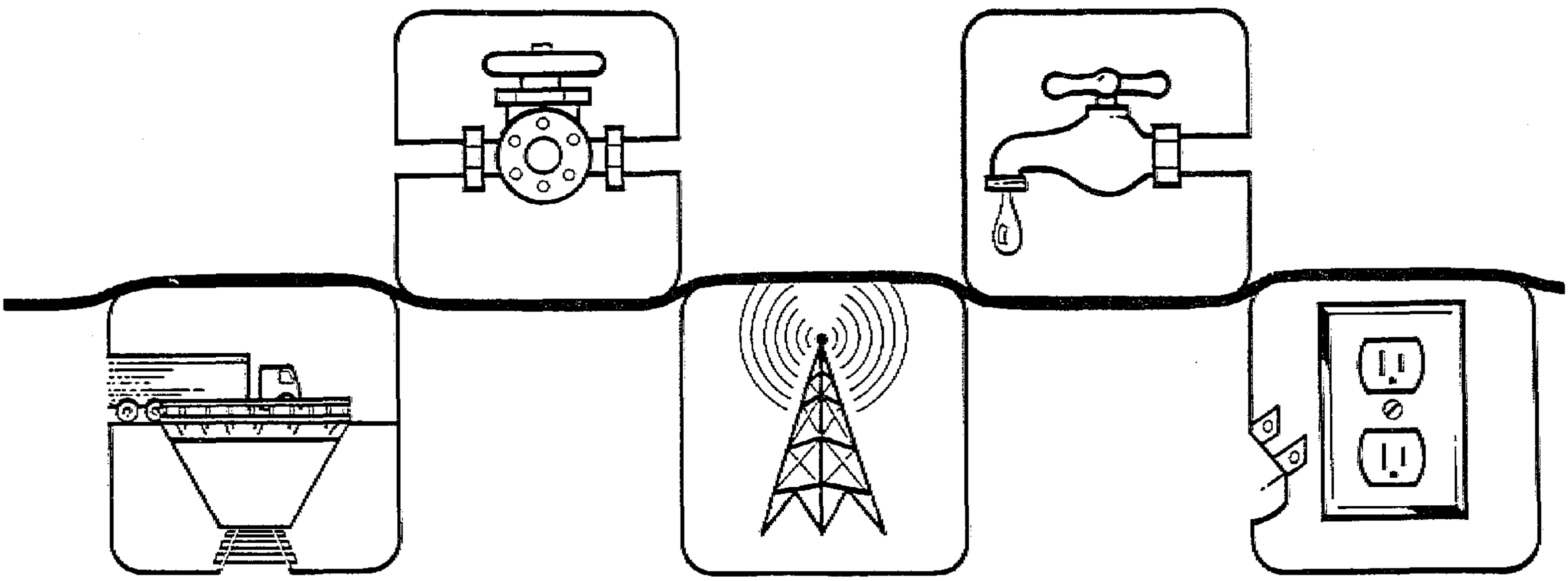
FEDERAL EMERGENCY MANAGEMENT AGENCY FEMA 225 / February 1992

Inventory of Lifelines in the Cajon Pass, California



Issued in Furtherance of the Decade
for Natural Disaster Reduction

Earthquake Hazard Reduction Series 60

Inventory of Lifelines in the Cajon Pass, California

Submitted to the Federal Emergency Management Agency
Washington, D.C.

Submitted by:

INTECH Inc.
11316 Rouen Dr.
Potomac, MD 20854-3126

Submitted August 1991

Co-Principal Investigators:
Dr. Phillip A. Lowe, INTEC, Inc.
Dr. Charles F. Scheffey, INTEC, Inc.
Mr. Po Lam, Earth Mechanics, Inc.

INVENTORY OF LIFELINES IN THE CAJON PASS, CALIFORNIA

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

INVENTORY OF LIFELINES IN THE CAJON PASS, CALIFORNIA

1.0 INTRODUCTION AND BACKGROUND

1.1 BACKGROUND

Lifelines (e.g., communication, electric power, liquid fuels, natural gas, transportation, water and sewer systems, etc.) are presently being sited in "utility or transportation corridors" to reduce their right-of-way environmental, aesthetic, and cost impacts on the community and on land use. The individual lifelines are usually constructed or modified at different time periods, resulting in their being built to different standards and in different siting criteria being applied to different segments of an individual lifeline or to different lifelines that provide similar functions. Presently, the siting review usually does not consider the impact of the proximity or collocation of one lifeline upon the risk to or vulnerability of other lifelines from natural or manmade hazards or disasters, either because the other lifelines have not yet been installed or because such a consideration has not been identified as a factor in the siting evaluation.

In August 1988, a train derailment in northern California also damaged a petroleum pipeline which was buried along the railroad right-of-way. The result was a spill of the pipeline fluids in addition to the derailment (but no significant loss of property and no injuries to or casualties)[(1-1)1]. The State of California Office of the Fire Marshall became involved as it is the California agent responsible for the inspection and enforcement of safety criteria for pipelines that transport liquids. When another derailment in San Bernardino occurred in May 1989[(1-2)], which resulted in severe property damage and the loss of life, the Office of the Fire Marshall also responded to see if the derailment had impacted a petroleum products pipeline that was buried along the railroad right-of-way. It was decided that the pipeline was not damaged, and the fire and safety personnel turned over the site to the railroad to allow them to clean up the site. About a week later the pipeline ruptured and the resulting fire caused considerable property damage and loss of life. The subsequent investigation[(1-2)] concluded that the pipeline may have been damaged during the derailment, but that the most probable cause of its damage was the derailment clean up operations.

In a similar sense, communication lines along a highway bridge would be vulnerable to failure if the bridge were to displace or fail during a disaster event. In fact, frequently highway bridges and overpasses are used to route other lifelines, such as communications and pipelines, over causeways and water bodies. Such lifelines can be damaged by failure of the superstructure, bridge foundation movement, or ground deformation

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[1]Numbers in parentheses refer to the bibliography found at the end of each major report section.

along the approaches to the bridge. Settlement and lateral displacement adjacent to abutments have been especially troublesome because such movements tend to impose deformations on the lifelines where they are locally constrained at the attachment or penetration of the abutment.

There are many such examples of lifeline interdependency that occurred during the 1989 Loma Prieta earthquake. For example[1-3,1-4], the lack of fire fighting water in the Marina district resulted from pipeline failures. Failed water pipelines have caused ground erosion that has failed the foundations of other lifelines. Loss of electric power prevented the fire department from closing remote, electrically-controlled valves that were intended to isolate damaged portions of the water lifeline system. This resulted in the loss of the use of storage reservoirs and the ability to provide critically needed, fire fighting water. Electrical failures and shorts have ignited leaks from fuel pipelines, increasing the level of damage associated with the failed flue delivery lifeline.

In response to these types of situations, the Federal Emergency Management Agency (FEMA) is focusing attention on the use of such corridors, and they initiated this study to examine the impacts of siting multiple lifeline systems in confined and at-risk areas.

1.2 PURPOSE, GOALS, AND STUDY APPROACH

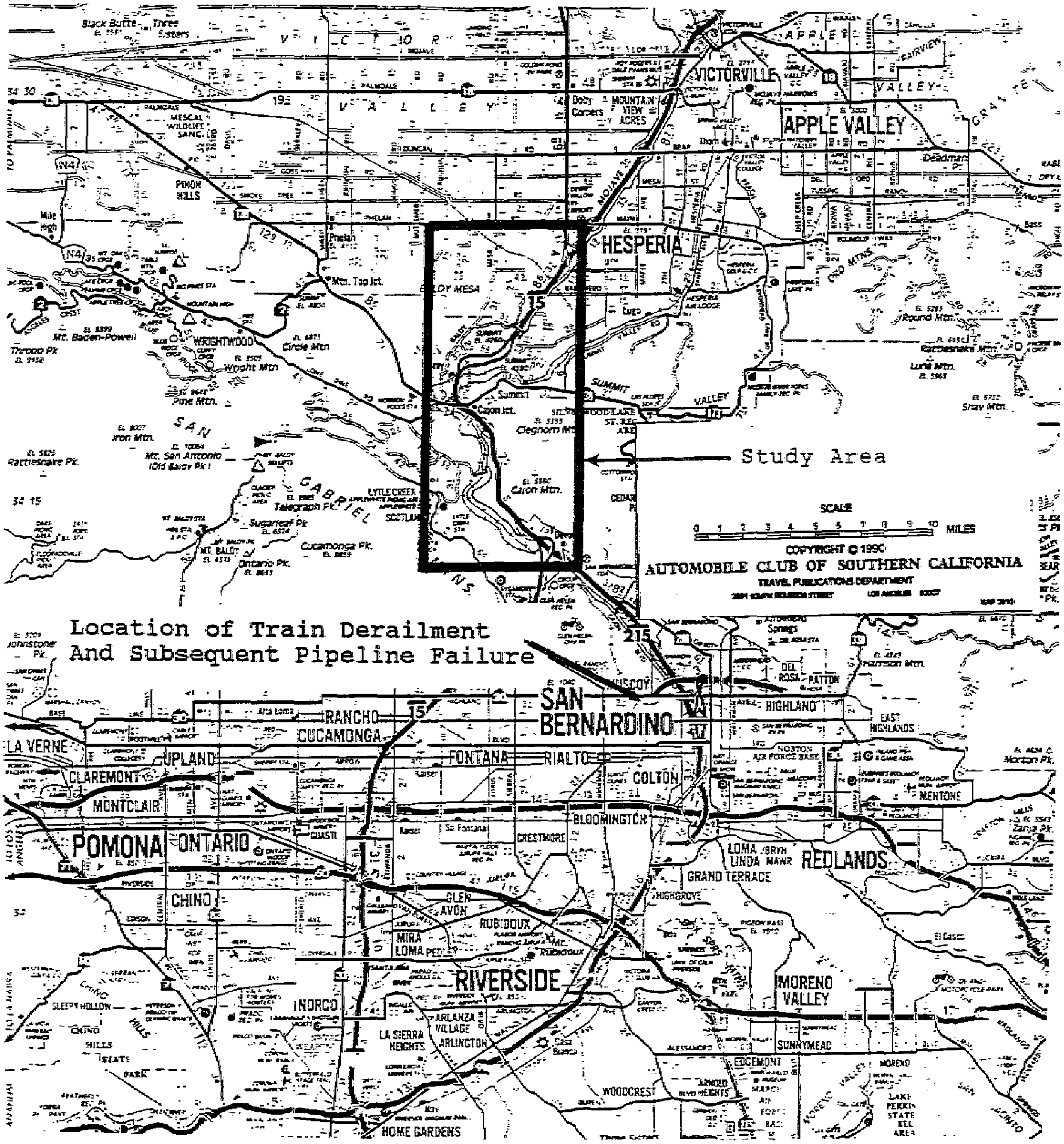
The overall FEMA project goals are to develop, for multiple lifeline systems in confined and at-risk areas, a managerial tool that can be used to increase the understanding of the lifeline systems' vulnerabilities and to help identify potential mitigation approaches that could be used to reduce those vulnerabilities. The goals also are to identify methods to enhance the transfer of the resulting information to lifeline system providers, designers, builders, managers, operators, users, and regulators.

To provide a specific example of how the managerial tool can be used, it was decided that the methods should be applied to the lifelines in the Cajon Pass, California, for an assumed earthquake event at the Pass.

The purpose of this report is to provide an inventory of the major lifeline systems in the Cajon Pass and the earthquake and geologic analysis tools available to identify and define the level of seismic risk to those lifelines. The information in this report can then become a validated data base for use in the development of the required analysis methodology for evaluating the impact of proximity or collocation of lifelines on the vulnerability of nearby lifelines.

Figure 1-1 is a reproduction of a highway map (courtesy of the Automobile Club of Southern California) of the San Bernardino, California, area (1:250,000-scale). The locations of the Cajon Pass study area and the May 12, 1989, train derailment and the subsequent May 25, 1989, petroleum products pipeline rupture are identified on the map.

Figure 1-1, Map of the Cajon Pass Area



The methodology used in developing the information for this report is as follows. Site reconnaissance surveys of the Cajon Pass were made to familiarize the researchers with the specific site conditions and to identify areas of special interest. Contacts were then made with each lifeline system owner and the study information needs were explained. The owners responded with engineering data on their specific system(s). Contact also was made with the regulatory agencies as well as with appropriate emergency planners. Those direct contacts provided basic data on each lifeline system, and they provided validation of the data (or in some cases raised questions as to our understanding of the data). Additional site visits were then made to confirm and further validate the available data. This report was then prepared, with heavy reliance on the validated data or on the data provided by each lifeline owner. As a final validation of the work, the draft report was submitted to each organization that provided information for the report with the request that it review the material to assure that the information provided was not misunderstood or to provide additional clarification data when appropriate.

Section 2.0 of this report presents an executive summary of the study. It also adds a discussion in which all of the separate data are combined onto a single map to identify the regions of greatest congestion. Section 3.0 presents the specific data for the lifeline systems and the seismic data and codes available to determine the earthquake impact on those lifelines. Section 4.0 presents a list of the organizations contacted during this study.

1.3 BIBLIOGRAPHY FOR SECTION 1.0

1-1 Source of information: conversations with the State of California Office of the Fire Marshall, Office of Pipeline Safety.

1-2 National Transportation Safety Board Railroad Accident Report NTBS/RAR-90/02 (PB90-916302), June 19, 1990.

1-3 T.D. O'Rourke, et. al., "Geotechnical and Lifeline Aspects of the October 17, 1989, Loma Prieta Earthquake in San Francisco", Technical Report NCEER-90-0001, National Center for Earthquake Engineering Research, January 1990.

1-4 T.D. O'Rourke, et al., "Response of the San Francisco Water Supply System During the 1989 Loma Prieta Earthquake", presented at the conference Putting the Pieces Together, San Francisco, CA, October 1990.

2.0 EXECUTIVE SUMMARY

2.1 SUMMARY

This report is the first phase of a study commissioned by the Federal Emergency Management Agency (FEMA) to evaluate the vulnerabilities occurring from the siting of multiple lifeline systems in confined and at-risk areas due to their interactions from natural and manmade disasters. The goals of the overall study are to identify the lifeline systems' vulnerabilities, to identify potential mitigation approaches that could be used to reduce those vulnerabilities, and to identify methods to enhance the transfer of the resulting information to lifeline system providers, designers, builders, managers, operators, users, and regulators.

The purpose of this report is to provide an inventory of the major lifeline systems in the Cajon Pass and the earthquake and geologic analysis tools available to identify and define the level of seismic risk to those lifelines. The Cajon Pass and an earthquake event will be used as a suitable test case for applying the evaluation methodology which will be developed as a part of the overall study. However, the overall program goal is to provide a methodology that can be readily applied to other regions and locations in the United States and that is adaptable to disaster conditions in addition to earthquakes. The information in this report can be used as a validated data base for use in the development of the required analysis methodology for evaluating the impact of proximity or collocation of lifelines on the vulnerability of nearby lifelines.

Figure 1-1 also shows that the Cajon Pass is a natural topographical opening between the San Bernardino and the San Gabriel mountain ranges. As such, it has been used for years as the major route for lifelines between the Los Angeles coastal plain and the high desert regions. Within the Pass the following lifeline systems (see Figure 2-1, it is provided in full-size in Volume 2 of this report) shows the lifelines that have been examined for the current study:

Communication Lifelines -- fiber optic cables, radio, cellular telephone, and microwave towers;

Electrical Lifelines -- high voltage transmission systems, a hydroelectric generation station, and a transmission system electric power substation;

Fuel Pipeline Lifelines -- natural gas transmission and petroleum products pipelines;

Transportation Lifelines -- interstate highways, state highways, bridges associated with the highways, passenger and freight railroad lines, and the bridges and tunnels associated with the railroad lines.

Although Figure 2-1 shows that the lifeline routes are often focused in a narrow band, the topology of the region is not the only reason for that as the Pass is generally several miles wide (it is about 1/2 mile wide at its narrowest at Blue Cut) and many of the lifeline routes could have been placed on the slopes of the mountains that form the edges of the Pass. There are large subregions in which there are only one or no lifelines in the overall study region. However, most of the lifeline systems are located near or in the foot of the Pass itself. This is the congested lifeline area. The figure shows a major focusing of the rail,

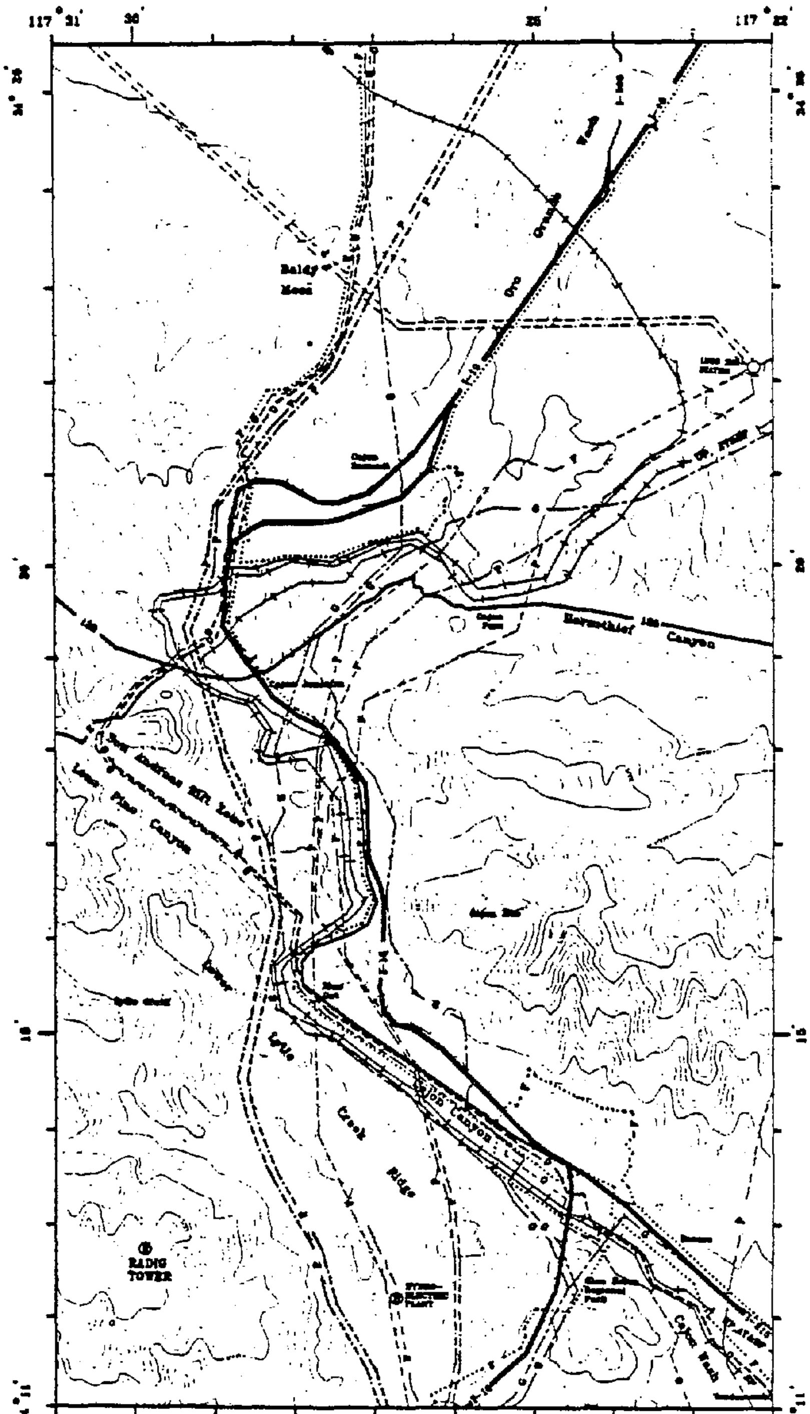


Figure 2-1 Composite Map of Lifelines In the Cajon Pass Study Areas

SCALE

0 1 2 MILES

0 1 2 KILOMETERS

N

CONTOUR ELEVATIONS IN FEET

CONTOUR INTERVAL 200 FEET

Larger Scale Figure Located at End of Document

EXPLANATION

- I-15 — INTERSTATE
- 2 — PAVED HIGHWAY
- RAILROAD
- P — POWER LINES
- W — FLUME-PENSTOCK
- O — PETROLEUM PRODUCT PIPELINES
- G — NATURAL GAS PIPELINES
- F — FIBER OPTIC CABLE

highway, communication, and fuel pipelines in the southern part of the Pass near the community of Devore, another congested area involving all of the lifeline systems near Blue Cut (which is also traversed by the San Andreas fault zone), and another congested area near and north of Cajon Junction. Above the summit of the Pass (in the high desert area), the lifeline systems spread out, although the communications and fuel pipeline lifelines remain collocated in that region.

In studying the Cajon Pass area, it has become apparent that the objectives considered in siting the lifelines were weighted heavily towards minimizing the lifelines' immediate impact on the aesthetics and the surface environment of the area and on the costs associated with acquiring the rights-of-way and installing of the lifelines. In a number of instances, the siting route was a response to Federally-imposed routing criteria. Thus, in may parts of the study area the lifelines are in parallel or coincident paths, thereby reducing the amount of land disturbed by their construction and the costs for acquiring the required rights-of ways. Very limited, documented analyses or considerations of the impact of the failure of one lifeline upon the operation and reliability of another lifeline were found during the current study. Part of the reason for this appears to be that a number of different agencies and offices are responsible for the siting design and approval for the individual lifelines. Each such authority does not have direct responsibility or authority for the evaluation of the other facilities in close proximity to the lifeline for which they are responsible. It is believed that this siting approach is representative of most lifeline siting situations within the United States, although that question has not been examined during this study.

Chapter 3.0 of this report provides more detailed maps. Figures 3.2-1, 3.3-1, 3.4-1, and 3.5-1 (for the communications, electrical, fuel pipeline, and transportation lifelines, respectively) show the routes of the separate lifeline systems. Figures 3.1-2, 3.1-3, 3.1-4, and 3.1-7 (for the earthquake fault zones, geologic conditions, landslide areas, and water table (e.g. potential soil liquefaction zones)) show the regions where seismic conditions could induce forces and stresses on the individual lifelines. All of these items must be examined together to obtain a realistic estimate of the probable failure conditions exerted on individual lifelines.

In the subsequent analysis of the potential hazards to and vulnerabilities of the lifeline systems from earthquakes (to be reported in a following report "Collocation Impacts on the Vulnerability of Lifelines During Earthquakes With Application to the Cajon Pass, California") it will be necessary to relate the composite of lifeline locations with geologic areas subject to landslides and liquefaction as well as to identify their physical relationship to the contours of equal earthquake shaking intensity. A part of that study will be to select and justify the appropriate earthquake event to be analyzed. As discussed in Section 3.1, the earthquake fault locations are well mapped and are available for use in the current study. The soil and bedrock conditions can be based on the United States Geological Survey (USGS) data[2-1]. That information will provide input to the QUAK2NW3 earthquake shaking intensity model developed at the USGS[2-2]. Landslide potential can be determined by applying the USGS models[2-3,2-4] with the results supplemented by the data of Figure 3.1-5. Liquefaction potential can be determined by applying the USGS methodology[2-5] with the results supplemented by the data of Figure 3.1-8. Thus, there are sufficient data and models available to allow the calculation of the earthquake and geologic impacts on the lifeline systems.

The study presented in this report was prepared by obtaining data from the lifeline system owners and regulators and by conducting numerous on-site examinations. The data were further validated by having the draft report reviewed by those who supplied the input data to assure that they were not misunderstood and that they were complete. As such, the information can be considered as a reliable data base upon which the rest of the FEMA-sponsored study can be built. Chapter 3.0 presents the results obtained, Chapter 4.0 identifies the organizations and offices contacted during the study.

2.2 BIBLIOGRAPHY FOR SECTION 2.0

2-1 J. Davis, et. al., "Earthquake Planning Scenario for a Magnitude 8.3 Earthquake in the San Andreas Fault in Southern California", California Division of Mines and Geology, Special Publication 60, 1982.

2-2 J. Evernden, et. al., "Seismic Intensities of Earthquakes of Conterminous United States - Their Prediction and Interpretations", USGS Professional Paper 1272, 1981, and "Predictive Model for Important Ground Motion Parameters Associated with Large and Great Earthquakes", USGS Bulletin 1838, 1988.

2-3 M. Legg, et. al., "Seismic Hazard for Lifeline Vulnerability Analysis", Proceedings of the Third International Conference on Microzonation, Seattle WA, 1982.

2-4 R.C. Wilson and D.K Keefer, "Predicting Earthquake-Induced Landslides with Emphasis on Arid and Semi-Arid Environments", Landslides in a Semi-Arid Environment with Emphasis on the Inland Valley of Southern California, Editors: P. Sadler & D. Morten, 1989.

2-5 T.L. Youd and D.M. Perkins, "Mapping of Liquefaction Severity Index", Journal of Geotechnical Engineering, V 113, No. GT 11, 1987, and "Mapping Liquefaction-Induced Ground Failure Potential", Journal of Geotechnical Engineering, V 104, No. GT 4, 1978.

3.0 SITE CONDITIONS AND LIFELINES

3.1 SITE CONDITIONS

This report section presents geologic and geotechnical information for the Cajon Pass Study Area including:

- Fault information and ground rupture (displacement) potentials
- Seismic events
- Soil and bedrock conditions
- Ground shaking hazards
- Topographic and ground relief features and landslide hazards
- Hydrologic and ground water conditions and liquefaction potentials

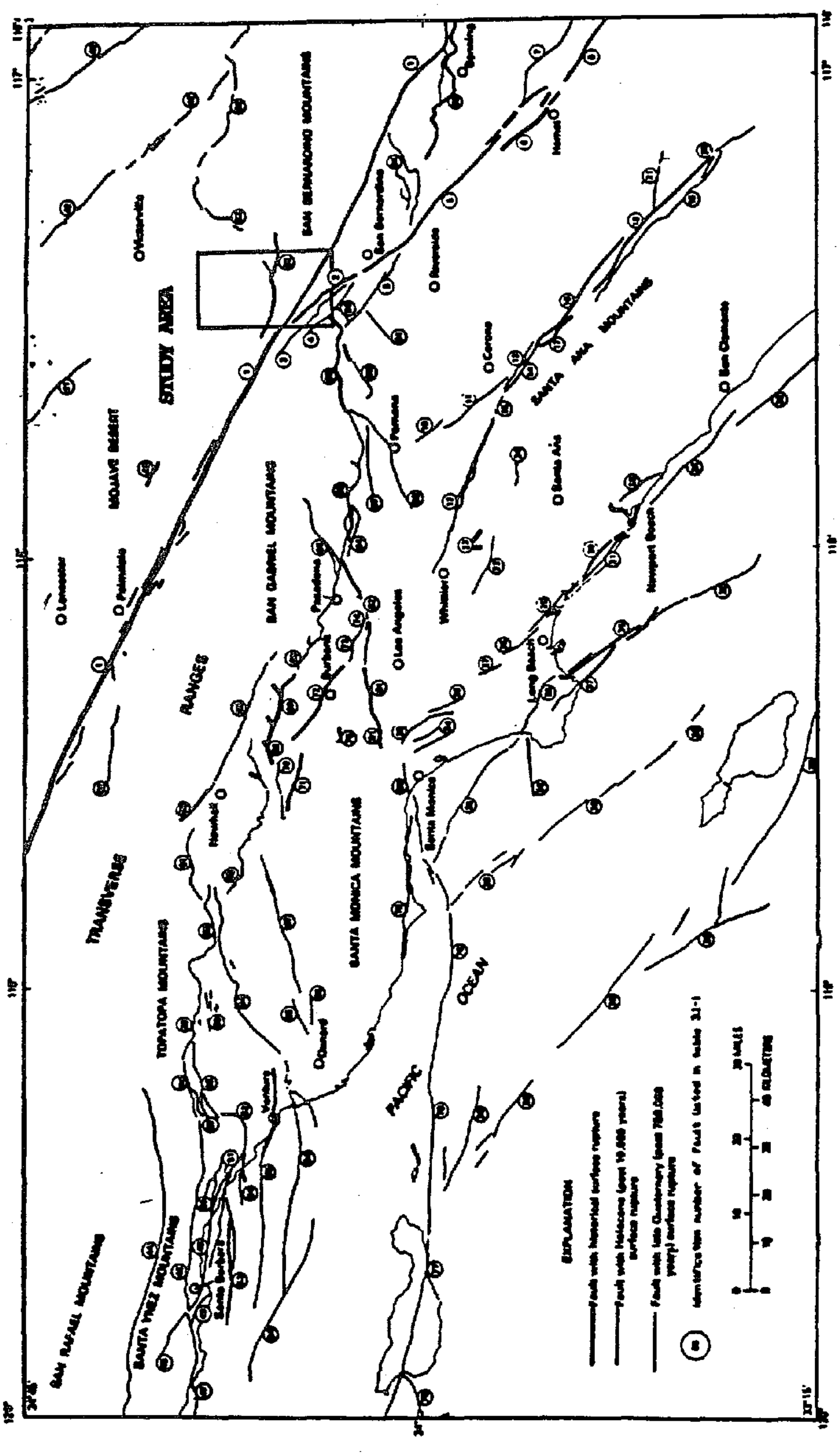
Discussions will also be presented on the earthquake hazards and predictive models that can be used to evaluate the damage potentials associated with the various earthquake hazards including: ground shaking, landslide, and liquefaction hazards. In addition, data (geologic, geotechnical, hydrological, and groundwater) gathered in the course of the project is presented. Actual applications of the predictive models to analyze the damage potentials on the lifeline systems at the study area will be provided in a separate, vulnerability analysis report to be issued.

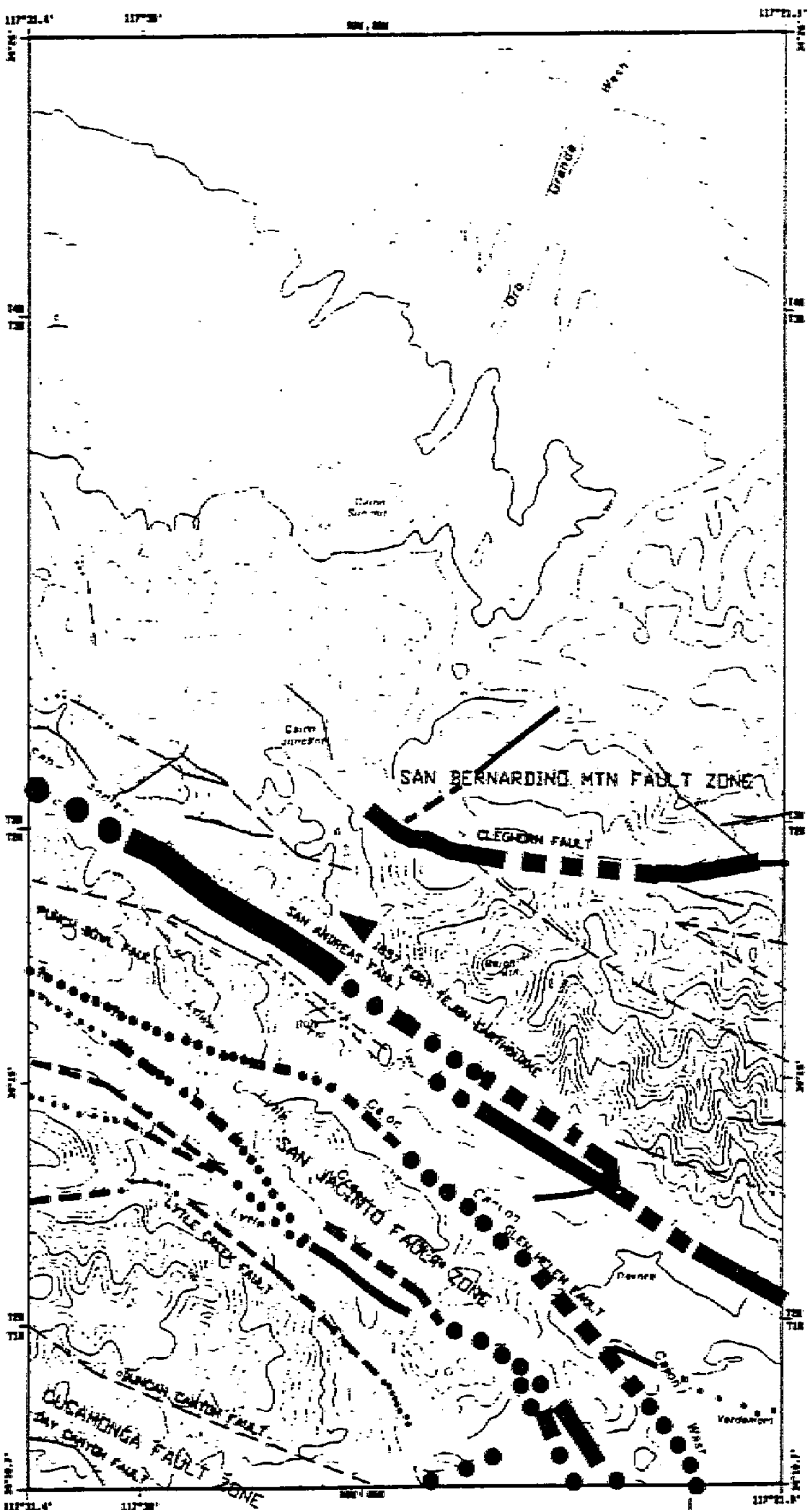
As shown in Figure 2.1, the study area covers approximately a 9.2 miles by 17.4 miles area (Longitude ranging from about 117° 21.9'W to 117° 31.4'W; Latitude ranging from about 34° 10.7'N to 34° 26'N). The study area covers portions of nine 7.5 minute quadrangles (as designated by U.S.G.S.): Phelan, Telegraph Peak, Cucamonga Peak, Baldy Mesa, Cajon, Devore, Hesperia, Silverwood Lake, and San Bernardino North. As shown in the figure, most of the lifelines at Cajon Pass generally follow the Cajon Canyon corridor in the southern part of the study area. The San Andreas rift zone intersects that lifeline corridor at the middle to southern part of the Cajon Pass study area. In the high desert region in the northern part of the study area the lifelines are spread apart to a greater degree than is found in the southern regions.

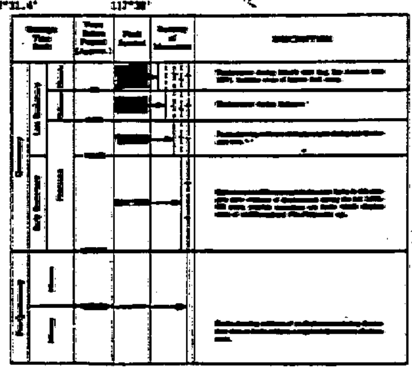
3.1.1 Fault Information and Ground Rupture (Displacement) Potential

An excellent compilation of information on potential active faults that could generate damaging earthquakes in Southern California has been presented by Ziony and Yerkes[3.1-1]. Figure 3.1-1 and Appendix A (which defines the terms used in Figure 3.1-1) are extracted from their work. They show that a number of different geologic faults can affect the Cajon Pass. Also, many of the faults shown in Figure 3.1-1 but which are not located directly within the Cajon Pass area still could present earthquake hazards in terms of ground shaking to the lifelines in Cajon Pass. Figure 3.1-2 is presented to provide a more detailed map of the active faults located within the study area that could present hazards related to surface fault rupture or relative ground displacements.

Figure 3.1-1, Regional Fault Map







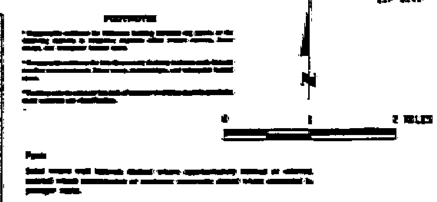


Figure 3.1-2 Active Fault Locations
In The Study Area

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It can be seen from Figure 3.1-2 that the faults which are located within the study area are:

(1) San Andreas fault zone (which is in Lone Pine Canyon).

(2) The San Jacinto fault zone (which generally follows Lytle Creek Canyon and is south and parallel to the San Andreas fault), including the following strands within the fault zone: (a) Glen Helen fault, (b) several strands of San Jacinto fault, (c) Lytle Creek fault, and (d) Punch Bowl fault.

(3) Faults along the southern margin of Transverse Ranges, especially the Cucamonga fault which is further south of the San Jacinto fault zone and which has two to three subparallel strands located within the study area including the (a) Duncan Canyon fault and the (b) Day Canyon fault.

(4) Faults along the margins of San Bernardino Mountains, the Cleghorn fault (which is north and approximately parallel to the San Andreas fault zone).

A discussion of each of the above four fault zones is presented below. Aspects related to potential surface fault ruptures that are directly relevant to lifeline damage evaluations are emphasized.

San Andreas Fault Zone. A very complete discussion on the San Andreas fault can be found in California Department of Conservation, Division of Mines and Geology (CDMG) reports[3.1-2, 3.1-3] and USGS reports[3.1-4, 3.1-5]. The San Andreas fault zone is the most dominant active fault in California. It is the main element of the boundary between the Pacific and the North American tectonic plates. Two great historical earthquakes have occurred along this fault: the renowned 1906 San Francisco earthquake and the lesser known but possibly more severe 1857 Fort Tejon earthquake. These two earthquakes were selected to serve as a basis for emergency planning in Northern California[3.1-6] and Southern California[3.1-7]. Approximately 400 km of the San Andreas fault between Parkfield-Cholame (e.g., Central California) and Cajon Junction (Southern California) ruptured during the 1857 Fort Tejon earthquake, which had an estimated magnitude of 8.3. The southern end of the fault rupture during the Fort Tejon earthquake is located within the study area (between Cajon Junction and Blue Cut). At Cajon Pass, the San Andreas fault zone generally has been reported to range from 0.3 to 1.5 km wide (0.2 to 0.9 miles). Bennett and Rodgers[3.1-2] reported that although very pronounced surface crustal movements can be observed north of Cajon Pass along the San Andreas fault, very little movement has been recorded along the segment of the San Andreas fault south of Cajon Pass.

