The Northridge Earthquake of 1994: Ground Motions and Geotechnical Aspects

M. K. Yegian
Northeastern University, Boston, MA

G. V. Ghahraman
Northeastern University, Boston, MA

G. Gazetas
National Technical University, Athens, Greece

P. Dakoulas
Rice University, Houston, TX

N. Makris
University of Notre, Notre Dame, IN

Proceedings: Third International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
April 2-7, 1995; Volume III, St. Louis, Missouri

The Northridge Earthquake of 1994: Ground Motions and Geotechnical Aspects

Paper No. 14.01

M.K. Yegian and G.V. Ghahraman
Northeastern University
Boston, MA, USA

G. Gazetas
National Tech. University
Athens, Greece

P. Dakoulas
Rice University
Houston, TX, USA

N. Makris
University of Notre
Notre Dame, IN, USA

Abstract: Following the January 1994 Northridge Earthquake in Southern California, the authors traveled to Los Angeles and surveyed the earthquake damage region. Subsequently, seismologic, geologic and ground motion data were compiled and evaluated. This paper presents our observations and evaluation of: geologic and soil effects; soil-structure interaction; liquefaction; slope failures and rock slides; and ground deformations.

INTRODUCTION

The January 17, 1994, earthquake of magnitude M_S=6.8 that struck the Los Angeles area was centered in Northridge. It caused heavy damage to highway bridges, lifeline facilities and residential and commercial buildings as well as other engineered facilities. Following the earthquake, the authors traveled as a team to Los Angeles and surveyed the earthquake damage region. The primary focus was on the geotechnical aspects of the Northridge earthquake and their role in contributing to damage. Observations were made of landslides, liquefaction, permanent ground deformations, bridge abutment movements, bridge and building damage. Potential "soil-amplification" and "soil-structure interaction" effects are discussed in the light of the numerous accelerograms, recorded at the basement of buildings and their parking lots. Questions are raised that future studies must answer.

GEOLOGIC AND SOIL EFFECTS

The soil and geologic conditions under a particular site have been known to affect the ground motions near the surface, which excite structures. In some past earthquakes such soil effects had spectacular consequences, as for example in Mexico City in the 1985 Michoacan earthquake, in Kirovakan and Leninakan in the 1988 Armenia , and in the San Francisco Bay area in the 1989 Loma Prieta earthquakes. In the Northridge Earthquake such soil effects, although not as conspicuous, may turn out to be also significant. The San Fernando Valley as well as the Los Angeles basin are mostly underlain by deep and stiff soils, with differences in the soil thickness and stiffness from place to place. So, the potential for different soil effects exists. Indeed, the recorded motions, from CSMIP, USGS, and USC arrays, show appreciable differences in the peak values and frequency content of the ground acceleration from place to place at about the same distance from the source. Here are a few examples: Looking at Fig. 1 (from the CSMIP array), one can notice that:

