Technical Report Documentation Page

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FHWA/CA/TL-80/17

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3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE
Roadway Damage During The San Fernando, California, Earthquake Of February 9, 1971

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7. AUTHOR(S)
R. H. Prysock and J.P. Egan, Jr.

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17. KEYWORDS
Earthquakes, earthquake effects, roadway damage, cut slopes, embankments, pavement, geological faults, slope stability, surveys, data collection, landslides, bridge approaches

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

REPORT NO. FHWA/CA/TL-80/17

ROADWAY DAMAGE DURING THE SAN FERNANDO, CALIFORNIA, EARTHQUAKE OF FEB. 9, 1971

Study Supervised by .... Raymond A. Forsyth, P.E.

Co-Principal Investigators .... R. H. Prysock, P.E.
J. P. Egan, Jr.

Report Prepared by .... R. H. Prysock, P.E.
J. P. Egan, Jr.

ROBERT O. WATKINS, P.E.
Chief, Office of Transportation Laboratory

CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quanity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40	millimetres (mm)
		.02540	metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2)	.09290	square metres (m^2)
	acres	.4047	hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour(mph)	.4470	metres per second (m/s)
	feet per second(fps)	.3048	metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity(G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^2)
Force	pounds (lbs)	4.448	newtons(N)
	kips (1000 lbs)	4448	newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds(ft-lb)	1.356	joules (J)
	foot-kips (ft-k)	1356	joules (J)
Bending Moment or Torque	inch-pounds(ft-lbs)	.1130	newton-metres (Nm)
	foot-pounds(ft-lbs)	1.356	newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

ACKNOWLEDGEMENTS

Thanks are extended to those individuals of Caltrans' District 7, and the local governments and utility companies who provided assistance when needed and were completely cooperative during the field investigation reported herein.

Appreciation also is extended to Bob Branch of the District 7 Materials Section, who prepared the "Effects of the Earthquake" portion of this report. Typing was by Lydia Burgin, and editorial assistance was by John Campbell and Max Alexander.

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INTRODUCTION

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. Although of moderate magnitude (6.4), it inflicted greater damage on the California freeway system than any previous earthquake. The major north-south link (Interstate 5) between the San Joaquin Valley and Los Angeles, which served 80,000 to 90,000 vehicles daily, was rendered inoperable and hence closed to traffic for a period of 15 hours. Sixty-six days elapsed before a 6-lane, long term detour could be provided to allow free movement of traffic. Other routes that sustained damage included Interstates 210 and 405 and State Routes 2, 14, and 118; the latter two being in various stages of construction and not open to traffic in the affected area at the time of the earthquake. Major road damage was concentrated within a remarkably small area of about 12 square miles in the northern portion of the San Fernando Valley and involved only about 10 miles of operating freeways. The above routes and area of major damage are shown in Figure 1, and to a larger scale in Figure 2.

Purposes and Scope of Study

The purposes of this study were to inspect and document roadway damage; determine, if possible, the mechanisms by which different types of damage occurred; and determine if the damage was related to design practices and/or construction methods then employed.

The scope of the study included the following:

1. A cursory review of roads and adjacent areas to delineate limits of major roadway damage and to determine overall damage patterns.

2. A review of ground breakage to provide insight to road damage and to select individual areas for further study.

3. A detailed inspection of road damage to provide photographic documentation and field notes of observations.

4. Special work at a few locations to obtain quantitative data primarily for aids in interpreting observations.

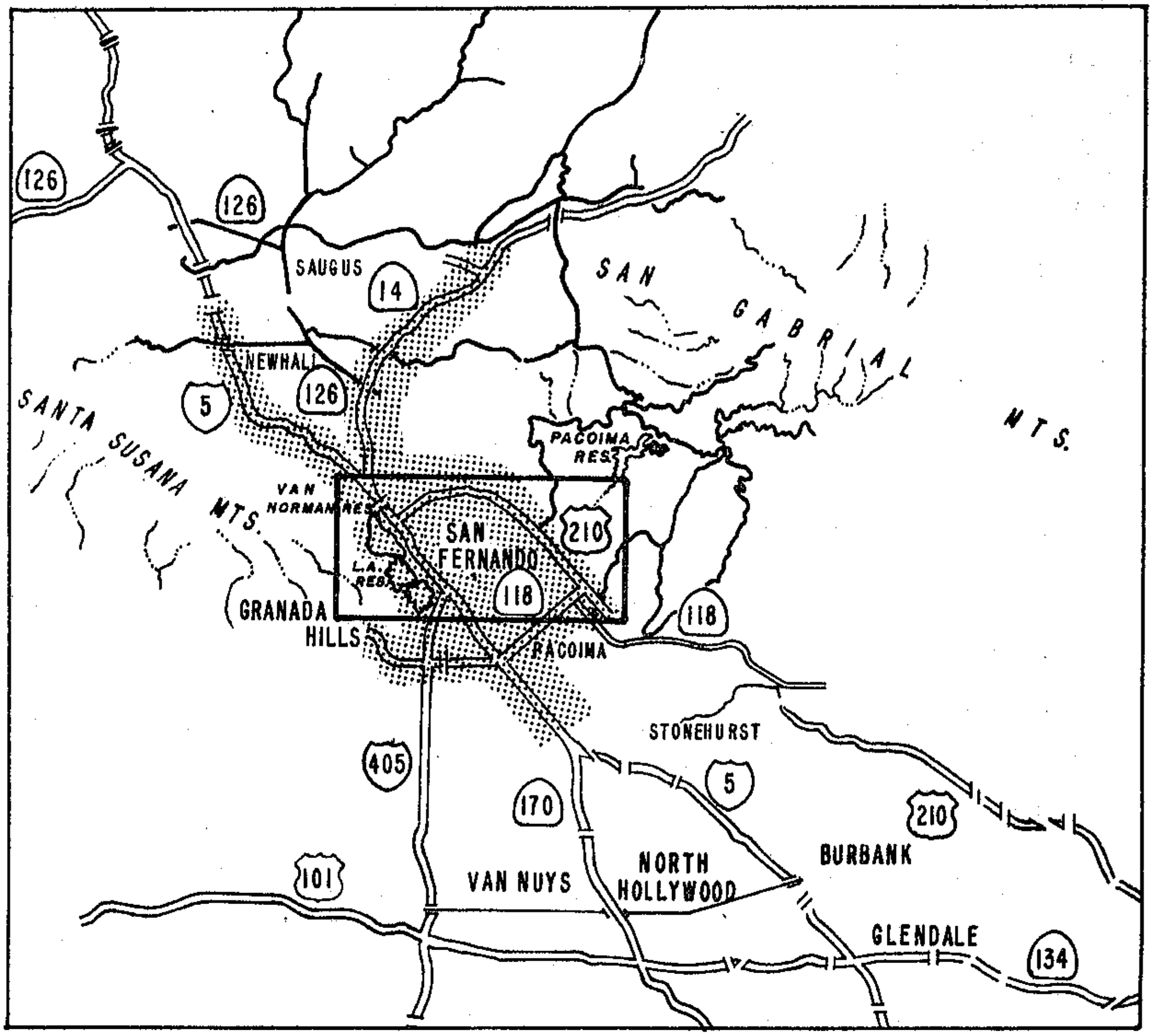
Although this study was oriented toward reviewing roadway earthwork damage (notably embankments and cut slopes), other elements of the roadway were reviewed for an overall appraisal of damage and for the sake of completeness. Furthermore, areas adjacent to, but outside, the highway rights of way were studied to provide more information regarding soil and earthwork behavior.

This Report

Much of the information presented in this report was included in earlier interim reports (1, 2). The purpose of the present report is to provide more photographic documentation, to describe the repair and reconstruction operations, and to discuss briefly the effect of the San Fernando event on Caltrans' position regarding earthquake engineering. It should be noted that a detailed description of bridge damage and subsequent changes in Departmental bridge aseismic design procedures are outside the scope of this project and may be found elsewhere (3,4).

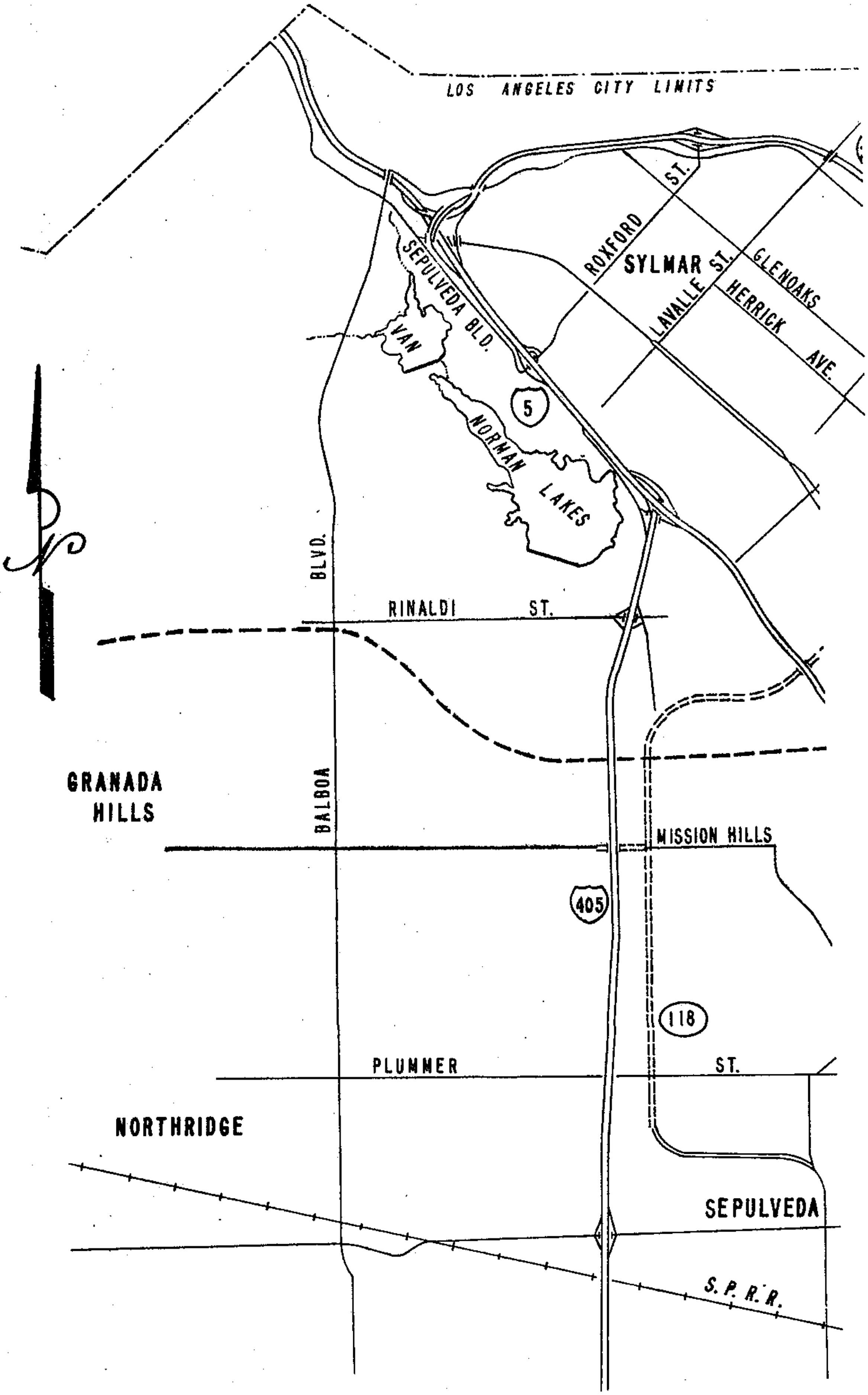
Information regarding seismological and geological aspects of the earthquake, as well as descriptions of damage to other facilities, may be found in References 5-7.

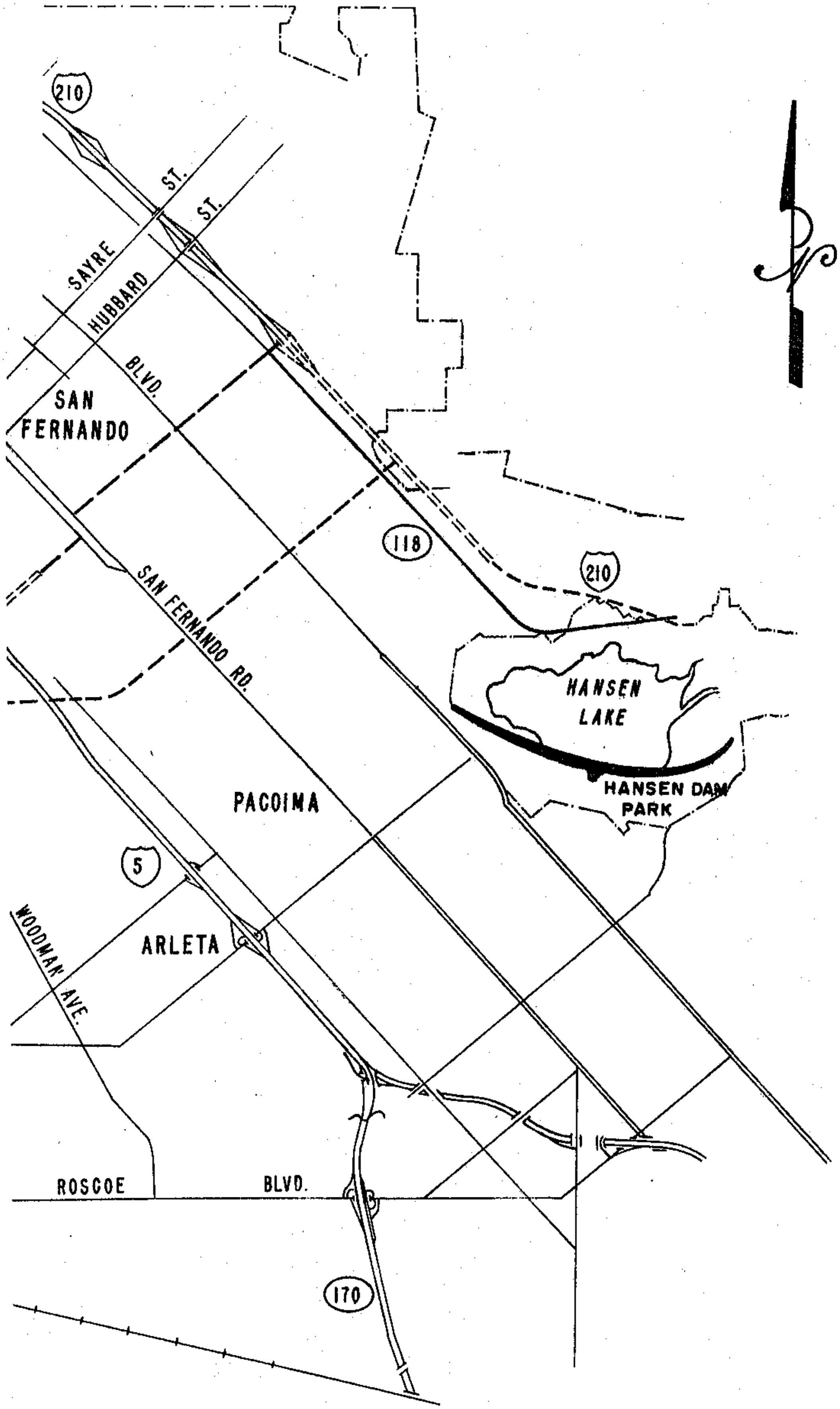
Figure 1
Vicinity Map of Freeway Damage Area



STREET MAP OF FREEWAY DAMAGE AREA

FIGURE 2




210
SAYRE ST.
HUBBARD ST.
BLVD.
SAN FERNANDO
118
210
HANSEN LAKE
HANSEN DAM PARK
SAN FERNANDO RD.
PACOIMA
5
ARLETA
WOODMAN AVE.
ROSCOE
BLVD.
170

ROADWAY DAMAGE

Within the field review area shown in Figure 1, all principal elements of the freeways sustained damage to varying degrees. The following descriptions and photographs of damage by route are included as documentation of field observations and as illustrations of the behavior of earthworks and other structural elements of roadways when subjected to ground shocks similar to those experienced during the San Fernando earthquake.

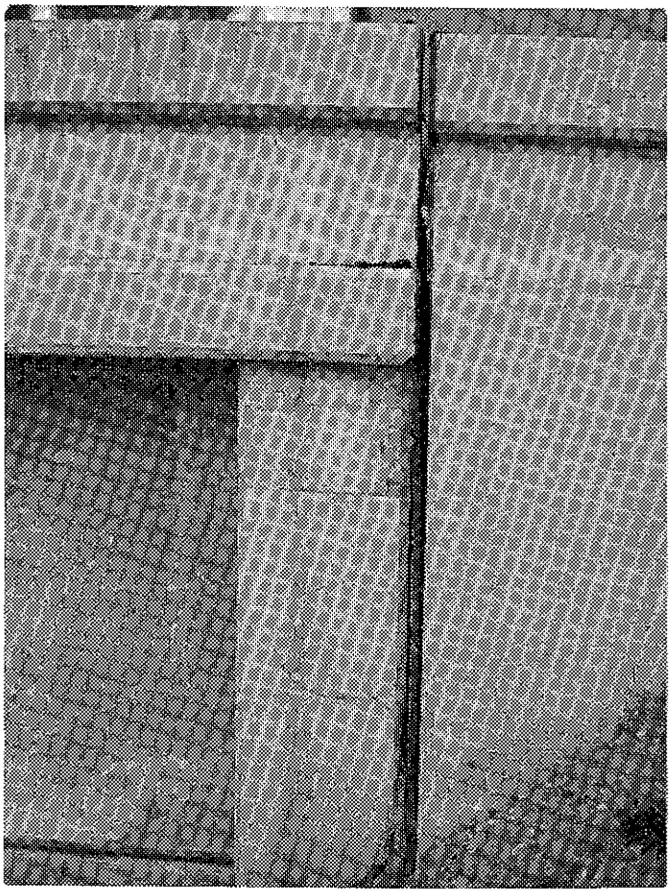
ROUTE 5, FROM OSBORNE STREET TO I-5/405 SEPARATION

Damage to the Route 5 freeway facility south of the Route I-5/405 Separation was slight, with no emergency repairs to the roadway or bridges required. With the exception of the Rinaldi Street Bridge and the East Canyon Channel structure, damage consisted of superficial cracking of curbs and sidewalks, some settlement of sidewalks at undercrossings relative to the bridge curtain walls, some settlement and separation of wingwalls, slight rotation of some bridge decks, spalling at construction or expansion joints, and minor soil cracking around abutments, both in fill and original ground.

Damage to the Rinaldi Street Undercrossing consisted of abutment settlement, shattering of the abutment corners, and wingwall movement. Settlement and separation of the south abutment wingwall are shown in Photo No. 1.

Reinforced concrete box pedestrian undercrossings suffered minor cracking and separation at construction joints.

Photo 1. Looking easterly at south abutment of Rinaldi Street Undercrossing. Note settlement of wingwall, separation at construction joint, and crack in diaphram.



At the East Canyon Channel, just north of Rinaldi Street, a reinforced concrete double 12x14 box crosses beneath the freeway. The box sustained cracks up to 1/4-inch wide in all walls. At the box crossing a slight rise was noted in the roadway profile due to fill settlement on either side of the box.

About 1/2 mile north of Rinaldi Street an AC patch had been placed across the southbound lanes prior to this investigation. Immediately west of the patch a concrete gutter had undergone compression spalling, which suggests the pavement had buckled.

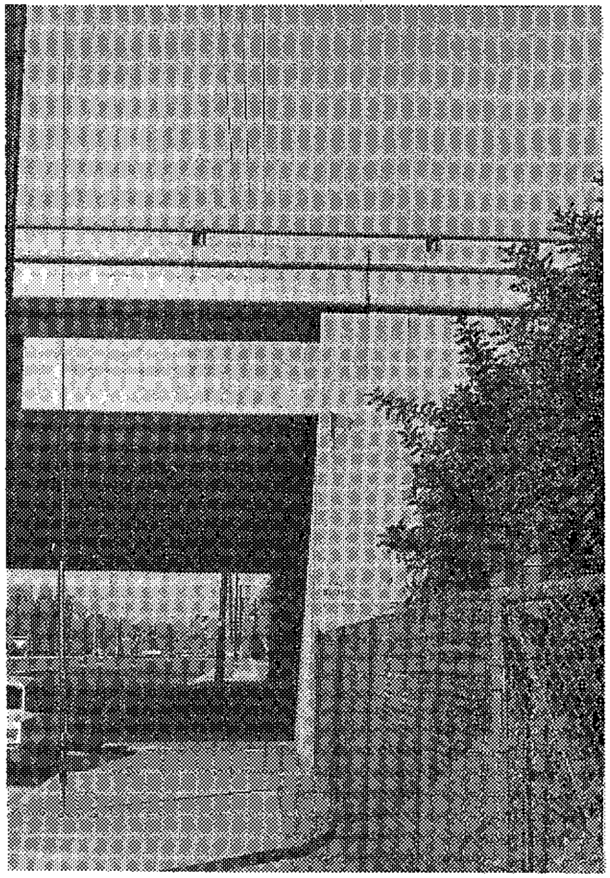
ROUTE 405, FROM ROSCOE BOULEVARD TO I-5/405 SEPARATION

South of the Route I-5/405 Separation, sixteen structure sites were reviewed, which were of two basic types: pedestrian undercrossings and street undercrossings. Each type of structure was of one design; consequently, the distress patterns were similar for all structures within each group. Damage with respect to structural integrity was considered to be negligible and traffic was using all surface streets and freeway structures, none of which required any type of shoring or immediate repair. Asphalt patches up to ±150 feet long had been placed at bridge approaches at some sites to eliminate bumps due to fill settlement. At several of these sites mud-jacking had been attempted but its effectiveness was not determined. There was no evidence of any other type of repair or remedial work.

A typical freeway undercrossing structure is shown in Photo No. 2. As may be noted, the entire fill end slope is enclosed by concrete curtain walls. Also, the concrete sidewalk at the surface street level extends full-width between curb and curtain wall. As these structures rotated in response to ground motion, forces were exerted through the sidewalks to the curbs causing shear cracks at numerous locations as illustrated in Photo Nos. 3 and 4.

At the San Fernando Mission Boulevard Undercrossing 3-1/2 inches of fill settlement occurred at the northeast wingwall, as shown in Photo No. 5. At this location, the evidence showed the structure tended to rotate counterclockwise.

Photo 2. Typical under-crossing structure on Route 405.



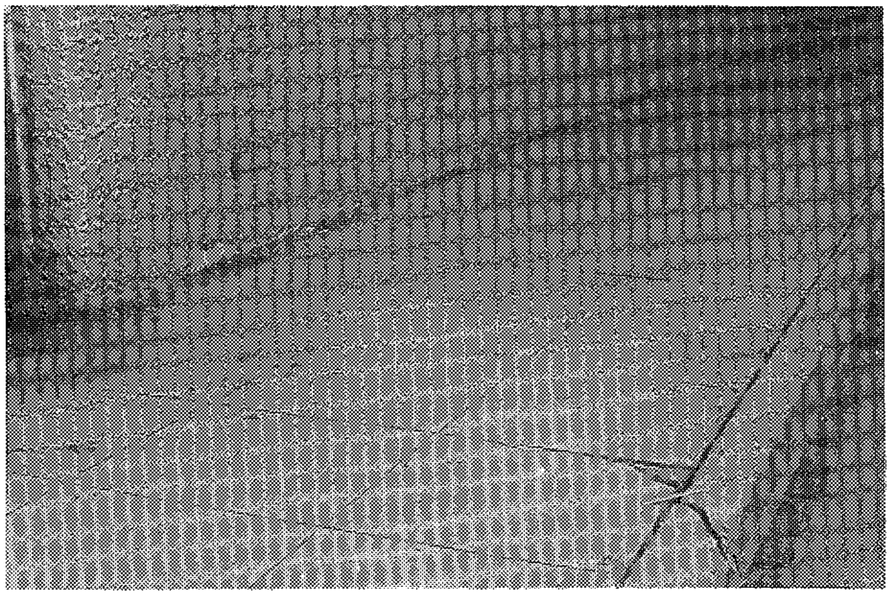


Photo 3. Typical curb crack and displacement caused by forces from curtain wall movement. Note cracks in sidewalk ajacent to curtain wall.

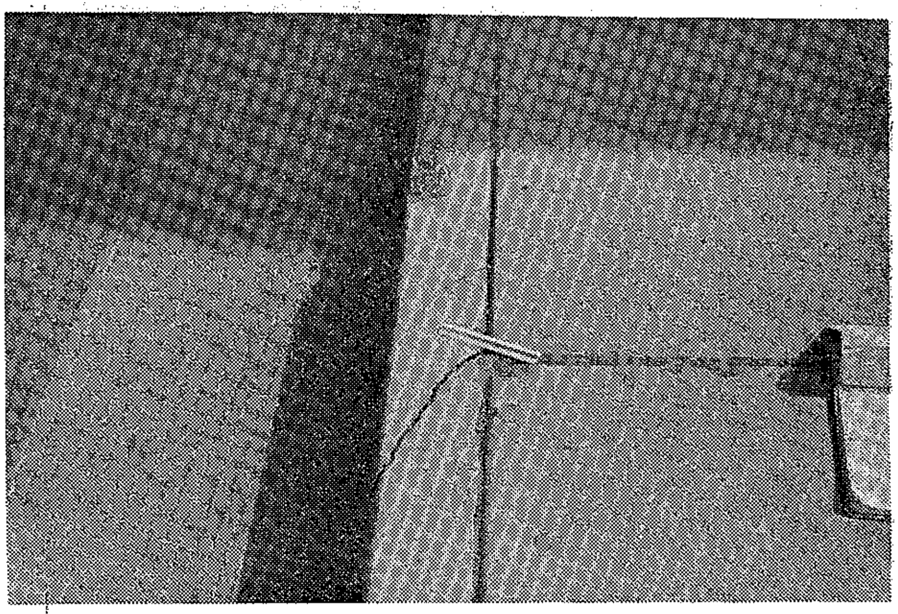


Photo 4. Typical curb crack and displacement caused by forces from curtain wall movement.

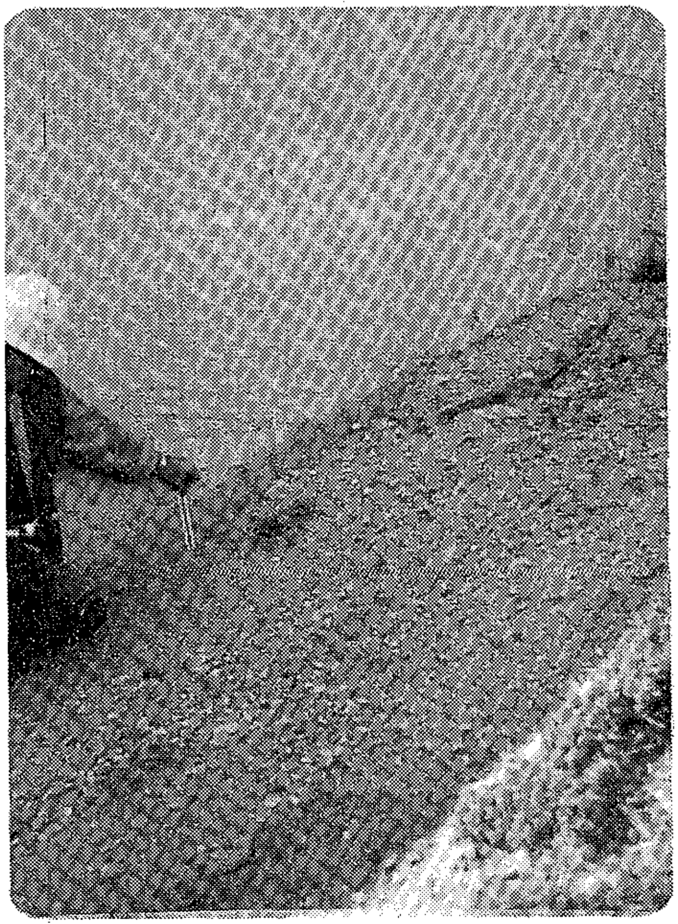


Photo 5. Looking westerly at northeast wingwall of San Fernando Mission Boulevard Undercrossing. Note fill settlement relative to wingwall.

It was interesting to observe that, south of Rinaldi Street, Route 405 fills clearly experienced more settlement than those of Route 5.

A definite progression of damage severity was noted on both Routes 5 and 405 north from Osborne Street and Roscoe Boulevard, respectively. South of San Fernando Mission Boulevard, damage was negligible and permanent displacements often were difficult to detect. The San Fernando Mission Boulevard structures were the first to show more than negligible (although still considered very minor) damage. Even more damage was noted at the Rinaldi structures; but it, too, was considered minor. In the Rinaldi area, damage to other structures became more apparent, the Holy Cross Hospital and the Indian Hills Medical Center, for example. It is of interest to note that the geological map of the San Fernando Quadrangle shows the Mission Hills Fault trending east-west and closely paralleling Rinaldi Avenue in this area (8).

ROUTE 5/405 SEPARATION AREA

The Route 5/405 Separation, shown in Figure 3, and Photo 6, is constructed in cut section immediately east of the lower San Fernando Reservoir. The terrain is composed of marine siltstone and mudstone (extreme right side of Photo 6) in contact with younger, nonmarine sandstones.

The following damage descriptions are keyed to location numbers on Figure 3.

Location 1

The most notable damage in the separation area was the collapse of the Route 5 southbound truck freeway bridge over Route 405 as shown in Photos 6, 7 and 8. A discussion of bridge damage may be found in Reference 5.

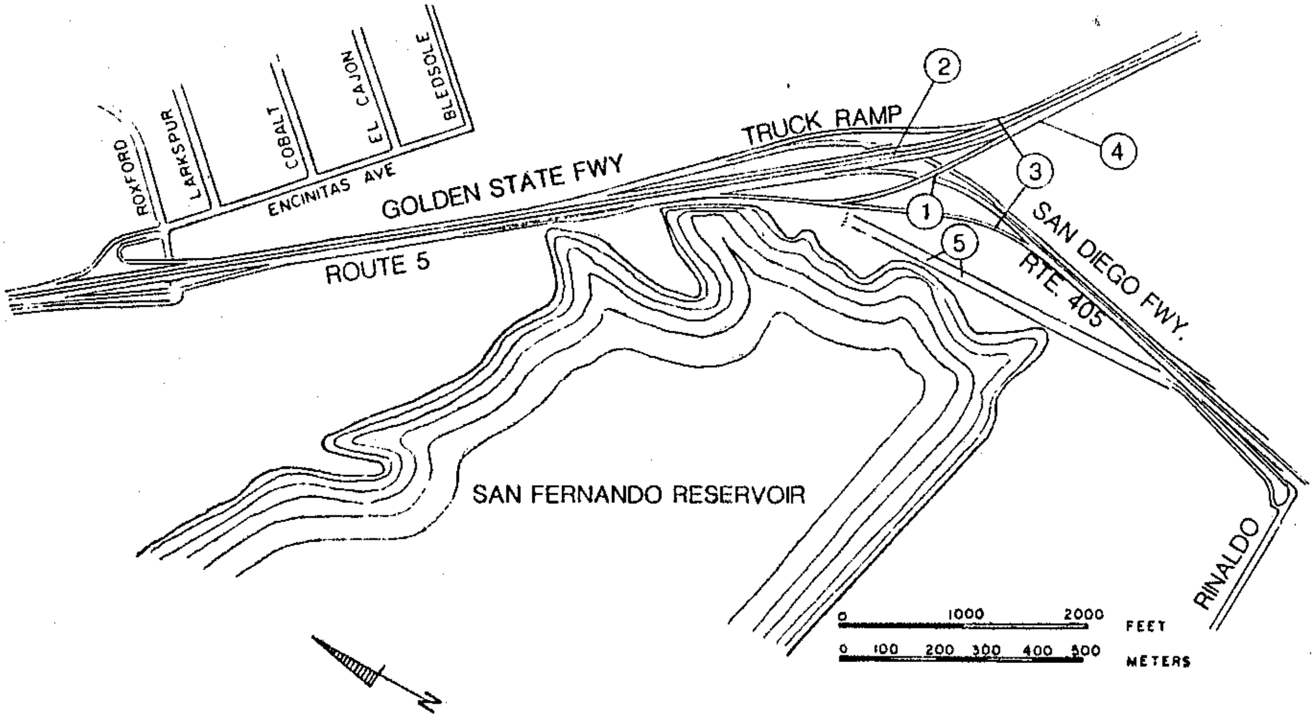
Location 2

At this location, northbound Route 405 traffic passes through a concrete box tunnel structure, shown in the left center of Photo 6. No visible disturbance of the soils surrounding the structure and the roadway within the structure was detected. Minor cracking in the walls and 1/4- to 1/2-inch separations in some expansion joints were observed. Also, a small amount of wingwall separation from the top deck at the southwest corner of the structure occurred. A report of the structure appears in Reference 5.

It is interesting to note that the tunnel structure suffered only very minor damage, yet 500 feet away a bridge was destroyed.