San Jacinto Fault Zone. Echelon segments (including: the Glen Helen, the various strands of San Jacinto faults, Punch Bowl fault, and the Lytle Creek fault) of the San Jacinto fault zone system extend southeastward for more than 300 km through the Imperial Valley and into northern Baja California, Mexico. The zone at its northern end appears to merge with the San Andreas fault at around the Cajon Pass region. For the past century, the San Jacinto fault zone has been the most active earthquake-generating feature in southern California; it has produced at least 10 earthquakes of about local magnitude 6.0 or greater since 1890. The maximum credible earthquake associated with the San Jacinto fault zone is a magnitude 7.5 earthquake[3.1-8].

Southern Margin of the Transverse Ranges. The southern boundary of the western Transverse Ranges is formed by an overlapping group of west- to east-northeast-trending, late Quaternary faults. These faults, which dip steeply to moderately northward, comprise an essentially continuous narrow belt more than 300 km long that adjoins many of the major urban centers of the Los Angeles region extending from Santa Barbara on the west to San Bernardino on the east[3.1-9]. Two to three subparallel strands of the Cucamonga fault rift (the Duncan Canyon fault and Day Canyon fault), which may be as wide as wide as 1 km, are located at the southern part of the study area. The maximum credible earthquake associated with this fault system is a magnitude 6.5 earthquake.

Faults along the margins of the San Bernardino Mountains. The northern edge of the San Bernardino Mountains is delineated by an arcuate group of discontinuous faults that have various trends and that generally dip southward into the mountain mass. The distribution and history of these faults are poorly understood but are the subject of several current investigation by State and Federal geological offices. The Cleghorn fault, a single strand of the San Bernardino Mountain fault zone, is located within the study area.

Figure 3.1-2 shows the fault locations within the study area. The fault activities (expressed in terms of how recent has been the fault movement) are depicted on the figure in terms of the thickness of the line. Fault traces are indicated by solid lines where well located, by dashed lines where approximately located or inferred, and by dotted lines where concealed by younger rocks. From the referenced literature, it can be concluded that zones of ground ruptures could be as wide as 1 to 1.5 km along the depicted fault lines when the map is used to evaluate potential damage to lifelines because of ground displacements related to fault rupture.

A number of researchers[3.1-10, 3.1-11, 3.1-12, 3.1-13, 3.1-23] have related actual rupture data (both length of break, displacement amount, and width of the displacement zone) to the earthquake magnitude. Slemmons[3.1-12] provides log-log plots of data for North America. Bonilla[3.1-14] also reported that the maximum main fault zone (e.g., the width of the disruption) for strike-slip faults is 320 feet. Rojahn[3.1-13] also provides equations and plots that relate the maximum fault displacement to the earthquake magnitude. These sources can be used in the current study to estimate the ground rupture potential once the seismic event has been selected (see Section 3.1.4).

3.1.2 Soil and Bedrock Conditions

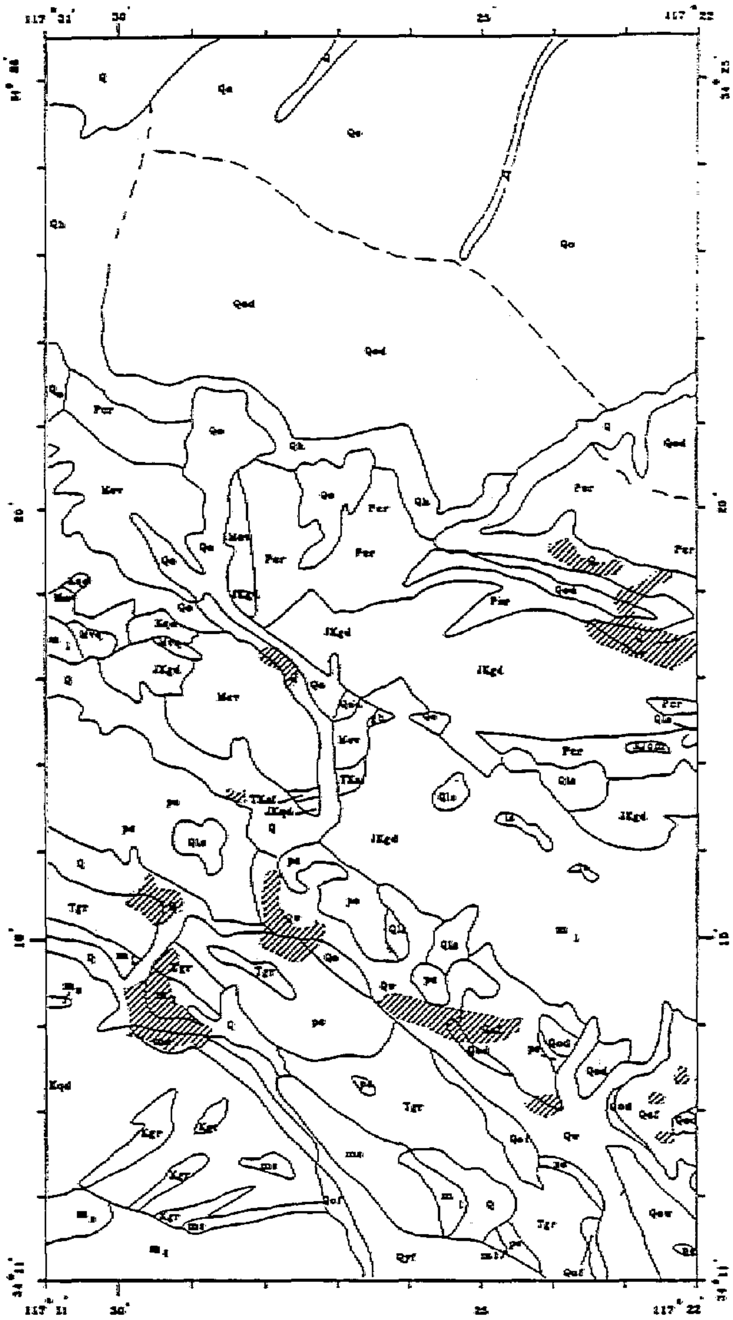
Areal differences in damage caused by shaking from earthquakes can be related to variations in soil conditions, especially to those near the surface (also see articles by Tinsley and Fumal and by Evernden in reference 3.1-1). A comparison[3.1-13, 3.1-15, 3.1-16, 3.1-17] of the earthquake shaking intensity maps of the 1906 San Francisco earthquake and that of the 1989 Loma Prieta earthquake reveals that severe damage occurred to the same locations where poor soil conditions exist, even though the epicenters of the two earthquakes were physically removed for each other.

A number of recently completed studies on geologic mapping at the Cajon Pass[3.1-18, 3.1-19, 3.1-20, 3.1-21] along with some traditional sources of information[3.1-2, 3.1-22, 3.1-9] offers detailed information on the geologic conditions at various locations in the study area. A number of scientific research programs, including the first deep scientific drill hole in Cajon Pass and the deep crustal seismic reflection profile at the western San Bernardino Mountains, have recently been completed. Unfortunately, most of the above studies cover a relatively small portion of the study area.

Traditional geologic mapping emphasizes the distribution and character of bedrock units, including lithology, age, and rock structure (bedding foliation, lineation, fractures, folds, faults, etc.). Areas underlain by flood plain and other water-laid sediments commonly are depicted as a single map unit, termed alluvium. Variation in the physical properties of alluvial deposits that pertain to hazards of interest to earthquake evaluations, such as ground shaking and ground failure, are not usually distinguished on the standard geologic maps. Therefore, conventional geologic maps have limitations with respect to evaluation earthquake hazards.

In the past two decades, specialized mapping techniques directed specifically at identifying and evaluating earthquake hazards in alluvial deposits have evolved[3.1-23, 3.1-24, 3.1-25, 3.1-26, 3.1-27], all of which are summarized in reference 3.1-1. However, such maps have only been presented for urban development areas and are not available for Cajon Pass.

For the above reasons, the geologic maps of the San Bernardino Quadrangle compiled by Bortugno and Spittler[3.1-36] were selected for the present study. An enlarged geologic map (scale: 1 inch = 1 mile) for the study area is presented in Figure 3.1-3. The age of the bedrock and soil deposit units denoted in the figure refers to various geologic times. Some common terminology used to denote geologic time scales are summarized in Appendix A, which is copied from reference 3.1-1. In general, alluvium, especially the Holocene alluvium, denoted as Unconsolidated Alluvium, Q; Wash Deposits, Qw; Older Wash Deposits, Qow; Younger Alluvium, Qya; Younger Fan Deposits, Qyf, Fan Deposits, Qf; Wind-Blown Sand, Qs; Large Landslide Deposits, Qls and lake Deposits, Ql would present the most seismic hazard potentials (in terms of ground shaking, liquefaction and landslide and ground failure). For convenience, the locations of high ground water table have been identified in the figure.



SCALE

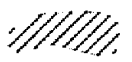
0 1 2 MILES

0 1 2 KILOMETERS

N

Figure 3.1-3 Cajon Pass Region Geologic Units With High Water Table Regions Identified

EXPLANATION



HIGH WATER TABLE

Q	ALLUVIUM	Mvq	VAQUEROS (?) FORMATION
Qw	WASH DEPOSITS	Tgr	TERTIARY GRANITIC ROCKS
Qow	OLDER WASH DEPOSITS	TKsf	SAN FRANCISQUITO (?) FORMATION
Qls	LANDSLIDE DEPOSITS	ps	PELONA SCHIST
Qyf	YOUNGER FAN DEPOSITS	Kgr	CRETACEOUS GRANITIC ROCKS
Qof	OLDER FAN DEPOSITS	Kqd	CRETACEOUS QUARTZ DIORITE
Qo	OLDER ALLUVIUM	KJqm	CRETACEOUS OR JURASSIC QUARTZ MONZONITE; QUARTZ MONZONITE OF PLEASANT VIEW RIDGE
Qwd	WELL DISSECTED ALLUVIAL FANS	JKgd	JURASSIC OR CRETACEOUS GRANODIORITE
Qh	HAROLD FORMATION AND SHOEMAKER GRAVEL	gb	GABBRO OF PLEASANT VIEW RIDGE
Pcr	CROWDER FORMATION	ms, ls	METASEDIMENTARY ROCKS OF UNCERTAIN AGE ls = LIMESTONE AND MARBLE
Pcv	PUNCHBOWL (?) FORMATION OF CAJON VALLEY	m_1 m_4	SHEARED AND DEFORMED METAMORPHIC ROCKS (AGE UNCERTAIN) m_1 = GNEISS m_4 = HIGH-GRADE METAMORPHIC ROCKS

GEOLOGIC CONTACT OBSERVED OR APPROXIMATELY LOCATED; QUERIED WHERE GRADATIONAL OR INFERRED.

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West of the San Andreas fault, a basement rock unit referred to as the "Pelona Schist", or "ps", is the most landslide prone basement rock unit in the Inland Valley region of Southern California[3.1-19]. A number of major deep-seated landslides[3.1-17, 3.1-28] in the region are underlain by the Pelona Schist. The Pelona Schist is comprised of several rock types but is mainly a fissile, white mica-albite-quartz schist that is relatively weak and distortable. A variety of landslides, regardless of the physically setting, have been recorded at the Pelona Schists. The landslides that have impacted the Cajon Pass electrical lifelines (see Section 3.3) and the natural gas pipeline lifeline (see Section 3.4) have occurred in schist deposit areas.

3.1.3 Seismic Events

Four seismic source zones have been identified within the study area and have been discussed in the preceding section (Section 3.1.1). Although other nearby faults or seismic source zones need to be considered when hazards associated with ground shaking are studied, the main hazards would be associated with the four fault zones within the study area. Furthermore, the San Andreas fault, which is highly active and could generate significantly larger magnitude earthquakes, would dominate the seismic loading considerations. Although the San Andreas fault has a total fault length exceeding 1000 km, seismologists and geologists anticipate that only a portion of the San Andreas fault would rupture in a single event. The fault is divided in three major segments which could generate very large magnitude earthquakes: (1) the northern segment from Point Delgada to San Juan Bautista (roughly coincident with the 1906 San Francisco earthquake fault rupture), (2) the central segment from around Parkfield to Cajon Pass (coincident with the 1857 Fort Tejon earthquake), and (3) the southern (Mojave) segment from Cajon Pass to Salton Sea. The maximum credible earthquakes associated with the central and the southern segment of the fault is a magnitude 8.25 and a 7.5 event[3.1-8], respectively. Both the central and the southern segments have been judged to be highly active[3.1-29], with a probability of sizable earthquakes exceeding a 40 percent chance over a 30-year exposure time. However, since Cajon Pass marked the end points of fault rupture associated with the two events, the damage scenario for the Southern California region as a whole due to disruption of major lifelines may be remarkably different depending on which event is chosen for damage evaluation. A potentially more damaging third event scenario associated with a fault rupture centered roughly at Cajon Pass and extending both northward beyond Palmdale (where another major natural gas pipeline crosses the San Andreas fault) and southward to beyond Thermal, California (where still another major power transmission line and also a natural gas pipeline cross the San Andreas fault) could be a plausible event.

Lifelines in general and especially electric power towers and buried lifelines, with the exception of highway and railroad bridges, have survived ground shaking effects remarkably well. Surface fault rupture and ground failure (including landslides and liquefaction) potentially would be more damaging to lifelines. Therefore, although the San Andreas fault would present the most intense ground shaking damage, other smaller faults which could generate surface ruptures at locations within the study area will need to be evaluated in terms of ground displacement effects.

3.1.4 Ground Shaking Hazards

Various models can be adopted to predict ground shaking for a given seismic event depending on the desired ground shaking parameters, including:

- o seismic intensity;
- o peak ground acceleration, velocity and displacement;
- o ground shaking durations; and
- o frequency content.

Models to predict fairly detailed ground shaking parameters, including peak ground acceleration, velocity, duration, and frequency content in terms of overall the overall shape of spectral intensity magnitude at various period ranges have been developed[3.1-23]. However, while such a model would be ideal for a local site-specific evaluation, they are not suitable for use in regional analysis such as being performed in this study.

A model[3.1-30, 3.1-31] which has been developed can be used to predict seismic intensities in terms of both Rossi-Forell (RF) and Modified Mercalli Intensity (MMI) scales for regional risk evaluations. Other ground motion parameters (e.g., peak ground acceleration, velocity and displacement) and the damage potential to a variety of structures can then be postulated from correlation of the intensity at the structure's location by using historical data on intensity-failure effects[3.1-13]. This approach has been used by Davis et. al.[3.1-6, 3.1-7] to estimate the general effects of hypothetical great earthquakes along the San Andreas fault on the lifeline systems in the Los Angeles and San Francisco metropolitan areas. This approach is expected to be used to predict the seismic intensity and resulting Cajon Pass lifeline damage from the various postulated earthquake events associated with the San Andreas fault and the other fault zones identified in Section 3.1.1.

The USGS seismic shaking intensity model[3.1-30, 3.1-31] has been coded in a computer program QUAK2NW3. Input to the program consists of:

(1) A fault data file, which represents the fault to be analyses, as a series of uniform point sources spaced as closely as desirable.

(2) A ground condition data file which performs two functions. It establishes each calculation point with respect to the fault, and it provides the soil condition at each calculation point. Ground conditions are typically discretized into 0.5 minute latitude by 0.5 minute longitude grids by the code developers.

(3) A pseudodepth term "C" which is chosen to give proper near-field die-off of the shaking intensities as a function of distance from the fault.

(4) An attenuation parameter "k" which controls the rate of die-off of peak acceleration as a function of distance from the fault.

With the above input data, the computer program QUAK2NW3 computes the acceleration associated with the energy release at each point source along the fault[3.1-32]. Then, the shaking intensity value is computed from the acceleration value. The shaking intensity is first calculated for a standard reference ground unit condition (e.g. saturated alluvium). Then, the intensity value at each grid point is adjusted for the actual ground condition specified in the ground condition input data file. Using this model, the model developer has predicted the patterns of intensity for many of the large earthquakes occurred throughout the United States. Many of these predictions compared favorably with the intensity iso-seismal maps estimated from historical records[3.1-31].

The USGS model will be used to predict the shaking intensity at the Cajon Pass region for all the referenced faults identified in Section 3.1.1. Several analyses will be conducted to evaluate the sensitivities of the various event scenarios postulated for the San Andreas fault, so that an appropriate scenario can be selected for the subsequent vulnerability analysis.

3.1.5 Topographic and Ground Relief Features and Landslide Hazards

A number of publications[3.1-19, 3.1-30, 3.1-38, 3.1-39] were reviewed and observed relics of landslides were used to develop a landslide map at Cajon Pass; this is shown in Figure 3.1-4. It was concluded that earthquake shaking will be one of the main triggering agents for landslides in the Cajon Pass area. A photograph showing very significant recent landslide scars where the Southern California Power Edison Co.'s power line transmission towers are located is presented as Figure 3.1-5. Figure 3.1-6 shows a typical landslide scar in the Lone Pine Canyon, the canyon which contains the San Andreas fault rift zone. It can be seen on Figure 3.1-4 that there are numerous landslide features at the Cajon Pass especially at areas where the Pelona Schist, ps, is the basement bedrock geologic unit. As discussed earlier, the Pelona Schist is the most landslide prone bedrock unit known in the study area[3.1-33]. This landslide map is presented to serve as an inventory of observed or recorded landslide features at the study area. It also can be used to validate landslide prediction models and analyses to be conducted in the subsequent damage evaluation report.

Although there are numerous analysis methods to analyze landslides for a variety of loading conditions (gravity, ground water seepage forces, and earthquake) in the literature, they are almost exclusively intended to be used for site specific studies. A frequently used analysis model for evaluating earthquake induced landslides that can be used in regional evaluations is a model presented by Wilson and Keefer[3.1-38, 3.1-40]. Their model has been used to analyze and correlate with slope failures from the

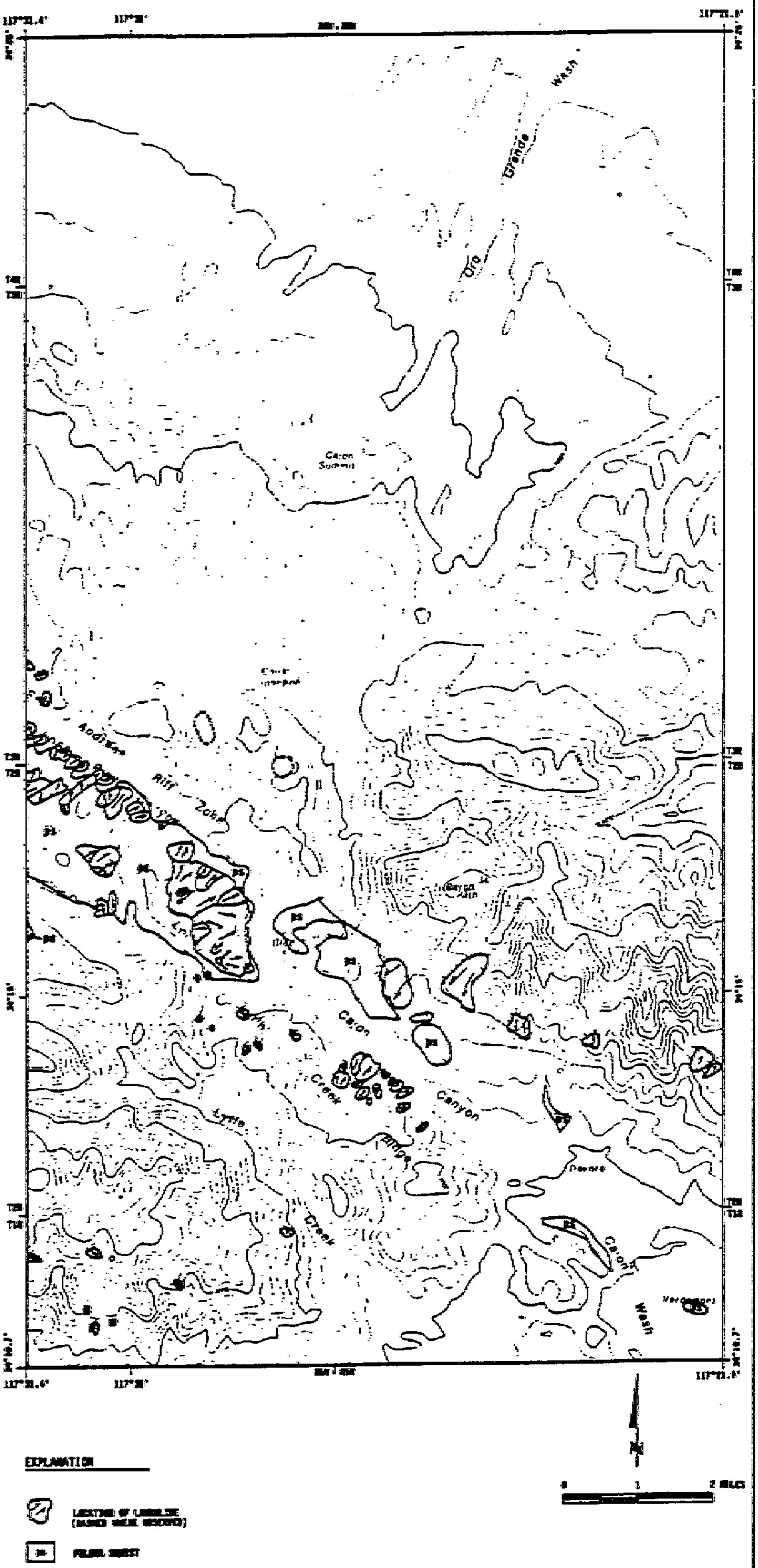

Figure 3.1-4 Observed Landslides Within the Study Area

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August 6, 1979, Coyote Lake, California, earthquake and the 1989 Loma Prieta earthquake. Preliminary information indicates that there is good agreement for the prediction with the Loma Prieta earthquake landslide data. Wieczorek[3.1-37] applied the analysis method to develop a map of relative landslide potential during earthquakes in San Mateo County, California. Nilsen, et. al.[3.1-39] also applied the method in a project jointly supported by USGS and the Department of Housing and Urban Development to develop maps of relative slope stability for land-use planning in the San Francisco Bay region, California.

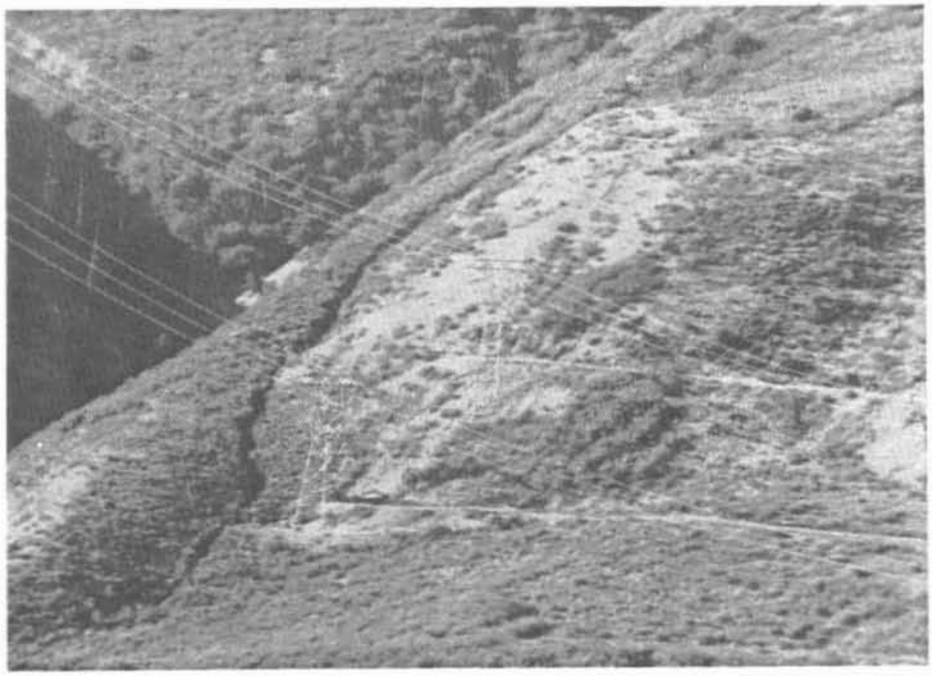

Figure 3.1-5 Rebuilt Power Transmission Towers on a Landslide Scar

Figure 3.1-6 Landslide Scar in Lone Pine Canyon Along The San Andreas Fault Zone

Wilson's method consists of the following basic steps:

Step-1 Solve for the factor of safety of the slope for a given combination of slope angle and soil strength.

Step-2 Using the Newmark method[3.1-43] and the factor of safety from Step-1, calculate the critical acceleration value which is the level of ground acceleration required to initiate downward slope movement.

Step-3 The above critical acceleration value can then be used in conjunction with a given design earthquake to solve for the magnitude of accumulated downslope movement associated with the design earthquake. This magnitude of accumulated slope movement is then used as an indicator of the potential for slope failure.

Wilson has presented several simplifying charts to facilitate application of the above procedures and they are summarized by Rojahn[3.1-13].

Existing information indicates that earthquake-induced landslides could pose significant damage to the lifelines at Cajon Pass. An evaluation of landslide potential will be very important in the current project. Wilson's method will be used to develop a map of the landslide potential at Cajon Pass. The digital elevation model data acquired in the course of the project will be used to develop a topographic map and subsequently a map of the ground relief data. Shear strength values will be assigned to each of the geologic units on the Cajon Pass geologic map. The ground relief and the shear strength maps will be used to calculate the critical acceleration value at each grid point in the study area. The critical acceleration and the MMI index value can be used to enter the tables provided by Rojahn to identify the slope failure state. The slope failure state can then be related to the lifeline damage state. This is similar to the analysis method of Wieczorek[3.1-37], where the landslide susceptibility was estimated in terms of a critical ground acceleration and a calculated slope displacement value. One advantage of this proposed method is that it relates the landslide susceptibility to the Modified Mercalli Indices as well as the geology and the slope of the surface formations.

3.1.6 Hydraulic, Groundwater Conditions, and Liquefaction Potential

The study area is situated far from oceans. There are also no major hydrologic features (lakes, rivers) within the study area. There are a number of minor creeks and streams (e.g. Lytle Creek Wash, Cajon Wash within the study area) which could be carrying large volume surface water during the rainy season (winter) or during flash floods. Therefore, areas where liquefaction could occur in the study area would be locations where the water table is close to the surface. The ground water table at Cajon Pass could fluctuate in relation to precipitation and ground-water management[3.1-34]. As an example from outside of the study area in the City of San Bernardino, the regional long-term trend is a lowering of the ground-water table due to withdrawal from water wells, although the City of San Bernardino is currently experiencing a rise in the depth-to-ground-water due to the reduction in agriculture and its impact on reducing the withdrawal rate of ground water in that specific local region. Available depth-to-ground-water maps[3.1-35] indicate that, in general, the water table will be relatively deep (over 100 feet) over most of the study region. However, perched water tables (5-20 feet deep) exist at isolated pockets within the study area.

In an effort to locate these pockets of higher perched water table zones, water-well data from the Department of Water Resource was examined. Locations of the water wells are identified in a map presented in Figure 3.1-7. Detailed information for the water well, including depth of the water table and date of the observation, are tabulated in Table 3.1-1. The water-well data were then divided into two categories:

- Shallow water table (depth less than 30 feet).
- Deep water table (depth more than 30 Feet).

Locations of shallow water table conditions are identified in Figure 3.1-4. and Figure 3.1-7. These are the locations where liquefaction could occur during an earthquake. It should be noted that due to the rugged terrain and sparse population in the study area, there is simply no well water data available over much of the Cajon Pass area. Therefore, it is fair to say that the map is incomplete and other locations with high perched ground water table could be present within the study area. Also, the dominance of fault features in the region adds complexities to the evaluation of the ground-water table conditions. Major faults appear to act as barriers to downslope movement of ground water, especially the San Andreas fault, as indicated by seeps and springs along many parts of the fault, particularly where it transects alluviated flood plains of canyons or alluvial slopes. In many instances along major faults, the ground water on the upslope side apparently backs up against the fault, which acts as an "underground dam", and the overflow reaches the ground surface as springs. The water table on the upslope side of the fault could be several tens of feet higher than on the downslope side of the fault. An example of this in the study area is the gravel pit located just south of Cajon Junction. On the upstream side of an apparent schist "dam" the water table is within 5-7 feet of the surface. Downstream of the schist the gravel pit operator had removed gravel at 50-70 feet below the surface and the pit was dry (when observed in the fall of 1990).

Although, widespread liquefaction is not expected at the study area, at local sites where the lifelines are collocated it can be anticipated that liquefaction could be the major factor for imposing collocation loads on the individual lifelines.

There are several liquefaction analysis approaches that can be used for regional evaluations. The most recognized model is the one by Youd and Perkins[3.1-41, 3.1-42]. The procedure used to determine areal variations in liquefaction potential requires the development of a liquefaction

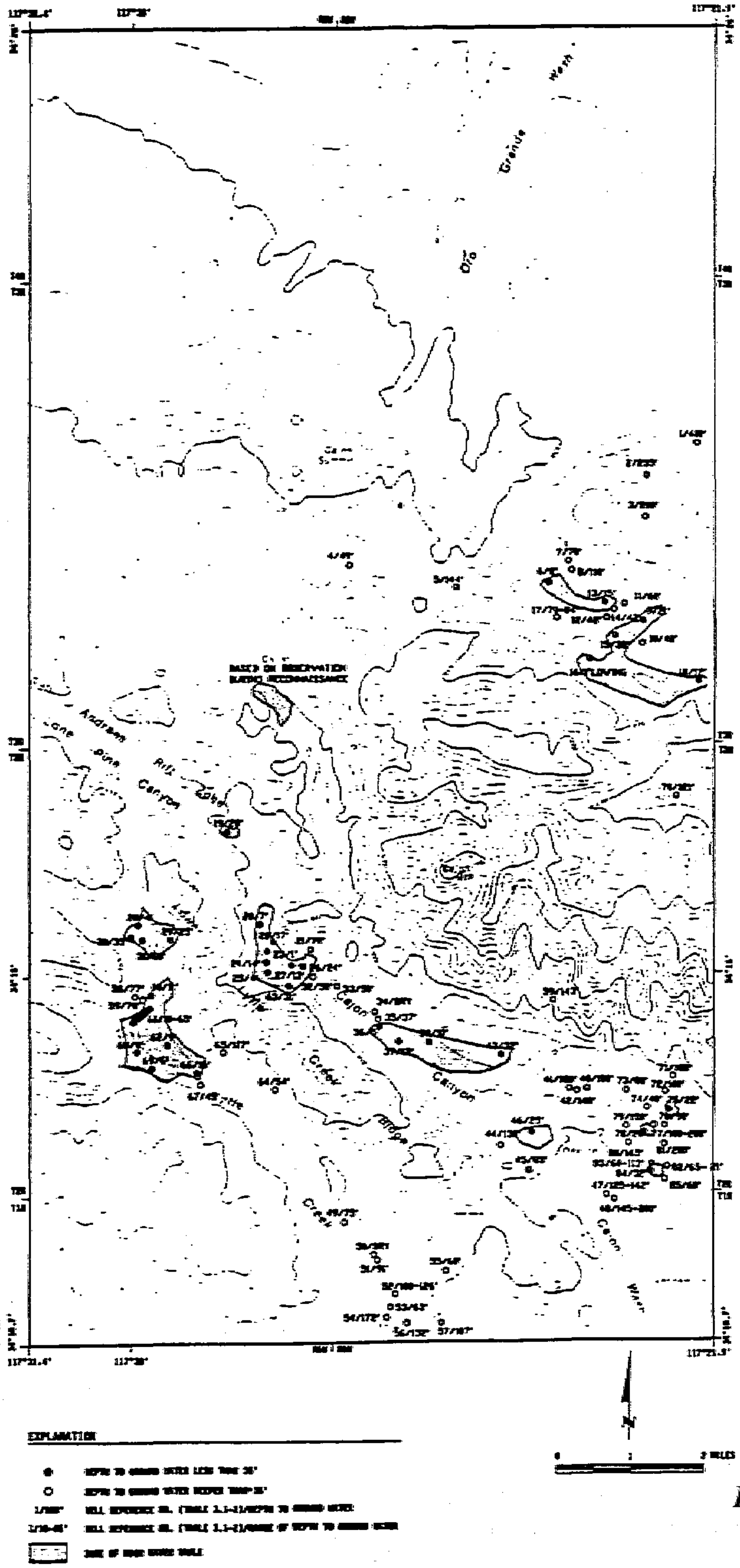

Figure 3.1-7 Location of Shallow Water Table Conditions

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Table 3.1-1, Depth to Ground Water Measured From Wells

Reference No.	Township & Range Section No.	State Well No.	Year	Depth (ft)
1	3N5W/11	R2	1984	410
2	14	D1	1963	255
3	14	N1	1984	200
4	19	M1	1986	49
5	20	Q1	1964	144
6	21	R1	1963	8
7	22	E2	1974	70
8	22	M1	1978	110
9	26	E1	1980	21
10	26	M1	1988	40
11	27	A1	1963	60
12	27	B1	1964	48
13	27	B3	1963	15
14	27	B4	1988	42
15	27	G1	1979	30
16	27	P1	1987	FLOWING
17	28	A6	1972	84
17	28	A7	1974	60
17	28	A8	1977	70
18	35	A1	1988	12
19	2N5W/11	B1	1955	28
20	13	E1	1967	7
21	13	K1	1951	70
21	13	K1	1960	70
22	13	M1	1967	17
23	13	M2	1967	1
24	13	N1	1967	14
25	13	N2	1967	4
26	13	Q1	1964	24
27	13	Q3	1967	13
28	15	F3	1964	4
29	15	J1	1980	25
30	15	L1	1986	35
31	15	L2	1985	30
32	24	A1	1985	50
33	19	D1	1979	50
34	19	K1	1970	DRY
35	19	K2	1987	37
36	19	Q1	1983	5

Table 3.1-1, Depth to Ground Water Measured From Wells
(Continued)

Reference No.	Township & Range Section No.	State Well No.	Year	Depth (ft)
37	2N5W/19	R1	1967	13
38	20	P1	1967	10
39	22	E1	1975	143
40	27	K1	1978	100
41	27	L1	1974	180
42	27	L2	1974	140
43	28	C1	1956	32
44	33	F1	1950	130
45	33	K1	1950	83
45	33	K1	1983	84
46	33	M1	1979	25
47	1N5W/ 3	A1	1927	125
47	3	A1	1982	142
48	3	A2	1952	145-200
49	6	G1	1987	75
50	6	K1	1953	DRY
51	6	K2	1987	91
52	7	H1	1931	126
52	7	H1	1977	117
52	7	H1	1987	100
53	7	H2	1918	63
54	7	J1	1918	172
55	8	B1	1938	60
56	8	N1	1918	132
57	8	Q1	1918	107
58	2N6W/22	F1	1988	77
59	22	F2	1987	70
60	22	G1	1988	11
61	22	L1	1988	52
61	22	L2	1987	35
61	22	L3	1986	38
61	22	L4	1985	60
61	22	L5	1985	64
61	22	L6	1985	60
61	22	L7	1985	25
61	22	L8	1985	10
61	22	L9	1985	60
61	22	L10	1987	50

Table 3.1-1, Depth to Ground Water Measured From Wells
(Continued)

Reference No.	Township & Range Section No.	State Well No.	Year	Depth (ft)
61	2N6W/22	L11	1986	40
61	22	L12	1987	65
61	22	L13	1986	32
62	22	P1	1986	9
63	24	C1	1967	31
64	25	L1	1985	54
65	26	B1	1978	117
66	26	L1	1982	15
67	26	L2	1973	45
68	27	C1	1985	8
69	27	G1	1985	6
70	1N5W/ 2	K1	1988	121
71	2N5W/26	G2	1979	180
72	26	K1	1978	100
73	26	M1	1977	80
74	26	P1	1979	40
75	26	Q2	1978	22
76	35	B1	1978	90
77	35	C1	1977	200
77	35	C2	1978	100
78	35	C3	1979	20
79	35	D1	1980	150
80	35	E1	1979	165
81	35	G1	1977	200
82	35	K1	1988	121
82	35	K2	1978	90
82	35	K3	1978	65
83	35	L2	1980	60
83	35	L3	1978	85
83	35	L4	1978	95
83	35	L6	1985	113
84	35	L5	1979	32
85	35	Q1	1977	60

susceptibility map and a liquefaction opportunity map. A liquefaction susceptibility map delineates areas where liquefiable materials are most likely to be present and is based chiefly on generalizations pertaining to the geology and hydrology of late Quaternary deposits in a sedimentary basin. The liquefaction opportunity map shows regions of earthquake shaking strong enough to generate liquefaction in susceptible materials and is based on an appraisal of regional earthquake potential. These two maps are then considered together to determine liquefaction potential, the relative likelihood that an earthquake will cause liquefaction in water-saturated cohesionless silts and sands that may be present. The use of this approach can also be validated with the analysis of Rojahn[3.1-13] where the liquefaction potential has been presented in a table and alternatively by the standard penetration resistance (e.g., blow count data) of the soils.

