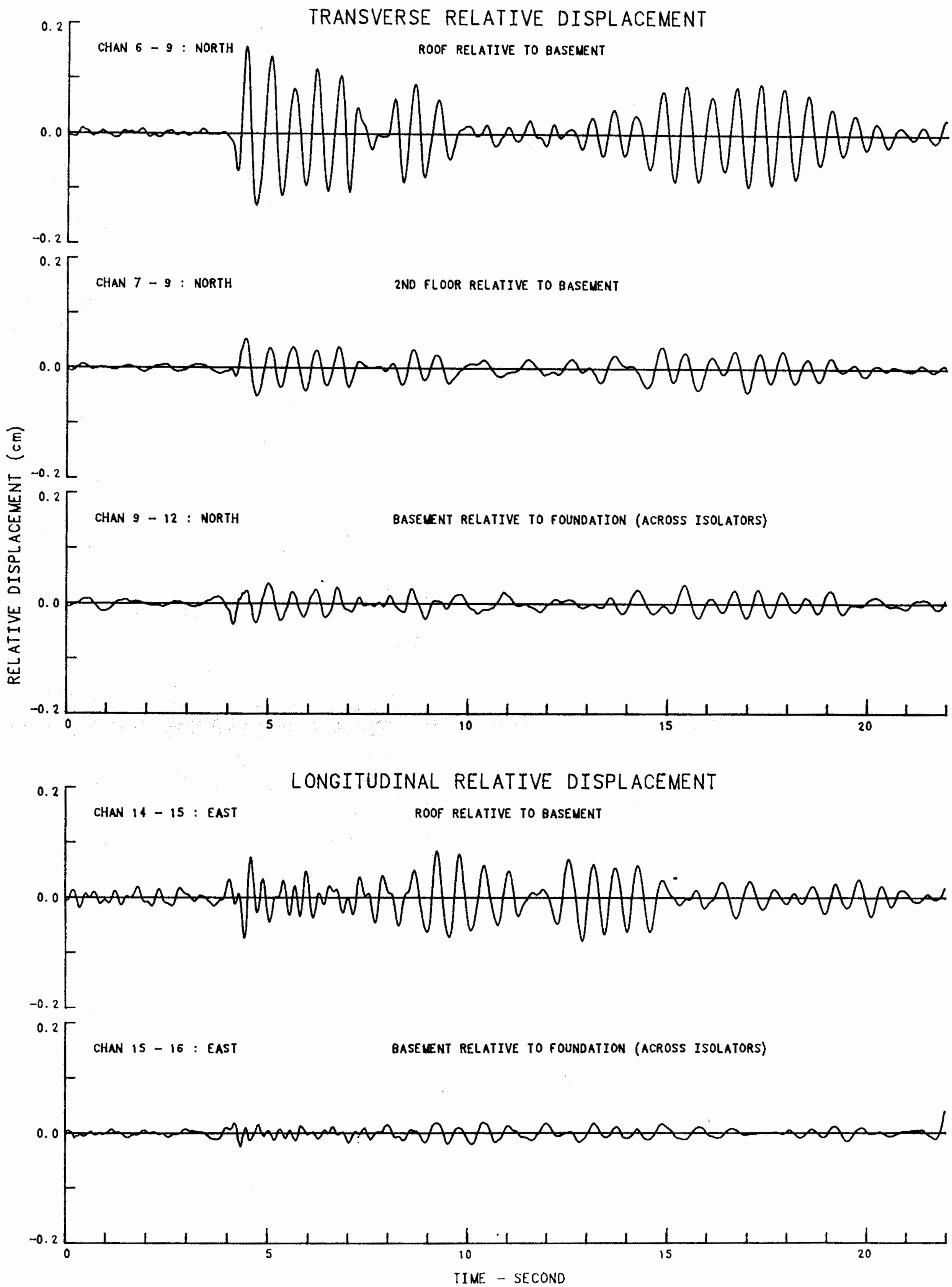

Fig. 7. Relative displacements in the transverse (upper) and longitudinal (lower) direction, Rancho Cucamonga Law and Justice building.

