THE SAN FERNANDO, CALIFORNIA, EARTHQUAKE OF FEBRUARY 9, 1971

by

P. C. Jennings[I] and G. W. Housner[II]

SYNOPSIS

The San Fernando earthquake of February 9, 1971 was a Magnitude 6.6 shock that killed 58 persons, injured 2400 and caused approximately 500 million dollars damage. Because of the broad scope of the earthquake's effects and the large number of consequent studies, this report is limited to a brief summary of the more important features of the earthquake, a listing of the more significant actions taken or proposed as a consequence of the shock, and a bibliography of some of the more important general reports about the effects of the earthquake.

INTRODUCTION

The Magnitude 6.6 San Fernando earthquake occurred on the northern edge of metropolitan Los Angeles shortly after 6 a.m., February 9, 1971. The shock took 58 lives, injured 2400 and caused an estimated 500 million dollars in property damage. Although only a moderate earthquake in seismological terms, the San Fernando earthquake was a major event from the engineering point of view because of the large number and variety of engineered structures and facilities that were subjected to strong ground shaking, the significant resulting damage and the excellent instrumental coverage.

It is not surprising, then, that the San Fernando earthquake is already one of the most thoroughly studied shocks in history. There are several general reports about the event as well as many detailed investigations of particular features of the earthquake, some of which are to be presented at 5WCEE. In addition, the earthquake has produced code changes, changes in standard practice, and has initiated detailed examinations and recommendations by task forces and advisory groups appointed by political bodies in the State of California.

GEOLOGIC FEATURES

Unlike the more usual California earthquake, which is generated by strike-slip faulting on an essentially vertical fault plane, the San Fernando earthquake was generated on a thrust fault which dipped approximately 45° to the north, underlying the east-west trending San Gabriel Mountains. The hypocenter lay about 8 miles deep, and the

[I] Professor of Applied Mechanics, California Institute of Technology, Pasadena, California.

[II] Professor of Civil Engineering and Applied Mechanics, California Institute of Technology, Pasadena, California.

east-west extent of the faulting was approximately 12 miles. At some locations the fault displacements reached the surface of the ground. In addition, a relatively large area of alluvial ground suffered deformation because of fault displacement at depth. A portion of the San Gabriel Mountains was elevated as much as 5 feet by the fault displacement. Numerous landslides were caused on the relatively steep slopes of the mountains and, in addition, there were landslides on relatively shallow sloping alluvial ground in the northern part of the San Fernando Valley.

In the general region where the fault displacement reached the surface of the ground, and to the north of this region, there was very severe ground shaking. Because of the proximity of the causative fault, this shaking of the ground would not have been more severe, it is thought, had the Magnitude of the earthquake been 8 or greater; but a much larger area would have been affected by strong shaking, and the duration of shaking would have been longer.

ACCELEROGRAPH AND SEISMOSCOPE NETWORK

Because of the requirement in Los Angeles that three accelerographs be installed in each building of ten or more stories, some 60 buildings were outfitted with three accelerographs each: one in the basement, one at midheight, and one at roof level. These code accelerographs provided good coverage in certain regions of Los Angeles city. In addition, the California Institute of Technology had 25 accelerographs and the National Oceanic and Atmospheric Administration (NOAA) had 17 accelerographs, installed at strategic locations. Other agencies had a smaller number of instruments located in their structures and on their grounds. Usable records were obtained from 241 accelerographs. At the time of the earthquake all of the strong-motion accelerographs were maintained by the Seismological Field Survey (NOAA).

The Los Angeles County Flood Control District had installed an accelerograph on a rock ridge adjacent to Pacoima Dam, located about two miles north of the surface expression of the faulting, just above the apparent center of energy release. This instrument recorded the strongest ground shaking ever recorded for any earthquake, with peak horizontal accelerations exceeding 1g (75%gvertical). Approximately five miles south of the surface expression of the fault, accelerographs in the seven-story Holiday Inn recorded the ground motion (28%g) and the building motion (40%g at the top). Other accelerometers and seismoscopes gave recordings on crystalline rock, sedimentary rock and alluvium.

