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A PRELIMINARY REPORT OF THE SAN FERNANDO EARTHQUAKE IN RELATION TO HIGHWAY DAMAGE

71-38

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

71-38

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THE SAN FERNANDO EARTHQUAKE

FOREWORD

For all of its devastation, the San Fernando Earthquake will undoubtedly add more to the technology of earthquake resistant design than any other earthquake the world has experienced. It was the best instrumented earthquake to date. There were many recording devices in and near to the area of worst destruction so that good measurements of the actual movement of the earth were obtained. In destroying the structures, both buildings and bridges, the earthquake provided the ultimate test of design theories which, up to that time, were being used for the design of structures in California.

The displacement, apparently centered deep under the San Fernando Mountains, surfaced in a horseshoe shaped area about 1½ miles wide. Within this area in the northeast corner of the San Fernando Valley, extending roughly from the Van Norman Dam to the Veteran's Hospital, the earth heaved and pulled and hauled, buckling pavements, cleaving buildings and pulling the support from under structures. Buildings and bridges designed to the latest earthquake criteria used by the Structural Engineers of California were demolished by the heaving and tearing of the earth.

Because this earthquake was so well instrumented and because it affected so many structures which had been designed to the best standards of earthquake resistance then known, this earthquake has been the subject of study by teams of engineers from all over the world. There will be many reports written. This report, a preliminary account of what actually happened and its immediate effect upon the activities of the Division of Highways, will be followed by a comprehensive report as soon as the necessarily extensive on-site examinations can be completed and analyzed. Emergency measures to restore traffic and secure damaged areas were completed within the first few weeks. Final reconstruction will proceed after the investigations and analyses are completed.

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CHAPTER 1

DATA ON THE EARTHQUAKE

Magnitude

The San Fernando earthquake of February 9, 1971, was the most damaging quake to occur in California since the Long Beach earthquake of March 10, 1933. It was felt north to Fresno, east to Las Vegas, and south to Mexico. The initial shock was registered by Cal Tech seismologists at 42 seconds after 6:00 a.m. with a magnitude of 6.6 (Richter) followed at 6:01 by a second shock of 5.4, then four other aftershocks close together. This series lasted five minutes, 11 seconds. During the period between 6:10 and 7:58 a.m., four aftershocks registering over 5.0 were recorded and in the first hour and 15 minutes there were 26 shocks between 4.0 and 5.0. Through February 23, 199 aftershocks of 3.0 or greater had been recorded.

Location

The epicenter of the quake was located by Cal Tech seismologists over the Soledad Canyon Fault (a minor rift some three miles in length) at its junction with the larger San Gabriel Fault. They further described the earthquake as taking place in the maze of faults that characterize the geologically unstable base of the San Gabriel Mountains. Geographically, this area is some 25-30 miles northwest of the Los Angeles Civic Center, or seven miles east of Newhall, as shown in Figure 1. With reference to damaged roads, the epicenter is located about eight miles south of Route 14 near Soledad Canyon. Focal depth has been determined to be about seven miles.

The earthquake occurred in an area which has had relatively low seismicity. Only one strong, destructive earthquake is known to have occurred previously in the San Fernando-Newhall area. This took place in 1893 about eight miles southwest of Newhall, registering about VIII-IX on the Modified Mercalli Scale.

C. R. Allen of Cal Tech has reported that nothing in the recent seismic history of the Northern San Fernando Valley would indicate the area to be a more likely candidate than any other area for a 6.6 magnitude earthquake.

Tectonic Movement

Regional tectonic movement consisted of an upper plate (Figure 2a), more or less delineated by the inverted "U"

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shape formed by the aftershock locations shown in Figure 1, that moved to the south and west along a thrust fault plane dipping about 45° to the north. This upper plate moved over the lower plate as rupture progressed along the thrust plane from the hypocenter to intercept ground surface in the Sylmar-San Fernando area. Because of the shallow fault depths and large ground displacements, this was the area in which damage to engineering works was concentrated.

