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Survey of Strong Motion Earthquake Effects on Thermal Power Plants in California with Emphasis on Piping Systems

Main Report

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Prepared for
U.S. Nuclear Regulatory Commission

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Abstract

Since 1982, there has been a major effort expended to evaluate the susceptibility of nuclear power plant equipment to failure and significant damage during seismic events. This was done by making use of data on the performance of electrical and mechanical equipment in conventional power plants and other similar industrial facilities during strong motion earthquakes. This report is intended as an extension of the seismic experience data collection effort and a compilation of experience data specific to power plant piping and supports designed and constructed to U.S. power piping code requirements which have experienced strong motion earthquakes.

Eight damaging (Richter Magnitude 7.7 to 5.5) California earthquakes and their effects on 8 power generating facilities in California were reviewed. All of these facilities were visited and evaluated. Seven fossil-fueled (dual use natural gas and oil) and one nuclear fueled plants consisting of a total of 36 individual boiler or reactor units were investigated. Peak horizontal ground accelerations that either had been recorded on site at these facilities or were considered applicable to these power plants on the basis of nearby recordings ranged between 0.20g and 0.51g with strong motion durations which varied from 3.5 to 15 seconds. Most U.S. nuclear power plants are designed for a safe shutdown earthquake peak ground acceleration equal to 0.20g or less with strong motion durations which vary from 10 to 15 seconds.

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Executive Summary

Since 1923, more than 25 major earthquakes in various parts of the world have affected approximately 42 conventional power plants containing piping that is similar to that found in nuclear power plants.[1] Strong motion shaking in this study is defined as 0.2g or greater zero-period ground acceleration at the power plant site. Four power plants (with a total of 20 generating units) were located in the strongly shaken area of the San Fernando (Los Angeles), California, earthquake of 1971, which had a Richter magnitude of 6.6. The Pasadena plant also experienced strong motion shaking following the Whittier Narrows earthquake, Magnitude 5.9, in 1987. In addition, three other plants have experienced strong motion earthquakes. The Kern Valley Steam Plant near Bakersfield, California was subjected to the Kern County (Taft) 1952, Magnitude 7.7 earthquake. The El Centro Steam Plant was subjected to the Imperial Valley 1979 and Superstition Hills 1987 earthquake Magnitudes 6.6 and 5.8 respectively, and the Humboldt Bay Plant was subjected to the Ferndale 1975 and Eureka 1980 earthquakes Magnitudes 5.5 and 7.0 respectively. All of the plants identified above were visited as part of this study.

Volume 1 of this report summarizes data currently available in the literature and includes a summary of additional data on the design basis, construction characteristics and performance of several power plant piping systems during strong motion earthquakes gathered as a result of this study. Volume 2 of this report contains appendices which provide detail regarding the behavior of the plants surveyed during strong motion earthquakes.

Data were gathered as a result of site visits for the following fossil and nuclear plants:

(1) Burbank (7 Units)
(2) El Centro (4 Units)
(3) Glendale (5 Units)
(4) Humboldt Bay
  (a) Fossil (2 Units)
  (b) Nuclear (1 Unit)
(5) Kern Valley (4 Units)
(6) Pasadena (4 Units)
(7) Valley (4 Units)
(8) Moss Landing (7 Units)

Also included are tables and histograms showing a sample of vertical and horizontal pipe support spacing of the plants surveyed.

The available plant design parameters, systems description, piping line lists and piping and support design and procurement specifications and the post-earthquake investigation reports for each of the seven conventional and one nuclear facilities were reviewed. In all cases, the operating power plant units were back on line within a few minutes to a few hours after the earthquake. Operating units that were subjected to peak ground accelerations below about 0.35g did not trip off line but remained in operation. Damage to piping and supports in all cases was limited to a few minor components with little or no correlation with design and had little effect on plant operation.