EFFECTS ON STRUCTURES

Hazardous Old Structures. Earthquake design provisions were first incorporated in the Los Angeles building code in 1933, following the Long Beach earthquake. In the San Fernando earthquake, buildings constructed before 1933 demonstrated much less resistance than buildings constructed after 1933. Fortunately, most of the structures in the region of very strong shaking were relatively new.

New Buildings. There were 13 high-rise buildings in Los Angeles, ranging from 26 to 52 stories in height, 15 to 25 miles from the center of the earthquake. These vibrated strongly during the earthquake, but none received structural damage, although there was a certain amount of plaster cracking and damage to equipment. Numerous structures, from 10 to 25 stories in height, in Los Angeles and in the southern San Fernando Valley were 10 to 20 miles from the center of the earthquake. Some of the closer of these had moderate structural damage, such as cracking of shear walls and columns. The Holy Cross Hospital building and the Indian Hills Medical Center building, both new seven-story reinforced concrete structures, were in the region of very strong shaking. Both structures were severely cracked and damaged and, had the strong shaking lasted longer, portions of these buildings might have collapsed. A number of single-story industrial buildings were severely damaged by the ground shaking in the region near the center of the earthquake. These structures had masonry or concrete walls and wood roofs. The connections of the wood roofs to the tops of the walls were inadequate, with consequent failure of the connection and partial collapse of the structures. Joints between tilt-up wall slabs were another weak point in some buildings of this type.

Behavior of Dams. Pacoima Dam (372 feet high concrete arch, constructed in 1928) at the center of the earthquake was not damaged by ground shaking, but one rock abutment showed evidences of movement and distortion during the earthquake. There were many earth dams in the region of moderately strong to strong shaking (15%g or greater), and the dams designed and constructed during recent years withstood the earthquake very well. On the other hand, the old earth dams performed poorly. The lower San Fernando Dam, a 140 foot high hydraulic-fill earth dam, impounding the water supply for the city of Los Angeles, was in the region of very strong shaking and was severely damaged. During the earthquake the upstream face and the crest slid into the reservoir, leaving only 5 feet of freeboard against overtopping. The condition of this dam appeared so hazardous that 80,000 persons living below the dam were evacuated from their homes for four days, until the reservoir could be reduced to a safe level.

Hospitals. It was a striking fact that in the region of strong shaking, four hospitals were damaged so severely that they could not be used after the earthquake. At the Veterans Administration Hospital a pre-1933 building that had not been designed to resist earthquakes, collapsed and killed 49 persons. The Olive View Hospital, a new $30 million facility, was so severely damaged by the earthquake as to be almost a total loss.

Highway Structures. In the region of strong shaking (25%g or greater) there were 70 bridge structures forming part of the freeway system. Of these, five collapsed and forty others suffered some damage. There was no significant damage to highway bridges where the ground shaking was less than about 25%g. In the central region of the earthquake, permanent deformation of the ground contributed to the damage.

Electrical Power Facilities. The Pacific Intertie Converter Station was the southern terminus of the high voltage transmission line bringing power to southern California from the State of Oregon. This new $110 million facility suffered extensive damage from ground shaking. Although the building itself was not seriously damaged, the electrical equipment was destroyed. Several other electrical power switching stations in the region of strong shaking also received severe damage to the electrical equipment, particularly circuit breakers.

Sewers and Water Supply. Some three hundred miles of buried sewer line were in the region of strong shaking, and it has been estimated that approximately 15 miles of it had to be replaced because of damage at numerous locations resulting from ground deformation. In the same region the buried pipelines of the water distribution system were reported to have had approximately 1000 breaks, so that this region was temporarily without water for drinking or for fighting fires.

Water Treatment and Storage Facilities. A large water treatment plant, under construction in the region of very strong shaking, received damage from landsliding and from ground shaking; in particular, a large underground reinforced concrete reservoir was severely damaged.