Figure 3

Layout of Route 5/405 Separation



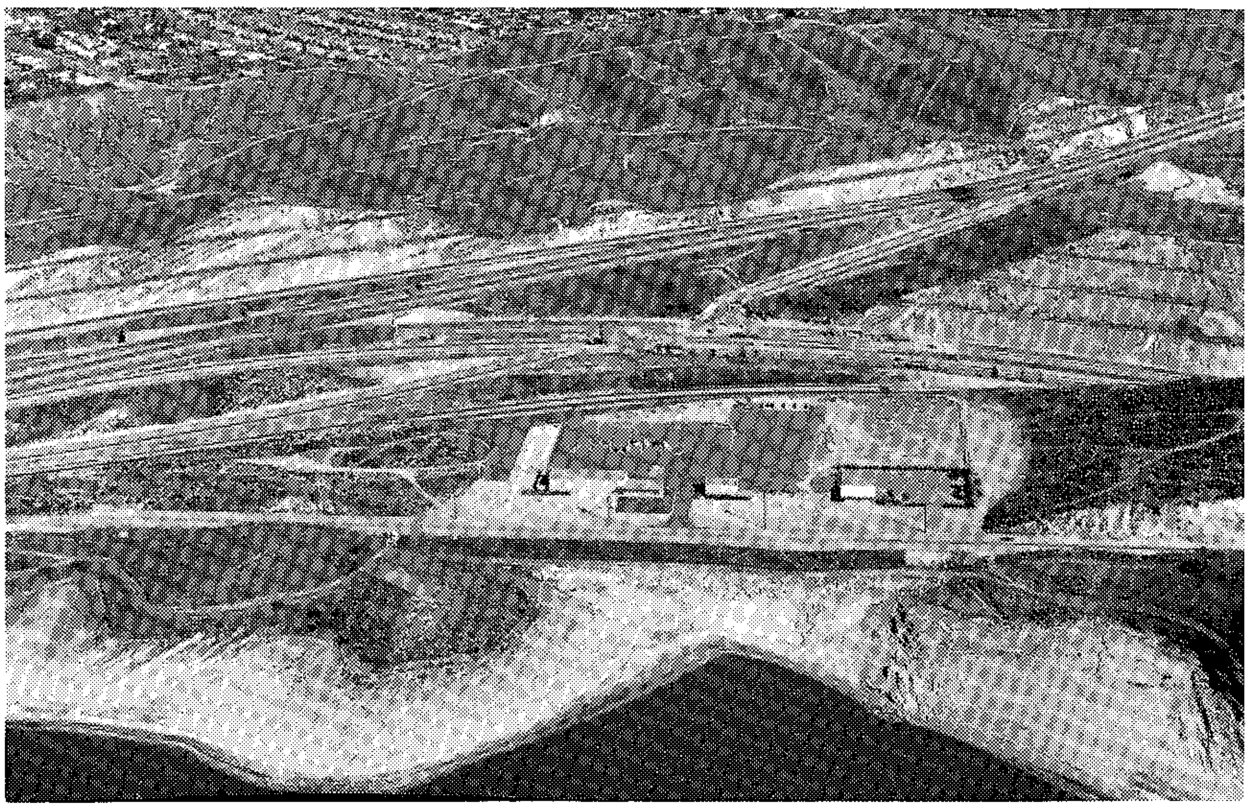


Photo 6. Looking easterly at the Route 5/405 Separation Area.

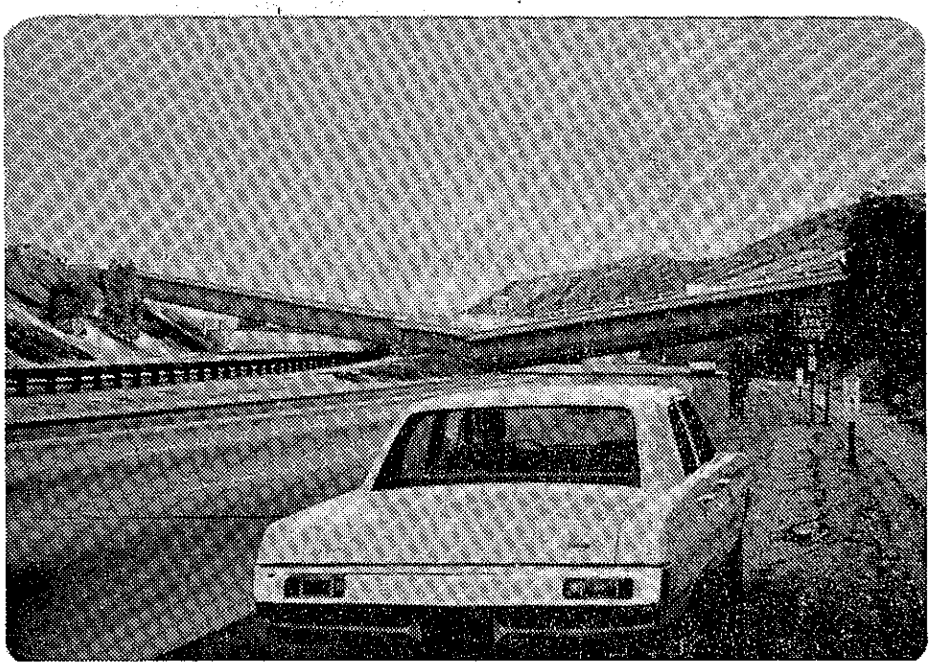


Photo 7. Looking northerly at the collapsed Route 5 southbound truck freeway bridge over Route 405.

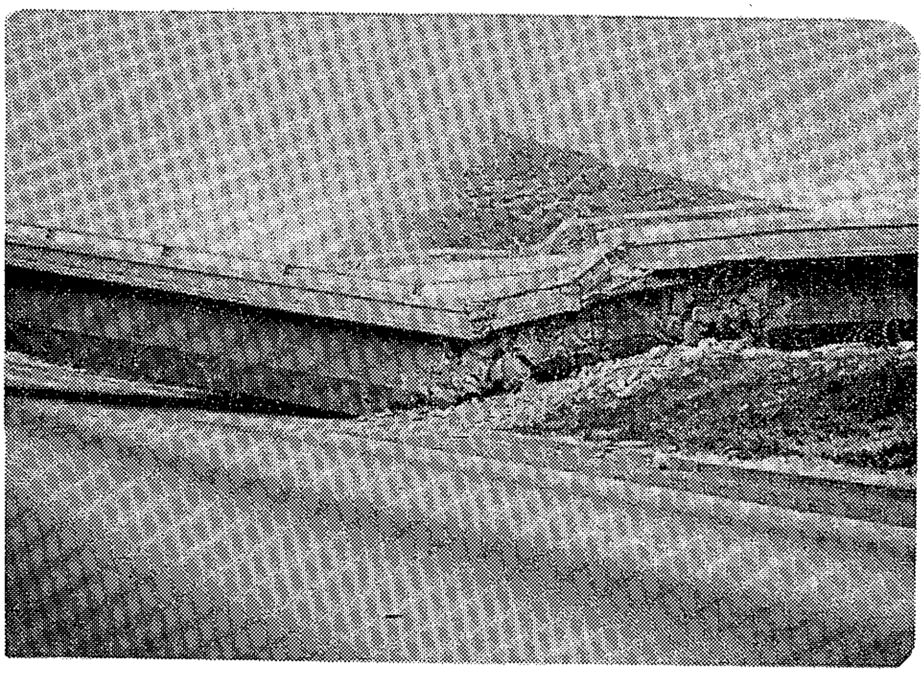


Photo 8. The center portion of the collapsed Route 5 southbound truck freeway bridge.

Location 3

Faulting occurred at this location in an east-west trend through the dark patch across Route 5 shown in Photo 6, upper right. The faulting is shown in more detail in Photos 9, 10, and 11. Two feet of reverse fault displacement, north over south, occurred. The writers believe the faulting continued in a westerly direction across Route 405 in a zone several hundred feet wide (see Ref. 2, p. 19, Item 6).

Undulations of the pavement, either visible or detectable when riding over the zone, were noted. Photo 12 is a southerly view of Route 405 across this zone. Immediately to the west of the photo a one-half foot rise in the ground was noted, northside up, but an actual break could not be found. A detail of the pavement buckle in the center of the photo is shown in Photo 13.

Although the above faulting may be localized, it is interesting to note that on a regional map (Reference 5) it appears to be an extension of the Sylmar Fault break of 1971.

Location 4

An earthquake-induced slump failure occurred at this location in a cut slope, shown in the center of Photo 14. The failure was confined entirely to the upper three-fourths of the 100-foot high cut.

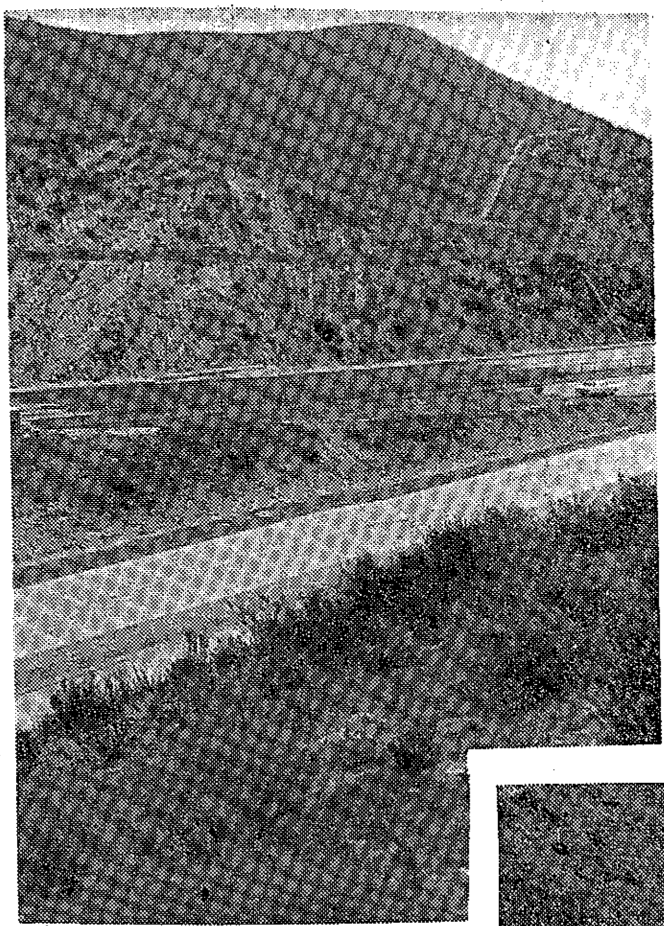


Photo 9. Looking easterly along discontinuous fault trace. Route 5 (patched) is in background, Route 5 southbound truck lane in center. Note break and disrupted profile in truck lane pavement.

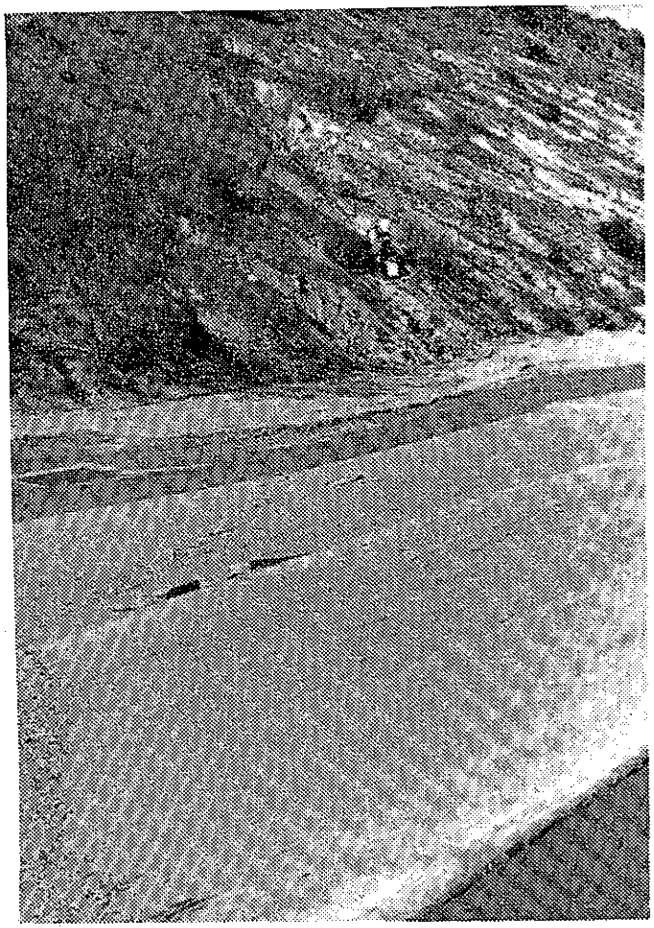


Photo 10. Looking westerly across truck lane pavement. Fault trace extended up cut slope in background.

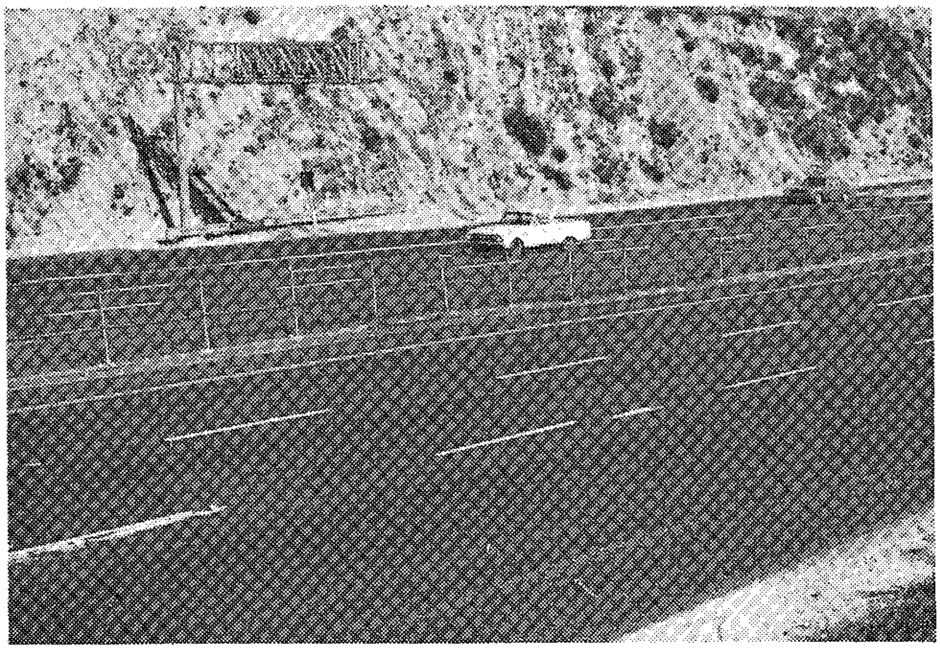


Photo 11. Looking easterly across the patched area of Route 5. A break in profile of the median fence may be noted directly in line with the vehicle near the center of photo.

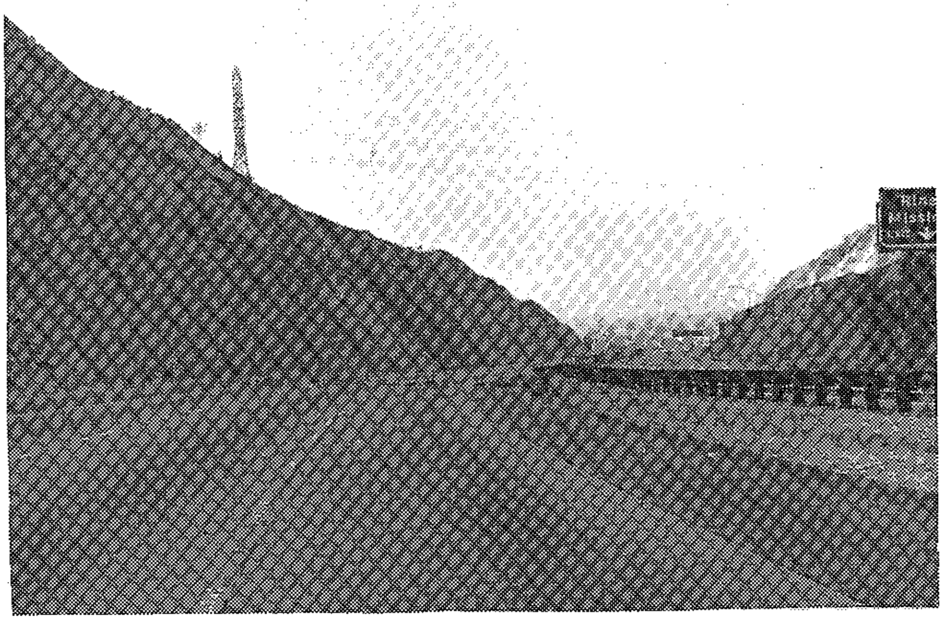


Photo 12. Looking southerly at northbound lanes of Route 405. Fault zone is believed to extend across the roadway in the area of broken pavement.

Photo 13. Looking westerly across northbound lanes of Route 405. Pavement break is on a general projection of nearby fault trace mapped by authors.

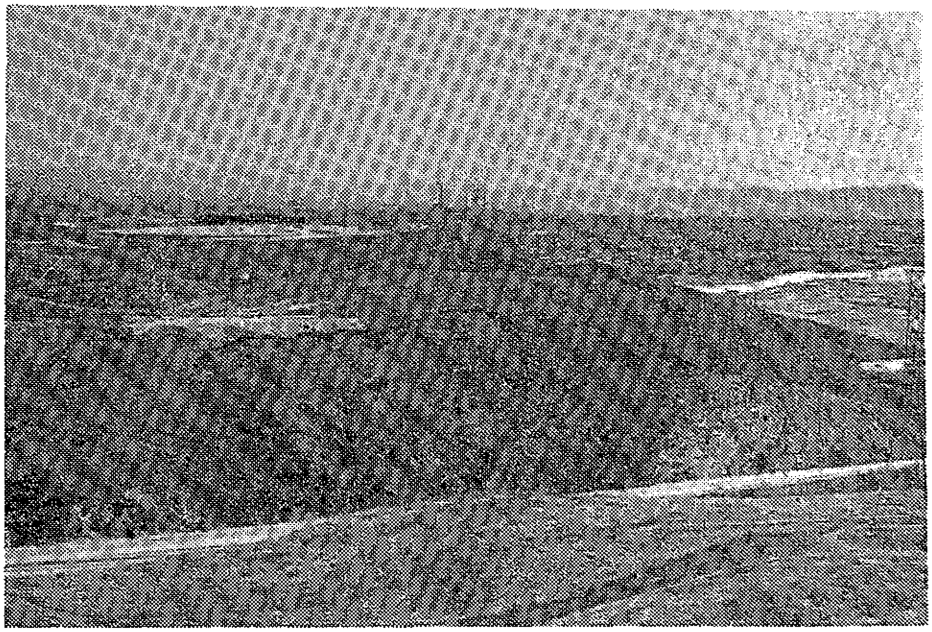


Photo 14. Looking westerly across Route 5. Note slide in cut slope.

Location 5

At this location, a Blucher Avenue fill slid toward the reservoir, as shown in the lower right center of Photo 6. Lateral movement of the fill and pavement damage are shown in Photo 15. Failure of the fill was possibly due to liquefaction of the saturated foundation material, although no supporting evidence to that effect was found.

Paved grounds of the Caltrans' maintenance yard immediately east of the slide suffered various amounts of pavement breakage. An example is shown in Photo 16 which illustrates a one-foot thrust of pavement, north over south. Another compressional feature was noted across Blucher Avenue, south of the slide where the roadway enters a cut section (Photo 6); however, details of the feature were not recorded.

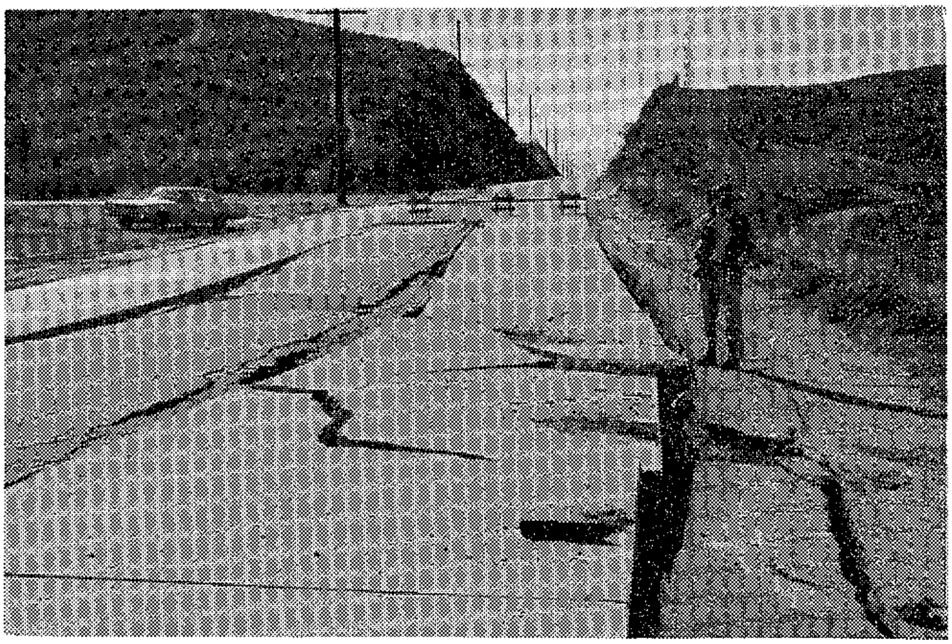


Photo 15. Looking southerly along Blucher Avenue at results of fill movement to the west.

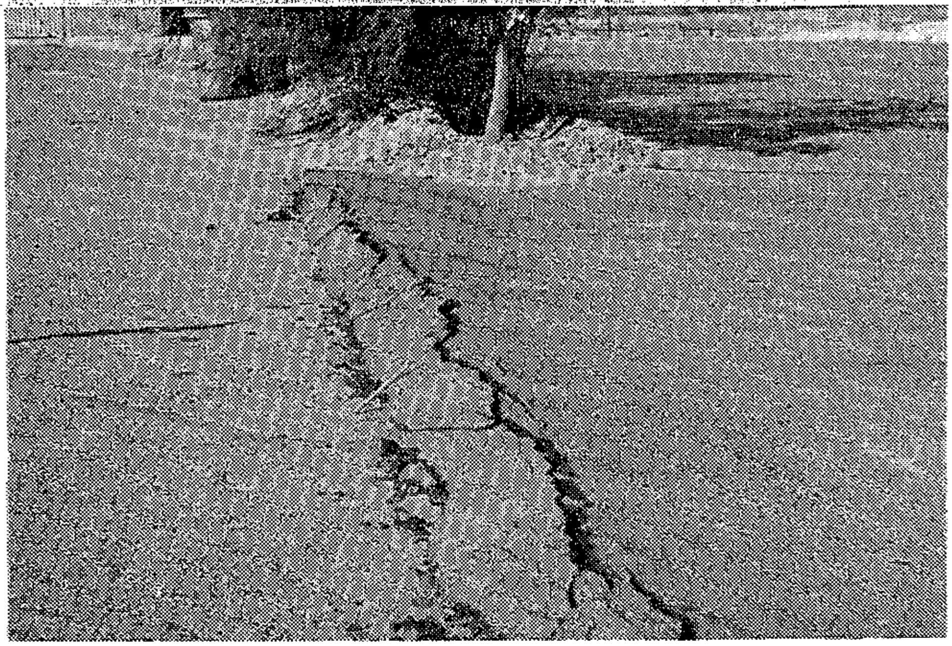


Photo 16. Looking westerly at maintenance station parking area. Note pavement breaks and thrusting of north over south.

ROUTE 5, BETWEEN THE ROUTE 5/405 SEPARATION AND ROUTE 5/210 INTERCHANGE

This 1.8 mile section of Route 5 passes through low-lying hills made up of nonmarine sediments and crosses canyons that contain shallow alluvial deposits. Groundwater is very near the surface of canyon bottoms at the southerly end of the section. Roadway and original ground profiles are shown in Figure 4.

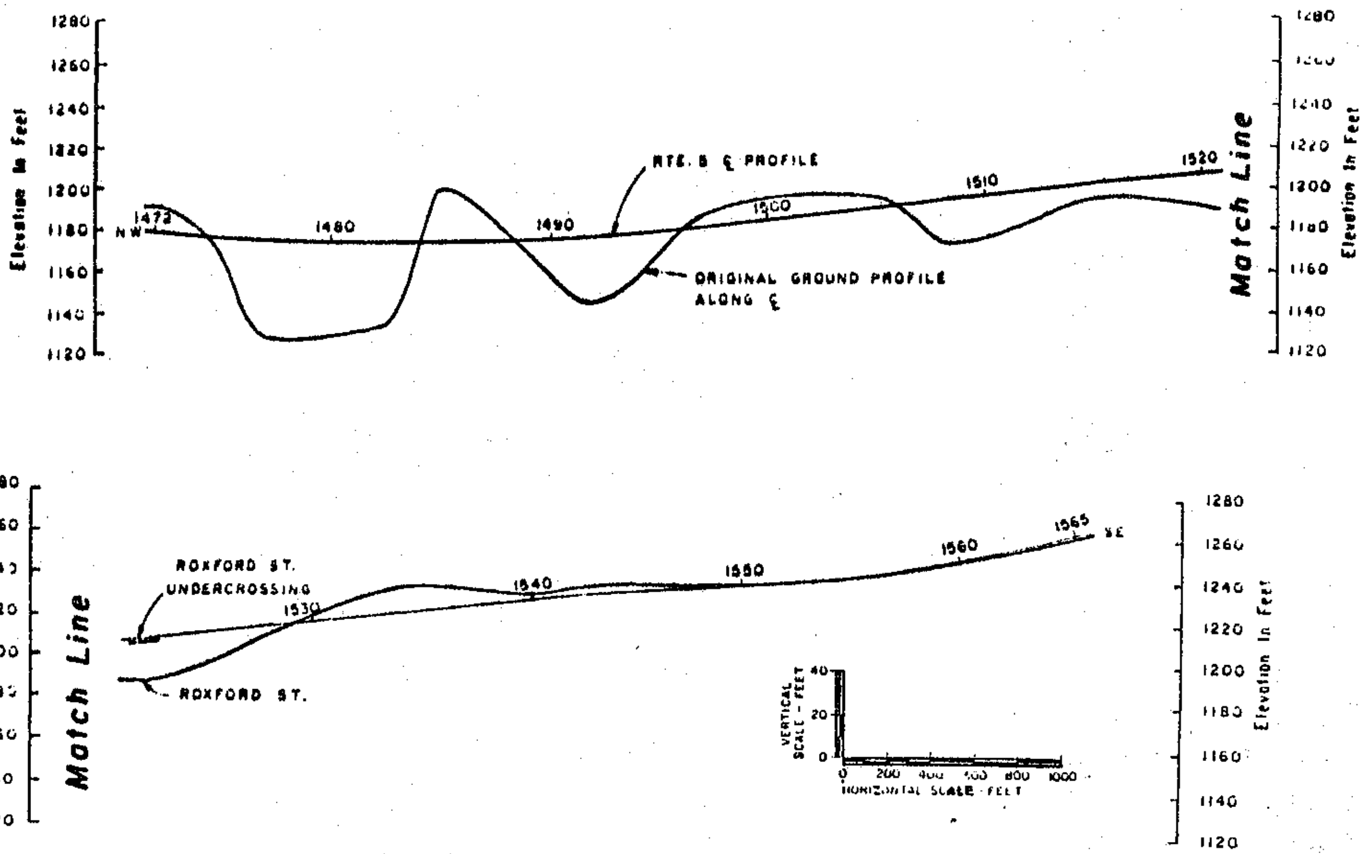


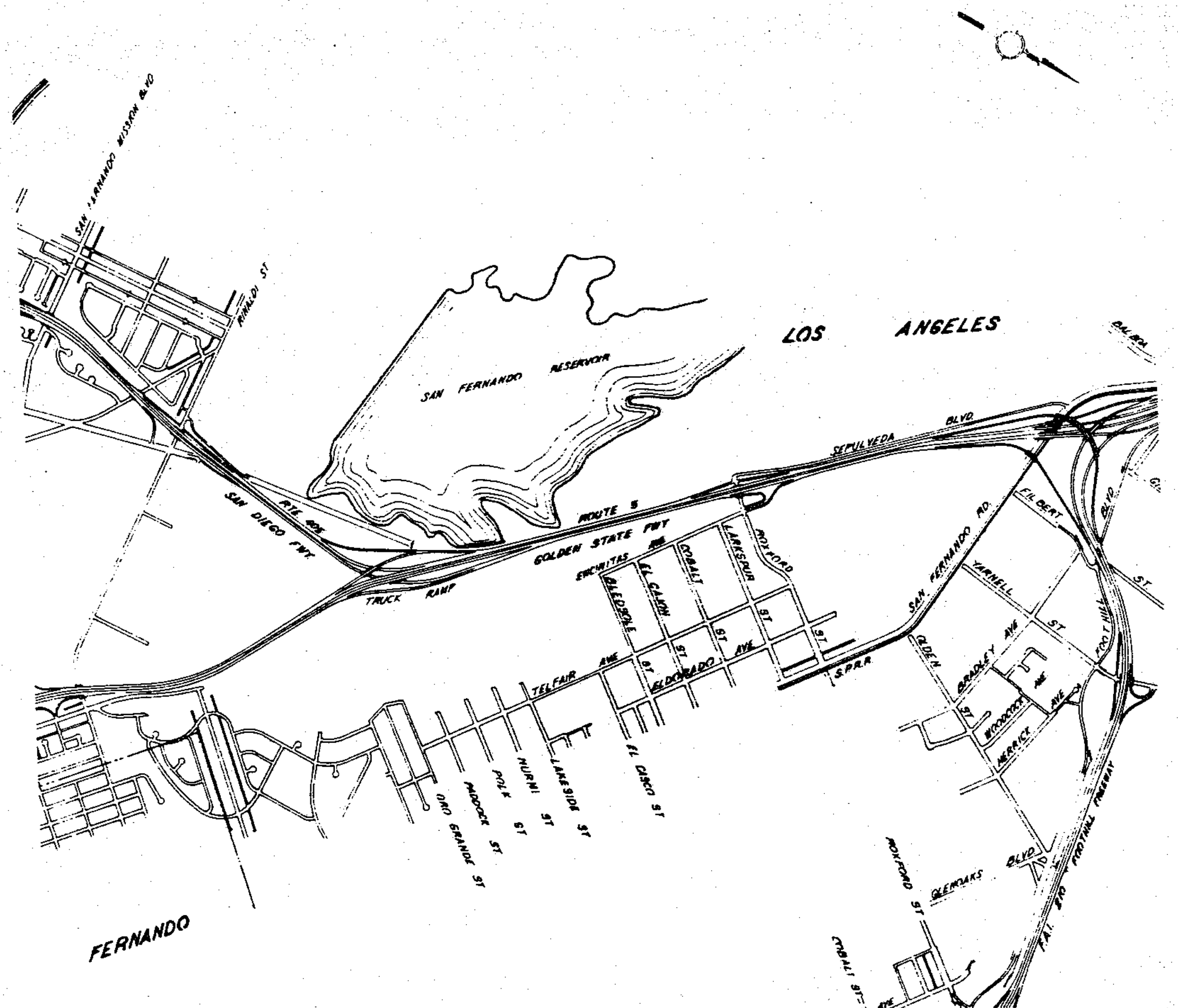
Figure 4
Original ground and Route 5 centerline profiles from Route 5/405 separation to Route 5/210 Interchange.

The following damage location numbers are shown on Figure 5.

Location 1

Immediately north of the 5/405 separation, the roadway crosses a canyon on about 45 feet of fill as shown in Photo 17. The embankment, founded on saturated, relatively weak fine-grained alluvial deposits, experienced vertical and lateral movement due to the foundation soil behavior. Cracking in slopes on both sides of the fill (Photos 18 and 19) suggest that much larger movements typical of foundation failures would have occurred had strong motion been of a longer duration. Vertical movement resulted in pavement slab displacements as shown in Photos 20 and 21.

Concrete pavement slabs were thrust together near the south cut-fill contact as shown in Photos 22 and 23, as well as being separated along the same contact shown in Photo 21. Longitudinal separation occurred between pavement slabs due to fill lateral movement as shown in Photo 24.



LAYOUT OF ROUTE 5 FROM ROUTE 5/405 SEPARATION TO ROUTE 5/210 INTERCHANGE

FIGURE 5

Photo 17. Looking northeasterly at Route 5. Note roadway embankment and pavement patches in left center of photo.

Photo 18. Looking northerly along easterly slope of Route 5 embankment.

Photo 19. Looking south at westerly slope of embankment. Note cracks and lateral movement in slope.

Photo 20. Vertical displacement along pavement slab joints near fill/cut contacts.

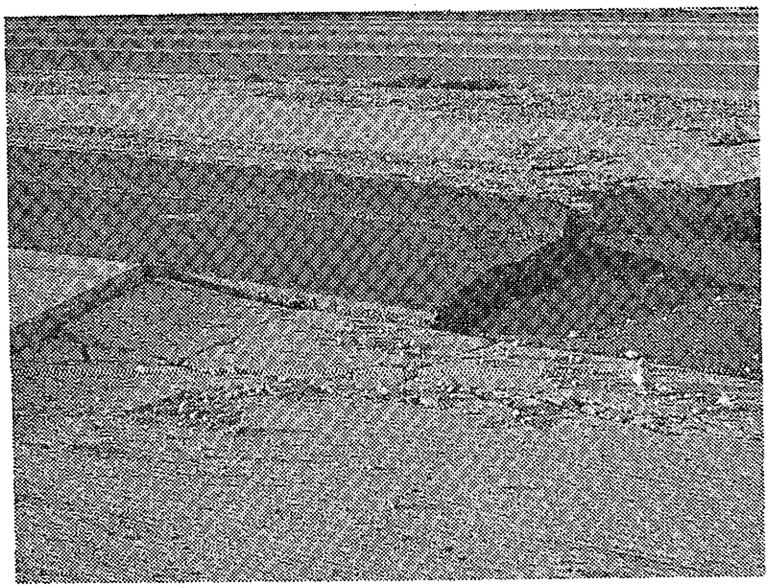


Photo 21. Vertical displacement along pavement slab joints near fill/cut contacts.

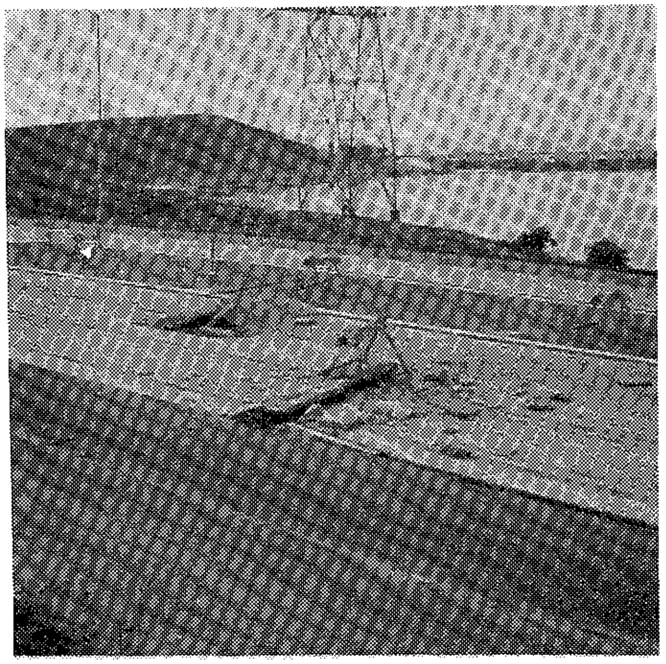


Photo 22 and 23. Breaking and overriding of pavement slabs at transverse joints due to longitudinal thrusting action.