The ground motion (free-field) response spectra and the few available amplified floor-response spectra for the earthquake-affected plants were compared with typical ground and amplified floor-response spectra from the safe-shutdown earthquake required for the nuclear power plants. In most cases, the ground motion spectra at the conventional plants exceeded the amplified floor spectra of nuclear plants east of the Rocky Mountains in zones of moderate to low seismicity in the ranges of dominate piping response below about 10 Hz.

Several fossil-fueled and one nuclear power plant in California were surveyed which have experienced earthquakes that subjected process piping to seismic loads exceeding those associated with design basis safe-shutdown earthquakes for most U.S. nuclear power plants. For most of the piping systems contained within these plants, there are no significant generic differences between the operating conditions for piping used in the nuclear power plants and those found in the conventional, fossil-fueled plants except that the fossil fired plant main heat transport piping operates at temperatures and pressures in excess of those found in water cooled nuclear power plants. Design and operation temperatures for fossil fired power plant main heat transport piping are typically in the creep rupture range for steel above 800°F while nuclear plant piping is at or below 650°F.

The following conclusions were reached as a result of the study:

- Except for the very limited use of sway braces in the Kern and Valley Power Stations and static seismic analysis and snubber installation in the Pasadena Plant Broadway Unit 3 there is almost no evidence of earthquake resistant design in the form of lateral restraints being applied to piping systems in the fossil power plants surveyed which had experienced strong motion earthquake peak ground acceleration equal or to greater than 0.2g ZPGA. The Humboldt Bay Unit 3 is a nuclear unit with seismically designed piping. The structure of Unit 2 was seismically upgraded after the 1975 earthquake to protect Unit 3.

- Deadweight (vertical) support spacing were generally in line with ASME/ANSI B31.1 recommendations except for small bore piping ($D_o \leq 2\frac{1}{2}$ inch). There are many instances where small bore pipe dead weight support spacing exceed by factors of two or three the recommended deadweight spacing.

- Piping spans (including nozzles, anchors and vertical legs more than 5.0 feet long acting as horizontal restraints) have horizontal restraint spans which are typically 3 to 4 times the dead weight spans and often exceed 8 times dead weight support spans.

- There was less than one pipe failure per unit per strong motion (ZPGA > 0.2g) earthquake observed in the plants surveyed. This suggests less than one pipe failure per 20000 feet of pipe at risk. The failures that did occur were associated with types of pipe connections (threaded joints), differential motions associated with rigid connection of piping to equipment or branch piping connected to main piping runs, interaction with other equipment or building structure and maintenance condition of the pipe associated with erosion and corrosion rather than any systematic design deficiency.

- Piping and support systems constructed to the requirements of the ASME/ANSI B31.1 piping code employing ductile standard support hangers with no or little consideration for seismic loads sustained essentially no damage up to at least 0.3g PGA.

- The experience gained from this survey suggests that the elaborate, rigorous piping design and lateral support hardware rigidity requirements placed on nuclear power plant piping and supports to resist seismic loads up to at least 0.3g PGA could be simplified.

- Socket welded connections appear to perform as well as butt joined, groove welded connections.

- Threaded connections do not perform as well as welded connections.

As a result of the survey of several California power plants which have experienced strong motion earthquakes it was determined that above ground power plant process piping and supports even when they are not designed to resist seismic loads appear to be inherently rugged and do not exhibit susceptibility to seismic damage except in a few uncorrelated and non-design related instances for seismic zero period ground accelerations of at least 0.30g. The number of such seismic related damage to nuclear power plant piping averaged less than one piping or support failure per unit per earthquake. For each unit there were typically several thousands of feet of pipe and several hundred supports typically at risk.

Evaluation of the earthquake experience data indicates that seismic qualification of piping by means of rigorous structural analysis to determine seismic stresses in the piping and supports and comparison of total stresses with design code allowables is unnecessary from a safety standpoint in plants with a design basis safe-shutdown earthquakes input at or below about 0.30g zero-period ground acceleration. In such plants seismic design adequacy effectively developed "by rule" rather than "by analysis" could provide necessary seismic resistance.