Schools. School buildings in general performed well during the earthquake if they had been constructed since 1933, when special earthquake provisions (The Field Act) were specified for their design. This contrasts strongly with the extremely poor performance of the school buildings during the 1933 Long Beach, California earthquake. Some of the school buildings in the northern San Fernando Valley were damaged by permanent ground displacement, a few received structural damage from ground shaking, and some received undesirable architectural damage, such as fallen light fixtures, pieces of the ceiling dropping, etc. The earthquake caused damage to a number of pre-1933 school buildings in Los Angeles and made it clear that the old masonry school buildings were very hazardous in the event of strong shaking. Following the earthquake, the City of Los Angeles demolished 90 pre-1933 school buildings and strengthened 100 others to make them safe for occupancy.

Architectural and Mechanical Damage. Many multistory buildings in the region of moderately strong to strong ground shaking survived with no structural damage, but did incur costly damage to architectural finishes and to mechanical equipment. Many new buildings suffered extensive plaster cracking, because the plaster was too stiff to accommodate the interfloor deformation of the structure. Although some of the older office buildings in Los Angeles had many windows broken, the new office buildings had very little glass breakage. (The code requires new buildings to have their windows so designed that they can accommodate interfloor deformation without shattering). Many office buildings suffered damage to the elevator systems. This was mostly a matter of the counterweights coming out of the guides and becoming tangled so that the elevator could not function. In many libraries, the bookshelves proved to have inadequate strength to resist the shaking and collapsed. In many buildings the air conditioning equipment jumped off its supports and furniture moved about and the less stable pieces overturned.

DISASTER RELIEF

The disaster relief operations following the earthquake were, in general, quite effective except for some breakdown in communications immediately after the earthquake. Following the earthquake, the Red Cross set up emergency shelters at five schools. Food was provided in the shelters and, in addition, two large feeding stations were set up. The Red Cross assisted over 11,000 families at a cost of over $1,100,000. Following the earthquake, the Federal Government announced that it would provide rehabilitation funds for damage to buildings and facilities owned by local city and county governments. In addition, the Federal Government made available low interest loans to individuals who had suffered damage to their homes or businesses during the earthquake. Some 7000 loans with a value of $34 million had been approved by April 30, 1971. Of this, 6800 loans worth $26 million were to repair or rebuild homes damaged in the earthquake. Repayment of the first $500 was required as well as everything above $3000, but the intervening $2500 was forgiven.

ACTIONS TAKEN AFTER THE EARTHQUAKE

As might be expected, the San Fernando earthquake prompted a number of actions for mitigating future earthquake damage that otherwise would not have been initiated. For example, the Los Angeles City building code was revised. Immediately following the earthquake, revisions were made to eliminate weaknesses that had been exposed by the disaster, such as the inadequate connections between the wood roofs and the masonry walls of one-story industrial buildings; and the poor behavior of inadequately reinforced concrete columns under the action of large strains. At present, it is required that high-rise buildings be designed on the basis of a dynamic analysis, and a completely revised earthquake design code is being developed for the City of Los Angeles.

Revisions have been made to the State Highway Department earthquake design criteria. Immediately after the earthquake, the design criteria were increased by over 100%; new and improved details were specified for new bridges; and a program of research was initiated to develop a satisfactory set of design criteria based on modern knowledge. Existing highway bridges were examined for weaknesses which had led to collapse of bridges during the San Fernando earthquake. Where these weaknesses existed, the structures are being strengthened.

A program was initiated by the State Department of Dam Safety to review all old dams from the point of view of earthquake resistance.

The electrical power companies in California initiated a study to develop better earthquake design specifications for electrical equipment. The counterpart of the severely damaged Pacific Intertie Station is located in the State of Oregon at the other end of the transmission system. Following the earthquake a study was made of the Oregon installation to investigate its weaknesses and to determine how it should be strengthened so that it would perform satisfactorily in the event of strong ground shaking.

Following the earthquake the Los Angeles County Government appointed an earthquake investigation commission which studied the overall consequences of the earthquake and made recommendations for mitigating the effects of future earthquakes. The report of the commission listed a series of recommendations and, to implement these, the County Government appointed a number of task forces. The only recommendation of the commission which has not been acted upon was that which recommended that steps be taken to eliminate the hazard provided by the old pre-1933 buildings. It has been estimated that there are more than 20,000 old masonry, pre-1933 buildings in metropolitan Los Angeles, having a value of approximately 8 billion dollars. Although these pose a massive threat in the event of future strong ground shaking, the problem of eliminating or strengthening them is so great that the local governments do not see how to take action.