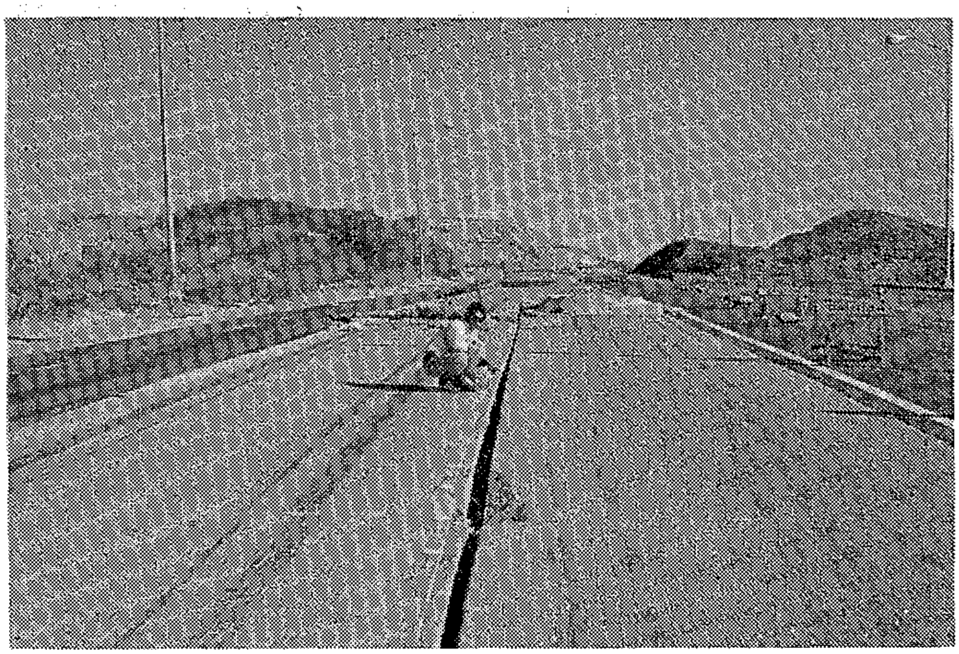


Photo 24. Slab separation along longitudinal joint due to lateral fill movement.

Location 2

The top of the cut slope (Photo 25) was distressed by slope-shattering and transverse cracks, shown in detail in Photo 26.

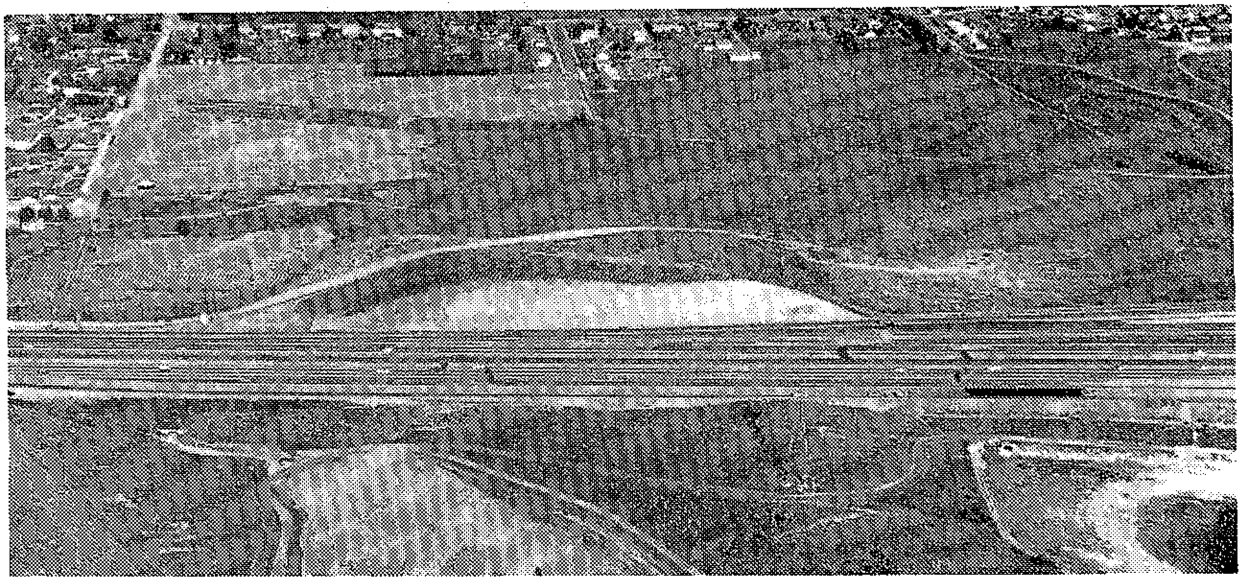


Photo 25. Looking northeasterly at Route 5. Cut slope in top center sustained cracking. Note patches in pavement.

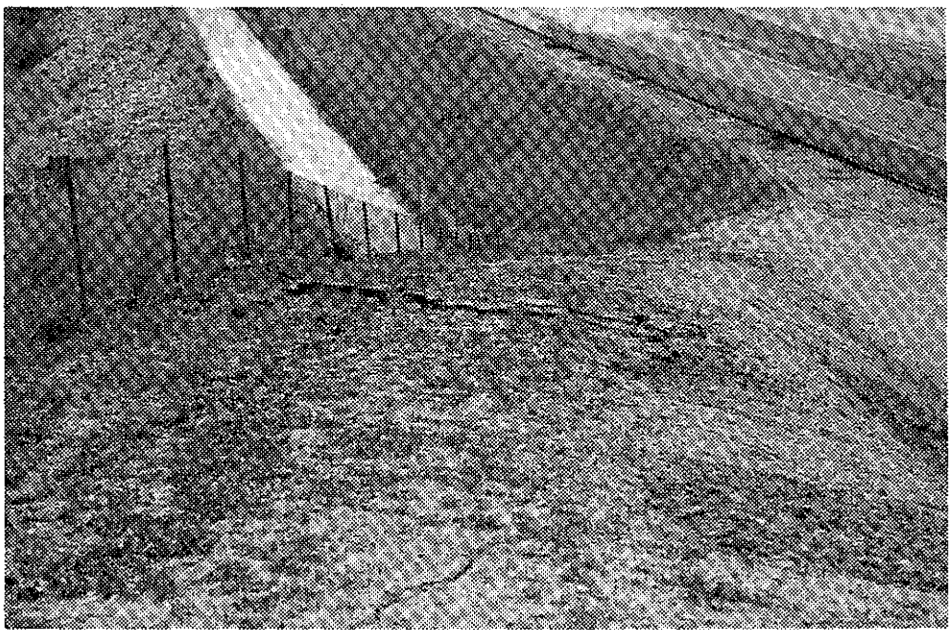


Photo 26. Typical cracks in cut slope shown in Photo 25.

Location 3

Just north of Location 2, a 30-foot high embankment underwent enough movement to cause cracking in both slopes, and settlement near the cut-fill contacts. The riding surface across this embankment required repairs in the south-bound lanes at the south cut-fill contact. A 12-foot steel plate drainage structure through the fill was distorted at the inlet (Photo 27), and outlet (Photo 28), but remained structurally intact.

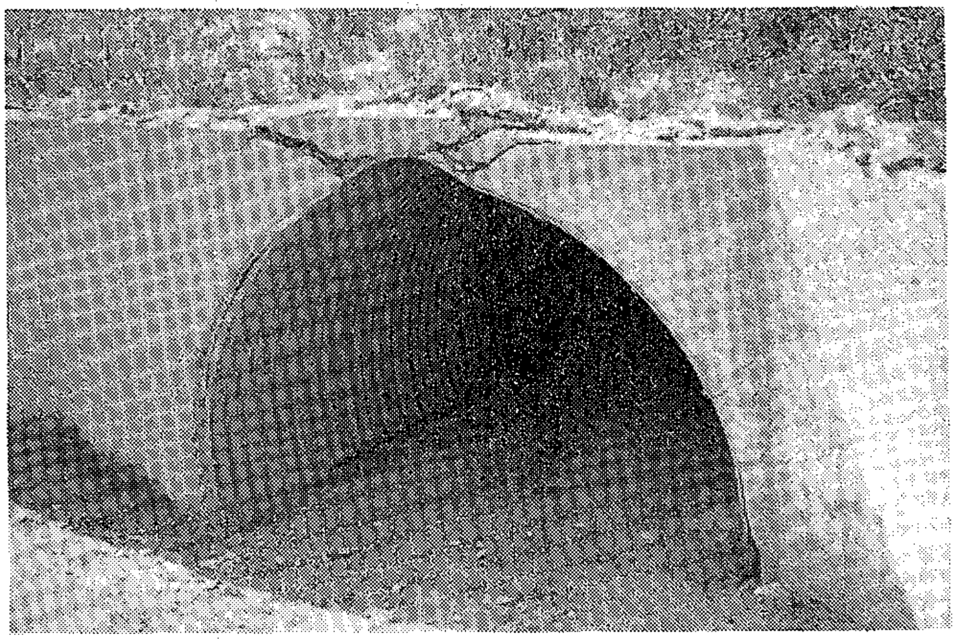


Photo 27. Cracking and distortion in drainage structure headwall.

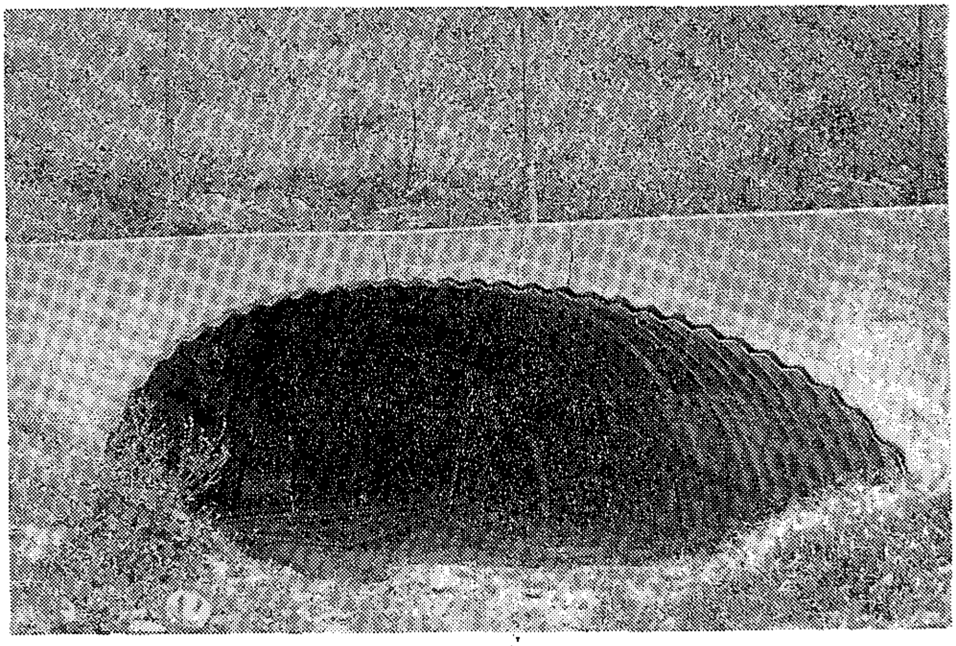


Photo 28. Cracking in drainage structure endwall. Note separation of concrete and metal at top of structure.

Location 4

Rotational movement occurred in the cut slope on the west side of the freeway shown in Photo 29. The movement, although small, was sufficient to develop cracks behind the top of cut (Photos 30 and 31) and to upthrust the south-bound roadway surface and cause slab separation, which required patching. Four hundred feet to the south, another upthrust bulge occurred in the roadway but it did not require immediate repairs. It was not obvious upon first observation that slope movements of this nature were the cause of the roadway riding surface damage.

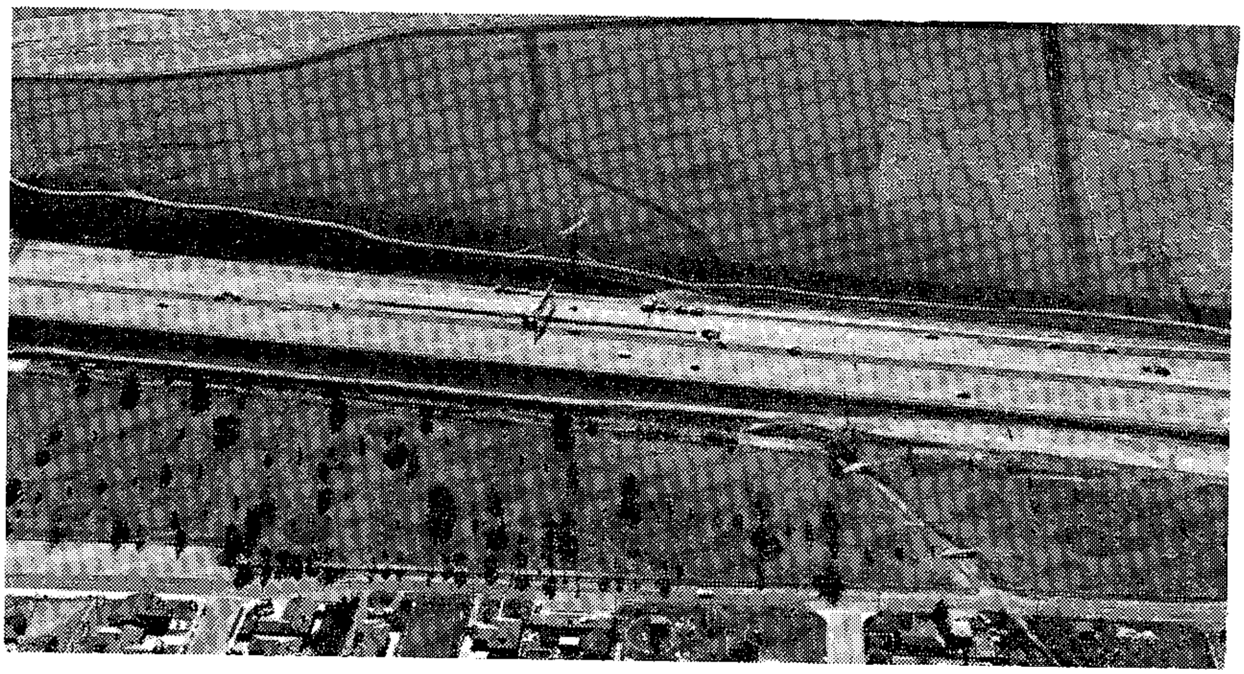


Photo 29. Looking westerly at Route 5.

Photo 30. Cracking behind top of cut slope.

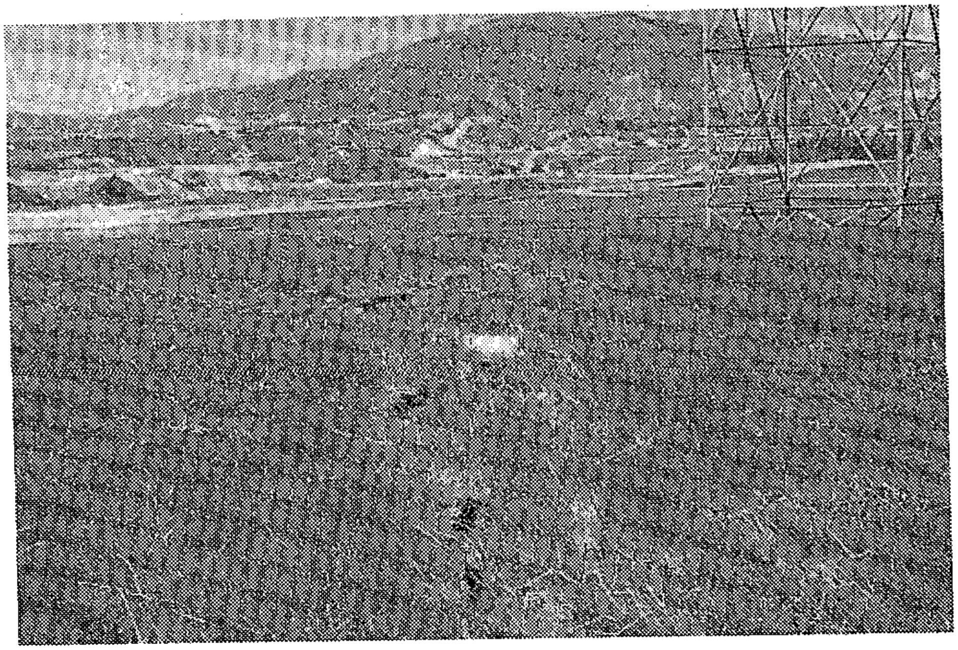


Photo 31. Cracking behind top of cut slope.

Location 5

Between the cut described for Location 4 and Roxford Street, Route 5 is carried on fill. An 84-inch concrete drainage pipe was located under most of the fill length, beginning at Roxford Street and outletting near the cut of Location 4. The outlet may be seen in Photo 29, right of center, at the bend in the open channel. This pipe was cracked badly from the headwall on the east side of the fill for a distance of about 600 feet to the south and west. Longitudinal cracking was practically continuous, mainly between the 8 and 11 o'clock and 2 and 4 o'clock positions when viewed looking westerly. Cracks up to one inch wide with lateral offsets up to one inch were noted. Also, peripheral cracks at joints had opened about 1/4-inch at several locations. The longitudinal crack pattern is shown in Photo 32.

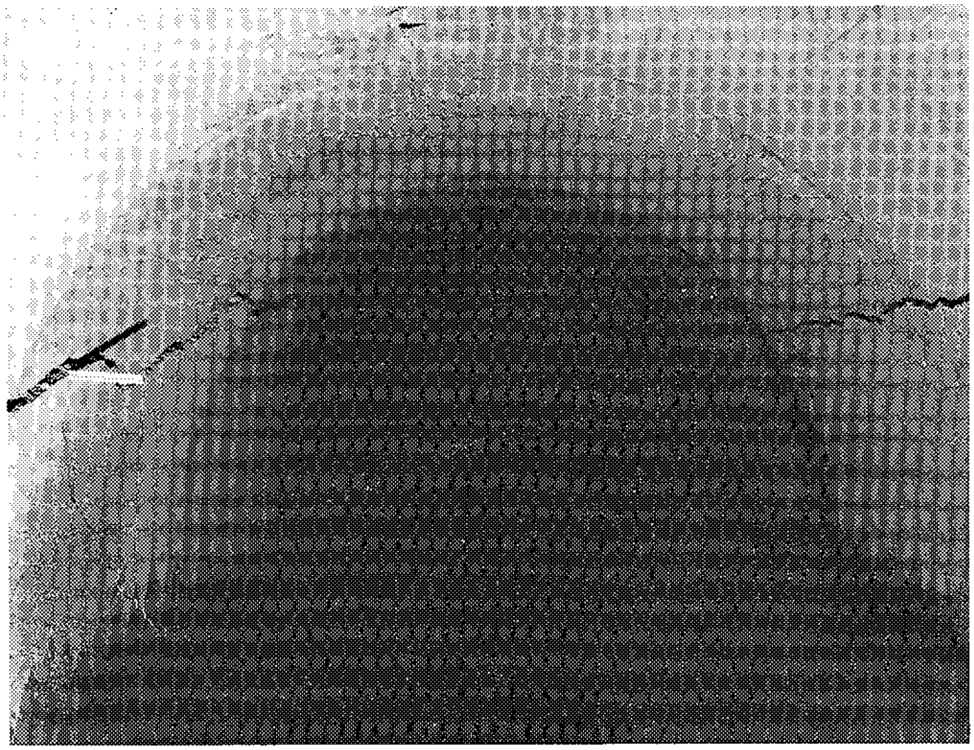


Photo 32. Typical longitudinal cracks in 84-inch concrete pipe.

Location 6

At the time of the earthquake a bridge widening project was under construction at the Roxford Street Interchange, shown in Photo 33. In addition to structural damage shown in Photos 34 and 35, settlement occurred in approach fills and structure backfill shown in Photo 36.

Photo 33. Looking westerly at the Route 5/Roxford Street Interchange.

Photo 34. Separation and settlement of wing·wall, cracking of abut·ment diaphram, Roxford Street Undercrossing.

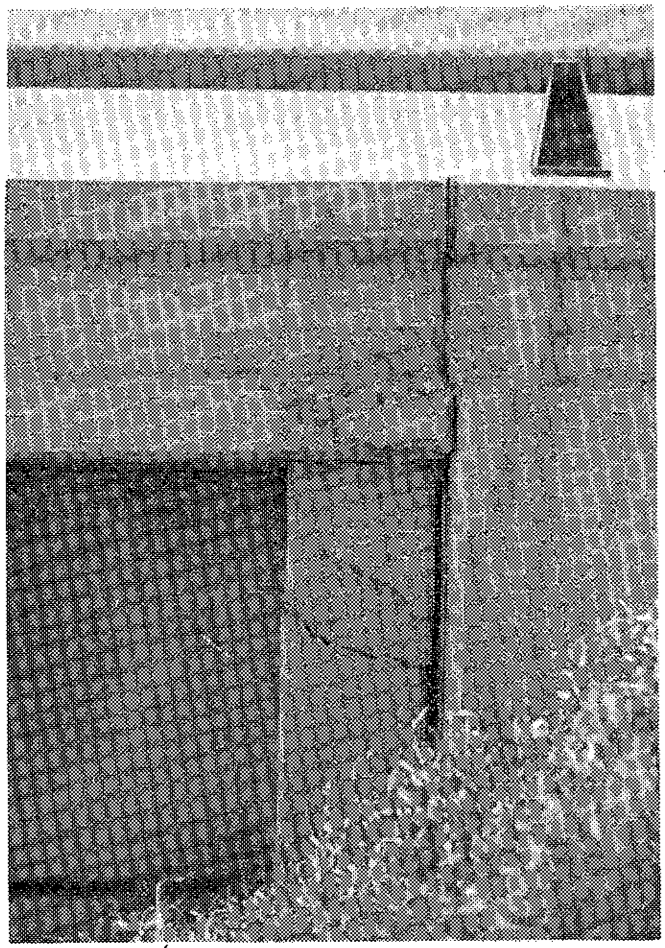


Photo 35. Settlement of concrete curtain wall from bridge girder. Note exposed rebars along separation.

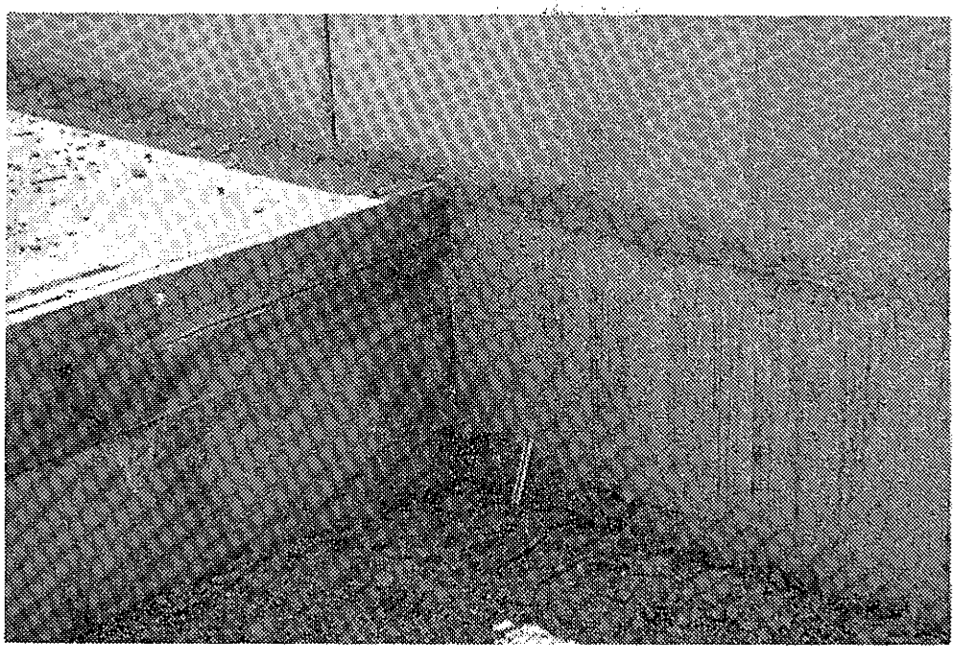


Photo 36. Abutment backfill settlement, north end of Roxford Street Undercrossing.

Location 7

Roadway settlement of a few inches occurred at the cut to fill contact shown in Photo 37, right of center. A low fill crosses the drainage-way that follows the alluvium contact with a slight hill made up of bedded sediments. From this location, the roadway is essentially constructed along the natural ground profile for a 1/4-mile distance, northward.

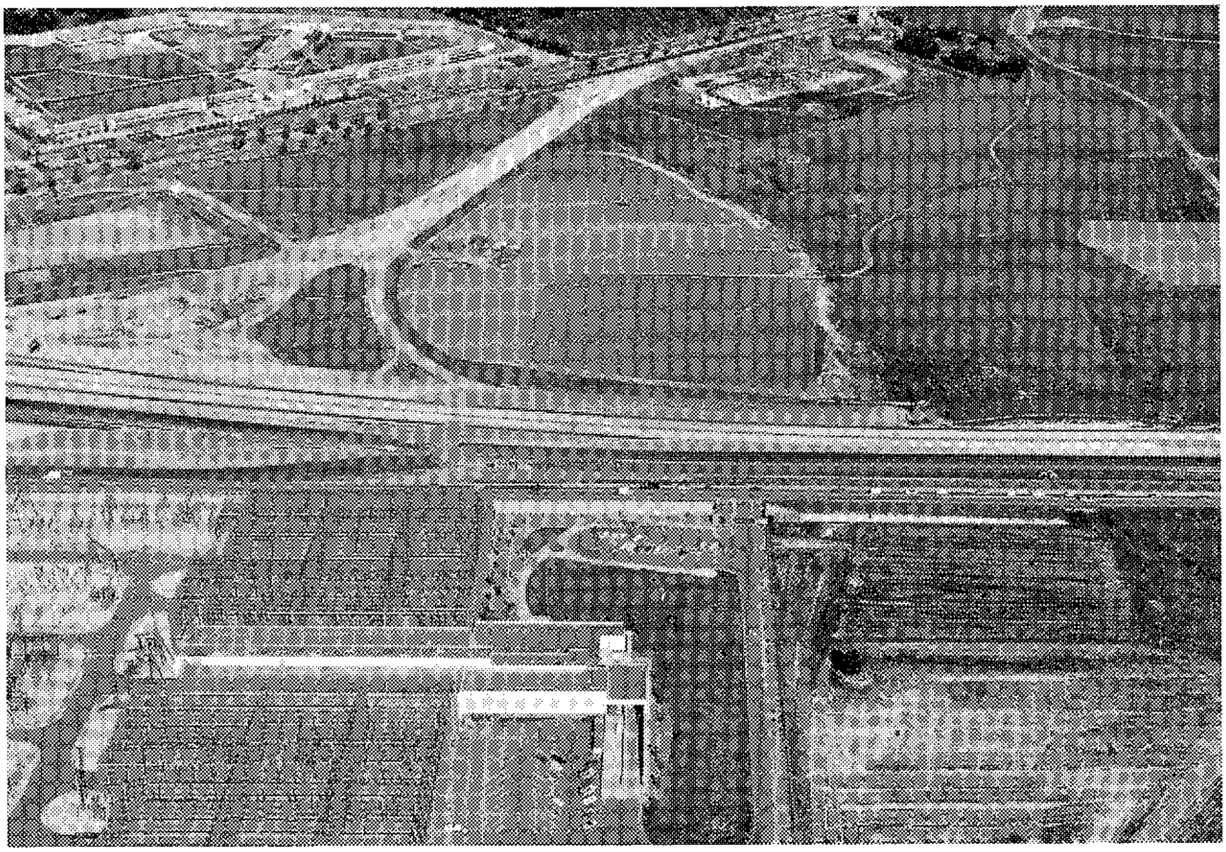


Photo 37. Looking easterly at Route 5. The Sylmar Converter Station is shown in lower left. Juvenile Hall complex is shown in middle left.

Location 8

The Juvenile Hall Landslide (Photo 37) displaced Route 5 in excess of 5 feet horizontally, transverse to the roadway (Photos 38 and 39). A compression buckle in the concrete pavement also occurred, as shown in Photo 39.

Lateral movement of the roadway along the northern flank of the slide resulted in separation, rotation, and differential heaving of pavement slabs as illustrated in Photo 40. Photos 41-43 show other features of the slide, detailed analyses of which may be found in References 7 and 9.

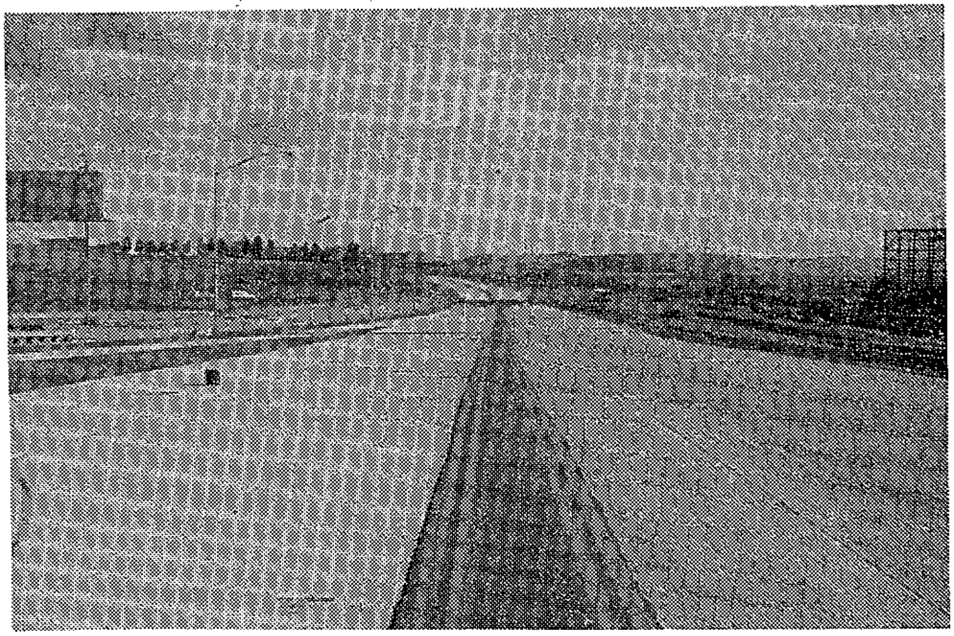


Photo 38. Looking south along Route 5. Note displacement of striping to right (west) caused by Juvenile Hall slide.

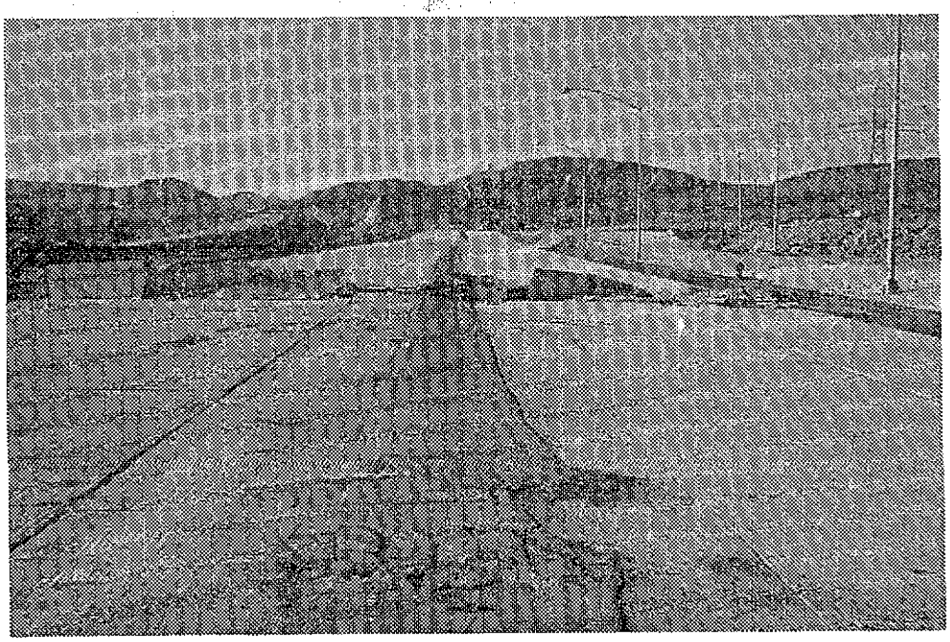


Photo 39. Looking north along Route 5. Note relative lateral slab displacement sharply delineated by striping. Northerly limit of slide displacement is shown by striping in far background. Note pavement buckle caused by extreme thrusting of slabs.

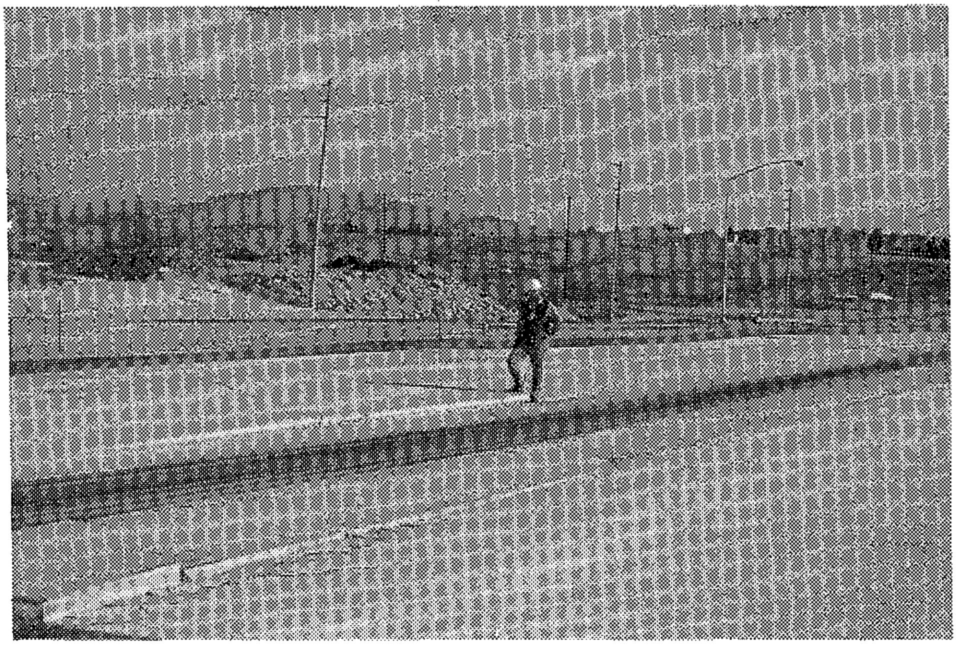


Photo 40. Looking southeasterly at Route 5. Northern flank of Juvenile Hall slide crossed pavement here, resulting in pavement slab movement.

