RECORDED STRONG-MOTION DATA FROM THE NORTHRIDGE, CALIFORNIA EARTHQUAKE OF JANUARY 17, 1994

by

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ABSTRACT

Some of the highest acceleration ever recorded at structures and ground response sites occurred in the Northridge earthquake. The peak ground accelerations are greater than most existing attenuation models would have predicted. The thrust mechanism of this event as well as its location under a metropolitan area may have contributed to the number of high acceleration recordings. Some vertical accelerations were larger than the horizontal, but in general this event fits the pattern observed in previous earthquakes. Processed strong-motion records show significant differences in acceleration and velocity waveforms and amplitudes across the San Fernando Valley.

Analysis of processed data from several buildings in the San Fernando Valley indicates that stiff, short-period buildings such as shear wall buildings experienced large forces and relatively low story drift during the Northridge earthquake. On the other hand, flexible, long-period buildings such as steel or concrete moment-frame buildings experienced large story drifts. For this earthquake, accelerations did not always amplify from base to roof for flexible structures like the moment-frame buildings, but the displacements were always larger at the roof. The records from a base-isolated building indicate that high-frequency motion was reduced significantly by the isolators, which only deflected 3.5 cm.

INTRODUCTION

The 6.7M (moment magnitude) earthquake that occurred near Northridge, California on January 17, 1994 produced an important set of strong-motion recordings from more than 250 ground-response stations, 400 buildings and 50 other structures. The California Strong Motion Instrumentation Program (CSMIP) recovered records from 116 ground-response stations and 77 extensively-instrumented structures (Shakal and others, 1994). These structures include 57 buildings, 12 dams, and 6 bridges.

The U.S. Geological Survey's National Strong-Motion Program (NSMP) recovered records from 60 ground response stations, 37 buildings, 12 dams, and seven other facilities (Porcella and others, 1994). The University of Southern California's Los Angeles Strong Motion Accelerograph Network recovered records from 71 ground-response stations (Trifunac and others, 1994). Records were also obtained from 7 facilities of the Los Angeles Department of Water and Power (Lindvall Richter Benuska, 1994).

Many cities in California have provisions in their local building codes that requires high rise building owners to install accelerographs. Significant records were obtained at many of these buildings during the Northridge

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earthquake. In cooperation with the City of Los Angeles, the National Science Foundation, Agbabian Associates and other groups, CSMIP is collecting and processing these records which will be presented in forthcoming data reports.

As of October 1994, more than 100 records have been digitized and processed (Darragh and others, 1994a-g). This paper presents some highlights of strong-motion records obtained during the Northridge earthquake and includes some interpretation results from the data.

GROUND RESPONSE

Several conclusions on the general features of ground motion can be drawn from an analysis of the accelerograms recorded at ground-response stations during the Northridge earthquake:

1) Maximum Accelerations The maximum horizontal accelerations from this earthquake are plotted and compared to a standard attenuation relationship (Joyner and Boore, 1988) in Fig. 1. The Northridge accelerations are greater than would have been predicted by this relationship and are also greater than those in the 1971 San Fernando earthquake. The tendency for observed strong-motion data to exceed values predicted by attenuation relationships was also observed for the 1987 Whittier earthquake, and the 1992 Landers and Big Bear earthquakes.

2) Vertical Acceleration The maximum vertical acceleration is often, on average, about two-thirds of the peak horizontal acceleration. Vertical accelerations were equal to or greater than the maximum horizontal acceleration at a few close-in stations for this earthquake. In general, the Northridge earthquake fits the pattern of most other earthquakes with regard to vertical accelerations.

3) Spectral Acceleration The spectral acceleration for three recent California earthquakes at ground-response stations near the fault is shown in Fig. 2. For reference, the spectral shape from the Uniform Building Code (UBC) is also shown. The spectral acceleration for the Northridge earthquake at the Sylmar and Newhall stations is significantly greater than the 7.1M Loma Prieta earthquake at the Santa Cruz station and the 7.3M Landers earthquake at the Joshua Tree station.

4) Duration The duration of strong shaking for three recent California earthquakes is shown in Fig. 3 for the same stations as in Fig. 2. The duration of strong shaking for the Northridge earthquake is about 10 seconds at Sylmar and Newhall. This is comparable to the durations for the 6.6M San Fernando and the 7.1M Loma Prieta events, but significantly less than the 30-second duration of the 7.3M Landers earthquake.