The San Fernando Veterans Administration Hospital suffered severe damage to many of its old buildings and the collapse of one caused the majority of the deaths in the earthquake. Following the earthquake, the Veterans Administration initiated a program for preventing similar disasters in the future. All existing Veterans Administration hospitals are being investigated to see if they are hazardous and those buildings which do pose a serious earthquake hazard are being either evacuated or strengthened. Revised earthquake design criteria have been formulated for new Veterans Administration hospital buildings. In addition, a program has been initiated for installing strong-motion accelerographs at many hospital sites in seismic regions throughout the country.

NOAA, through the Seismological Field Survey, is purchasing a large number of strong-motion accelerographs for installation throughout the country in seismic regions with an inadequate number of instruments at present.

The State of California has initiated an accelerograph installation program, which will install strong-motion accelerographs in regions of the State not at present covered. This program is financed by a small charge on building permits in cities that do not have an accelerograph installation program like that of Los Angeles.

Following the earthquake, insurance companies revised their programs, in particular, they have made insurance cheaper and more convenient to purchase for the individual home owner.

PRINCIPAL CONCLUSIONS FROM THE EARTHQUAKE

The information provided by the large number of accelerographs and seismoscopes in the Los Angeles area demonstrated the value of good instrumental coverage. Countries and seismic regions that want to develop satisfactory earthquake engineering should install strong-motion accelerographs to record the shaking of the ground and the vibration of buildings during future earthquakes.

Analyses of buildings whose motions were recorded during the earthquake showed that the dynamic response of a building can be calculated with satisfactory accuracy by means of a digital computer, when the earthquake ground motion is given.

The San Fernando earthquake demonstrated again that the greatest hazard from earthquakes comes from old, weak buildings. Cities in seismic regions would be well advised to initiate programs for eliminating old, hazardous buildings or strengthening them so that they can resist future earthquakes without collapse.

The San Fernando earthquake damage emphasized the vulnerability of hospitals to earthquake ground shaking. A badly damaged hospital building must be evacuated, and even if the building itself is not damaged, the shaking may so damage the equipment and otherwise disrupt operations that the hospital is no longer functional just when hospital services are especially needed. Cities that are subject to strong ground shaking should require hospital buildings and equipment to be designed to remain functional during severe earthquakes.

Damage to new buildings by the San Fernando earthquake showed that the building code needed improvement; not only were there specific structural details that required improvement, but it appeared that the actual strength specified by the code would not be sufficient to ensure safety in the event of very strong ground shaking of prolonged duration.

The damage to the San Fernando Dam showed that old dams pose a great hazard in the event of strong shaking. All existing dams should be investigated for earthquake safety and the maximum allowable reservoir elevation under which the dam will be safe should be specified.

The damage sustained by public utilities (electrical, water, gas, sewers) demonstrated that public welfare and safety would be much enhanced if the public utilities were checked for performance during strong shaking.

Although the emergency operations following the San Fernando earthquake were adequate, the question was raised as to what would happen if a great earthquake were to shake the entire metropolitan area. It is clear that to mitigate future earthquake disasters, the local government should establish earthquake disaster programs.

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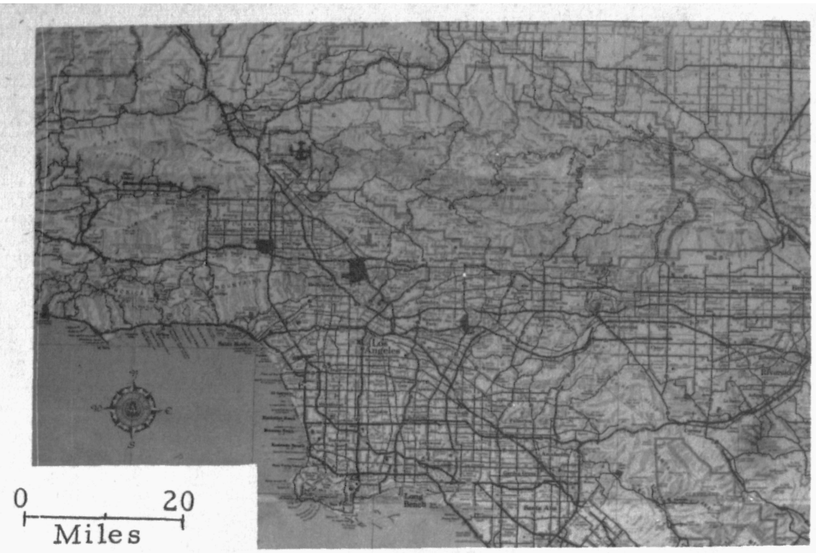