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The author appreciates the help and cooperation of the staffs of the Burbank, El Centro, Glendale, Humboldt Bay, Kern Valley, Pasadena, San Fernando Valley and Moss Landing Power Stations as well as the Utility Owners of these power stations who made this Survey possible.

The author also appreciates the help of Terry Yahr and Sam Moore of the Oak Ridge National Laboratory for their reviews and comments.

1 Introduction and Program Description

1.1 Introduction

Since 1923, more than 25 major earthquakes in various parts of the world have affected approximately 42 conventional power plants containing piping that is similar to that found in nuclear power plants.[1] Strong motion shaking in this study is defined as 0.2g or greater zero-period ground acceleration at the power plant site. Four power plants (with a total of 20 generating units) were located in the strongly shaken area of the San Fernando (Los Angeles), California, earthquake of 1971, which had a Richter magnitude of 6.6. The Pasadena plant also experienced strong motion shaking following the Whittier Narrows earthquake, Magnitude 5.9, in 1987. In addition, three other plants have experienced strong motion earthquakes. The Kern Valley Steam Plant near Bakersfield, California was subjected to the Kern County (Taft) 1952, Magnitude 7.7 earthquake. The El Centro Steam Plant was subjected to the Imperial Valley 1979 and Superstition Hills 1987 earthquake Magnitudes 6.6 and 5.8 respectively, and the Humboldt Bay Plant was subjected to the Ferndale 1975 and Eureka 1980 earthquakes Magnitudes 5.5 and 7.0 respectively. All of the plants identified above were visited as part of this study.

The Ormond Beach Generating Station was affected, by the Point Mugu 1973 earthquake. However, the nearest recording stations, 1.5 miles further away from the epicenter recorded a peak ground acceleration (PGA)[1] of only 0.13g and the Ormond Beach site acceleration was estimated at approximately 0.2g. The Terminal Island and Seal Beach Power Stations were also severely affected by the Long Beach Earthquake of 1933 but were of a much earlier design vintage. The Ormond Beach, Terminal Island and Seal Beach Power Stations were not visited as part of this study. Summaries of the behavior of these plants during strong motion earthquakes can be found in Appendices A and B to this report. Starting around 1982, there has been a significant effort sponsored by the Seismic Qualification Utility Owner's Group (SQUG) to verify seismic design adequacy of selected mechanical and electrical equipment by use of strong motion earthquake experience data.[2] This type of experience data review effort was extended to piping starting in 1984.[1,3,4] This report is intended to build on these earlier reconnaissance studies relative to power plant piping behavior effected by strong motion earthquakes by current site visits to selected plants to better document the actual behavior and design parameters used in piping and support design and construction.

The peak ground accelerations (PGA) that were recorded at nearby locations to the power plant sites visited were typically higher than the PGAs of safe shutdown earthquakes (SSE) that are used in the design of most nuclear power plants in the U.S. east of the Rocky Mountains. Because no significant damage occurred at the plants visited, they were not extensively investigated after the earthquakes except for Unit 4 of the El Centro power station,[4,5]; thus, the existing literature is relatively silent about earthquake effects on these facilities. Fortunately, the plants and their piping systems are either still operating or in a standby condition; iso-seismic intensity and in some cases acceleration records exist; the plant logs and reports are still available; and many of the personnel who were on duty at the time of the earthquake are still working in the plants. Additional data on the original design basis, layout and performance of piping is therefore still obtainable.

This report, while summarizing data currently available in the literature, includes a summary of additional data on the design basis, construction characteristics and performance of several power plant piping systems during strong motion earthquakes not previously available in the published literature.