5) Site Amplification of Strong Motion No clear trend in amplification of ground motion at soil sites is apparent in the strong-motion data for the Northridge earthquake, in contrast to the 1989 Loma Prieta earthquake. Further investigation of the effects of site geology and basin effects will be necessary to determine the role of local site conditions on ground motions during this earthquake.

The recorded accelerograms and processed data at five stations were selected to highlight important features of the ground-response data. The accelerations for these stations are shown in Fig. 4 and the corresponding velocities are shown in Fig. 5.

Tarzana The record from the Tarzana station, about 5 km south of the epicenter, shows repeated accelerations over 1 g for 7 to 8 seconds, with a maximum horizontal acceleration of 1.8 g. Only moderate damage was observed in the vicinity. Structural types in the area are limited to 1- and 2-story buildings. The peak velocity was over 100 cm/sec at Tarzana; velocities this high were also observed at Sylmar site and the LADWP Rinaldi station. The station is located near the crest of a low (20 m) natural hill on the south side of the San Fernando Valley. The site is underlain by a variable thickness of colluvial soil (silty clay) estimated to be about 0.5 to 1.5 m in thickness. During the 1987 Whittier earthquake this site also had an unusually high acceleration, but not during the principal aftershock.

Additional accelerographs were deployed near the station after the Northridge earthquake and numerous aftershock records were obtained, some with peak acceleration as high as 0.25 g. The accelerations and response spectra at Tarzana and a nearby reference station are compared in Fig. 6 for the largest aftershocks. The reference site is located about 120 m from the Tarzana station, off the gentle hill. For the largest aftershock (5.3M) the stations have almost identical peak accelerations of about 0.25 g. In other words, no amplification of peak acceleration occurred for the largest aftershock. For that event, the spectra for Tarzana and the reference site (Fig. 6) are similar at short periods and long periods but show an amplification of 2 to 3 times near 0.2 seconds (5 Hz) at Tarzana. For the 4.4M aftershock, the Tarzana peak acceleration was 0.12 g, three times that at the reference site (0.04 g). For this event, the Tarzana spectrum is nearly 4 times that of the reference site in the 3 to 5 Hz range, but now the Tarzana spectrum is also amplified at short periods, reflecting the amplified peak acceleration. These two stations document the large variability of strong ground motion possible over a distance of only 120 m and indicate the source of some of the scatter in peak accelerations in Fig. 4.

Arleta The second closest CSMIP ground response station, approximately 10 km east of the epicenter, recorded a maximum horizontal acceleration of 0.35 g, but a higher vertical acceleration of 0.59 g. Arleta recorded significantly lower accelerations, velocities and displacements than Tarzana.

Sylmar This station is 16 km northeast of the epicenter. With a peak acceleration of 0.89 g and a peak velocity of 129 cm/sec, the motion at this site is among the highest ever recorded in terms of damage potential.

Newhall The Newhall station is located about 20 km north of the epicenter, in the direction of rupture propagation. This station recorded a maximum acceleration near 0.6 g on all three components. As shown in Fig. 6 the maximum velocity is about the same as Tarzana. Maximum velocities near 100 cm/sec were also recorded at Sylmar.

Santa Monica The ground-response station at Santa Monica City Hall recorded a peak horizontal acceleration of 0.93 g. This station is approximately 23 km south of the epicenter, in an area with many damaged buildings. The velocity record in Fig. 5 shows a peak velocity of over 40 cm/sec in the later phase near 15 seconds. This phase is also observed at other stations in the Los Angeles basin.

BUILDING RESPONSE

Maximum roof accelerations exceeding 0.15 g were recorded at more than 100 buildings during the Northridge earthquake. Fig. 7 shows the maximum roof acceleration for 38 buildings located in the San Fernando Valley and West Los Angeles. The building height ranges from 6 to 36 stories and the maximum roof acceleration ranges from 0.2 to 1.5 g. In general, concrete or steel moment frame buildings experienced larger drifts but lower forces than shear wall buildings. Records from three specific buildings are discussed below.