5th CSMIP Quick Report of January 25, 1994

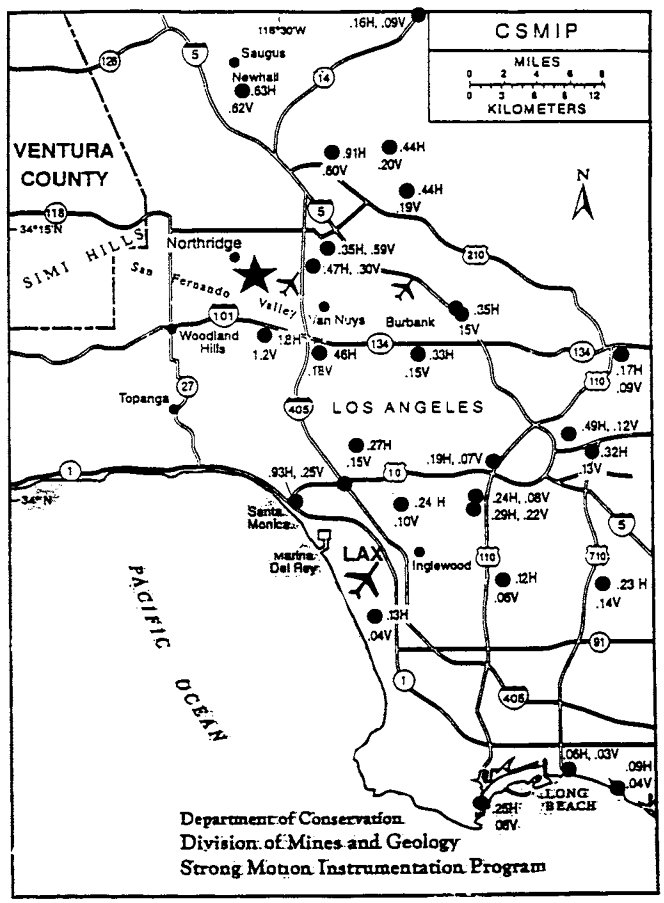

Fig. 1 Map of peak accelerations from CSMIP.

- Along and near Highway I-10, the peak ground accelerations (PGA's) vary from 0.93g at the City Hall near the Santa Monica Beach (24 km from the epicenter) to 0.27g at the Century City-LACC site (20 km from the epicenter), with the Hollywood Storage building site reaching an intermediate 0.41g value (23 km from the epicenter). Since these sites are at similar distances, and in the same general direction from the fault, soil "amplification" effects appear to be the most likely reason for the large differences in the recorded accelerations.

- In the Long Beach area, nearly 60 km from the epicenter, several records exhibit PGA's in the range of 0.06g to 0.09g. Yet, nearby, at the base of Vincent Thomas Bridge, the recorded peak acceleration was 0.25g. For the reasons stated above, soil "amplification" is again a very likely culprit.
- In the San Fernando Valley, and in its northern extension, peak accelerations vary widely, almost regardless of epicentral distance. Examples: Olive View Hospital 0.91g (distance = 15 km), Arleta Nordhoff Ave. Fire Station 0.39g (distance = 9 km), Newhall 0.63g (distance = 19 km), Sepulveda VA Hospital 0.94g (distance = 8 km). Soil amplification effects may have played a role in such differences, although, so close to the source other seismological factors, including azimuthal orientation and "directivity" effects, may have contributed as well.

A definitive answer on the above and other cases must await the results of comprehensive seismological-geotechnical studies.

Topographic effects on ground motions seem very likely in at least two cases. The first is at the Pacoima Dam (17 km from the epicenter). Whereas two records, one downstream ("free field") and one at the base of the dam, have peak accelerations of about 0.45g, on the two steep abutments accelerations in excess of 1.0g were recorded! It is recalled that the 1971 San Fernando earthquake also produced a very high acceleration (1.2g) at a point just above one of these abutments. That peak had been attributed to topographic effects.

The second is at the Tarzana Cedar Hill Nursery located about 7 km from the epicenter. The ground motion record at this site displays an unusually large number of pulses with peak acceleration values of 1.82g and 1.01g in the two horizontal directions, and 1.18g in the vertical direction. Fig. 2 shows the traces of the ground motions recorded in Tarzana. Similar "anomalously" high ground motions (PGA ≈ 0.60g) were also recorded in Tarzana during the 1987 Whittier earthquake (epicentral distance ≈ 40 km). Tarzana is located at the northern foothills of the Santa Monica mountains. Very localized soil and, especially, topographic effects may have contributed to these high motions.

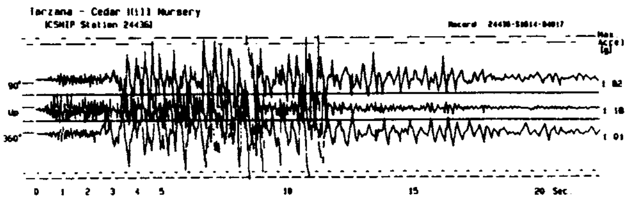

Fig. 2 Ground motion record from the recording station in Tarzana (3 components).

