ANALYSIS OF RECORDS FROM FOUR BASE-ISOLATED BUILDINGS DURING THE 1992 LANDERS EARTHQUAKE

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ABSTRACT

Strong-motion records were obtained from four base-isolated buildings during the 1992 Landers earthquake. The buildings are 2, 5, 8, and 9 stories in height. The distances from these buildings to the Landers earthquake range from 106 to 163 km. The peak accelerations at the foundation level of the buildings were between 0.04 g and 0.11 g. The acceleration responses of the buildings were as high as 0.19 g at the roof.

For each building, the drifts between the roof and the base of the superstructure and the relative displacements across the isolators were derived from the Landers earthquake records. The results show that the 2-story building had negligible drift and its structure above the isolator responded almost like a rigid body during the Landers earthquake. On the other hand, the superstructure drifts for the other three buildings were not negligible. The deformations of the isolators for these four buildings range from 0.8 to 1.6 cm, which are much smaller than the design values (25 to 40 cm), and the fundamental periods are slightly longer than the fixed-base periods.

INTRODUCTION

Four instrumented base-isolated buildings in California are part of the strong motion network of the California Strong Motion Instrumentation Program (CSMIP) in the Division of Mines and Geology of the California Department of Conservation. All four buildings have experienced low levels of earthquake ground shaking. The locations of these four buildings and the epicenters of three recent earthquakes are shown in Figure 1. The most significant earthquake recorded at these building is the magnitude 7.5 Landers earthquake of June 28, 1992. The distances of the buildings to the Landers epicenter range from 106 to 163 km. Although the peak accelerations in the Landers earthquake are similar to those recorded from other earthquakes, the duration of shaking is much longer than in any of the other records obtained at these buildings.

The Landers strong-motion records are analyzed and presented in this paper. A comparison is made between the responses of these four base-isolated buildings to the Landers earthquake. The responses compared include the periods of vibration, the displacements across the isolator bearings, and the drifts of the superstructures.

DESCRIPTION AND INSTRUMENTATION OF BUILDINGS

1) Rancho Cucamonga - 4-story Law & Justice Building. The San Bernardino County Law and Justice building in Rancho Cucamonga is a 5-story structure and is the first building constructed using a base-isolation system in the United States. The building is 414 by 110 feet in plan and 74 feet in height from the basement to the roof. The lateral force-resisting system of the superstructure consists of 4-story braced steel frames in the upper four stories and concrete shear walls in the basement. The structure is isolated by 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 in Tarics et al. (1984).

   The Law and Justice Building was instrumented by CSMIP in 1985 with 16 accelerometers in the building and 3 at a reference free-field site. The locations of the accelerometers are shown schematically in Figure 2. Since 1985, low-level strong-motion records from seven earthquakes have been obtained at this building. The first records from the 1985 Redlands earthquake were discussed in Huang et al. (1986). The closest earthquake is the magnitude 5.5 Upland earthquake and the farthest earthquake is the magnitude 7.5 Landers earthquake.

2) Los Angeles - 2-story Fire Command and Control Building. The Los Angeles County Fire Department's Fire Command and Control Building is a base-isolated 2-story structure which has a plan dimension of 188 by 84 feet. The lateral force-resisting system consists of perimeter braced steel frames supported by isolation bearings under all 32 columns. The isolators have a restraint system to control the uplift and the horizontal displacement across the bearings. Detailed information on the building is given in Bachman et al. (1990) and Anderson (1990).

   The Fire Command and Control Building was instrumented by CSMIP in 1990 with 16 sensors in the building and 3 at a reference free-field site. The locations of the sensors are shown schematically in Figure 4.

3) Los Angeles - 7-story University Hospital. The USC University Hospital is a 7-story steel braced frame building with a 1-story basement. The floor plan is quite irregular and has two wings connected by a narrow section. The seismic isolation system consists of 68 lead-rubber isolators and 81 elastomeric isolators. Most of the lead-rubber isolators are located under the perimeter frame. Detailed information on the building is given in Asher et al. (1990).

   The University Hospital was instrumented with assistance from CSMIP in 1991. The locations of the 24 accelerometers in the building and three at a reference free-field site are shown in Figure 6.

4) Seal Beach - 8-story Office Building. The Seal Beach Office Building is a 8-story non-ductile concrete frame structure. The building was built in 1967 and was seismically strengthened in 1990 by installing isolators at the ground floor level and adding new exterior frames with supporting foundation. The 26 interior and four corner columns have one isolator

per column. The remaining 24 exterior columns have two isolators each. Detailed information on the building is given in Hart et al. (1990) and Sveinsson et al. (1990).

The Seal Beach Office Building was instrumented by CSMIP before and after the seismic strengthening was completed in 1991. The locations of the 22 accelerometers in the building and 9 outside the building are shown in Figure 8.

RECORDED STRONG-MOTION DATA

Accelerations

Strong-motion records obtained from four base-isolated buildings are summarized in Table 1. Peak accelerations recorded at the foundation level (below the isolators), the base level (above the isolators) and the roof level are listed in the table. The 1991 Sierra Madre, the 1992 Landers and the 1992 Big Bear earthquakes were recorded at all four buildings. In addition to these three earthquakes, the Rancho Cucamonga building recorded four earlier earthquakes.

The acceleration records obtained from four base-isolated buildings during the 1992 Landers earthquake are included in the CSMIP data report by Shakal et al. (1992). Portions of the acceleration records from selected sensors in the transverse direction are shown in Figure 3 for the Rancho Cucamonga Building and Figure 5 for the Fire Command Building. Similarly, Figure 7 shows records for the University Hospital and Figure 9 for the Seal Beach Office Building.

Comparison of the acceleration across the isolators for each building shows that relatively high frequency horizontal motions were filtered out by the isolators. Significant amplifications of the motions from the base of the superstructure to the roof can be seen in all except in the Fire Command Building. As shown in Figure 5, the motions at the roof, the 2nd floor level and the base of the Fire Command Building are almost identical, which indicates that the building superstructure responded like a rigid body above the isolators.

Differencing the records from a pair of parallel horizontal sensors on the same floor allows estimation of the torsional motion at the floor. The results show that significant torsional motions occurred at the Rancho Cucamonga Building. On the other hand, rigid body rotation of the entire superstructure above the isolators, which does not cause torsional deformation of the superstructure, is significant for the Fire Command Building.

Relative Displacements

To show the drift of the superstructure, the computed displacements of the upper floors relative to the base (above the isolators) are plotted in Figures 10 through 13. The deformation of the isolators for each building is shown by the displacement of the base relative to the foundation, also plotted in these figures. The deformation of the isolators ranges from 0.8 to 1.6 cm, which is much smaller than the design value that ranges from 25 to 40 cm. As shown in Figure 11, the superstructure of the Fire Command Building had negligible drift and most deformation occurred at the isolators. The same results are also seen in the Sierra Madre earthquake record for this building.