3.1.7 Bibliography For Section 3.1

3.1-1 J.I. Ziony & R.F. Yerkes, "Evaluating Earthquake and Surface-Faulting Potential", Evaluating Earthquake Hazards in the Los Angeles Region-An Earth-Science Perspective, USGS Professional Paper 1360, 1985.

3.1-2 "San Andreas Fault in Southern California : A Guide To San Andreas Fault from Mexico to Carrijo Plain", California Division of Mines and Geology (CDMG) Special Report 118, 1975.

3.1-3 "Earthquake Hazards and Tectonic History of the San Andreas Fault Zones, Los Angeles County, California", CDMG Open-file Report 85-10, 1985.

3.1-4 D.C. Ross, "Map Showing recently Active Breaks Along the San Andreas Fault Between Tejon Pass and Cajon Pass, Southern California", U.S. Geological Survey, Miscellaneous Investigation Series, Map I-553, 1969.

3.1-5 "The San Andreas Fault System", USGS Professional Paper 1515, Editor R.E. Wallace, 1990.

3.1-6 J.F. Davis, et. al., "Earthquake Planning Scenario for a Magnitude 8.3 Earthquake on the San Andreas Fault in Southern California", CDMG Special Publication 60, 1982.

3.1-7 J.F. Davis, et. al., "Earthquake Planning Scenario for a Magnitude 8.3 Earthquake on the San Andreas Fault in the San Francisco Bay Area", CDMG Special Publication 61, 1982.

3.1-8 R.W. Greensfelder, "Maximum Credible Rock Acceleration From Earthquakes in California", CDMG Map Sheet 23, 1974.

3.1-9 "Recent Reverse Faulting in the Transverse Ranges, California", U. S. Geological Professional Paper 1339, 1987.

3.1-10 M. Bonilla and J. Buchanan, "Interim Report on Worldwide Historic Faulting", USGS Open-File Report, 1970.

3.1-11 M. Bonilla, et. al. "Statistical Relations Among Earthquake Magnitude, Surface Rupture Length, and Surface Fault Displacement", USGS Open-File Report 84-256, 1984.

3.1-12 D. Slemmons, "Determination of Design Earthquake Magnitude for Microzonation", Proceedings of the 3rd International Conference on Microzonation, Seattle, Washington, 1982.

3.1-13 C. Rojahn and R. Sharpe, "Earthquake Damage Evaluation Data for California", ATC-13, 1985.

3.1-14 M. Bonilla, "Historic Surface Faulting in Continental United States And Adjacent Parts of Mexico," USGS Report (NTIS No. TID-24124), 1967.

3.1-15 "The Loma Prieta Earthquake of October 17, 1989, What Happened..... What is Expected.....What can be Done", USGS Memo, January 1990.

3.1-16 "Lessons Learned from the Loma Prieta, California, Earthquake of October 17, 1989", USGS Circular 1045, G. Plafker and J.P. Galloway, Editors, 1989.

3.1-17 "Loma Prieta Earthquake Reconnaissance Report", Earthquake Spectra, The Professional Journal of the Earthquake Engineering Research Institute, Supplement to Volume 6, Earthquake Engineering Research Institute (EERI), May 1990.

3.1-18 K.E. Meisling and R.J. Weldon, "Late Cenozoic Tectonics of the Northwest San Bernardino Mountains, Southern California", Geological Society of America Bulletin, V. 101, pp. 106-128, January 1989

3.1-19 P.M. Sadler and D.M. Morton, Editors, "Landslides in a Semi-Arid Environment with Emphasis on the Inland Valleys of Southern California", Landslides in a Semi-Arid Environment, Publications of the Inland Geological Society, Volume 2, 1989

3.1-20 R.J. Weldon, "The Late Cenozoic Geology of Cajon Pass; Implications for Tectonics and Sedimentation along the San Andreas Fault", Ph D. Thesis, California Institute of Technology, Pasadena, California, 1986.

3.1-21 R.J. Weldon et. al., "Implications of the Age and Distribution of the Late Cenozoic Stratigraphy in Cajon Pass, Southern California," San Andreas Fault, Cajon Pass to Wrightwood, American Association of Petroleum Geologist, Pacific Section, Volume and Guidebook Number 55, R. Hester and D. Hallinger, editors, 1984.

3.1-22 T.W. Dibbles, Jr., "Areal Geology of the Western Mojave Desert, California", USGS Professional Paper 522, 1067.

3.1-23 W.B. Joyner and T.E. Fumal, "Predictive Mapping of Earthquake Ground Motions", Evaluating Earthquake Hazards in the Los Angeles Region, USGS Professional Paper 1360, J.I. Ziony, Editor, 1985.

3.1-24 K.R. Lajoie and E.J. Helley, "Classification and Mapping of Quaternary Sediment for Purposes of Seismic Zonation", Studies for Seismic Zonation of San Francisco Bay Region, R.D. Borcherdt editor, USGS Professional Paper 941-A, 1975.

3.1-25 R.D. Borcherdt, "Effect of Local Geology on Ground Motion near San Francisco Bay", Bulletin of Seismological Society of America, v. 60, p. 29-61, 1970.

3.1-26 R.D. Borcherdt, et. al., "Response of Local Geologic Units to Ground Shaking", Studies for Seismic Zonation of San Francisco Bay Region, editor R.D. Gorchert, USGS Professional Paper 941-A, 1975.

3.1-27 "Landsliding and Mudflows at Wrightwood, San Bernardino County, California", USGS Special Report 136, 1979.

3.1-28 "Geologic Hazards in Southwestern San Bernardino County, California", USGS Special Report 113, 1976.

3.1-29 T.C. Hanks, "The National Earthquake Hazards Reduction Program-Scientific Status", USGS Bulletin 1659, 1985.

3.1-30 J.F. Evernden, et. al., "Seismic Intensities of Earthquakes of Conterminous United States - Their Predictions and Interpretations", USGS Professional Paper 1223. 1981.

3.1-31 J.F. Evernden and J.M. Thompson, "Predictive Model for Important Ground Motion Parameters Associated With Large and Great Earthquakes", USGS Bulletin 1838, 1988.

3.1-32 J.F. Evernden, et. al., "Interpretation of Seismic Intensity Data", Bulletin of the Seismological Society of America, v. 63, 1973.

3.1-33 D.M. Morton and R. Streitz, "Preliminary Reconnaissance Map of Major Landslides, San Gabriel Mountains, California", CDMG Map Sheet 15, 1969.

3.1-34 "San Bernardino County General Plan Update Background Appendix Draft: Water Distribution Systems, Groundwater Supply and Quality", Environmental Public Works Agency-Land Management Department, Office of Planning, Pages 113-165, April 1989.

3.1-35 "Meeting Water Demands in the Bunker Hill-San Timoteo Area", State of California, The Resources Agency, Department of Water Resources, Bulletin No. 104-5, December 1970.

3.1-36 E.J. Bertugno and T.E. Spittler, "Geologic Map of the San Bernardino Quadrangle", CDMG Geologic Map Series, Map No. 3A (Geology), 1986.

3.1-37 G.F. Wieczorek, et. al., "Map Showing Slope Stability During Earthquakes in San Mateo County, California", USGS Map I-1257-E, 1985.

3.1-38 R.C. Wilson and D.K. Keefer, "Predicting Aerial Limits of Earthquake Induced Landsliding", Evaluating Earthquake Hazards in the Los Angeles Region, USGS Professional Paper 1360, J.I. Ziony, Editor, 1985.

3.1-39 T.H. Nilsen, et. al., "Relative Slope Stability and Land-Use Planning in the San Francisco Bay Region, California", USGS Professional Paper 944, 1979.

3.1-40 R.C. Wilson and D.K. Keefer, "Dynamic Analysis of a Slope Failure From the 6 August 1979 Coyote Lake, California, Earthquake", Bulletin of the Seismological Society of America, Vol. 73, No. 3, pp. 863-877, 1983.

3.1-41 T.L. Youd and D.M. Perkins, "Mapping Liquefaction-Induced Ground Failure Potential", Proceedings of the American Society of Civil Engineers, Journal of the Geotechnical Engineering Division, V 104, No. GT4, 1978.

3.1-42 T.L. Youd and D.M. Perkins, "Mapping of Liquefaction Severity Index", Journal of Geotechnical Engineering, V 113, No. GT 11, 1987.

3.1-43 N.M. Newmark "Effects of Earthquakes on Dams and Embankments", Geotechnique, V 15, No. 2, p. 139-160, 1965.

3.2 COMMUNICATION LIFELINES

The Cajon Pass region includes hardwired and fiber optic telephone systems and microwave and radio towers. The hardwired telephone primarily services the local distribution system. The fiber optic lines primarily are transmission and major trunk lines. The microwave and radio towers serve both local communications within the Pass and transcontinental communication, but separate towers are used to support local or long distance transmission. The tower systems are identified in this study for completeness, but they are mostly isolated and thus have no direct collocation impacts. Figure 3.2-1 is a map of the communication lifelines. For reference purposes, the location of photographs provided in this Section are also shown on the Figure. Consistent with the concept used for evaluating other lifeline systems (that is, this study focuses on the

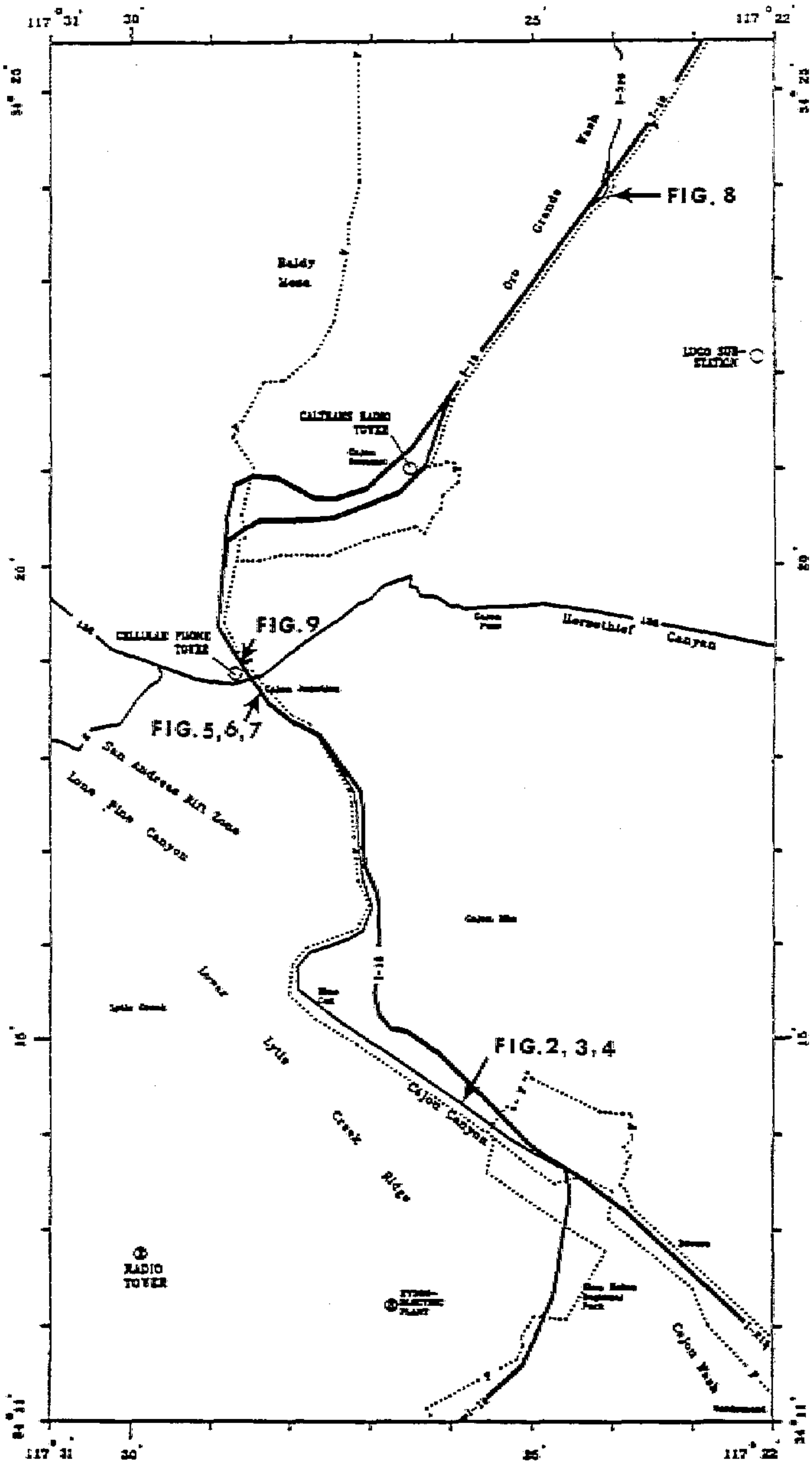

Figure 3.2-1 Map of the Communication Lifelines

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SCALE

0 1 2 MILES

0 1 2 KILOMETERS

N

EXPLANATION

I-15 INTERSTATE

PAVED HIGHWAY

F F FIBER OPTIC CABLE

transmission or primary systems and not the local or distribution systems), the hardwired and wooden pole telephone systems were not included in this study. However, the fiber optic systems are similar to a transmission system in that they are used to transfer many calls between the Los Angeles Basin and other regions in the nation. Thus, they were included in detail in this study. There are no state or Federal documented seismic criteria or standards for the installation of fiber optic cables, hence each company is free to include seismic considerations as it determines necessary.

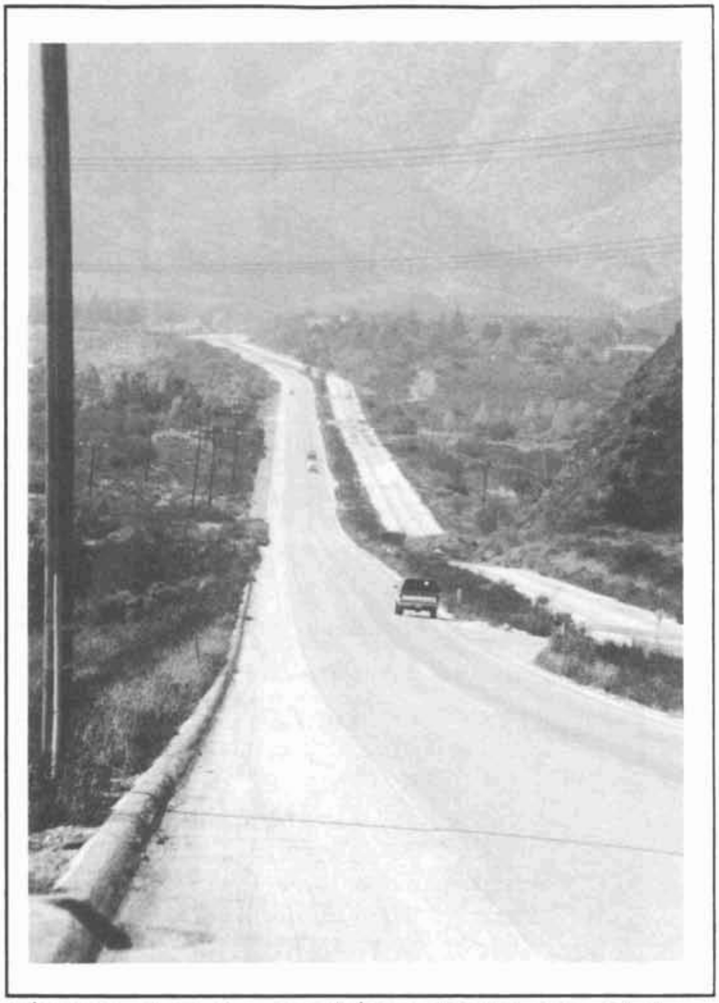

Figure 3.2-2, Looking North on Old Highway 66 (Now Cajon Canyon Rd.)

3.2.1 Fiber Optic Cables

On-site surveys identified that five fiber optic systems are located in the study area. They are American Telephone and Telegraph (AT&T), Continental Telephone (CONTEL), MCI Communications (MCI), WilTel (now WTG West), and US Sprint. Contact[3.2-1] was made with these firms, and AT&T, CONTEL, and US Sprint responded with information. Review of the U.S. Forest Service maps, on-site evaluations, and contact with the California Utility Underground Service were used to supplement the information and to obtain additional details on the routing of the various systems.

A fiber optic cable is a multi-layered cable with an inner structure that allows the cable to be pulled and maintained in a state of tension without putting tension on the individual glass fibers. Various materials are used for insulating the glass fibers, including a metal sheath. In the fall of 1986, both MCI and WTG West contacted the U.S. Forest Service to obtain right-of-ways for their cables (See Figure 3.2-1). To reduce the number of locations where trenching would be required, the Forest Service required each of those firms to trench conduits that could support four different fiber optic systems (for a total of eight systems in the two routes). They also required that the routes coincide whenever possible, so from just north of the Cajon Junction to the southern end of the old Cajon Canyon Road the cables are collocated (see Figure 3.2-2 which is a photograph of the old Highway 66, now called Cajon Canyon Rd.. Note that the divided highway has been converted to a two lane highway by blocking the eastern side of the road). Each of the firms installed two metal conduits. They are four inches in diameter and can accommodate up to three separate fiber optic cables in each conduit, although it is anticipated that at most eight separate firms will actually install cable in the conduits. AT&T was the last firm to install their cable, completing the work in late 1989.

The separate telephone connections for AT&T, MCI, US Sprint, and WTG West are parts of a much larger network owned by each of those companies. If there were problems with the cables in the Cajon Pass, the companies indicated that by rerouting the calls they could continue their service. A similar situation exists for CONTEL, except that they do not maintain as many separate lines from their Victorville, California, center to their Los Angeles Basin center. Thus, they may have to reroute their calls using the existing lines of one of the other firms identified above. The exact excess rerouting capacity of each firm is confidential.

Referring to Figure 3.2-1 and starting from the southern edge of the study area, the AT&T cable enters from San Bernardino on the eastern side of the study area. Much of its route is along city streets in San Bernardino and Devore, where AT&T already had existing right-of-ways. Part of the cable path is along the street parallel and next to I-215 (Outer Highway and Little League Drive). It crosses under highway I-15 at the Kenwood exchange. From there it enters the cable conduits installed by WTG West. The US Sprint cable also enters the study area from the Rialto area. It travels north on Sycamore street, then east on Highland Ave., then north on Macy St. until it insects Cajon Boulevard. It travels northwest along Cajon Blvd. parallel to the Atcheson Topeka and Santa Fe (AT&SF) and the Union Pacific railroads. At Devore it turns northeast along Devore Road. It crosses under I-215 along Devore Road and then turns parallel to I-15 along Nedlee Ave.. Just north of the I-15 and I-215 intersection it crosses under I-15 and connects to the existing fiber optics conduit (which was installed by MCI) located along the old Highway 66 (which is parallel and west of I-15). The WTG West cable enters the study area from the western side of the southern boundary. It heads northeast along Devore Road (which is north of and roughly parallel to I-15). It crosses the Lytle Creek Wash, turns south, and then crosses under I-15 where it continues to follow Devore Road. Next it enters Cajon Wash and crosses under the AT&SF and the Union Pacific railroads, then it turns northwest and crosses under I-15 near to the US Sprint cable. It enters the existing conduit at the same location that the US Sprint cable enters it, but it enters a different conduit. Also located in one of those two conduits is the CONTEL cable. The CONTEL fiber optic cable enters the study area from San Bernardino from the southeast study boundary. It moves northwest along Cajon Blvd., turns east on Devore Road and crosses under I-215. It follows Devore Rd., turns west along Kenwood Ave., crosses under I-15 along Kenwood Ave., and enters the conduit installed by MCI.

The fiber optic conduits (four in number) are located together and run mostly along the median region of the old Highway 66 (see Figure 3.2-2 which shows the general nature of the old highway and the wide nature of the Cajon Pass in that region). Again, in order to limit the amount of potential environmental damage due to trenching, the U.S. Forest Service had the fiber optic cables located parallel and near to the existing two petroleum product pipelines (an eight and a 14-inch line). The are routed in the median zone of the old Highway 66. The cables are located from one to four feet from the pipelines and are buried three to four feet deep (during the cable trenching, the pipeline operator indicated that the trencher struck the pipeline on at least two occasions, requiring repair efforts by the pipeline owner).

However, at bridge or culvert locations they are routed above ground along the bridge or above the culvert but still underground. Figure 3.2-3 is a typical example of the supports used to hang the cable conduits from the bridge. Earthquake criteria were not used in designing these supports. It is noted that this

Figure 3.2-3 Fiber Optic Conduits Crossing a Cajon Canyon Road Bridge

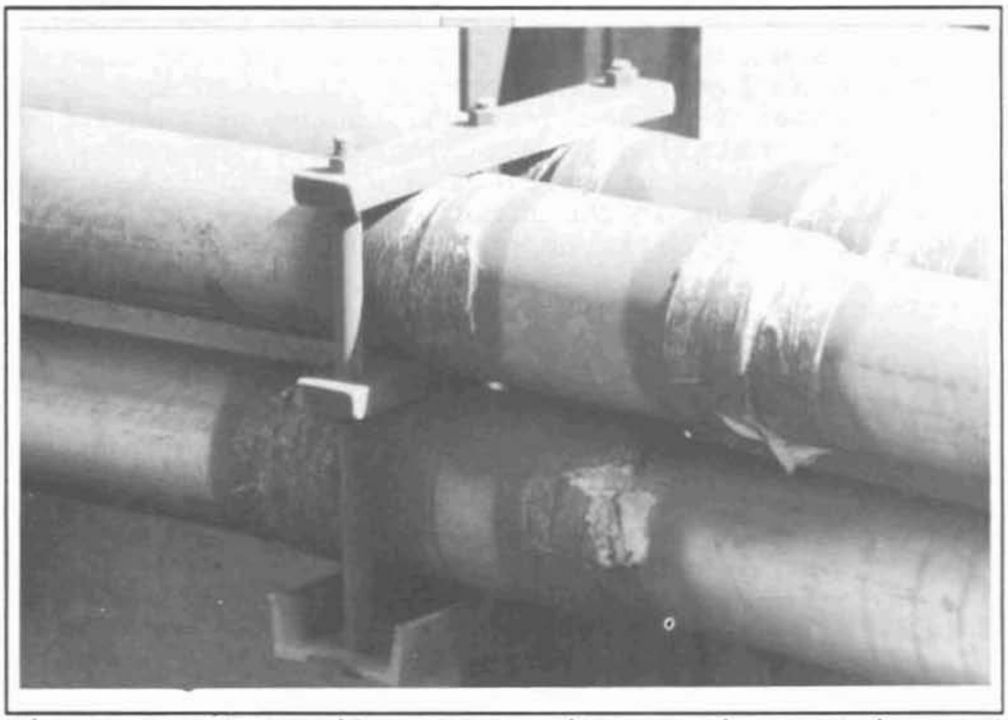

Figure 3.2-4 Details of the Fiber Optic Conduits and Hangers on a Cajon Canyon Road Bridge

side of the Cajon Canyon Road and the bridge are "abandoned" and some concrete spalling of the piers was noted during the site inspections. Figure 2.3-4 gives further details of the conditions of the conduits and their wall supports.

Figure 3.2-5 Crib Wall Retaining the Southbound Lanes of I-15 With Fiber Optic Conduits Buried at the Wall Toe

Continuing north, the cables pass at the toe of a crib wall used to retain the southbound lanes of I-15 (see Figure 3.2-5). That site is a potential liquefaction site due to the high water table and alluvium deposits. Immediately north of the crib wall the conduits are brought to the surface and hung from a concrete wall that forms a culvert under I-15. Figure 3.2-6 shows details of how the conduits are hung from the concrete, and Figure 3.2-7 shows then entering the culvert as they head north and under I-15. On the eastern side of I-15 they are again buried and routed north along Baldy Mesa Rd. (an unimproved dirt road at this location).

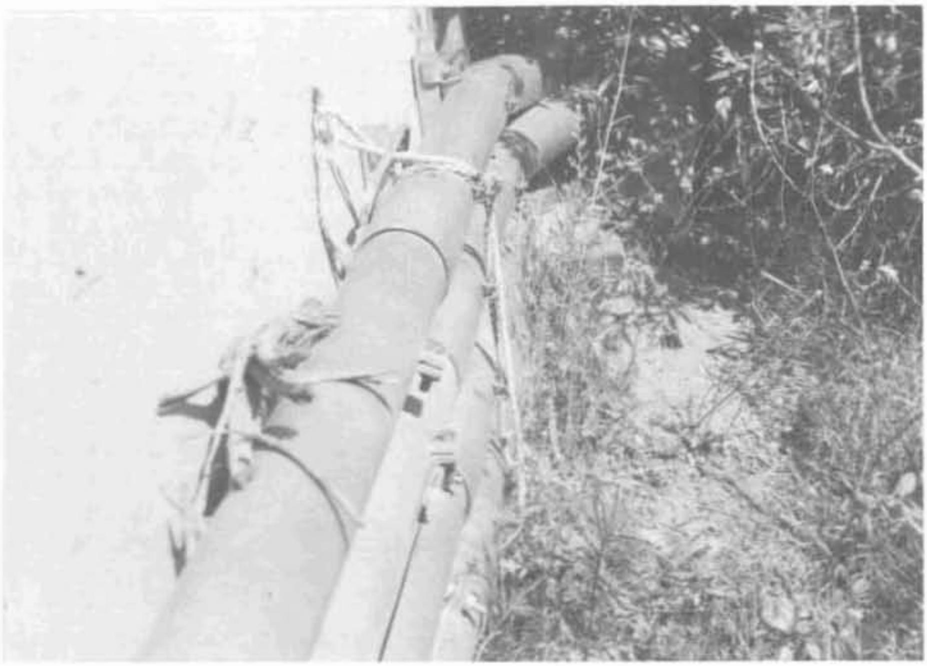

Figure 3.2-6 Details of Fiber Optic Conduits Supports on a Concrete Culvert Wall

North of Cajon Junction, as the

fiber optic conduits follow Baldy Mesa Rd., they cross under several old AT&SF, Southern Pacific, and Union Pacific railroad bridges (which are discussed in Section 3.5 of this report). After crossing under the Southern Pacific railroad bridge the conduits separate. Two conduits containing CONTEL, MCI, and US Sprint continue northward along Baldy Mesa Road. AT&T and WTG West conduits turn east and follow parallel to the Southern Pacific railroad line along an unimproved access road.

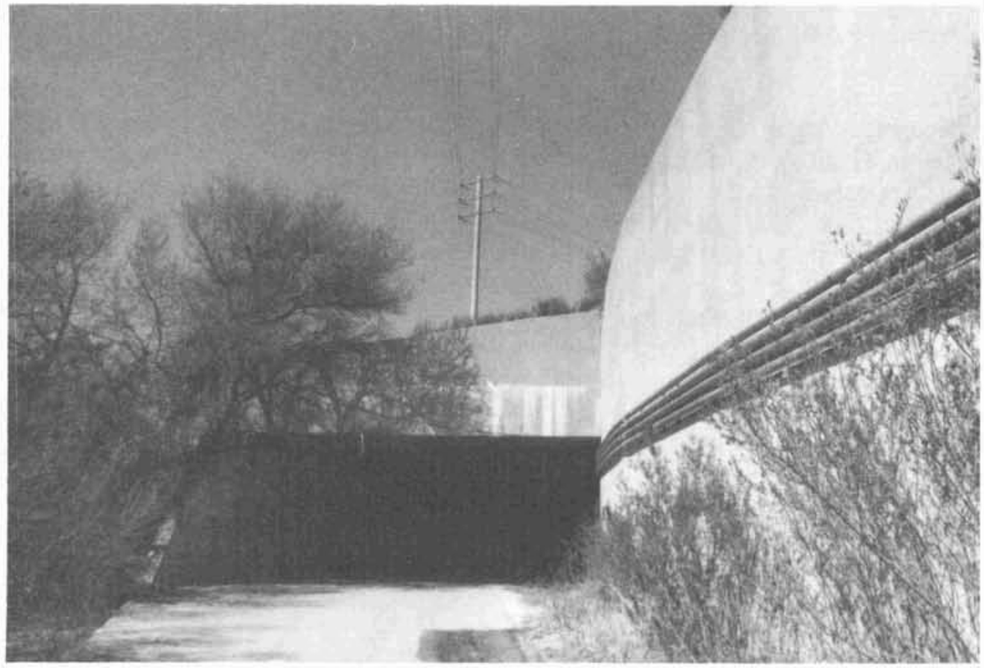

Figure 3.2-7 Fiber Optic Conduits Heading Under I-15, Attached to a Concrete Culvert Wall

After about 2.25 miles the unimproved road (and AT&T and WTG West conduits) turn north by northeast. The conduits follow this winding road and approach the north bound section of I-15 about 0.5 miles south of the first I-15 intersection north of the Cajon Summit (the Caliente and Mariposa intersection) where they connect with and then follow the route of Mariposa Road. Mariposa Road runs parallel and east of the northbound lanes of I-15. As was done on the old Highway 66, whenever there is a bridge on the Mariposa Road the conduits are placed above ground on the bridge. Figure 3.2-8 shows a typical conduit routing at a bridge. The figure shows an additional pipe (believed to be an unidentified water distribution pipe) hung directly above the conduit.

The CONTEL, MCI, and US Sprint conduits, after separating from the AT&T and WTG West conduits, continue to follow Baldy Mesa Road. The cross under the north bound lanes of I-15 next to the location where two petroleum products pipelines cross under the highway. They then separate from the products pipelines and continue north until they approach the south bound lanes of I-15. Again, they combine with the petroleum products pipelines to cross under I-15. Thereafter, they continue within the petroleum products pipeline rights-of-way. This route also places them (and the petroleum products pipelines) parallel and near to the Los Angeles Department of Water and Power's two high voltage transmission lines. When the power transmission lines join with Baldy Mesa Road the conduits (and the petroleum products pipelines) are routed along the road next to and between the two power transmission lines. After about 2 miles, Baldy Mesa Road turns due north and leaves the power transmission lines. The fiber optic cables and the pipelines continue along Baldy Mesa Road. About 1.5 miles further north they are joined by a 36-inch natural gas transmission line, and all of these lifelines continue along Baldy Mesa Road until they leave the study area. It is instructive, however, to examine how the cables and pipelines cross over the California Aqueduct (about another 2 miles north of the study northern boundary. All of the lifelines are brought to the surface to cross the aqueduct. One fiber optic cable conduit is hung from the side of the bridge with light fasteners as was done on other bridges. The other conduit is hung under the bridge. The petroleum products pipelines also are hung from the bottom of the bridge while the natural gas pipeline separately spans the aqueduct (see Section 3.4 for photographs of how these fuel pipeline lifelines cross the aqueduct).

Figure 3.2-8 A Fiber Optic Conduit Hung From a Bridge With a Water Distribution Pipe Directly Above It

3.2.2 Microwave and Radio Towers

Because of their remote locations and the need to use trucks with winches in order to assure travel to their sites, the radio and microwave towers that support regional communications were not examined during the site visits. The cellular phone and radio towers which are used by CALTRANS and PAC TEL for local communications within the Cajon Canyon Pass itself were examined during the site visits. Refer to the map of Figure 3.2-1 for the following discussions.

Starting from the southern boundary of the Cajon Pass study region, a radio tower is located at the western edge of the study boundary about two miles west of the Los Angeles Department of Water & Power's high voltage transmission lines and about 2.5 miles north of the southern edge of the study boundary. It is serviced by an unpaved road and distribution electric power lines. Plans call for the expansion of this site into a much larger communications center. At that time the collocation of the communications equipment with the electric and telephone service may create some at-risk siting conditions. However, for the present study it is an isolated communications facility.

East of Interstate I-15 and about 4.5 miles east of the western edge of the study boundary and 6.3 miles north of the southern edge of the study boundary is a microwave tower (it is sited near the Cajon Mountain Lookout station). Access to this remote site is by unpaved roads from the Silverwood Lake State Recreation Area, which is to the east of the study area. This tower is part of the regional telephone communications system, but its isolated site means that it does not cause impacts due to collocation of lifelines.

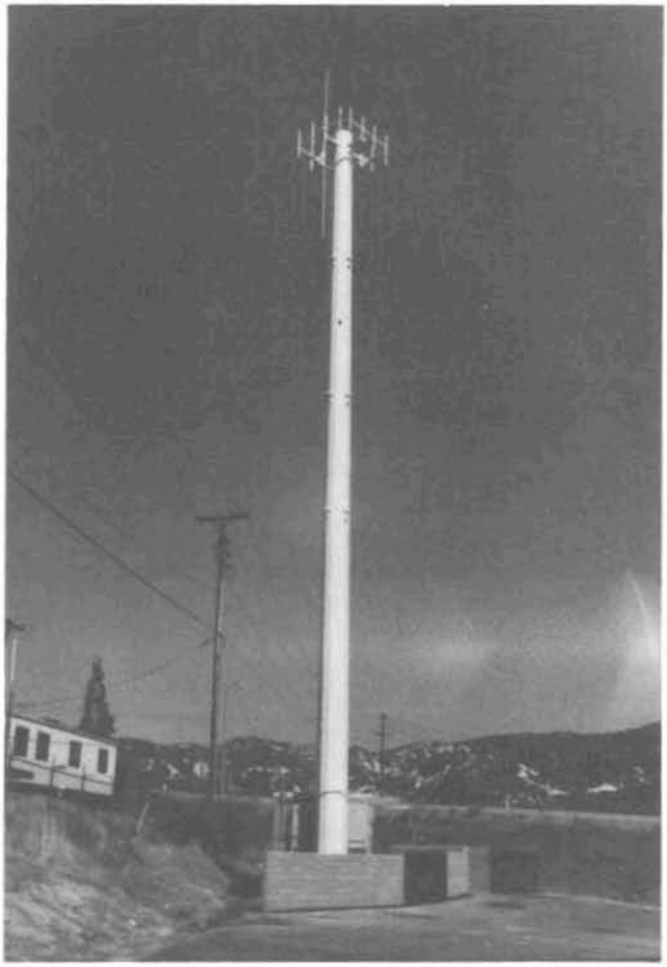

Figure 3.2-9 Cajon Junction Cellular Phone Antenna

The cellular phone antenna is located behind a motel at the Cajon Junction for highways I-15 and 138. Figure 3.2-9 is a photograph of the tower. It is located near to a motel and a large motel water storage tank (which isn't shown in the figure). Seismic design criteria were not specified for the cellular phone antenna or the water storage tank. The tower provides for stationary and mobile cellular phone communications within the Cajon Canyon area, which otherwise would be in a dead band area for such communications.

At the Cajon Summit located between the north and south bound sections of I-15 (about 11.7 miles north of the southern edge of the study boundary and 3.5 miles east of the western edge of the study boundary) there are two communication towers. One tower provides for microwave telephone communications on the AT&T system. It is aligned with other microwave towers outside the study boundaries, and it connects the high desert region with the Los Angeles Basin microwave systems. The second tower is used by CALTRANS[3.2-2] to provide a communications link between the maintenance facility and radios installed in their service vehicles. It allows the Cajon Junction maintenance station to communicate both southward through the Cajon Canyon and northward to regions below the Cajon Summit (without the tower the summit would shadow the northern regions from a communications viewpoint).

3.2.3 Bibliography for Section 3.2

3.2-1 Source of information: discussions with US Sprint, discussions and construction drawings and routing maps from AT&T, CONTEL, and discussions with and routing maps from the US Forest Service.

3.2-2 Source of information: discussions with the CALTRANS staff at the maintenance station at Cajon Junction.

3.3 ELECTRICAL POWER LIFELINES

The electric power lifelines (See Figure 3.3-1) located in the Cajon Pass study area include a hydroelectric power generation station, high voltage transmission lines, a transmission system substation, and wood pole distribution lines and transformers. For reference purposes, the locations of the photographs provided in this Section are shown on the Figure. In accordance with the basis for this study, only the facilities that relate to regional or bulk transfer of electrical energy are being examined. Thus, the distribution systems are not described.

Some of the electric power towers have two circuits of three wires each and some have one circuit of three wires. In conversation, the circuits are often referred to as "lines". Multiple circuits on a single tower save right-of-way acquisition and construction costs, but the towers are larger and cost more. Wind loading criteria generally control the tower designs. Specific earthquake design criteria usually are not applied. However, operating experience throughout the industry has confirmed that towers so designed will perform well under earthquake conditions.

The maps of the U.S. Geological Survey were used as a starting point to locate the appropriate electrical power lifelines. An initial site survey confirmed that not all of the transmission lines were identified on the maps. Subsequent meetings with the lifeline owners were held to gather detailed information, and that information was validated by additional site visits, meetings with regulators, and examination of the right-of-way files of the U.S. Forest Service.

The City of Los Angeles Department of Water and Power is self-regulating with respect to applying, implementing, and inspecting the application of seismic hazard standards. The California Public Utilities Commission regulates the activities for the Southern California Edison Company facilities in the Cajon Pass. However, their criteria are general and non-specific in nature, mostly requiring that the consequences of earthquake events be accounted for in the design, siting, and operation of the electric lifelines. Consequently, the transmission systems are not designed to specific seismic standards, but are designed to standards, including wind loading, which have been accepted as "being more restrictive than would be seismic standards alone".