Sylmar County Hospital This 6-story hospital replaced the hospital that was heavily damaged in the 1971 San Fernando earthquake. The structure has concrete shear walls on the lower two stories and steel shear walls on the upper four stories. Fig. 8 shows a profile of the acceleration records at the roof, 4th, 3rd and ground floors in the north-south direction. The building is relatively stiff and has a fundamental period of about 0.4 second. In addition, the total drift between the roof and the ground floor is about 5 cm, much less than the maximum ground displacement (28 cm). The building suffered no apparent structural damage, although there was damage to non-structural components and equipment.

Parking Structure A 6-story parking structure near downtown Los Angeles is the first parking structure from which significant strong-motion data have been recorded. In this structure, the lateral forces are resisted by six exterior concrete shear walls in the north-south direction and two interior shear walls in the east-west direction. The acceleration records for selected locations are shown in Fig. 9. Four features are observable from these records: 1) the in-plane motion of the shear wall was amplified from 0.28 g at the base to 0.58 g at the top, with a fundamental period of about 0.5 second; 2) diaphragm motion of the roof slab is apparent as indicated by 0.58 g at the end wall and 0.84 g at center of the roof; 3) large accelerations occurred at a parapet (1.21 g); 4) large vertical motion (0.52 g) with a period of about 0.25 second occurred at the center of the girder that supports the slab. In addition, rocking motion of the shear wall occurred as indicated by the records from a pair of vertical sensors at the base.

Base-isolated University Hospital The University Hospital is a 7-story braced steel frame building with a 1-story basement. The seismic isolation consists of 149 isolators. Strong-motion records for selected locations in the north-south direction are shown in Fig. 10. The peak horizontal acceleration at the free-field site was 0.49 g and the peak acceleration at the foundation below the isolators was 0.37 g. In the superstructure above the isolators, the peak acceleration was 0.13 g at the base and 0.21 g at the roof level. The records indicate significant reduction of the earthquake force by the isolators. The relative displacement across the isolators and the drifts in the superstructure computed from the integrated displacements are shown in Fig. 11. The relative displacement indicates that the isolators deformed about 3.5 cm, much less than the design displacement (about 40 cm). The response spectra indicate that the first mode of the building was near 1.3 seconds and the second mode was near 0.5 second.

SUMMARY

The strong-motion records from the Northridge earthquake provide important information on the ground motions and the response of structures to the strong shaking that occurred in this event. Design criteria, assumptions and analysis techniques for structures can be verified by analyzing these records in greater detail. The processed data for these records are available from CSMIP and LADWP, and additional records are currently being processed by CSMIP and the USGS.

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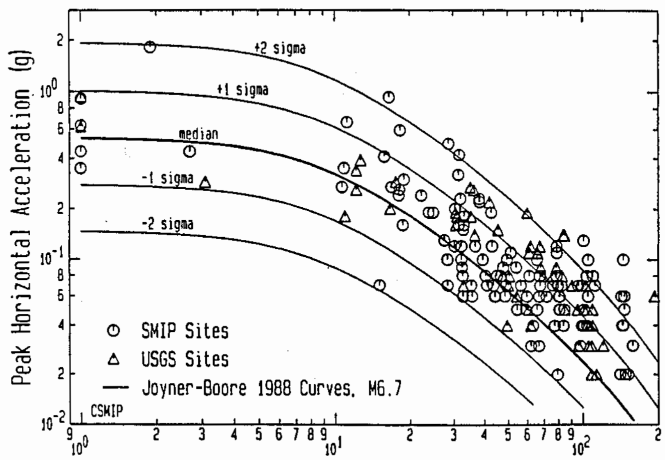

Fig. 1. Maximum horizontal acceleration versus distance (km) for the Northridge earthquake. Distance is from the surface projection of the aftershock zone, as defined by Joyner and Boore (1988). Bold line is the median curve of Joyner-Boore (1988) for a 6.7M earthquake.