Profiles of the maximum displacement at each floor level relative to the foundation are plotted in Figure 14. The deformations of the isolators during the Landers earthquake are about the same for all four buildings. The superstructure of the Fire Command Building responded as a rigid body although the isolator deformations were much smaller than the design values.

The hysteretic response of the isolators at the Fire Command Building can be investigated from the lateral force versus relative displacement diagram. Since the building responded as a rigid body, the lateral force (or the base shear) experienced by the isolator is proportional to the acceleration recorded by Sensor 9, directly above the isolator. The relative displacement across the isolator, computed from the motions recorded by Sensors 9 and 6, is shown in Figure 11. The hysteresis loops corresponding to small motions, from 17 to 20 seconds, and large motions, from 29 to 32 seconds, are shown in Figure 15. The reduction of the stiffness of the isolator at large response can be seen in this figure. The equivalent viscous damping ratio calculated from the loop is about 10%.

Periods of Vibration

Periods of the fundamental mode are estimated from the records and are compared with the periods for the fixed-base structure (without isolators) and the design periods for the entire structure with isolators in Table 2. The periods during earthquakes were estimated from the portions of the records where the maximum response occurred. The fixed-base periods were obtained from either ambient measurements or computer modelling by the design engineers. As shown in Table 2, the vibration periods during the Landers earthquake are only slightly larger than the fixed-base periods. This is expected since the deformations of the isolators were much smaller than the design values.

SUMMARY

The records obtained at four base-isolated buildings during the 1992 Landers earthquake provide valuable information on the response of four different base-isolated structural systems to low-level shaking. Although the motions were of low amplitude, the 2-story Fire Command and Control Building responded as the designer expected for a stronger shaking. The design assumptions and numerical modelling for these buildings can be verified by using and analyzing these records in greater detail. The complete results of processing the records from these buildings during the Landers earthquake are available on floppy disks and in a report by Darragh et al. (1993).

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Table 1 - Strong-Motion Records Obtained From Base-Isolated Buildings

Name of Building	Type of Superstructure	Max. Horiz. Accel.(g) Foundation	Base	Roof	Earthquake	Epicentral Distance(km)
Rancho Cucamonga - 4-story Law & Justice Center (CSMIP Sta. No. 23497)	Braced steel frame (19 sensors)	0.03	0.02	0.03	10/02/86 Redlands M=4.8	30
		0.02	0.02	0.05	07/08/86 Palm Springs M=5.9	90
		0.03	0.03	0.06	10/01/87 Whittier M=5.9	47
		0.14	0.05	0.16	02/28/90 Upland M=5.5	12
		0.03	0.04	0.08	06/28/91 Sierra Madre M=5.8	43
		0.11	0.10	0.19	06/28/92 Landers M=7.4	106
		0.06	0.05	0.07	06/28/92 Big Bear M=6.4	70
Los Angeles - 2-story Fire Command/Control Bldg. (CSMIP Sta. No. 24580)	Braced steel frame (19 sensors)	0.08	0.09	0.11	06/28/91 Sierra Madre M=5.8	28
		0.05	0.08	0.12	06/28/92 Landers M=7.4	161
		0.05	0.05	0.05	06/28/92 Big Bear M=6.4	125
Los Angeles - 7-story University Hospital (CSMIP Sta. No. 24605)	Braced steel frame (27 sensors)	0.09	0.05	0.09	06/28/91 Sierra Madre M=5.8	29
		0.04	0.09	0.09	06/28/92 Landers M=7.4	163
		0.05	0.03	0.06	06/28/92 Big Bear M=6.4	127
Seal Beach - 8-story Office Bldg. (CSMIP Sta. No. 14578)	Concrete moment frame (31 sensors)	0.02	0.02	0.03	06/28/91 Sierra Madre M=5.8	57
		0.04	0.09	0.09	06/28/92 Landers M=7.4	160
		0.04	0.05	0.08	06/28/92 Big Bear M=6.4	126

Table 2 - Fundamental Periods of Base-Isolated Buildings

Name of Building	Periods (in seconds) of the Fundamental Mode Transverse	Longitudinal	Torsional
Rancho Cucamonga - 4-story Law & Justice Center			
Without Isolators (fixed base)	0.57	0.61	0.49
1990 Upland	0.75	0.74	---
1992 Landers	0.73	0.76	---
With Isolators (design)	2.00	2.00	---
Los Angeles - 2-story Fire Command/Control Bldg.			
Without Isolators (fixed base)	0.36	0.32	0.13
1991 Sierra Madre	0.91	0.86	---
1992 Landers	1.05	1.00	1.05
With Isolators (design)	2.17	2.17	1.85
Los Angeles - 7-story University Hospital			
Without Isolators (fixed base)	1.0	1.0	---
1992 Landers	1.28	1.24	---
With Isolators (design)	2.21	2.30	1.92
Seal Beach - 8-story Office Bldg.			
Without Isolators (fixed base)	1.1	1.1	---
1992 Landers	1.48	1.36	---
With Isolators (design)	2.75	2.75	---