3.3.1 Los Angeles Department of Water & Power Facilities

The Los Angeles Department of Water and Power owns two 287.5 kV

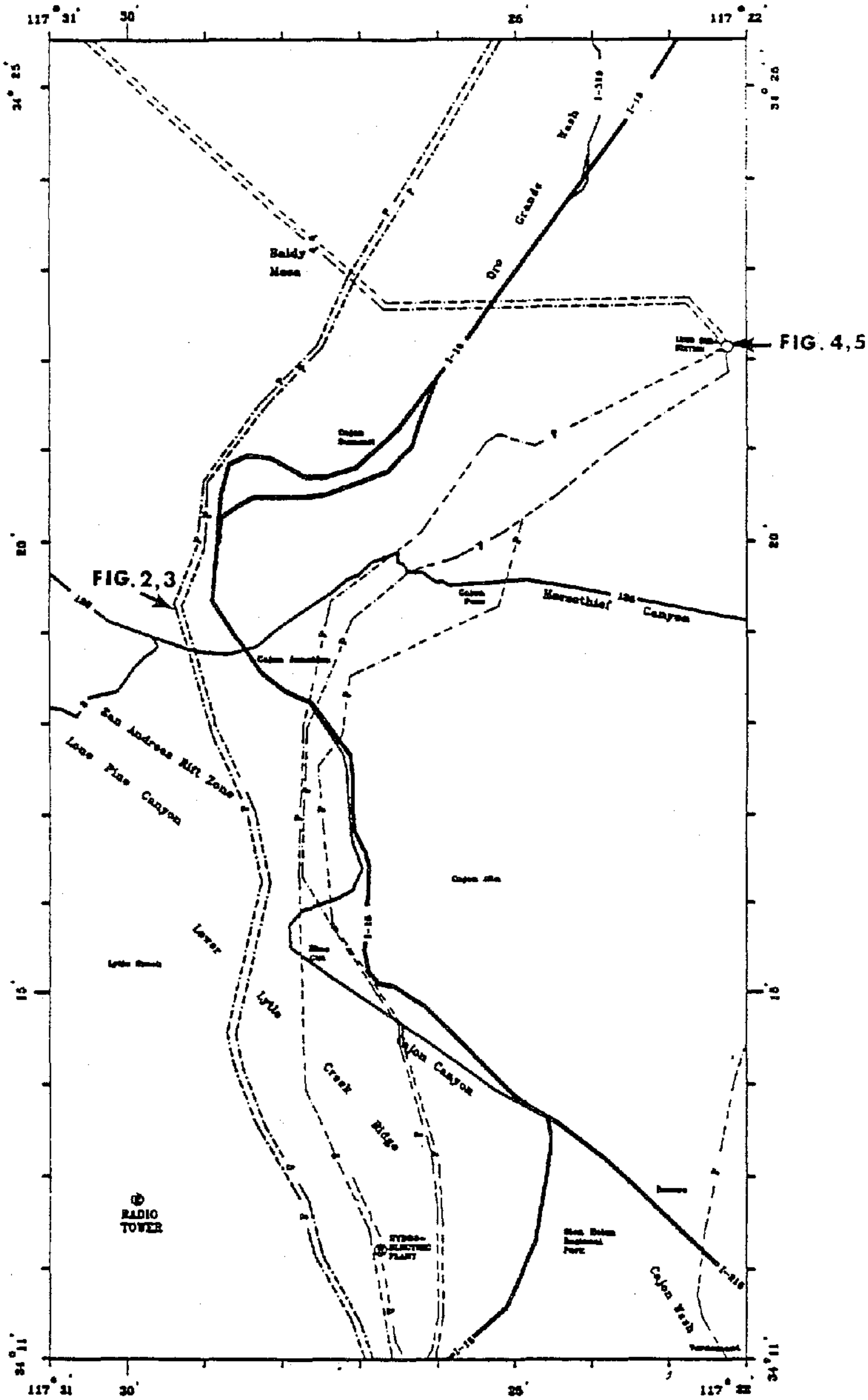

Figure 3.3.1 Map of the Electric Power Lifelines

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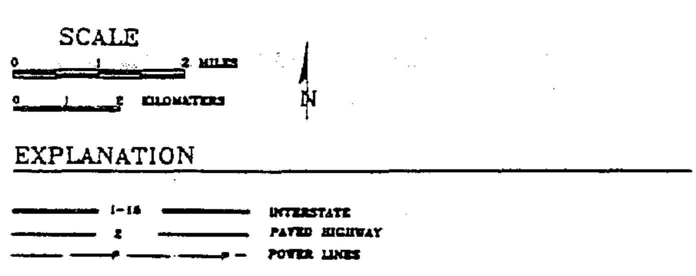


transmissions lines that pass through the study area. They were installed in 1936 to transmit power from the Hover Dam hydroelectric project in Nevada. At that time they were the highest voltage, long distance transmission lines in the world. Although seismic design criteria were not explicitly considered, the transmission system was at the leading edge of technology at that time, and it was conservatively designed. It has performed well except for some local impacts due to soil flow, landslides, and brush fires. The conductor is an air insulated, hollow, segmented copper cable. The system is considered by the Department to be more than adequately designed when compared to current Department design standards.

Today, these lines can transmit up to about 600 MW of power. They transmitted 95% of the City of Los Angeles' power supply when they were built, they now transmit about 5% of the City's power needs. However they are also important in assisting in voltage control and in maintaining transmission system reliability.

North of the study area the transmission lines are connected to the Victorville Substation, south of the study area they are connected to the Century Substation in Los Angeles. Originally completed in 1936, the Victorville Substation has been updated in 1970, 1974, and 1980 to add switching capabilities between the 287.5 and 500 kV lines as well as other system controls. Seismic criteria have increased over this time period, and the 1985 Adelanto converter and switching station (which permits switching to and from the Victorville station) included subjecting full-scale equipment to shaker table tests before accepting the equipment.

Figure 3.3-1 shows the route of the transmission lines. Starting from the southwest border of the study area, the transmission lines move northeast along the foothills of the National Forest. The two transmission lines are routed parallel throughout the study area. An access road is provided along the route. In this region, prior brush fires have annealed the copper conductor cables causing them to sag. Repairs have restored their ground clearance. At the edge of the

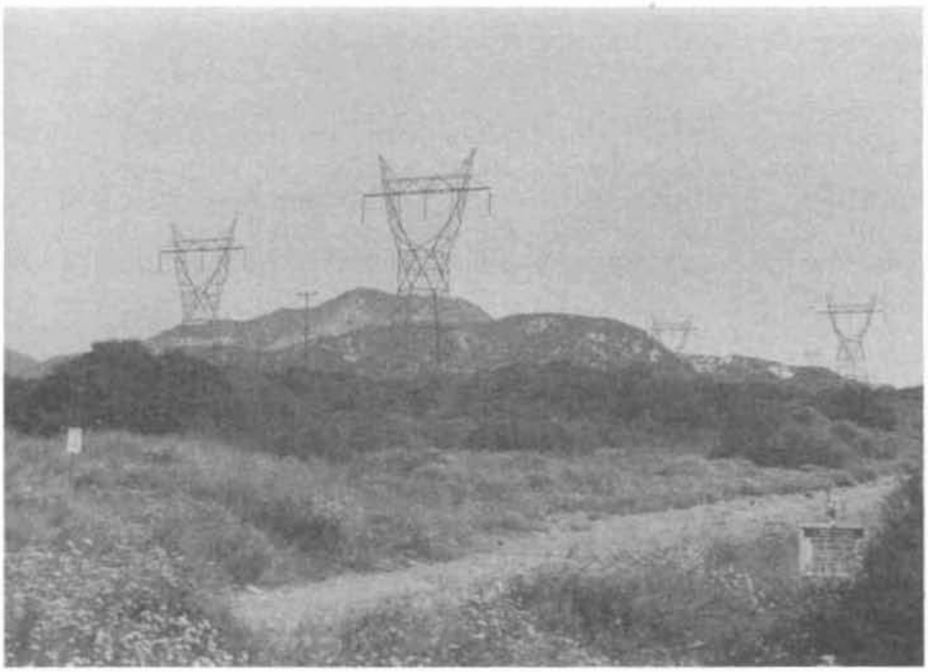


Figure 3.3-2 A View of Power Lines and Buried Fuel Pipelines Crossing the San Andreas Fault Zone

foothills and the Lytle Creek Wash they turn north by northeast and are routed in the steep portions of the west side of Lytle Creek Canyon. The October 1990 and August 1991 brush fires in Lytle Creek annealed parts of these lines, causing them to sag. The repairs are implemented by retensioning and replacement/retensioning, as appropriate.

Just south of the Lytle Creek Ranger Station the lines turn north and cross Lytle Creek Canyon. They are routed through steep, difficult to access terrain. It was reported that there have been rain-induced landslides in this area that have impacted towers, necessitating repairs. These locations were not observed during the site visits. The lines turn lightly north east and descend down from the higher mountains to the Cajon Canyon floor near Blue Cut. There they also pass near the railroad lines. They continue north by north west across the Lone Pine Canyon, which also contains the San Andreas Rift Zone. They cross the Rift Zone in a north west direction, indicating that fault movement can be expected to add slack to the lines crossing the fault (the San Andreas is a right lateral fault). Figure 3.3-2 shows the power lines where they cross the San Andreas Fault. They are located above and close to a 36-inch buried natural gas pipeline and the 8-inch and 14-inch petroleum products pipelines (they actually cross over the petroleum products pipelines and are roughly parallel to the path of the natural gas pipeline). Figure 3.3-3 is a photograph taken in the opposite direction to Figure 3.3-2. It shows that the power tower immediately before the intersection of the power lines and the fuel pipelines is located at the edge of a steep ravine. Also, the tower shown is typical of the design used at Cajon Pass.

About 0.75 miles south and west of Cajon Junction the lines cross over a small bowl. This region experienced slow ground sliding towards the center of the bowl. Over 15-20 years the movement was enough to put slack into lines within the bowl and tension on the lines just outside the bowl. The Department has reset the towers and placed soil-concrete mixtures and drains on the bowl surface. It appears that by moving surface

Figure 3.3-3 Power Towers At The Edge Of A Steep Ravine Near The San Andreas Fault Zone

waters out of the bowl the slow sliding has been arrested. However, during an earthquake liquefaction or ground sliding might occur in this region.

The lines cross the railroad tracks south of Highway 138 and west of I-15 near the Cajon Junction. Next they continue north by northwest, turn northeast, and again cross the railroad tracks. They then approach parallel to the south bound route of I-15 (just south of where I-15 divides into widely separated north and south bound segments). Thereafter, they continue north parallel to the southbound segment of I-15 and the petroleum products pipelines. When I-15 turns east the transmission lines turn northeast and connect with the general route of Baldy Mesa Road. The terrain is very steep as they move up the Baldy Mountain slope, and surface erosion is a continuing problem. In this area and along the Baldy Mesa Road the power transmissions lines are parallel to petroleum products and fiber optic lifelines. After the Cajon Summit the power lines proceed northeast and continue in a straight path until they leave the study area. In this downslope side of the high desert region they also cross under two 500 kV Southern California Edison power lines and over the Southern Pacific Railroad line.

3.3.2 Southern California Edison Company Facilities

Figure 3.3-1 also shows the location of the Southern California Edison (SCE) electric power lifeline facilities. This includes a hydroelectric power generation station in Lytle Creek, a major Substation (Lugo Substation) in the northeast portion of the study area, and a number of high voltage power lines. Three 500 kV transmission lines (the Lugo:Mira-Loma lines) run north-south through the Cajon Pass, a short segment of the Arrowhead:Calectric Shannin 115 kV line passes through the southeast section of the study area in the Devore-San Bernardino area, and two Lugo:Vincent 500 kV transmission lines pass from east to west through the northern half of the study area (north of the Cajon Summit in the high desert region). The high voltage transmission lines are air insulated aluminum lines with a steel core that provides the needed tensile strength.

The Lytle Creek Hydroelectric power generation station (located about two miles north of the study southern boundary) uses the surface runoff of Lytle Creek for its water supply. There is some capability to pump from deep wells to add water flow to this station, if needed. The station was built in 1904 and has operated since then. It directs the Lytle Creek through a 3,092 foot channel to the buried penstocks. From there, the water is directed underground in a piping system through the Lytle Creek Wash to a second hydroelectric station at Fontana just outside the southern boundary of the study area. Afterwards the water is treated and distributed to local water districts for their subsequent use. The Lytle Creek substation is rated at 680 kW, but in 1989 it generated at an average daily power level of just under 300 kW. Its output is transmitted at 12 kV on a wood pole distribution system.

The Lugo Substation is located at the eastern edge of the study boundary and about 4.5 miles south of the northern boundary. It is just south of the City of Hesperia. It is a major lifeline facility, it handles over 2,500 MW of power, and it provides interconnections and switching between five 500 kV SCE transmission lines and a 500 kV Los Angeles Department of Water and Power line (that line's connection to City ownership is north and outside of the study boundaries). Figure 3.3-4 shows the administrative and control facilities housed a brick building, the communications microwave tower that provides SCE with a secure, direct, communications link with the substation, and some of the station equipment. Most of the facility was designed for a 0.2g horizontal load. Figure 3.3-5 shows the circuit breakers in more detail. After the 1971 San Fernando earthquake the circuit breakers were retrofit with earthquake resistant bases and their clamp anchorage was welded to their skid frames for more positive anchorage. The transformers

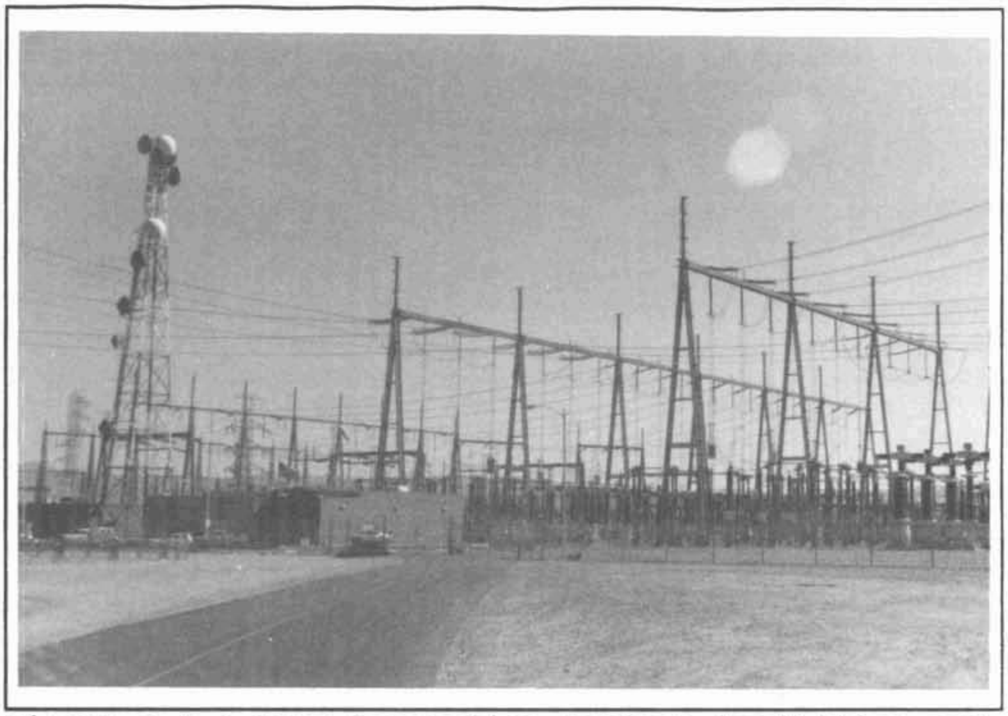


Figure 3.3-4 Lugo Substation Control Facilities and Equipment

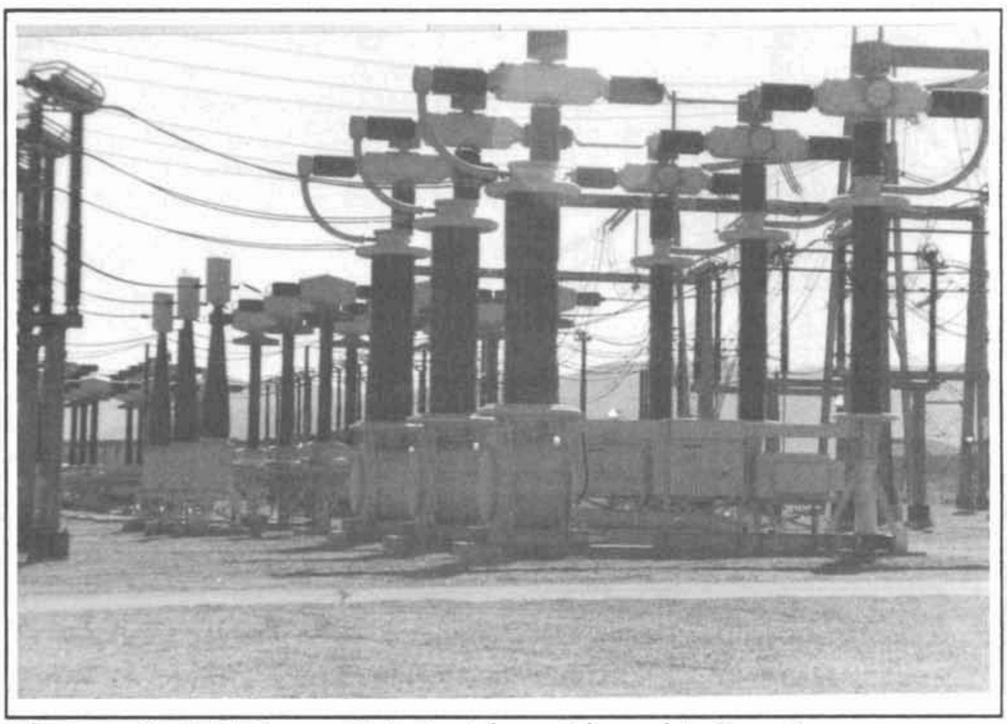


Figure 3.3-5 Lugo Substation Circuit Breakers

have also had their anchorage improved with welding and clamping to their skids. Recent purchases for the station have been designed against a 0.5g dynamic evaluation criteria. Although SCE recognizes that the station is still subject to equipment failures during an earthquake, they have extensive plans for mitigating the impact of such an event (e.g., managing the risk of failure). For example, they have alternative plans that could keep the substation on line under emergency conditions using as few as about 10% of the circuit breakers.

Starting from the southern boundary of the study area, SCE has three 500 kV transmission lines that connect the Lugo and Mira-Loma substations. Two of the lines were installed in the early 1960s for about 300 kV service. They were upgraded to 500 kV service in the early 1970s, and the third line was added in 1983. A single tower system brings the lines north by northeast to the study boundary. The original two lines split into separate tower systems just inside the study boundary. Just outside the study boundary the new line separates from the single tower system and heads due east. It turns north at the Lytle Creek Wash and rejoins the most eastern of the two original lines. The western line heads approximately due north crossing the railroads (several times) and the old Cajon Pass highway near Blue Cut. North of Blue Cut it is rejoined by the second original line and both head due north.

The new transmission line joins the most eastern of the original lines in a parallel tower system just north of the southern boundary of the study area at the mouth of Lytle Creek. Together they head up the steep slopes of the lower Lytle Creek Ridge and then descend to the floor of Cajon Pass. In the 1970s there was a landslide on the slope just before where they reach the Cajon Pass floor. It damaged the towers and they had to be repaired. Figure 3.1-5 shows the landslide scar and the towers that were rebuilt on the scar.

After the landslide area, the two lines cross over the Cajon Canyon and run approximately parallel to the west side of I-15. Figure 3.3-6 shows typical tower footings. SCE reported that mostly bell

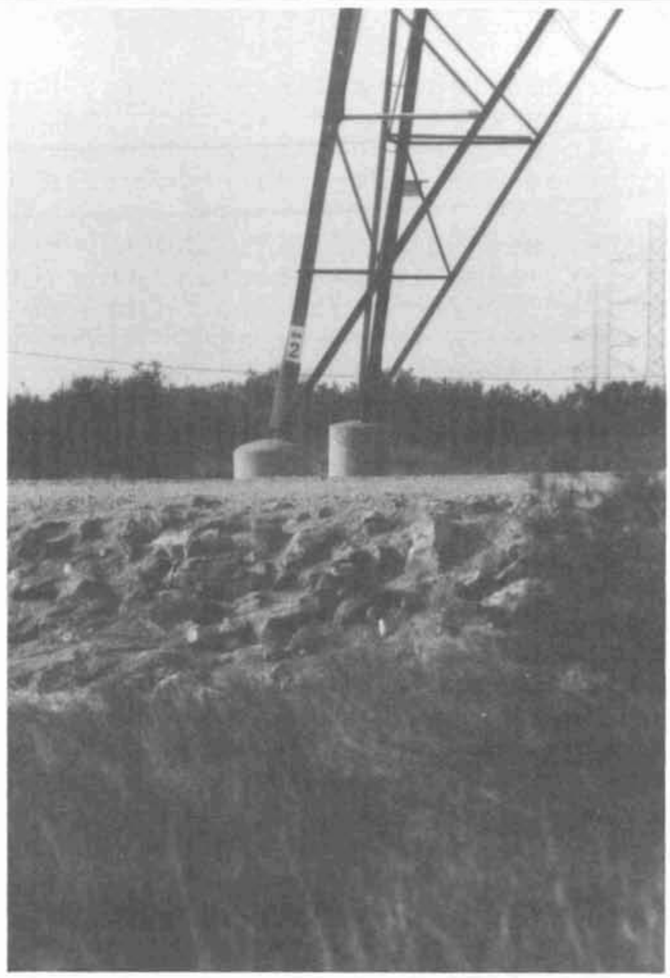


Figure 3.3-7 Typical Electric Transmission Tower Footings

foundations are used, and if they can't be formed then deep column footings are used. At Blue Cut the new line separates from the older original line while the older line continues northwest until it joins the other original line. The new line crosses over the railroads and Highway I-15 about 2 miles north of where it separated from the original line. It then travels on the east side of I-15 by itself until it joins the eastern most of the original lines north of the railroad summit and north of highway 138. All of the power lines cross the San Andreas Rift Zone just north of Blue Cut. Fault movements should put slack into the lines that bridge the fault.

After they rejoin just north of Blue Cut, the two original lines travel north for about two miles. This takes them back into steep terrain. Just before they redescend to the Cajon Pass floor about 0.5 mile south of Cajon Junction, they approach the railroads, petroleum pipelines, fiber optic lines, and highway I-15. It is noted that just before the location where the towers descend in this region there was some surface erosion or displacement near the tower foundations. SCE has protected those towers by covering the ground surface with a soil-cement to seal the surface material.

The original power lines proceed northeast but are more widely separated than they were in the southern section of the study area. All three of the lines come together at the Lugo Substation. Then they continue northeast and leave the study area.

Another set of two, SCE, 500 kV, power transmission lines (the Lugo-Vincent line) leave the Lugo Substation heading northwest, then they turn due west. Since they are on the north side of the Cajon Summit they are in relatively flat terrain. About 1.25 miles after they cross I-15 they turn northwest and leave the study area. They are connected to the Vincent Substation to the northwest.

The third SCE transmission system is the 115 kV line that enters and exits the study area in the Devore region. This lifeline was not examined in detail, but it is interesting to note that in November 1990 a high wind caused a power line in the foothills behind Devore to break. The downed line ignited a brush fire which burned about 200 acres, destroyed four homes, and damaged others. The towers, however, were not damaged by the wind. That incident points out that the danger to transmission lifelines is not just a tower failure, but also a line break.

3.3.3 Bibliography For Section 3.3

No reports were used for this section of the report, the information was obtained during direct discussions with the lifeline owners.

3.4 FUEL TRANSPORTATION LIFELINES

The fuel pipeline lifelines (see Figure 3.4-1) in the Cajon Pass study area include two high pressure petroleum products transmission lines, two high pressure natural gas transmission lines, and an intermediate pressure

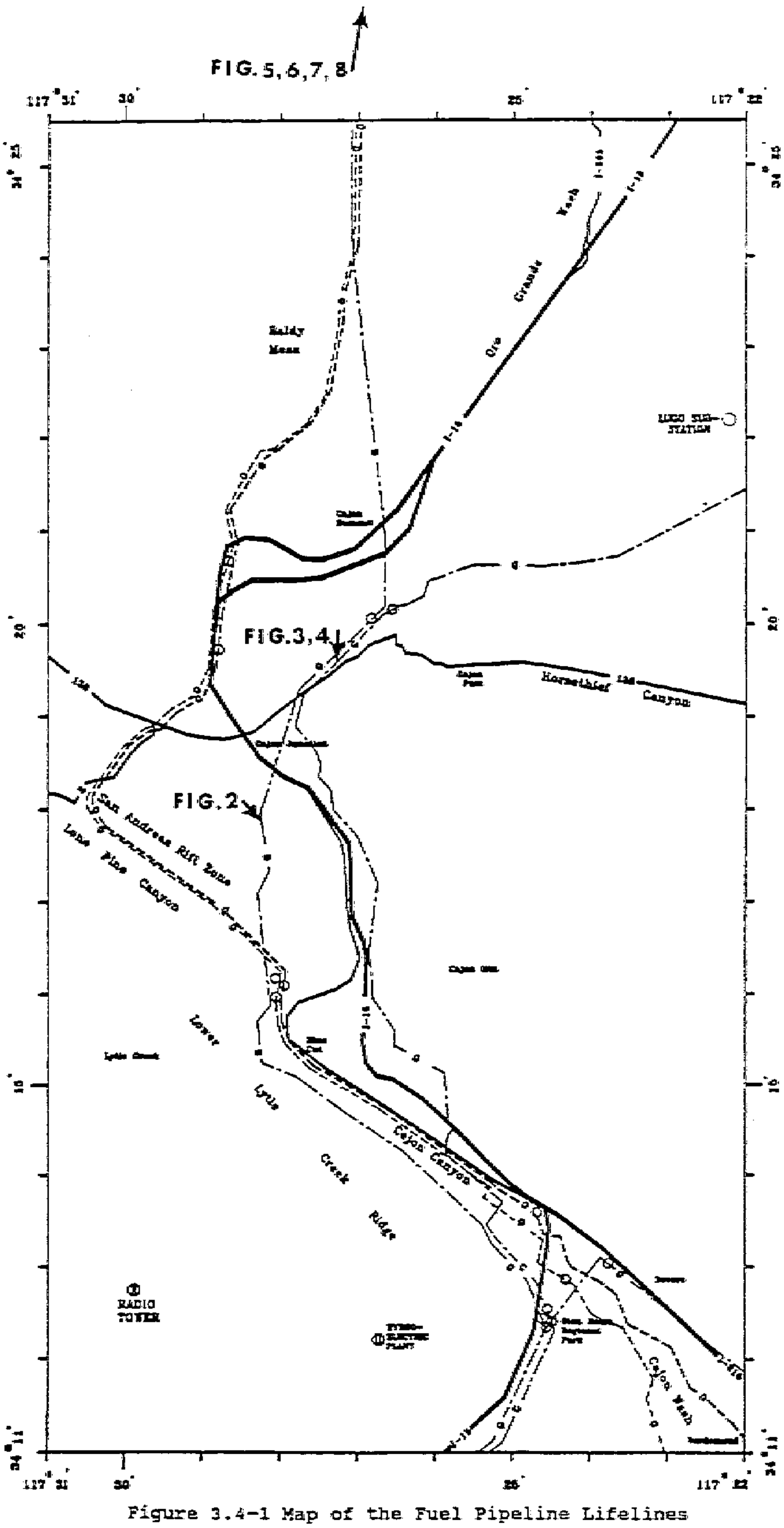
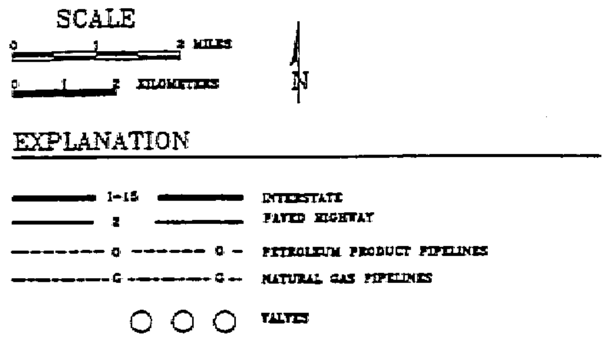


Figure 3.4-1 Map of the Fuel Pipeline Lifelines



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natural gas distribution line. For reference purposes, the locations of the photographs provided in this Section are shown on the Figure. Also included are a number of valve stations in each pipeline system. Responsibility for the independent for inspection and safety monitoring (including accounting for seismic safety) these lifelines lies with the U.S. Department of Transportation Office of Pipeline Safety. They, in turn, have delegated their authority for petroleum products pipelines to the California Office of the Fire Marshal, and for natural gas pipelines to the California Public Utilities Commission. The Office of Pipeline Safety's seismic hazards mitigation requirements are very broadly stated in such terms as "earthquakes should be considered during the design and installation of such systems". The Office of the Fire Marshal has retained the broad language in its requirements. The Public Utility Commission has specific, detailed, seismic design criteria for liquified natural gas facilities, but the requirement for natural gas pipelines retains the broadly stated guidelines.

3.4.1 Natural Gas Pipelines

Southern California Gas Co. operates two 36-inch high pressure (about 845 psig) natural gas transmission lines in the Cajon Pass and a 16-inch intermediate pressure (350 psig) trunk line that delivers natural gas from the two 36-inch lines to the San Bernardino region (see Figure 3.4-1 which is a map of the fuel transmissions lines in the study area). A third north-south gas pipeline (which on the map appears to be an extension of the more western 36-inch pipeline) is a 36-inch line to the high desert region. It operates at 936 psig and is connected through a valving station directly to the two 36-inch high pressure lines. In the study area, one of the transmission lines is routed on the west side of highway I-15, the other on the east side. At Cajon Junction the western pipeline crosses under I-15 and joins the eastern pipeline and the north-south pipeline at a valving station. There is another valving station near Devore that connects the two transmission lines and the trunk line.

Piping wall thicknesses are in accordance with the California Public Utilities Commission General Order No 112-D[3.4-1]. Spacing between the pipeline valves and separately the pipe wall thickness are controlled by criteria which in turn are controlled by the population density of the area. Retrofits requiring more frequent valves and thicker wall pipes can be required by changes in the population density. Although no changes have been required in the study area, it appears that business growth plans near the Cajon Junction and residential population growth in the high desert region of the study area may require such modifications in the near future.

The eastern most transmission line (line 4000) was installed in 1966 using X-60 grade pipe with wall thicknesses ranging from 0.375-0.438 inches. It operates between the Newberry Compressor station to the north of the study area and the Fontana pressure limiting station south of the study area. The western most transmission line (line 4002) was installed in 1960 (it was the original line) using X-52 and X-60 grade pipe with wall thicknesses ranging from 0.375-0.500 inches. It operates between the

Cajon summit valving station north and east of the Cajon Junction and the Fontana station south of the study area. The north-south line (line 1185) was installed in 1976 using X-60 grade pipe and wall thicknesses ranging from 0.391-0.562 inches. It runs from the Cajon Summit valving station north to the Adelanto Compressor Station.

Southern California Gas Company operates another 36-inch pipeline that crosses the San Andreas fault zone north and west of the Cajon Pass. The three transmission lines (the 1185 and 4002 lines and the 4000 line in the study area and the third lines west of the study area) supply about 90% of the Company's natural gas to the Los Angeles Basin. The transmission lines in the study area presently provide about 750 million cubic feet of natural gas each day, although their combined total capacity is up to 1 billion cubic feet per day. In addition, the Company maintains natural gas storage in the coastal area that could provide 30-90 days supply for its core customers.

Maintenance staff and supplies are maintained in the Los Angeles Basin and in Victorville. The emergency planning assumes that up to 1/2 mile of pipeline on either side of the San Andreas fault zone could be failed during a major earthquake. They maintain prepositioned material to replace that piping, if needed, they have written procedures for responding to such a requirement, and they have existing agreements with a helicopter company to provide helicopters for their use during such times.

The following discussion tracks the pipelines from the south of the study region to the north. This is counter to the flow direction of the natural gas, but it is consistent with the descriptions provided for the other lifelines. The 36-inch transmission lines enter the study area southern boundary in the Lytle Creek Wash just west of I-15. They also pass under the new SCE 500 kV transmission line where they enter the study area. Block valves are used to sectionalize the line. Just south of the study area is the Fontana valving station that can be used to control the pressure in each line and to cross-connect the

Figure 3.4-2 Natural Gas Pipeline Crossings Under Two Railroads

lines. In the study area, they proceed east by northeast for about two miles. At the western edge of the Cajon Wash there is another valving station and that is where the 16-inch trunk line to San Bernardino takes gas from the 36-inch lines. The 36-inch lines then turn northeast and approximately due west of the I-15/I-215 junction they separate.

Figure 3.4-3 An Exposed Section Of The Natural Gas Pipeline

The western line (line 4002) follows the Southern Pacific and Atcheson Topeka & Santa Fe (AT&SF) railroad right-of-ways to Blue Cut. It crosses the Southern Pacific railroad track several times, running either parallel and west of the track or in the space between the tracks of those two railroads. These crossings are buried but uncased. From Blue Cut the line heads generally north. It runs parallel and near to the Los Angeles Department of Water and Power's two high voltage transmission lines for about one mile. In the Lone Pine Canyon it crosses the San Andreas fault zone very close to two power transmission lines. It also crosses the two petroleum products pipelines at that location. This crossing is discussed in more detail in Section 3.3.

Further north (just south of the Cajon Junction) the 36-inch natural gas pipeline crosses the Southern and the Union Pacific railroad lines. Figure 3.4-2 shows the pipeline right-of-way descending to and then under those railways. The crossing under the Southern Pacific is uncased, it is cased under the Union Pacific. Between Blue Cut and the railroad crossings south of Cajon Pass there are five sections of exposed line with spans ranging from 57-118 feet. Figure 3.4-3 shows one of the longer exposed sections, and Figure 3.4-4 shows a close of up the pipe exiting the ground. It shows the connection of the pipe corrosion protection material wrapping (the gray line) as it is connected to the pipe. The pipe crosses under the AT&SF railroad and I-5 and continues parallel to the eastern pipeline to the Cajon summit valving station located north of highway 138. In this route there are two more exposed sections with 68 and 80 foot spans. A recent realignment of Highway 138 brings it very close to one of the exposed crossings. At that location, the two 36-inch pipelines are located parallel. The line to the left is exposed, the one to the right is buried.

When the eastern natural gas pipeline (line 4000) separates from the western one near the junction of I-15 and I-215 it turns northeast and crosses under the Southern Pacific and AT&SF railroads and the Cajon Wash. The pipeline then runs parallel and west of the old highway for about 0.75 miles, then crosses under the old highway and I-15. When it crosses the old highway it also crosses perpendicular to the two petroleum products pipelines. This region also has a high water table and could be subject to liquefaction during an earthquake event.

Figure 3.4-4 Details of the Ground Support For Exposed Sections Of Natural Gas Pipelines

The 36-inch pipeline continues roughly parallel to I-15 on the eastern side of I-15. In these steep mountains there have been a number of times when fires have burned off the vegetation and surface erosion and stream-bed erosion have occurred, and in the 1970's a landslide after heavy rains damaged such a portion of this pipeline. Just north and east of the Cajon Junction the routing turns north by northeast and the pipeline crosses Highway 138. It runs parallel and north of the highway, and new highway crossings will result when Highway 138 is rerouted in 1991. Between the Cajon Junction and the summit valving station there are five separate locations of exposed pipeline, with the spans ranging from 98-138 feet. After the valving station, the pipeline (line 4000) turns east and then northeast and leaves the study area. Twice it crosses the three railroads in this section. The highway, railroad, and power line crossings are a mixture of cased and uncased crossings.

The third pipeline (line 1185) is routed north from the Cajon Summit valving station. It crosses under the railroads next to short railroad bridges. It continues north, crossing under the northbound and then the southbound portions of I-15. All of these crossings are cased. Continuing north, it crosses under power transmission lines and then connects to and runs parallel to Baldy Mesa Road. It is routed on the east side of the road, the petroleum products pipelines and three fiber optic cables are also routed parallel to this road. A valve station is located on the shoulder of Baldy Mesa Rd., and Figure 3.4-5 shows the posts installed around the valves to protect them from a vehicle accidently crashing into them.

North of the study boundary it crosses the California Aqueduct. Figure 3.4-6 shows that crossing.

