U. S. DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Preliminary Evaluation of Structures: Whittier Narrows Earthquake of October 1, 1987

by

M. Çelebi
G. Brady
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

and

H. Krawinkler
Stanford University
Stanford, CA 94305

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TABLE OF CONTENTS

Page No.

INTRODUCTION

The October 1, 1987 Whittier Narrows, California earthquake ($M_L = 6.1$ - NEIS, Caltech) occurred at 1442 GMT (0742 PDT), had its epicenter at 34.058°N and 118.077°W and had a depth of 12 km. The earthquake was the strongest shaking that has occurred in the Los Angeles basin since the February 9, 1971 San Fernando earthquake ($M_L = 6.4$). The earthquake was followed by several small aftershocks and a $M_L = 5.5$ aftershock on the morning of October 4. The location of the epicenters of the 1987 and the 1971 events as well as the faults are shown in Figure 1.

The main shock caused at least 2 fatalities and a number of reported injuries. Several deaths after the main shock were also attributed to the earthquake. The $M_L = 5.5$ aftershock caused one additional death and injuries to several people. The loss of property was extensive in the township of Whittier and to a lesser extent throughout neighboring communities of Los Angeles County. Most of the severe structural damage noted during this cursory survey was caused in old and unreinforced masonry buildings. This is not to say that damage in engineered structures was minor, as more and more cases of structural damage are becoming known. Examples of serious structural damage in engineered structures noted during our visit were at the campus of the California State University at Los Angeles, in a parking garage in Whittier, and at the Highway 5/605 interchange—an important lifeline. Nonstructural damage was observed at many places, ranging from cracked infill walls to severe ceiling damage.

The purpose of this report is to provide a preliminary evaluation of the performance of structures and also to deliberate on the recorded motions, particularly in structures instrumented by the U.S. Geological Survey.

THE EARTHQUAKE RECORDS

In addition to the stations of the permanent network of the U.S. Geological Survey triggered by the earthquake, significant contributions to the total recordings will be made by the California Division of Mines and Geology network, the University of Southern California network, the California Institute of Technology, instruments in structures operated for the City of Los Angeles, and smaller public agency and private utility networks.

To date, the USGS has recovered the records from 52 stations with epicentral distances ranging from 3 to 107 km and peak horizontal accelerations as high as 0.63 g. CDMG's CSMIP network has provided records from 35 stations with epicentral distances from 7 to 47 km and peak horizontal accelerations as high as 0.45 g. Both agencies will be recovering more records from outlying stations. Ground-level records generally provide 3 channels each. Structural records from the installations of both agencies provide up to 12, 24, or more channels at each station.

Characteristics of selected records obtained from the USGS stations, with epicentral distances and azimuths and peak accelerations are listed in Table A–1 of Appendix A. A map of the closer stations is shown in Figure A–1. The tables and the figure have been adapted from USGS Open-File Report 87–616 (Porcella, Etheredge, and others, 1987). The reader is referred to this report for complete information related to the records obtained by the USGS. However, sample records are provided in Appendix A. Three of these records are from the Garvey Reservoir station closest to the epicenter (3 km) and the Whittier Narrows Dam crest and upstream stations at 4 km from the epicenter (Figure A–2). The other set of records are from the 32-story 1100 Wilshire Blvd. Building (an extensively instrumented structure) at 17 km from the epicenter (Figures A–3 to A–5).

DAMAGE IN ENGINEERED STRUCTURES

Burbank Airport

Most of the windows in the airport control tower were broken and for this reason the airport was closed for more than one hour after the earthquake. No other damage was observed at this airport. A general view of the tower is seen in Figure 2.

California State University at Los Angeles

This campus was closed down after the earthquake because buildings on the campus suffered varying degrees of damage. Several buildings had extensive nonstructural damage, a chemical spill caused a fire in the Physical Sciences Building, and at least two buildings suffered structural damage. A general campus map is shown in Figure 3.

Primary attention on the campus is focused on a large, two-story parking garage where one of the heavy, second-story architectural panels fell on a passing student during the main shock, causing her death. The fallen panel is shown in Figure 4. The anchors of the panel to the reinforced concrete spandrel beam appeared to be very shallow and broke away from the concrete during the shaking (see Figure 5). Structural damage in the garage was small, with only minor spalling of concrete observed at the intersections of columns or shear walls with the floor system. Furthermore, several poorly-anchored utility pipe hangers were sheared off from the cast-in-place portion of the ceiling slab (Figure 6).

Another building with considerable damage is Salazar Hall. Most of the classrooms had severe ceiling damage, with rather heavy hanging ceiling panels spread all over the rooms (Figure 7). There were clearly visible shear cracks in interior walls and considerable cracking and spalling of concrete in some of the exterior architectural columns (Figure 8).

Structural damage was evident in the walkway between the two wings of the Kennedy Library (Figure 9). All four support columns (two per axis) in the first story had shear cracks, ranging from light to rather severe. Typical cracks in two of the columns are seen in Figure 10. The walkway building was separated from the two library wings through flexible joints (covered over 2"–3" gaps) and may have pounded against the wings, since the glass panels at the two ends of the walkway building were shattered on all stories.

It is important to note that the campus was founded on a slight slope behind which are small hills with one- or two-story homes—where no damage was observed. It was reported by a CSU engineer that the campus buildings were founded on cut and fill when the original topography of the area was altered according to a master plan.

May Company Parking Garage in Whittier

This large, two-level cast-in-place reinforced concrete structure was in part collapsed and in part very severely damaged and close to collapse. This garage, built around 1965, presents illustrative examples of design problems that should be avoided according to the present state of knowledge and modern seismic design criteria. A general view of the garage is seen in Figure 11. The partially collapsed section of the garage is seen in Figure 12. A cursory inspection of the damaged building brought forth the following characteristics:

1. Very stiff exterior panels as well as deep webs of T-beams created "short columns" all around the perimeter of the building (Figure 13).

2. The 16 × 16 in. exterior columns were not designed for the high shear forces created by the short-column effect. The stirrups of the surveyed exterior columns were undeformed #2 bars spaced 12 inches or further apart (Figure 14).

3. The joint detailing did not permit much moment transfer between the deep floor beams and the small exterior columns. The joints were not confined and the bottom bars of the beam were cut at the exterior column faces, preventing the development of positive moment at the joints (Figure 15a). In one column, a longitudinal bar was left outside the ties (Figure 15b).

4. Bond between concrete and rebars was very poor.

5. Several of the interior circular columns had collapsed or were badly damaged and were barely able to support the heavy floor system (Figure 16).

Fortunately, the parking garage had been closed for some time and no cars were in the garage. Thus, the structure had to support only its own weight without any superimposed live loads.

I-605 Overpass over I-5

Severe structural damage was observed in the columns of an interior bent of the I–605 overpass. The overpass, constructed in 1964, is skewed and has 8 bents with five columns each (Figure 17) (J. Gates, 1987, private commun.). Figure 17 also shows the dimensions of the structure, the pattern of shear cracks and the restrainers implemented in 1981 (Klein and Mellon, 1987). Severe damage was found only in the one bent between the north- and south-bound lanes of I–5, the other bents appeared to have little or no damage. The damage consisted of shear cracking that was relatively light at the northernmost column and increased significantly in the columns further south.

The columns are 12 feet high with section dimensions of 36 in. × 48 in., heavily reinforced with 34 #14 longitudinal bars, spaced about 6 to 7 inches apart, and have #4 shear reinforcement spaced about 10 to 12 inches apart. The shear cracks looked rather dramatic, with large portions of the concrete cover spalled off and clearly visible shear cracking inside the confined core (Figure 18). However, judging from past experience with reasonably well-confined columns, it is estimated that considerably larger shear deformations could have been sustained before actual collapse of the columns would have occurred. Nevertheless, the damage was severe and the intersection of I–5 and I–605 was closed for one day until temporary timber bracing and shoring could be installed. The temporary support structure is visible in Figure 19.

From an engineering viewpoint, the damage to this overpass represents probably the most interesting and educational case study. Why was the damage so severe although there were no evident gross violations of sound seismic principles, and there was relatively little damage to other bents in this multi-span overpass or to structures in the surrounding area?

Whittier High School

The auditorium, the administration building and the library of the school suffered minor damage. Books fell from well-anchored bookshelves in the library (Figure 20); some walls in the corridors of the administration building had small cracks; very light non-structural damage occurred in the large open auditorium.

Shell Structures in Whittier

There were a few shell structures in downtown Whittier. None of the shell structures surveyed exhibited any sign of distress.

DAMAGE TO UNREINFORCED MASONRY STRUCTURES

To no one's surprise, the most evident examples of damage were in unreinforced masonry buildings. Probably hardest hit was the Uptown Whittier area where a number of buildings were severely damaged and had partially or completely collapsed walls. In the cases observed by the field team, the damage occurred in buildings where the walls were not tied together properly. Perhaps the only surprise was that more collapses had not occurred, considering the relatively heavy ground shaking and the poor condition of many of the unreinforced masonry buildings. Although other cases may have existed, we saw only one building in the uptown Whittier area that could be considered a complete collapse. In this case the supporting wall of the roof trusses was sufficiently damaged to cause a cave-in of the roof trusses (Figure 21).

A complete collapse of an unreinforced masonry building occurred in Pasadena at the corner of Green and Fair Oaks (Figure 22). Again, this collapse is no surprise as engineers had pointed out the poor condition of this building in the past. Next to this collapsed building, another building that was being retrofitted suffered no significant damage (Figure 23), except that the upper part of the back wall fell onto the collapsed structure (seen in Figure 22).

DAMAGE TO RESIDENTIAL HOUSING

Damage to residential housing was evident in the hills of north Whittier, particularly around Beverly Boulevard. Timber houses fared rather well, with damage limited primarily to collapsed or cracked chimneys (Figure 24) and distorted porches and garage doors. In some of the masonry houses the damage was severe and of the type shown in Figure 25.