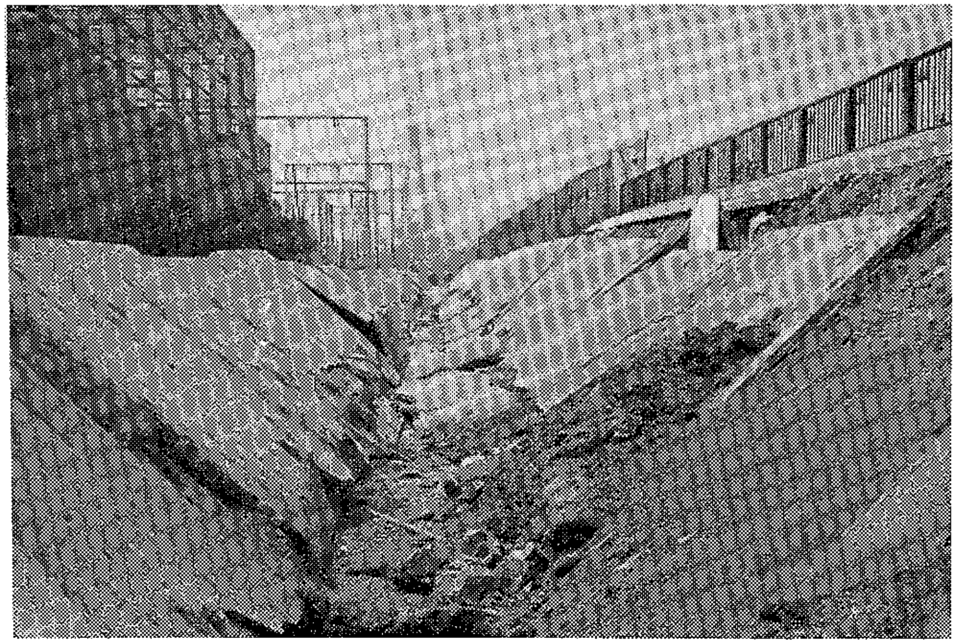


Photo 41. Looking north along concrete lined drainage channel between Route 5 (right) and the Sylmar Converter Station (left). Lateral movement of Juvenile Hall slide (right to left) was largely absorbed by the channel.

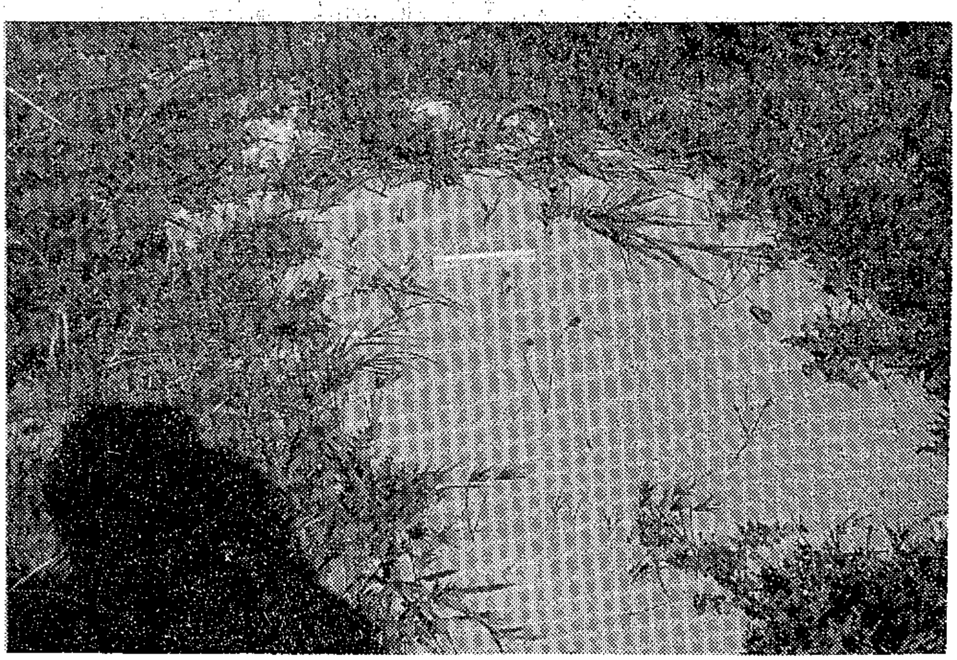


Photo 42. Liquefaction sand boil in central portion of Juvenile Hall slide.

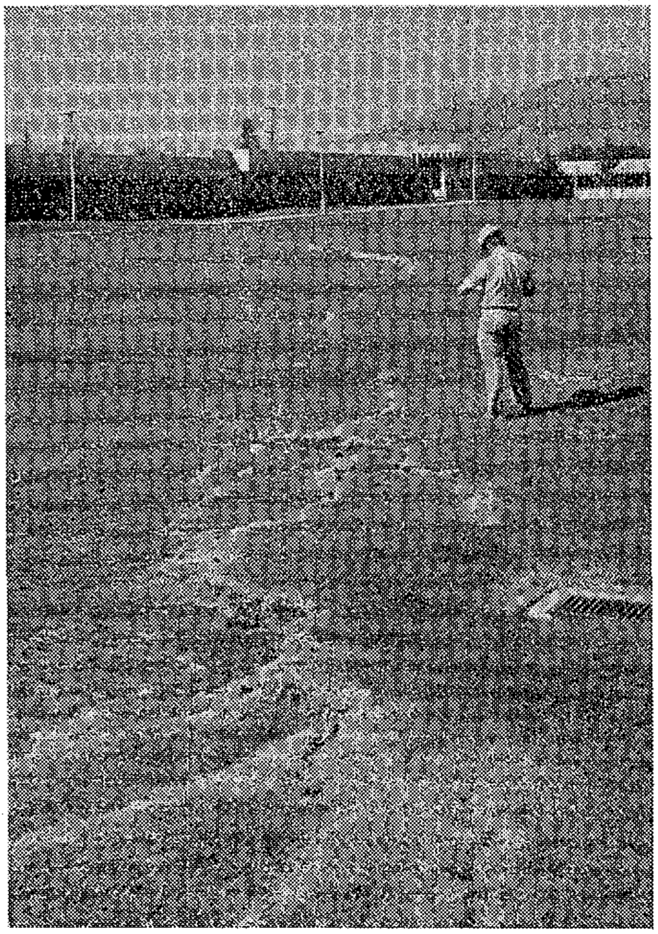


Photo 43. Northern flank of slide, viewed from inside Juvenile Hall complex.

ROUTE 5/210 INTERCHANGE AREA

The Route 5/210 Interchange area suffered the most severe damage of the entire earthquake-damaged transportation system. In addition to collapsed bridges that blocked vehicular and railroad traffic, the roadway was distressed by tectonic uplift, differential settlement, embankment shear, spreading, and tension cracking.

Photos 44 and 45 show the interchange as it appeared the day after the earthquake. Specific damage locations to be discussed are indicated by number in Figure 6.

The terrain in the Route 5/210 area has over 100 feet of relief and is made up of sandstones of the Saugus formation. The canyons contain deposits of recent alluvium. Original ground and roadway profiles of Route 5 northbound and the A-Y Connector are shown in Figures 7 and 8.

Figure 6
Layout of the Route 5/210 Interchange

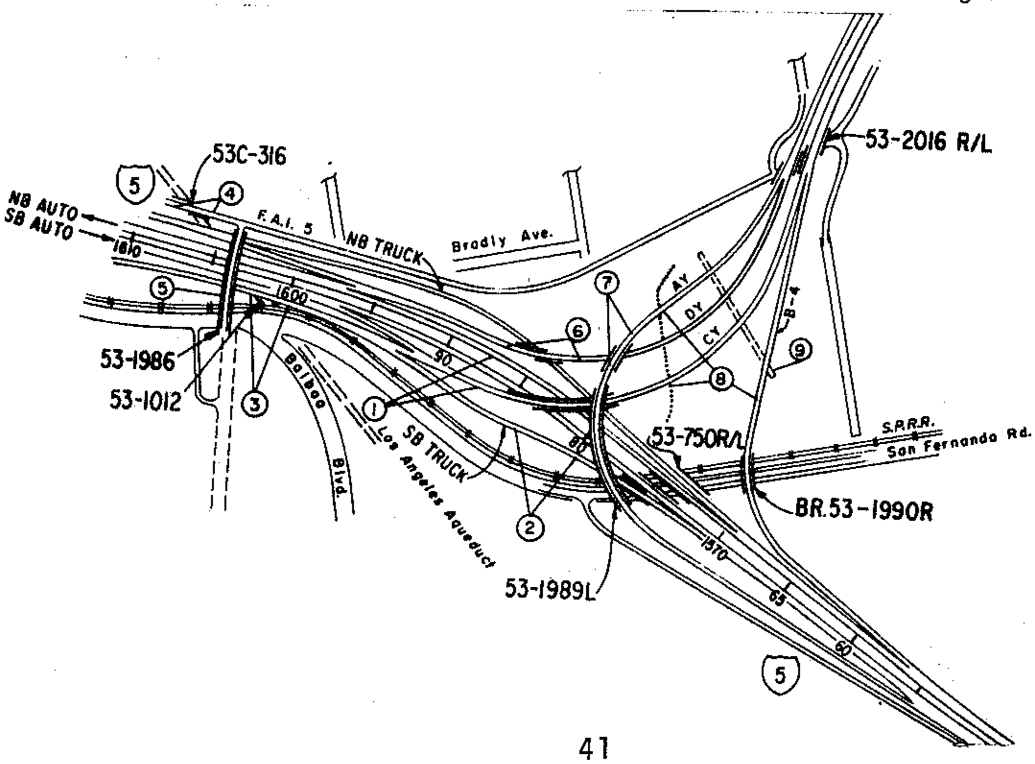
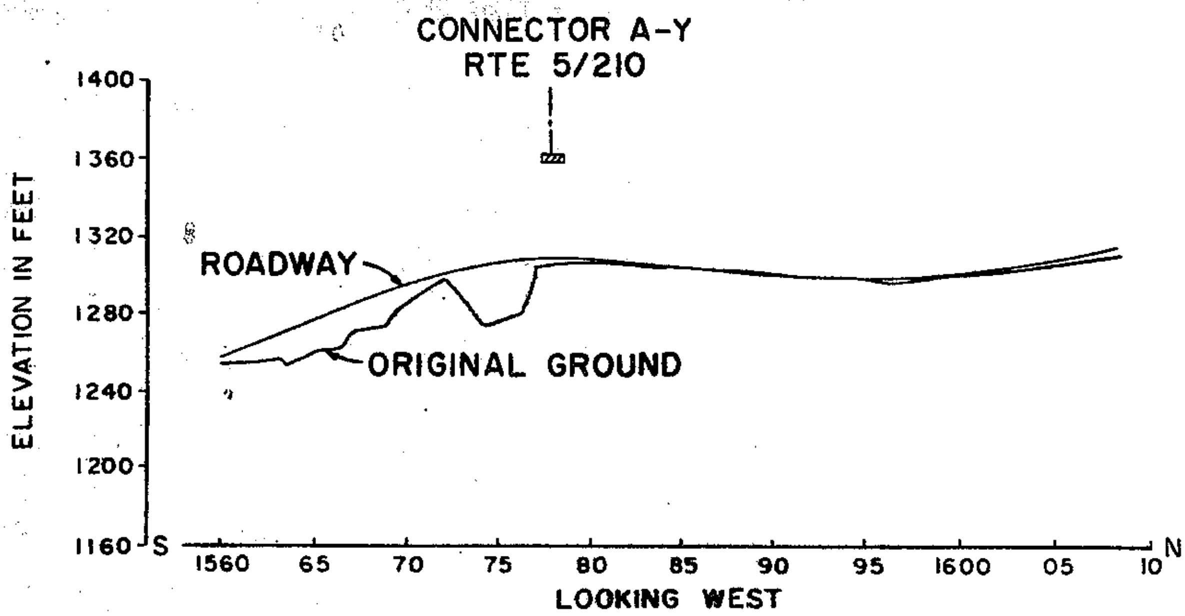


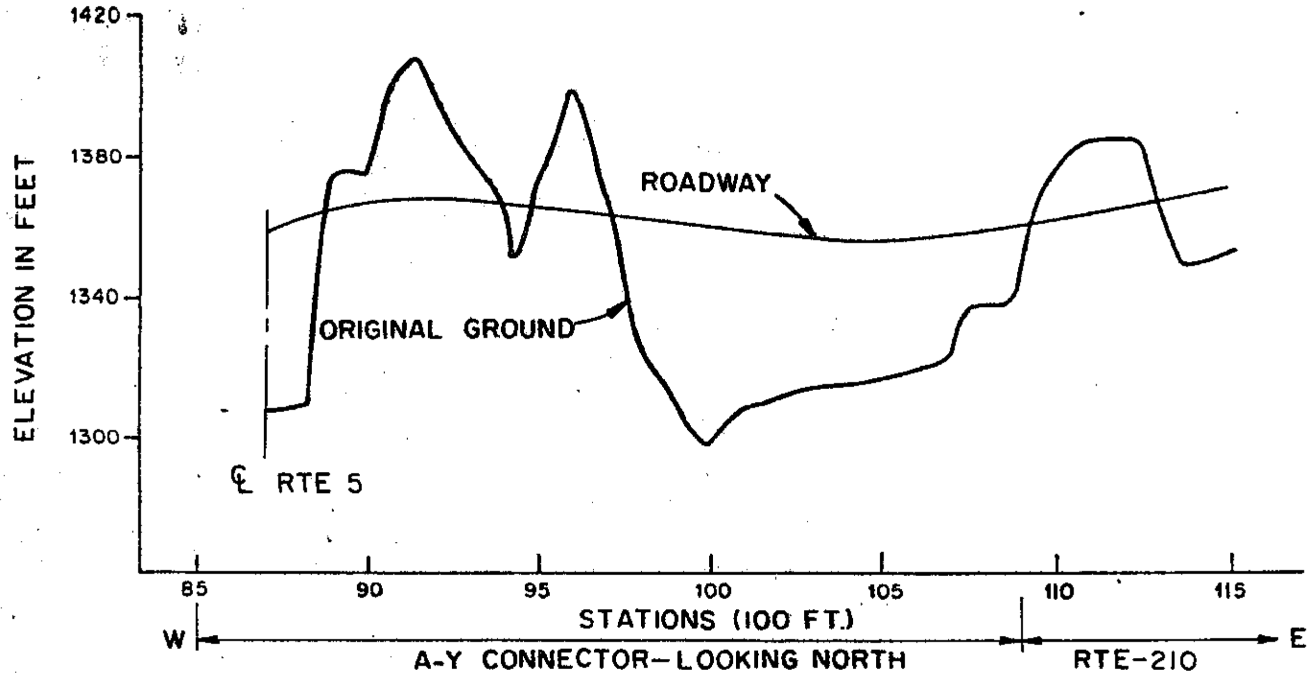
Photo 44. Looking easterly at Route 5. The Balboa Boulevard Overcrossing structure is in left center. The Los Angeles Aqueduct crosses the freeway from upper left to lower right. The Route 5/210 Interchange off the photo to the right.

Photo 45. Looking easterly at the Route 5/210 Interchange. Route 5 is shown left to right and Route 210 at the top of the photo. Note the Juvenile Hall complex in upper right and the Sylmar Converter Station in right center.



ORIGINAL GROUND AND NORTH BOUND ROUTE 5 PROFILES IN ROUTE 5/210 INTERCHANGE AREA

FIGURE 7



ORIGINAL GROUND AND ROADWAY PROFILES IN ROUTE 5/210 INTERCHANGE AREA

FIGURE 8

Location 1

Pavement slabs were faulted badly across the northbound roadbed of Route 5 and Connectors C-Y, D-Y, and M-Y. As may be noted from Photos 46, 47, and 48, typical faulting and slab separation occurred at both longitudinal and transverse joints. The large displacement shown in Photo 47 is the result of a large crack extending up the fill slope. An interesting feature of the pavement distress is that Route 5 at this location is essentially at original ground level (Figure 7) although the slab behavior was typical of pavement on fills.

Design and post-quake profiles of Connectors C-Y and M-Y are shown in Figures 9 and 10, respectively. The plots show that despite a regional uplift in this area the post-quake profile is lower than the design profile due to fill settlement caused by spreading and densification.

East of this location, natural slopes in the steep hills were shattered in a north-easterly trending belt approximately 500 feet in width.

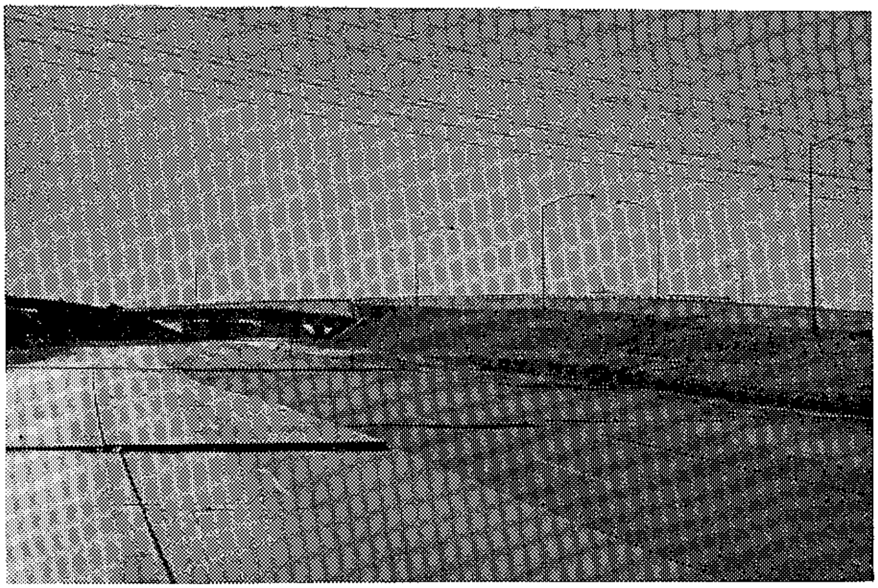


Photo 46. Looking southeasterly at Route 5 northbound truck lanes. Note slab separation, laterally and vertically, at joints. Damaged D-Y Connector Structure is in background.

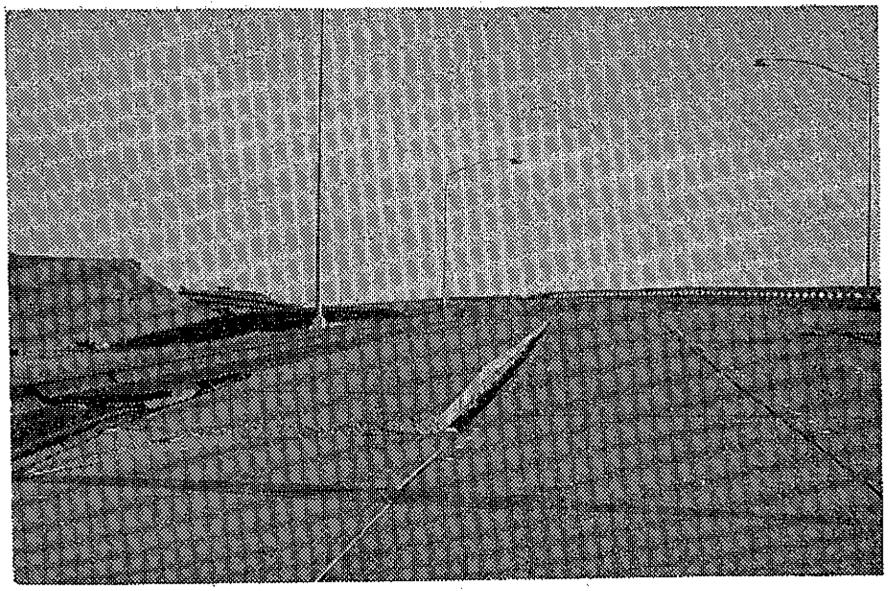


Photo 47. Looking southeasterly along Connector D-Y, at damaged fill-supported pavement.

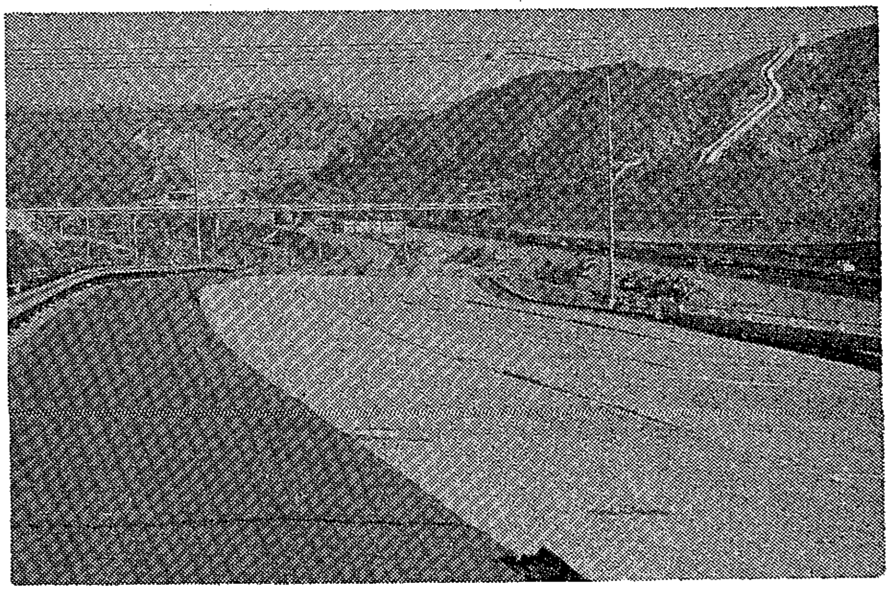
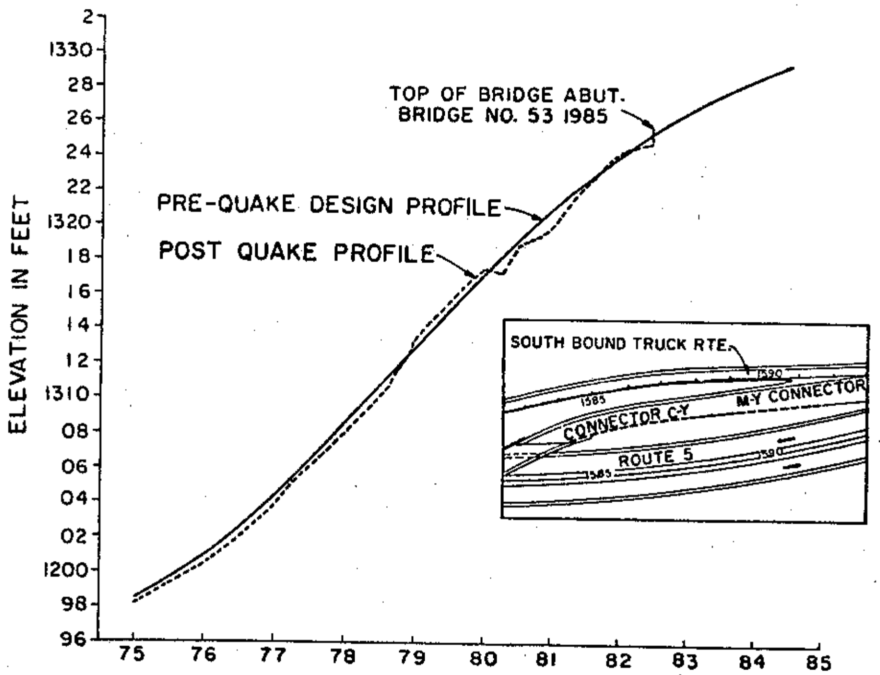
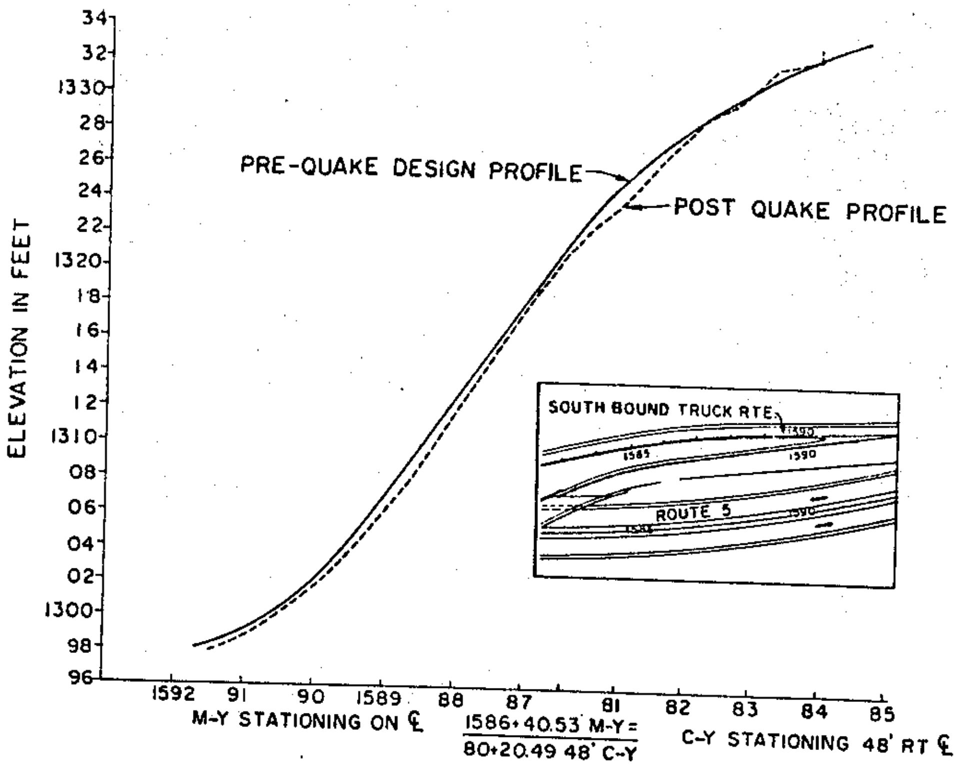


Photo 48. Looking northwesterly along Connector D-Y, at pavement slab faulting, separation, and undulations due to fill movement.



C-Y CONNECTOR PRE-QUAKE AND POST-QUAKE PROFILES

FIGURE 9



M-Y CONNECTOR PRE-QUAKE AND POST-QUAKE PROFILES

FIGURE 10

Location 2

The pavement of the Route 5 Southbound Truck Freeway was faulted and displaced laterally due to shearing action in the fill (Photo 49). The shear pattern, traced diagonally down the fill slope, outlined a complete volume of material that probably would have collapsed had strong motion been of a longer duration. The roadway profile and alignment were deformed as shown in Figures 11 and 12.

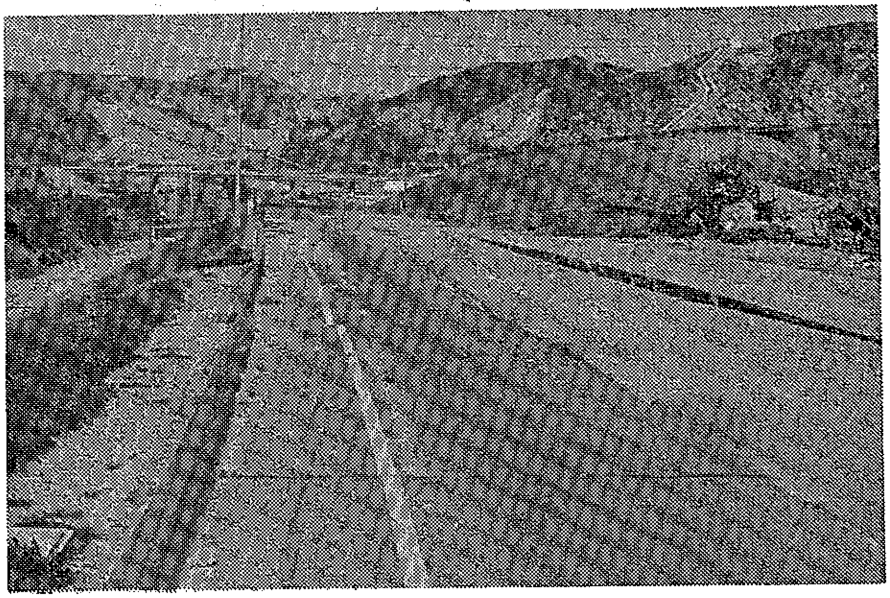
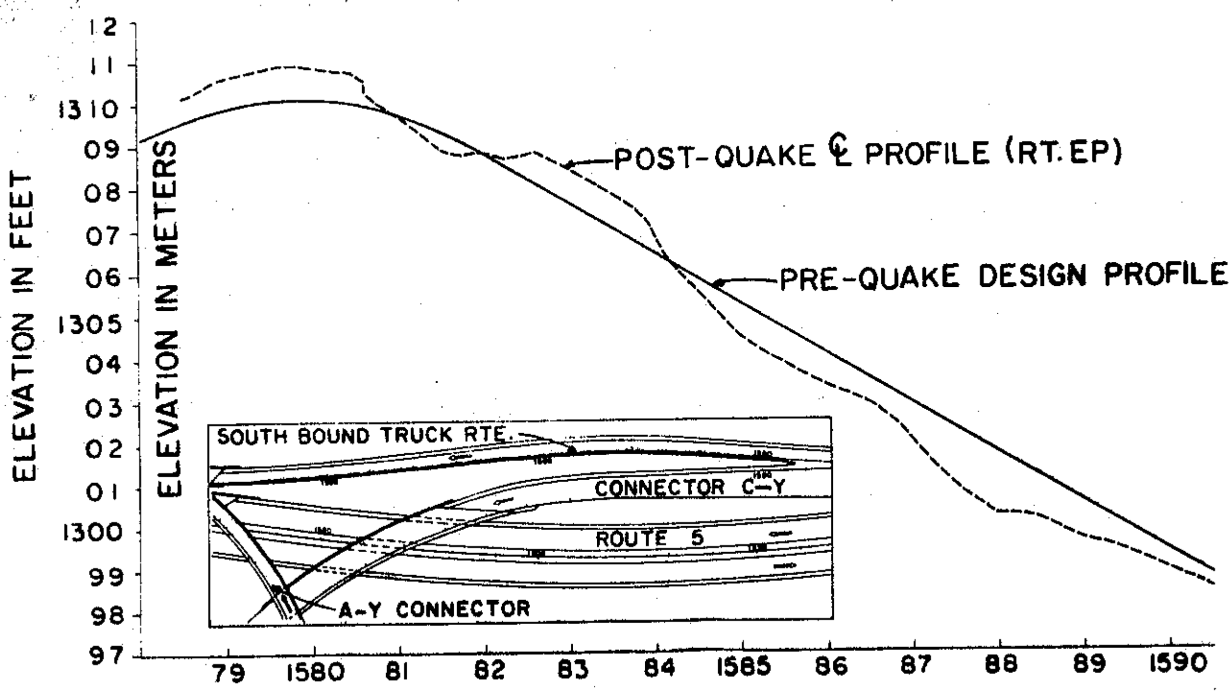


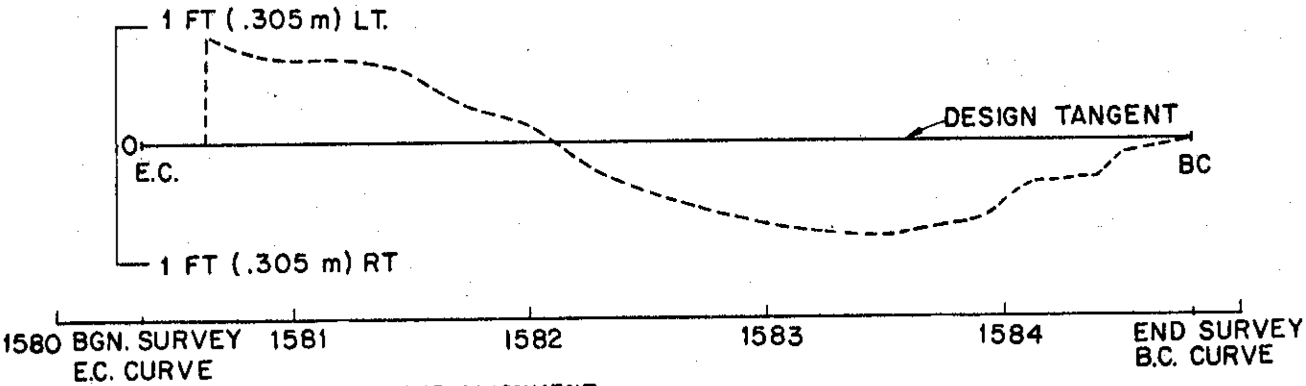
Photo 49. Looking northerly at damaged pavement of Route 5 southbound truck freeway caused by fill movement.



CENTERLINE PROFILE SB RTE 5 TRUCK FREEWAY

REFERENCE: SURVEY TLA 005K 135-136
PLAN 07-LA-5,210 SHT. 13

FIGURE 11



PRE-QUAKE ALIGNMENT RELATIVE TO POST-QUAKE E.C. & B.C.

POST-QUAKE ALIGNMENT RELATIVE TO POST-QUAKE E.C. & B.C.