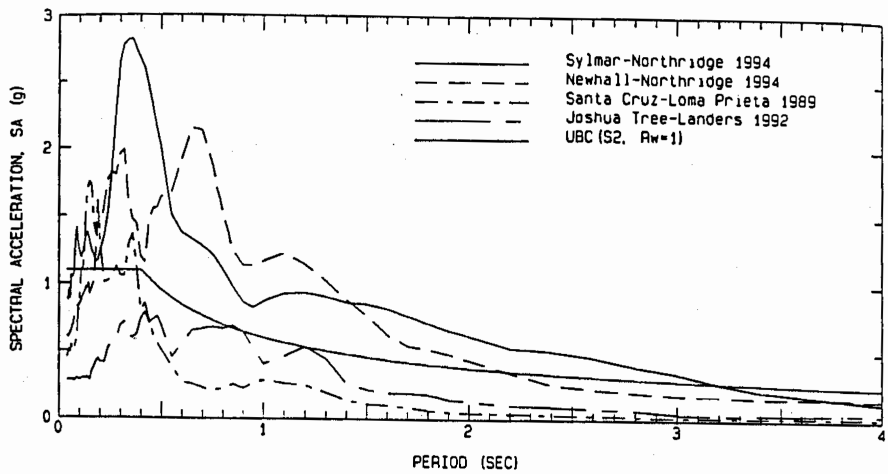

Fig. 2. Spectral acceleration (5% damped) at similar distances (10 - 20 km) from the fault. Stations include Sylmar and Newhall for the 6.7M Northridge earthquake, Santa Cruz for the 7.1M Loma Prieta earthquake, and Joshua Tree for the 7.3M Landers earthquake. The UBC spectrum is included for reference.

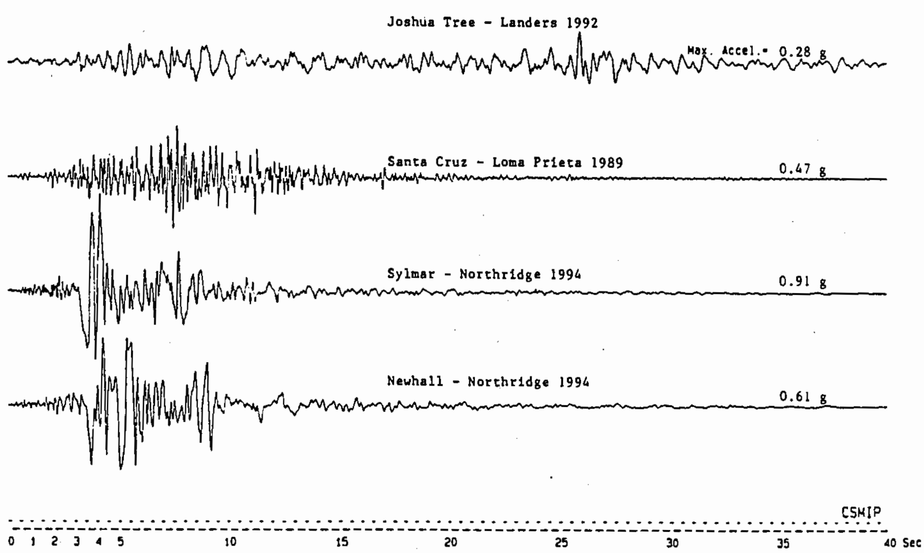

Fig. 3. Duration of strong ground shaking. Accelerograms are from Joshua Tree for the 7.3M Landers earthquake, Santa Cruz for the 7.1M Loma Prieta earthquake, and Sylmar and Newhall for the 6.7M Northridge earthquake. Stations are at similar distances (10 - 20 km) from the fault.