NONSTRUCTURAL DAMAGE

Nonstructural damage was evident in most places that were subjected to severe ground shaking. Most observers very commonly saw fallen ceiling panels (*e.g.,* California State University at Los Angeles, Lucky store in Whittier), damage to shelved goods (library at Whittier High School, Lucky store), cracks in infill walls and between infill walls and framing, shattered glass, and deformations around expansion joints. A view from the Lucky store in Whittier is seen in Figure 26.

ASSESSMENT OF DAMAGE

Although the total property loss is reported to be substantial (in the order of 200 million dollars), in general, the earthquake-stricken area of the Los Angeles basin survived the main shock and aftershock reasonably well considering the rather strong ground motions recorded in these events. In a sense, it is surprising that there was not more damage to the older, unreinforced masonry buildings.

Even though at the writing of this report the records obtained were not studied to the full extent, it is quite reasonable to state that well-engineered structures performed well during this moderate earthquake. The degree of the impact of local geological formations on the various sites where the records were obtained and damage occurred is not yet known.

In a way, the observed damage confirms the soundness of current design criteria. In cases when such criteria was not followed (May Company parking garage), damage was very severe. In recently built structures, most of the damage was non-structural—as it should be during moderate earthquakes such as the Whittier Narrows earthquake of October 1, 1987.

REFERENCES

Etheredge. E., Porcella, R.,and et.al., 1987, Strong-motion data from the October 1, 1987 Whittier Narrows earthquake, *USGS Open-File Report 87-616*.

Gates, J., 1987, private communication.

Klein, E. G. and Mellon S., 1987, Report of post earthquake investigation team (Los Angeles area earthquake of October 1, 1987), *CALTRANS-Division of Structures Report*.

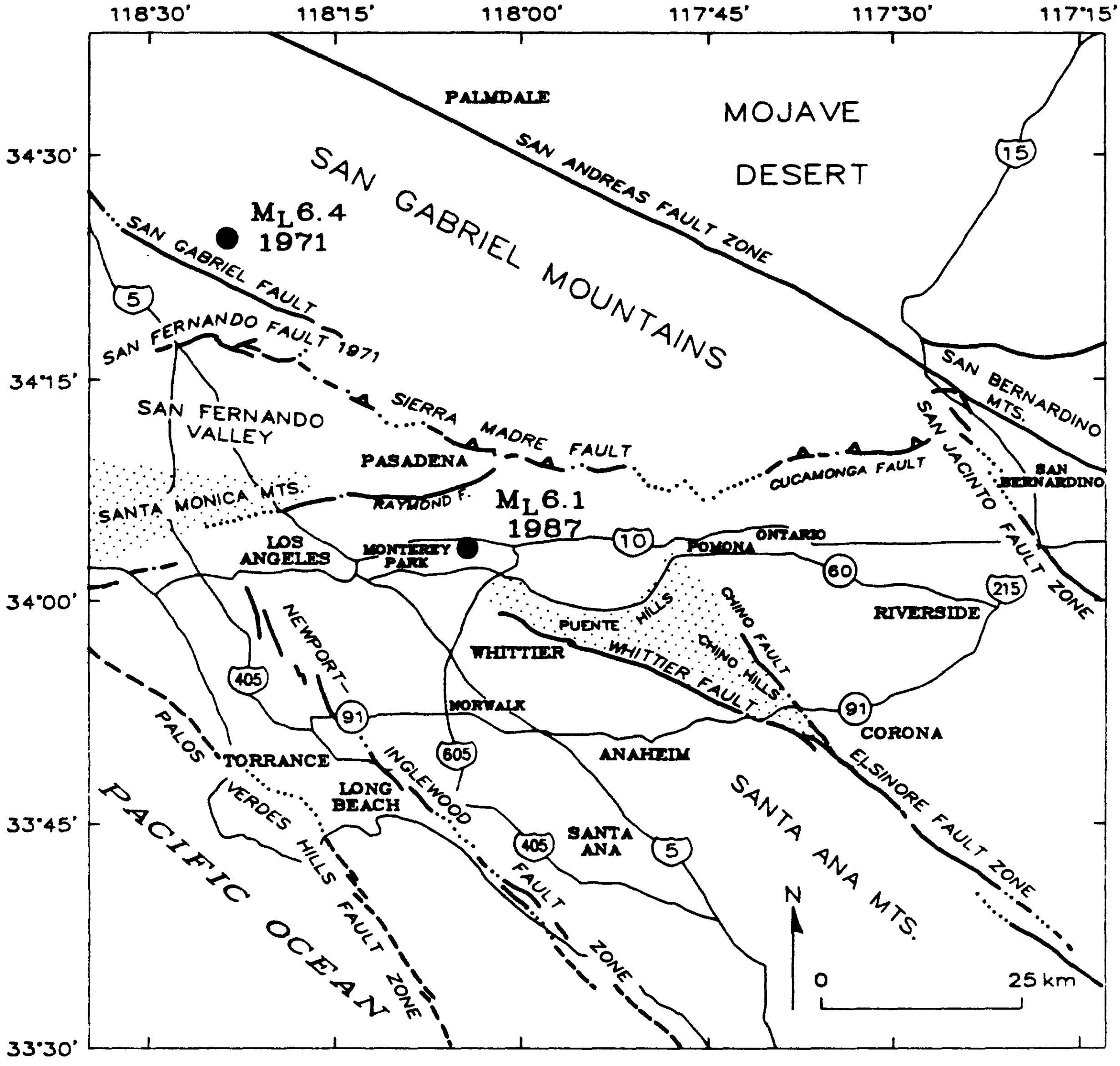
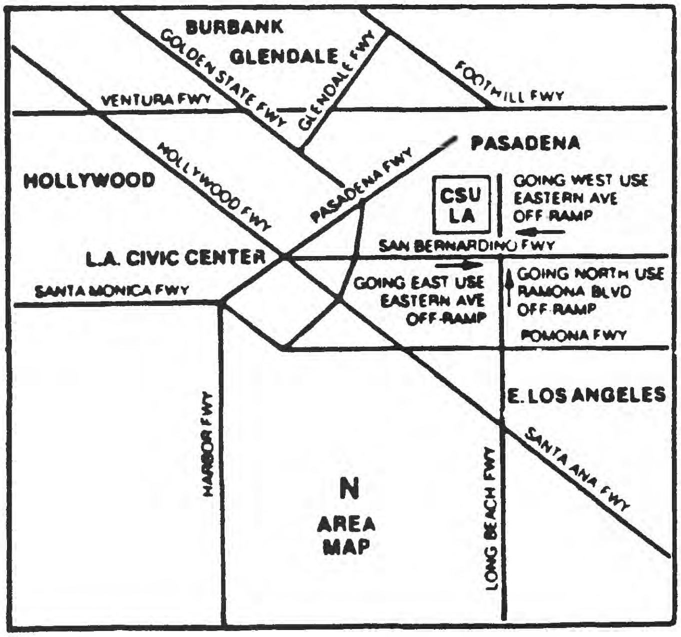


Figure 1. The location of the epicenters of the 1985 and 1971 events and the known fault systems in the Los Angeles basin.

Figure 2. Control tower of Burbank Airport. The glasses were broken and as a result the airport was closed for approximately two hours.



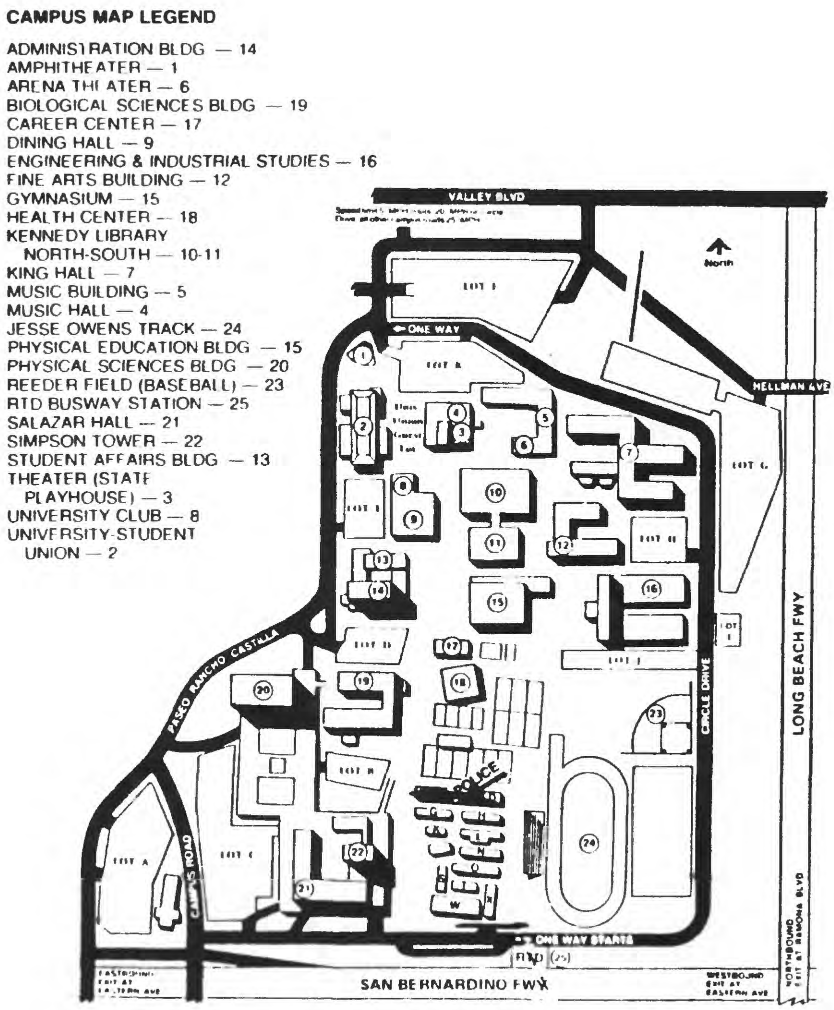


Figure 3. Location and general campus map of California State University at Los Angeles.