REFERENCE: SURVEY TLA 005 K-132
PLAN 07-LA-5,210 SHT. 13

HORIZONTAL ALIGNMENT OF A PORTION OF ROUTE 5 SOUTHBOUND TRUCK FREEWAY BEFORE AND AFTER THE QUAKE

FIGURE. 12

Location 3

At this location, the Southbound Truck Freeway crosses the Los Angeles aqueduct and the penstock over separate structures. The aqueduct structure is founded on piles and covered with about six feet of fill. The penstock structure is founded on piles with the top of the structure serving as the roadway. The "rigid inclusion" effect of the aqueduct structure may be noted from Photo 50, which shows an undulating roadway profile caused by differential vertical movements. The before and after earthquake profiles are shown in Figure 13. This type of distress is typical of locations where large rigid structures cross through or below fills which, along with foundation materials, are subsequently densified by ground shocks. Bridge design borings indicate slightly compact to dense sand and sandy gravel to depths of about 40 feet below the original ground surface. From Figure 13 it appears that nearly all the "settlement" occurred due to compaction of the foundation soils. Since the regional uplift due to the earthquake in the area was approximately 0.3 foot, densification of fill material appears to have been minimal as determined by a comparison of pre-post earthquake profiles over the buried structure (Br. 53-1011), Figure 13.

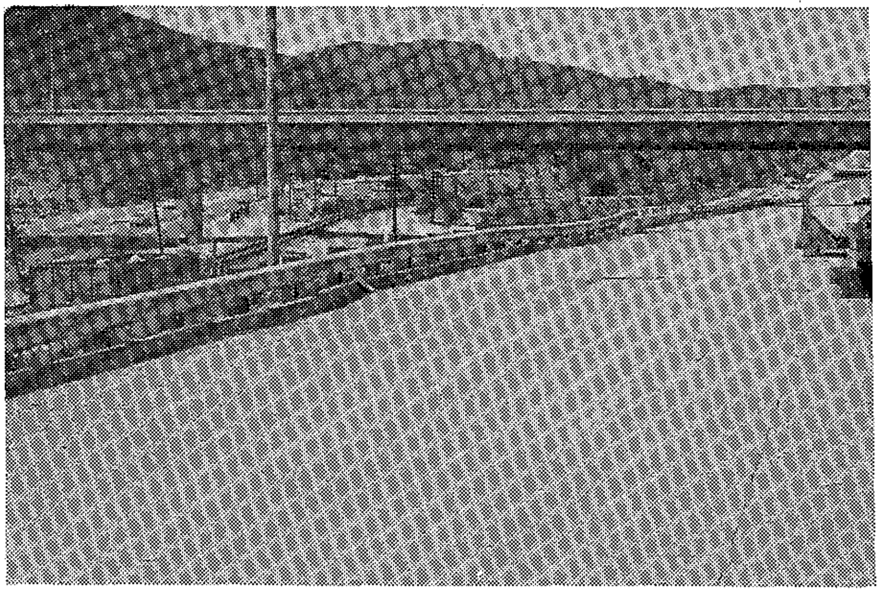
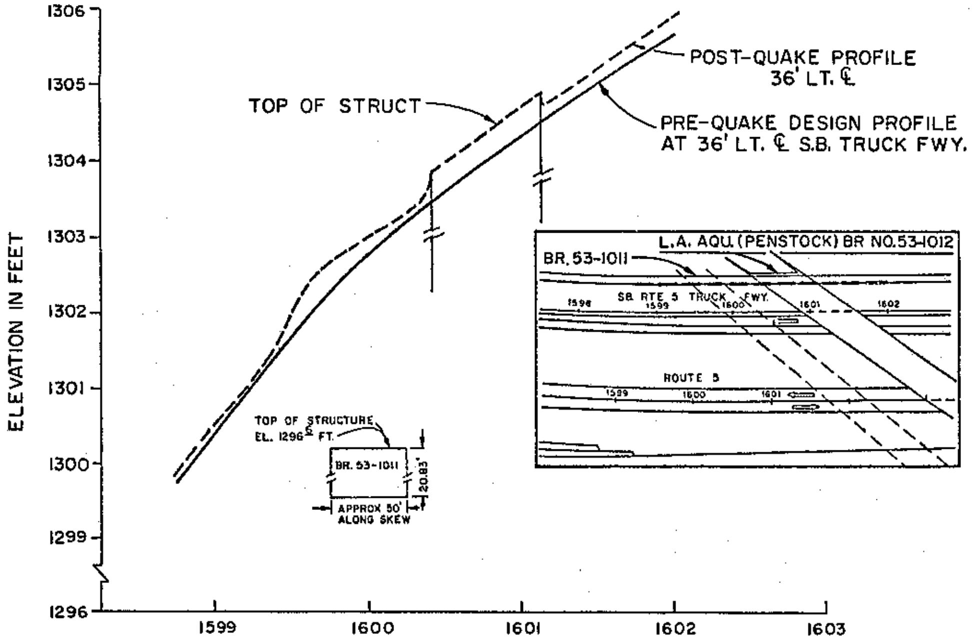


Photo 50. Looking northerly at undulating pavement of Route 5 caused by differential settlement. Balboa Boulevard Overcrossing structure is in background.



BEFORE AND AFTER QUAKE PROFILES
OF PAVEMENT SHOWN IN PHOTO 50.

FIGURE 13

Location 4

Foothill Boulevard crosses the northerly end of the aqueduct structure (Bridge No. 53-1011) on about 22 feet of fill above the deck, and then, proceeding northwesterly, immediately crosses the penstock on Bridge 53c-316 (extreme left center of Photo 44). A closer view of the two structures is given in Photo 51. Shortly after the earthquake, fill material was removed from the deck of Br. 53-1011 to relieve stress on the sheared deck of the structure. Photo 52 is a view of the deck soffit, the portion that was overlain by about 22 feet of fill.

Backfill at the northwesterly abutment of Br. 53c-316 settled about 8 inches as shown in Photo 53. The settlement is clearly defined in the photograph because the pavement was asphalt concrete which does not provide a bridging effect as do the portland cement concrete slabs.

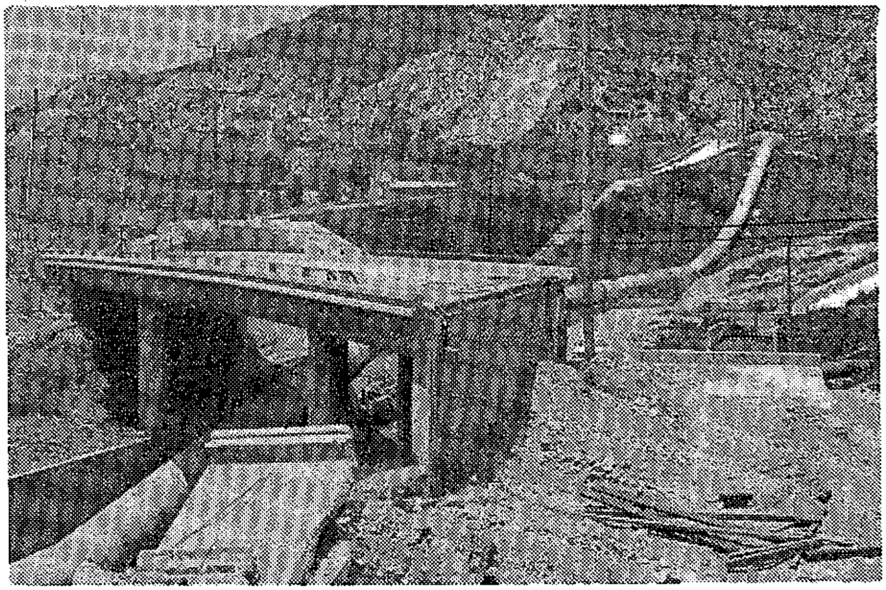
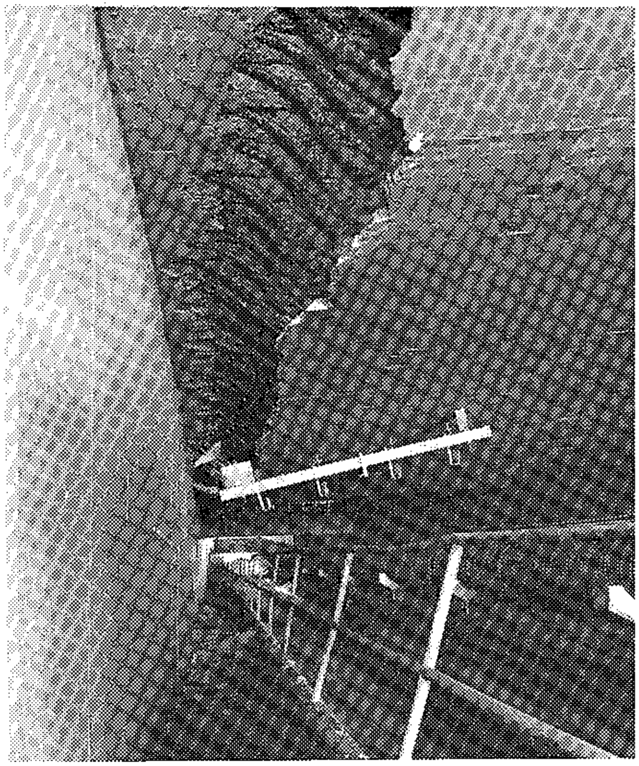


Photo 51. Looking northeasterly at Bridge 53c-316 which carries Foothill Boulevard over the penstock. Immediately to the right of the bridge, the uncovered deck of the aqueduct structure, Bridge 53-1011, is visible.

Photo 52. Southwesterly view from inside Bridge 53-1011 showing damage.



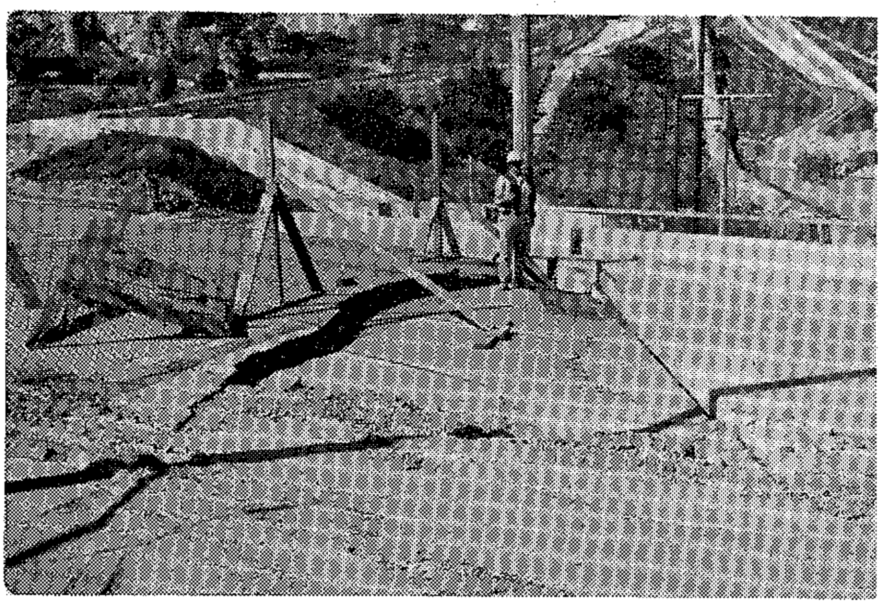


Photo 53. Settlement of abutment backfill at northerly end of Bridge 53c-316.

Location 5

Both approaches to Balboa Boulevard Overcrossing suffered backfill settlement. Photo 54 shows the easterly approach settlement of about 8 inches at the bridgedeck and wingwall joint. The bridge abutment was founded on piles while the wingwalls were on spread footings founded in the embankment. Approximately 25 feet of fill rests over original ground at the easterly bridge approach.

The westerly approach was constructed in cut section with both the bridge abutment and wingwalls founded on spread footings. Backfill at the paving notch settled several inches, while the bridge deck and wingwall remained in essentially the same place, as shown in Photo 55. The abutment failed in shear and rotation about a horizontal axis as shown in Photo 56 and tended to arch the deck as can be seen along the neat line of the concrete quardrail shown in Photo 57.

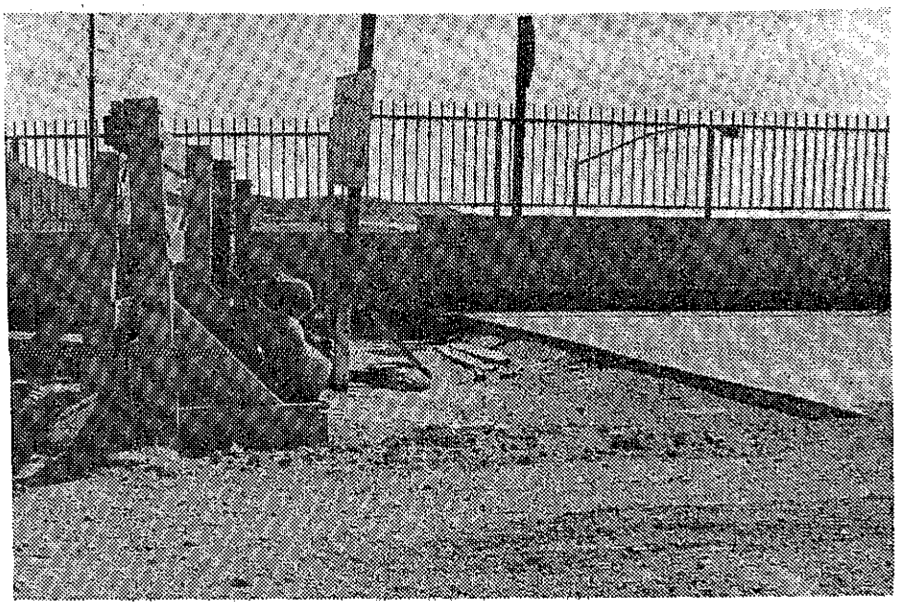


Photo 54. Approach and wingwall settlement at easterly end of Balboa Boulevard Overcrossing.

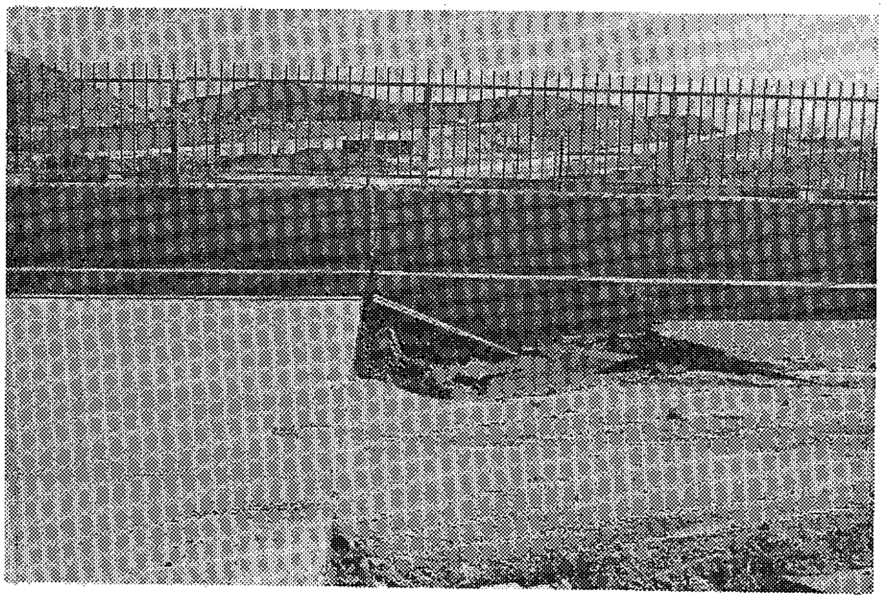


Photo 55. Westerly approach to Balboa Boulevard Overcrossing. Note abutment backfill settlement but lack of differential settlement between wingwall and abutment.

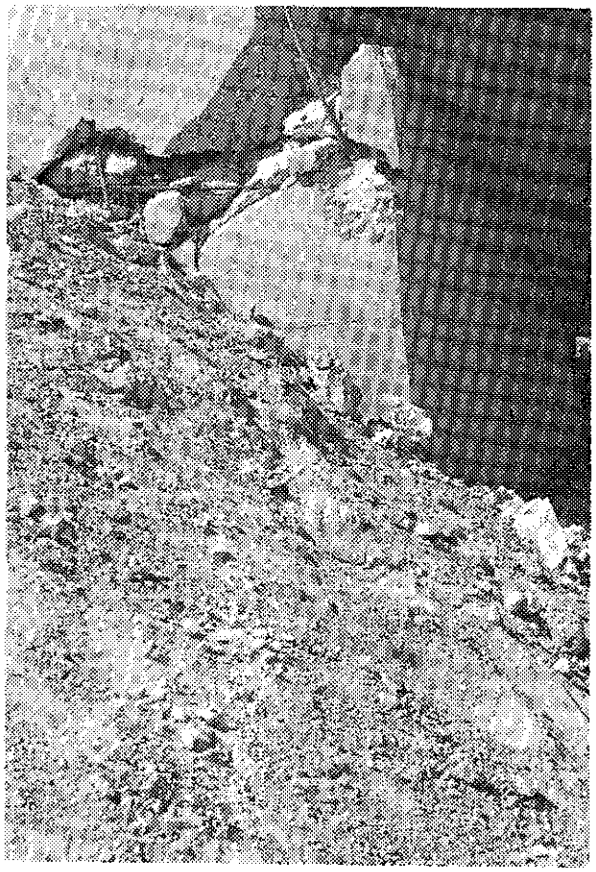


Photo 56. Damaged westerly abutment of Balboa Boulevard Overcrossing.

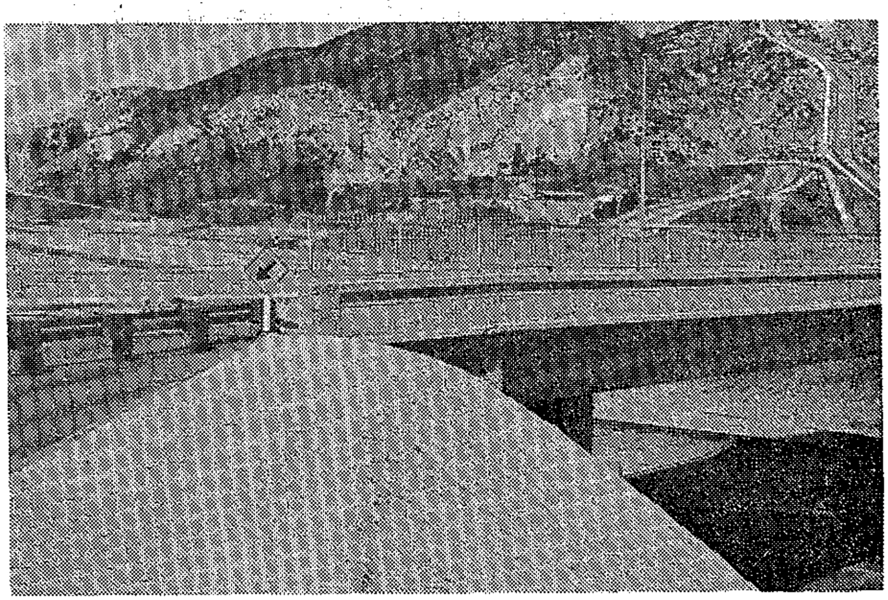
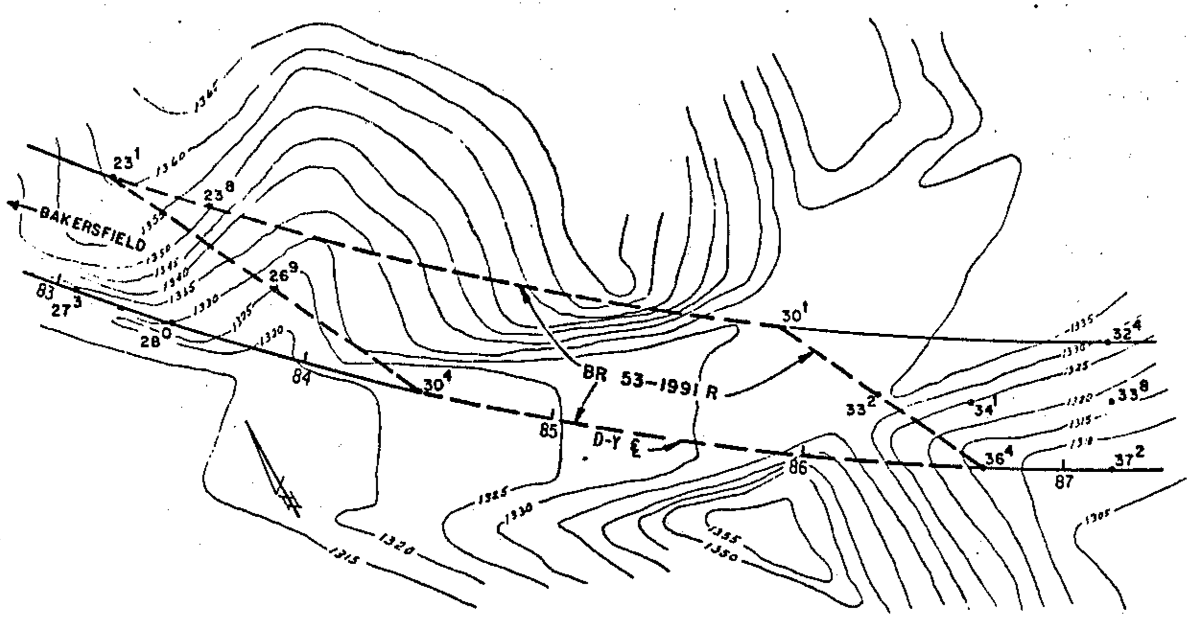


Photo 57. Looking northeasterly at westerly abutment of Balboa Boulevard Overcrossing. Note slight arch in structure caused by abutment movement.

Location 6

The approaches to this structure (Br. 53-1991R) are a combination of cut and fill. Figure 14 shows the original ground topography with the structure superimposed over it. The entire bridge is founded on spread footings in original ground that is composed of very dense sand, gravelly sand, and sandy gravel with cobbles of the Saugus formation. "Settlement" at the easterly bridge approach, Photos 58 and 59, was about two feet at its maximum. At the westerly abutment, "settlement" was several inches; with a portion of the resulting distress to pavement shown in Photo 60.

The vertical alignment of the bridge and retaining wall (wingwall) remained essentially the same, as can be seen in Photo 59. Since both were founded on spread footings in very dense original ground, and the vertical alignment remained uniform, the observed settlement is believed to be due to densification and loss of backfill material into voids created by the superstructure displacement during strong seismic shaking.



CONTOURS SHOWING ORIGINAL GROUND TOPOGRAPHY
AT BRIDGE 53-1991R ON THE D-Y CONNECTOR OF
THE ROUTE 5/210 INTERCHANGE

LEGEND
28^3 = FINISH GRADE ELEV.
— 1330 = ORIGINAL GROUND CONTOURS
20 40 FEET
5 10 15 METERS

FIGURE 14

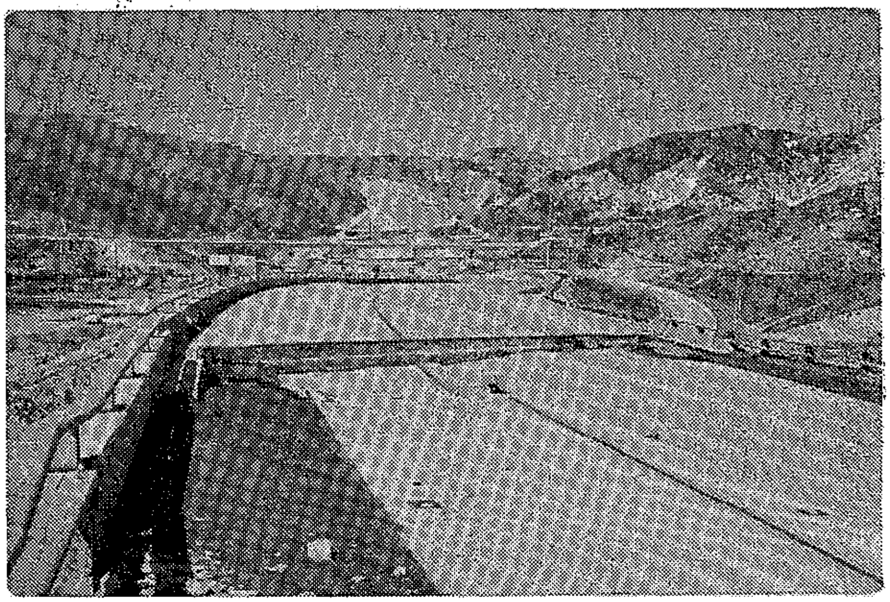
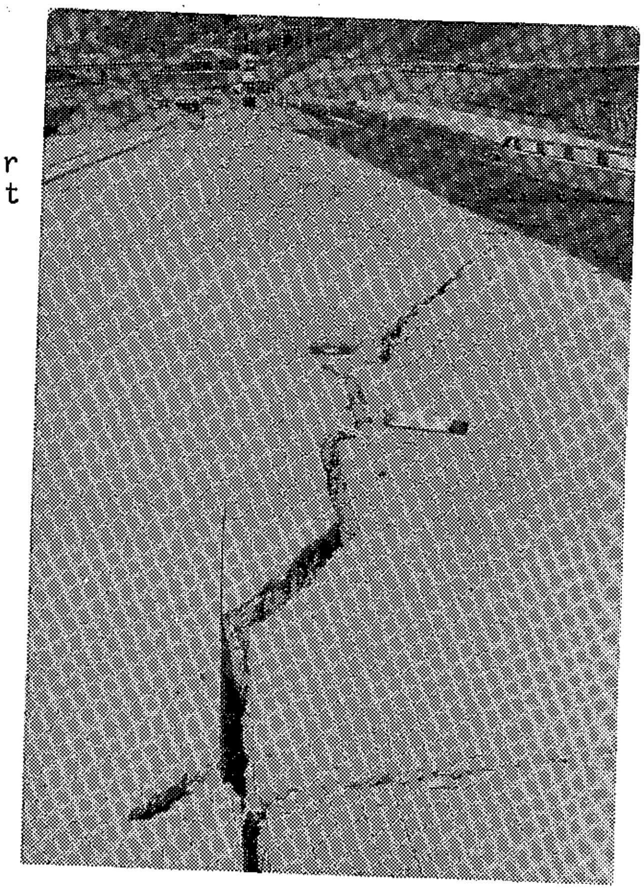


Photo 58. Settlement at the easterly approach to Bridge 53-1991R on the D-Y Connector, Route 5/210 Interchange.

Photo 59. Settlement at the easterly approach to Bridge 53-1991R on the D-Y Connector, Route 5/210 Interchange.

Photo 60. Cracking and movement of D-Y Connector pavement immediately west of Bridge 53-1991R.



Location 7

The bridge at this location is founded on spread footings in original ground. The westerly approach is entirely within cut, while the easterly approach is made up of 12 to 30 feet of fill across a narrow steep canyon. The easterly approach pavement slabs cracked, separated, and settled a few inches at the bridge deck, as shown in Photos 61 and 62; whereas little or no pavement distress was noted at the westerly approach. Severe shaking of the bridge did occur as evidenced by the cracked wingwalls and abutment (Ref. 4, p. 207, Index 10), which would allow fill spreading and consequent pavement distress.

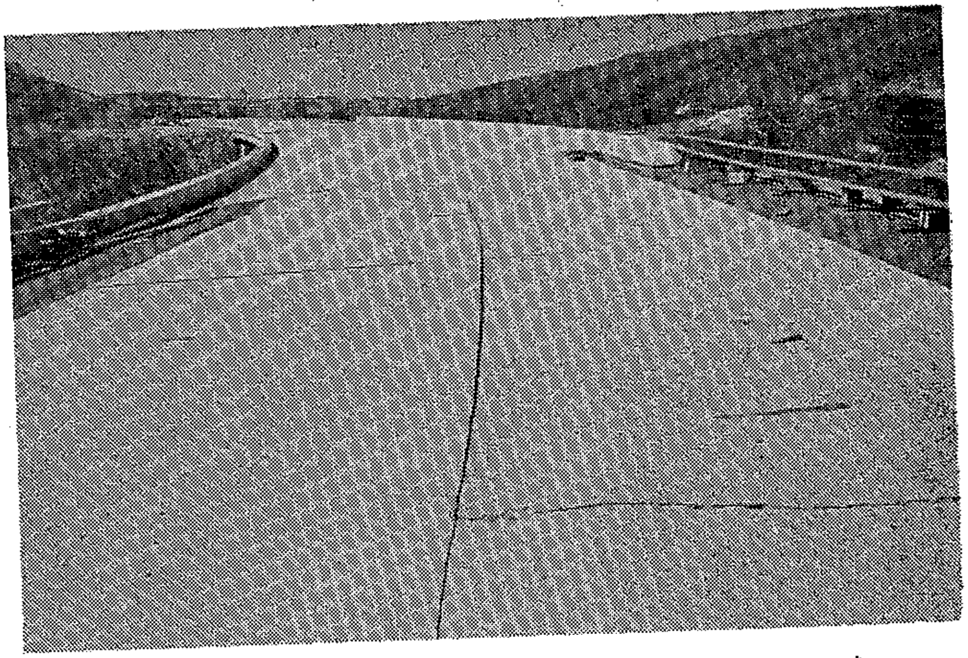


Photo 61. Pavement cracks and movement at the easterly approach to Bridge 53-1988L on the A-Y Connector, Route 5/210 Interchange.

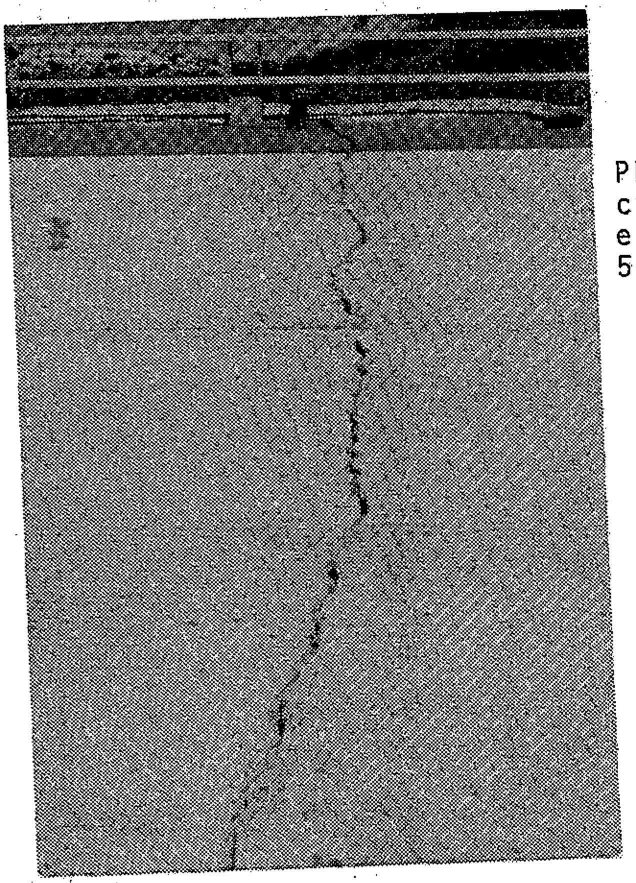


Photo 62. Transverse pavement crack at cut/fill contact near easterly approach to Bridge 53-1988 on the A-Y Connector.

Location 8

Pavement and soil-cracking occurred in the general area of the cut-fill contact shown in plan on Figure 6. From Connector C-Y the cracking diverged away from the contact in a southerly direction. The cracking progressed from one crack across Connector A-Y, Photo 63, to a zone approximately 200 feet wide south of Connector C-Y. Individual cracks show up to one inch of horizontal separation and generally 1 to 2 inches of vertical separation with the east side down relative to the west. Photo 64 shows the pavement displacement across Connector D-Y and Photos 65 and 66 show the cracking and displacement across Connector C-Y. No cracking on either fill slope was found in this zone. However, south of the toe of fill for a distance of about 70 feet cracking was observed in original ground.

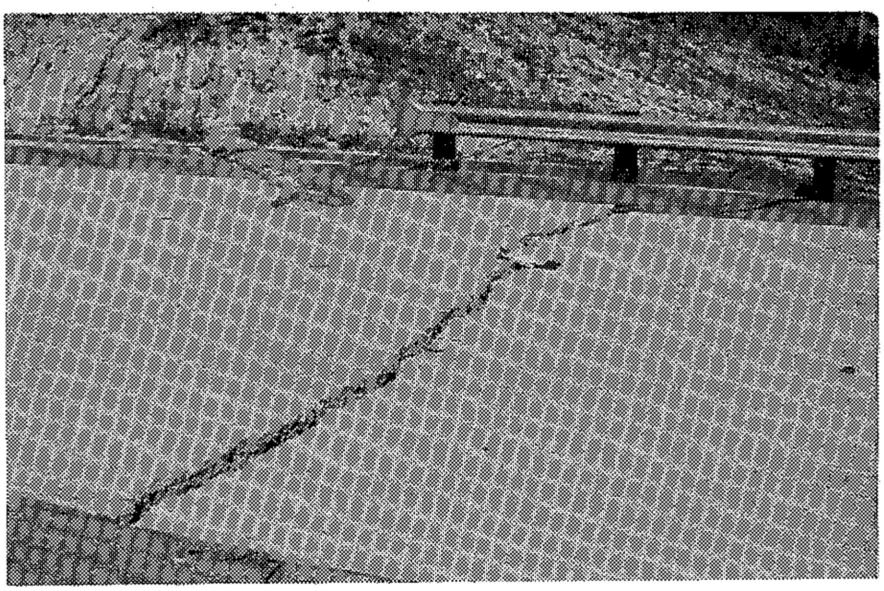


Photo 63. Looking northerly at transverse pavement crack at the cut/fill contact on A-Y Connector. Note horizontal and vertical separation along crack.