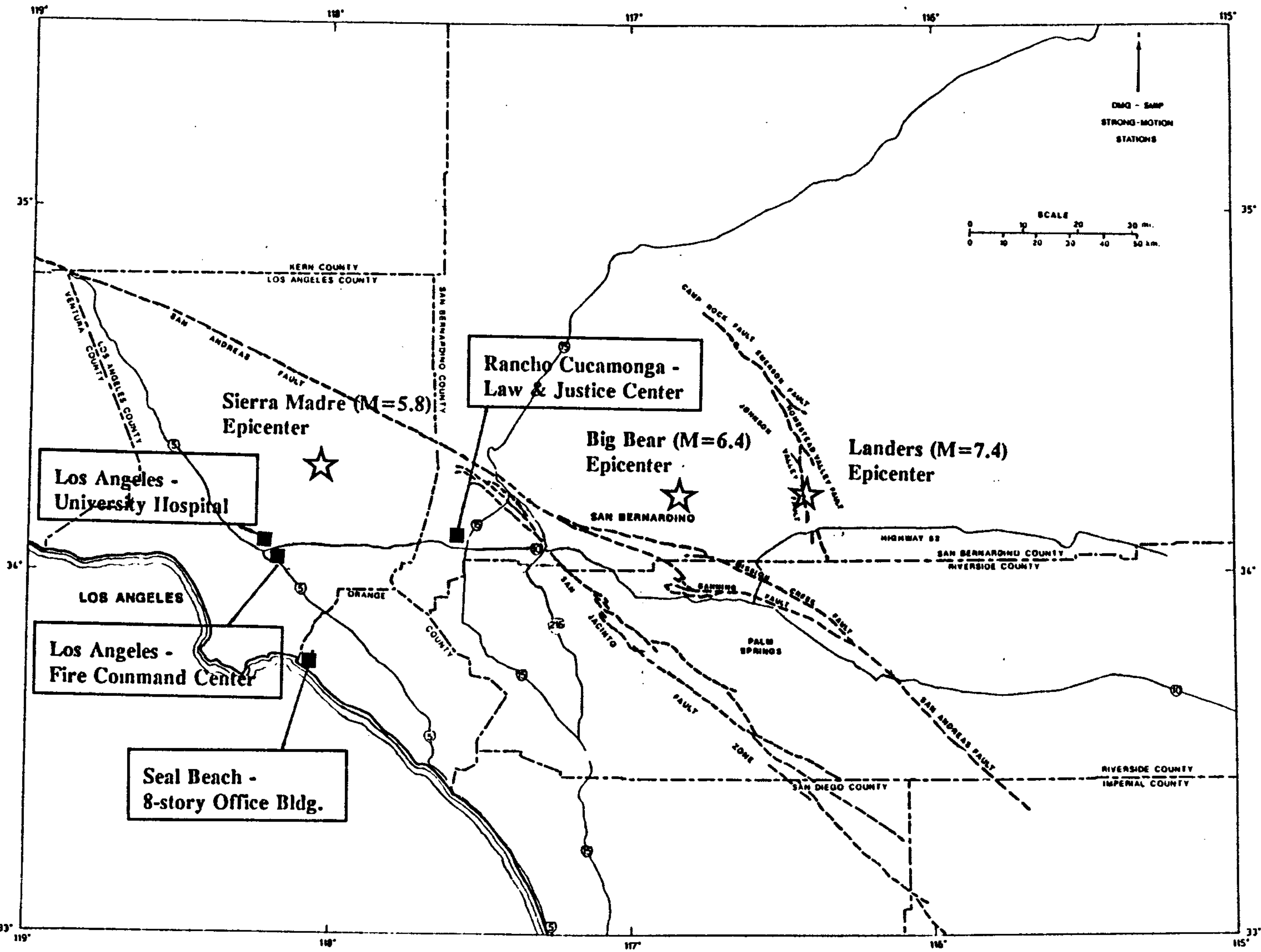

Fig. 1. Map showing locations of four base-isolated buildings and the epicenters of the 1992 Landers, the 1992 Big Bear and the 1991 Sierra Madre earthquakes. These three earthquakes were recorded at all four buildings.

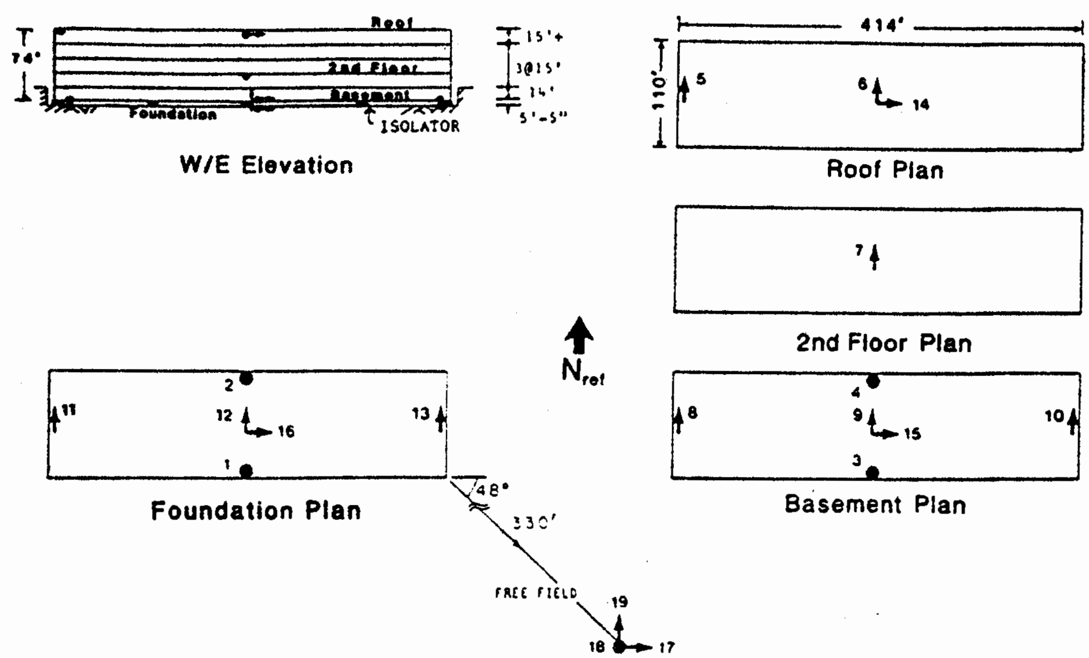

Fig. 2. Locations of accelerometers in San Bernardino County's Rancho Cucamonga Law and Justice Building.

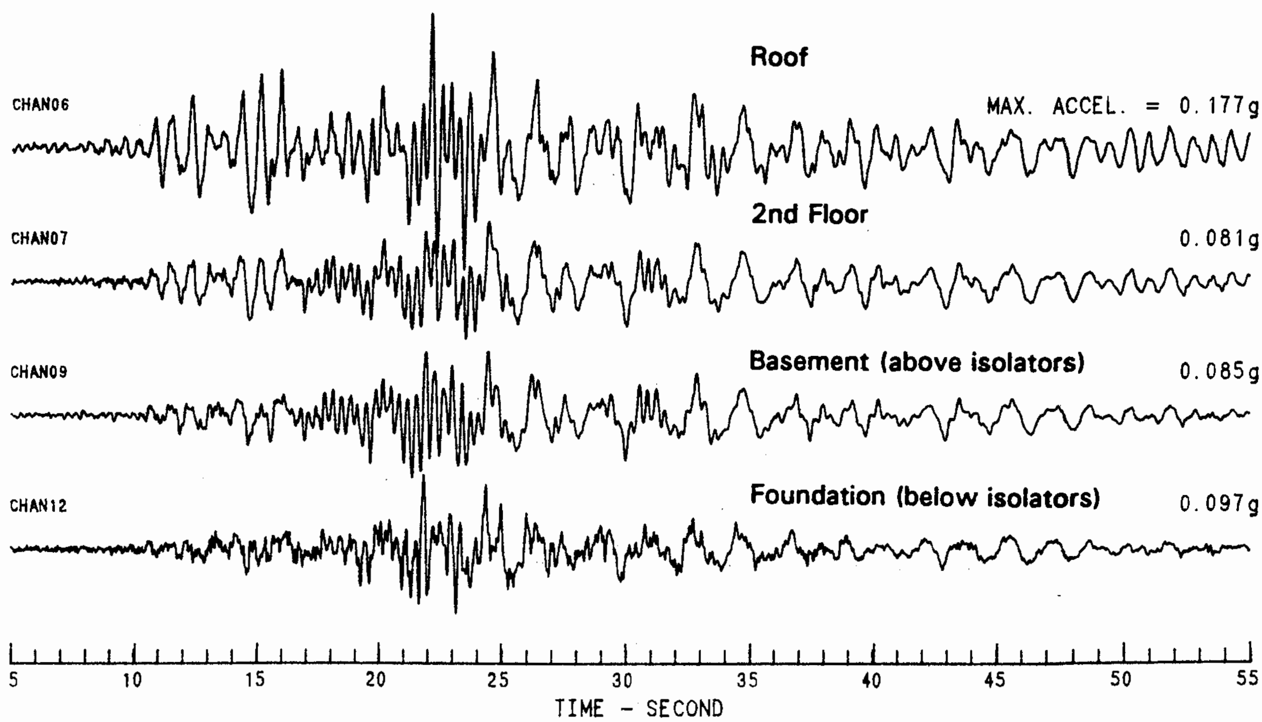

Fig. 3. Acceleration records in the transverse direction obtained at the Rancho Cucamonga Law & Justice Bldg. during the 1992 Landers earthquake.