Figure 4. Precast side panel previously "anchored" to the cast-in-place spandrel beam of the garage. The panel caused the death of one student.

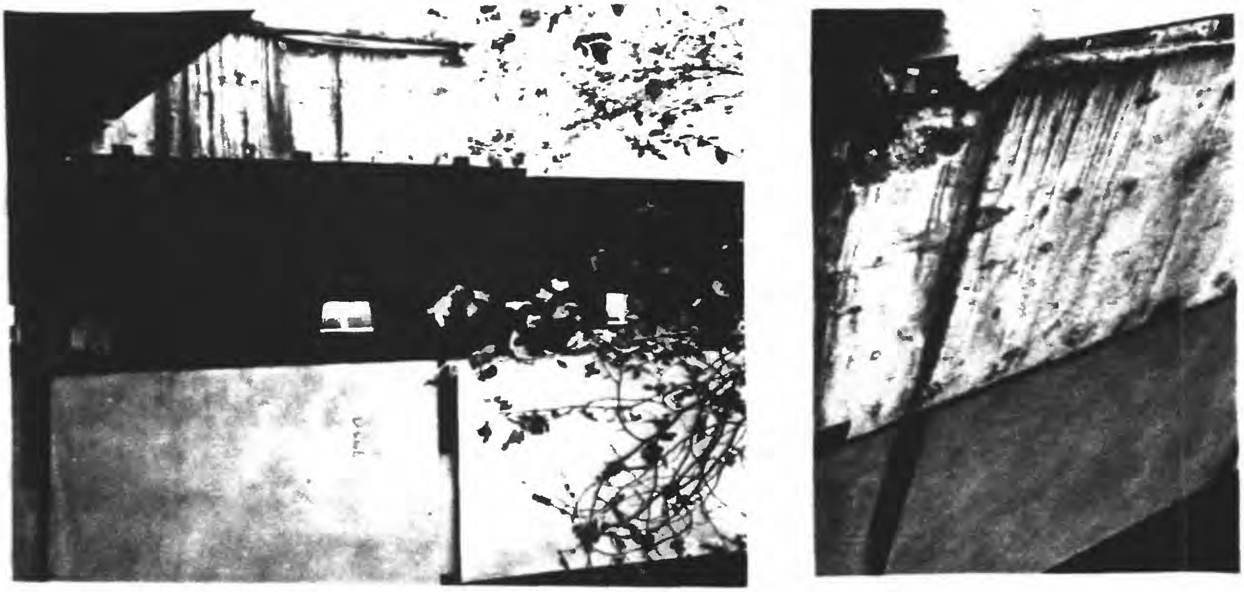


Figure 5. Details of the anchorage of the panel to the spandrel beam.

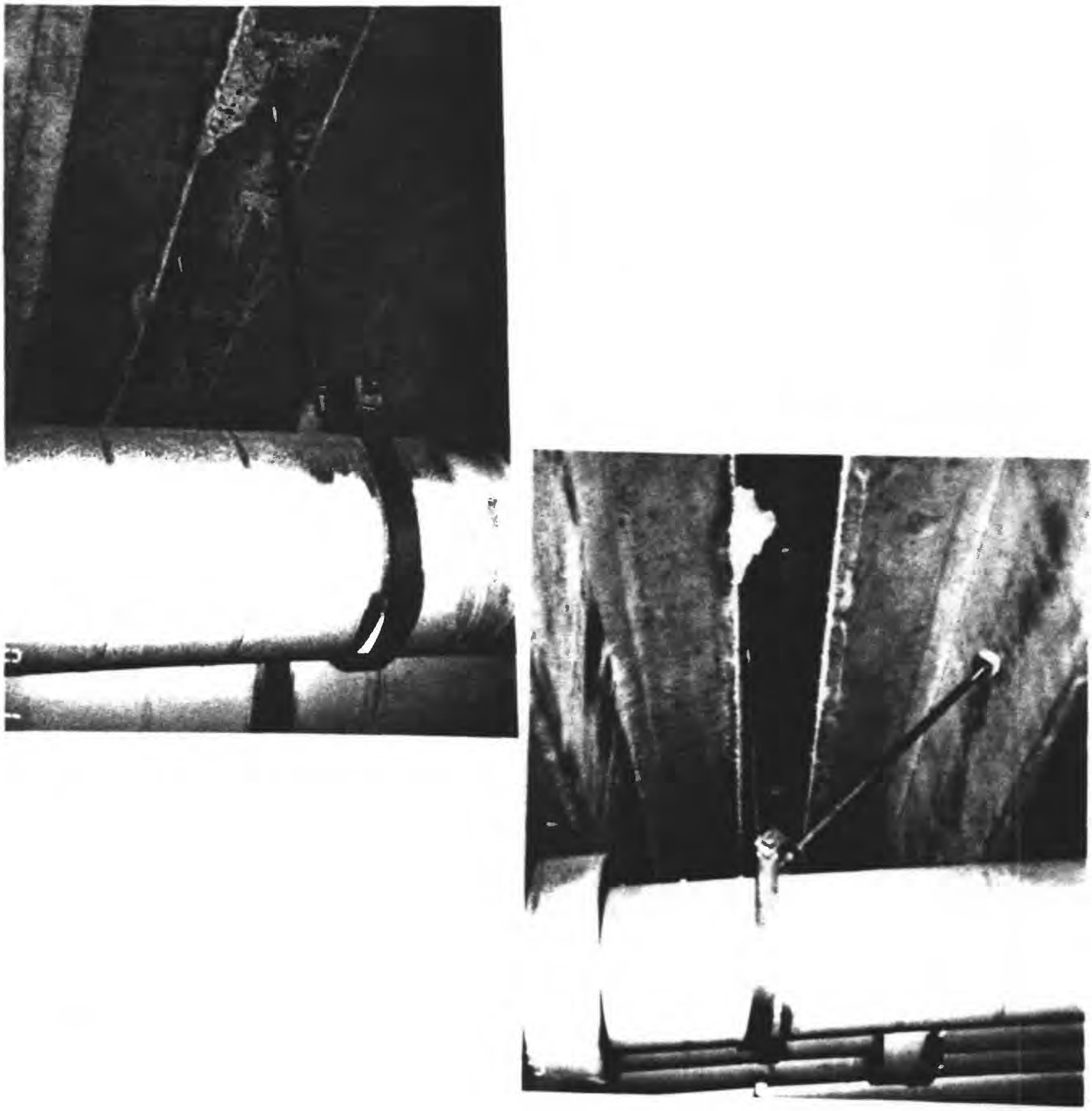


Figure 6. Utility pipe anchors sheared off from the cast-in-place portion of the ceiling slab.

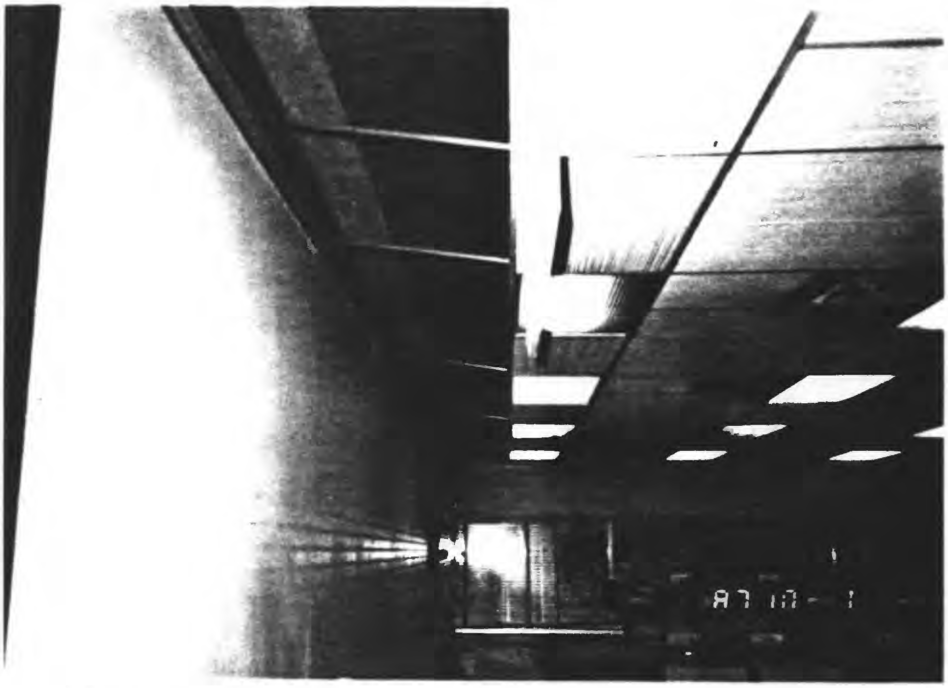


Figure 7. Hanging ceilings in most of the classrooms of the Salazar Building were severely damaged.