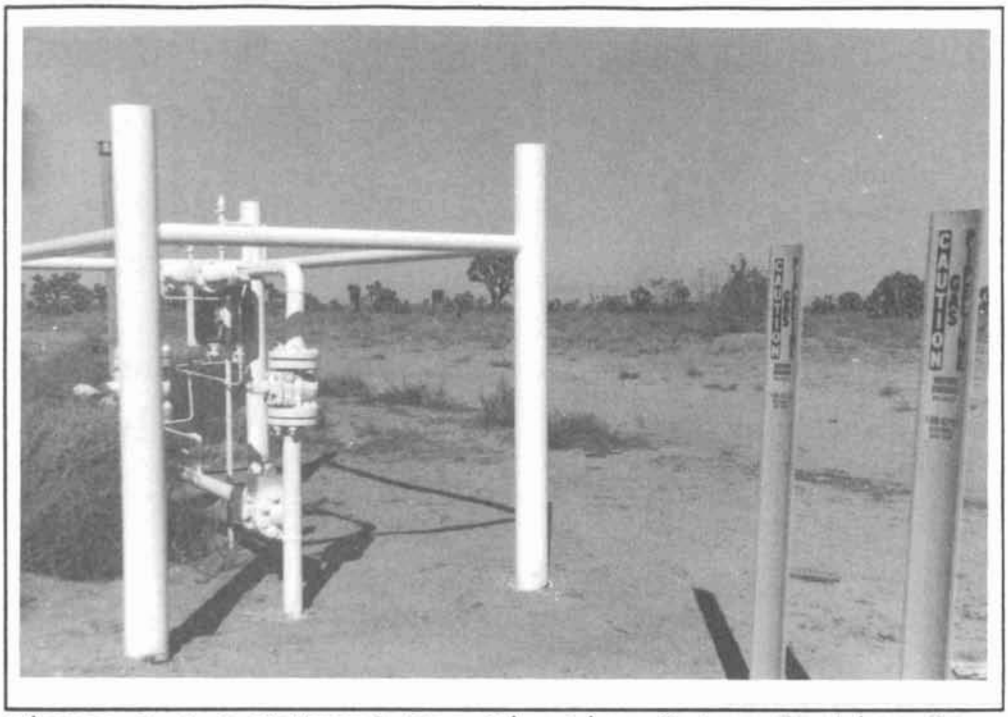


Figure 3.4-5 Natural Gas Pipeline Valve Station On Baldy Mesa Road

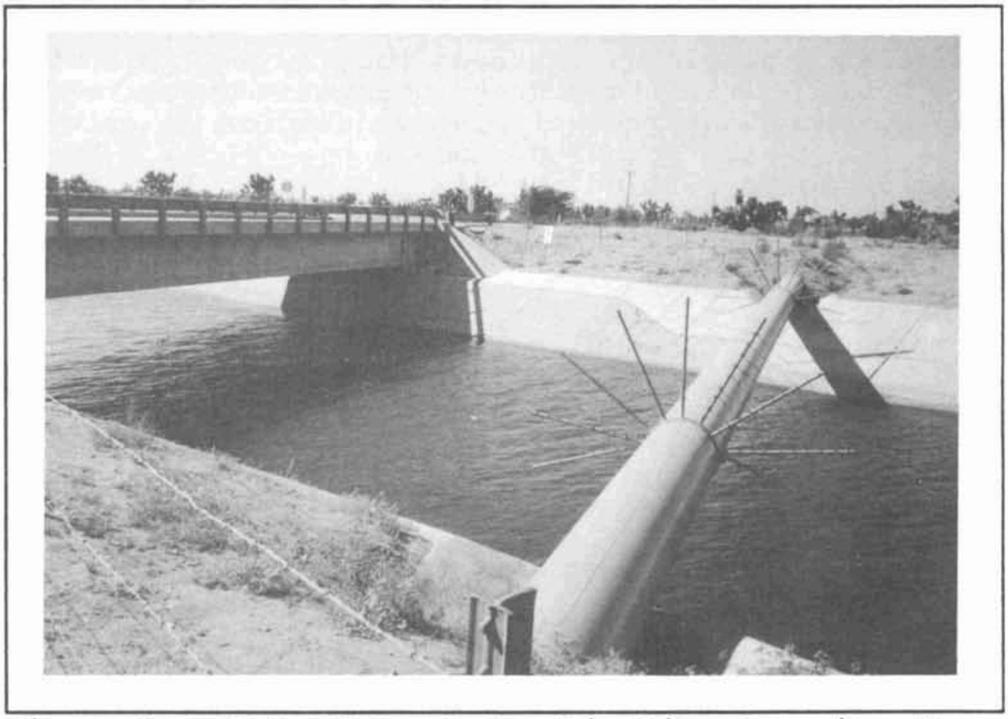


Figure 3.4-6 The Natural Gas Pipeline Crossing the California Aqueduct

3.4.2 Liquid Fuel Pipelines

There are two petroleum products pipelines operated by CALNEV Pipe Line Company in the study area. Figure 3.4-1 shows the routes of these lifelines. In 1960 an 8-inch pipeline was installed, in 1969-70 a second 14-inch pipeline was installed, and in 1980 several miles of the 8-inch line that were installed in the Cajon Wash were rerouted to be parallel to the 14-inch line located east of the Wash (it was reported[3.4-2] that the 8-inch line in Cajon Canyon Wash frequently would be uncovered during the spring runoff, and that the Forest Service requested and CALNEV concurred that it would be safer to move the line to a region where water runoff would be less troublesome). The lines are about 250 miles long and were installed in accordance with the then current American Petroleum Institute's standards. Those standards required that reasonable protection for anticipated and unusual external conditions be included in the design, but specific earthquake criteria were not identified in the standards. In California, the Office of the Fire Marshall is responsible for the inspection and enforcement of the federal and California pipeline safety standards[3.4-3]. For the federal requirements, they are the agent for the U.S. Department of Transportation Office of Pipeline Safety, who has statutory safety responsibilities.

The fuel pipelines are buried 3-14 feet deep, depending on their location. When they cross state highways or railways they are normally cased. When they cross unpaved roads they may not be cased. They operate at 1060-1690 psig. The pipe outside is coated with coal tar and impressed cathodic corrosion protection is used, the locations for impressing the required voltage on the pipeline are at the pipeline terminuses. Check valves and motorized valves are installed on the pipelines, there is no backup emergency driver if the electricity fails. However, each motorized valve can be manually operated. The operations are controlled by computers in the San Bernardino station, there is 100% redundancy in the computer controls. Twice a year the company conducts training for emergency response, they fly over the line route every other week, they drive most of the line route weekly, and they conduct an annual inspection of the line route. Extra pipe for emergency repairs is stored at various cities along the route path. There are pump stations in San Bernardino and Barstow, CA.

The lines pump about 80,000 barrels (bbl)/day of product. The product provides about 90% of the Las Vegas area fuel and 100% of the fuel for three Air Force bases. They have 560,000 bbl of storage at the San Bernardino terminal (normally this capacity is mostly full), and they have 237,000 bbl of gasoline and 106,000 bbl of diesel storage in Las Vegas, 105,000 bbl of storage in Barstow, and 64,000 bbl of jet fuel storage on one of the Air Force bases.

As a result of the May 1989 derailment and subsequent pipeline failure/fire in San Bernardino, the side hinged check valves (which had failed to close during that accident) were replaced with top hinged check valves. However, the check valve near the accident site was replaced with a motorized control valve. In early 1990 another train derailment in which the engine and cars came to rest over the pipeline occurred in Las Vegas. It was reported(3.4-4) that as was the case in San Bernardino, the derailment itself did not rupture the pipeline. A 100% pipeline excavation and inspection at Las Vegas indicated that the pipeline was not damaged by the derailment. In 1988-89 when the fiber optic cables were installed in the pipeline right-of-way, it was reported(3.4-4) that on at least two occasions the trencher struck the pipeline, requiring piping repairs (the location of these incidents was not identified).

The 8-inch pipeline enters the study area on the western side of the Cajon Wash. Just south of the study area there is a check valve (located east of the San Bernardino County Prison Farm). The pipeline runs north along the western edge and within the Cajon Wash. Just after it passes under Devore Road there is another check valve. It continues in a north west direction crossing under I-15 before the I-15/I-215 intersection, turns north and crosses under the Union Pacific, Southern Pacific, and AT&SF railroads. It then continues for about 1 mile along the eastern edge of the AT&SF right-of-way. After it crosses the natural gas pipeline it turns north east, crosses the Cajon Canyon floor and connects with the existing 14-inch pipeline right-of-way along the old Cajon Canyon highway. From there it and the 14-inch pipeline are routed in parallel trenches.

The 14-inch pipeline enters the study area in the southeast corner. About two miles south of the study area there is a motorized check valve just north of Duffey St. The 14-inch pipeline follows the Southern Pacific railroad right-of-way, sometimes crossing under the tracks, most of the time parallel to and outside of the tracks. When the AT&SF and Southern Pacific railroads come together south of Devore Road, the pipeline's route is between the tracks of the two railroads. It leaves the railroad right-of-ways just past Devore Road, turns north east and crosses under I-15 at the I-15/I-215 intersection. It continues north east and joins the old Cajon Canyon highway. Just as it enters under the median strip there is another check valve. It is joined

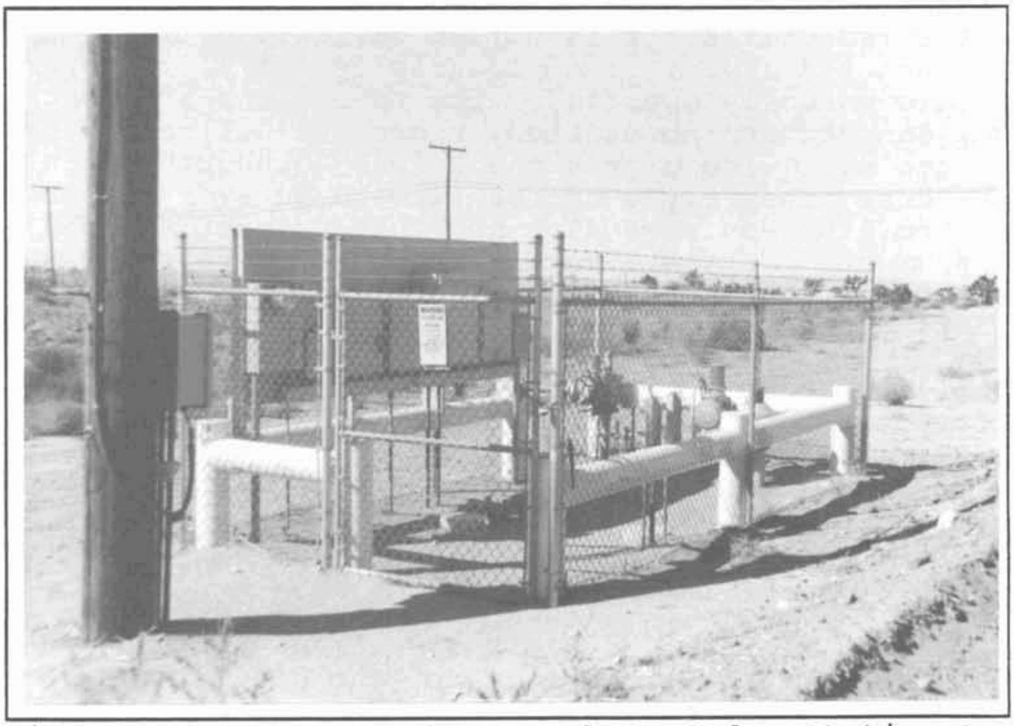


Figure 3.4-7 The Petroleum Products Valve Station On The Shoulder of Baldy Mesa Rd.

by the 8-inch pipeline at about Kenwood Road. The pipelines (and the fiber optic conduits) follow the old highway along a northwest route until they reach the point at Blue Cut where the old highway makes a broad right turn. There the pipelines turn north for about 0.5 miles. Both the 8- and the 14-inch lines have check valves in this region. When the route reaches Lone Pine Canyon (which is also the San Andreas Fault Zone) they turn left and follow the canyon floor for about 3 miles. This was the original route of the 8-inch pipeline, and the same right-of-way was used when the 14-inch line was installed. It is parallel to a dirt road. When the road connects with Lone Pine Canyon Road the pipelines turn northeast. They cross the Lone Pine Canyon Road several times in cased and uncased crossings. They continue in their northeast route until they cross under I-15, where they turn north. Just prior to crossing the railroads, there is another check valve on the 14-inch line. They follow the general route of Baldy Mesa Road and cross under I-15 again. In the region between the north and southbound sections of I-15 there is a check valve on the 8-inch pipeline. After crossing under the southbound section of I-15 the pipeline turns northeast and is parallel to the Los Angeles Department of Water and Power's two 287.5 kV electric power transmission lines. At the summit of Mt. Baldy there was a pressure reading station. Vandalism has caused CALNEV to move the gauges to a less prominent location, but the pressure stems off of the pipelines to the valves are still exposed and it appears that vandals have been trying to rupture them. When Baldy Mesa Road separates from the electric power transmission lines the pipelines follow the road in a northern direction. There they are joined by one of the natural gas transmission lines, with the pipelines on the western side of the road and the natural gas pipeline on the eastern side of the road. About two miles north of the northern boundary of the study area the pipelines cross the California Aqueduct. Just before the crossing there is another valve station for each of the pipelines. Figure 3.4-7 shows the above ground valve station that is on the shoulder of Baldy Mesa Rd.. The barriers were installed to protect the valves from vehicles. At the

Figure 3.4-8 Petroleum Products Pipelines Hung Under The Baldy Mesa Rd. Bridge Over the California Aqueduct

aqueduct crossings the pipelines are hung exposed under the Baldy Mesa Road bridge over the aqueduct, and Figure 3.4-8 shows this.

3.4.3 Bibliography for Section 3.4

3.4-1 Public Utilities Commission of the State of California General Order No. 112-D, "Rules Governing Design, Construction, Testing, Maintenance and Operation of Utility Gas Gathering, Transmission and Distribution Piping Systems", November 1988.

3.4-2 Source of information: meetings with the US Forest Service at the Lytle Creek station.

3.4-3 Source of information: meetings with the US Office of Pipeline Safety and separately with the California Office of the Fire Marshall, Pipeline Safety Division.

3.4-4 Source of information: conversations with CALNEV Pipeline Company.

3.5 TRANSPORTATION LIFELINES

The Cajon pass has served as a route for passage of people and goods between the Los Angeles basin and the high desert region from earliest times, since it is the only relatively easy penetration of the San Gabriel and San Bernardino mountains. One of the old main transcontinental highways, Route 66, used this route, as did the Atcheson, Topeka and Santa Fe (Santa Fe) railroad. At the present time, the old Route 66 has been replaced by Interstate Highway 15 (I-15) with a spur into San Bernardino (I-215), and Route 66 in the southern portion of the Cajon Pass has since become a county road restricted to two lane, opposing traffic. A primary State highway, Route 138, runs east-west from the Silverwood and Arrowhead Lake recreation areas in the east to Palmdale in the northwest. Route 138 intersects with I-15 at Cajon Junction. There are also three mainline railroads in the study area: the Santa Fe, the Union Pacific, and the Southern Pacific. Under emergency conditions it might be possible to route all railroad traffic on one rail line because their close proximity could facilitate making such connections. However, this possibility was not examined during the present study. Figure 3.5-1 shows the transportation lifeline routes in the study area. For reference purposes, the locations of the photographs provided in this Section are also shown on the Figure.

3.5.1 Highways

The interstate highway through the Cajon Pass was originally completed in the era of 1965-1969. It follows the old alignment of Route 66, except for the section through the steeper part of the route in the pass itself, where the new interstate highway is laid on an improved alignment which begins its climb earlier and yields lesser grades and more gentle curves. It also increased the traffic capacity, with up to four lanes in each direction in the sections with greatest grades. The traffic on I-15 has

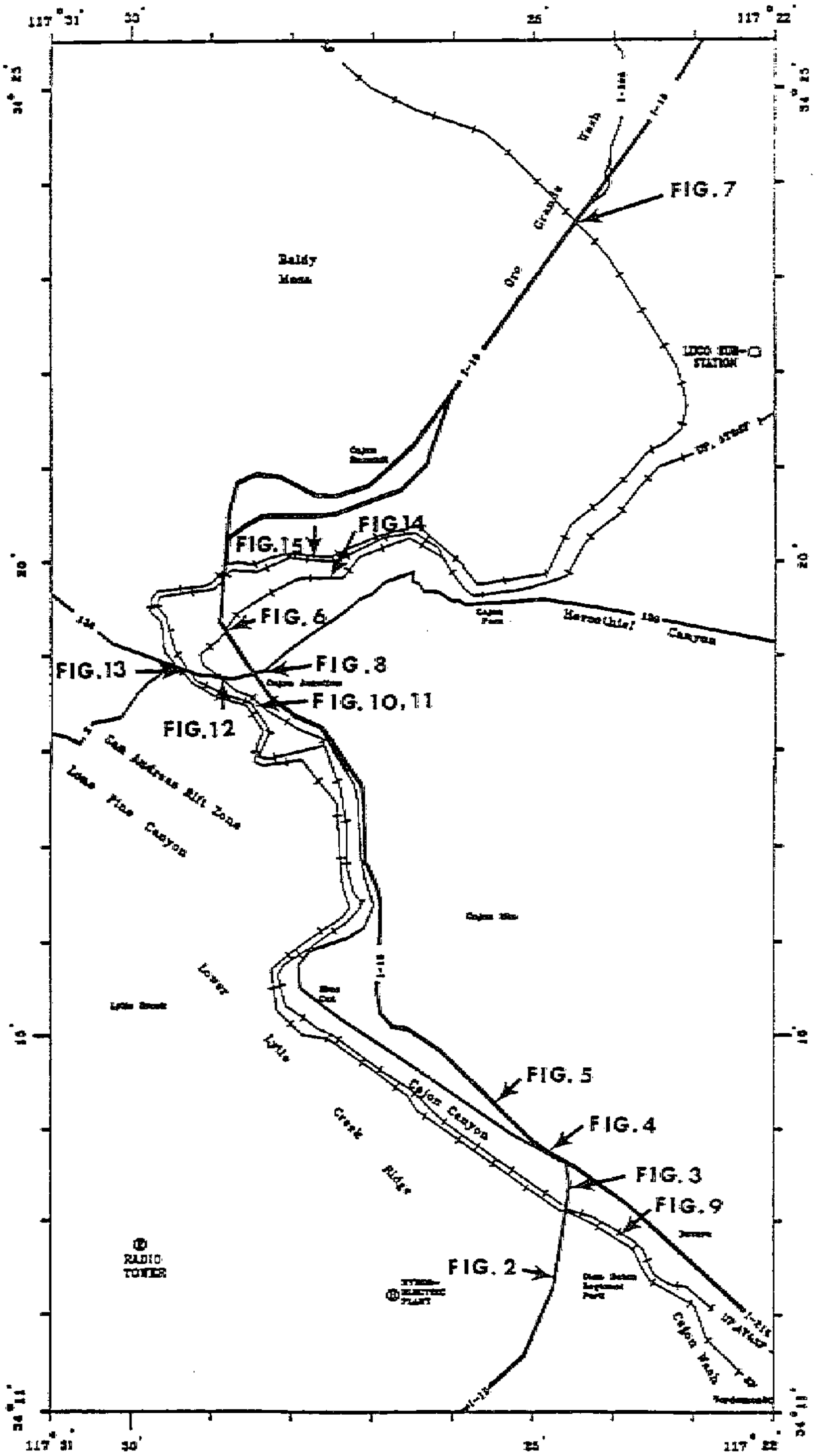
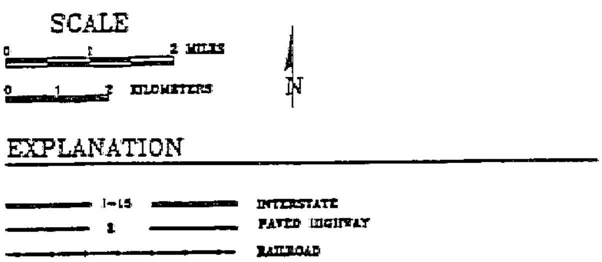


Figure 3.5-1 Map of the Transportation Lifelines



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increased over recent years, with the average daily traffic now approaching 60,000 vehicles/day in the section below Cajon Junction. On weekdays, this traffic includes about 28% large trucks.

In 1975, a new interstate section was completed connecting the area near Devore at the south end of the Pass directly with I-10 near Ontario, thus bypassing the city of San Bernardino for traffic bound for the Los Angeles area farther west. The existing I-15 section from Devore to San Bernardino was redesignated as I-215.

The highway lifelines would be of major value to the immediate recovery phase after an earthquake or other disaster, since they provide access to the area from supporting communities to the north. Also, they provide a vital link to the several military airfields in the high desert area which are likely to be less affected than the airports in the Los Angeles-San Bernardino corridor.

Damage to the highway lifelines may result from several aspects of the earthquake. The bridges are vulnerable to forces generated by ground shaking. The roadway itself may be interrupted by landslides coming down onto the roadway or by the failure of man-made fill sections. There are also some areas where there is a potential for liquefaction of the ground, with loss of both structures and embankments: for example, at the Cajon Wash at the southerly entrance to the Pass just south of the I-15/I-215 intersection, and separately, just north of that intersection; near Blue Cut; and at the alluvial deposits in Cajon Creek just south of the junction of I-15 and Route 138. The highways cross the San Andreas fault trace, and the traces of other numerous faults in the area. In those locations there is the potential for direct shearing ground displacements. There is also a significant possibility for interaction with other lifelines, since the highways cross over or pass under major rail lines at ten points, cross over natural gas and petroleum products pipelines and communications lines at numerous points, and cross under the high voltage power transmission lines, as discussed in previous sections of this report.

The main highways operated by the California Department of Transportation (CALTRANS) include 55 bridges in the study area. CALTRANS has been evaluating all of the thousands of highway bridges under its jurisdiction for earthquake vulnerability, using a special screening technique[3.5-1, 3.5-2, 3.5-3] for the first level evaluation in order to identify the most hazardous in proper priority for their retrofit program. This screening work has been completed on 28 of the 55 bridges in the study area as of the fall of 1990. For the 28, there has been a tentative decision to retrofit or replace 12, leave 13 as is, and hold 3 for further consideration. Screening of the remaining 27 is in process.

Fortunately many of the bridges could be easily bypassed for limited emergency traffic. Most of the interchanges on I-15 are of the "diamond" type, so that if the main route bridge is damaged, limited traffic could be routed on the existing ramps down to and across the intersecting roadway, and then back up onto the Interstate. There are some cases where this will not be possible, such as at the longer bridges and separation structures at the I-15/I-215 junction at Devore. There are some local roads in the area which also could be used for bypass, and there is a long section of old Highway Route 66 which has been partially abandoned and which parallels the lower southbound section of I-15 for about 7 miles from Devore to just south of Cajon Junction. This old facility was a four lane divided highway, but now only the west roadway is in service. Unfortunately, sections of this roadway are, no doubt, more vulnerable to earthquake damage than is the new Interstate, especially at Blue Cut, where it passes over trace of the San Andreas fault. It should be noted that the bridges on this old alignment carry conduits for a number of fiber optic communication lifelines, and the two petroleum product pipeline lifelines are located in the center median of the alignment. Because of the semi-desert climate of the region, it may also be possible to route some detour traffic across open off-highway areas, especially in the

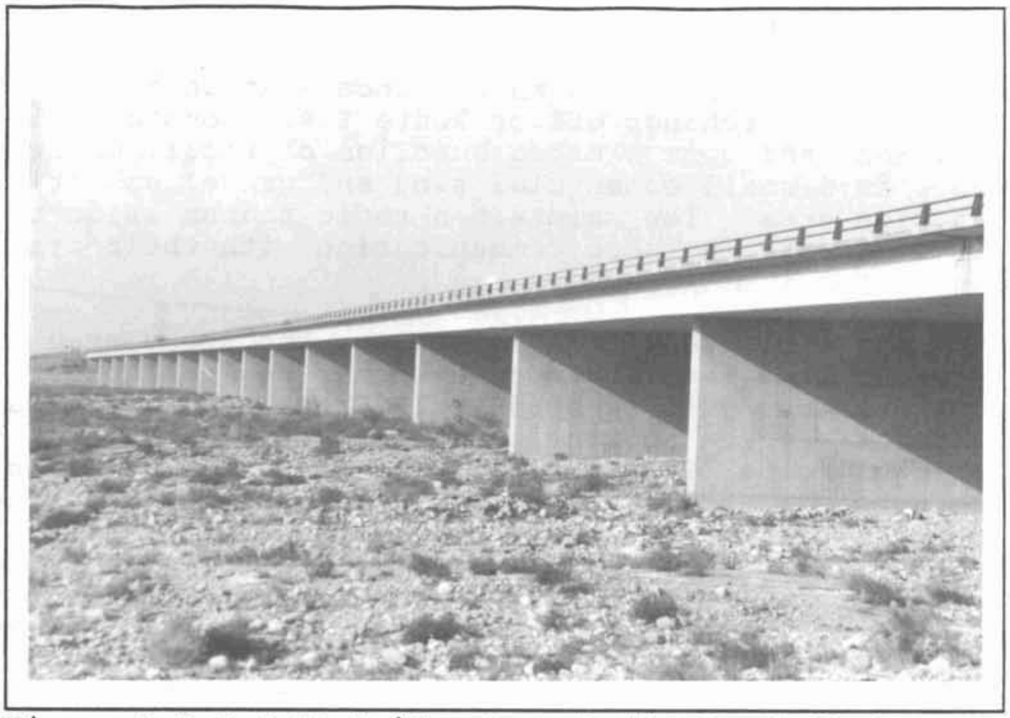


Figure 3.5-2 I-15 Bridge Over Lytle Creek Wash

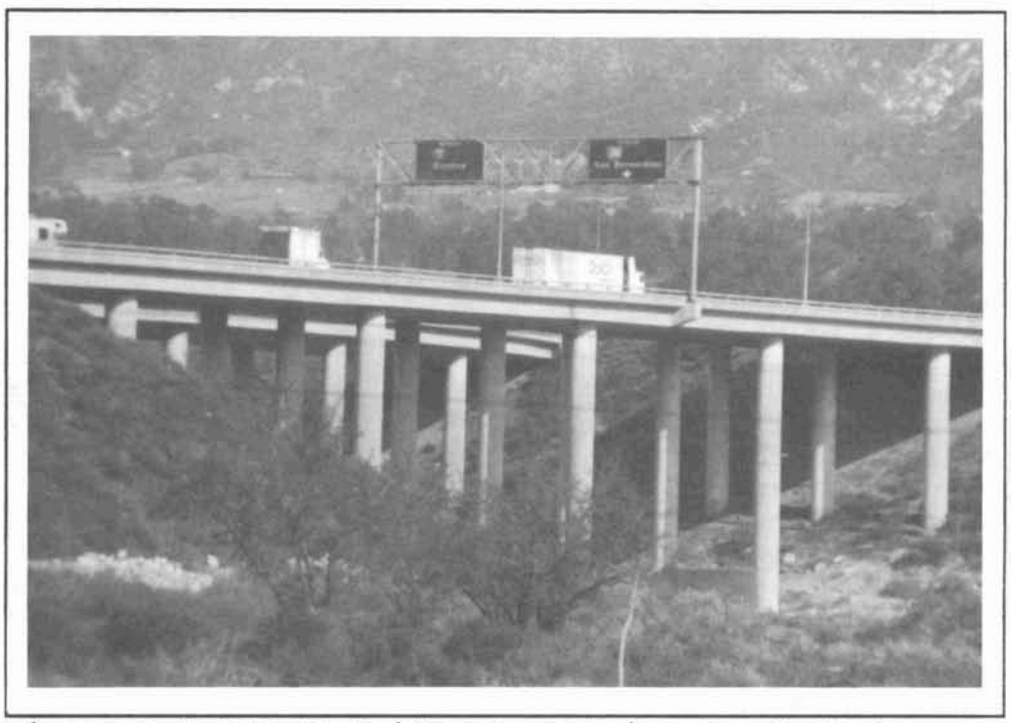


Figure 3.5-3 I-15 Bridge Over Cajon Creek Wash

northern portions of the study area.

CALTRANS has a District Maintenance Station just west of the Cajon Junction interchange off of Route 138. Considerable construction equipment and some limited supplies of repair materials are stored there. There is a small commercial sand and gravel operation in the Cajon Junction area. The maintain a radio transmission tower near the highway summit to aid in radio communication with their transportation equipment operators.

Interstate Highway 15 (I-15) enters the study area from the southwest as two four lane separate roadways near Nealyes Corner, where it crosses Sierra Avenue just west of Lytle Creek Wash. The pavement is concrete. There is a grade separation structure for each of the I-15 roadways (Bridges No.54-0891R and L), consisting of cast in place pre-stressed concrete girders. The highway continues northeast on a long viaduct of concrete box girders, each continuous over several spans (Bridge No.54-0982R and L), crossing Lytle Creek Wash and the San Jacinto fault zone in this area (see Figure 3.5-2). It then ascends the west slope of Lytle Creek Ridge across Sycamore Flats, crossing over Devore Road just west of the ridge on a concrete box girder (Bridge No. 54-0779R and L). It then descends and crosses Glen Helen Road on Bridge No. 54-0780R and L, and the rights-of-way of the Southern Pacific, the Union Pacific, and the Santa Fe railroads on Bridge No. 54-0818R and L. It then crosses the Cajon Wash on a set of continuous concrete box girder structures designated as Bridge No. 54-0781 (see Figure 3.5-3), which carries the north and southbound main roadways, the west-south connector, and the east-south connector roadways. At this point, I-15 joins I-215 coming up from the southeast from San Bernardino at a complex set of separation structures (Bridge Nos. 54-0782, -0783, and -0771). All of these bridges are constructed from prestressed concrete. The taller separation structures are supported on multiple column bents.

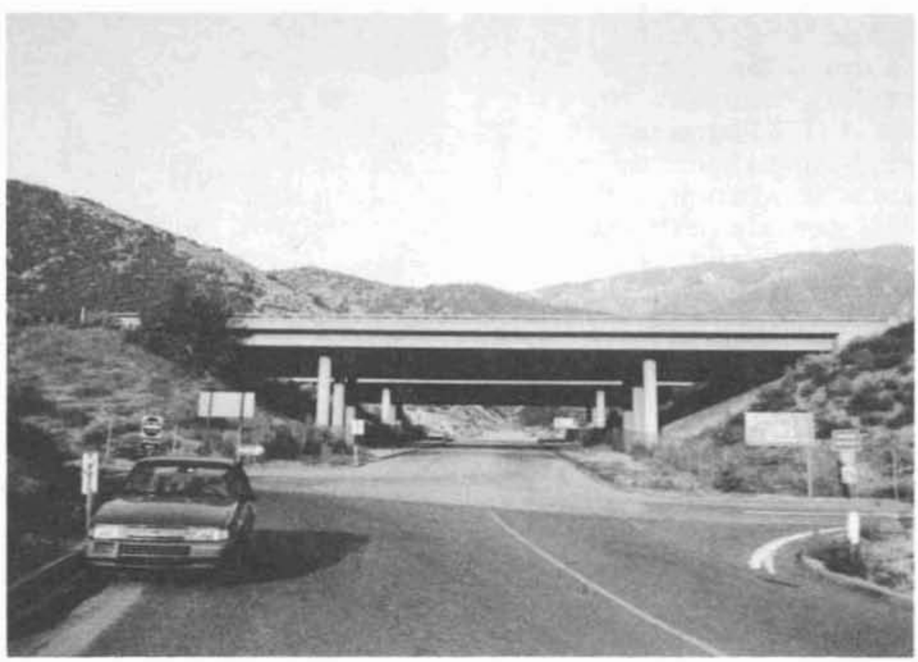


Figure 3.5-4 I-15 Bridge Over Kenwood Avenue

On the section of I-215 coming up from San Bernardino, which enters the study area at Verdemont, there are three concrete box girder bridges on the main three lane roadways, which are at Palm Avenue, Cypress Avenue, and Devore Road (Bridge Nos. 54-0532, 54-05433, and 54-0525), and one prestressed concrete structure on the east-south connection and collector roadway at Devore (Bridge No. 54-0844).


Figure 3.5-5 I-15 Arch Bridge Over Matthews Rd.

As the I-15 highway continues north from its junction with I-215, it is two independent roadways of four lanes each, concrete paved. It passes over Kenwood Avenue on a continuous box girder (Bridge No. 54-0772), with a typical diamond type interchange. Kenwood Avenue connects with the old alignment of Route 66 about 0.2 miles further west (see Figure 3.5-4).

I-15 continues over Matthew Road with a 21 ft. span, multiplate arch (Bridge No. 54-0915, Figure 3.5-5). I-15 then passes through a steep cut about 1.5 miles north of this point, and on the north side of the ridge swings to the east away from the old alignment. Both the old and the new alignment cross the trace of the San Andreas fault in this vicinity. At mile 18.48, I-15 crosses Cleghorn Creek on another concrete box girder (Bridge No.54-0773) just east of the settlement of Cosy Dell, north of which it again runs parallel with the old alignment for 1.5 miles but at a higher elevation. It crosses debris-filled Cone Creek at mile 19.29 on a prestressed concrete structure (Bridge No. 54-0774), Brush Creek on a concrete box girder (Bridge No. 54-0775), and then Cleghorn Road at mile 20.0 on another concrete box girder (Bridge No. 54-0776). This is another diamond type interchange with connections to Cleghorn Road, the old alignment of Route 66, the settlement of Cajon, and the railroads to the west of the highway.

Just south of Cajon Junction, I-15 spreads out to accommodate north and southbound truck weighing stations. The roadway is on a moderately high fill, supported on the west side by a metal crib retaining wall approximately 18 feet high (see Figure 3.2-5). The East Fork of Cajon Creek passes under this fill through a large concrete box culvert designated as Bridge No. 54-0777. This structure is on a curved alignment and is 39 feet wide and 15 feet high, with a length of 440 feet along the center line. As noted in Section 3.2.1 above, four communications conduits are attached high on the east wall of the culvert waterway (see Figure 3.2-7). The outlet end of the culvert directs the creek flows into the railroad bridges of the Sante Fe and Union Pacific. The ground water is close to or at the surface in this entire region, and lush plant growth indicates that the high water table extend at least to the foot of the metal retaining wall crib.

Figure 3.5-6 I-15 Box Bridge Over the Railroad

Approximately 0.7 miles northwest of the weighing station, I-15 passes under Route 138, which is carried on a two span, welded steel girder with a central pier located in the median of I-15). There are steep slopes just to the east of this junction, and construction is underway on the realignment of Route 138 to the east. From this point, I-15 climbs steeply toward Cajon Summit, crossing the Union Pacific at mile 22.0, the Sante Fe at mile 23.7, and the Southern Pacific at mile 22.7 at Alray. These crossing structures are all tunnel-like box structures (see Figure 3.5-6), with lengths from 250 to 300 feet, crossing the highway fill at a skew. Beyond the last of these rail crossings, the northbound and southbound roadways of I-15 separate. The northbound lanes swing to the east sooner than the southbound and run along the steep slopes at an elevation about 200 feet lower and on an alignment about one thousand feet south of the southbound roadway. The petroleum products pipelines and some of the fiber optic communication lifelines pass under the highways in this region. Also, an unimproved road used for access to those lifelines (the Baldy Mesa Road) crosses under I-15 in cement culverts. The northbound roadway of I-15 climbs to rejoin the southbound roadway at the Oak Hill Road interchange at mile 28.7. This interchange structure (Bridge No. 54-0740) is a steel girder which provides for connections with local roads and the service roadways which parallel I-15 from this point to the north in the relatively flat high desert land.

At mile 31.1, I-15 again crosses the tracks of the Southern Pacific at

Bridge No. 54-0664, a continuous slab structure supported on multiple column bents (see Figure 3.5-7). This bridge is flanked by others which carry the service roads over the railroad, the easterly bridge has water pipelines and fiber optic communication conduits attached (see Figure 3.2-8). There is a grade separation structure of welded steel girders (Bridge No. 54-0665) at mile 31.8 which connects the northbound lanes of I-15 to the northbound lanes of I-395 leading north to Adelanto, and 0.5 miles further north, I-15, now reduced to three lanes in each direction, is crossed by Phelan Road on a concrete box girder (Bridge No. 54-0624). Just at the north end of the study area, I-15 and both frontage roads are carried over the California aqueduct on a double box, concrete culvert (Bridge No. 54-0828). I-15 continues northeast out of the study area towards Victorville and Barstow.