Continuing studies of the aftershocks by Cal Tech seismologists are contributing to the overall picture of tectonic movement. These shocks, with an average focal depth of about four miles (maximum eight miles), have been divided into the eastern group, the epicentral group, and the Chatsworth group (Figure 1). According to Hanks, et al, (1) the focal depths of the eastern group are fairly shallow and are above the thrust plane as defined by the epicentral group (Figure 2b). Depths of the Chatsworth group, on the other hand, are deeper than the thrust plane. Based partly on this information, Whitcomb (2) has suggested a model to describe the overall movement.

According to Whitcomb's model, the upper plate is breaking up in a complex pattern in the zone of the eastern group of aftershocks; movement of the upper plate became arrested along its northwestern boundary (Chatsworth group of aftershocks) by the adjacent crustal materials; the lower block is thrusting under the upper plate along a near vertical fault striking to the northeast along the axis of the Chatsworth group of aftershocks.

Ground Accelerations - Measured and Estimated

Although the San Fernando earthquake's magnitude was only moderate, the severity of ground motion was close to the maximum generated by any earthquake - up to 75% of the earth's natural gravitational acceleration (0.75 g) according to the findings of a 12 man panel, headed by Dr. Clarence R. Allen of Cal Tech.

(1) Hanks, Thomas C., Jordan, Thomas H., and Minster, J. Bernard, "Precise Locations of Aftershocks of the San Fernando Earthquake 2300 (GMT) February 10 - 1700 February 11, 1971," Contribution No. 1994, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California. Submitted for publication Bul. Seismological Soc. Assoc. 27 Feb. 1971.

(2) Whitcomb, James H., "Fault Plane Solutions of the February 9, 1971, San Fernando Earthquake and Some Aftershocks -- A Preliminary Report," Contribution No. 1991, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California. Submitted for publication to the Bul. Seismological Soc. Assoc., 27 Feb. 1971.