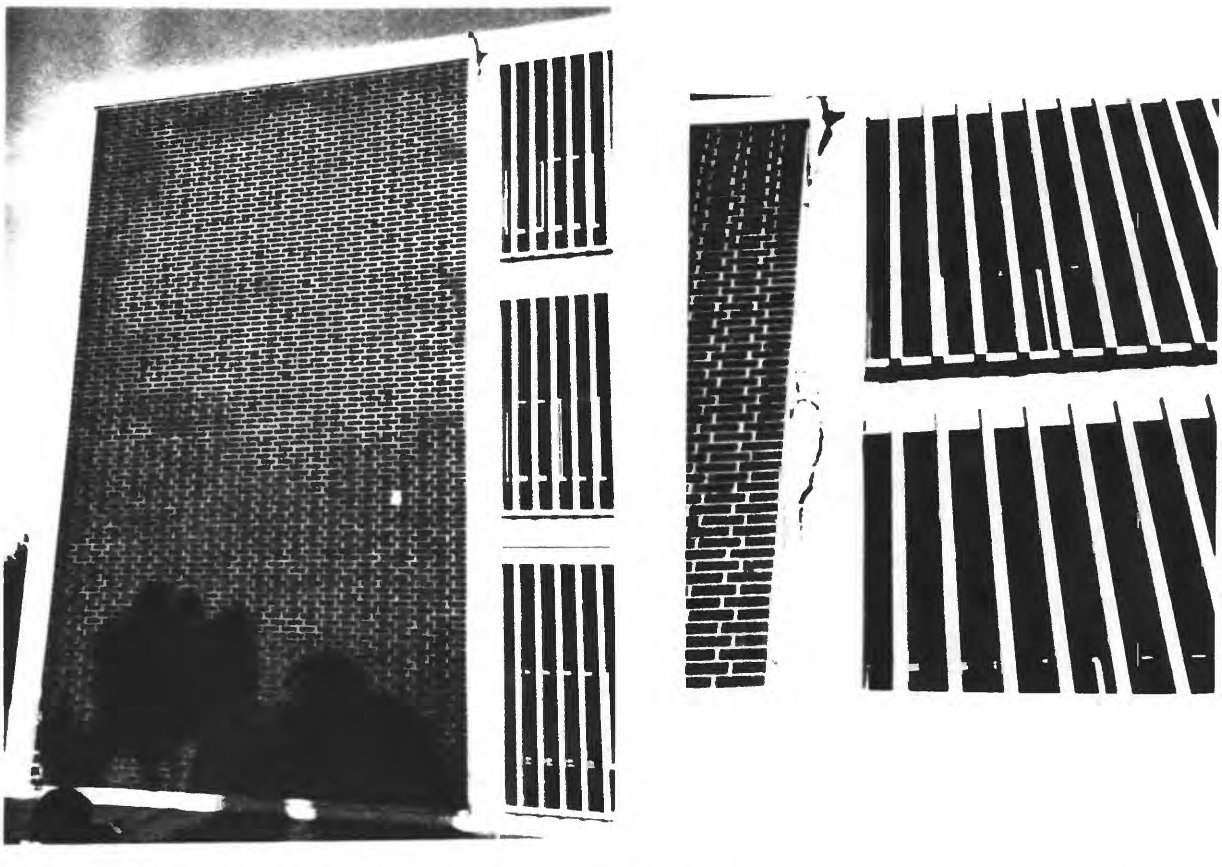


Figure 8. Exterior architectural columns cracked and spalled (Salazar Building).

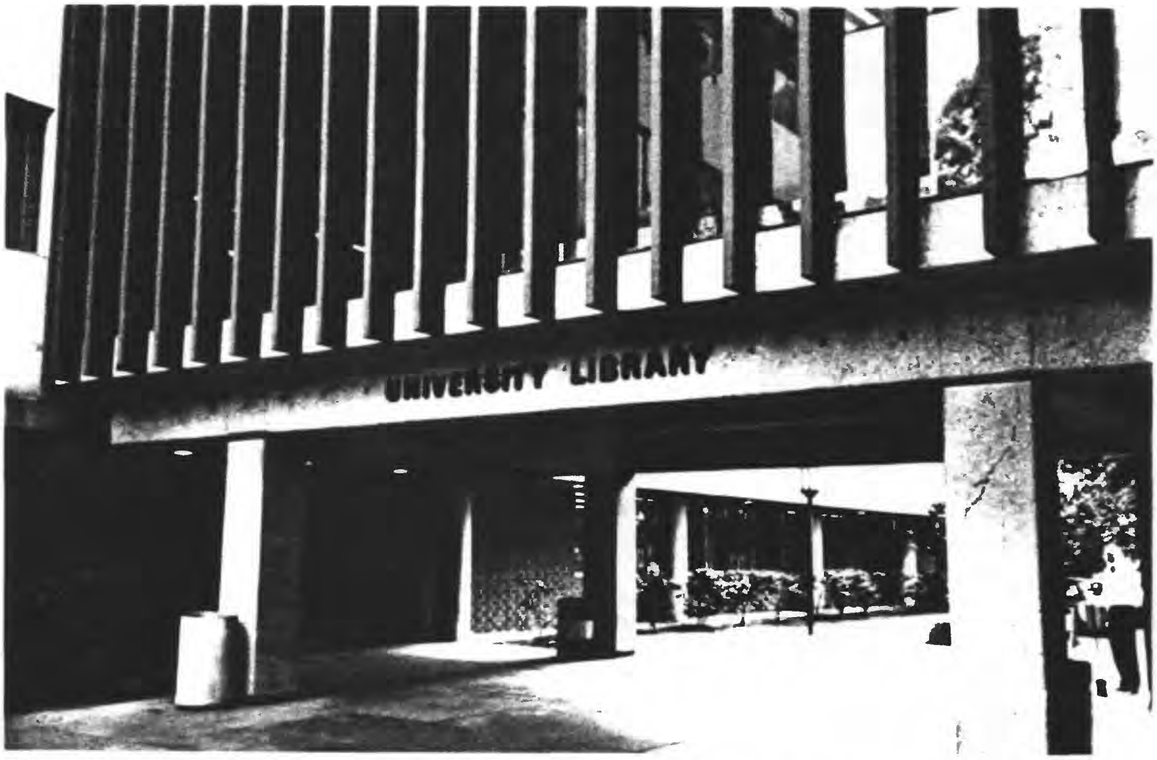


Figure 9. Walkway between two wings of the Kennedy Library. Windows broken. Columns cracked.

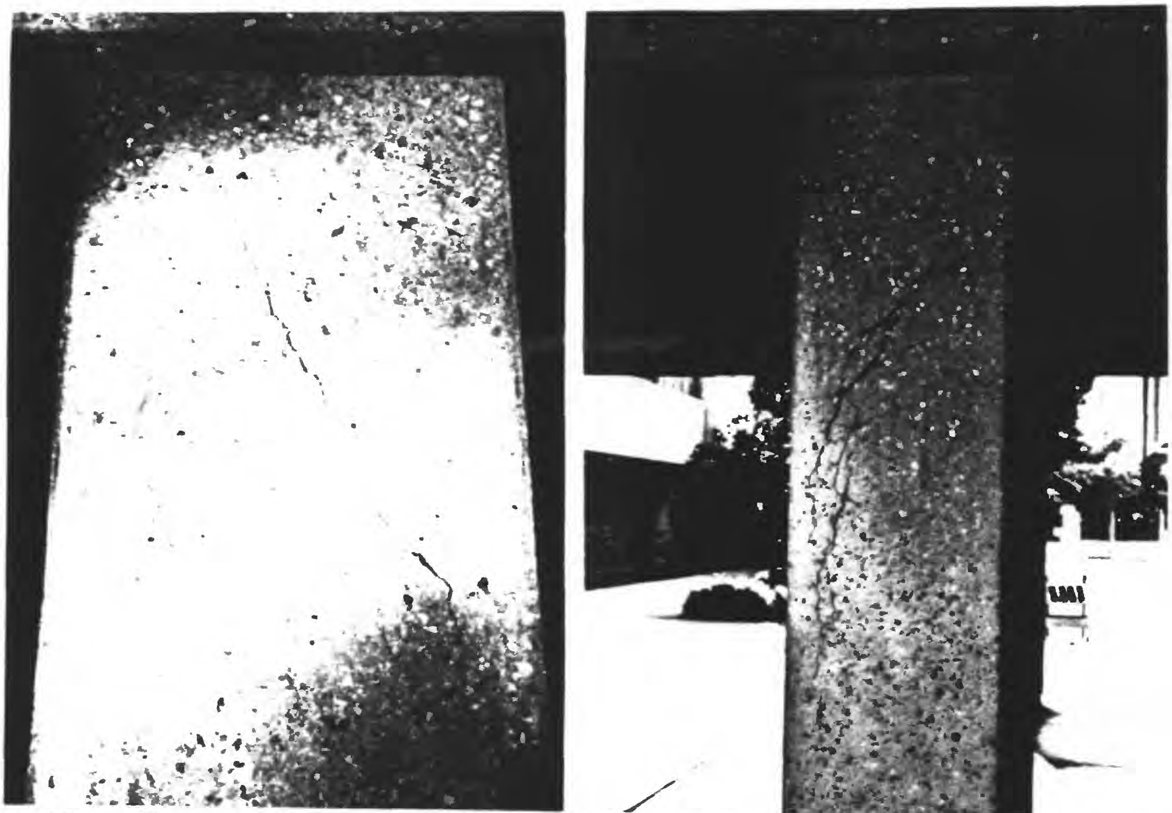


Figure 10. Shear cracks in two of the four columns of the walkway between the wings of the Kennedy Library.

Figure 11. A general view of the May Company Parking Garage in downtown Whittier.

Figure 12. Partially collapsed section of the May Company Parking Garage.