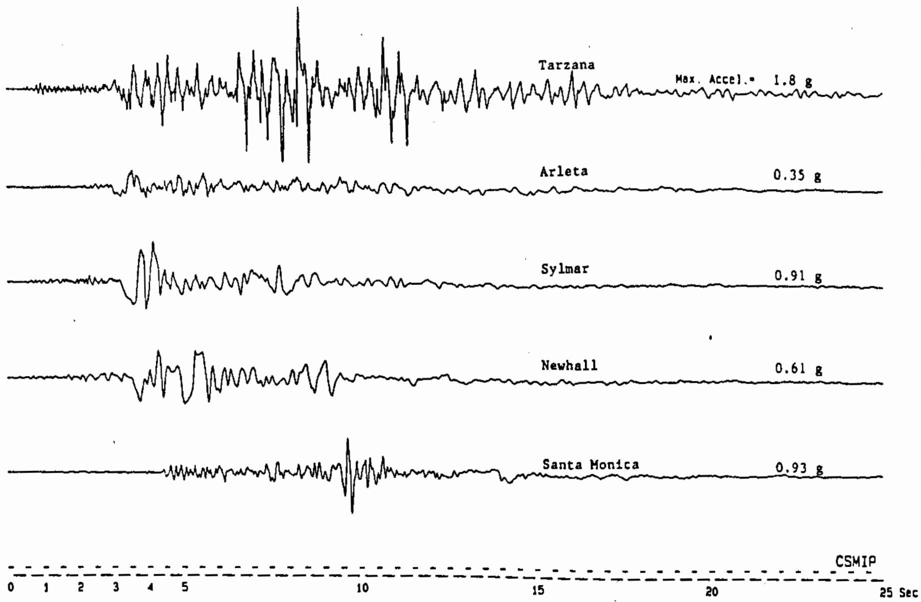

Fig. 4. Comparison of acceleration waveforms at five ground-response stations within 25 km of the epicenter of the Northridge earthquake. Tarzana, Arleta and Sylmar are in the San Fernando Valley. Newhall is north of the valley and Santa Monica is located to the south in the Los Angeles basin.

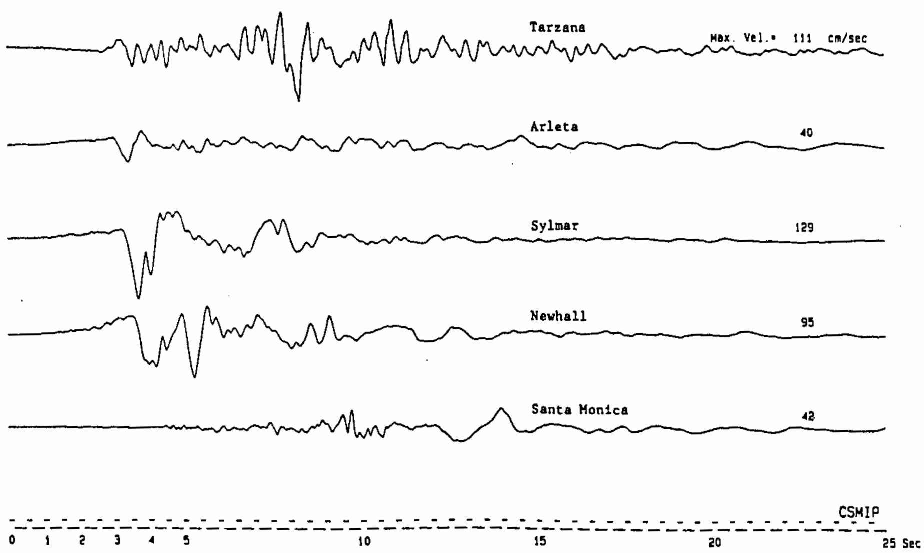

Fig. 5. Comparison of velocity waveforms at the five ground-response stations considered in Fig. 4.