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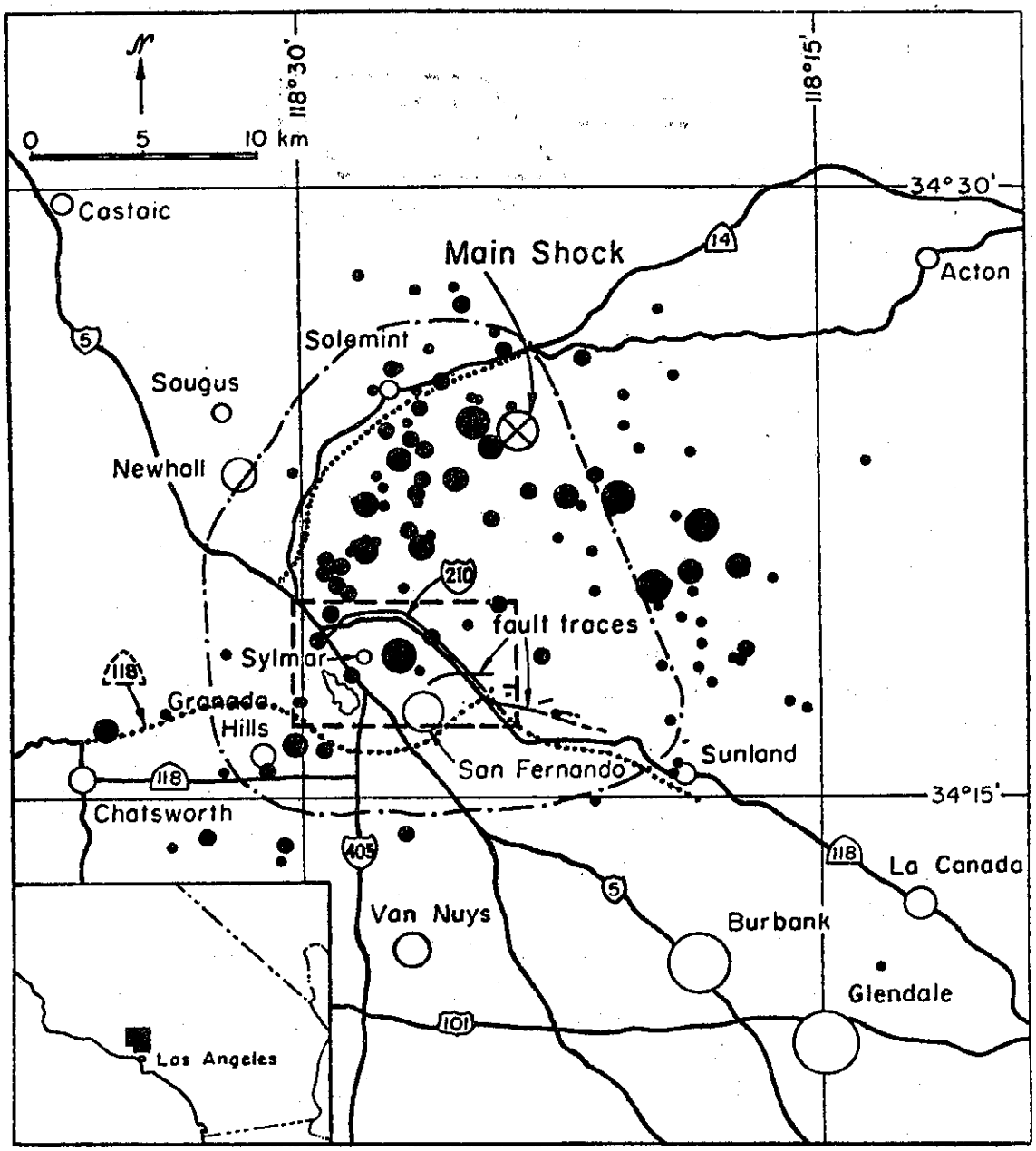

MAP AFTER ALLEN ET. AL. (REF. 1)