Fig. 1. Map of Metropolitan Los Angeles. Cross Indicates Center of Earthquake.

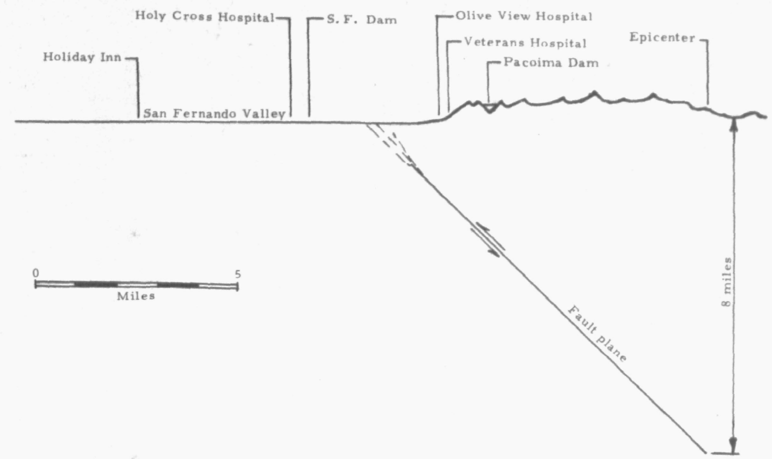

Fig. 2. Vertical Section Showing Fault Plane.

Fig. 3. Overlap (18 in.) of Fractured Curb in Region of Ground Deformation.

Fig. 4. View of Failed Lower San Fernando Dam After the Earthquake.

Fig. 6. Olive View Hospital. First Story Has 2 ft. Permanent Displacement.

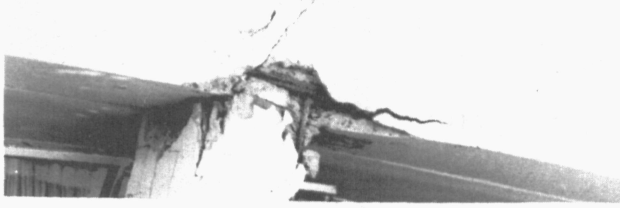

Fig. 5. Second Story Column Fracture of Olive View Hospital.

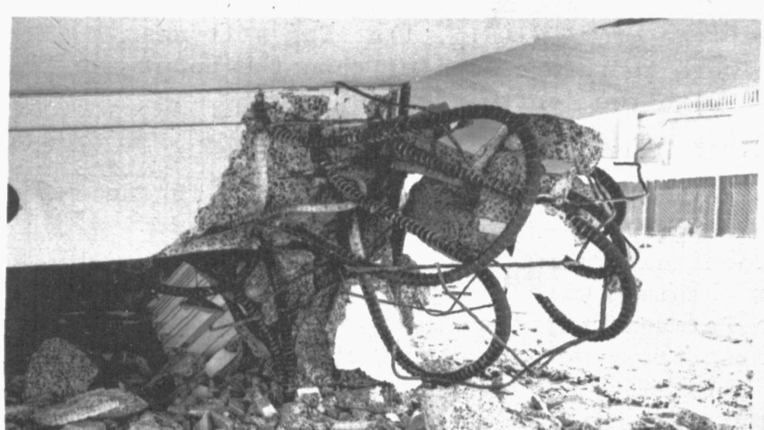

Fig. 7. Collapsed First Story of Psychiatric Building at Olive View Hospital.

Fig. 8. Fractured Column of Freeway Overpass.