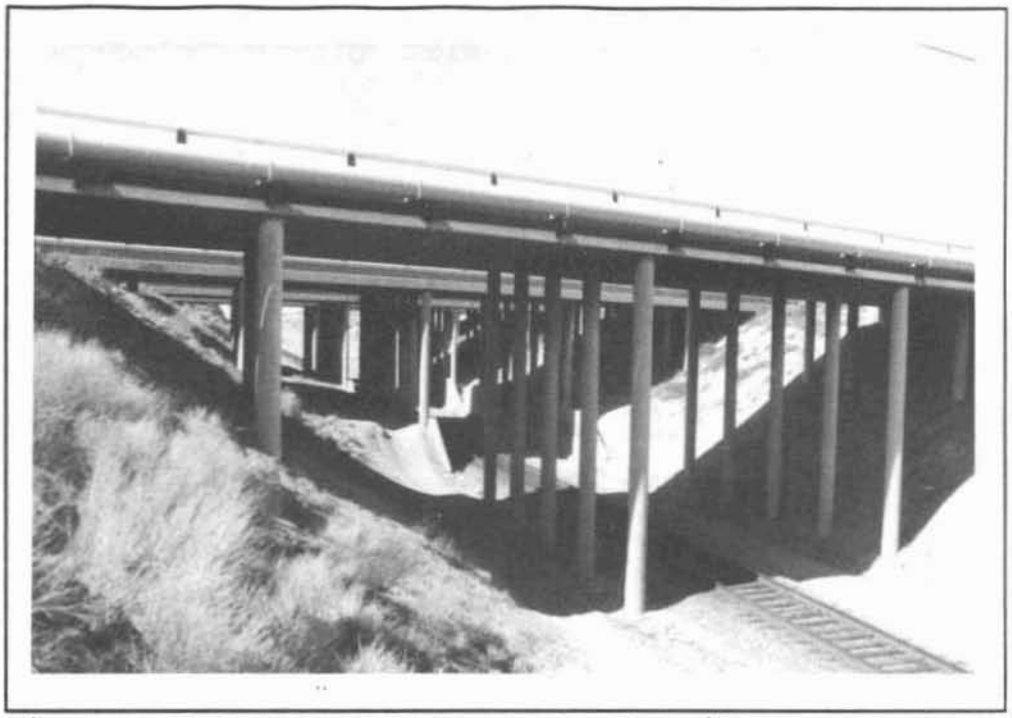


Figure 3.5-7 I-15 and Access Road Bridges Over the Railroad

Route 138 enters the study area from the west, joining the I-15 at Cajon Junction. Approximately one

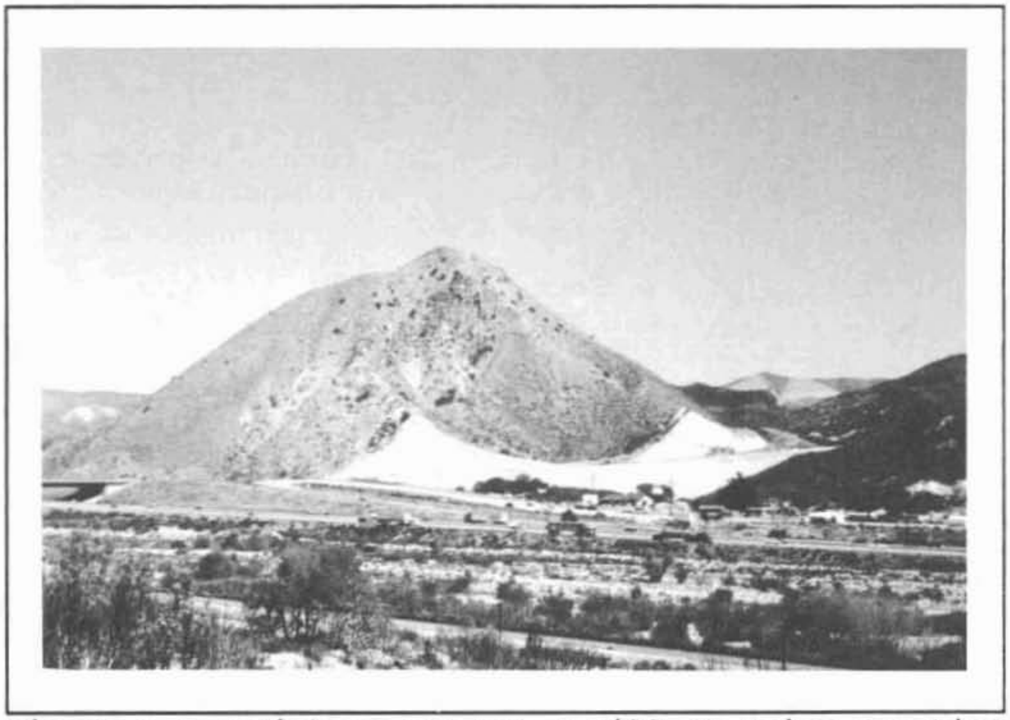


Figure 3.5-8 Highway 138 Cut & Fill At Cajon Junction

mile west of this point, it passes under the Southern Pacific, which is carried on a steel, through-plate girder (Bridge No. 54-0832), then over the eastbound and westbound combined tracks of the Sante Fe and Union Pacific on Bridges No. 54-1056 and -1057 respectively, and then over the upper reaches of Cajon Creek on Bridge No. 54-0561. It crosses over I-15 on a steel girder structure as indicated above, and then continues along the south side of steep slopes to the east. This section of Route 138 has been recently reconstructed to improve its grade and alignment, since it carries heavy recreational traffic to the Arrowhead and Silverwood Lakes. The new alignment includes large cut and fills next to I-15 (see Figure 3.5-8). Plans for 1991-92 include extending the realignment for another 2-3 miles to remove the numerous switch backs and their supporting fills. Observations of a number of those fills indicates that they have settled, causing surface cracking of the roadway pavement.

3.5.2 Railways

The main lines of the Atcheson, Topeka and Santa Fe (Santa Fe), the Southern Pacific, and the Union Pacific railways all run through Cajon Pass in close vicinity to each other. In fact, there is some mutual use of the right-of-ways, and a short section near Cajon Junction where interconnection of the Santa Fe and the Union Pacific is possible (but there is little special construction there). The Santa Fe and Union Pacific presently jointly use the Union Pacific tracks for eastbound traffic up the Pass, and the Santa Fe tracks for westbound traffic down the pass. The rail traffic in the Cajon Pass is about 75 trains per day and they experience about one minor derailment each year. The traffic also includes four AMTRAC passenger service runs per day. The Southern Pacific has major yard operations and repair facilities at their Coulton Yard in San Bernardino.

At the time of completion of this inventory phase of the project, the information for the railroad bridges, except for the highway crossings which were available from the California Department of Transportation, were incomplete. The railroads were unable to provide detailed information on their systems for this study.

The officials of the Southern Pacific indicated that it was standard policy to require all pipeline crossings to be cased, and the field data and data from the pipeline utilities confirms this. Most of the pipeline crossings for the Santa Fe and Union Pacific are cased, but not all of them are.

The Southern Pacific enters from the southeast corner of the study area from San Bernardino in the vicinity of Verdemont, and runs northwest parallel to and about 0.2 miles west of Cajon Blvd. along Cajon Wash. The Union Pacific and Sante Fe enter near the same point, but run, adjoining each other, on the east side of this same roadway. The 14-inch petroleum products pipeline is buried in the Santa Fe and Union Pacific right-of-ways, and periodically runs on the east side and then in the space between the railroad beds.

The Santa Fe and Union Pacific cross over to the west side of Cajon Blvd. just south of its junction with Kendell Drive. There the track expand to a four track section about 1.2 miles long ending at Devore. This section allows the railroads to switch back to their own tracks after they have descended the Cajon Pass. They then continue together with the Southern Pacific over bridges across Cajon Creek and under highway I-15. Figure 3.5-9 shows the railroad bridges in the wash area with the I-15 bridge in the background. All three lines then continue northwest along the west side of Cajon Wash close to the steep slopes, crossing several culverts and small bridges up to Blue Cut. While in the region of the steep slopes, one of the 36-inch natural gas pipelines is buried west of and in the right-of-way of the Southern Pacific. Occasionally, it crosses under the Southern Pacific and is buried between the beds of the Southern and Union Pacific railroads.

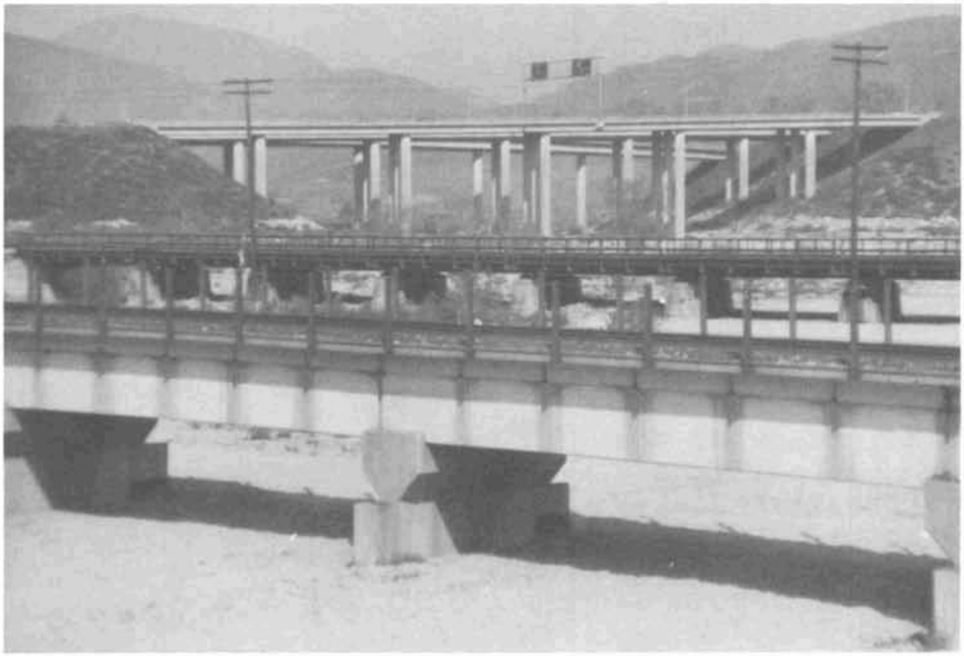


Figure 3.5-9 Railroad Bridges In Cajon Wash, I-15 Bridge In The Background

At Blue Cut the Sante Fe and the Union Pacific are close together on the west bank of Cajon Creek in the narrow gorge region, while the Southern Pacific has begun to diverge slightly to the northwest. All three lines cross Lone Pine Creek and the San Andreas fault zone in this general vicinity, and then continue northward next to the steep slopes on the west side of Cajon Canyon to the vicinity of Cajon Junction. Here the Southern Pacific is on a new alignment which begins the climb to the summit west of Cosy Dell, and is some 100 feet higher than the other two railroads when it swings west from Cajon Creek.

The Sante Fe and the Union Pacific cross to the east bank of Cajon Creek on a steel girder bridge, and have a section about one mile long which is four tracked in the flat land west of the Cajon community (it allows for siding a slow train to allow an express to pass, etc.). The Santa Fe and Union Pacific return to only two tracks, with the eastbound crossing Cajon creek to the west on a concrete deck structure supported on steel piles (see Figure 3.5-10) and the westbound a steel girder bridge on rubble concrete piles (see Figure 3.5-11). In the areas of the bridges of

Figures 3.5-10 and 3.5-11, the water table is high as indicated by the lush plant growth in the figure (also see Figure 3.2-5).

The railroad then climbs the hills west of Cajon community in a long "S" curve where it joins and parallels the alignment of the Southern Pacific as it approaches Route 138 about one mile west of Cajon Junction. The Southern Pacific track crosses over Route 138 on a new steel through girder with a ballasted deck (see Figure 3.5-12). This skewed, single span bridge potentially could fail during an earthquake. From there the railroads cross over the upper reaches of Cajon Creek on a multi-span, steel deck, girder bridge, and then head eastward under I-15 at Alray.

The eastbound Sante Fe and Union Pacific track passes under Route 138 about 0.1 mile east of the Southern Pacific bridge, then Cajon Creek on an old, multispan, steel deck, girder bridge. It then parallels

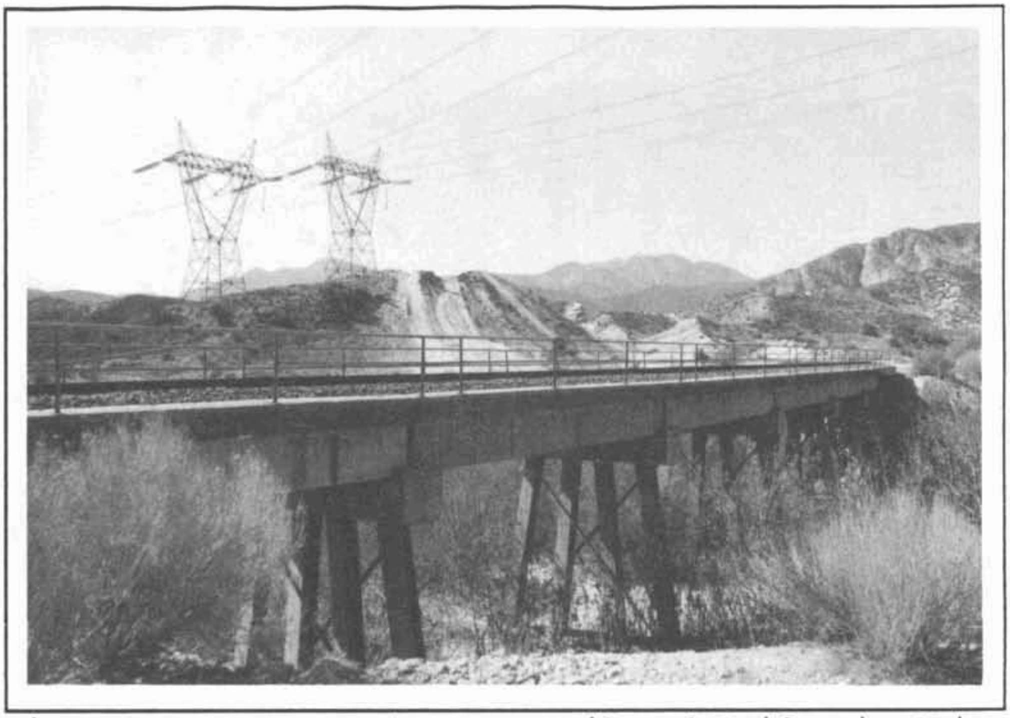


Figure 3.5-10 Concrete Beam Railroad Bridge in Cajon Creek Near Cajon Junction

Figure 3.5-11 Rubble Pier Railroad Bridge in Cajon Creek Near Cajon Junction

the alignment of the Southern Pacific, crossing under I-15 to the east just about 200 feet short of that railroad at Alray. The westbound track of the combined Sante Fe and Union Pacific crosses to the west of Cajon Creek just to the west of the I-15 truck weighing station, and continues northwest to cross under Route 138 about one half mile west of Cajon Junction (see Figure 3.5-13). It then turns east and crosses under I-15 about 0.6 mile south of the eastbound track.

After the Cajon Junction (heading north), all three rail lines run east, climbing the grade to the railroad Cajon summit near the head of Horsethief Canyon. The Southern Pacific and the eastbound Sante Fe-Union Pacific are on improved alignments, whereas the westbound Sante Fe-Union Pacific still involves a few short tunnels, which were constructed in about 1916, (see Figure 3.5-14) about one mile east of the I-15 crossing. In this region there

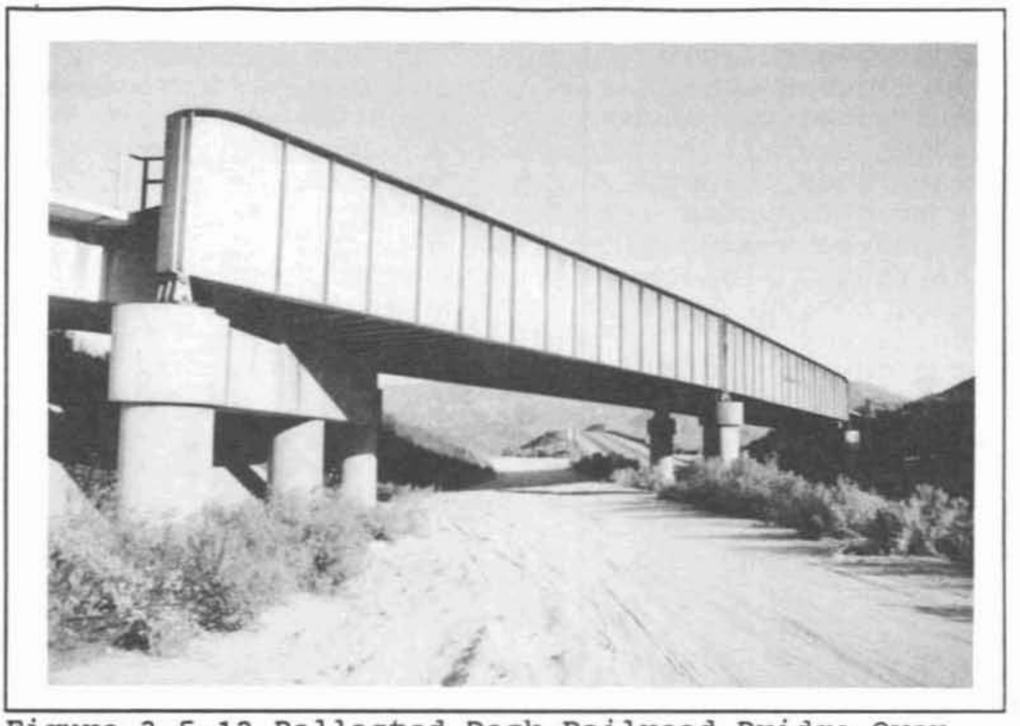


Figure 3.5-12 Ballasted Deck Railroad Bridge Over Highway 138

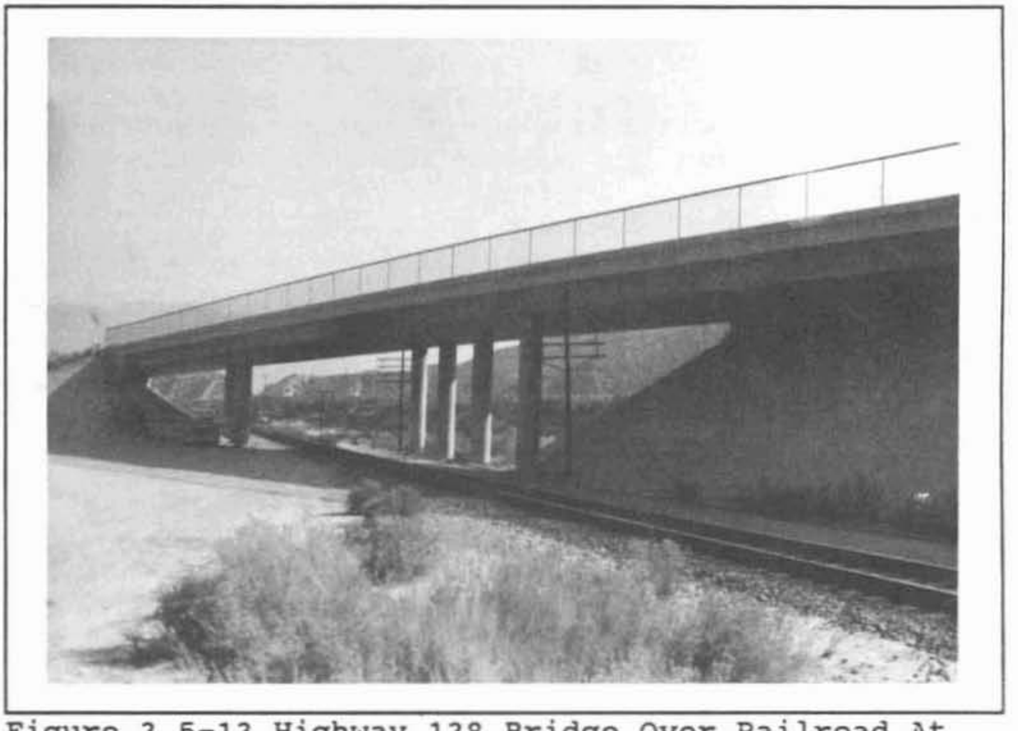


Figure 3.5-13 Highway 138 Bridge Over Railroad At Cajon Junction

are a number of short span bridges (see Figures 3.5-15 which shows two such bridges) on all three lines. They are used to cross unimproved roads and fire roads. In some cases, buried natural gas and petroleum products pipelines and fiber optic cables are located under the embankments next to the bridges. From the summit, the eastbound and westbound tracks of the Sante Fe-Union Pacific run on a common alignment in a northeasterly direction toward Barstow, while the Southern Pacific follows this same direction with a double track section for about one and one half miles, then a single track for about one mile. Afterward, it swings northwest to pass under Interstate I-15 just south of its junction with I-395, and then heads towards Palmdale and out of the study area.

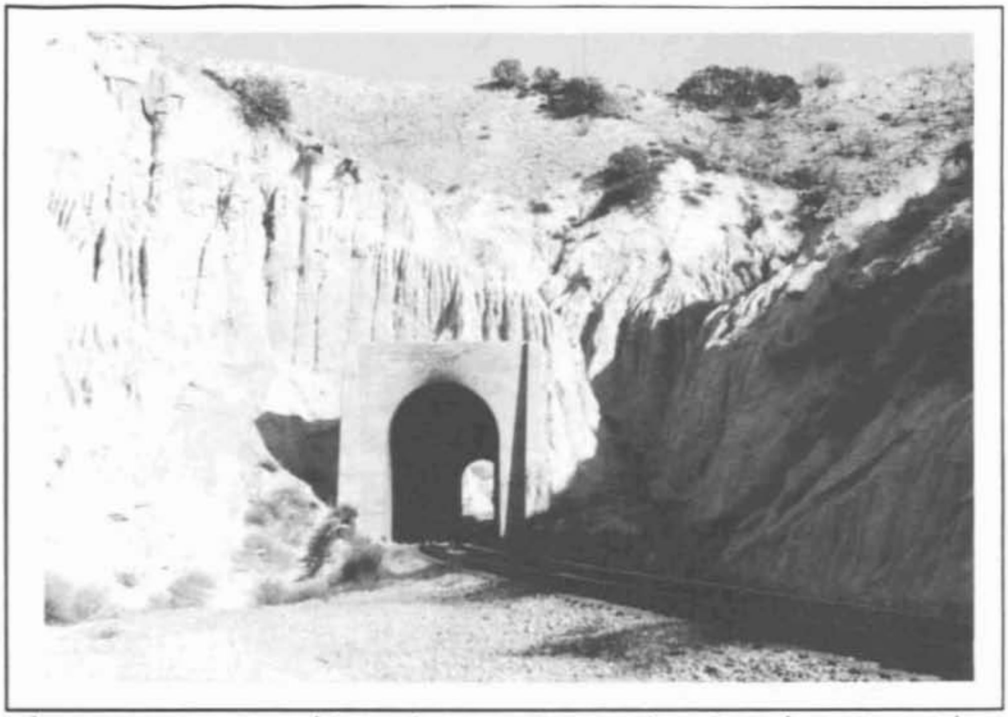


Figure 3.5-14 Railroad Tunnel North of Cajon Junction

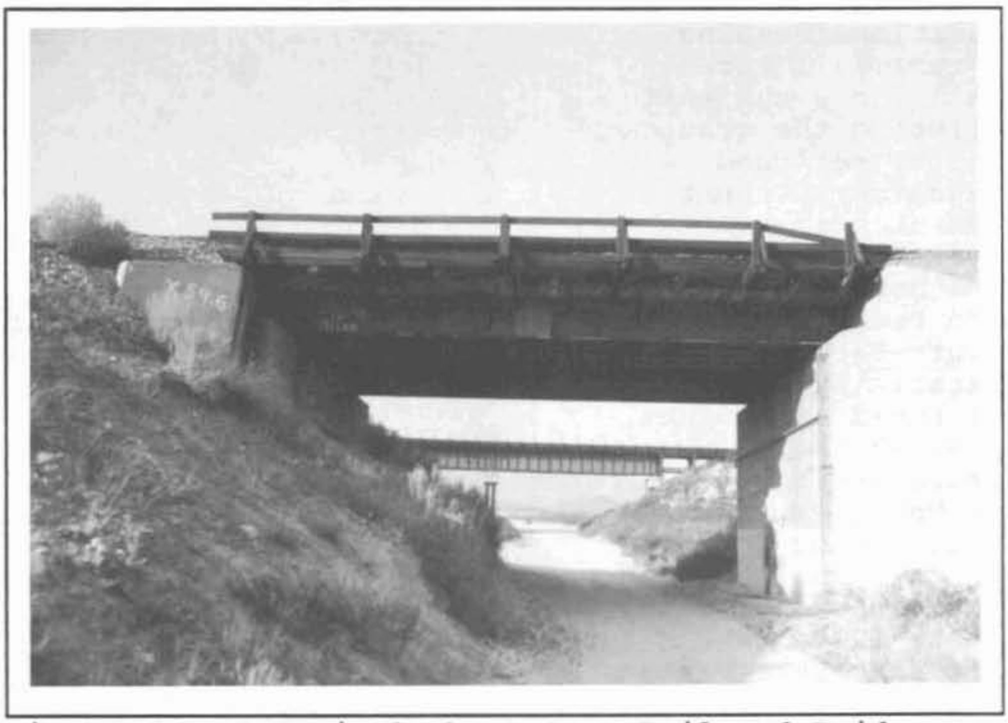


Figure 3.5-15 Typical Short Span Railroad Bridges North of Cajon Junction

3.5.3 Bibliography for Section 3.5

3.5-1 "Seismic Design Procedures and Specifications 1940 to 1968" CALTRANS Division of Structures, undated.

3.5-2 B. Maroney and J. Gates, "Seismic Risk Identification & Prioritization in the CALTRANS Seismic Retrofit Program", undated.

3.5-3 "Seismic Risk Algorithm For Bridge Structures", CALTRANS SASA Division of Structures, June 1990.

4.0 CONTACTS MADE DURING THE STUDY

The following list identifies the offices and organizations contacted during the preparation of this report.

American Telephone & Telegraph, 4430 Rosewood Dr., Pleasanton, CA 94566-9089

American Petroleum Institute, 1220 L St., Washington DC.

California Department of Conservation, Division of Mines & Geology, 630 Bercut Dr., Sacramento, CA 95814-0189

California Department of Transportation (CALTRANS), 1801 30th St. West Bldg, Sacramento, CA 95816

California Department of Water Resources Southern District, 849 So. Broadway, Suite 500, Los Angeles, CA 90055

California Energy Commission, 1516 9th St., Sacramento, CA 95814-5512

California Office of Emergency Services, 2151 East D St., Suite 203A, Ontario, CA 91764

California Public Utilities Commission, 505 Van Ness Ave, San Francisco, CA 94102

California Seismic Safety Commission, 1900 K St. Suite 100, Sacramento, CA 95814

California Utility Underground Service, 3030 Saturn St., Suite 200, Brea, CA 92621

CALNEV Pipe Line Co. 412 W. Hospitality Lane, Suite 202, San Bernardino, CA 92412

Continental Telephone, 16071 Mojave Dr., Victorville, CA 92392

Gas Research Institute, 8600 West Bryn Mawr Ave., Chicago, IL 60631

Earthquake Engineering Research Institute, 6431 Fairmount Ave., Suite 7, El Cerrito, CA 94530

Electric Power Research Institute, 3412 Hillview Ave., Palo Alto, CA 94303

Los Angeles Department of Water & Power, 111 North Hope St., Los Angeles, CA 90051

MCI, 400 International Parkway, Richardson, TX 75081

National Association of Corrosion Engineers, 1440 South Creek Dr., Houston, TX 77084

National Center for Earthquake Engineering Research, Buffalo, NY, 716 636-3391

Northern Telecom Canada Ltd. 2800 Dixie Rd. Brampton, Ontario, Canada L6V 2M6

San Bernardino Valley Municipal Water District, 1350 So. E St., San Bernardino, CA 92412-5906

Southern California Edison Company, 2244 Walnut Grove Ave, Rosemead, CA 91770

Southern California Gas Company, 3208 N. Rosemead Blvd., El Monte, CA 91731

State of California Office of State Fire Marshal, Pipeline Safety Division, 1501 W. Cameron Ave, South Bldg, Suite 250, West Convina, CA 91790.

US Sprint, 521 West Rialto Ave., Rialto, CA 92376

U.S. Department of Transportation, Office of Pipeline Safety, 400 7th St., SW, Washington, DC 20590

U.S. Geologic Survey, 345 Middlefield Rd., Menlo Park, CA 94025

U.S. Forest Service, Cajon Ranger District, San Bernardino National Forest, Star Route Box 100, Fontana, CA 92336-9704

APPENDIX A

DETAILS FOR FIGURE 3.1-1, REGIONAL EARTHQUAKE FAULT DATA

TABLE 3.1-1 Geologic and seimologic characteristics of late Quaternary faults in the Los Angeles region

(Evidence of faulting age: OS, offset stratigraphy; P, fault-produced physiographic features; W, ground-water impediment within late Quaternary alluvial deposits. Type of faulting: R, reverse; N, normal; SR, right-lateral strike slip; SL, left-lateral strike slip; RRO, reverse right oblique; RLO, reverse left oblique; NRO, normal right oblique; NLO, normal left oblique)

Map number and fault	Geometric aspects	Age and evidence of latest surface faulting	Type of late Quaternary offset	Seismicity	Sources of information
1 San Andreas fault zone	Numerous subparallel faults of varied length in zone generally 0.3–1.5 km wide (as wide as 4 km near Palmdale and Lake Hughes). Zone strikes N. 65°–70° W. but near Banning strikes N. 40° W. Most faults are approximately vertical, although SE. from Cajon Pass generally dip 55°–60° NE. The most recently active element within zone typically composed of linear segments 0.5 to 11 km long arranged in echelon manner in belt as wide as 100 m. Scattered splay faults locally diverge from trend of main zone. Subsidiary south-dipping faults common on southern side of zone adjacent to Antelope Valley. Fault zone extends as continuous surface feature from near Banning NW. more than 1,000 km to Cape Mendocino. Connected by Banning fault (95) to Indio segment of San Andreas fault NE. of Imperial Valley.	Historical (1857) SE. to Wrightwood. Holocene (OS, P) from Wrightwood to near Banning. Splay and subsidiary faults chiefly late Quaternary (OS, P).	SR	Source of 1857 Fort Tejon earthquake (estimated M 7.9), whose epicenter probably was in the Parkfield–Cholame area of central California. Possible source of July 22, 1899, earthquake (estimated M_L 6.5) near San Bernardino. Diffuse belt of scattered small earthquakes associated with fault zone.	Mapping, Quail Lake–Wrightwood: Barrows and others (1985) Mapping, Quail Lake–Palmdale: Beeby (1979) Kahle (1979) Kahle and others (1977) Kahle and Barrows (1980) Mapping, Palmdale–Wrightwood: Barrows and others (1976) Barrows (1979, 1980) Schubert and Crowell (1980). Mapping, Wrightwood–Banning: J. C. Matti (unpublished data, 1983). Miller (1979) Morton and Miller (1975) Ross (1969) Slip/recurrence: Davis and Duebendorfer (1982). Rasmussen (1982a) Rust (1982) Sieh (1978a, c, 1984) Weldon and Sieh (1981) Seismicity: Green (1983) Hileman and Hanks (1975) C. E. Johnson (unpublished data, 1982).
San Jacinto fault zone:					
2 Glen Helen	Single strand. Strikes N. 40°–60° W. Presumed vertical dip. Length at least 8 km.	Holocene (P, W)	SR	Closely associated small earthquakes. Geometrically compatible fault-plane solutions. Possible source for two damaging earthquakes of $M_L \geq 6$ (1899, 1907).	Cramer and Harrington (1984, in press). Pechmann (in press) Sharp (1972) Thatcher and others (1975)
3 San Jacinto	Several strands in zone as wide as 0.3 km. Strikes N. 40°–60° NW. Dips 35° NE. to vertical. Length approximately 25 km.	Late Quaternary (OS)	SR, RRO	Numerous small earthquakes near fault trace. Geometrically compatible fault-plane solutions.	Cramer and Harrington (1984, in press). C. E. Johnson (unpublished data, 1982). Morton (1975, 1976)
4 Lytle Creek	Single strand. Strikes N. 45° W. Dips 65° SW. Length at least 12 km.	Late Quaternary (OS, W)	RRO	Numerous small earthquakes near fault trace. Geometrically compatible fault-plane solutions.	Cramer and Harrington (1984, in press). C. E. Johnson (unpublished data, 1982). Mezger and Weldon (1983) Morton (1975, 1976)
5 Claremont	Single strand composed of closely overlapping breaks. Strikes N. 40°–55° W. Dip vertical or steeply NE. Length approximately 65 km.	Holocene (OS, P, W); historical creep near Hemet possibly related to subsidence due to ground-water withdrawal.	SR	Scattered small earthquakes near fault trace. Possible source for four damaging earthquakes of $M_L \geq 6$ (1890, 1899, 1918, 1923).	Fett (1967) Given (1981) Green (1983) C. E. Johnson (unpublished data, 1982). Morton (1978) Sharp (1972) Thatcher and others (1975)

TABLE 3.1–1 Geologic and seimologic characteristics of late Quaternary faults in the Los Angeles region—Continued

Map number and fault	Geometric aspects	Age and evidence of latest surface faulting	Type of late Quaternary offset	Seismicity	Sources of information
San Jacinto fault zone—Continued:					
6 Casa Loma	Several closely overlapping echelon strands. Strikes N. 35°–40° W. Dips 50°–70° NE. Length approximately 18 km.	Holocene (OS, P, W); creep movement since at least 1939, possibly related to subsidence due to ground-water withdrawal.	N or NRO	Scattered small earthquakes near fault trace.	Given (1981) Fett (1967) Morton (1978) Proctor (1962, 1974) Rasmussen (1981, 1982b) C. E. Johnson (unpublished data, 1982).
7 Hot Springs	Single strand. Strikes east-west to N. 45° W. Dips steeply NE. Length approximately 29 km.	Probably late Quaternary (P)	R or RRO	Scattered small earthquakes at southern end of fault trace.	Given (1981) Sharp (1967)
8 Clark	Single strand composed of closely overlapping breaks. Strikes N. 50°–60° W. Dips vertically to 60° NE. Length at least 85 km.	Holocene (OS, P)	SR and RRO	Numerous closely associated small earthquakes along northern and southern sectors. Geometrically compatible fault-plane solution. Possible source for M_L 6 earthquake in 1937.	Given (1981) Sanders and Kanamori (1984) Sharp (1967, 1972, 1981a) Thatcher and others (1975)
9 Rialto-Colton	Two echelon strands. Strikes N. 45°–55° W. Presumed vertical dip. Total length 28 km.	Late Quaternary (W); no surface expression.	SR	Numerous small earthquakes nearby.	California Department of Water Resources (1970). C. E. Johnson (unpublished data, 1982).
10 Central Avenue	Presumed single strand. Strikes N. 35° W. Dip unknown. Length at least 8 km.	Late Quaternary (W); no surface expression.	?		Morton (1976) Ziony and others (1974)
11 Chino	Single strand. Strikes N. 35°–50° W. Dips 60°–65° SW. Length at least 18 km.	Late Quaternary (OS, P, W)	RRO	Scattered small earthquakes SW. of fault trace.	Durham and Yerkes (1964) Heath and others (1982) C. E. Johnson (unpublished data, 1982). Weber (1977)
12 Whittier	One to three subparallel strands in zone as wide as 1.2 km. Strikes N. 65°–80° NE. Dips 65°–80° NE. Length at least 40 km.	Late Quaternary (OS, P) NW. of Brea Canyon; Holocene (OS) SE. to near Santa Ana River.	RRO	Numerous small earthquakes closely associated with fault.	Durham and Yerkes (1964) Hannan and others (1979) C. E. Johnson (unpublished data, 1982). Lamar (1972, 1973) Morton and others (1973) Yerkes (1972)
Elsinore fault zone:					
13 Main Street	Several overlapping strands. Strikes N. 60°–80° W. Presumed to dip steeply SW. Length approximately 7 km.	Probably Holocene (P)	R or RRO		Hart and others (1979) Weber (1977)
14 Fresno-Eagle	Single strand. Strikes N. 55°–65° W. Dips 15°–50° SW. Length at least 16 km.	Late Quaternary (P)	R or RRO		Weber (1977)
15 Tin Mine	Single strand. Strikes N. 50° W. Vertical dip. Length approximately 5 km.	Late Quaternary (P)	SR		Weber (1977)

TABLE 3.1–1 Geologic and seimologic characteristics of late Quaternary faults in the Los Angeles region–Continued

Map number and fault	Geometric aspects	Age and evidence of latest surface faulting	Type of late Quaternary offset	Seismicity	Sources of information
Elsinore fault zone—Continued:					
16 Glen Ivy North	Single strand of closely overlapping breaks. Strikes N. 40°–55° W. Dips 70° SW. except for vertical to steeply NE. dip near Lake Elsinore. Length at least 28 km.	Holocene (OS, P)	NRO	Numerous closely associated small earthquakes at northern end. Possible source of M_L 6 earthquake in 1910.	C. E. Johnson (unpublished data, 1982). Langenkamp and Combs (1974). Millman (1985) Rockwell and others (1985) Weber (1977)
17 Glen Ivy South	Single strand. Strikes N. 35°–65° W. Dips 45°–50° SW. Length 7 km.	Holocene (P)	RRO	Numerous closely associated small earthquakes.	C. E. Johnson (unpublished data, 1982). Langenkamp and Combs (1974). Millman (1985) Weber (1977)
18 Wildomar	One to five subparallel strands in zone locally 0.7 km wide. Strikes N. 45°–65° W. Dips steeply SW. Length at least 40 km.	Holocene (OS, P)	NRO	Scattered small earthquakes nearby.	C. E. Johnson (unpublished data, 1982). Kennedy (1977) Lamar and Swanson (1981) Langenkamp and Combs (1974). Weber (1977)
19 Willard	Several discontinuous echelon strands. Strikes N. 50°–55° W. Presumed to dip steeply NE. Total length at least 35 km.	Late Quaternary (OS, P)	NRO	Scattered small earthquakes nearby.	C. E. Johnson (unpublished data, 1982). Hart and others (1979) Langenkamp and Combs (1974). Kennedy (1977) Weber (1977)
20 Wolf Valley	Single strand. Strikes N. 55°–75° W. Presumed vertical dip. Length 6 km.	Late Quaternary (OS, P, W)	SR	Numerous closely associated small earthquakes.	Hart and others (1979) C. E. Johnson (unpublished data, 1982). Kennedy (1977)
21 Murietta Hot Springs.	Several overlapping strands. Strikes N. 80° E. to N. 70° W. Dips 80°–85° S. Length at least 12 km.	Late Quaternary (OS, P, W)	N		Kennedy (1977)
22 Norwalk	Presumed single strand. Strikes N. 65°–85° W. Dips steeply NE. Length at least 14 km.	Possibly late Quaternary (P)	R(?)	Scattered small earthquakes NE. of fault trace. Possible source for damaging 1929 earthquake (M_L 4.7).	Lamar (1973) C. E. Johnson (unpublished data, 1982). Richter (1958) Yerkes (1972)
23 Faults in West Coyote Hills.	Four subparallel faults in zone 2.0 km wide. Strikes N. 10°–45° W. Dips 70° SW. to 55° NE. Lengths from 1 to 1.5 km.	Late Quaternary (OS); historical (1968) surface rupture along westernmost fault probably related to withdrawal of oil and gas.	RLL		Morton and others (1973) Yerkes (1972)
24 Peralta Hills	Single strand. Strikes N. 80° W. to N. 80° E. Dips 0°–60° N. Length at least 8 km.	Late Quaternary (OS, P)	R	Numerous small earthquakes nearby.	Bryant and Fife (1982) Fife and others (1980) C. E. Johnson (unpublished data, 1982). Morton and others (1973) Schoellhamer and others (1981).