Chapter 2 contains an overview of the piping system survey program. Chapter 3 contains the strong motion earthquake descriptions applicable to the power plant sites. Chapter 4 discusses typical thermal power plant design parameter and layout considerations. Chapter 5 presents a summary of plant specific earthquake response data gathered for the following power plants:[2]

(1) Burbank (7 Units)
(2) El Centro (4 Units)
(3) Glendale (5 Units)
(4) Humboldt Bay

[1]The peak ground acceleration for a given site is the value of acceleration that corresponds to zero (<0.03 seconds) period in the design response spectra for the largest of three orthogonal directions for that site. At zero period, the acceleration in the design response spectra is identical for all damping values and is equal to the maximum (peak) ground acceleration specified for that site.

[2]One Unit represents a single boiler. In some instances more than one boiler supplies steam to a single turbine-generator set.

(a) Fossil (2 Units)
(b) Nuclear (1 Unit)

(5) Kern Valley (4 Units)
(6) Pasadena (4 Units)
(7) Valley (4 Units)
(8) Moss Landing (7 Units)[3]

Chapter 6 presents a summary of the information gathered and the results and conclusions of this study including some suggested caveats which should be applied to power plant piping to improve its earthquake resistant design. Chapter 7 contains references cited in the report. Appendices A-L contained in Volume 2 provide the detailed data used in the preparation of this Volume 1 summary report.

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[3]It is included herein only to the extent that piping support spacing data from Moss Landing Units 1 - 5 has been used to construct piping support histograms contained in this report.

2 Overview of the Plant Survey Program

2.1 Purpose and Goals

The objectives of this report are as follows:

- Based on review of operating utility files, better documentation of the design basis used for power plant piping and supports which have undergone strong motion earthquakes.
- Develop a data base description on the performance of process piping and supports in conventional thermal power plants during and after strong earthquakes.
- Comment on the similarity between conventional thermal power plant piping and supports and that found in nuclear power plants.
- Suggest design caveats based on experience which may be used to improve the earthquake resistance of power plant piping and supports.

2.2 Work Scope

To narrow the data collection effort to the facilities that would be most useful for study, a survey of California fossil fired power plant facilities was conducted. The work was performed in the following manner.

- The existing literature was reviewed to determine which sites have seen significant earthquake motions equal to or above 0.2g PGA, hence should be visited.
- The cognizant utility organization was contacted to arrange for a plant visit.
- One to two day visits for each plant were conducted.
- Two of the larger plants and plant units, El Centro and Valley Steam Plants, were revisited to better document typical piping support spacings.

Approximately half the time was spent in a plant walkdown and half the time in the utility offices gathering pertinent available engineering data. A photographic record of several hundred piping system installations was compiled. Many of the plants were designed by Architect-Engineering firms whose files may contain more design basis data. However, evaluation of this potential source of additional information was outside the scope of this report. Two of the larger plants; El Centro, which has a total generating capacity of 174 Mwe consists of four units having rated capacities of 20, 30, 44, and 80 Mwe respectively, and Valley Steam Plant which has total capacity of 513 Mwe also consisting of four units, with capacities of 100, 100, 157 and 157 Mwe respectively, were revisited to better document pipe support spacings.

In general the fossil plants included in this survey are significantly smaller in generating capacity than typical nuclear stations. However, process piping up to at least 12 inch nominal diameter are well represented in the plants surveyed. The vast bulk of piping in nuclear as well as fossil power plants are equal to or less than 12 inch nominal diameter, hence the survey is generally representative of piping sizes used for both nuclear as well as fossil power plants.

3 Earthquake Descriptions and Summary of Seismic Motions at Plant Sites

3.1 Earthquake Descriptions

3.1.1 Introduction

The nine power plants evaluated in this study were subjected to eight strong motion earthquakes identified as follows:

(1) Kern County (Taft) - 1952
(2) San Fernando - 1971
(3) Ferndale - 1975
(4) Imperial Valley - 1979
(5) Eureka - 1980
(6) Whittier Narrows - 1987
(7) Superstition Hills - 1987
(8) Loma Prieta - 1989

The basic data for the seven earthquakes can be found in Table 3.1.