Soil amplification and topography may also have played a significant role in contributing to the failures of a number of bridges, buildings and parking garages since many similar structures in other locations within the epicentral region survived. (This does not preclude the possibility that structural differences among the various bridges may have been a major cause of different degrees of damage.) In any case, these potential soil amplification and topographic effects need to be investigated using site specific geotechnical and geologic data, before definitive conclusions can be drawn and practical recommendations made.

SOIL - STRUCTURE INTERACTION

Another phenomenon of geotechnical interest that appears to have played a role in the seismic performance of bridges and buildings is called *soil-structure interaction*. In simple words, the term describes the unavoidable interplay between a structure (building, bridge pier, bridge abutment) and its supporting soil. One is transmitting forces to the other, while their motions must be compatible. Unfortunately, it is very difficult to actually "observe" this interplay in the field after an earthquake. There have, however, been several instrumental manifestations of the phenomenon. For instance, in nearly all cases where accelerations were recorded in both the parking lot ("free field") and the base of a structure, the measured peak accelerations were different. In buildings, the peak base motion was usually only about 80% of the "free-field" peak. Examples: Hollywood Storage building: 0.29g at the base versus 0.41g at the free field; Los Angeles University Hospital: 0.37g at the base versus 0.49g at the free field; and so on. Fig. 3 summarizes a compilation of all such data, in the form of the ratio of peak accelerations recorded at the foundation and the free field, A_B/A_S. Notice that for all buildings this ratio was less than 1.

On the other hand, in the few bridges where such pairs of records were available, the opposite seems to have been the case: the motion at the base of the pier has larger peaks than the motion of the free field. For example, in San Bernardino's Hwy I-10/215 Interchange bridge, the free-field PGA of 0.10g increased to 0.14g atop the footing. Moreover, the interaction between the abutment retaining walls of a bridge and the bridge deck and piers, although difficult to

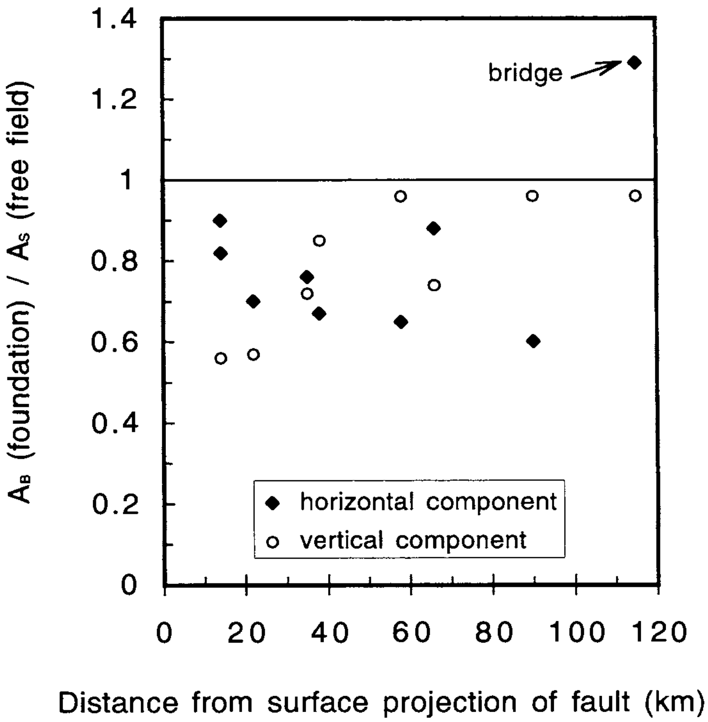

Fig. 3 An indication of the effect of soil-structure interaction is that the ratio of peak acceleration, A_B, recorded on the base of buildings (foundation) was almost always smaller than the peak ground acceleration, A_S, at the nearby parking lot (free field).

ascertain with a simple visual observation, could have played a detrimental role in some of the bridge failures (e.g., Highway 118 - Mission Gothic Undercrossing, and Rte 14/I-5 Interchange). For one thing, the abutments in many of the failed bridges subsided significantly, contributing no doubt to the "distress" of the bridge. Comprehensive and systematic studies are needed to shed light to these soil-structure interaction issues that may turn out to be of vital importance in seismic design.