AREA OF FIELD STUDY
MAPPED AREA
ADOPTED OR UNDER CONSTRUCTION

AFTER SHOCKS
3.0 - 3.4
3.5 - 3.9
4.0 - 4.4
4.5 - 5.1

Figure 1 GENERAL AREA OF FIELD STUDY, MAPPED AREA, AND AFTERSHOCKS

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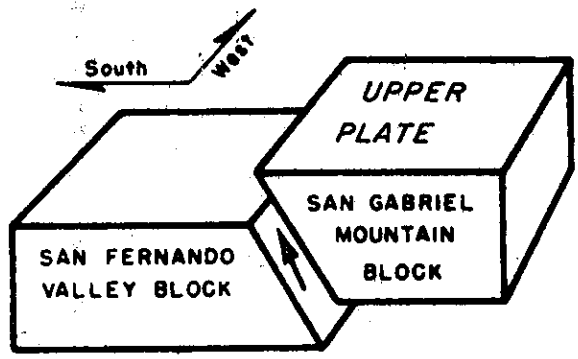
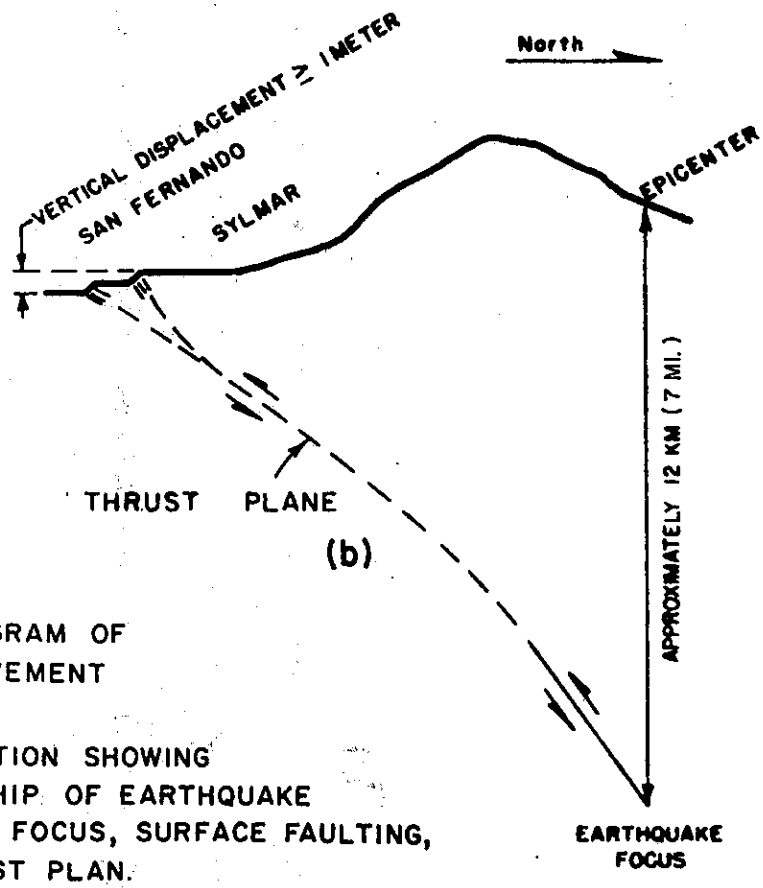


(a)



(b)

(a) BLOCK DIAGRAM OF FAULT MOVEMENT

(b) CROSS-SECTION SHOWING RELATIONSHIP OF EARTHQUAKE EPICENTER, FOCUS, SURFACE FAULTING, AND THRUST PLAN.

Figure 2 BLOCK DIAGRAM AND CROSS SECTION OF FAULTING

AFTER R. GREENFELDER, (REF. 2)

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Los Angeles County Engineer John A. Lambie stated that "the tremendous energy release in the locality (of Olive View Hospital) caused horizontal and vertical ground shaking exceeding the 6.5 earthquake." He further stated that "ground shaking equaled or exceeded an 8.0 earthquake at the point of maximum intensity." George Housner, director of Cal Tech's earthquake engineering research, believes the acceleration force of the temblor at Olive View Hospital was 30 to 50% of the force of gravity. This would be the highest ever recorded throughout the world. Readings at Century City in western Los Angeles were 0.17 g and in downtown Los Angeles, a force of 0.13 g was measured. The accelerometer at Pacoima Dam, located about five miles south of the epicenter and about 3.5 miles east of Olive View Hospital, showed a maximum horizontal acceleration somewhat greater than that of gravity (1.05g on the S16°E horizontal component). The ground motions experienced during the San Fernando earthquake were much more severe than would have been expected for a shock of its magnitude.

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CHAPTER 2

GEOLOGY OF THE REGION AND OBSERVED MOVEMENTS

Study Area

A geologic investigation of earthquake damage to roads in the San Fernando Valley area was begun on February 19 and is still in progress. The area being studied is shown in Figure 1 and consists of the northern portion of the San Fernando Valley and the Newhall-Solemint Junction area northeast of and separated from the San Fernando Valley by the San Gabriel Mountains. This is the area in which damage to freeways, private dwellings, and other structures was concentrated, although scattered damage (generally not involving roads) did occur in other areas of metropolitan Los Angeles.

The mapped area is shown in Figure 1, and will be referred to later as the "map area." Practically all faulting and other ground breakage that affected major highways occurred in the map area.