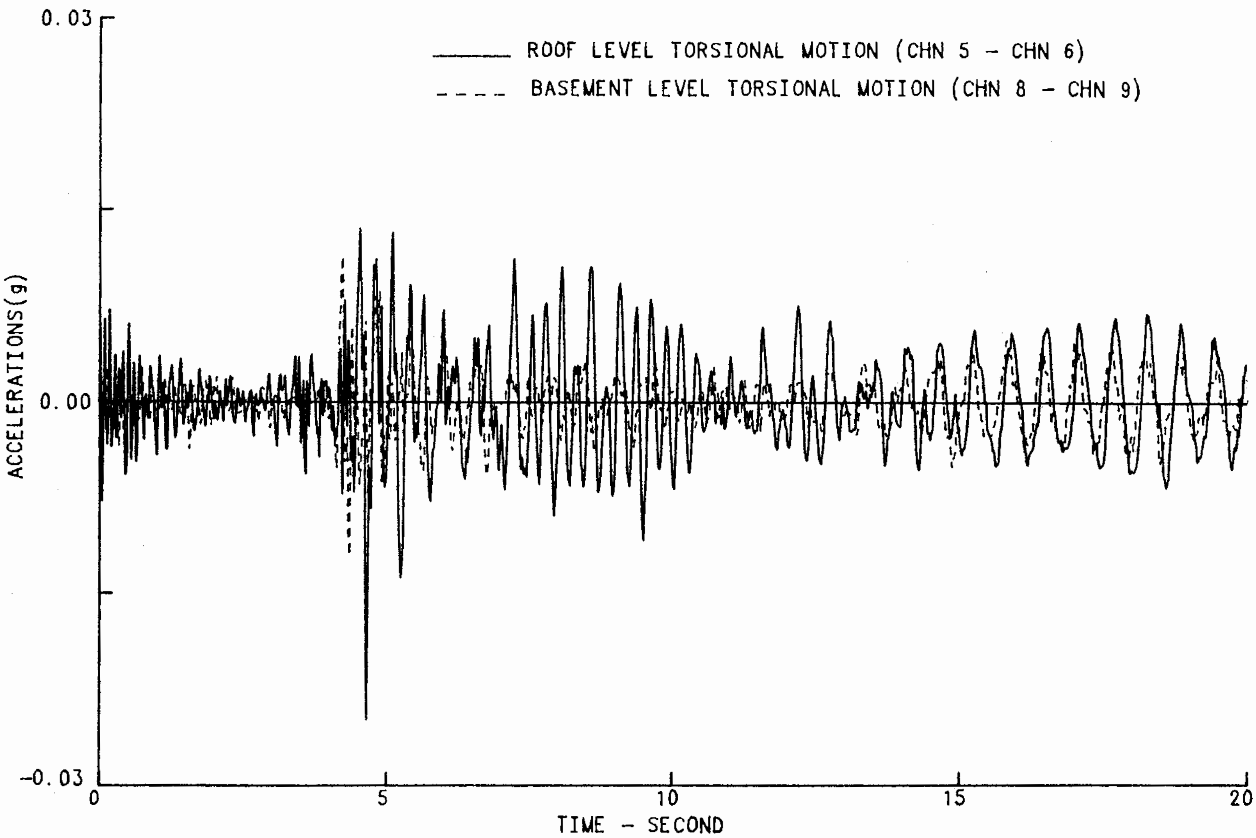

Fig. 8. Torsional motions at the roof and basement levels computed from parallel horizontal sensors 5, 6, and 8, 9, respectively.

REFERENCES

"Selected Accelerograms from the Redlands, California Earthquake of October 2, 1985 (Including First Records from a Base-Isolated Building)," Report OSMS 85-02, Office of Strong Motion Studies, Calif. Div. of Mines and Geology, Sacramento, California.

Huang, M.J., A.F. Shakal, D.L. Parke, J.T. Ragsdale and R.W. Sherburne, 1986, "Processed Data from the Strong-Motion Record Obtained at a Base-Isolated Building in Rancho Cucamonga, California During the Redlands Earthquake of 2 October 1985," Report OSMS 86-01, Office of Strong Motion Studies, Calif. Div. of Mines and Geology, Sacramento, California.

Tarics, A.G., D. Way and J.M. Kelley, 1984, "The Implementation of Base Isolation for the Foothill Communities Law and Justice Center," Report to the National Science Foundation and the County of San Bernardino, 1984.