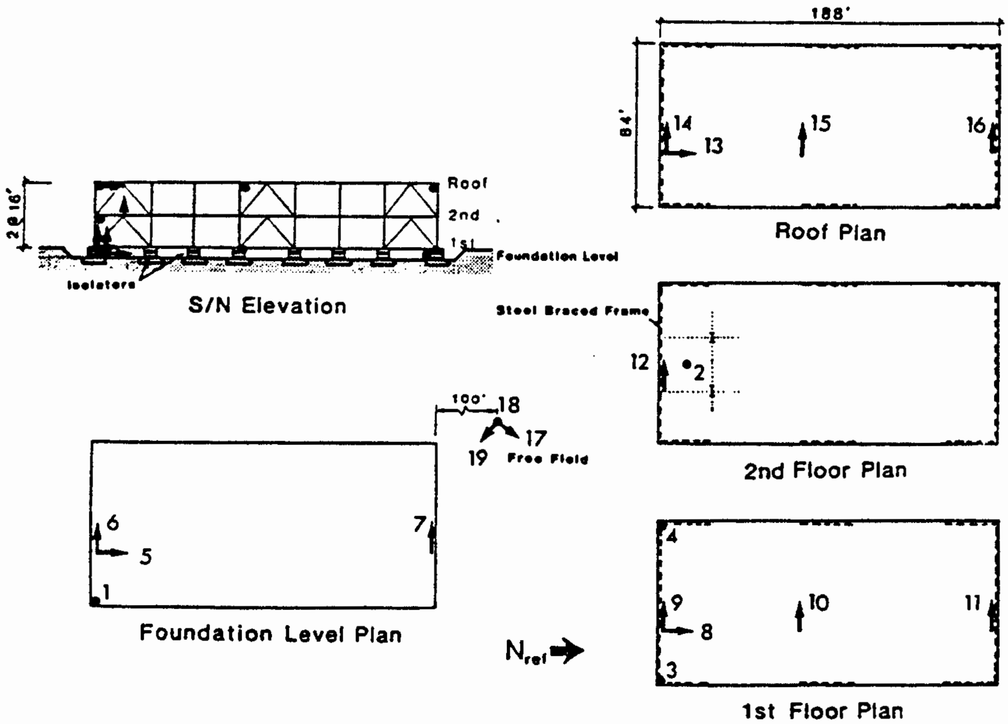

Fig. 4. Locations of accelerometers in the Los Angeles County Fire Control and Command Building.

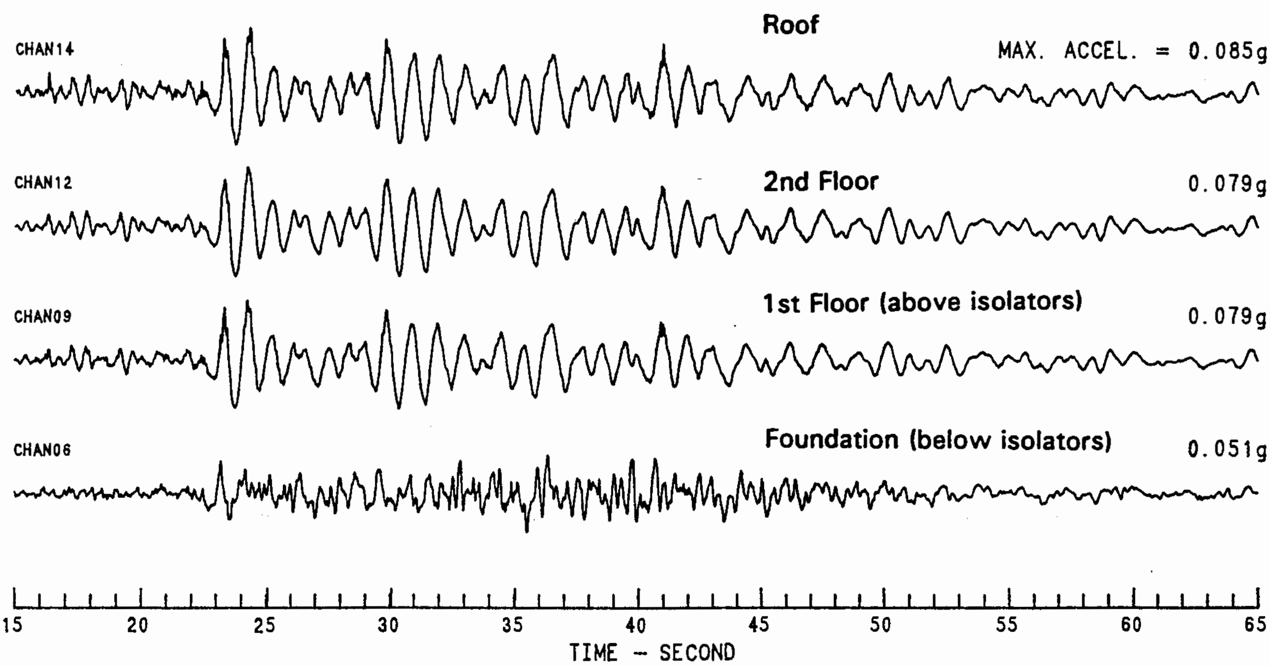

Fig. 5. Acceleration records in the transverse direction obtained at the Los Angeles County Fire Command Bldg. during the 1992 Landers earthquake.