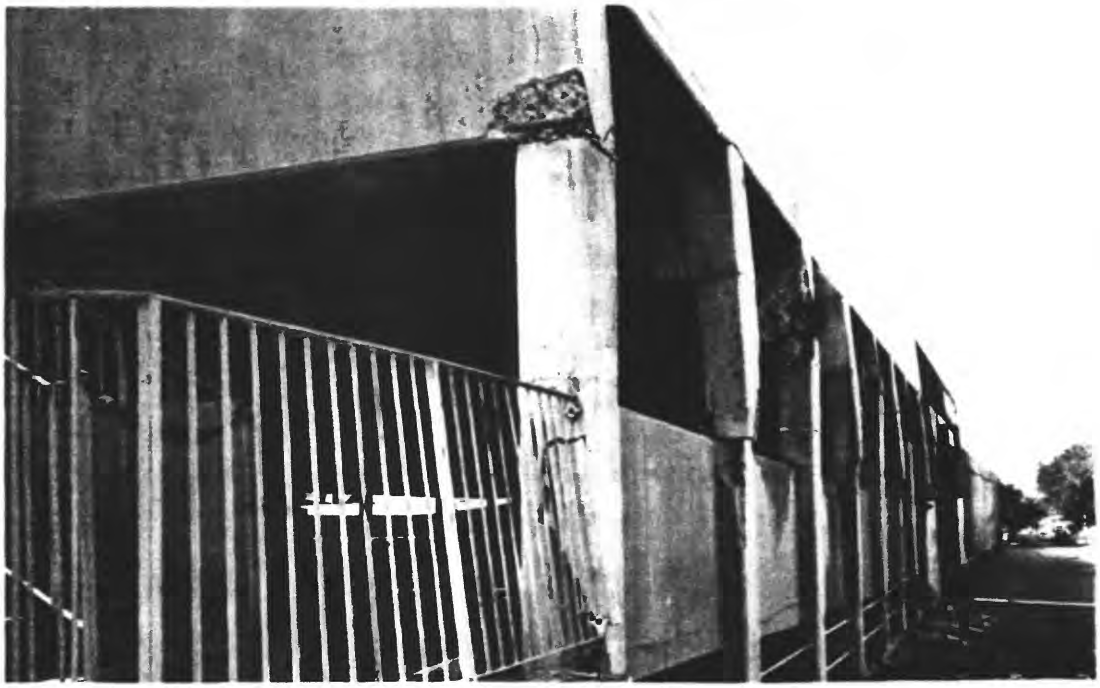


Figure 13. Stiff exterior panels and deep webs of T–beams created "short column" effect all around the perimeter of the May Company garage building.

Figure 14. Shear reinforcement of exterior columns were insufficient (#2 undeformed bars spaced 12 inches or further apart). Note buckling of longitudinal bars.

Figure 15a. Beam column joints unconfined. Bottom longitudinal bar of the girder cut.

Figure 15b. Longitudinal bar in this column was left outside the ties.

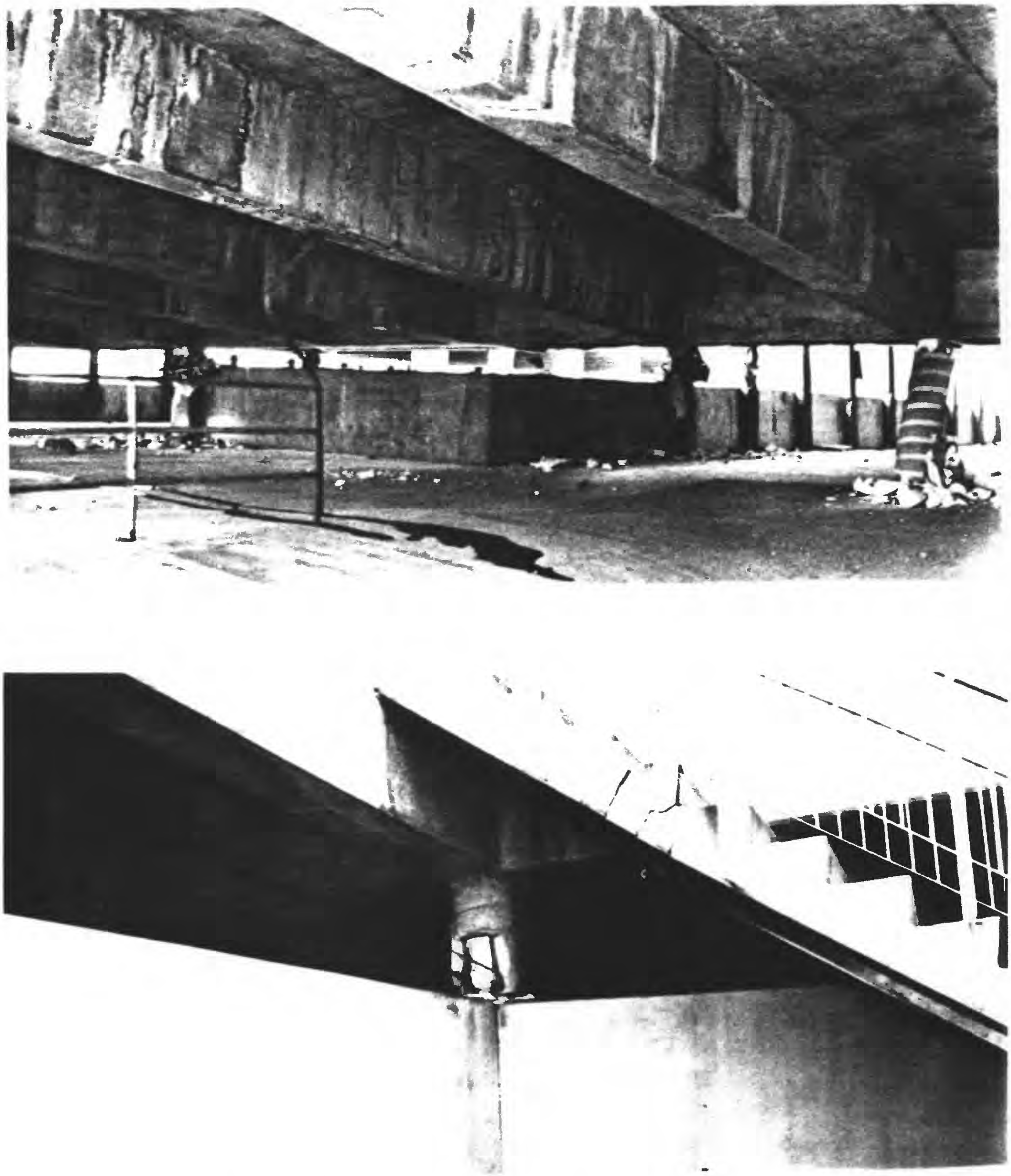


Figure 16. Interior circular columns collapsed and barely supported the heavy floor system.

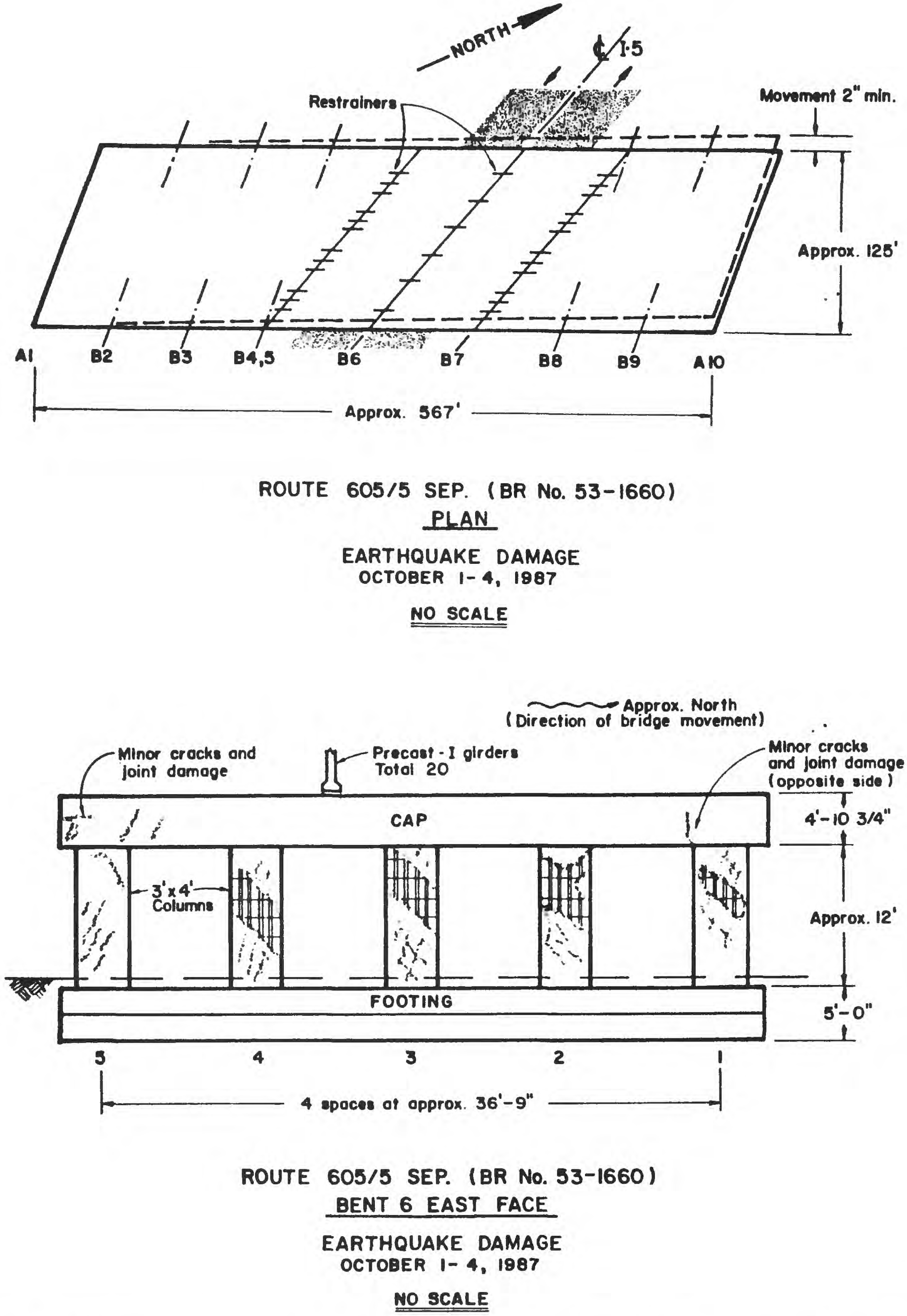


Figure 17. I-605 overpass over I-5 severely damaged during the main shock. General sketch of the skewed deck and the shear crack pattern of bent #6 are shown (adapted from Klein and Mellon, 1987).