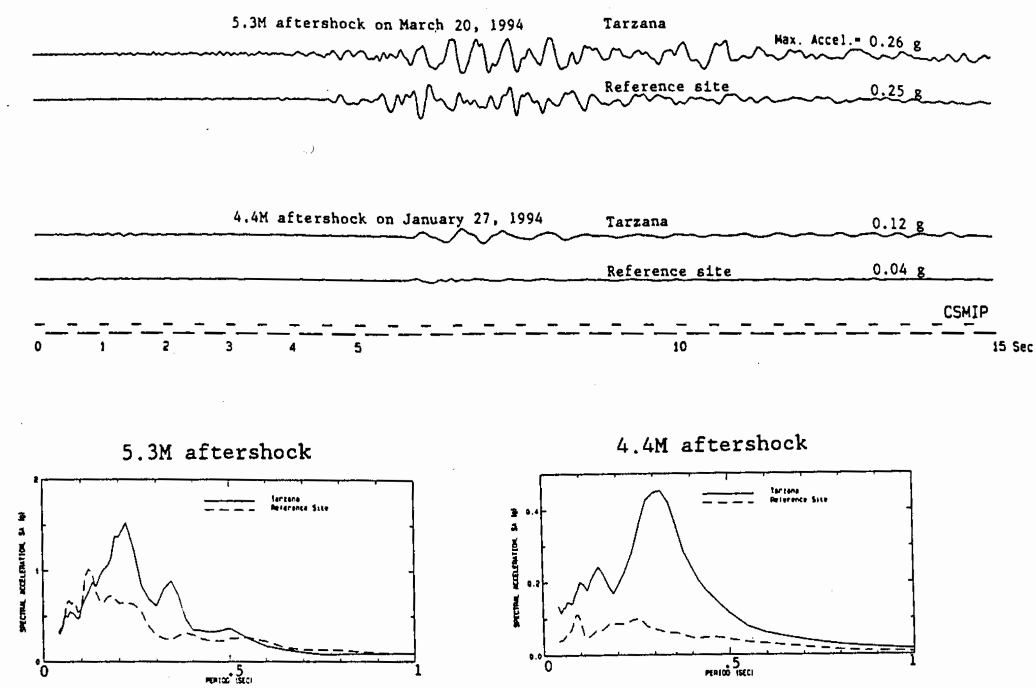

Fig. 6. Comparison of accelerograms and spectra (5% damped) for the two largest Northridge aftershock records from the Tarzana CSMIP station and a nearby reference site off the hill and about 120 m from the Tarzana site.

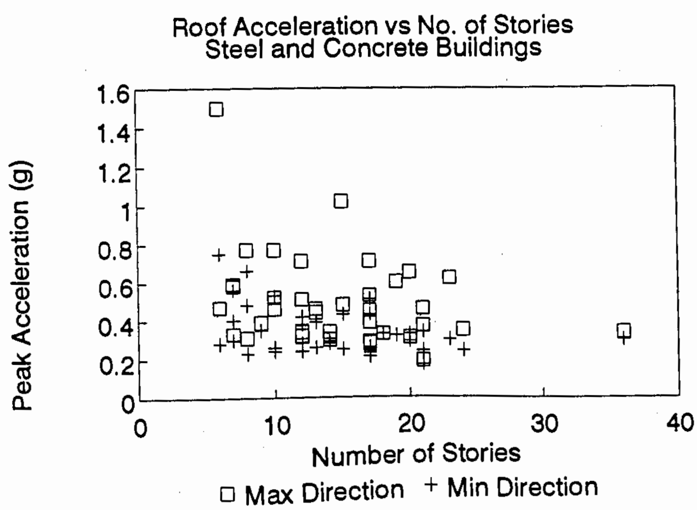

Fig. 7. Peak roof accelerations recorded at 38 buildings located in the San Fernando Valley and West Los Angeles during the Northridge earthquake.

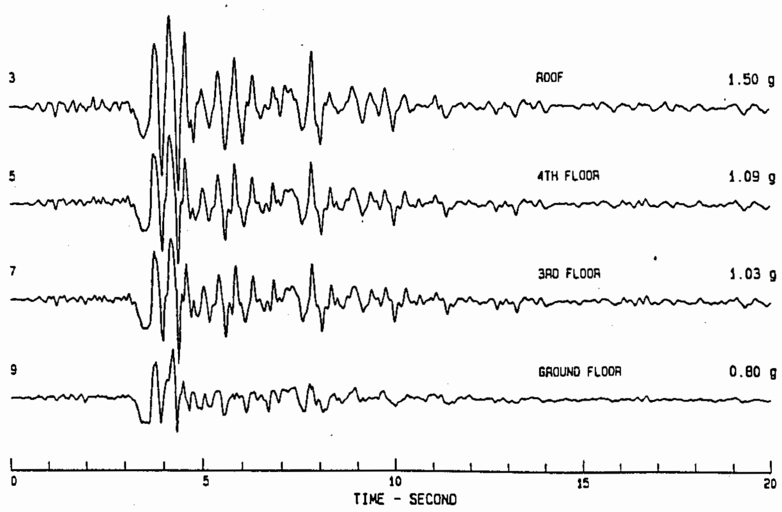

Fig. 8. Accelerations in the north-south direction recorded at the Sylmar 6-story County Hospital during the 1994 Northridge earthquake.