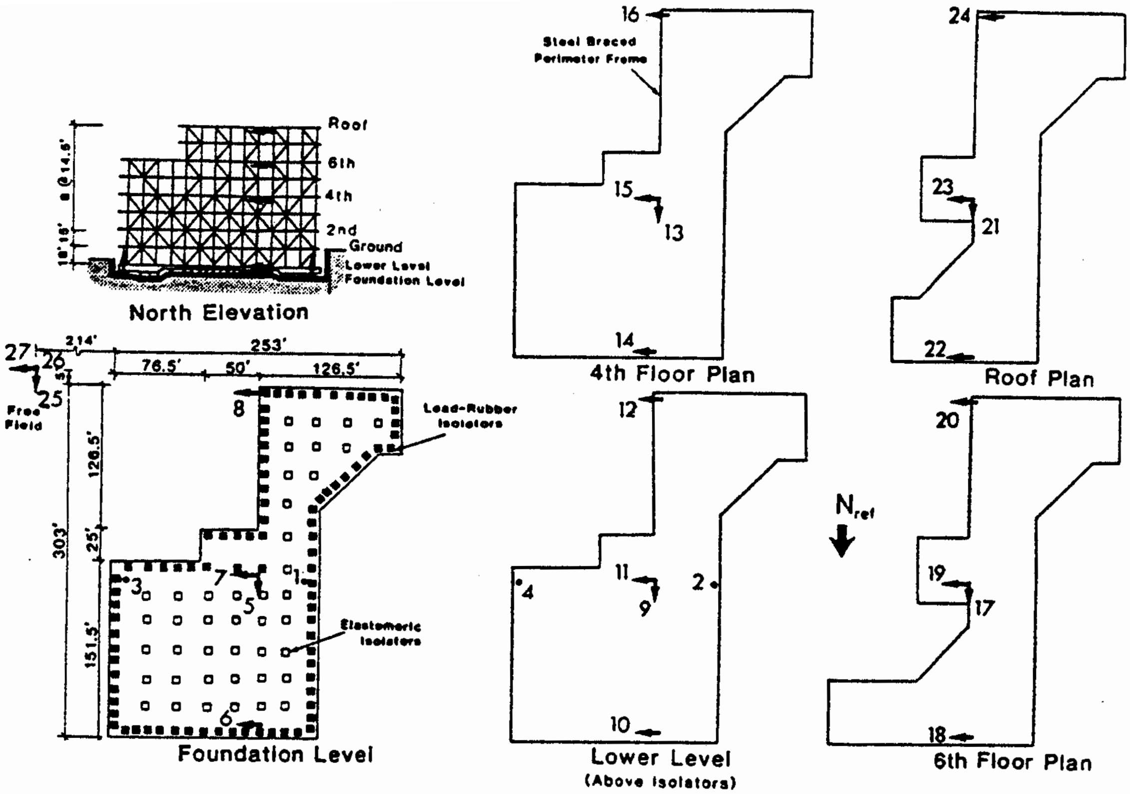

Fig. 6. Locations of accelerometers in the Los Angeles University Hospital Building.

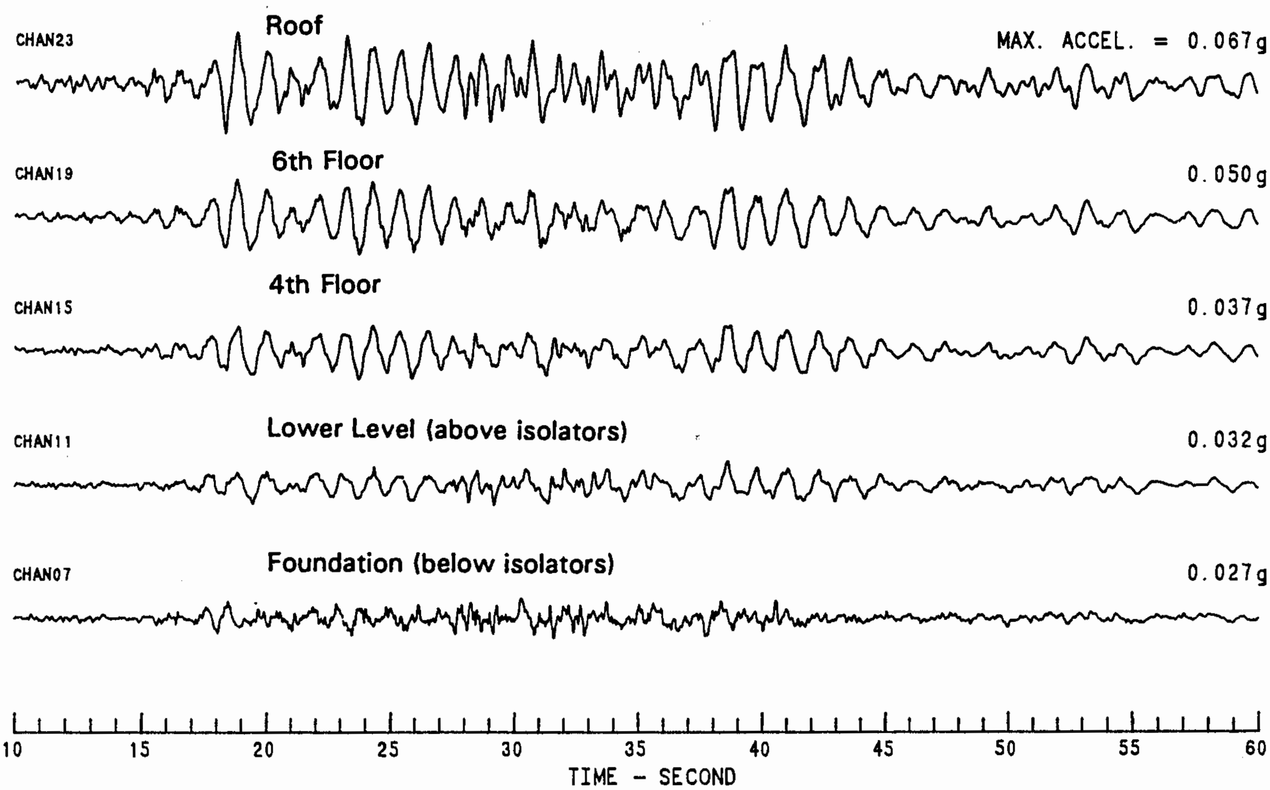

Fig. 7. Acceleration records in the transverse direction obtained at the Los Angeles University Hospital Bldg. during the 1992 Landers earthquake.