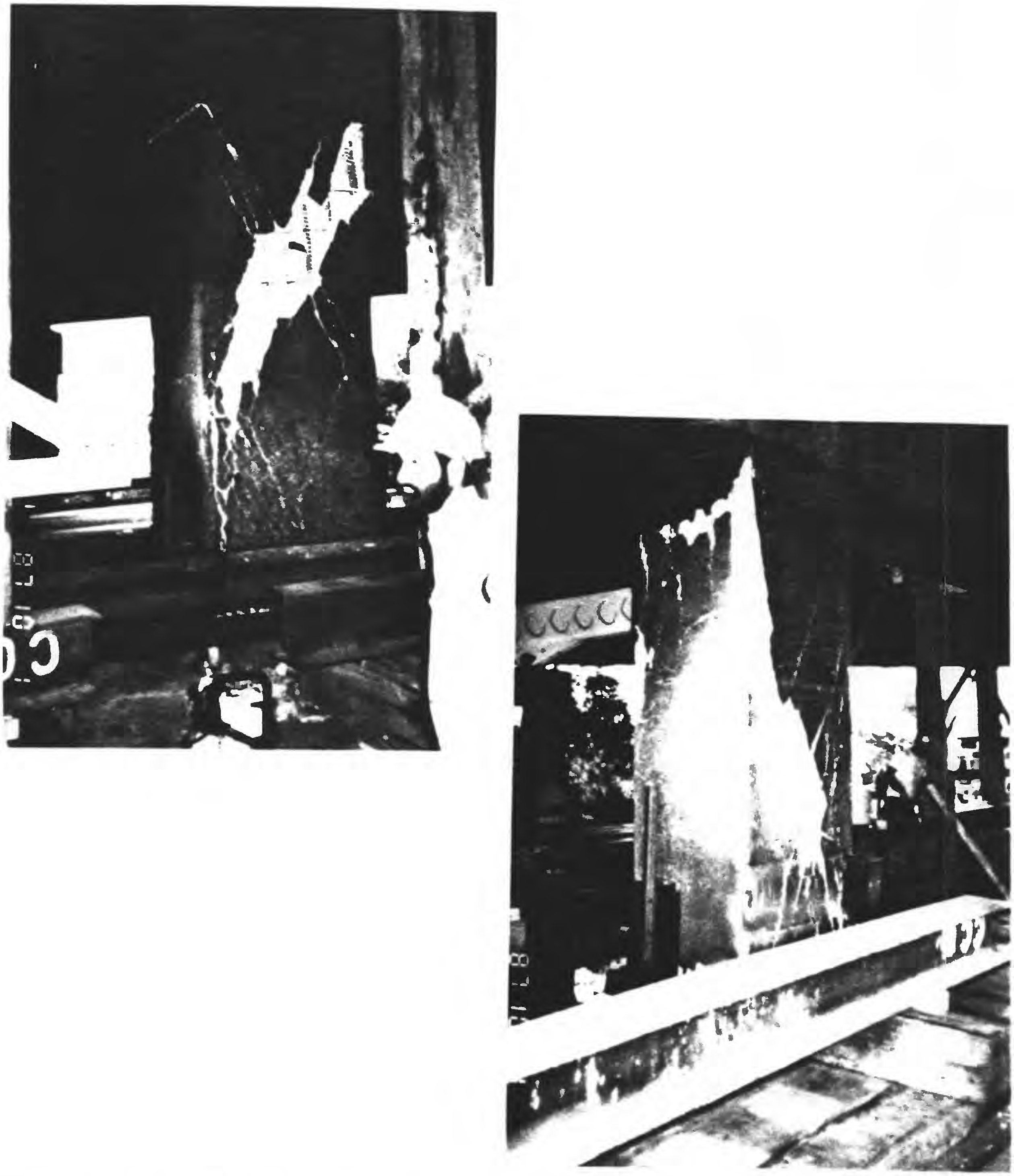


Figure 18. Two of the bent #6 columns with extensive shear cracks.

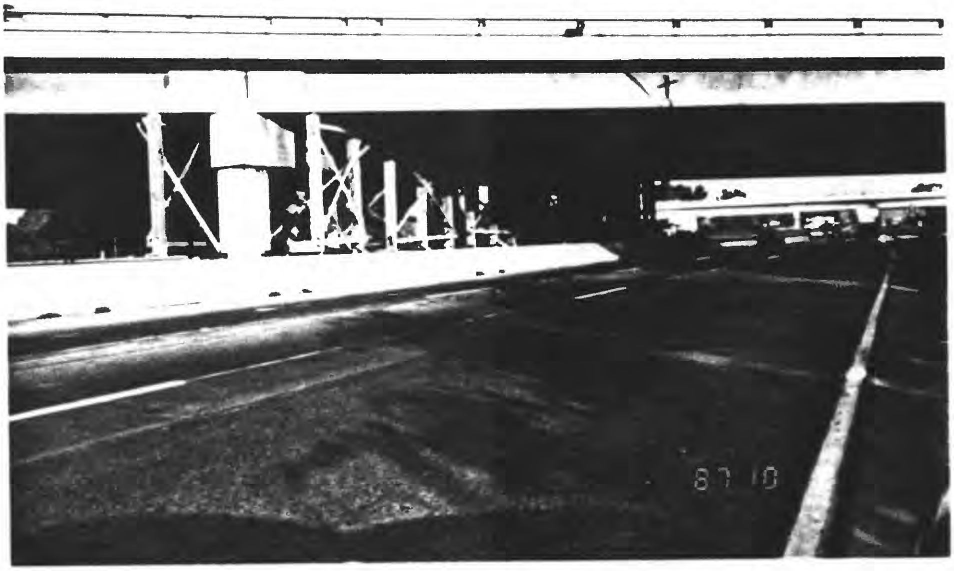


Figure 19. Temporary timber bracing and shoring to provide extra support to the I-605 overpass deck. The I-605/I-5 interchange was opened to traffic 24 hours after the main shock.

Figure 20. The bookshelves in Whittier High School Library were anchored properly—none overturned. Only the books fell.

Figure 21. The supporting wall of the roof truss sufficiently damaged to cause a cave-in of the roof trusses.

Figure 22. Collapsed unreinforced masonry building in Pasadena (corner of Green and Fair Oaks). The building in the background (next figure) was being retrofitted and the top part of the back wall fell onto the collapsed structure.

Figure 23. Next to the collapsed building (previous figure). this unreinforced masonry building. being retrofitted. did not exhibit significant damage other than the top part of the back wall.

Figure 24. Collapsed chimney of a timber house in Whittier.

Figure 25. Partial front wall of this residence in Whittier collapsed.

Figure 26. A view of the Lucky store in Whittier. The hanging ceiling damaged and groceries displaced from the shelves.

APPENDIX A

CHARACTERISTICS AND SAMPLES OF RECORDS

Table A-1. Characteristics of selected records
(abstracted from Etheredge and Porcella, 1987).

Station Name	Latitude (North)	Longitude (West)	Epicentral Distance	Hypocentral Distance	Azimuth from Epicenter	Peak Accelerations (g) Ground Level Hor.	Vert.	Structural Hor.	Vert.
Garvey Reservoir Abutment Bldg.	34.05	118.11	3	12	253.7	.47	.38	–	–
Whittier Narrows Dam	34.03	118.05	4	13	141.4	–	–	.32	.46
Alhambra	34.09	118.15	8	14	297.9	.30	.19	.47	.19
Whittier 7215 Bright Ave.	33.977	118.036	9.8	15	157.2	.63	.26	.61	.54
Los Angeles 4407 Jasper St.	34.081	118.188	10.5	16	284.1	.33	.13	–	–
Bell, Los Angeles Bulk Mail	33.99	118.16	11	16	225.4	.46	.52	–	–
Vernon, CMD Terminal Bldg. 4814 Loma Vista	34.00	118.20	13	18	240.4	.29	.17	–	–
Norwalk 12440 Imperial Hwy.	33.92	118.07	15	19	177.6	.21	.07	.40	.18
Norwalk 12400 Imperial Hwy.	33.92	118.07	15	19	177.6	.21	.10	.41	–
					(Downhole)	.16	.10	–	–
Los Angeles 1111 Sunset	34.07	118.25	16	20	274.8	.16	.07	.18	.22
Los Angeles 1100 Wilshire	34.052	118.263	17.1	21	267.8	.18	.08	.26	–
Los Angeles Griffith Park	34.12	118.30	22	25	288.6	.15	.06	–	–
Morris Dam	34.17	117.88	22	25	55.5	.05	.04	–	–
Orange County Reservoir	33.935	117.883	22.5	26	127.3	.23	.10	–	–
Brea Dam Left Abutment	33.890	117.930	23.1	26	144.0	.16	.09	–	–
Brea Dam Downstream	33.889	117.926	23.4	26	143.4	.32	.09	–	–
Brea Dam Crest	33.889	117.926	23.4	26	143.4	–	–	.31	.14
Carbon Canyon	33.92	117.84	27	29	125.0	.22	.07		
Dam Crest Left Abutment								.20	.13