TABLE 3.1–1 Geologic and seimologic characteristics of late Quaternary faults in the Los Angeles region–Continued

Map number and fault	Geometric aspects	Age and evidence of latest surface faulting	Type of late Quaternary offset	Seismicity	Sources of information
Newport–Inglewood fault zone:					
25 Inglewood	Single strand locally offset by short north- and NE-trending faults. Strikes N. 5°–30° W. Dips 70° W. Length at least 13 km.	Late Quaternary (OS, P); surface faulting since 1957 locally along north-trending faults in response to withdrawal of oil and gas.	N or NRO	Numerous small earthquakes nearby. Geometrically compatible fault-plane solution. Possible source of 1920 earthquake (M_L 4.9).	Barrows (1974) Buika and Teng (1979) Castle and Yerkes (1976) Poland and others (1959) J. C. Tinsley (unpublished data, 1983).
26 Potrero	Single strand. Strikes N. 25° W. Dips 77° W. at surface, 82° W. at depth. Length 7 km.	Late Quaternary (P, W)	N or NRO	Numerous small earthquakes nearby.	Barrows (1974) Buika and Teng (1979) Poland and others (1959)
27 Avalon-Compton	Single strand. Strikes N. 20°–30° W. Presumed vertical. Length at least 4 km.	Late Quaternary (P, W); historical (1941, 1944) faulting within 1.5 km of surface along subsidiary south-dipping reverse faults.	SR(?)	Scattered small earthquakes nearby. Epicenters of 1941 (M_L 4.9) and 1944 (M_L 4.5) lie SW. of fault trace.	Bravinder (1942) Buika and Teng (1979) Mariner (1948) Poland and others (1959)
28 Cherry-Hill	Single strand. Strikes N. 39°–50° W. Dips 80° E. Length at least 9 km.	Late Quaternary (OS, P, W)	R or RRO	Numerous small earthquakes lie east of trace. Fault overlies aftershock zone of 1933 Long Beach earthquake (*M* 6.2). 1941 Torrance–Gardena earthquake (M_L 5.4) located SW. of fault trace.	Hileman and others (1973) C. E. Johnson (unpublished data, 1982). K. R. Lajoie (unpublished data, 1983). Poland and Piper (1956) Yerkes and others (1965)
29 Reservoir Hill–Seal Beach.	Single strand. Strikes N. 59° W. Dips near vertical. Length at least 12 km.	Late Quaternary (OS, P, W)	NRO or SR	Numerous small earthquakes near trace. Fault overlies aftershock zone of 1933 Long Beach earthquake (*M* 6.2).	Hileman and others (1973) C. E. Johnson (unpublished data, 1982). Poland and Piper (1956)
30 Newport–Inglewood (North Branch).	One to three closely spaced strands. Strikes N. 40°–60° W. Dips steeply SW. Length at least 18 km.	Holocene (OS, W); possible historical surface faulting (1933) at Newport Mesa.	SR	Scattered small earthquakes near trace. Fault is adjacent to aftershock zone of 1933 Long Beach earthquake (*M* 6.2).	California Department of Water Resources (1966, 1968). Guptill and Heath (1981) Hileman and others (1973) C. E. Johnson (unpublished data, 1982).
31 Newport–Inglewood (South Branch).	Single strand. Strikes N. 45° W. Dips steeply SW. Length at least 10 km and possibly joins similarly oriented fault offshore Dana Point.	Late Quaternary (P)	SR	Scattered small earthquakes near trace. Fault is adjacent to aftershock zone of 1933 Long Beach earthquake (*M* 6.2).	California Department of Water Resources (1966) Hileman and others (1973) C. E. Johnson (unpublished data, 1982). Poland and Piper (1956)
32 Faults offshore of San Clemente.	Two echelon strands. Strikes N. 45°–55° W. Dip unknown. Length of each fault at least 25 km.	Late Quaternary (OS, P)	SR(?)	Concentrations of small earthquakes locally along traces.	Clarke and others (this volume). C. E. Johnson (unpublished data, 1982).
33 Pelican Hill	Several strands. Strikes N. 15°–35° W. Dips 75° W. at surface but 45° W. at depth.	Late Quaternary (OS) along subsidiary fault.	N or NRO	Scattered small earthquakes west of trace.	Castle (1966) Morton and others (1973) J. E. Slosson (personal communication, 1973).

TABLE 3.1–1 Geologic and seimologic characteristics of late Quaternary faults in the Los Angeles region—Continued

Map number and fault	Geometric aspects	Age and evidence of latest surface faulting	Type of late Quaternary offset	Seismicity	Sources of information
34 Charnock and Overland Avenue.	Two fault strands. Strikes N. 35° W. Presumed vertical dip. Length at least 10 km.	Late Quaternary (OS); no surface expression.	SR(?)	Numerous small earthquakes nearby. Geometrically compatible fault-plane solutions.	Buika and Teng (1979) Poland and others (1959)
35 Palos Verdes Hills	Several echelon strands locally in a zone as wide as 2 km. Strikes N. 20°–60° W. Onshore segment generally not exposed. Dip 70° SW. in subsurface of Palos Verdes Hills, although exposed subsidiary fault dips 75° NE. Total length at least 80 km.	Holocene (OS) in San Pedro Bay. Late Quaternary (OS, P) onshore and probably overlain by Holocene alluvium. Inferred late Quaternary (OS) in Santa Monica Bay.	R or RRO	Numerous small earthquakes near and west of fault trace. Geometrically compatible fault-plane solution in Santa Monica Bay.	Buika and Teng (1979) Clarke and others (this volume). Hileman and others (1973) Junger and Wagner (1977) Nardin and Henyey (1978) Poland and others (1959) Woodring and others (1946) Yerkes and others (1965)
36 Redondo Canyon	Presumed single strand. Strikes N. 80°–85° E. Dip unknown. Length approximately 13 km.	Holocene (P)	R(?)	Scattered small earthquakes near trace.	Nardin and Henyey (1978) Yerkes and others (1967)
37 Cabrillo	Several echelon strands. Strikes N. 20°–50° W. Dips 50°–75° onshore. Length approximately 18 km.	Holocene (OS) offshore	N or NRO	Scattered small earthquakes near fault trace.	Clarke and others (this volume). Darrow and Fischer (1983) Hileman and others (1973) Lajoie and others (1979) Woodring and others (1946)
38 San Pedro Basin fault zone.	Series of separate, left-stepping echelon strands in zone locally as wide as 5 km. Strikes N. 35°–50° W. Presumed vertical dip. Length of individual strands 4–12 km; length of entire zone at least 70 km.	Late Quaternary (OS)	SR or RRO	Numerous small earthquakes near and east of fault traces. Geometrically compatible fault-plane solutions.	Hileman and others (1973) Junger and Wagner (1977) Nardin (1981) Yerkes and Lee (1979a, b) C. E. Johnson (unpublished data, 1982).
39 Faults of the Santa Cruz-Catalina sea-floor escarpment.	Echelon strands in zone locally 4 km wide. Strikes N. 50°–60° W. Length of individual strands 5 to 40 km; length of entire zone at least 120 km.	Possibly late Quaternary (P)	SR	Source of 1981 Santa Barbara Island earthquake (M_L 5.2) and aftershocks.	Corbett and Piper (1981) C. E. Johnson (unpublished data, 1982). Junger and Wagner (1977) Yerkes and Lee (1979a, b)
Faults of Mojave Desert region:					
40 Llano	Single strand. Strikes N. 65° W. Presumed dip to SW. Length at least 6 km.	Holocene (P) monoclinal folding.	R		Guptill and others (1979) Ponti and Burke (1980)
41 Mirage Valley	Several echelon strands, each 1–7 km long, locally in zone 3 km across. Strike N. 40°–50° W. Presumed vertical dip. Total length of zone approximately 30 km.	Late Quaternary; overlain by unfaulted Holocene alluvial fan deposits.	SR(?)		Ponti and Burke (1980)
42 Helendale	Numerous echelon strands, 1 to 4 km long, forming narrow linear zone as wide as 1 km. Strands strike N. 45°–50° W. Presumed vertical dips. Total length of zone at least 90 km.	Holocene (P)	SR	Closely associated small earthquakes.	G. S. Fuis (unpublished data, 1983). C. E. Johnson (unpublished data, 1982). Miller and Morton (1980) Morton and others (1980)

TABLE 3.1–1 Geologic and seimologic characteristics of late Quaternary faults in the Los Angeles region—Continued

Map number and fault	Geometric aspects	Age and evidence of latest surface faulting	Type of late Quaternary offset	Seismicity	Sources of information
Faults of Mojave Desert region (Continued):					
43 Lenwood	Numerous closely overlapping echelon strands, 1–5 km long, forming continuous narrow zone. Strands strike N. 25°–40° W. Presumed vertical dips. Total length of zone at least 65 km.	Late Quaternary (P). Possible historical fault creep at northern end.	SR	Closely associated small earthquakes.	Church and others (1974) G. S. Fuis (unpublished data, 1983). C. E. Johnson (unpublished data, 1982). Miller and Morton (1980) Morton and others (1980)
Faults within Transverse Ranges:					
44 Santa Ynez	One to seven strands in zone as wide as 0.3 km. Strikes N. 80° W. to N. 85° E. Dips 45°–80° S., generally steepens eastward. Total length 130 km; late Quaternary length approximately 80 km.	Possibly Holocene (OS) along one strand near Lake Cachuma. Late Quaternary (OS, P) as far east as near Wheeler Springs	SL		Darrow and Sylvester (1983) Dibblee (1966) Keaton (1978) Yerkes and Lee (1979a, b) J. I. Ziony (unpublished data, 1981). R. E. Troutman (unpublished data, 1984).
45 San Jose (A)	One to two strands. Strikes N. 60° W. Dip unknown. Length approximately 13 km.	Late Quaternary (OS)	N(?)		Dibblee (1966) Olson (1982)
46 Mission Ridge–Arroyo Parida.	Single strand. Strikes N. 80° E. to N. 85° W. Dips steeply S. near Santa Barbara but dips 60°–80° N. further east. Length approximately 40 km.	Late Quaternary (OS, P); apparently overlain by unfaulted Holocene alluvium.	N	Scattered small earthquakes near trace. Mission Ridge fault possible source of 1978 earthquake (M_L 5.1).	Dibblee (1966) Jackson and Yeats (1982) Yerkes and Lee (1979a, b) Rockwell (1983) Rockwell and others (1984) Yeats and Olson (1984)
47 More Ranch	One to two strands. Strikes N. 80° W. to N. 80° E. Dips 75°–85° S. Length at least 14 km.	Late Quaternary (OS, P)	R	Scattered small earthquakes near trace.	Dibblee (1966) K. R. Lajoie (unpublished data, 1983). Upson (1951) Yerkes and Lee (1979a, b)
48 Mesa–Rincon Creek	Single strand. Strikes N. 60° W. to east-west. Dips 65°–35° S. near surface; probably vertical at depth. Length approximately 37 km.	Late Quaternary (OS, P)	R	Scattered small earthquakes near trace.	Dibblee (1966) Jackson and Yeats (1982) Yerkes and Lee (1979a, b)
49 Lavigia	One to two strands. Strikes N. 50°–75° W. Dips 45° SW. Length at least 7 km.	Late Quaternary (OS)	R	Scattered small earthquakes near trace.	Dibblee (1966) Olson (1982)
50 Shepard Mesa	Single strand. Strikes N. 60°–70° W. Dips 70° S. Length 6 km.	Late Quaternary (OS, P)	R		Jackson and Yeats (1982)
51 Carpinteria	Single strand. Strikes N. 75° W. Dips 40° S. Length 4 km.	Late Quaternary (OS)	R		Jackson and Yeats (1982) K. R. Lajoie (unpublished data, 1983). A. M. Sarna-Wojcicki (unpublished data, 1982).

TABLE 3.1-1 Geologic and seimologic characteristics of late Quaternary faults in the Los Angeles region—Continued

Map number and fault	Geometric aspects	Age and evidence of latest surface faulting	Type of late Quaternary offset	Seismicity	Sources of information
Faults within Transverse Ranges—Continued:					
52 Red Mountain	Several strands in zone 1 km wide. Strikes N. 85° W. to N. 60° E. Dips 55°–65° N. near surface; 70°–75° N. at depth; 85° N. at western end. Length approximately 38 km.	Late Quaternary (OS, P); southern branch overlain by unfaulted Holocene marine terrace deposits (2,000–6,000 yr B.P.).	RLO	Numerous closely associated small earthquakes. Geometrically compatible fault-plane solutions.	Jackson and Yeats (1982) K. R. Lajoie (unpublished data, 1983). A. M. Sarna-Wojcicki (unpublished data, 1982). Yeats and others (1981, in press). Yerkes and Lee (1979a, b)
53 Fault Y	Probably several strands. Strikes east-west to N. 60° E. Dip unknown. Length approximately 33 km.	Holocene (P)	R(?)	Scattered small earthquakes near trace.	Crippen and others (1982) Yerkes and Lee (1979a, b) Yerkes and others (1981)
54 Javon	Single strand. Strikes N. 80° W. Dips 66° S. Length at least 4 km.	Holocene (OS)	R		A. M. Sarna-Wojcicki and others (in press).
55 Pitas Point–Ventura	Presumed single strand. Strikes N. 70° W. to east-west. Dips steeply north. Length at least 50 km.	Holocene (OS, P)	RLO	Closely associated small earthquakes near eastern end. Geometrically compatible fault-plane solutions. Possible source of 1941 Santa Barbara earthquakes (M 6.0). Alternate possible source for 1978 Santa Barbara earthquake (M_L 5.1).	Corbett and Johnson (1982) Greene and others (1978) Lee and others (1978, 1979) A. M. Sarna-Wojcicki (unpublished data, 1976). Yerkes and Lee (1979a, b)
56 Santa Ana	Two strands at western end. Strikes east-west. Dip inferred steeply south. Length 13 km.	Late Quaternary (P, W)	R(?)		Keller and others (1980) Rockwell and others (1984)
57 Faults near Oak View.	Five separate strands. Strikes N. 60° E. Dips 30°–60° SE. May become bedding-plane faults at depth. Length from 1 to 3 km.	Holocene (OS, P)	R		Keller and others (1982) Rockwell (1983) Rockwell and others (1984) Yeats and others (1981)
58 Lion Canyon	Single strand. Strikes N. 80° E. Dips 30°–50° S. Length approximately 15 km.	Late Quaternary (OS, P)	R		Schlueter (1976) Keller and others (1980)
59 San Cayetano	Two strands about 0.5 km apart west from Sespe Creek; single strand to east. Strikes N. 60° W. to N. 70° E. Dips 5°–35° N. near surface, 55°–70° N. at depth. Length approximately 40 km.	Holocene (OS, P)	R	Scattered nearby small earthquakes. Geometrically compatible fault-plane solution.	Cemen (1977) Keller and others (1982) Rockwell (1982, 1983) Schlueter (1976) Yerkes and Lee (1979a, b)
60 Faults of Orcutt and Timber Canyons.	Eight separate strands. Strikes N. 80° E. Dip 55°–70° N. near surface. May become shallow bedding-plane faults at depth. Lengths from 2 to 6 km.	Late Quaternary (OS, P)	R		Keller and others (1980) Rockwell (1983) Yeats and others (1981)

TABLE 3.1–1 Geologic and seimologic characteristics of late Quaternary faults in the Los Angeles region—Continued

Map number and fault	Geometric aspects	Age and evidence of latest surface faulting	Type of late Quaternary offset	Seismicity	Sources of information
Faults within Transverse Ranges—Continued:					
61 Holser	Several closely spaced strands. Strikes N. 80° E. to N. 70° W. Dips 60°–70° S. Length approximately 12 km.	Late Quaternary (OS, P)	R		Cemen (1977) Stitt (1983) Weber (1978, 1982)
62 Clearwater	One to two strands. Strikes N. 80° W. to east-west. Generally dips 70°–80° N. but locally 25°–40° N. Late Quaternary length approximately 14 km.	Late Quaternary (OS) near San Francisquito Canyon but overlain by unfaulted late Quaternary river terrace deposits elsewhere.	R(?)		Los Angeles County Engineer, unpublished data, 1965). Stanley (1966)
63 San Gabriel (central portion).	Several echelon strands in zone 0.5 km wide. Strikes N. 45°–65° W. Dips 50°–80° N. Late Quaternary length at least 32 km.	Holocene (OS, W) near Castaic. Late Quaternary (OS, P) between Newhall and Big Tujunga Canyon.	N or NRO		Cotton and others (1983) Nelligan (1978) Stitt (1983) Weber (1978, 1982; unpublished data, 1984).
64 Oak Ridge	One to three strands in zone as much as 0.5 km wide. Strikes N. 60° W. to N. 50° E. Generally dips 65°–80° S. but south of Fillmore dips 5°–30° S. near surface. Length approximately 100 km.	Late Quaternary (W, P); possibly Holocene south of Fillmore (P) and offshore.	R	Numerous closely associated small earthquakes near western end. Geometrically compatible fault-plane solution south of Santa Paula. Western end possible source of 1925 Santa Barbara earthquake (M 6.8).	Ricketts and Whaley (1975) Rieser (1976) Weber and Kiesling (1975) Yeats and others (1981, 1982) Yerkes and Lee (1979a, b)
65 Springville	Two strands in zone about 0.6 km wide. Strikes N. 65°–75° E. Dips 55°–80° N. Length about 9 km.	Late Quaternary (P, W)	R(?)		Jakes (1979)
66 Camarillo	Single strand. Strikes east-west. Presumed vertical dip. Length at least 6 m.	Late Quaternary (P, W)	R(?)		Gardner (1982) Jakes (1979)
67 Simi	Single strand that bifurcates at western end. Strikes N. 70°–80° E. Dips 60°–75° N. Length approximately 31 km.	Late Quaternary (OS, P); overlain by unfaulted Holocene alluvium (about 4,000 yr B.P.).	R	Closely associated small earthquakes, including M_L 3.1 event in 1969.	Jakes (1979) C. E. Johnson (unpublished data, 1982). Hanson (1981) Weber and Kiesling (1975)
68 Santa Susana	Several strands in zone as much as 1 km wide. Strikes N. 75° W. to N. 50° E. Dips 0°–30° N. near surface; 55°–60° N. at depth. Length 28 km.	Late Quaternary (OS); overlain by unfaulted Holocene stream terrace deposits (approximately 10,000 yr B.P.). Locally at northeastern end, historical surface faulting accompanied 1971 San Fernando earthquake.	RLO	Scattered associated small earthquakes, including M_L 4.6 event near Gillibrand Canyon in 1976. Geometrically compatible fault-plane solutions.	Leighton and others (1977) Lung and Weick (1978) Simila and others (1982) Weber (1975) Yeats and others (1977) Yerkes and Lee (1979a, b)
69 San Fernando	Five major echelon strands. Strikes N. 75° E. to N. 70° W. Dips 15°–50° N. near surface; 35° N. at depth. Total length at least 15 km.	Surface faulting accompanied 1971 San Fernando earthquake.	RLO	Source of 1971 San Fernando earthquake (M 6.6) and aftershocks. Geometrically compatible fault-plane solutions.	Allen and others (1975) Barrows (1975) Bonilla (1973) Kahle (1975) Sharp (1975) U.S. Geological Survey Staff (1971). Weber (1975)

TABLE 3.1-1 Geologic and seimologic characteristics of late Quaternary faults in the Los Angeles region—Continued

Map number and fault	Geometric aspects	Age and evidence of latest surface faulting	Type of late Quaternary offset	Seismicity	Sources of information
Faults within Transverse Ranges—Continued:					
70 Mission Hills	Presumed single strand. Strikes N. 80° E. to east-west. Dips 80° N. near surface, 45° N. at depth. Length at least 10 km.	Late Quaternary or Holocene (OS, P, W).	R(?)		Kowalewsky (1978) Saul (1975) Shields (1978)
71 Northridge	Several echelon strands in zone 0.7 km wide. Strikes N. 70°–80° W. Dips 35° N. near surface, 80° N. at depth. Length approximately 15 km.	Late Quaternary or Holocene (P, W).	R ?	Several aftershocks of 1971 San Fernando earthquake are closely associated with fault.	Barnhart and Slosson (1973) Shields (1978) Weber (1980)
72 Verdugo	Presumed multiple strands in zone 0.5–1.0 km wide. Strikes N. 50°–70° W. Inferred to dip 45°–60° NE. Length at least 20 km.	Holocene (OS, P, W)	R(?)	Scattered small earthquakes near trace.	C. E. Johnson (unpublished data, 1982). Weber (1980)
73 Eagle Rock	Single strand. Strikes N. 60° W. to east-west. Dips 15°–30° N. at western end. Length at least 5 km.	Possibly late Quaternary (OS, P).	R(?)		Weber (1980)
74 San Rafael	Echelon strands. Strikes N. 60°–70° W. Presumed near-vertical dip. Total length approximately 6 km.	Possibly late Quaternary (P)	?		Weber (1980)
75 Possible fault in North Hollywood.	Presumed single strand. Strikes N. 80° E. Presumed vertical dip. Length approximately 2 km.	Possibly Holocene (P)	?		Weber (1980)
Faults along southern margin of Transverse Ranges:					
76 Santa Rosa Island	Single strand. Regionally arcuate, striking N. 50° W. at western end and N. 60° E. at eastern end. Dip unknown. Length at least 72 km.	Late Quaternary (OS, P)	RLO	Probable source of April 1, 1945, earthquake (M_L 5.4).	Hileman and others (1973) Junger (1976, 1979) Kew (1927)
77 Santa Cruz Island	One to three echelon strands in zone as wide as 0.5 km. Strikes N. 70°–80° W. Dips 70°–75° N. Length at least 68 km.	Late Quaternary (OS, P)	RLO	Generally lacks small earthquakes. Possible source of M_L 5.0 earthquake near Anacapa Island in 1973.	Junger (1976, 1979) Patterson (1979) Yerkes and Lee (1979a, b)
78 Anacapa (Dume)	Presumed single strand in west; multiple strands in east. Strikes N. 80° W. to N. 60° E. Inferred to dip moderately north. Length at least 45 km.	Probably late Quaternary (P)	R	Source of 1973 Point Mugu earthquake (M 5.3) and aftershocks. Geometrically compatible fault-plane solution.	Junger and Wagner (1977) Lee and others (1979) Yerkes and Lee (1979a, b)
79 Malibu Coast	Several subparallel strands in zone as wide as 0.5 km. Strikes east-west and dips 45°–80° N. Length at least 27 km.	Late Quaternary (OS)	R	Numerous small earthquakes nearby.	K. R. Lajoie (unpublished data, 1983). Yerkes and Wentworth (1965). C. E. Johnson (unpublished data, 1982).

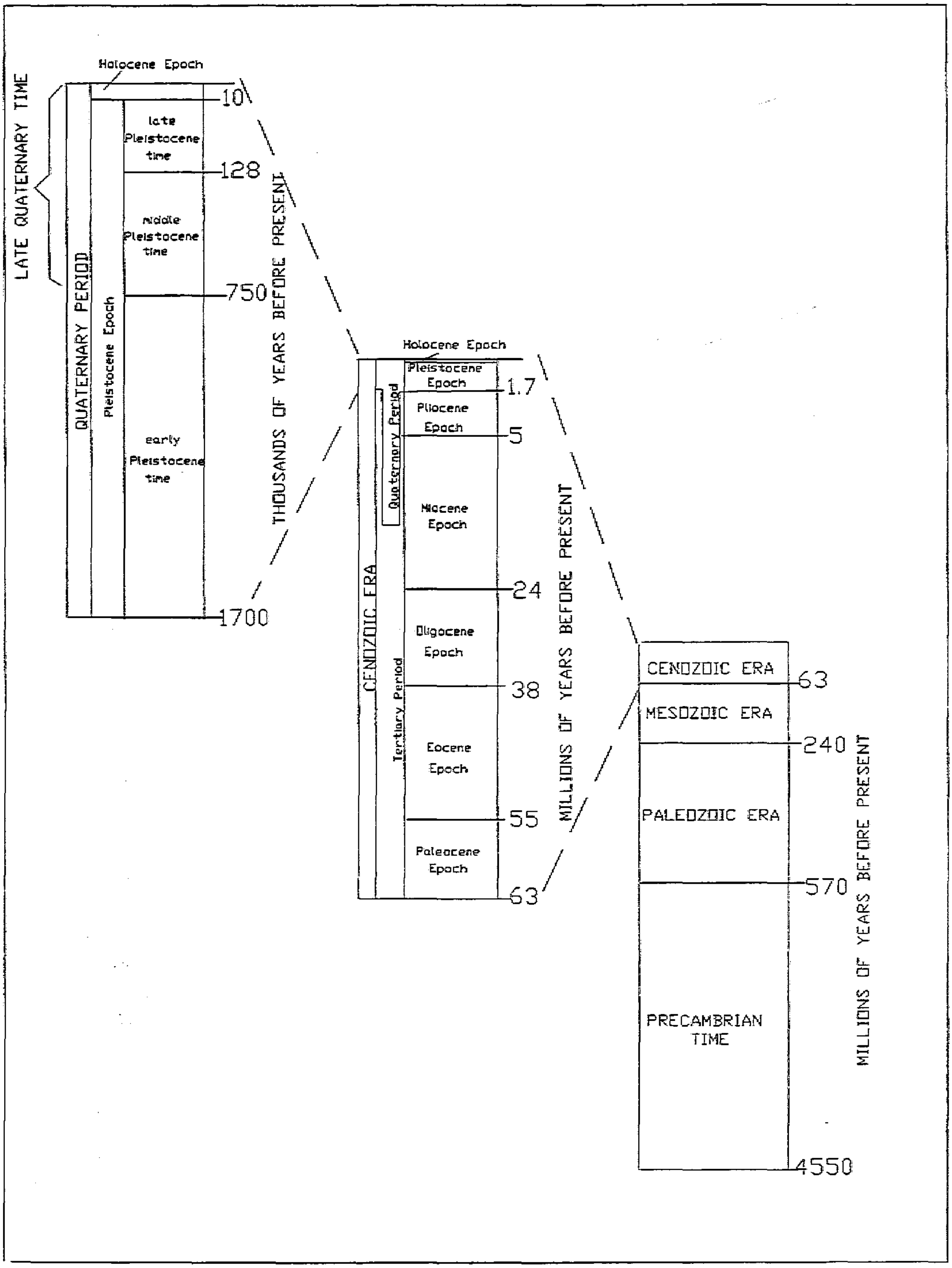
TABLE 3.1–1 Geologic and seimologic characteristics of late Quaternary faults in the Los Angeles region—Continued

Map number and fault	Geometric aspects	Age and evidence of latest surface faulting	Type of late Quaternary offset	Seismicity	Sources of information
Faults along southern margin of Transverse Ranges—Continued:					
80 Santa Monica	One or more strands. Geometry poorly known. Strikes N. 60°–80° E. Presumed to dip 45°–65° NW. at depth; some near-surface traces are vertical. Length at least 40 km.	Late Quaternary (OS, P, W)	RLO	Small earthquakes closely associated with eastern end. Geometrically compatible(?) fault-plane solution.	Buika and Teng (1979) Crook and others (1983) Hill (1979) Hill and others (1979) McGill (1981, 1982) Real (in press)
81 Hollywood	Presumed single strand. Geometry poorly known. Strikes N. 80° W. to N. 80° E. Inferred to dip about 60° N. Length approximately 17 km.	Possibly Holocene (P)	R or RLO	Some small earthquakes associated with eastern end.	Crook and others (1983) Hill and others (1979) Weber (1980)
82 Raymond	One to three strands locally in zone 0.4 km wide. Strikes N. 80° W. to N. 70° E. Dips 50°–55° N. Length 22 km.	Holocene (OS, P, W). Overlain by unfaulted soil (1,600 yr B.P.).	R or RLO	Scattered small earthquakes lie north of fault trace. Possible source of 1855 Los Angeles earthquake (Modified Mercalli intensity VIII). Geometrically compatible fault-plane solution.	Bryant (1978) Crook and others (in press) Real (in press) Weber (1980) Yerkes (this volume)
83 Sierra Madre	One to five anastomosing strands in zone as wide as 1 km. Four distinct salients. Strikes N. 55° W. to east-west. Dips 15°–50° NE. and north. Total length approximately 65 km.	Holocene (OS, P) between Big Tujunga and Dunsmore Canyons. Elsewhere, late Quaternary (OS, P, W). Overlain by unfaulted Holocene alluvium in several places.	R	Few and scattered small earthquakes.	Crook and others (in press) Pechmann (in press)
84 Duarte	One to two subparallel strands locally in zone 1.5 km wide. Strikes N. 60° W. to N. 70° E. Presumed to dip steeply NE. Length approximately 14 km.	Late Quaternary (W); possibly Holocene (P, W) along northern strand near Azusa.	R		Crook and others (in press)
85 Clamshell - Sawpit Zone.	Several subparallel strands in zone as wide as 1 km. Strikes N. 60° E. Dips 35°–70° NW. Length approximately 16 km.	Late Quaternary (OS)	R		Morton (1973) Crook and others (in press)
86 Cucamonga	Two to three subparallel strands in zone as wide as 1 km. Strikes N. 70° E. to east-west. Dips moderately to steeply north. Length at least 25 km.	Holocene (OS, P) along southern strands. Late Quaternary (OS) along northern strand.	R	Numerous small earthquakes. Geometrically compatible fault-plane solutions.	Matti and others (1982, in press) Morton and Matti (in press) Morton and others (1982) Pechmann (in press)
87 Indian Hill	Presumed single strand. Strikes east-west Dip presumed steeply north. Length approximately 9 km.	Late Quaternary (P, W)	SL(?)	Scattered small earthquakes nearby.	California Department of Water Resources (1970). Cramer and Harrington (1984, in press). C. E. Johnson (unpublished data, 1982).

TABLE 3.1–1 Geologic and seimologic characteristics of late Quaternary faults in the Los Angeles region–Continued

Map number and fault	Geometric aspects	Age and evidence of latest surface faulting	Type of late Quaternary offset	Seismicity	Sources of information
Faults along southern margin of Transverse Ranges—Continued:					
88 San Jose (B)	Single strand. Strike N. 45°–80° E. Dip presumed steeply north. Length approximately 22 km.	Late Quaternary (W); overlain by unfaulted Holocene alluvium.	SL(?)	Scattered small earthquakes nearby. Geometrically compatible fault-plane solutions.	California Department of Water Resources (1970). Cramer and Harrington (1984, in press). C. E. Johnson (unpublished data, 1982).
89 Red Hill	Presumed single strand. Strikes N. 20° W. to N. 70° E. Dip inferred steeply north. Length approximately 13 km.	Late Quaternary (P, W) except Holocene (P) at eastern end.	SL(?)	Scattered small earthquakes nearby. Geometrically compatible fault-plane solutions.	California Department of Water Resources (1970). Cramer and Harrington (1984, in press). Hadley and Combs (1974) C. E. Johnson (unpublished data, 1982). Morton (1976)
90 "Barrier J"	Presumed single strand. Strikes N. 45° E. Dip unknown. Length at least 5 km.	Late Quaternary (W); no surface expression.	SL(?)	Numerous closely associated small earthquakes.	California Department of Water Resources (1970). Cramer and Harrington (1984, in press). Hadley and Combs (1974) C. E. Johnson (unpublished data, 1982). Morton (1976)
91 Inferred fault near Fontana.	Presumed single strand. Inferred from seismicity to strike N. 45° E. Dip unknown. Length at least 8 km.	Possibly late Quaternary; no surface expression.	SL(?)	Numerous closely aligned small earthquakes. Composite fault-plane solutions suggest left-lateral strike-slip faulting.	Cramer and Harrington (1984, in press) Hadley and Combs (1974) Morton (1976)
Faults along margins of San Bernardino Mountains:					
92 Cleghorn	Single strand. Strikes N. 60° W. to N. 75° E. Dip near vertical. Length at least 23 km.	Probably Holocene (P)	SL	Numerous small earthquakes near eastern end of trace.	C. E. Johnson (unpublished data, 1982). Meisling and Weldon (1982a, b). Meisling (1984)
93 North Frontal Fault Zone of San Bernardino Mountains.	Numerous discontinuous arcuate strands averaging 2–4 km long, locally in a zone as wide as 6 km. Strikes N. 10° E. to N. 50° W. Dips from 10°–70° SE. or SW. One 5-km-long NW.-striking segment is vertical. Total length of zone at least 50 km.	Late Quaternary (OS, P); overlain by unfaulted active Holocene alluvial fans.	R (except vertical (NW.-striking strand may be SR)	Numerous closely associated small earthquakes near eastern part of zone.	C. E. Johnson (unpublished data, 1982). Meisling (1984) Miller (in press)
94 Faults of the Crafton Hills (Crafton, Chicken Hill, and Casa Blanca faults).	Several arcuate echelon strands, each 2–8 km long. Strikes N. 50°–80° E.	Late Quaternary (OS, P)	N(?)		Green (1983) J. C. Matti (unpublished data, 1983). Morton (1976)
95 Banning	Two to three strands in zone locally 4 km wide. Northern strand strikes N. 70° W. to N. 85° W. and dips 35°–70° N. Southern strands are complex, arcuate segments 3–10 km long that strike N. 65° W. to N. 50° E. and presumably dip moderately north. Total length of zone at least 45 km.	Holocene (OS, P, W)	R (except NW.-striking segments probably SR).	Numerous closely associated small earthquakes. Geometrically compatible(?) fault-plane solutions.	Allen (1957) Green (1983) Matti and Morton (1982) Yerkes (this volume) C. E. Johnson (unpublished data, 1982).