LIQUEFACTION

Manifestations of geotechnical failures and damage could be observed at many different locations as far away as 50 km from the general epicentral region. Fig. 4 shows the approximate locations of sites where liquefaction and landslides were observed. Evidence of liquefaction has been observed in the Simi Valley, 15 km northwest of the epicenter. Also, soil liquefaction near the toe region of a section of Highway 126 near the town of Piru may have contributed to its failure. In the parking lot of the Santa Monica Pier, liquefaction of the underlying sands had caused extensive cracking of the pavement and ejection of sand, as shown in Fig. 5.

In Redondo Beach, about 45 km from the epicenter, the King's Harbor wharf experienced a spectacular failure with permanent ground deformations reaching 1.5 m laterally and

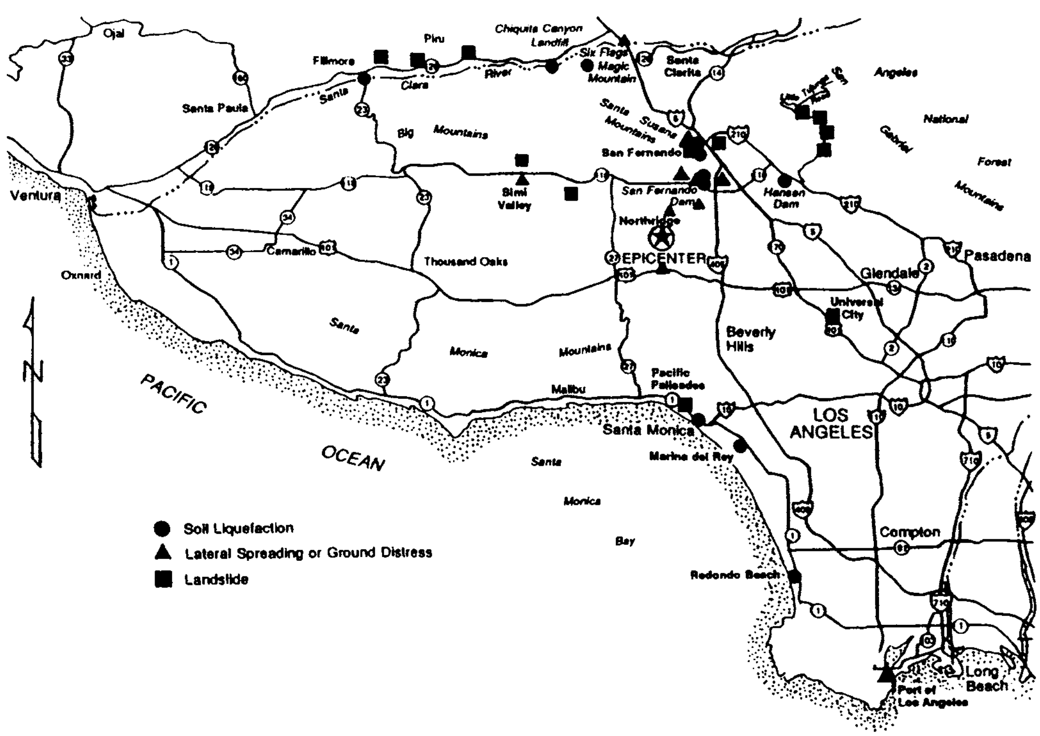

Fig. 4 Map of the earthquake affected region with locations of geotechnical observations. (from EERC Report, 1994)

Fig. 5 Liquefied sand ejected from cracks in the pavement of the parking lot in Santa Monica Beach.

Fig. 6 Movement of the retaining wall of the pier in Redondo Beach.