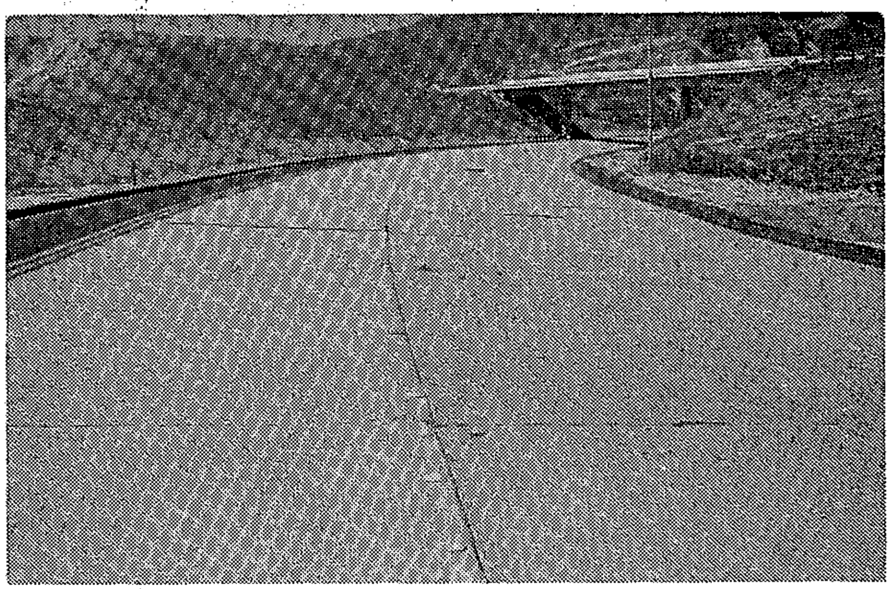


Photo 64. Looking northwesterly at pavement slab displacement through cut/fill zone on Connector D-Y.

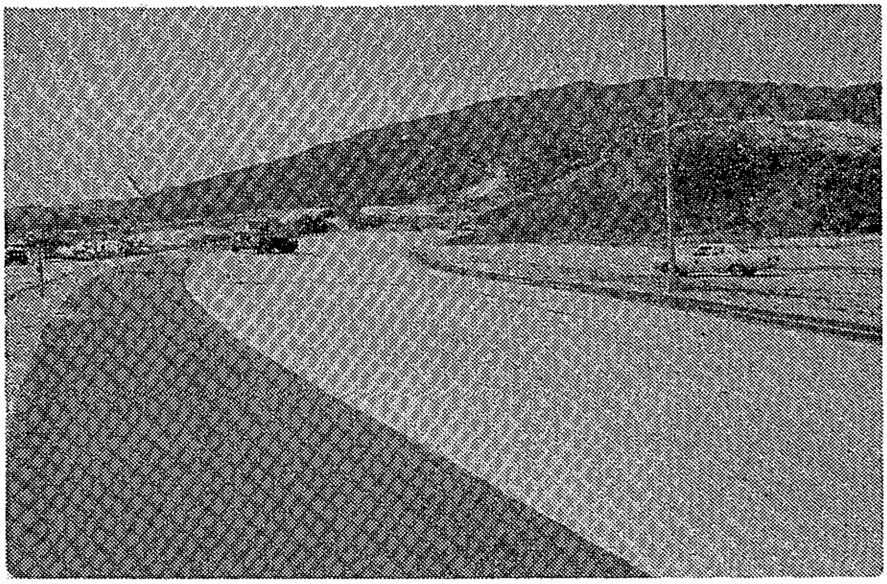


Photo 65. Looking northwesterly at pavement slab displacement through cut/fill zone on Connector C-Y.

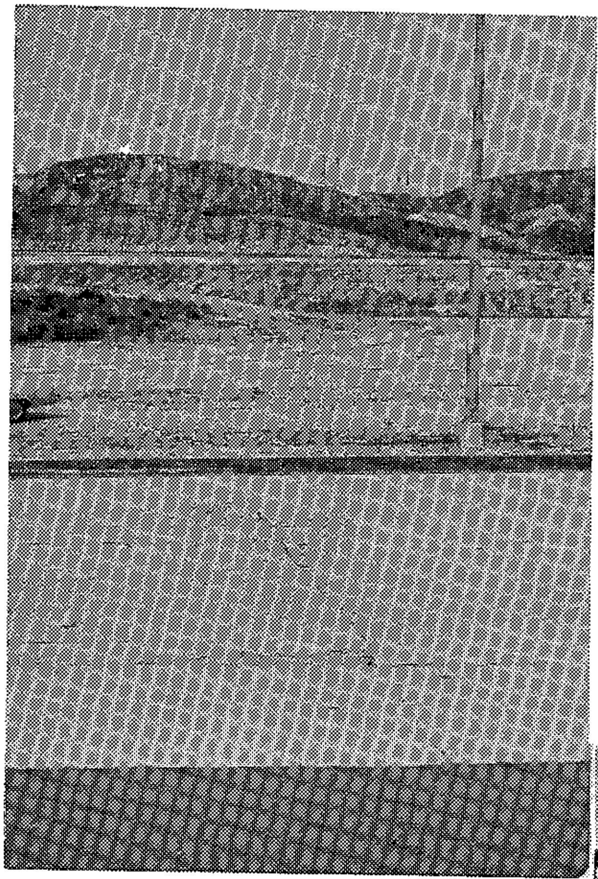


Photo 66. Transverse pavement crack on Connector C-Y. (Light standard is same as shown in Photo 65.)

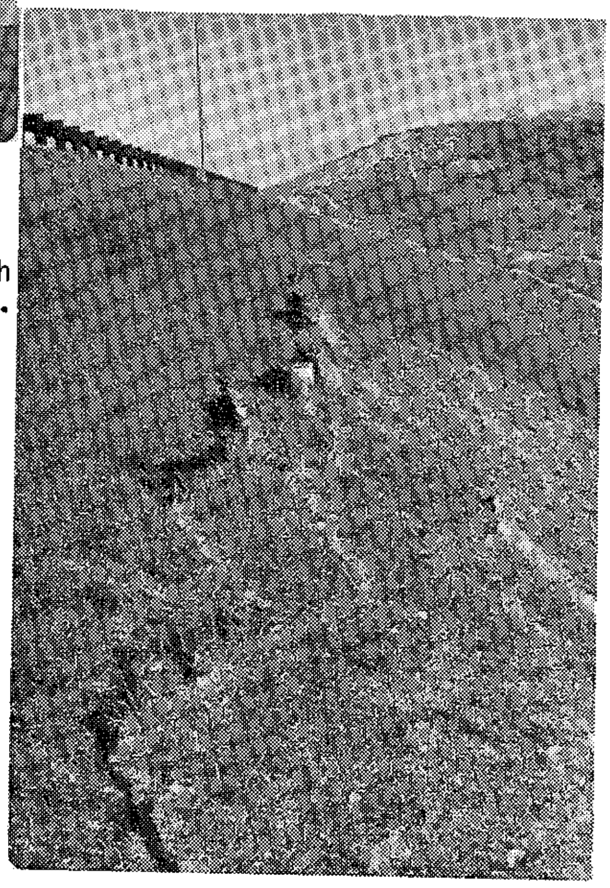


Photo 67. Cracking in north fill slope of Connector A-Y. The pavement crack shown in Photo 63 occurred at cut/fill contact in background.

On the north slope of the fill and about 300 feet east of the cut-fill contact a surficial slide occurred that is shown in Photo 67. This failure extended up into the roadway causing minor pavement distress and a slight dip in profile.

Location 9

The conduit at this location is a double reinforced concrete box 6 feet wide by 11 feet high at the outlet (south end). Fill height over the southerly portion of the box was about 65 feet. Vertical members of the box experienced cracking as shown in Photo 68 that extended into the box for a distance of about 200 feet.

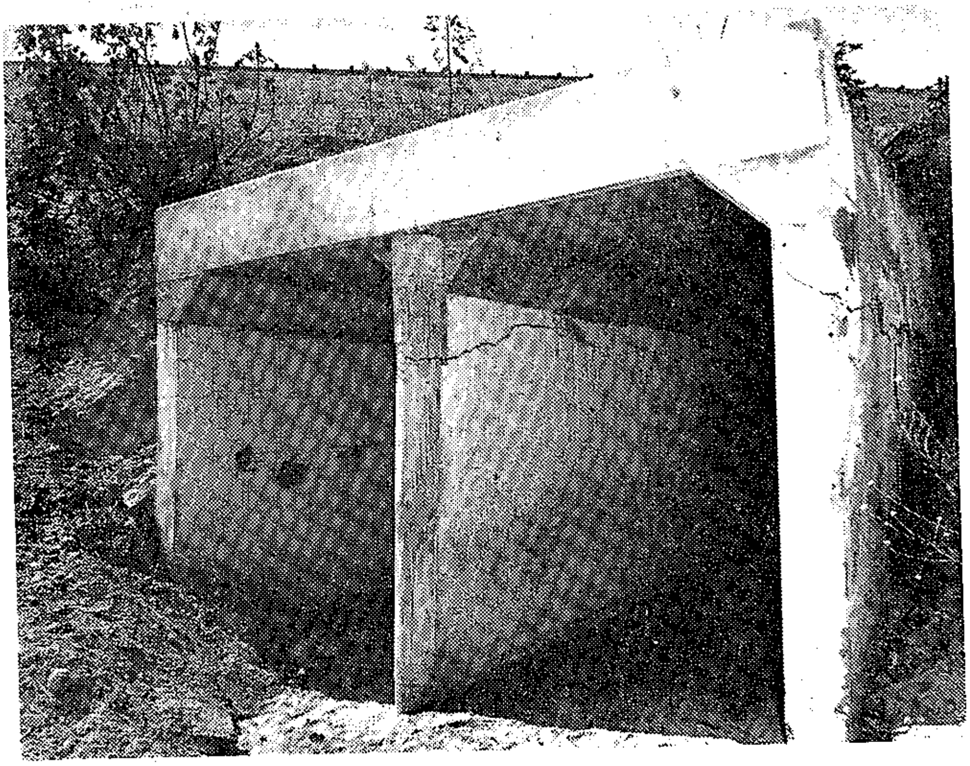
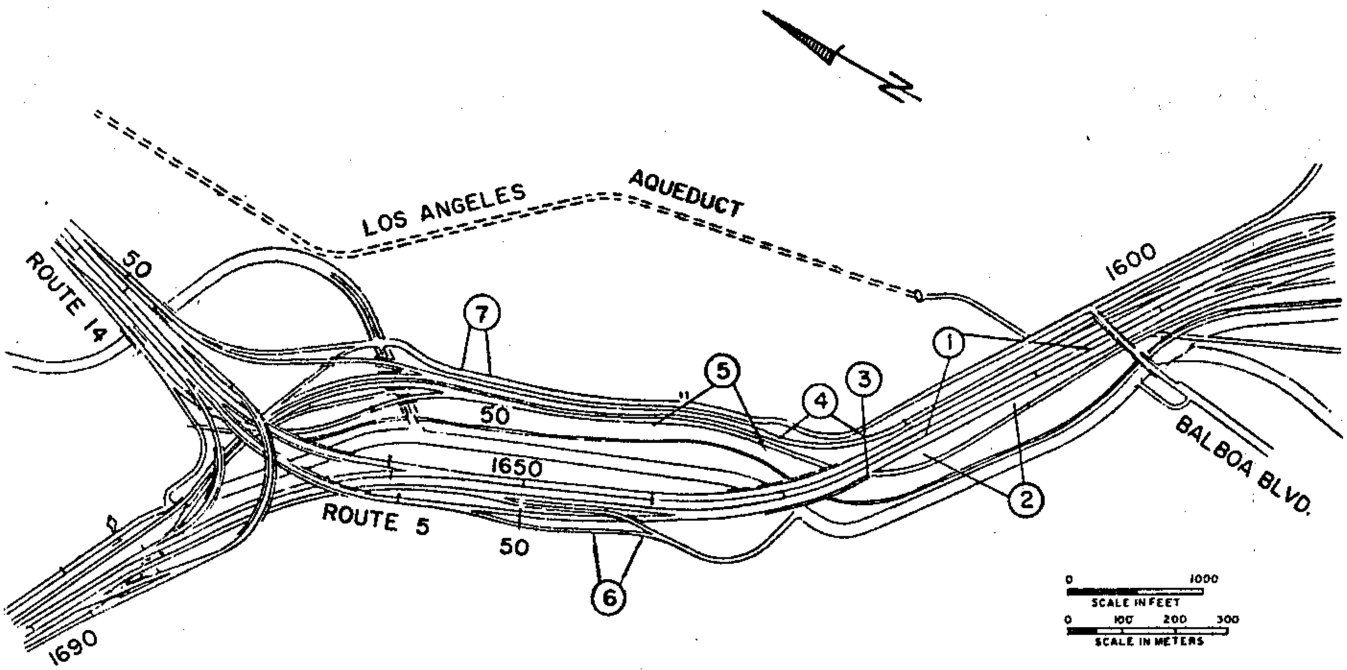


Photo 68. Cracking in reinforced concrete double box culvert. Note vertical members are out of plumb.

I-5, FROM BALBOA BLVD. THROUGH 5/14 INTERCHANGE

From Balboa Boulevard northward, Route 5 is constructed on both sides of a steep canyon with high cut and fill sections. At the time of the earthquake, widening of the system was in progress with extensive cut and fill operations nearly complete on the west side of the canyon. The east side of the canyon carried traffic along the old alignment. The realignment of Foothill Boulevard along the east side of the canyon and east of the freeway was complete and involved a large cut section. Photos 69-72 show progressive aerial views from north to south of this portion of Route 5, taken the day after the earthquake. Photo 73 is a southerly view of the Route 5/14 Interchange, also taken the day after the earthquake.

Figure 15 is a map of the area showing the locations of the following descriptions.



LAYOUT OF ROUTE 5 BETWEEN BALBOA BOULEVARD AND THE ROUTE 5/14 INTERCHANGE

FIGURE 15

Photo 69. Looking easterly at the Route 5/14 Interchange.

Photo 70. Looking easterly at Route 5, immediately south of the Route 5/14 Interchange.

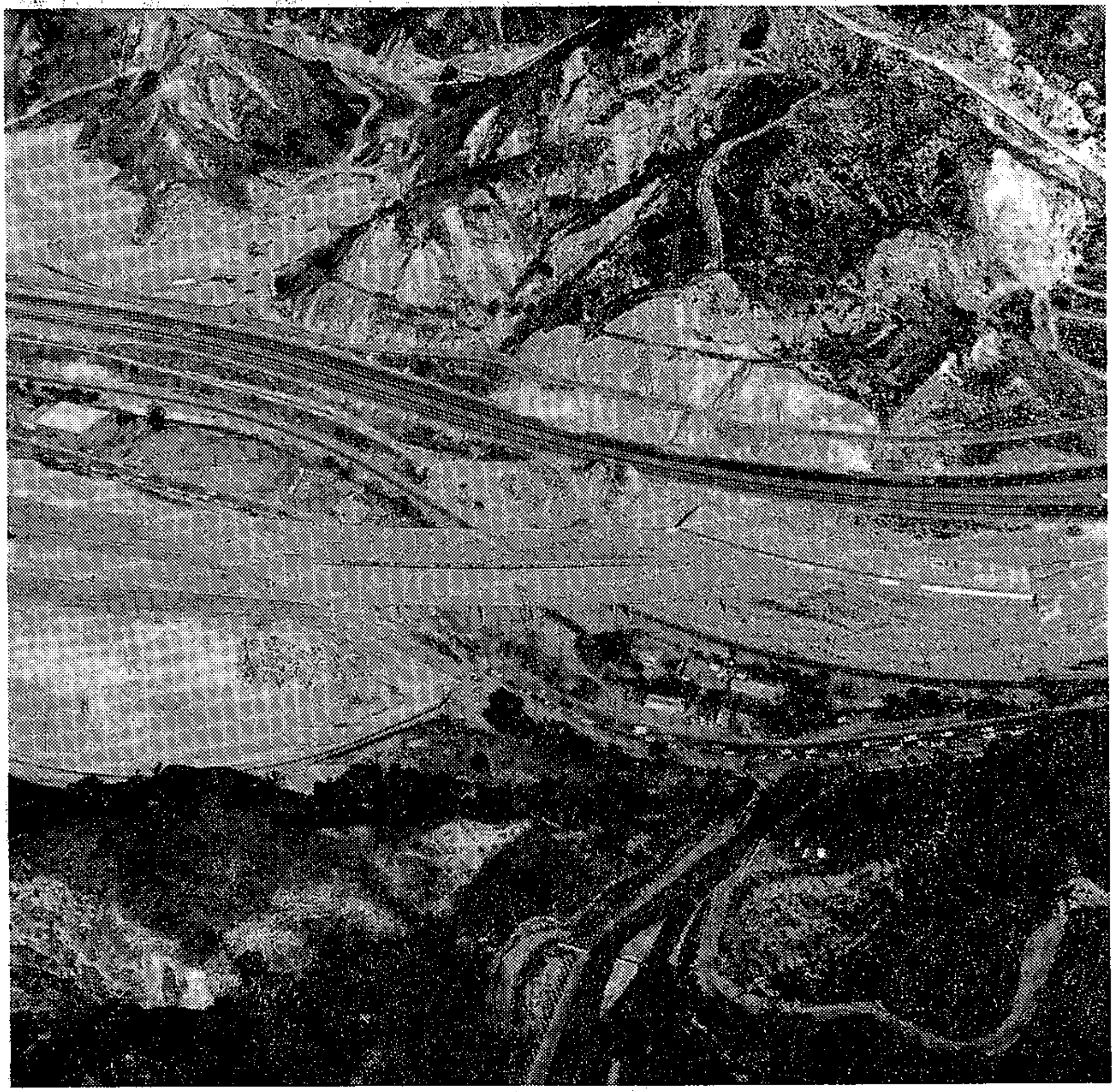


Photo 71. Looking easterly at Route 5.

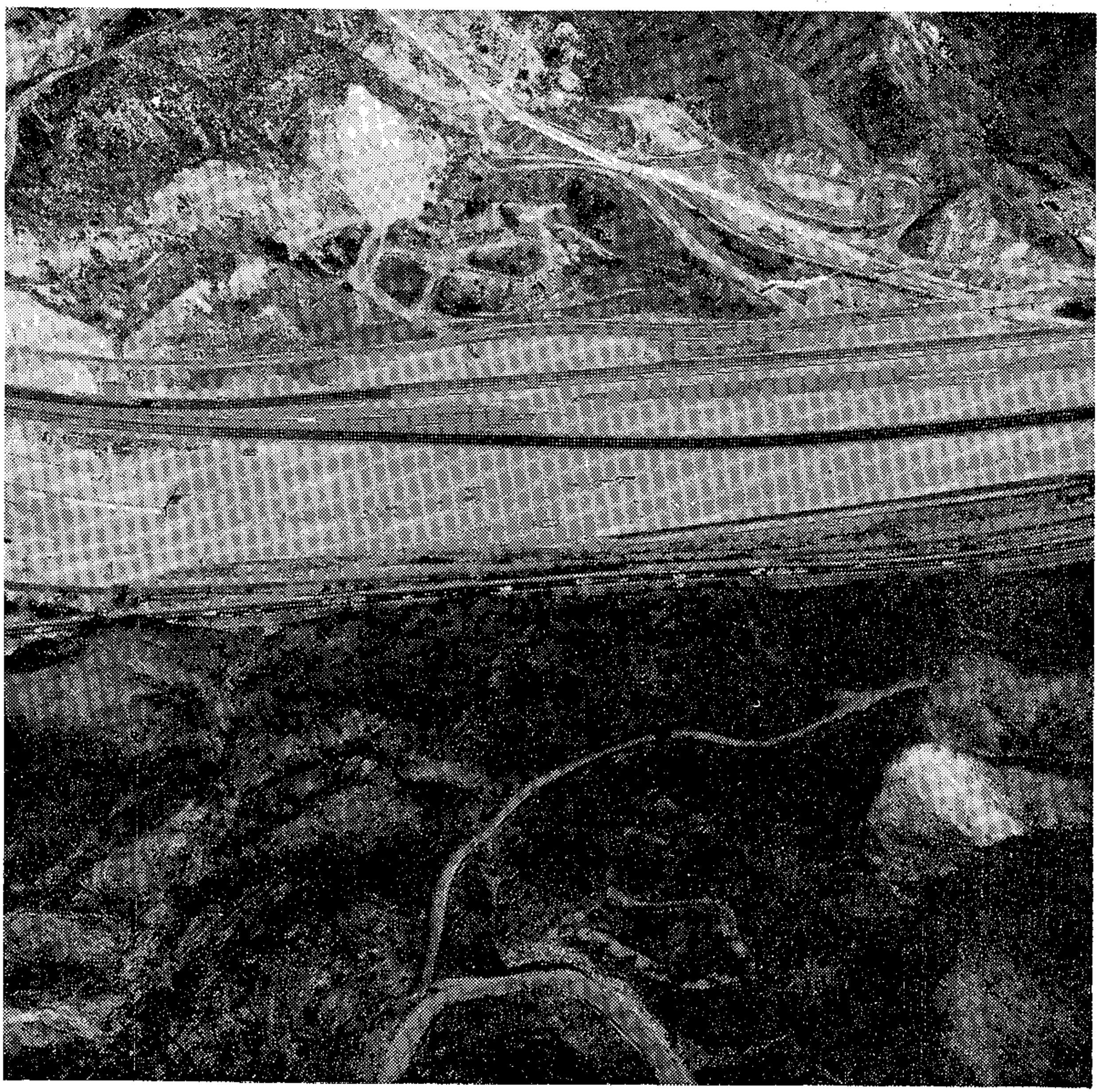


Photo 72. Looking easterly at Route 5 immediately north of Balboa Boulevard Overcrossing.

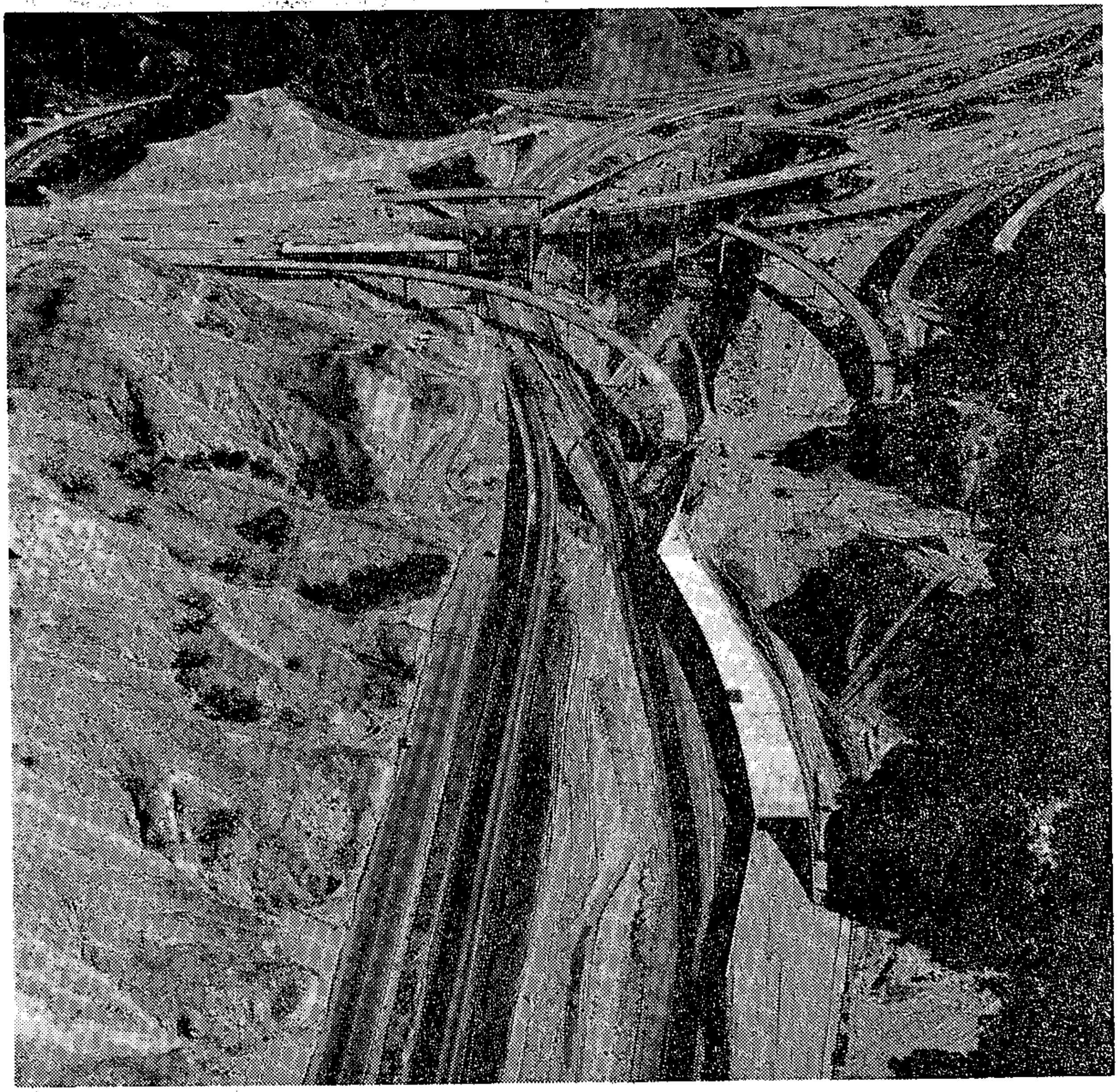


Photo 73. Looking southerly at the Route 5/14 Interchange. Route 14 is in upper left of photo.

Location 1

Very little soil or pavement distress was found in this area. A crack across the asphalt pavement of temporary Route 5 (right central portion of Photo 72) showed 1/2-inch of lateral displacement, south side moved west relative to north side. About 450 feet north of this offset, a tension crack appeared in the pavement with one inch of separation.

Location 2

A natural drainage channel at this location was routed through a double reinforced concrete box 8 feet wide by 12 feet high. The north end joined an existing reinforced concrete arch over which the railroad crossed. No damage was observed at the north end. However, at the south end, longitudinal hairline cracks occurred in the walls for at least 200 feet into the culvert.

Location 3

Cracking of both soil and concrete occurred transverse to the highway at this location. Photo 71 shows roadway concrete broken (right center above the curved reinforced concrete box structure) at what appears to be very near the cut-fill contact. Photos 74 and 75 are close-ups of this break, looking east. Soil cracking occurred through the above concrete box structure and continued westerly into the bridge abutment area (barely visible right of center in Photo 71). The hills to the east of the roadway along the trend of the cracking were shattered in a 100-ft wide zone. The above cracking appears to follow closely the upper Santa Susana thrust fault as mapped by others (Ref. 5, Vol. III, p. 213, Figure 1). East of the shattered slopes a large rockfall occurred, which is visible in Photo 71 (top right).

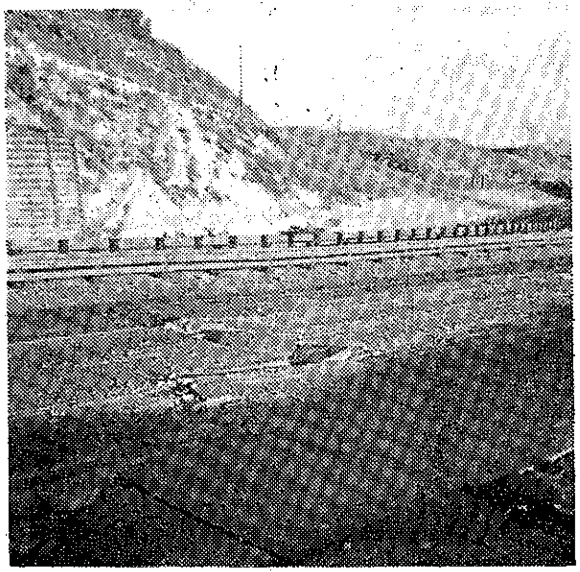


Photo 74. Looking easterly at pavement damage on Route 5 north of Balboa Boulevard.

Photo 75. Closer view of pavement damage shown in Photo 74.

Location 4

Rockfalls occurred in the steep, well-indurated sandstone cut face (upper right central portion of Photo 71).

Location 5

Minor compression spalling occurred at the construction joints in a retaining wall that separates the railroad from highway embankment. The fill supported by the wall slumped and longitudinal cracking occurred in the roadway, as shown in Photo 76.

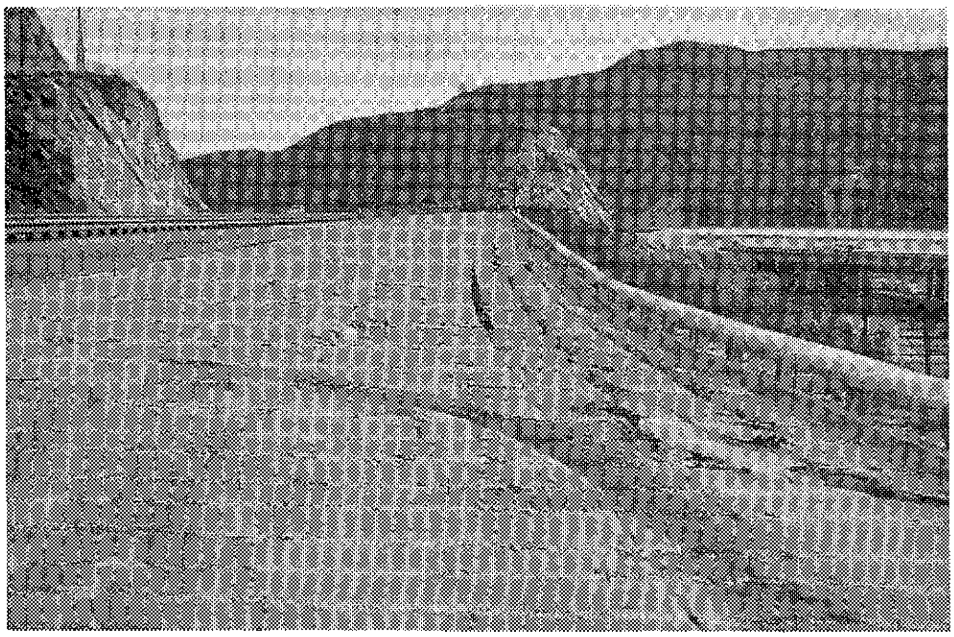


Photo 76. Longitudinal cracking in pavement due to lateral movement at top of cantilever retaining wall. Pavement has been broken mechanicall for removal.

Location 6

A large landslide occurred in a cut slope at this location (Photos 77 and 78). Had the roadway been completed, frontage road access from one approach would have been blocked by the slide. An interesting aspect of this slope is that

Photo 77. Looking westerly at a cut slope slide immediately south of the Route 5/14 Interchange.

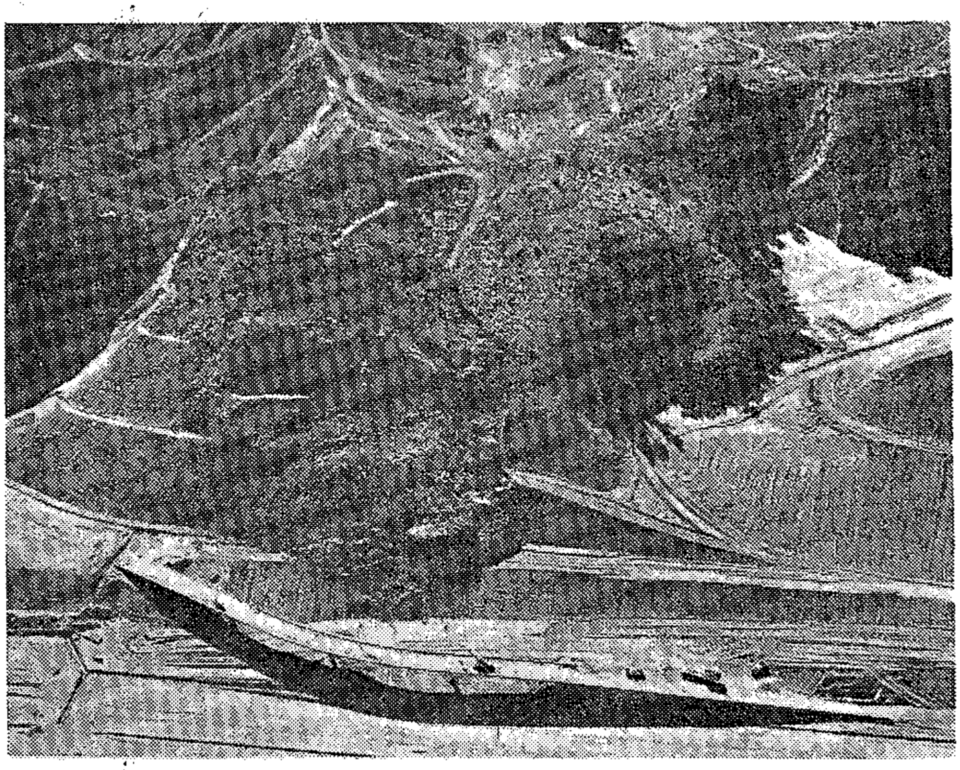


Photo 78. Aerial view of slide shown in Photo 77. Note blockage of unfinished connector by slide debris.

the cut left a nob with a rather high slenderness ratio. The bedding planes of the friable sediments dipped toward the cut face, and the top of the slide was at the apex of the cut and a very steep natural slope facing west. The top of the slide and west-facing slope may be seen in the lower right of Photo 70.

Location 7

A slump landslide that occurred in a cut slope is shown in Photos 69 (upper right) and 79. The slide, which did not encroach upon the roadway, occurred in a clayey silt with a high moisture content.