Six major roads (five freeways and one State highway) traverse the earthquake affected area as shown in Figure 1. The most important single road is Interstate Route 5 (Golden State Freeway) which is the main north-south artery for traffic entering and leaving the northern metropolitan Los Angeles area. Interstate Route 405 (San Diego Freeway) junctions with Route 5 in the northern San Fernando Valley to provide a more direct north-south route through the metropolitan area westerly of downtown Los Angeles. About 2.2 miles north of the Route 5/405 junction, Route 5 interchanges with Interstate Route 210 (Foothill Freeway) at the southern base of the San Gabriel Mountains. Route 210 is a new freeway with only five miles having been completed in the general area. East of Maclay Avenue, where pavement ends, only fills have been constructed for another two miles. This route will be a perimeter facility beginning at Route 5 and skirting along the northern and eastern fringes of the metropolitan area paralleling and very close to the base of the San Gabriel Mountains.

About 1.8 miles north of the Route 5/210 Interchange, the Sierra Highway (Old Route 14), an older four-lane road, junctions with Route 5 and extends easterly through Solemint Junction. At the Route 5/Sierra Highway Junction the new Route 14 (Antelope Valley Freeway) interchanges with Route 5 and also extends easterly, closely paralleling the Sierra Highway. From the interchange east to Solemint Junction the new Route 14 is under construction, in the earthwork and structures stage. The section of Route 5 between the

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Route 5/14 and Route 5/210 Interchanges is also under construction as new lanes (truck and auto) and connector roads are being added to ultimately provide a complex, high volume roadway system. To the south (two miles) of the Route 5/405 junction, the new Route 118 (Simi Valley Freeway) will interchange with both Routes 5 and 405. Route 118, a stage construction project with fills only having been constructed in the study area, is an east-west route extending from its eastern terminus, a planned interchange with Route 210 about one mile east of Maclay Avenue, to the west along the base of the Santa Susana Mountains into Simi Valley. This route will provide residents of the northwestern metropolitan area freeway access to the north-south freeways and hence the entire metropolitan area.

GEOLOGIC SETTING

General

The western San Gabriel Mountains show a history of complex faulting and folding that has occurred in the Cenozoic Era. The crystalline massif of the San Gabriels has been uplifting for the last several million years overriding the younger sedimentary strata along the south flank of the range along a series of north dipping discontinuous thrust faults. The series of discontinuous thrust faults comprise the Sierra Madre Fault Zone. The relatively weak sedimentary strata that flank the crystalline massif, form steep outcrops from the valley floor. The steep mountain front of the south side of the San Gabriels is an indication that the structural geology configuration of the San Fernando Valley area is very young in geologic time.

Topography

The map area under study is bounded on the north by the southerly base of the western end of the San Gabriel Mountains. Sedimentary rocks rise abruptly from the broad valley floor and are cut by deep canyons with steep walls that form a series of ridges oriented generally north-south and are nearly perpendicular to the strike of the steeply dipping bedded sediments.

The western boundary of the mapped area extends into the eastern end of the Santa Susana Mountains that are made up of sedimentary rocks that rise gently to moderately out of the valley floor.

The eastern end of the mapped area extends into sedimentary rocks of the San Gabriel Mountains where the valley is abruptly truncated by steeply rising stratified sediments.

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The southern boundary of the mapped area extends across the San Fernando Valley from the southern base of the Santa Susana Mountains to the base of the San Gabriel Mountains on the east.

Alluvium

With a few exceptions, the alluvium that makes up the San Fernando Valley within the map area is made up of thick, loose gravel and sand with the source material derived mainly from the hard crystalline rocks of the San Gabriel Mountains that lie to the north. Alluvium in the valley floor in the vicinity of the Van Norman Lakes is composed of sand and silt with some gravel whose source area is probably the sedimentary rocks that lie to the north and to the west of the lakes. The alluvium in Grapevine Canyon was probably derived from crystalline rocks of the San Gabriels and sedimentary rocks from the northwest.

Tectonics

The tectonic history of the Cenozoic Era "shows that intermittent, frequent, uplift of the San Gabriel mountain range took place, accelerated at times, with faulting, folding, and readjustment around the margins of that competent crystalline block (crystalline rocks of the San Gabriel Mountains)... a major zone of reverse faults separate the crystalline block from flanking Cenozoic stratified rocks along the south side of the range."