0.75 m vertically. Evidence of possible liquefaction of the sands, used as the fill material of the pier, was observed. A 1.50 m high retaining wall that was constructed upon a rock berm, as shown in Fig. 6, experienced lateral movements of the order of a meter. The top of the rock berm is estimated to be about 3 m above the mudline. There is evidence of lateral movement at and near the toe of the rock berm as shown by the tilting of the mooring piles (Fig. 7). Furthermore, the ground surface level on the pier experienced significant subsidence. Fig. 8 shows one of the two buildings on the pier that is founded on a concrete slab that experienced about 0.3 m of settlement relative to the section of the wharf that did not move. It is not yet clear as to what the failure mode of this pier was. Further investigations of the geotechnical data and the profile geometry may reveal the mechanism of this failure.

SLOPE FAILURES AND ROCK SLIDES

There were a number of rock slides that were observed mostly in the region north of the epicenter. Fig. 9 shows photographs of typical rock slides. In Santa Monica, along the Pacific Coast Highway, spectacular landslides occurred damaging many of the homes built on the cliffs overlooking the Ocean. Fig. 10 shows a section of this landslide. Also, in Simi Valley, a major slide occurred in a slope built with the tailings from a mining operation. Fig. 11 shows the failed slope where lateral and vertical permanent deformations were as large as 1 m and 2 m, respectively. A survey of the slope region revealed that water used in the mining operations is directed through trenches away from the top of the slope towards its toe. The failed slope was observed to be free of ground water. Geotechnical investigations including analysis of the strength properties of the tailing may lead to definitive reasons for this failure.

Fig. 7 Tilting of the mooring piles at the toe of the rock berm of the pier in Redondo Beach.

Fig. 8 Liquefaction-induced settlement of a building on the pier in Redondo Beach.

Fig. 9 Rock slides in the region north of the epicenter.

Fig. 10 Landslides in Santa Monica along the Pacific Coast Highway.

Fig. 11 Slope failure in Simi Valley at a rock quary.

GROUND DEFORMATIONS

In Granada Hills, on Balboa Street, immediately north of Highway 118, there was evidence of significant permanent ground deformations. About three blocks along this street, and one block on each side of the street, there were many cracks in the ground running perpendicular to Balboa Street. Some of these were tensile cracks with widths as large as 6 to 10 inches, as shown in Fig. 12. Other cracks were of compressive type resulting in ridges in the sidewalks, as shown in Fig. 13. In this section of Balboa Street, there were many ruptures of gas lines leading to fires that destroyed many residential houses. Also, the water main in this section of Balboa Street ruptured causing major floods. The cause of these ground fissures is not well understood yet. Since the fault in this region is closer to the ground surface than anywhere else in the Valley, it is possible that the ground deformations in this region within the San Fernando Valley, have a more direct connection with the fault rupture. Alternatively, since the cracks in the ground are limited to the section of Balboa Street that is on a hill, shallow slope failures (where blocks of soil moved downhill and relative to one another) can not be precluded as a reason for theses cracks.

SUMMARY

In Summary, geotechnical factors have played an important role in the Northridge Earthquake. Results from ongoing research, involving analyses of observations with site-specific geologic/geotechnical information (supported by number of federal/local agencies and institutions) will certainly shed light towards better understanding of the causes and mechanisms of the related phenomena.

Fig. 12 Ground fissures along Balboa Street in Granada Hills.

Fig. 13 Compressive ground deformation along Balboa Street in Granada Hills.

REFERENCES:

1. California Strong Motion Instrumentation Program (CSMIP), "Quick Reports on CSMIP Strong-Motion Data from the Northridge/San Fernando Valley Earthquake of January 17, 1994." Reports OSMS 94-01 to 94-05, California Division of Mines and Geology (CDMG), January, 1994.

2. Moehle, J. (Editor), "Preliminary Report on the Seismological and Engineering Aspects of January 17, 1994 Northridge Erathquake." Univ. of Calif. at Berkeley, Earthquake Engineering Research Center, Report No. UCB/EERC-94/01, January, 1994, 84 pps.