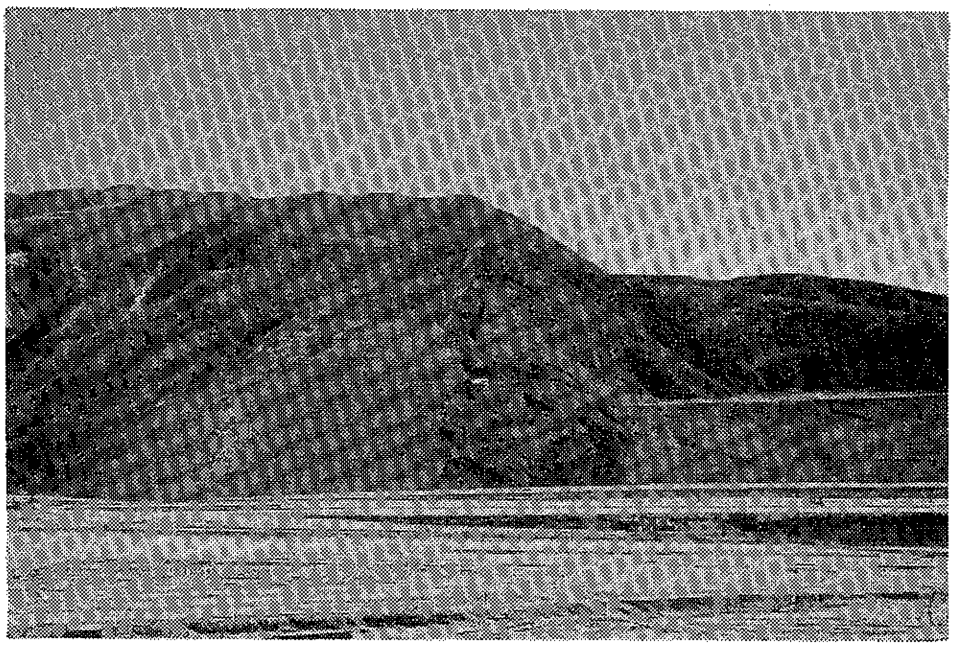


Photo 79. Looking easterly at a slide in a cut slope, immediately south of the Route 5/14 Interchange.

Embankment Settlement

Embankments in this area settled up to four inches as determined by construction stake checks, and cracking up to two inches wide occurred along what appeared to be cut to fill contacts. Since construction had not reached the paving stage at the time of the earthquake, embankment settlement and cracking were of minor consequence compared to that within paved areas.

ROUTE 5, NORTH OF THE 5/14 INTERCHANGE

Geodetic surveys conducted after the earthquake show that regional warping of the earth's crust extended at least ten miles northerly of the 5/14 Interchange (5). However, damage to Route 5 north of the 5/14 Interchange appeared to be due to seismic shaking and secondary local ground movement, as opposed to damage caused by geologic faulting or upheaval.

Damage to bridge structures included slight shifting of the superstructure and concrete spalling at the hinges of Gavin Canyon Undercrossing. Other bridge damage consisted of minor cracking and spalling of concrete and shifting of bearing seats on two steel girder bridges.

Damage to the roadway was confined to an area approximately two miles north of the interchange and appeared to be the aggravation of an existing problem area. Photo 80 shows the flank of an ancient landslide (slide on left) in the cut face. Earthquake-induced movement of the old slide occurred and resulted in uplifting of the roadway shown at the bottom of the photo. Photo 81 shows a close-up view of the uplifted AC curb of the previous photo.

Further north, a cut slope on the east side of the highway had ground breakage behind the top of cut as shown in Photos 82 and 83.

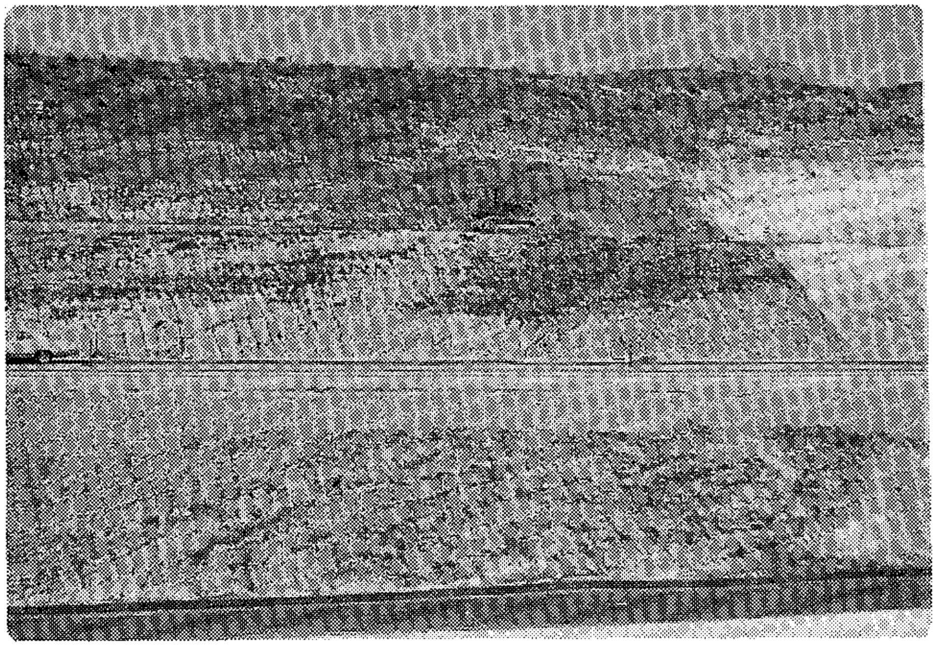


Photo 80. Looking easterly at quake-activated ancient slide in cut slope.

Photo 81. Upthrusting of pavement (Note AC dike) caused by movement of ancient slide.

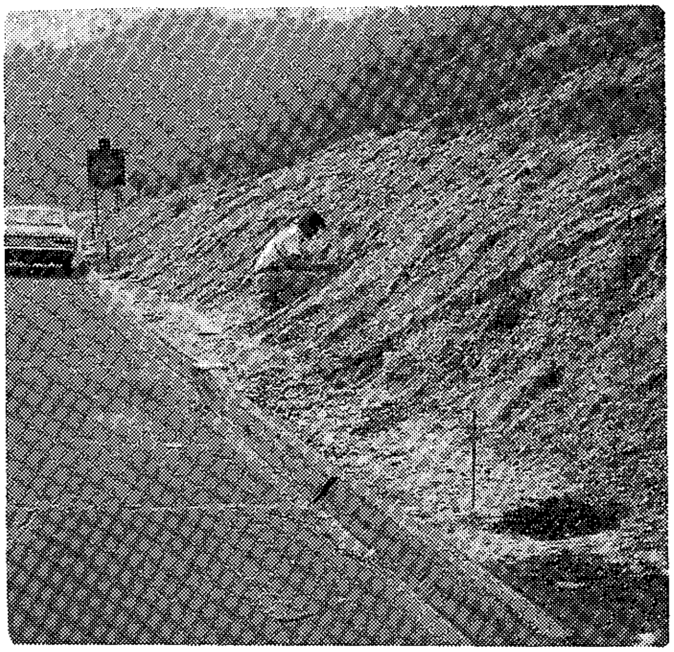


Photo 82. Ground breakage at top of cut slope on east side of Route 5.

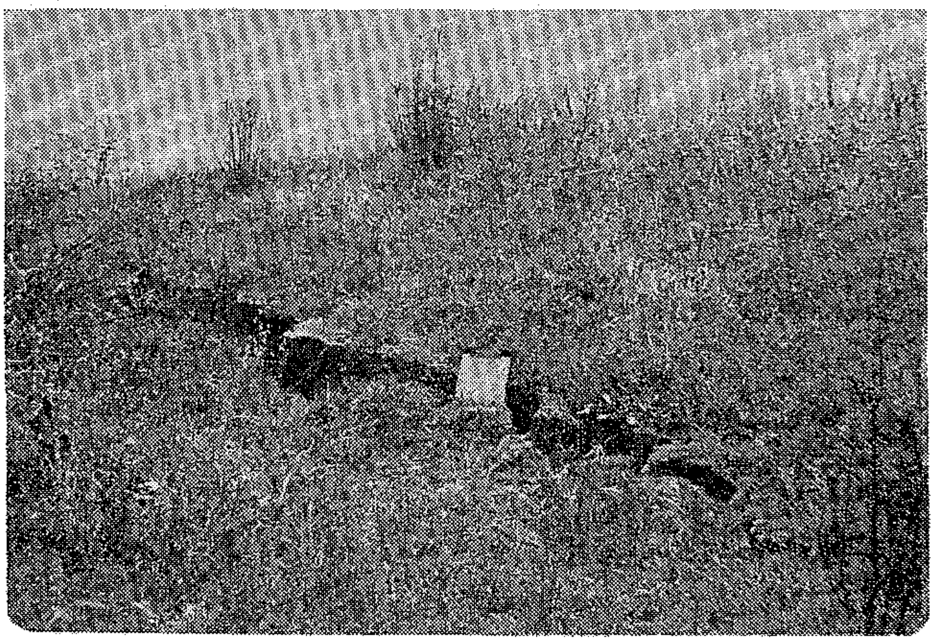
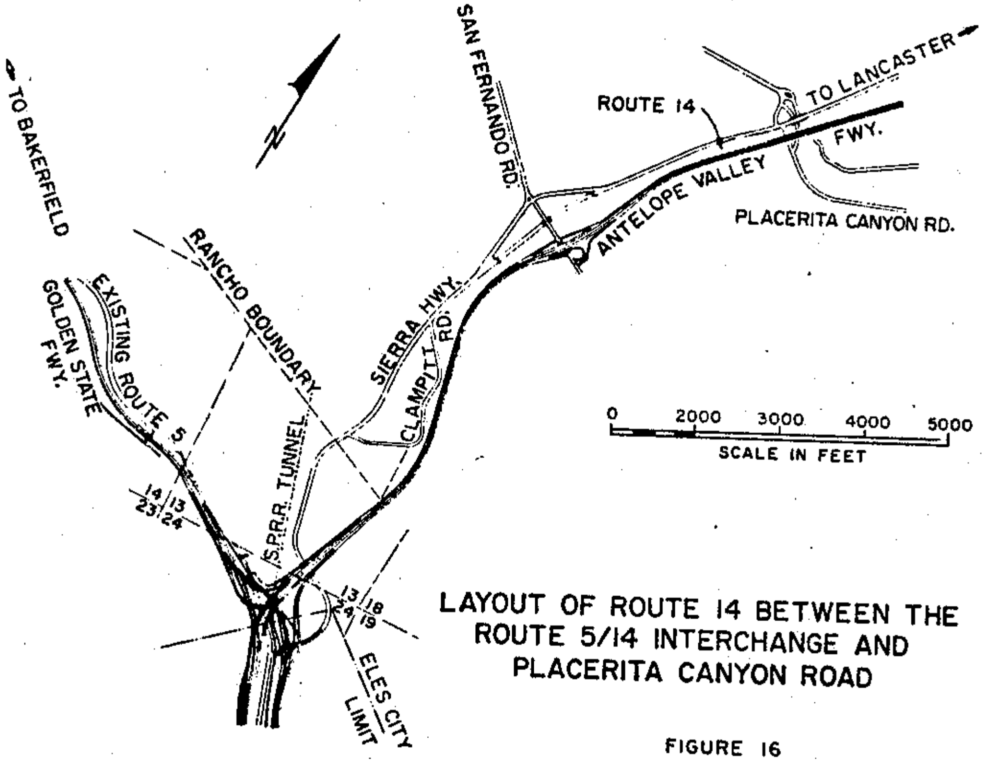


Photo 83. Ground breakage at top of cut slope on east side of Route 5.

ROUTE 14, FROM THE 5/14 INTERCHANGE THROUGH THE SANTA CLARA RIVER CROSSING

At the time of the earthquake, Route 14 was under construction from Route 5, east, through the Santa Clara River Crossing. Figure 16 shows the alignment to Placerita Canyon Road. The Santa Clara River Crossing is approximately four miles northeast of Placerita Canyon. The route is constructed in high cut and fill sections through highly faulted and folded sedimentary rock units that range from well-indurated conglomerates and sandstones to friable and unstable lake bed deposits of mudstones and claystones. Photo 84 shows the contorted lakebed deposits typical of the roadway section from 1-1/2 miles east of Placerita Canyon to the Santa Clara River. Photo 85 shows the scale of the cut and fill construction typical of Route 14.



LAYOUT OF ROUTE 14 BETWEEN THE ROUTE 5/14 INTERCHANGE AND PLACERITA CANYON ROAD

FIGURE 16

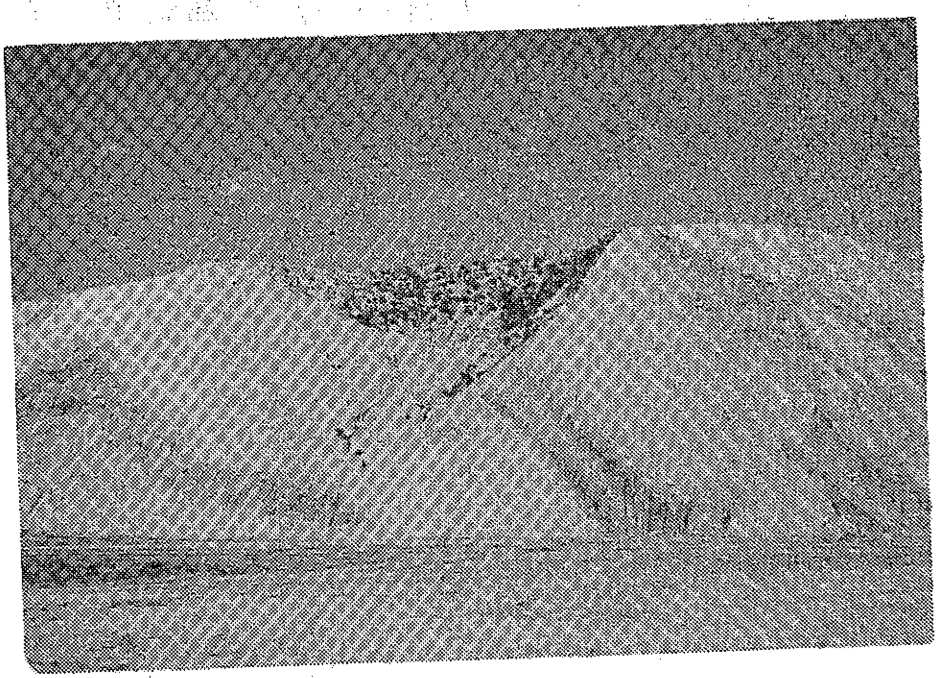


Photo 84. Looking northwesterly at typical contorted geological features east of Placerita Canyon Road.

Photo 85. Looking northeasterly at typical scale of earthworks on Route 14.

At the time of the earthquake, the construction stages of the various bridges ranged from forming to complete. Backfill settlement at the abutments, observed at several locations along the route, amounted to an inconvenience only, as the roadway finished grade had not been completed.

Photo 86 shows 8 to 10 inches of backfill settlement that occurred at the west abutment of the westbound structures for the Via Princessa Undercrossing. Photo 87 shows the area to be backfilled at the west abutment of the east-bound structure. Assuming that construction practices were similar for both structures, a comparison of the two photos show the settlement was confined to the backfilled area. It is probable that the settlement resulted from spreading during seismic shaking as the wingwalls were not yet constructed. The abutments of the structures were either sheared or distressed similar to that shown in Photo 88, with the exception of the west abutment of the eastbound structure.

Backfill settlement of 6 to 8 inches at the west abutment of the westbound roadway structure of the Santa Clara River Crossing is shown in Photo 89. The settlement was confined to the backfilled area of the abutment. No displacement of the wingwalls and abutment wall (constructed as a unit) was noted. Photo 90 shows a few inches of backfill settlement at the west abutment of the eastbound structure. The abutment and wingwalls were constructed as a unit and no bridge damage was detected. Again, the settlement appears to be confined to the backfilled area.

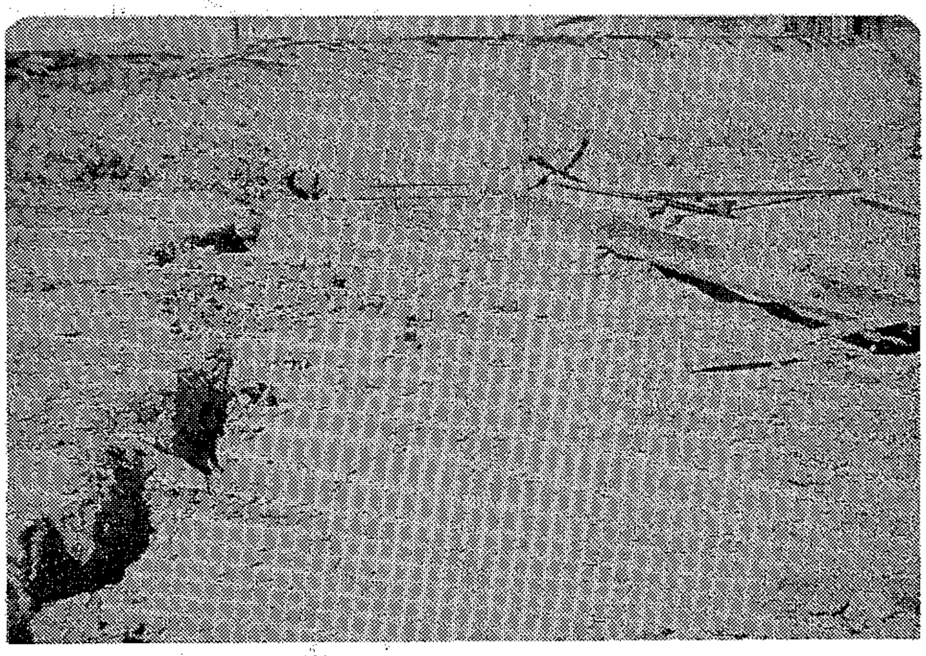


Photo 86. Abutment backfill settlement at the Via Princessa Undercrossing. Note large crack which delineates limit of backfill.

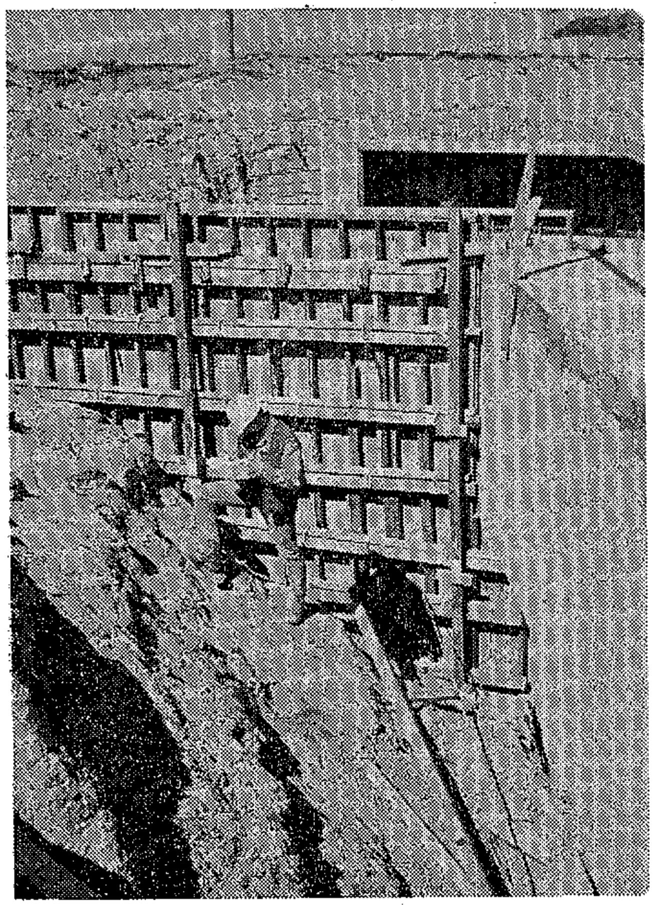
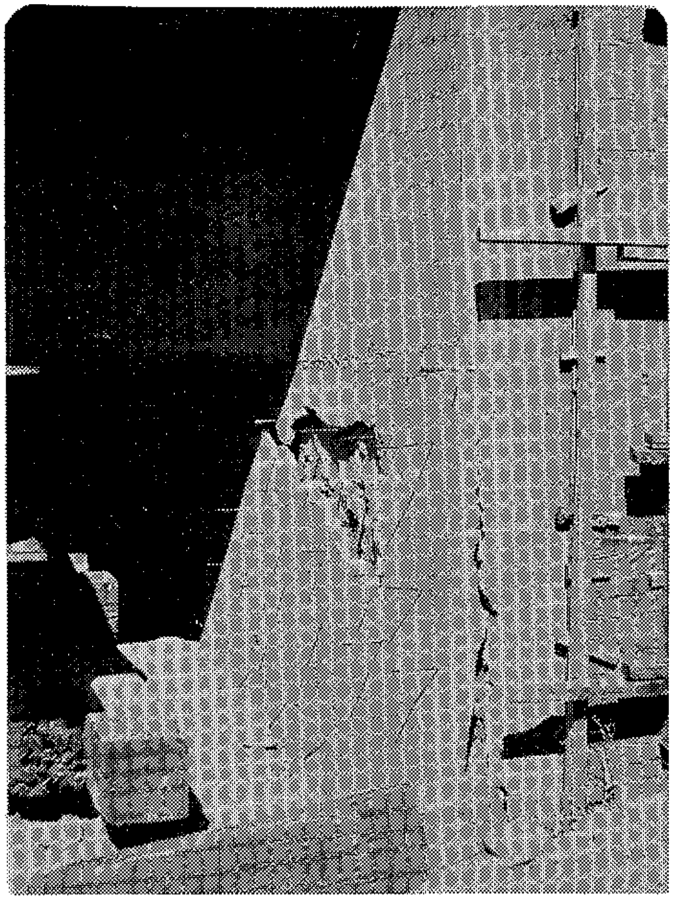


Photo 87. Abutment prior to backfilling at the Via Princessa Undercrossing.

Photo 88. Typical abutment damage through the eastern portion of Route 14.



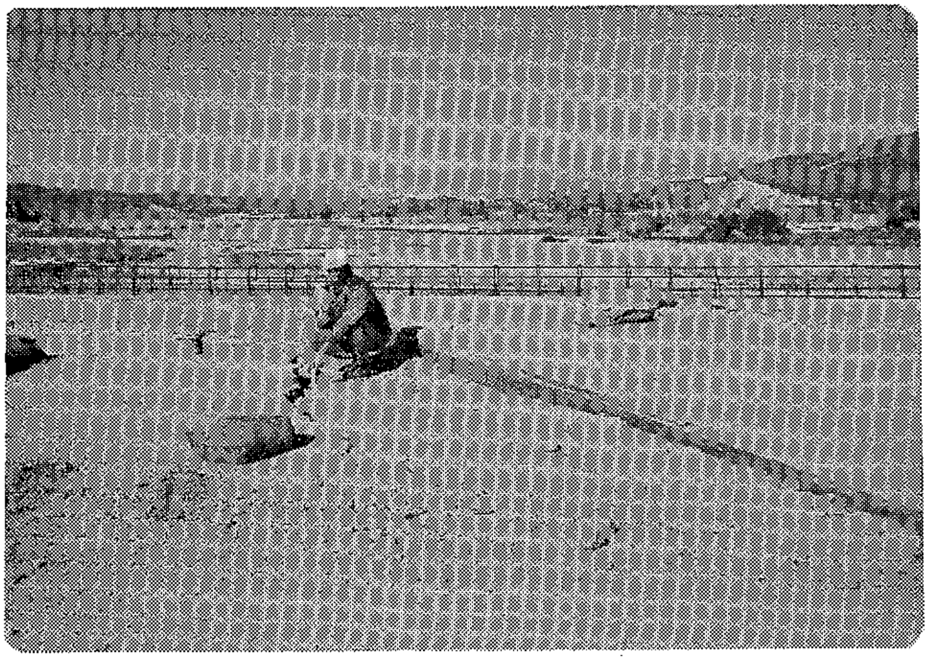


Photo 89. Abutment backfill settlement at the Santa Clara River Bridge (west abutment, westbound structure).

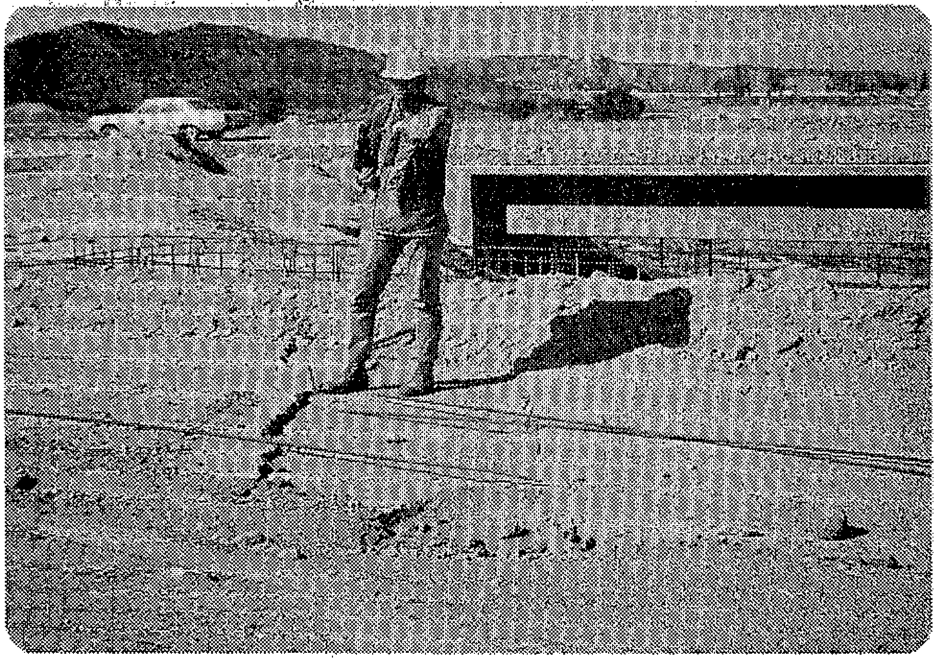


Photo 90. Abutment backfill settlement at the Santa Clara River Bridge (west abutment, eastbound structure).

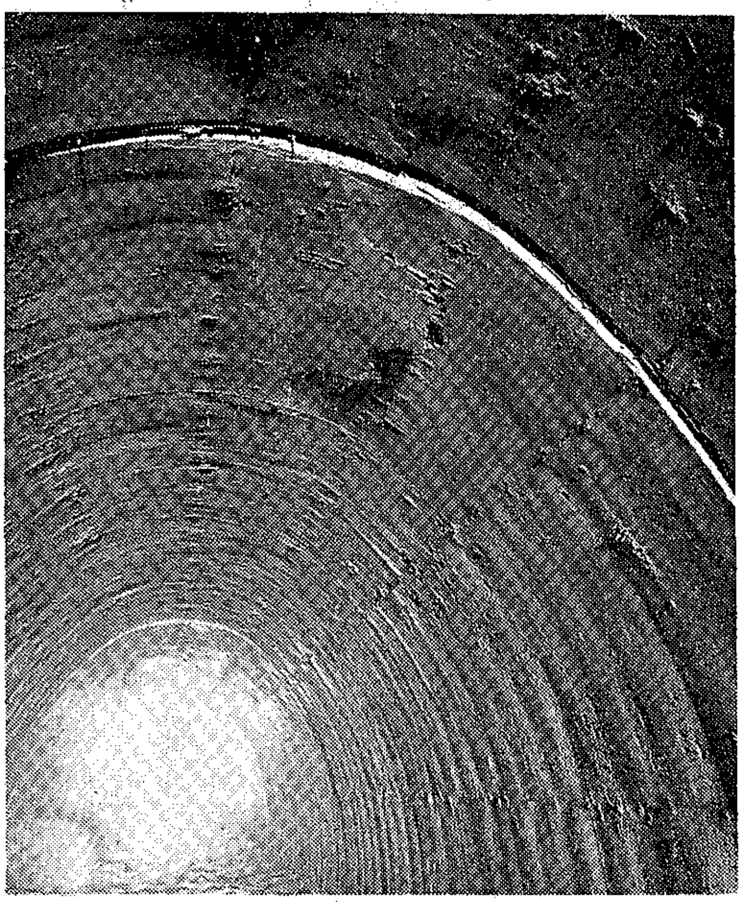


Photo 91. Minor spalling and joint separation in an 11-foot concrete arch culvert.

The above descriptions are typical of the distress encountered at other structures along Route 14. Structures west of Placerita Canyon Overcrossing to the 5/14 Interchange area appeared to be undamaged and only minor amounts of backfill settlement were noted at some structures.

An 11-foot span reinforced concrete arch culvert near the Via Princessa Overcrossing was completed, backfilled, and had roadway embankment placed over it to specified grade. Plans specified that backfill around the arch include baled straw, one bale thick, for those sections under embankment heights greater than 30 feet above the crown. Maximum fill height over the crown was about 55 feet for a 150-foot length of the culvert, and at least 30 feet of fill height for a 250-foot length of the culvert. Damage to the culvert beneath 30 feet or more of fill consisted of expansion joint separation of ±1 inch; longitudinal cracking in the upper one-half of the culvert ranged from hairline to about 1/4-inch; and one section of the top spalled, as shown in Photo 91.

Slight cracking was noted in other portions of the culvert but it appeared to be very minor. The effect of the baled straw over the culvert for the higher fill-covered areas may have been beneficial in cushioning the culvert during earthquake-induced ground movements.

A 72-inch diameter reinforced concrete pipe crossing under Route 14 just east of the Sierra Highway Undercrossing had hairline to 1/8-inch longitudinal cracks in the upper 1/3 of the pipe on the east wall for nearly the length of the pipe and some discontinuous cracking in the top. No distortion of the invert was noted and the pipe appeared to be in good condition, overall.

Other drainage conduits investigated under Route 14 included a 10-foot wide x 8-foot high double reinforced concrete box and a 14-foot span reinforced concrete arch. No visible damage to either structure was detected.

ROUTE 210 FROM ROUTE 5/210 INTERCHANGE THROUGH MACLAY STREET

At the time of the earthquake, Route 210 was open to traffic from the Route 5/210 Interchange on the west, to Maclay Street on the east. Embankment was placed from Maclay Street easterly for approximately 7000 feet as staged construction. Construction had not been started on the proposed Route 118/210 Interchange.

The completed portion of Route 210 and the surrounding topography are shown in Photo 92. Profiles of original ground, roadway design gradeline, and a post-earthquake change in elevation profile of the roadway are shown in Figure 17. As-built plans were used in the compilation of Figure 17 for the roadway and original ground profiles. Post-earthquake elevation surveys of the roadway were compared to the as-built profile and the change in elevation for each station is plotted on the figure.

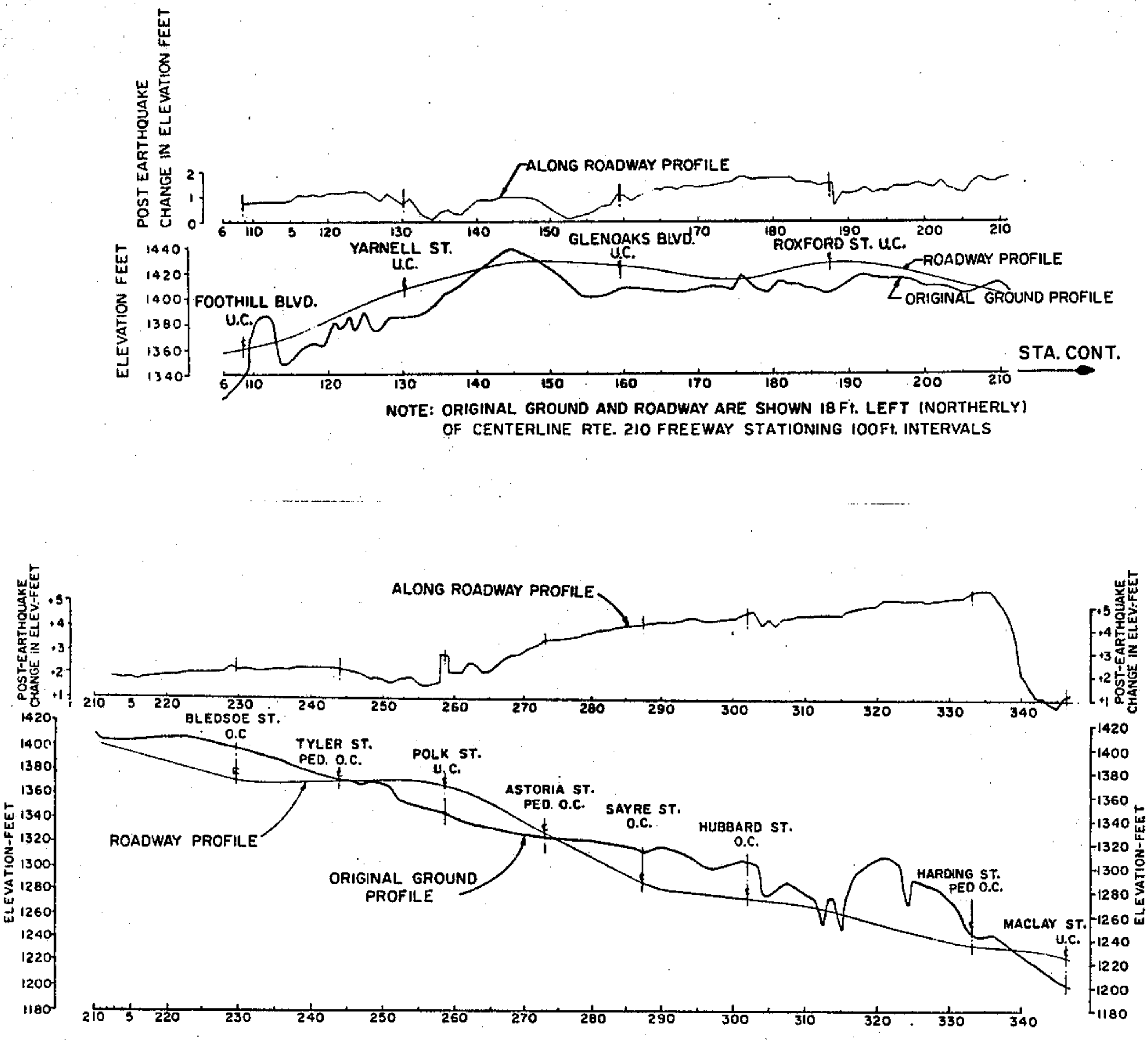
The general trend of the post-earthquake survey shows that a regional tilt of the ground surface occurred, sloping upward to the east as measured along the Route 210 alignment. Maximum bedrock uplift was 5.6 feet at the Sylmar Fault (Freeway Station 335) and the minimum bedrock uplift was about 0.75 feet at the Foothill Boulevard Undercrossing (Freeway Station 109).

Damage description location numbers are shown on Figure 18.