In and near the map area along the south side of the crystalline rocks of the San Gabriel Mountains a series of north dipping reverse faults had been mapped. The Sierra Madre Fault zone extends from the northeast end of the Santa Susana Fault (about 0.8 mile northwest of Route 5/210 Interchange) on the west to the Rowley Fault zone on the east, a distance of approximately 14 miles.

The Sylmar and Tujunga Faults shown on the map are the 1971 fault breaks that occurred at the time of the San Fernando earthquake. These faults lie within the Sierra Madre Fault zone.

The San Fernando earthquake and the resulting tectonic movements show that the activity of the Cenozoic Era described above is continuing today.

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GEOLOGIC SIGNIFICANCE OF THE SAN FERNANDO EARTHQUAKE

General

The 1971 fault breaks shown on the map and observed out of the map area indicate that regional deformation of the earth's crust occurred in the northern part of the San Fernando Valley and along the southern base of the San Gabriel Mountains. Regional is defined to include an area of several tens of square miles, but at this time the limits cannot be established.

In order to determine the limits and magnitude of deformation that has occurred, precise survey data will have to be analyzed when it becomes available. At the present time Division of Highways District 07 Surveys, in conjunction with others, are re-establishing precise horizontal and vertical control in the damage area.

Regional Uplift

The City of Los Angeles measured a series of relative vertical changes in the Sylmar-San Fernando area based on the assumption that no change in elevation occurred at the intersection of Foothill and Van Nuys Boulevards. The vertical changes indicate that regional uplift, relative to the south, occurred on the north side of the Sylmar Fault zone. Table 1 is a summary of the vertical changes at various locations within the map area.

LOCATION	APPROXIMATE VERTICAL CHANGE (FT.)
Intersection of Route 210 freeway and Harding Avenue	+4
Intersection of San Fernando Road and queried Sylmar Fault	+1
Near Route 210 and Roxford Street interchange	+1.6
Near Route 210 and Foothill Boulevard intersection	+1.1
Route 5/210 Interchange and San Fernando Road	+2.6
Pacoima Dam (located about 1.3 miles northeast of the Veterans Hospital)	+1.1

Table 1

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Faulting

Observations made along the Sylmar Fault and Tujunga Fault show that they are reverse faults dipping north with the north thrust over the south. Where the extension of the Sylmar Fault crosses Routes 5, 405, movement has occurred in an old fault zone that is well exposed in the road cuts.

The Sylmar Fault extension is vividly exposed where it crosses the Route 5 southbound truck lane and continues through the cut slope to the east. Movement has occurred along bedding planes that dip about 60°N, with the north thrust over the south. The truck lane has been elevated about two feet on the north side along the fault trace.

The Tujunga Fault, where it is exposed in the bedrock east of the Foothill Nursing Home as shown on the map, dips from about 15° north to nearly vertical. The north block has been thrust over the south block. Six hundred feet west of Lopez Canyon Road a fence that crosses the fault scarp at about a 45° angle has been shortened 2.7 feet along the fence line and the north side elevated about two feet. At this location the fault appears to parallel bedding planes that dip 30° north and strike east-west. The observed trace of the Tujunga Fault is nearly continuous to the east from the east map limit for a distance of approximately three miles along the base of the foothills.

The Sylmar Fault has a component of left lateral strike-slip movement that shows up vividly where the fault crosses Route 210, 550 feet west of Maclay Street. The faulting occurred in a zone approximately 400 feet wide where it crosses the freeway. Ground breakage along the Sylmar Fault west of the freeway continues in a zone a few hundred feet wide to about 300 feet west of Glenoaks Boulevard.