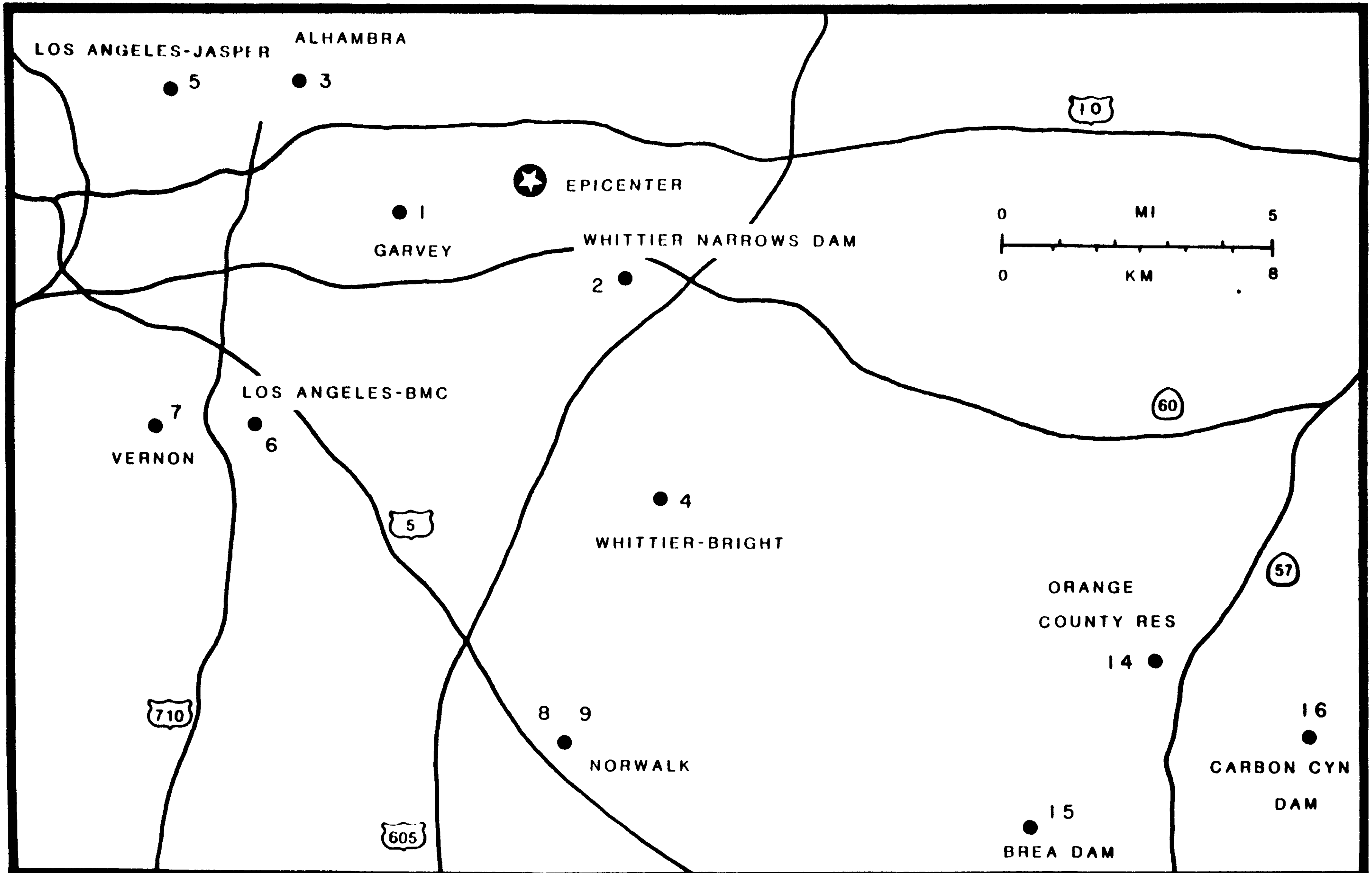


Figure A-1. Close-in map of USGS stations triggered during the Whittier Narrows earthquake (adapted from Etheredge, Porcella and others, 1987).

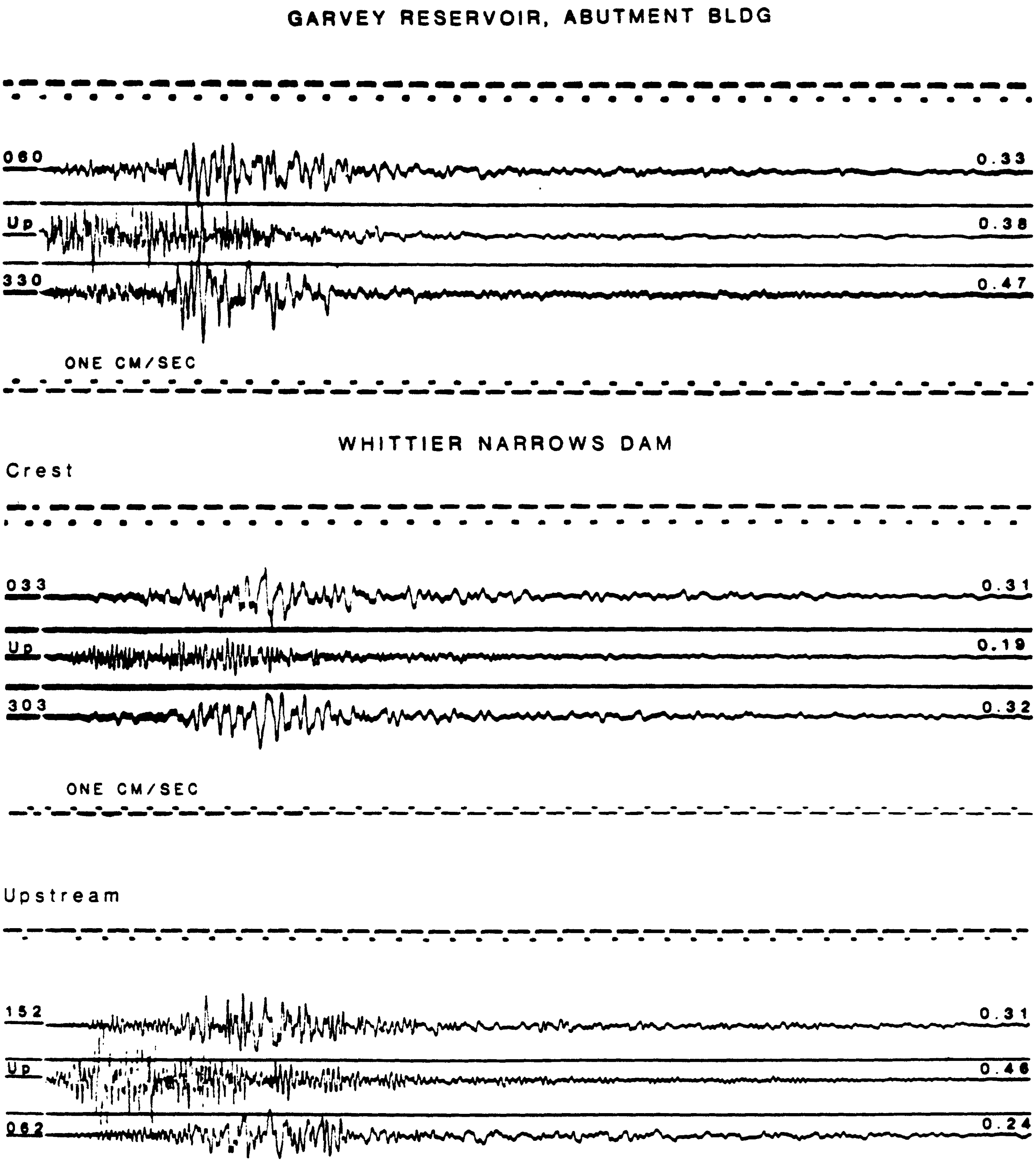


Figure A–2. Acceleration records obtained at the closest stations to the epicenter (3 km)—the Garvey Reservoir and the crest and upstream stations of the Whittier Narrows Dam at 4 km from the epicenter (from Etheredge, Porcella and others, 1987).