3.1.2 The Kern County (Taft) Earthquake of July 21, 1952

The Kern County-1952 earthquake occurred at 4:52 a.m. local time on July 21, 1952, and was located on the White Wolf Fault near Bakersfield, California. The epicenter was established at 35.00° N, 119 .033° W about 26 miles south of Bakersfield, and a Richter magnitude of 7.7 was established.

The White Wolf Fault generally runs between Highways 58 and U.S. 99 just below Arvin, and its known length is 34 miles. It was first traced in the early 1900's but was presumed inactive prior to the earthquake. In general, it lies under Wheeler Ridge, then extends northeast into Sycamore Canyon and along the northern slopes of Bear Mountain, and dies out near Caliente.

The Kern County-1952 earthquake was the largest in California since 1906 and the largest in Southern California since 1857. It was felt over an area of some 160,000 square miles and awakened people throughout the southern part of the state, The surface of the earth was ruptured for 17 miles between Arvin and Caliente. An iso-seismal map including the epicentral location of this earthquake, the Kern Valley Power Station and the closest recording is shown in Figure 3.1. The estimated peak ground acceleration at the Kern Valley Steam Plant site was 0.25g based on the measured acceleration of 0.17g at the Lincoln school in Taft, California.

3.1.3 San Fernando Earthquake of February 9, 1971

The San Fernando, California earthquake occurred at 6:01 a.m. local time on February 9, 1971. Its Richter magnitude was 6.6. The epicenter was located at 34.400°N and 118.395°W. The strong motion of the main shock lasted about 12 seconds. The earthquake was caused by movement on northward-dipping thrust faults. Most of the movement occurred on a single fracture striking N 72° W and dipping about 45° toward the north, although the dip near the surface was about 20°. The overall fault motion was a thrusting of the north side southwestward, with approximately equal amounts of vertical uplift, north-south compression, and left lateral slip. The overall displacement was about 6 feet. In Figure 3.2 is given the locations of the epicenter of the main shock the power plants affected and the recording stations and associated iso-seismic intensities and peak ground accelerations. The focus of the main shock was at a depth of about eight miles.

Four power plants, containing a total of 20 units, were located in the earthquake area with site peak ground accelerations equal to or greater than 0.2g. All four power plants are located within the Modified Mercalli Intensity (MMI) iso-seismal contours of VII or higher.

3.1.4 Ferndale Earthquake of June 7, 1975

The earthquake of June 7, 1975 occurred at 1:46 a.m. local time about 15 miles south of the Humboldt Bay Power Plant with a Richter Magnitude of 5.5. The epicenter was located at 40.536° N latitude, 124.292° W longitude, which is about 4 miles south and slightly west of the town of Ferndale, California. The depth of focus of the earthquake was 23.5 km (15 miles), and the diagonal distance from the hypocenter to the Humboldt Bay Power Plant is 21 miles. The iso-seismic intensities are shown in Figure 3.3 together with the epicentral location and the Humboldt Bay Power Station. The seismic motions applicable to this power plant were measured at the power plant site. At least 30 after-shocks were recorded in the first 36 hours after the earthquake, none of which triggered strong motion instruments.

The nuclear power Humboldt Bay Unit 3 is instrumented with a Teledyne MTS-100 strong motion recording system, with three FB-103 triaxial Force Balance accelerometers. This system was installed in September 1971. A description of the location and response of these in plant strong motion instrumentation is given in

3.1.5 Imperial Valley Earthquake of October 15, 1979

The Imperial Valley (Southern California) earthquake occurred at 4:16 p.m. local time at 32.63°N latitude, 115.33°W longitude. The earthquake had a Richter magnitude of 6.6. The strong motion lasted about 15 seconds. The earthquake was caused by movement on the Imperial and Brawley faults, the faulting extending north-westward from near the border with Mexico almost to Brawley. A maximum right-lateral displacement of about 3 feet was recorded. The faults are branches of the San Andreas fault. The epicenter of the earthquake was near the point where faulting was initiated, just south of the border with Mexico and the location of the plant and recording instrument are shown in Figure 3.4 together with Iso-seismic intensity contours.