Location 1

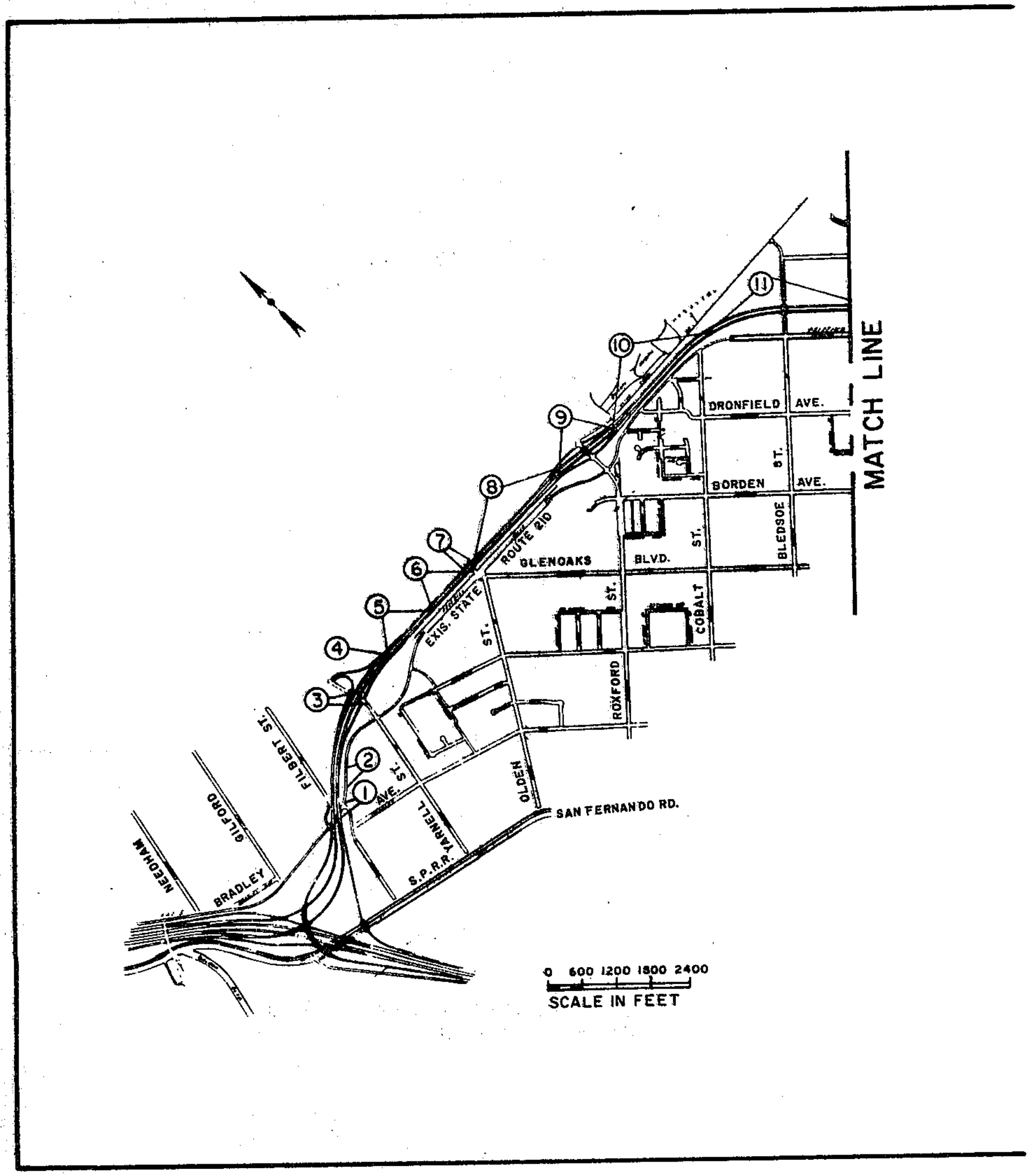
In addition to the structural damage to the Foothill Undercrossing (Photo 93), embankment distress in the form of shear cracks and settlement occurred at the approaches. Backfill settlement measuring up to one foot resulted in approach slab breakage.

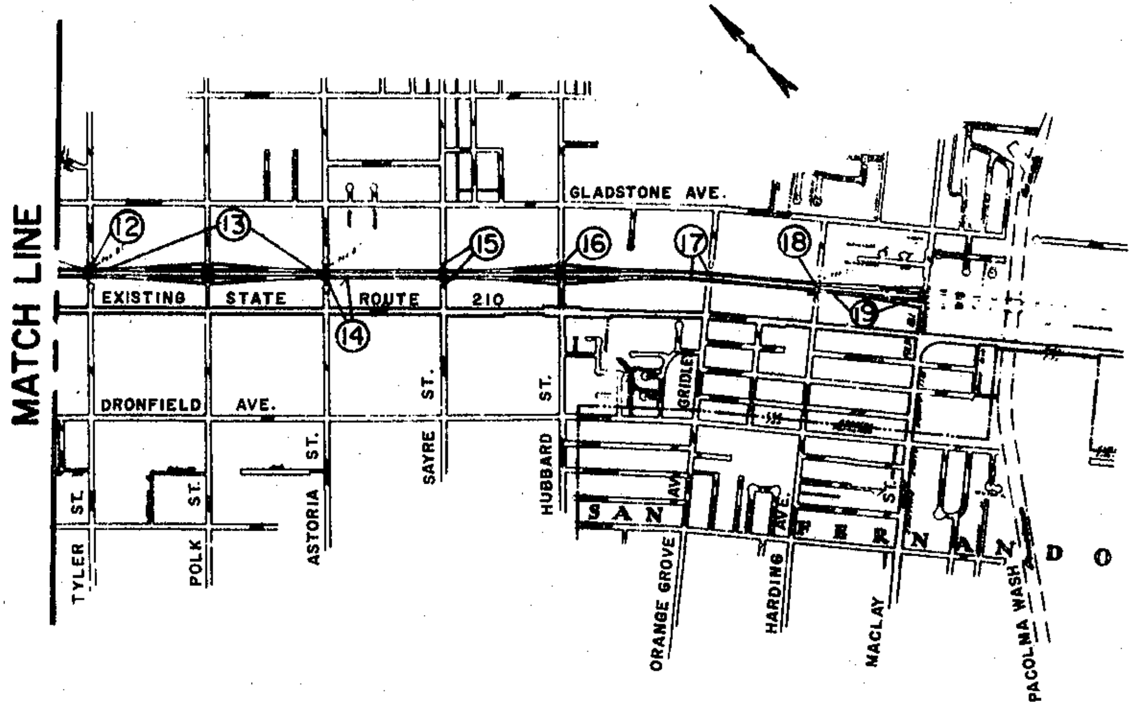
Photo 92. Looking easterly at the completed portion of Route 210. The Juvenile Hall complex is in right center of photo.



ROUTE 210 DESIGN AND ORIGINAL GROUND PROFILE AND POST QUAKE CHANGE IN DESIGN PROFILE

FIGURE 17


MATCH LINE
DRONFIELD AVE.
BORDEN AVE.
BLEDSOE ST.
GLENOAKS BLVD.
COBALT ST.
ROXFORD ST.
ROUTE 210
EXIS. STATE
OLDEN ST.
SAN FERNANDO RD.
YARNELL ST.
AVE.
S.P.R.R.
FILBERT ST.
GILFORD
NEEDHAM
BRADLEY
0 600 1200 1800 2400
SCALE IN FEET



LAYOUT OF THE COMPLETED PORTION OF ROUTE 210

FIGURE 18

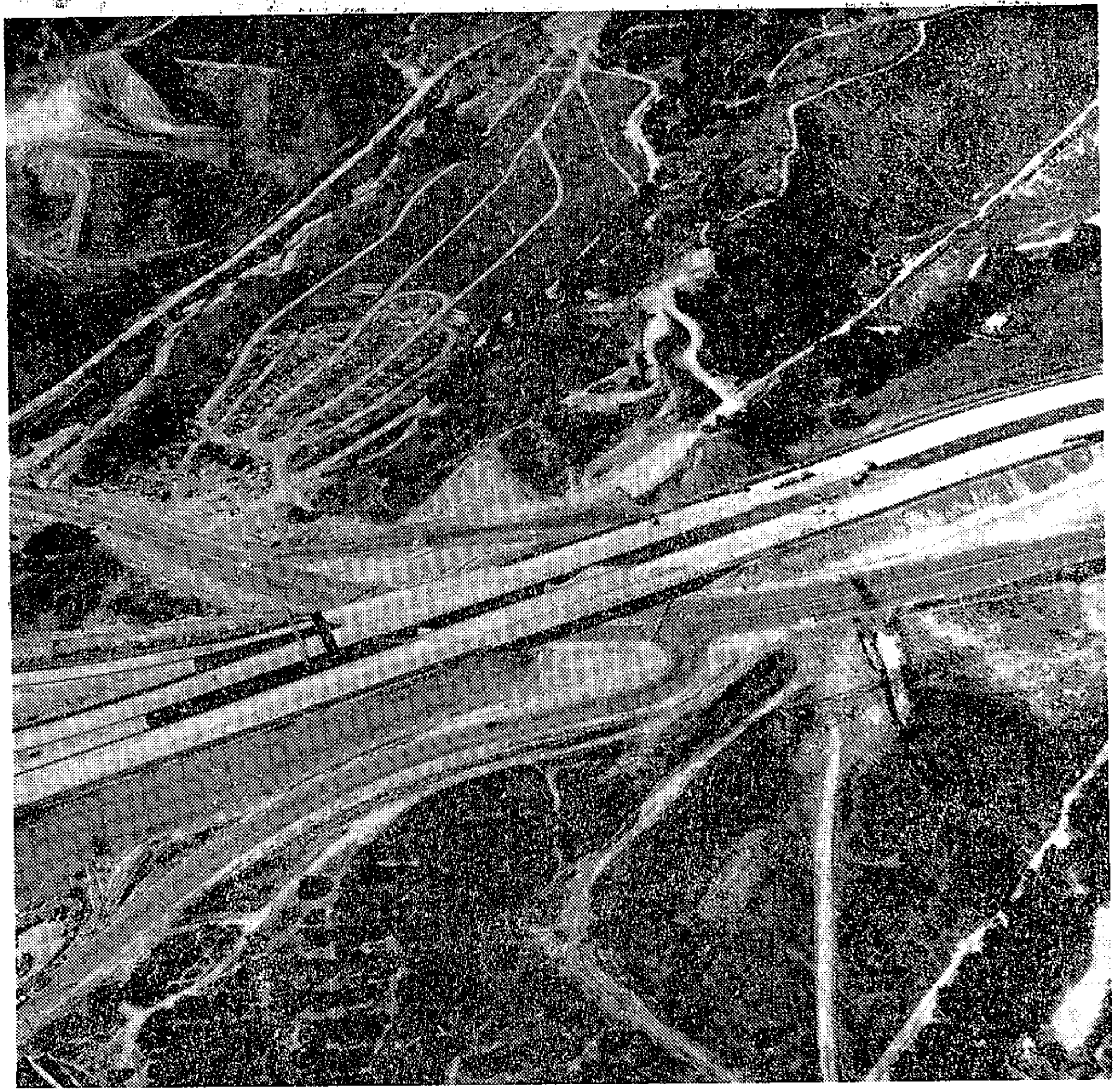


Photo 93. Looking northerly at the Foothill Boulevard Undercrossing.

Location 2

Pavement slab separations of 1/4 to 1/2-inch occurred along expansion joints in the outside lanes of the eastbound roadway for a distance of 650 feet east of Foothill Boulevard. Minor undulations in the roadway profile between Foothill Boulevard and Yarnell Street resulted from fill and/or foundation densification.

Location 3

Fills at the Yarnell Street Undercrossing (Photo 94) settled about three inches at the west approach (Photos 95 and 96) and about six inches at the east approach. Photo 97 shows cracking and settlement in the median at the wing wall. Again, settlement appears to be the combined result of densification of fill and underlying aluvium caused by the seismic shaking.

Both bridges are single spans with abutments supported on piles. Piles extended through the fill to about 25 feet below the original ground surface and were founded in very dense sand and sandy gravel. Inspection of the bridge log of test borings shows about a four-fold increase in energy required to penetrate the foundation material at the pile-tip elevation as opposed to the uppermost ten to fifteen feet of material. Overburden material continuously increased in density from the original ground to the pile-tip foundation material.

Photo 94. Looking northerly at the Yarnell Street Undercrossing.

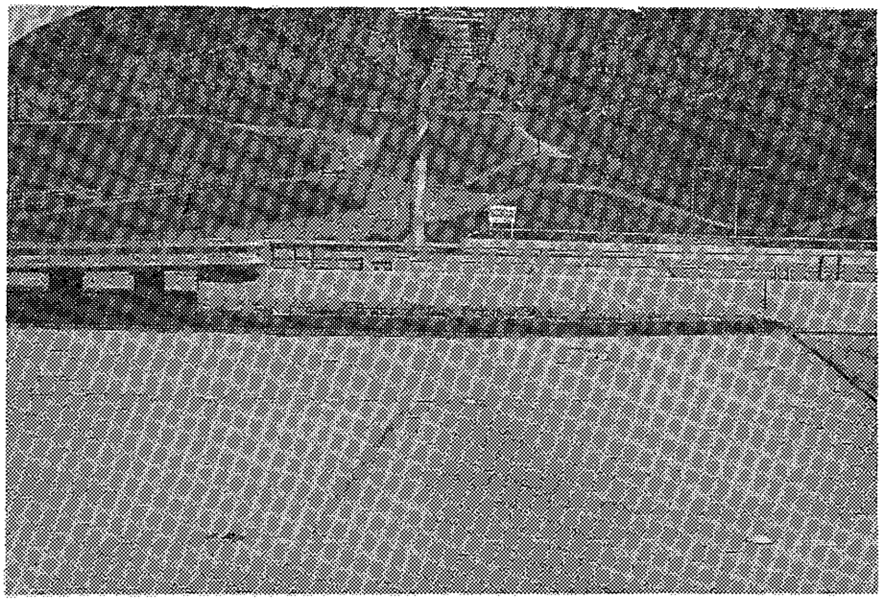


Photo 95. Fill and abutment backfill settlement at the Yarnell Street Undercrossing, eastbound roadway, west approach. Note ramp effect of approach slab to structure deck.

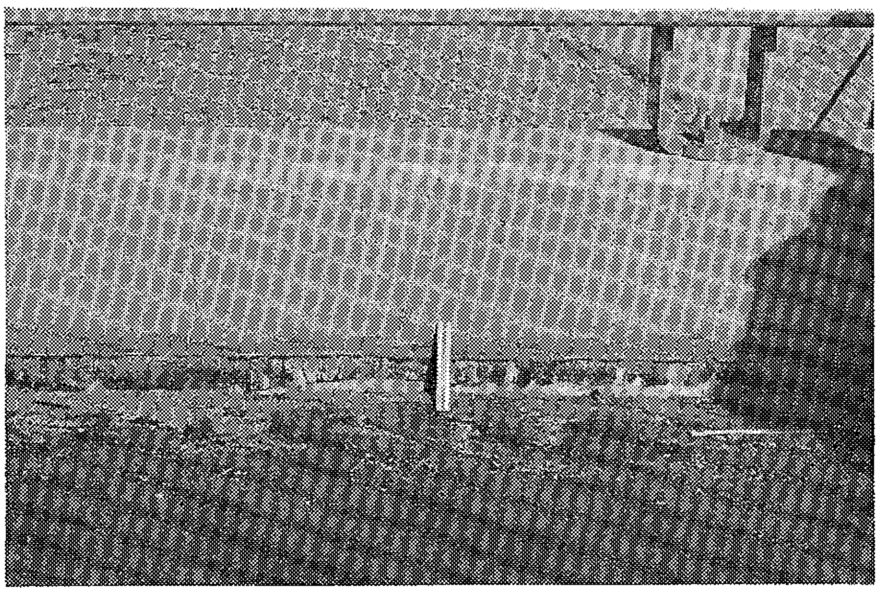


Photo 96. Same location as Photo 95. Note settlement of AC shoulder pavement relative to wingwall.

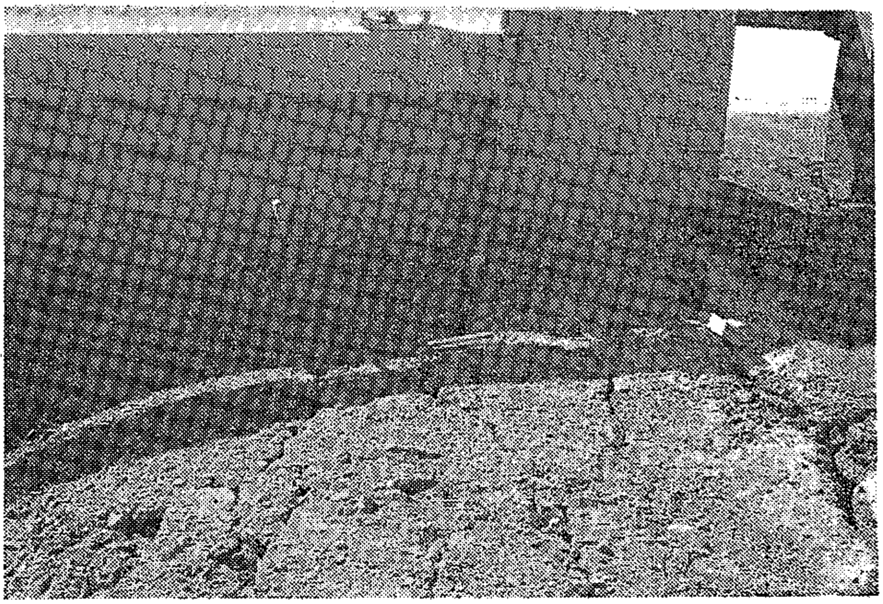


Photo 97. Fill cracking and settlement in median at Yarnell Street Undercrossing.

Location 4

Pavement slab separation of the longitudinal construction joint of 1/2-inch to 1-1/4-inches occurred in the westbound roadway for a length of 560 feet at this location. Fill height through this section varied from 12 feet at the east limit to 24 feet at the west limit as shown in Figure 17.

Location 5

Pavement undulations through this location appear to reflect the cut/fill profile and varying fill thickness.

Location 6

The asphalt concrete paved median ditch at this location had a longitudinal crack along the flowline for a distance of about 850 feet. The ditch pavement had collapsed in places for a width of up to 1/2-foot. This section of roadway is on fill that is about 20 feet high at the freeway centerline. The roadway starts into cut section about 150 feet west of the median tension crack. The portland cement concrete pavement in both roadways showed separation along the longitudinal construction joints ranging from 1/4-inch to more than one inch.

Location 7

In the Glenoaks Boulevard area (Photo 98), Route 210 is constructed on about 20 feet of fill over alluvium that is made up of gravelly sands. A comparison of the constructed profile vs. the post-earthquake profile (Figure 17) shows that slightly more than three inches of fill settlement occurred at the west bridge approaches and about 4-1/2 inches of fill settlement occurred at the east approaches. Both bridges are set on piles that are founded about 30 feet below original ground.

No structural damage to the bridges was found (4), but concrete slope paving beneath the superstructures caused minor damage to the concrete sidewalks and curbs along Glenoaks Boulevard (Photo 99).

The slope paving, which settled about 3 inches at the bridge abutment and about 2 inches at the sidewalk, transmitted forces from the abutments to the sidewalk and curbs.

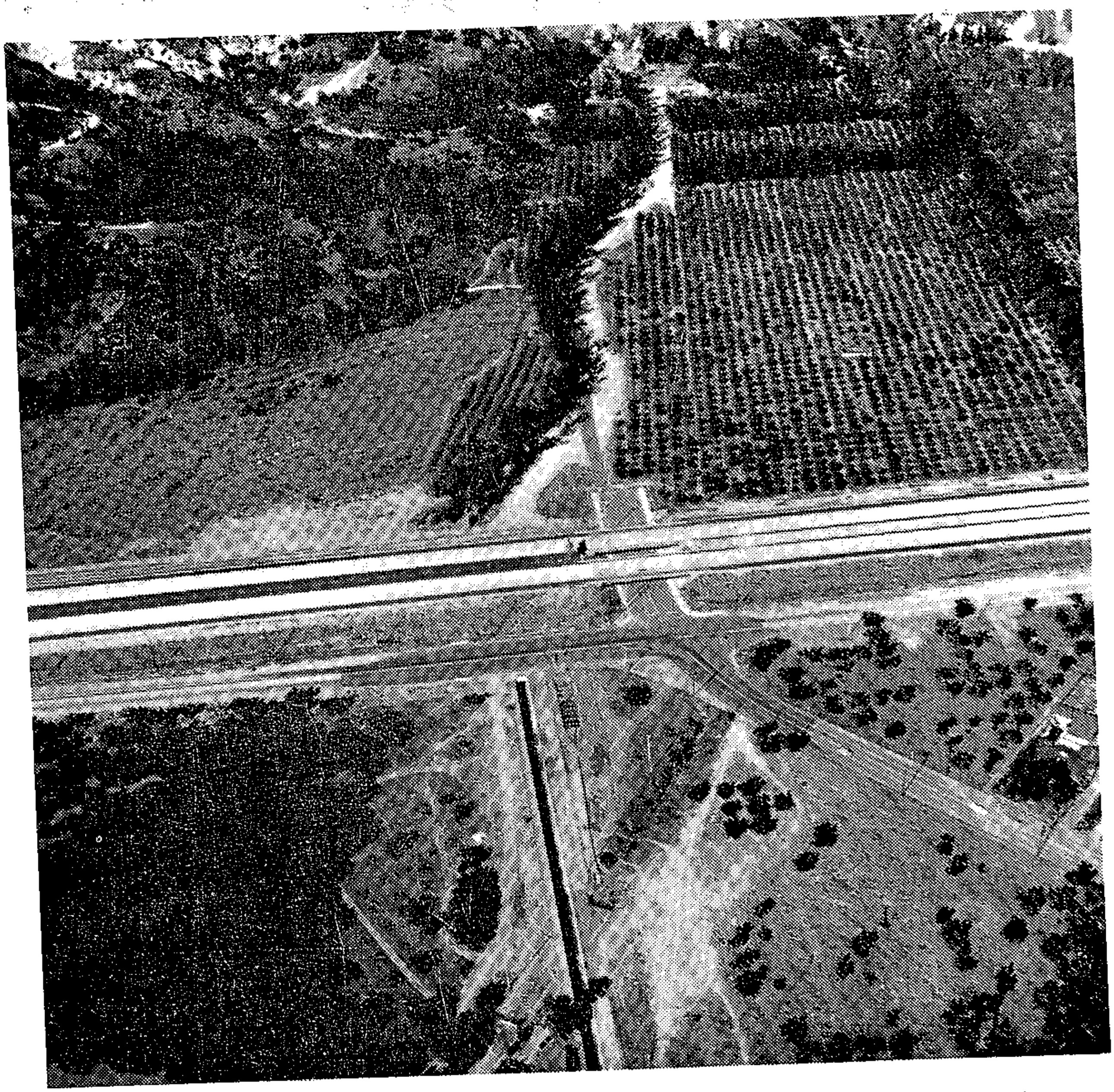


Photo 98. Looking northerly at the Glenoaks Boulevard Undercrossing.

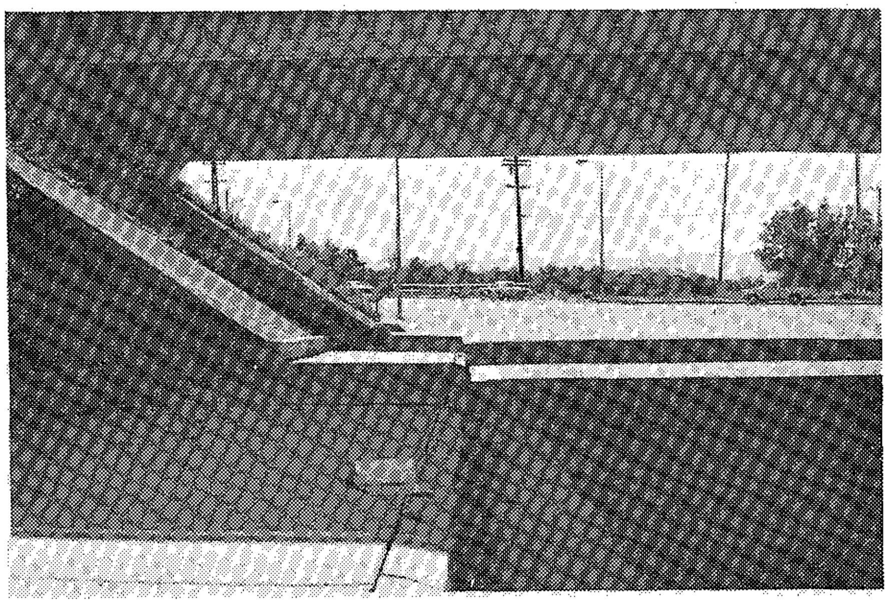


Photo 99. Looking south along Glenoaks Boulevard. Note rotated and displaced curb due to lateral force of displaced slope paving that was transmitted through sidewalk.

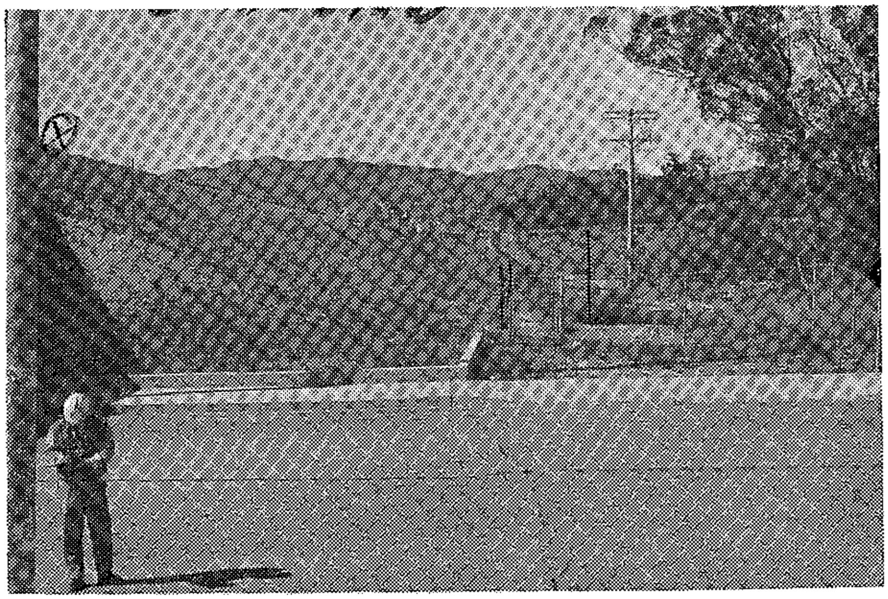


Photo 100. Looking west across Glenoaks Boulevard at tension cracks in AC pavement caused by differential settlement.

The asphalt concrete pavement of Glenoaks Boulevard settled differentially where it crosses beneath the freeway, resulting in transverse tension cracks as shown in Photos 100 and 101. The cracks are nearly coincident with the freeway toe of fill line. The break in pavement profile appears to be nearly over the southerly edge of a buried 11-foot wide by

Photo 101. Looking west across Glenoaks Boulevard at tension cracks in AC pavement caused by differential settlement.

8-foot high reinforced concrete box storm drain covered by about 3 feet of earth. The storm drain begins to curve near the centerline of Glenoaks Boulevard and crosses the centerline of Route 210 (beneath fill) about 150 to the west. No break in the pavement profile could be discerned along the north edge of the box.

Location 8

An undulating roadway surface, shown in Figure 17, was the result of tectonic uplift combined with differential settlement in the roadway embankment and underlying gravelly sands.

Location 9

Seismic shaking at the I-210/Roxford Street Interchange (Photo 102) appears to have been much more intense than that to the west for a distance of about one mile along the freeway alignment. The east abutment for the eastbound structure separated from the pilings and the structure shifted about three feet to the south as shown in Photo 103. Fill spreading and settlement disrupted the roadway profile (Photos 104 and 105). Pavement slab separation and longitudinal cracks resulted from fill displacement (Photos 106, 107, 108, and 109). A compression buckle formed in asphalt concrete pavement in the eastbound off-ramp (Photos 105 and 110). Lateral shear displacement of fill is evidenced by bulging and a developed thrust offset near the toe of fill at the west approach to the eastbound bridge. Bulging occurred at the toe of fill along the eastbound off-ramp for a distance of several hundred feet.

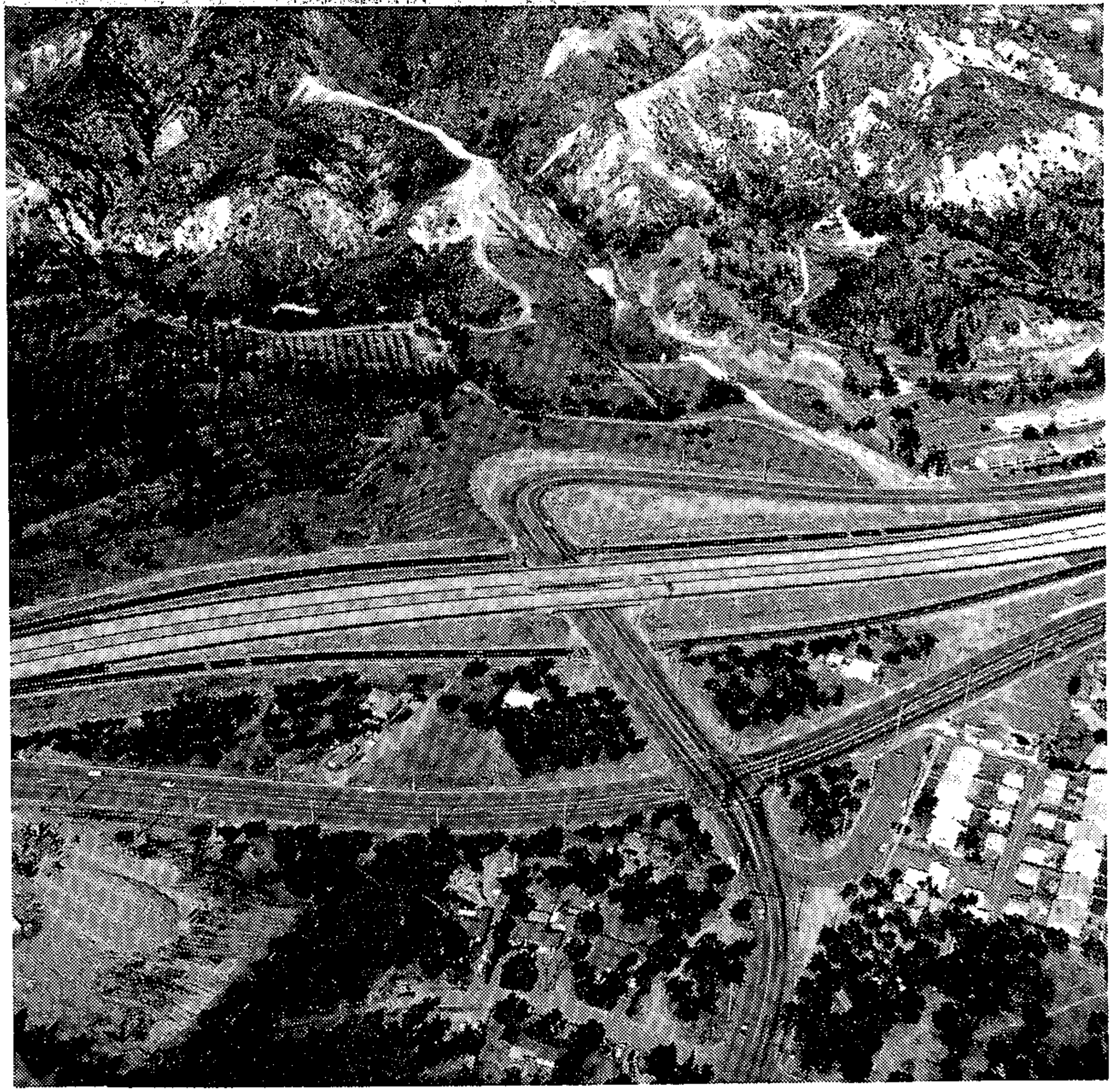


Photo 102. Looking northerly at the Roxford Street Undercrossing.

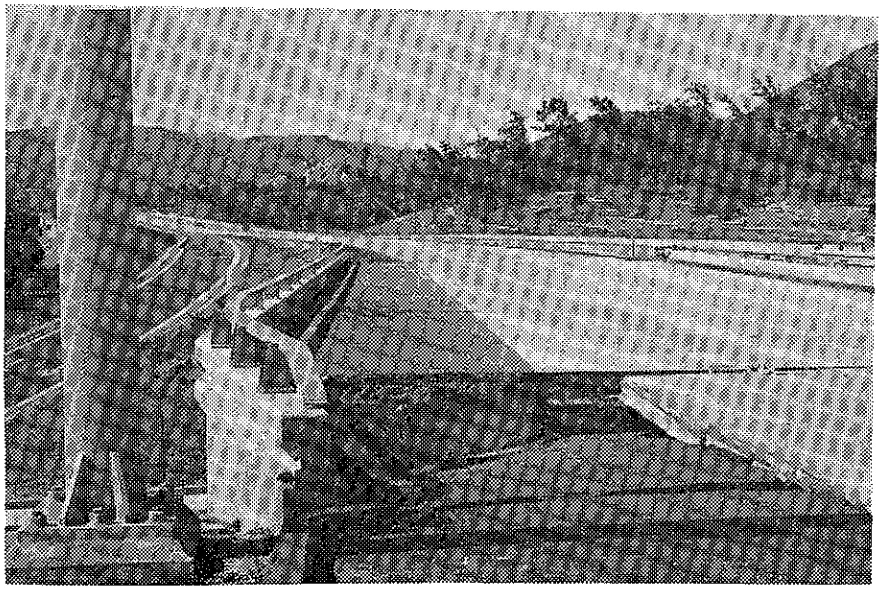


Photo 103. Looking west at the eastbound structure of the Roxford Street Undercrossing. Note rotational movement of structure.

Photo 104. Looking east at the eastbound structure of the Roxford Street Undercrossing. Note settlement of pavement relative to structure deck. Note also separation of pavement slabs and the broken approach slab. The tire skid marks leave little doubt as to the whereabouts of one motorist at the time of the earthquake.