Chart of Quaternary Time Period



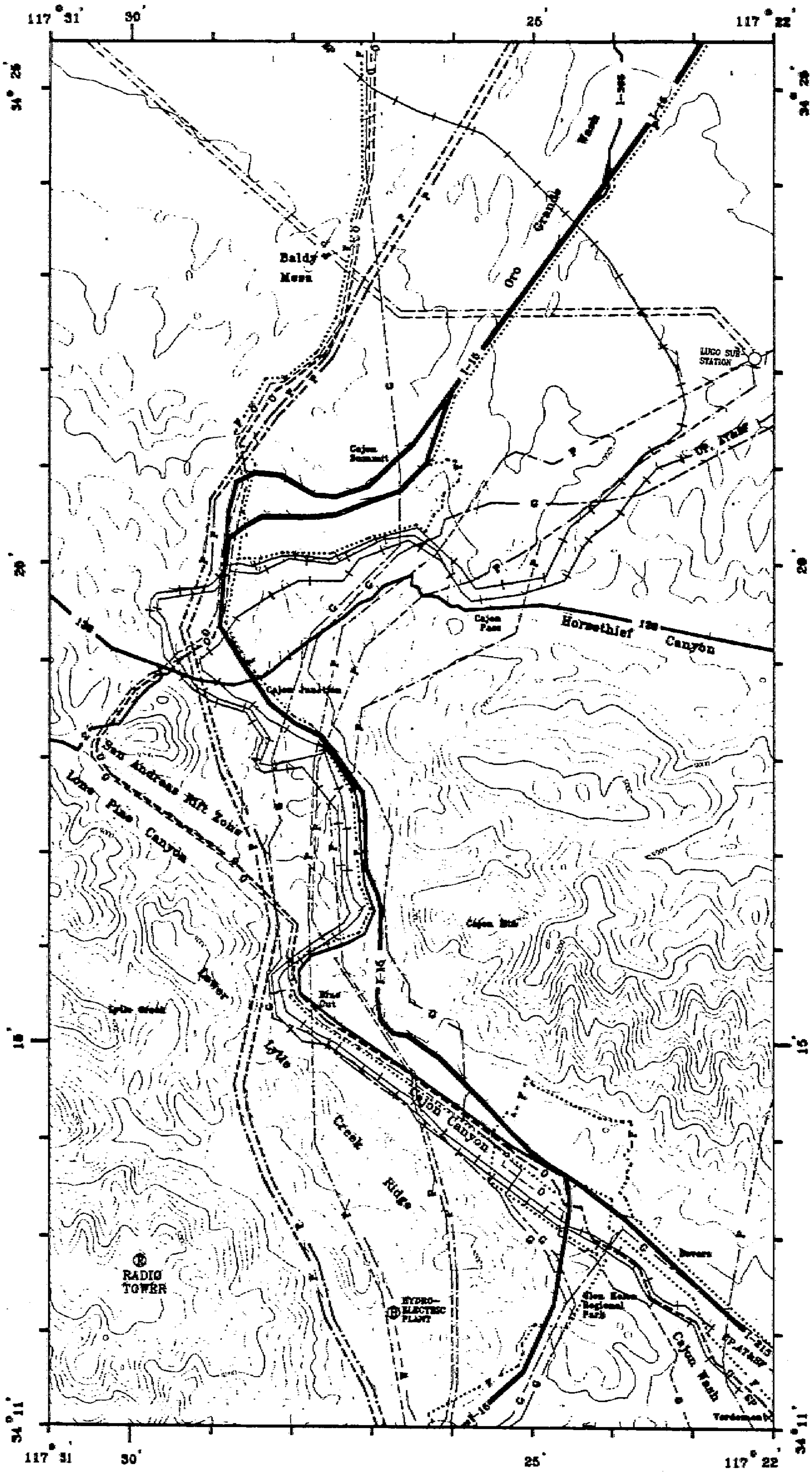


Figure 2-1 Composite Map of Lifelines In the Cajon Pass Study Areas

SCALE

0 1 2 MILES

0 1 2 KILOMETERS

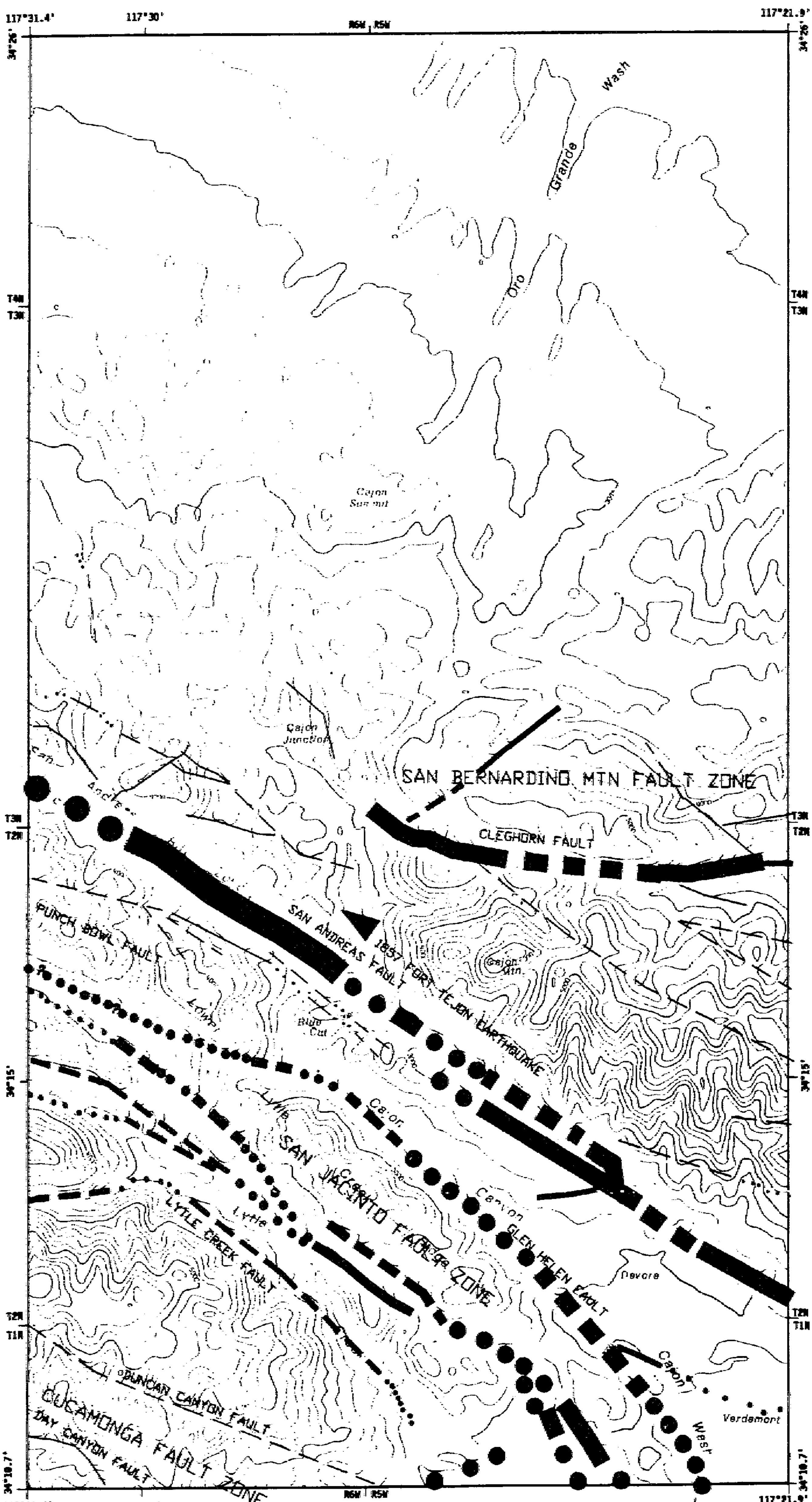
N

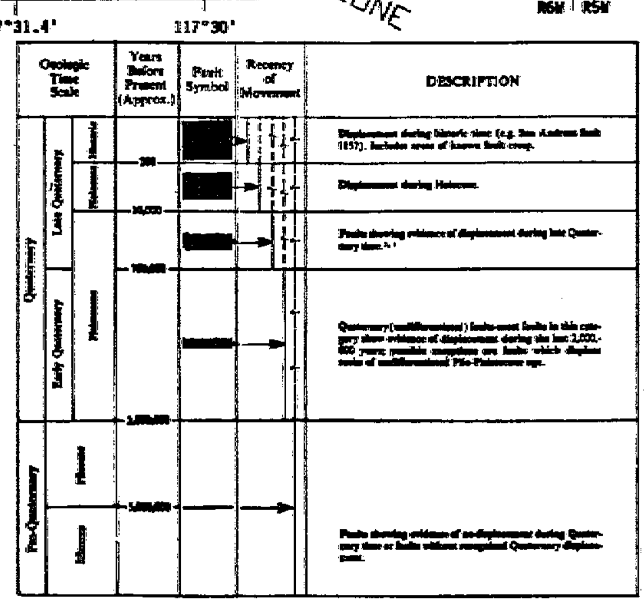
CONTOUR ELEVATIONS IN FEET

CONTOUR INTERVAL 200 FEET

EXPLANATION

I-15	INTERSTATE
2	PAVED HIGHWAY
	RAILROAD
P	POWER LINES
W	FLUME-PENSTOCK
O	PETROLEUM PRODUCT PIPELINES
G	NATURAL GAS PIPELINES
F	FIBER OPTIC CABLE





FOOTNOTES

[1] Geomorphic evidence for Holocene faulting includes sag ponds, or the following features in Holocene deposits: offset stream courses, linear scarps, and triangular faceted spurs.

[2] Geomorphic evidence for late Quaternary faulting includes such features as offset stream courses, linear scarps, shutterridges, and triangular faceted spurs.

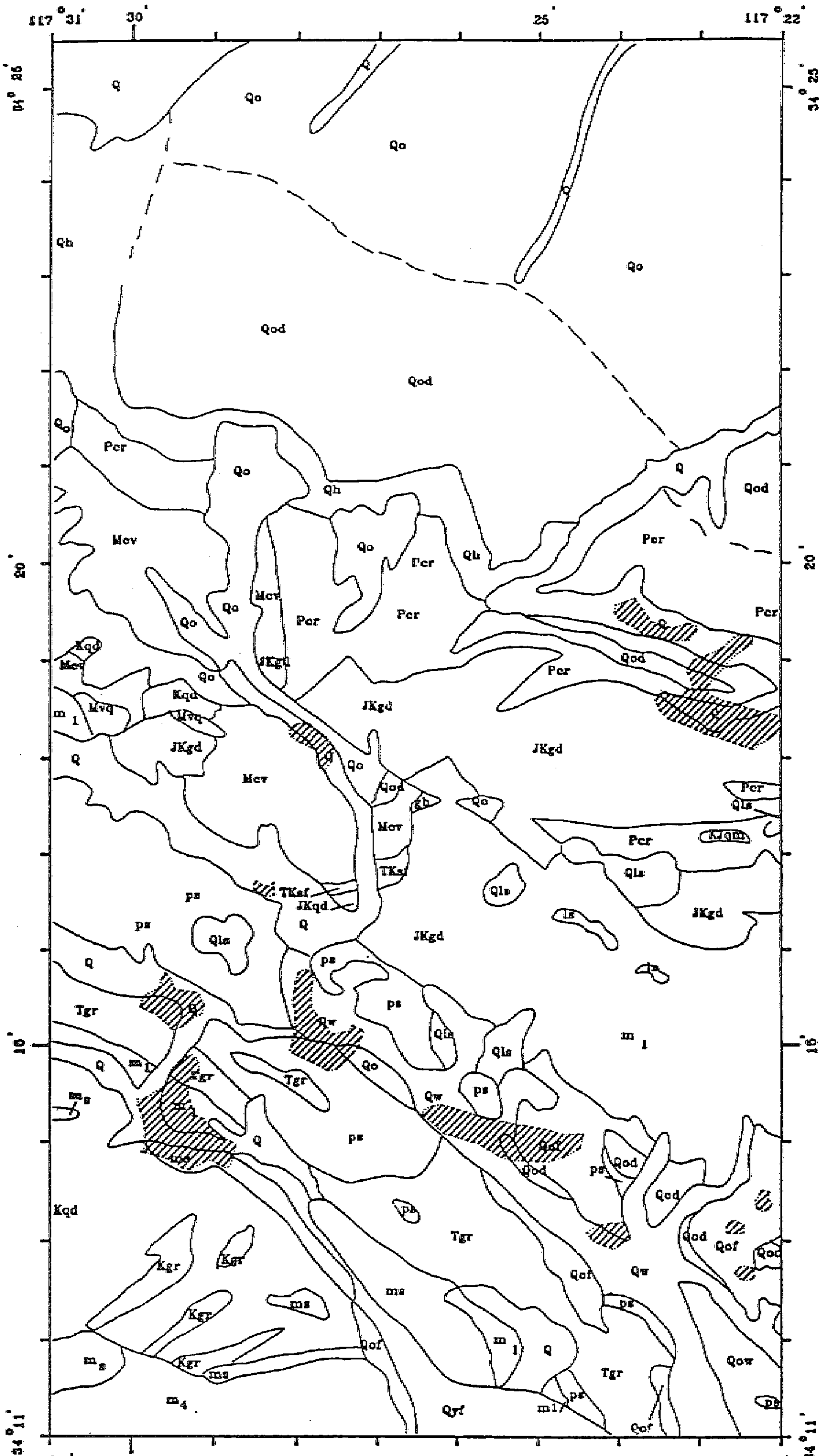
[3] Faulting may be younger but lack of younger overlying deposits precludes more accurate age classification.

0 1 2 MILES

Fault

Solid where well located; dashed where approximately located or inferred, queried where continuation or existence uncertain; dotted where concealed by younger rocks.

Figure 3.1-2 Active Fault Locations In The Study Area



SCALE

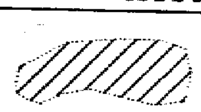
0 1 2 MILES

0 1 2 KILOMETERS

N

Figure 3.1-3 Cajon Pass Region Geologic Units With High Water Table Regions Identified

EXPLANATION



HIGH WATER TABLE

Q	ALLUVIUM
Qw	WASH DEPOSITS
Qow	OLDER WASH DEPOSITS
Qls	LANDSLIDE DEPOSITS
Qyl	YOUNGER FAN DEPOSITS
Qof	OLDER FAN DEPOSITS
Qo	OLDER ALLUVIUM
Qod	WELL DISSECTED ALLUVIAL FANS
Oh	HAROLD FORMATION AND SHOEMAKER GRAVEL
Pcr	CROWDER FORMATION
Mcv	PUNCHBOWL (?) FORMATION OF CAJON VALLEY
Mvq	VAQUEROS (?) FORMATION
Tgr	TERTIARY GRANITIC ROCKS
TKsf	SAN FRANCISQUITO (?) FORMATION
ps	PELONA SCHIST
Kgr	CRETACEOUS GRANITIC ROCKS
Kqd	CRETACEOUS QUARTZ DIORITE
KJqm	CRETACEOUS OR JURASSIC QUARTZ MONZONITE; QUARTZ MONZONITE OF PLEASANT VIEW RIDGE
JKgd	JURASSIC OR CRETACEOUS GRANODIORITE
gb	GABBRO OF PLEASANT VIEW RIDGE
ms, ls	METASEDIMENTARY ROCKS OF UNCERTAIN AGE; ls = LIMESTONE AND MARBLE
m_1, m_4	SHEARED AND DEFORMED METAMORPHIC ROCKS (AGE UNCERTAIN); m_1 = GNEISS; m_4 = HIGH-GRADE METAMORPHIC ROCKS

——— - - - ? GEOLOGIC CONTACT OBSERVED OR APPROXIMATELY LOCATED; QUERIED WHERE GRADATIONAL OR INFERRED.

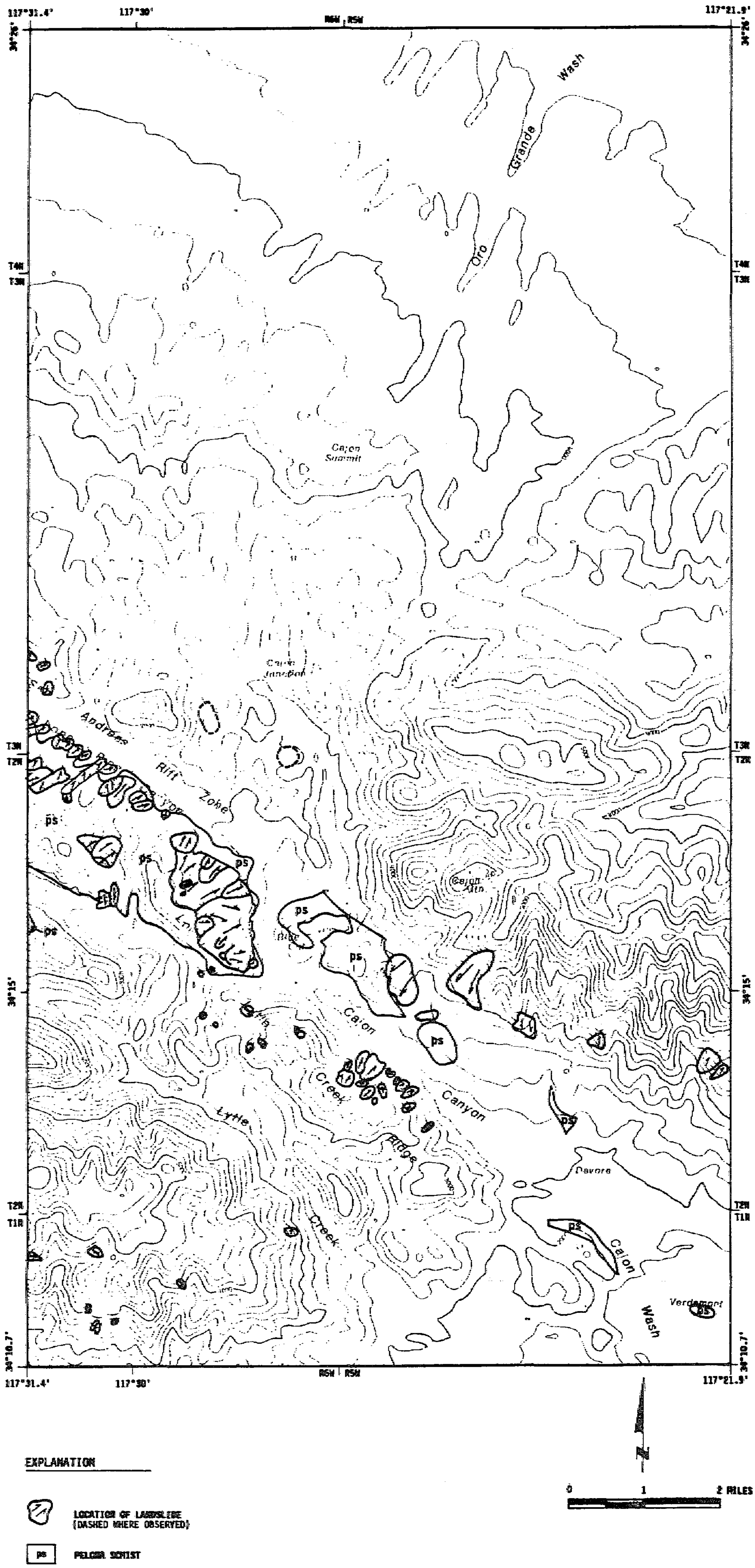
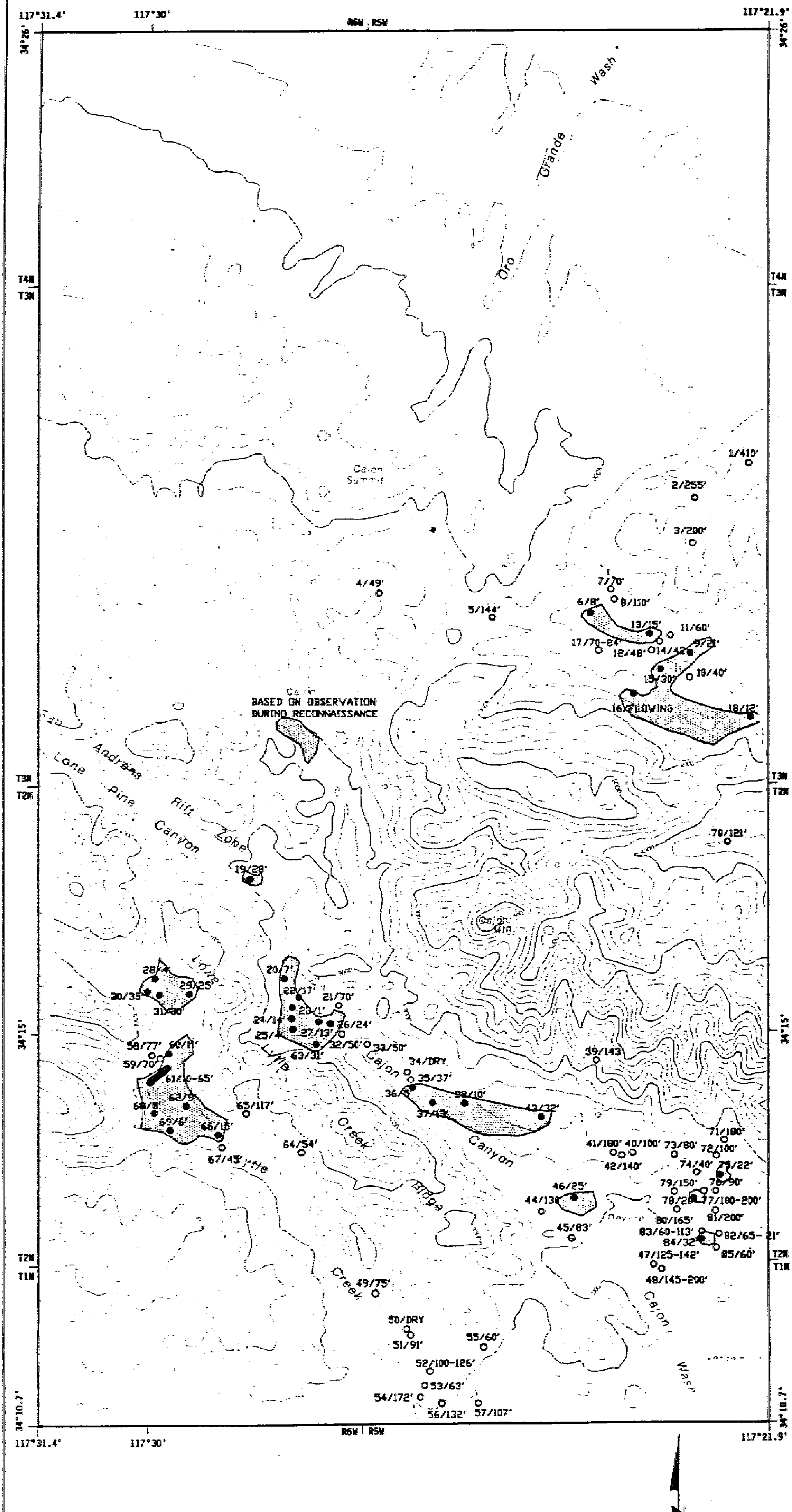


Figure 3.1-4 Observed Landslides Within the Study Area



EXPLANATION

- ● DEPTH TO GROUND WATER LESS THAN 35'
- ○ DEPTH TO GROUND WATER DEEPER THAN 35'
- 1/100' WELL REFERENCE NO. (TABLE 3.1-2)/DEPTH TO GROUND WATER
- 1/10-65' WELL REFERENCE NO. (TABLE 3.1-2)/RANGE OF DEPTH TO GROUND WATER
- ZONE OF HIGH WATER TABLE

Figure 3.1-7 Location of Shallow Water Table Conditions

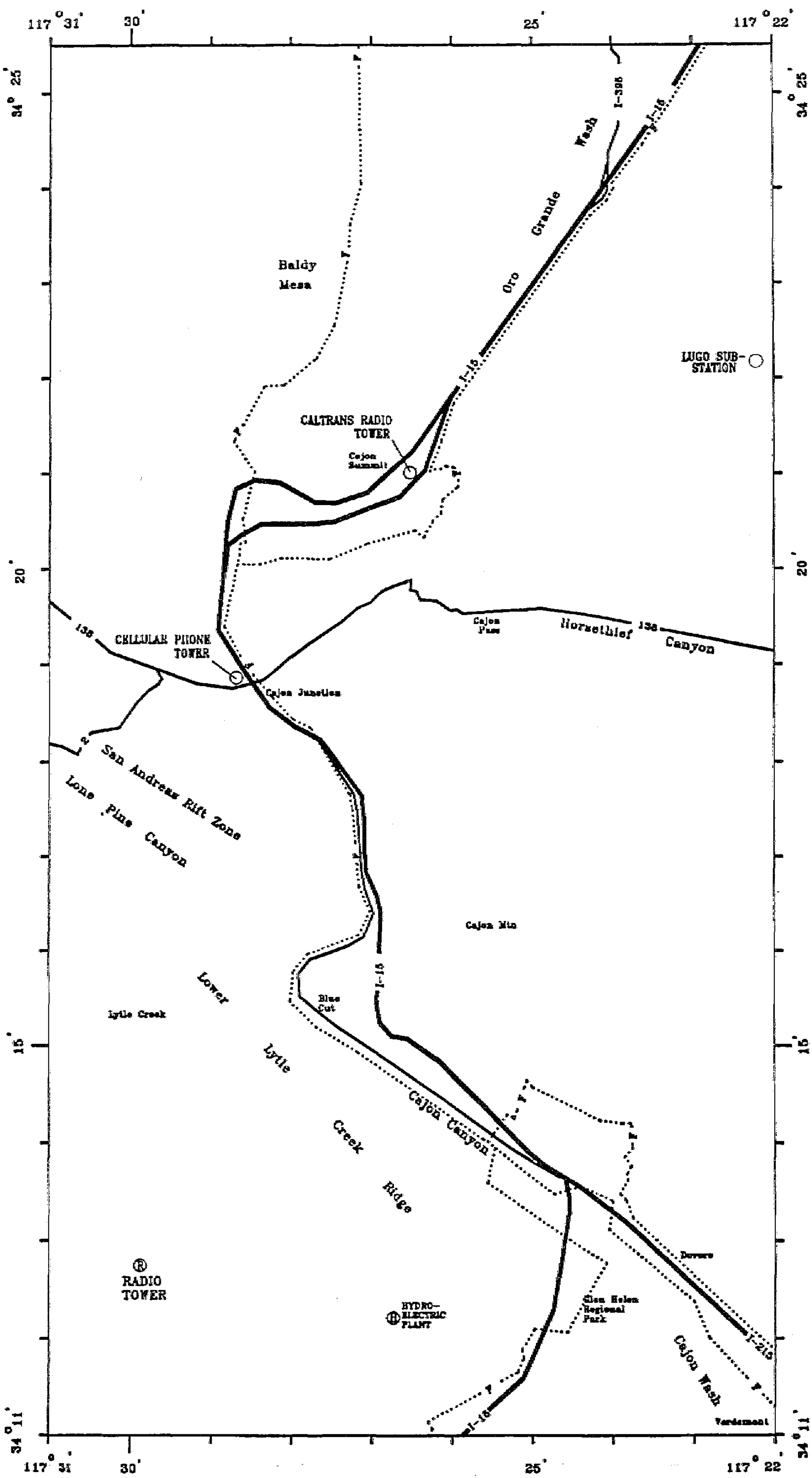


Figure 3.2-1 Map of the Communication Lifelines

SCALE

0 1 2 MILES

0 1 2 KILOMETERS

N

EXPLANATION

I-15 INTERSTATE

2 PAVED HIGHWAY

F F FIBER OPTIC CABLE

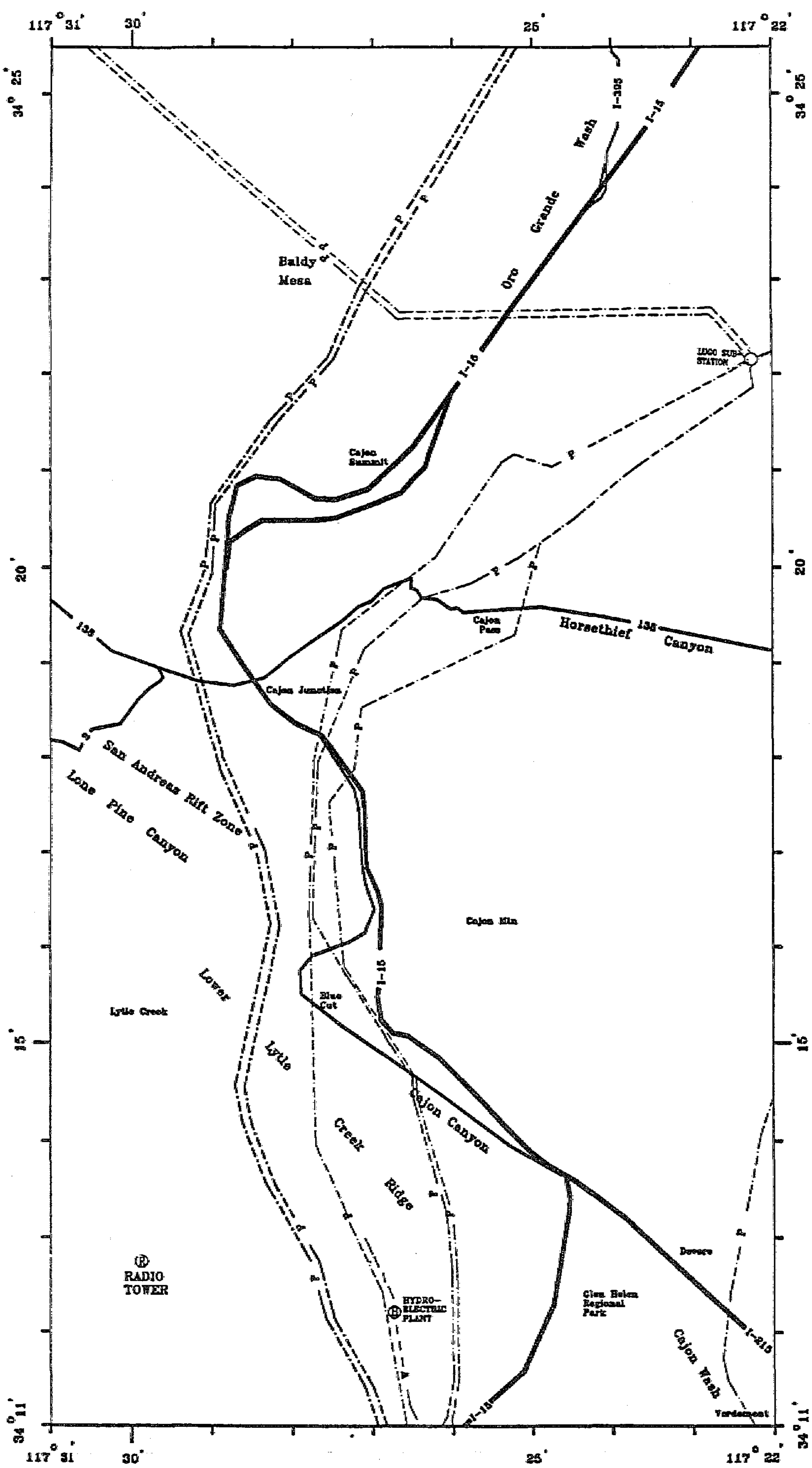
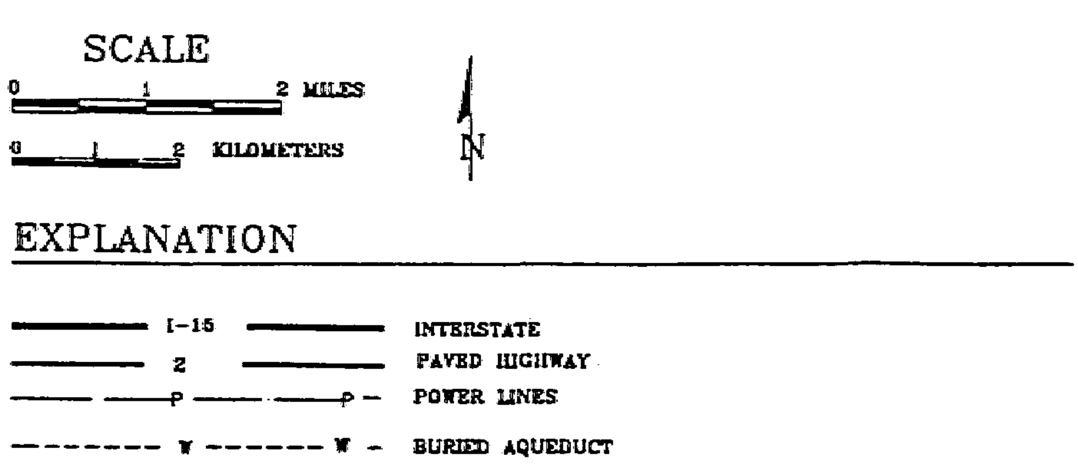


Figure 3.3.1 Map of the Electric Power Lifelines



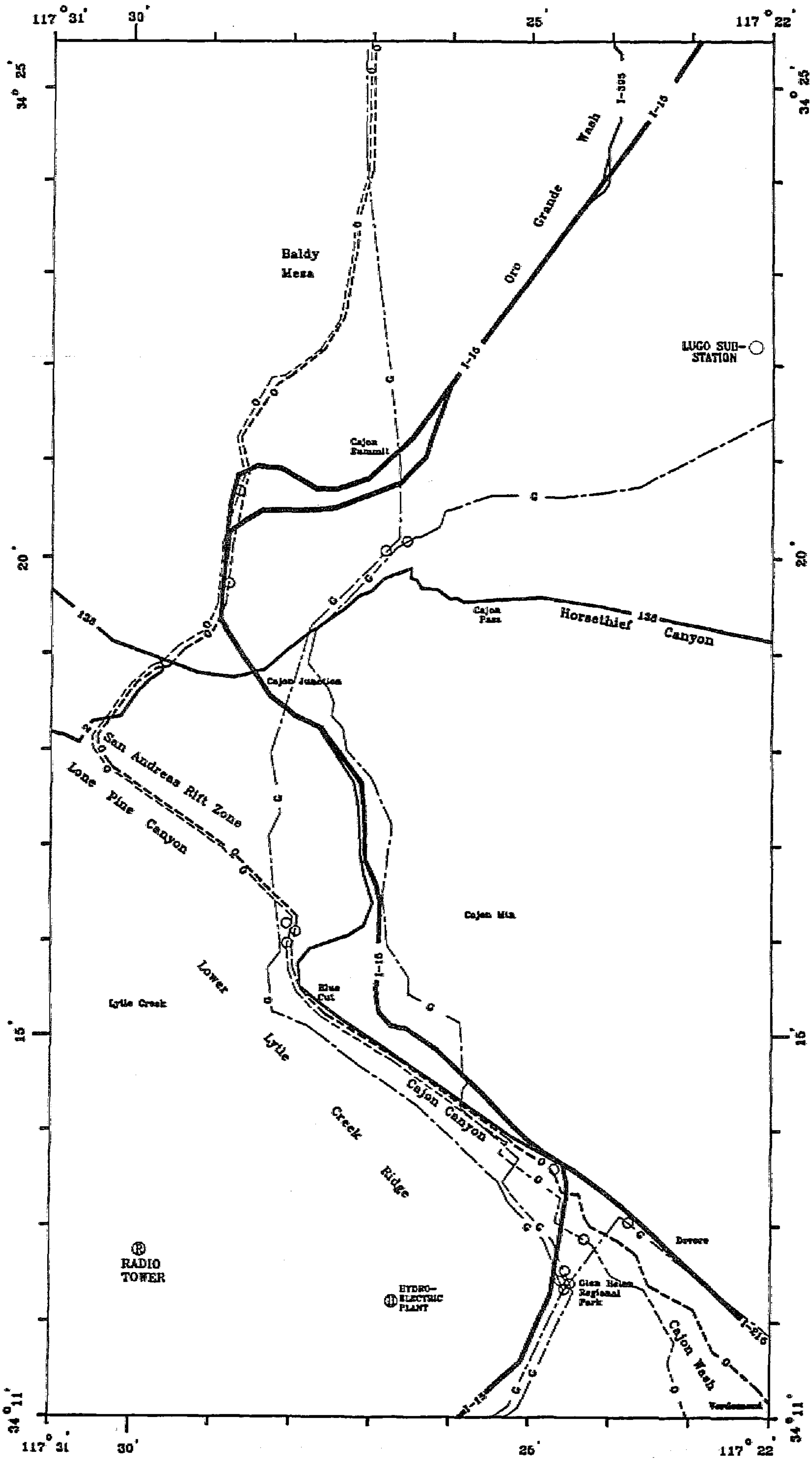


Figure 3.4-1 Map of the Fuel Pipeline Lifelines

SCALE

0 1 2 MILES

0 1 2 KILOMETERS

N

EXPLANATION

I-15		INTERSTATE
2		PAVED HIGHWAY
------- 0	------ 0 -	PETROLEUM PRODUCT PIPELINES
---·---·--- G	---·---- G --	NATURAL GAS PIPELINES
○ ○ ○		VALVES

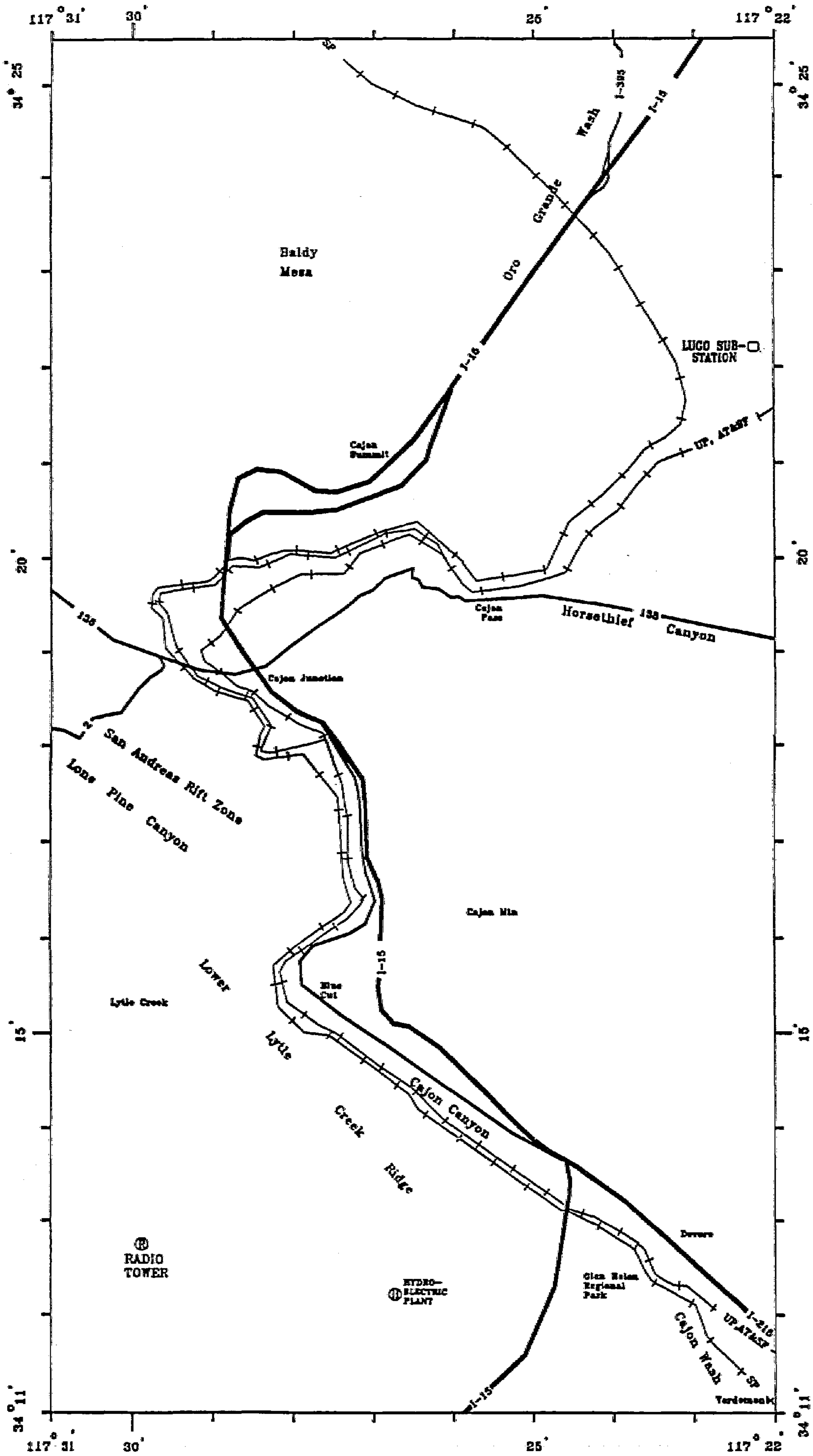


Figure 3.5-1 Map of the Transportation Lifelines