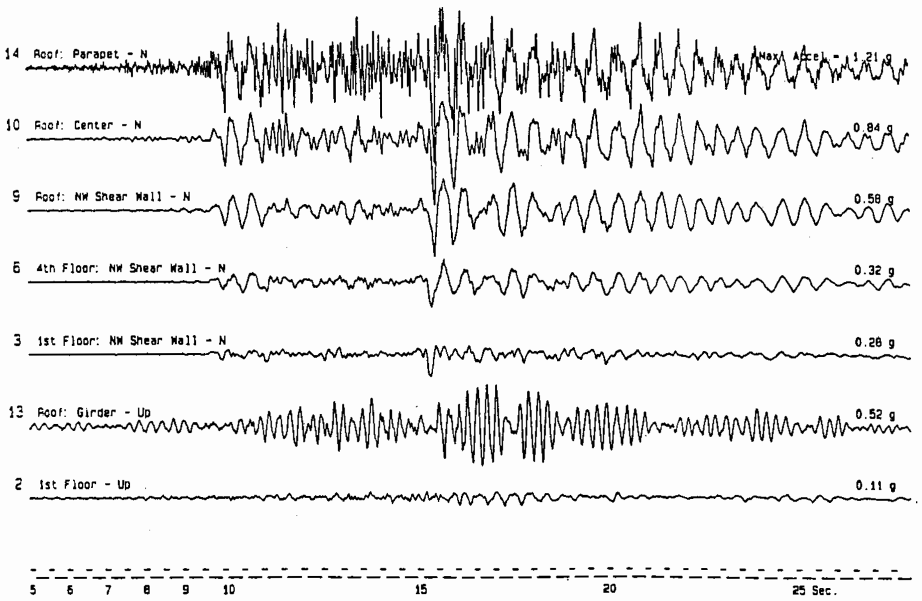

Fig. 9. Accelerations in the north-south and vertical directions recorded at the Los Angeles 6-story Parking Structure during the Northridge earthquake.

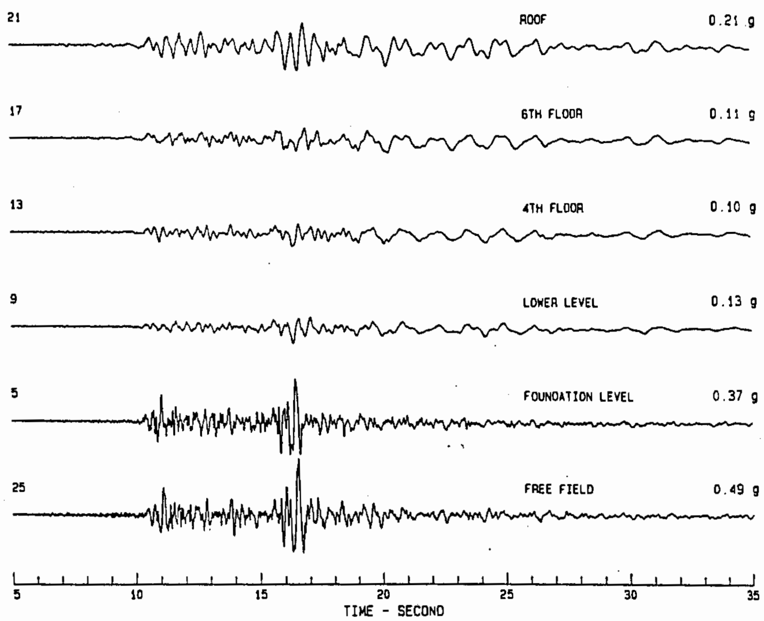

Fig. 10. Accelerations in the north-south (longitudinal) direction from the base-isolated University Hospital in Los Angeles for the Northridge earthquake.

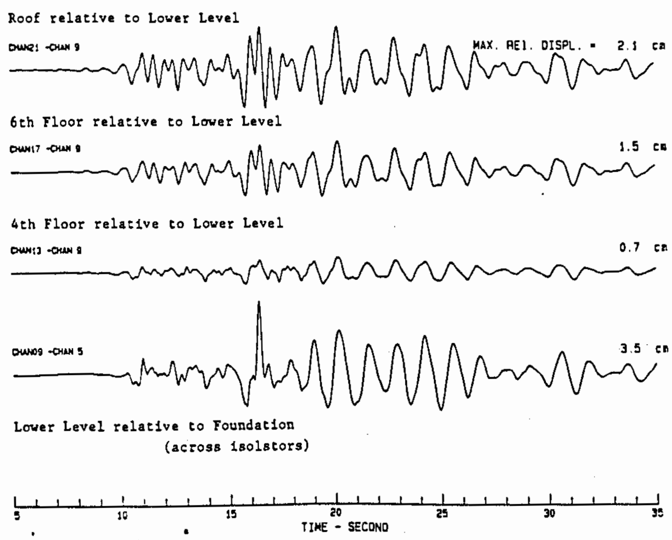

Fig. 11. Relative displacements in the north-south direction at the base-isolated University Hospital during the Northridge earthquake.

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