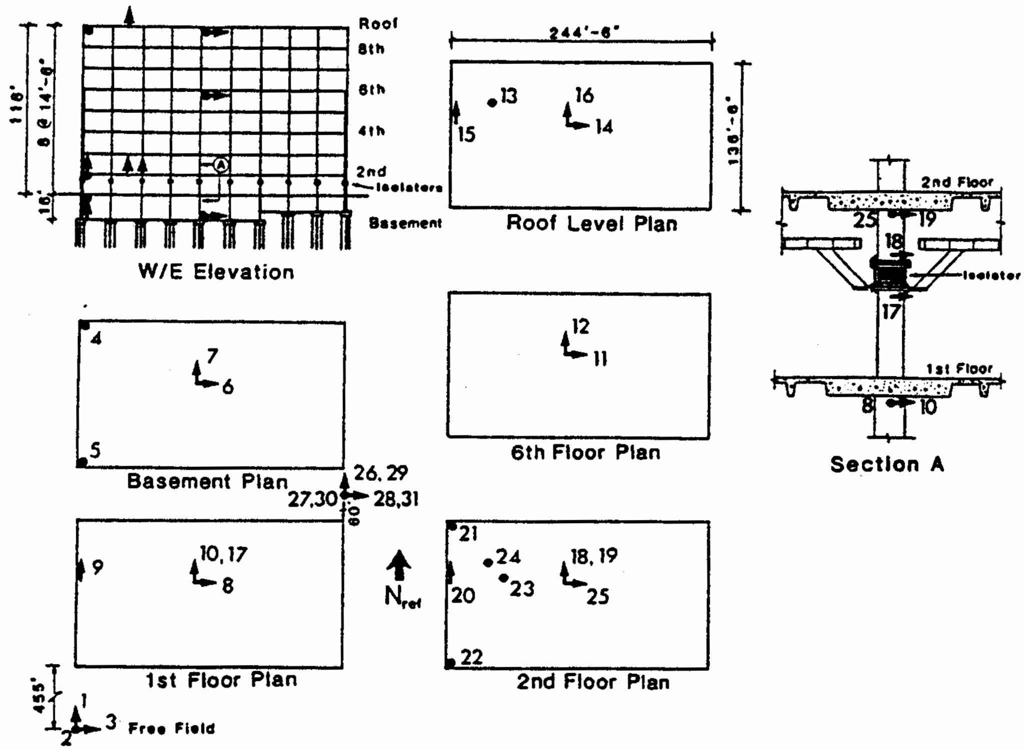

Fig. 8. Locations of accelerometers in the Seal Beach Office Building.

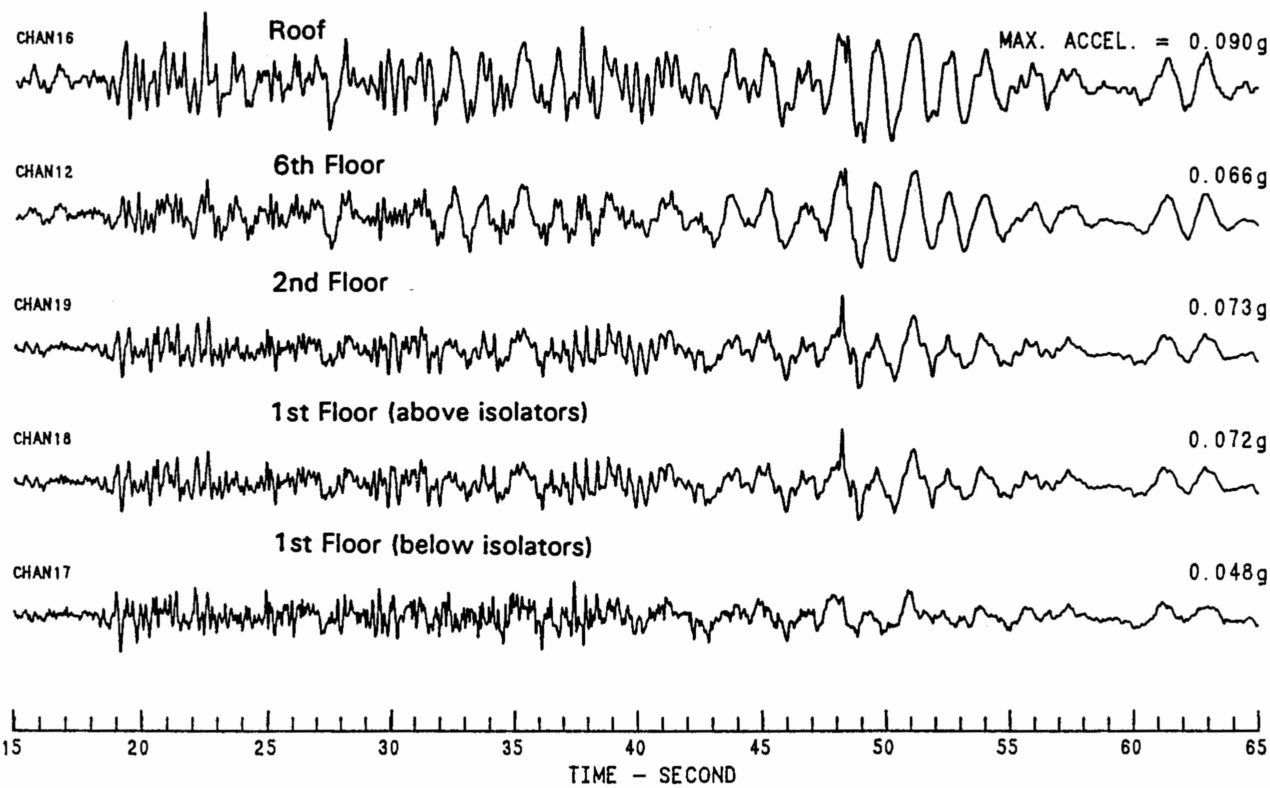

Fig. 9. Acceleration records in the transverse direction obtained at the Seal Beach Office Bldg. during the 1992 Landers earthquake.

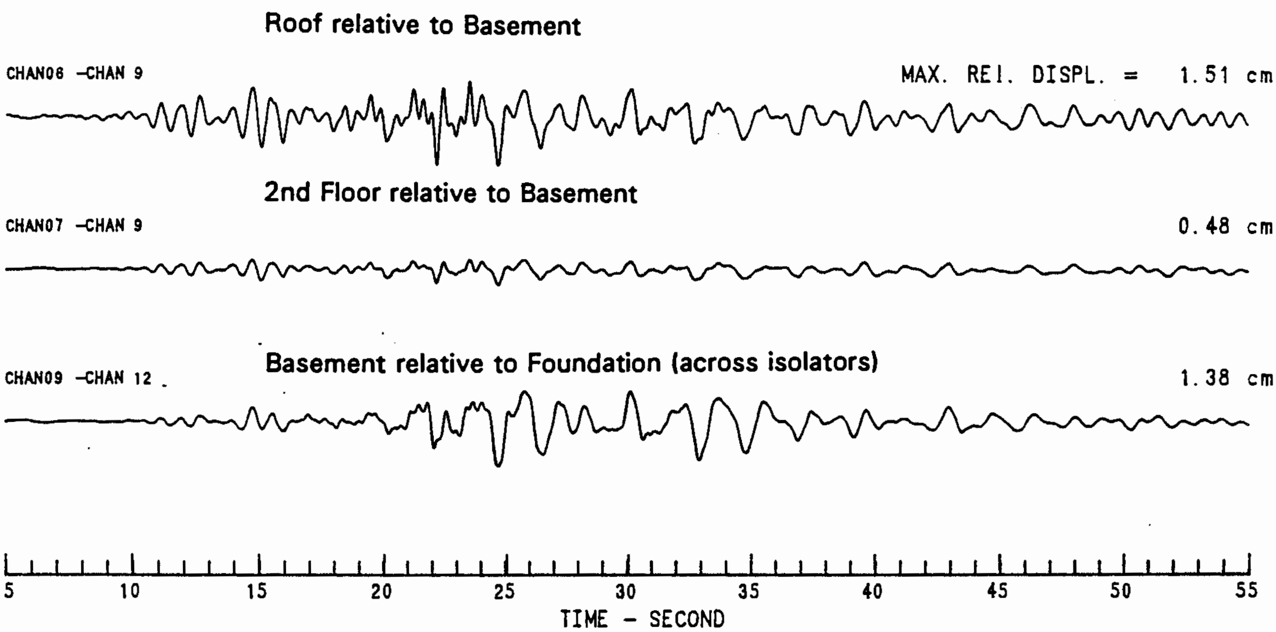

Fig. 10. Relative displacements in the transverse direction at the Rancho Cucamonga Law & Justice Bldg. during the 1992 Landers earthquake.