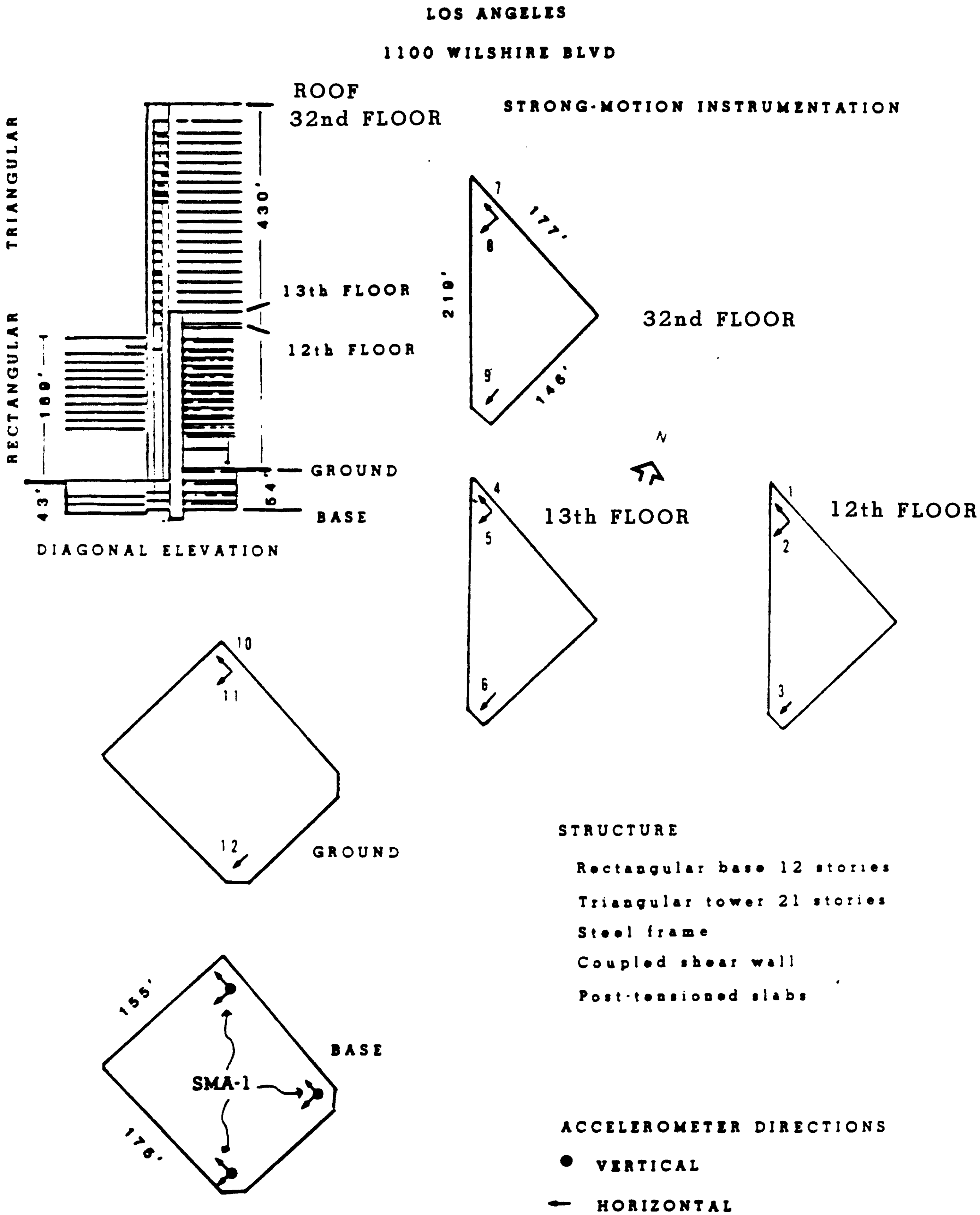


Figure A–3. Strong-motion instrumentation scheme of 1100 Wilshire Finance Building—an extensively instrumented structure located at 17 km from the epicenter.

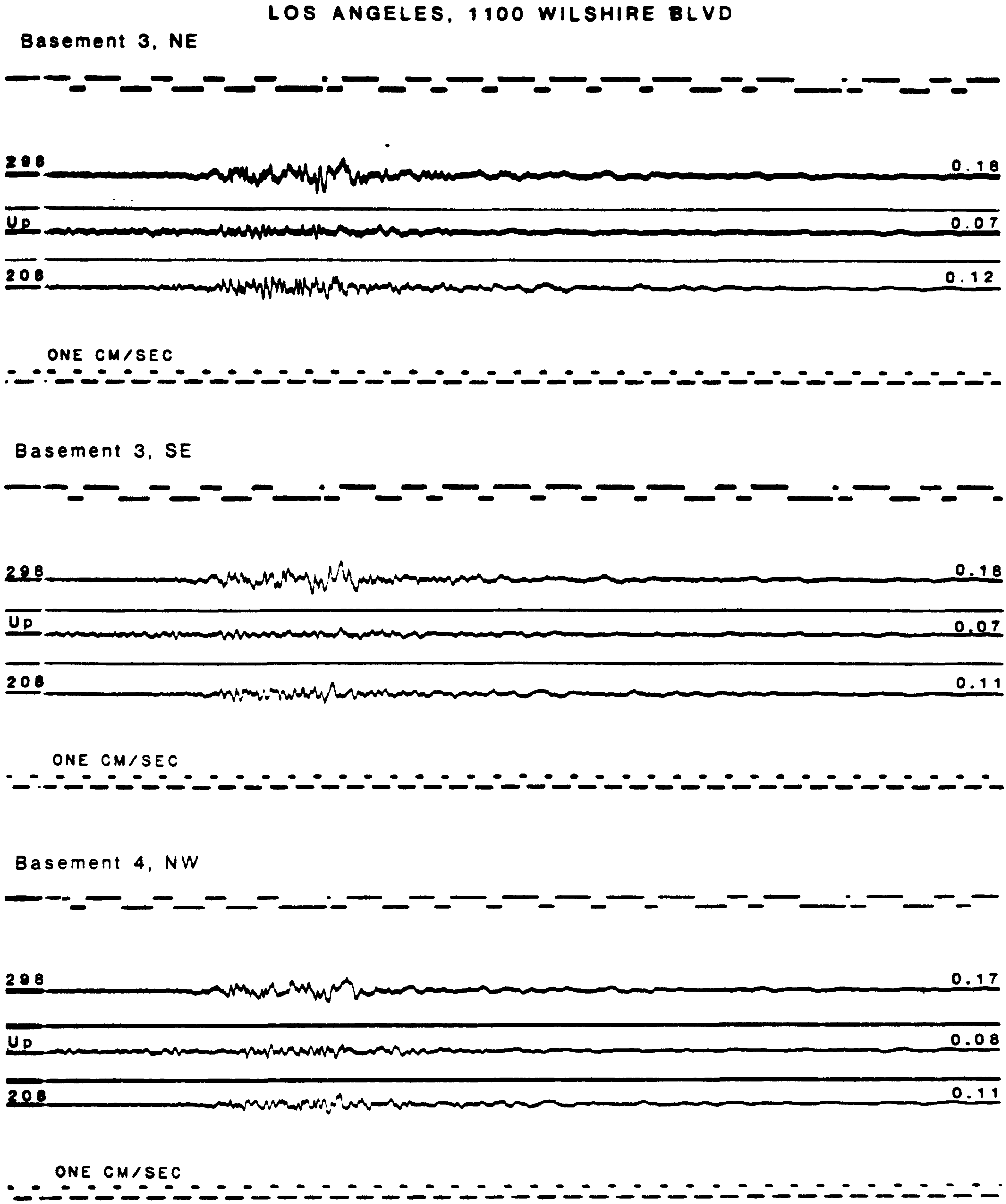


Figure A–4. Acceleration records obtained at the basement of the 1100 Wilshire Finance Building.

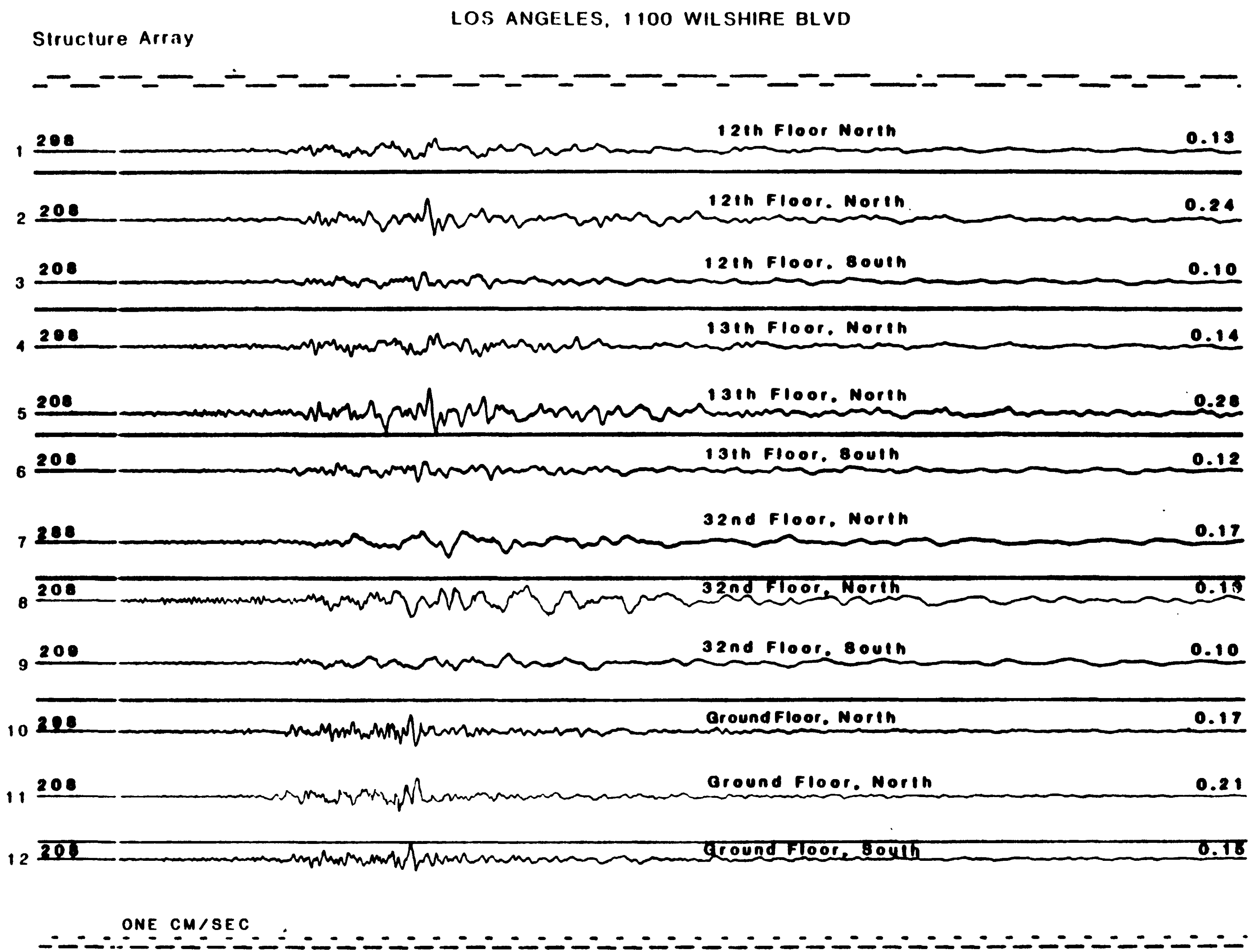


Figure A-5. Acceleration records obtained at different levels of 1100 Wilshire Finance Building.