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CHAPTER 3

EFFECTS ON HIGHWAYS AND STRUCTURES

The main routes which happened to be within the disturbed zone and therefore suffered the worst damage were I-5 (the main north-south route), Route 210 (the foothill freeway to Pasadena, Route 14 (the Antelope Valley Freeway), as well as parts of Routes 126, 118, and 405. The highway damage was mainly buckled pavement, settled fills and horizontal and vertical displacements. These movements became critical adjacent to structures where the heaving earth created sudden differences in elevation of as much as two feet. In other areas checking known benchmarks revealed that the ground had risen as much as four feet.

These displacements in the pavement have made extensive exploration necessary to discover the extent of the loss of subgrade support. It is evident that considerable pavement will have to be removed and the subgrades regraded and, in some cases, recompacted. Some approach fills will have to be built up to meet the adjacent structure grades. There were some slides caused by the earth movement which will require reshaping of the slopes.

In general the small drainage structures sustained minor damage and will be easily repaired.

Immediate action was taken to restore traffic through the disturbed area. Broken concrete was pushed out of the way and temporary pavement laid. A temporary detour bridge was built to restore the Interstate 5 traffic where it crosses over the railroad in one of the most violently shaken areas. Having met the immediate traffic emergency, further repairs will be undertaken on a regular contract basis.

Most of the major damage to bridge structures was in the general area of the Route 5/210 and the Route 5/14 interchanges. Five structures were completely demolished and have been removed. Portions of two other structures were damaged and will have to be replaced. The remaining structures (about 60 in all) which are in the immediate area of the worst destruction sustained some degree of damage but are repairable. It is worthy of note that outside of the narrow belt of extreme earth disturbance, there were dozens of structures nearby and literally hundreds of structures at a slightly greater distance which very adequately demonstrated their earthquake resistant design by sustaining only the most minor damage. In most of these cases, the damage was confined to cracked abutments - where the structure bounced back and forth between restraining walls; and chipped

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expansion joints - where the pounding of the huge bridge sections banging against each other chipped off corners. There was some distress at the tops of some pile supports under footings and abutments. The great majority of the structures involved continued to carry their traffic loads safely and will be easily restored to good condition with minor repairs.

Investigative teams from the Division of Highways began an immediate careful study of the damage, beginning on the day of the earthquake. Even though the most generally accepted standards for the earthquake design of structures had been followed in all of these structures, the earthquake served as a gigantic laboratory experiment to test these designs, surpassing their expected working loads and going on to destruction. As with any laboratory test, much can be learned about the possible weaknesses of a structure by observing its final resistance to collapse. Careful studies were initiated of each failure to determine how it occurred and what, if any, change in design might have improved its chance for survival.

While it is generally acknowledged that no structure can be designed to survive in the center of the destructive heaving of the earth at the vortex of an earthquake, it was observed that certain improvements of details would help to correct weaknesses and increase the structures' earthquake resistance. These changes were immediately instituted in all of the structures being designed for California's State Highways. Many going contracts were amended to incorporate these improvements. The earthquake design factors heretofore in general acceptance for the design of structures were increased to double or more when used on the State Highway bridges. Although the completion of the many studies now under way will undoubtedly develop additional desirable changes, those changes which were immediately obvious have already been incorporated into our regular design procedures.

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CHAPTER 4

SUMMARY

The San Fernando Earthquake, with some of the most violent accelerations ever recorded, for the first time tested to destruction highway structures which had been designed to be earthquake resistant. Although thousands of bridges had been designed to the best accepted earthquake design criteria, never before had there been a case where a full scale test was observed of the effectiveness of the theory. Testing equipment does not exist which could perform such a test. Therefore, from this earthquake has come a wealth of knowledge which already is being put to use in the new designs. The damage will be assessed and repairs will be made, restoring the highway and the structures to full usefulness. From this costly and tragic catastrophe, valuable lessons have been learned by every branch of the structural profession. From this bitter experience will come newer and better structures which will more adequately resist the violence of an earthquake.

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