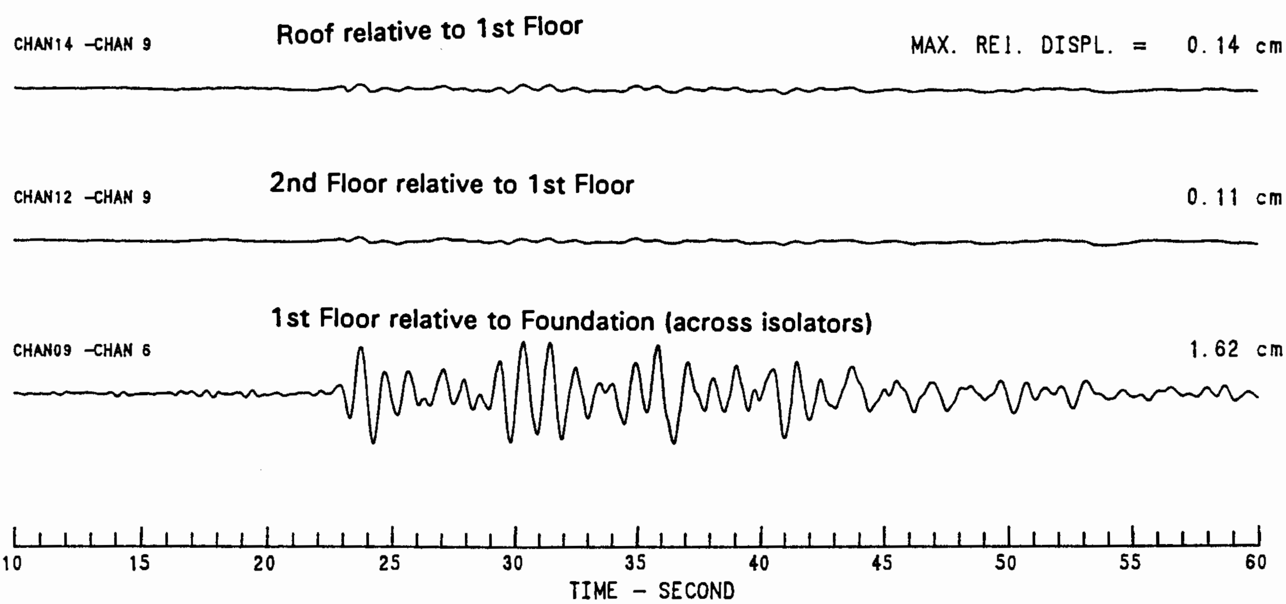

Fig. 11. Relative displacements in the transverse direction at the Los Angeles County Fire Command Bldg. during the 1992 Landers earthquake.

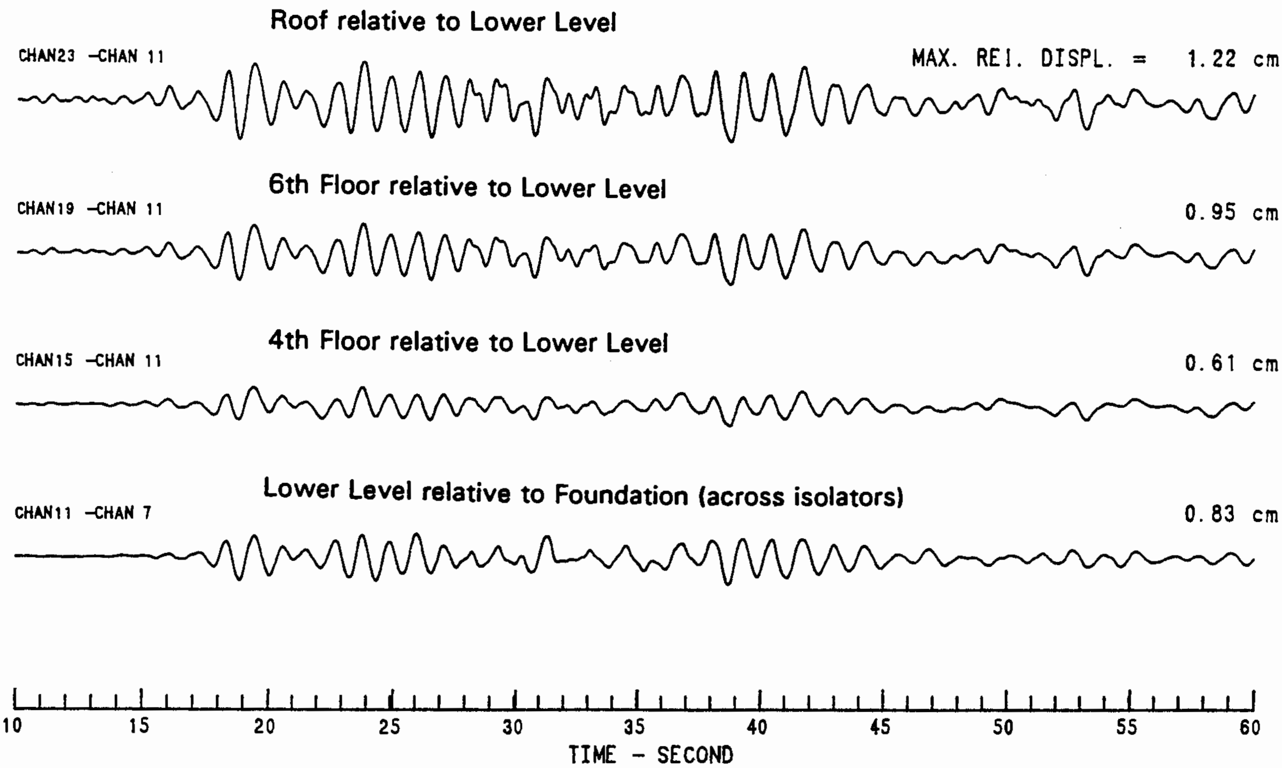

Fig. 12. Relative displacements in the transverse direction at the Los Angeles University Hospital Bldg. during the 1992 Landers earthquake.

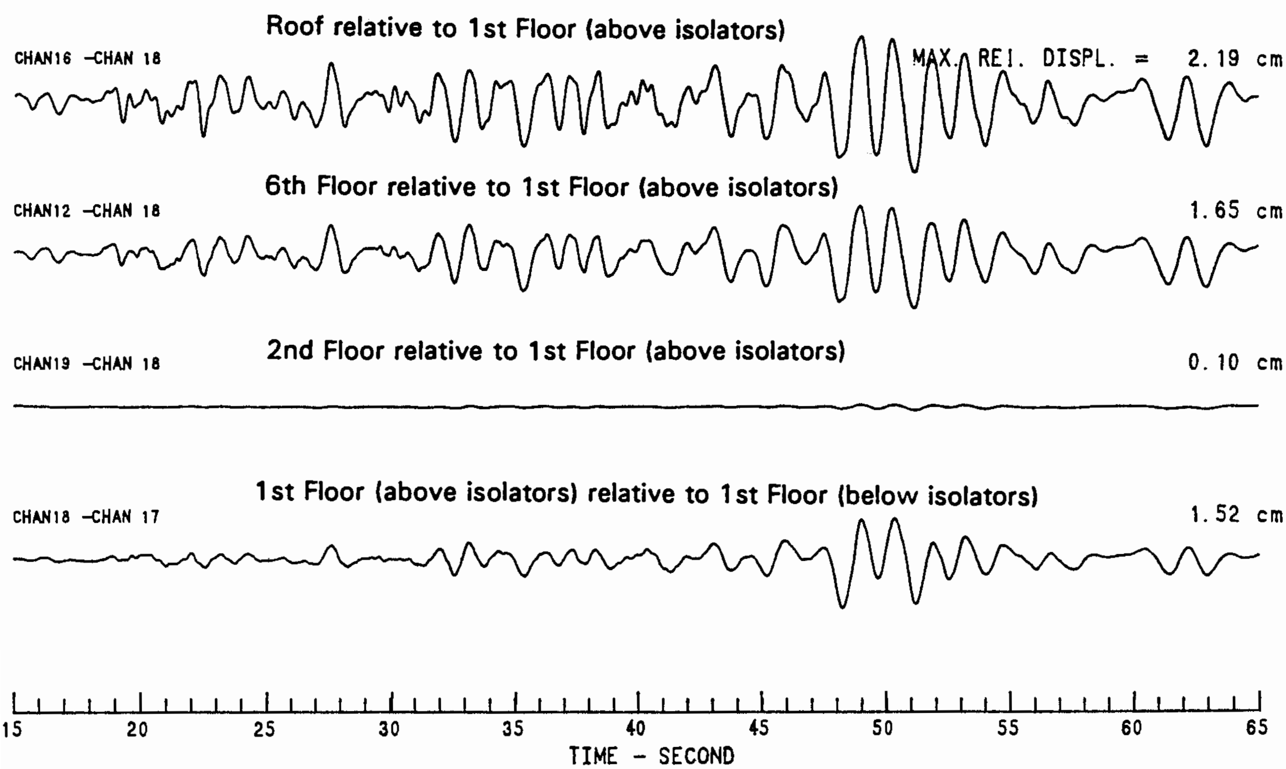

Fig. 13. Relative displacements in the transverse direction at the Seal Beach Office Bldg. during the 1992 Landers earthquake.

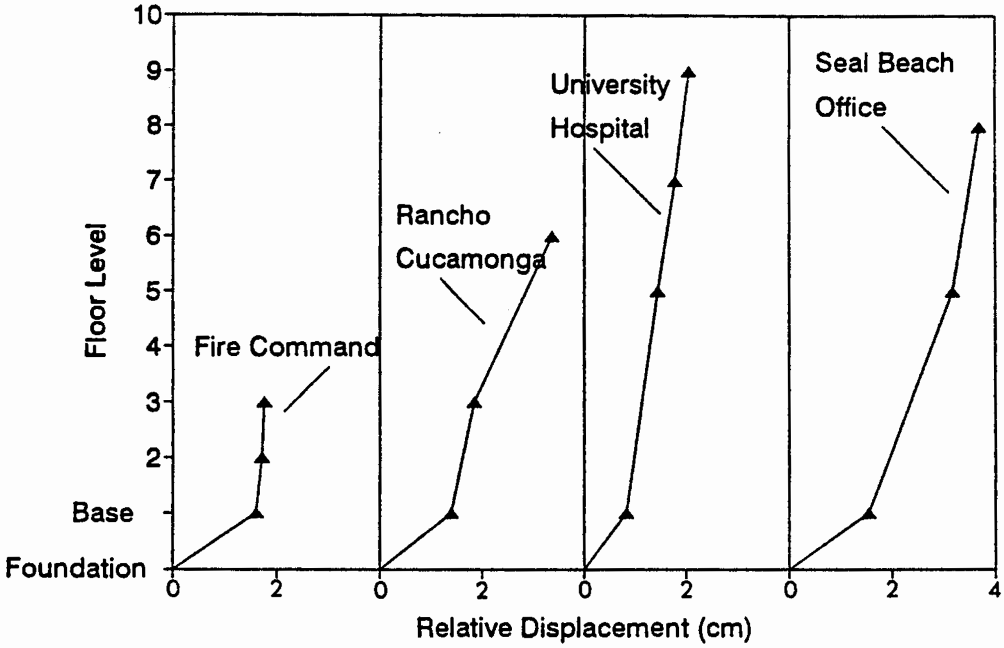

Fig. 14. Profiles of displacements relative to the foundation (below isolators) in the transverse direction at four base-isolated buildings during the 1992 Landers earthquake.

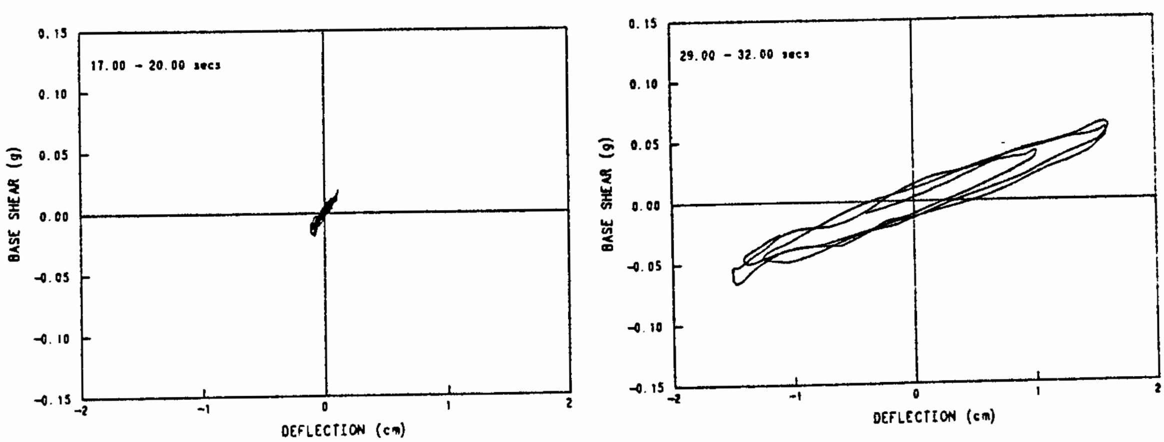

Fig. 15. Hysteresis loops for the isolators at the Los Angeles County Fire Command Bldg. derived from the motions in the transverse direction recorded by sensors 9 and 6 during the Landers earthquake. Loops for time from 17 to 20 and from 29 to 32 seconds are shown.