It should be noted that there was an exception to the maximum intensity VII rating for this earthquake. The Imperial County Services Building in El Centro was assigned an intensity IX. This building, a six-story reinforced concrete-framed structure which was designed to the UBC-1967 Code, suffered significant structural damage and was torn down after the earthquake.

The affected area was instrumented by a large network of strong-motion accelerometers. About 50 strong-motion records were made at distances from 4 miles to 122 miles from the earthquake epicenter. Several records were taken from instruments less than 0.6 mile from the ruptured fault. A significant set of records was obtained from a 13-accelerometer local array that was located transverse to the Imperial fault through the town of El Centro. The motions recorded from this event include the highest ground acceleration recorded to date in the U.S. One instrument, 0.6 mile from the fault and 17 miles from the epicenter (shown in Figure 3.4), recorded a vertical acceleration of 1.74g. The thermal power plant affected by the earthquake is the El Centro Steam Power Plant whose location relative to the epicenter and El Centro recording stations is also shown in Figure 3.4.

3.1.6 Eureka Earthquake of November 8, 1980

On November 8, 1980 at 2:28 a.m. Pacific Standard Time, an earthquake of a reported surface wave magnitude of 7.0 occurred off the coast of California, west of Eureka. The epicenter was located at 41.12° N and 124.66° W. Iso-seismic contours showing both the epicenter and plant location are shown in Figure 3.5.

Unfortunately, the strong motion accelerometers which recorded the Ferndale 1975 earthquake located at the Humboldt Bay Power Plant did not record properly, apparently because of a degraded power supply.

Only the peak accelerations of 0.4 g (E-W), 0.2 g (N-S), and 0.16 g (Vert) which were measured at the operating floor in the refueling building at grade (as shown in Appendix K) of Humboldt Bay Power Plant Unit 3 (Nuclear) are considered reliable.

3.1.7 Whittier Narrows Earthquake of October 1, 1987

On October 1, 1987, at 7:42 a.m., a Richter magnitude 5.9 earthquake occurred due east of Los Angeles near the city of Whittier, California. The epicenter of the shock was located at 34 .050°N and 118 .080°W. The shock caused damage over a large area of the Los Angeles Basin.

The earthquake associated fault rupture apparently occurred along a northwest extension of the previously mapped Whittier fault. The earthquake appears to have been an upward shift of the northeast side of the Whittier fault relative to the southwest side. The epicenter of the October 1 main shock was about 7 kilometers beyond the end of the region of known active faulting. The Whittier fault has traditionally been defined as the northwest extension of the Elsinore fault, running from the Santa Ana area northwest to the Whittier Narrows on the San Gabriel River. The October 1 main shock and its after-shocks imply a fault rupture starting near the end of the previously mapped fault at Whittier and trending northwest toward Pasadena.

In Figure 3.6 is shown the epicentral, plant and recording instrument locations. Also shown are iso-seismic contours and peak recorded percent gravity acceleration resulting from the Whittier Narrows earthquake.

3.1.8 Superstition Hills Earthquakes of 23 and 24 November 1987

On November 24, 1987 at 5:16 a.m. a Richter magnitude 6.0 earthquake struck with an epicenter approximately 10 miles northwest of the town of Westmorland in the Imperial Valley of southern California. The epicenter was located at 33.083° N. and 115.775 W. The event was attributed to slippage of the Superstition Hills fault, which is west of and essentially parallel to the valley's better known Imperial fault. This earthquake had been preceded by smaller shocks in the M4.0 to M5.8 range beginning approximately 5:32 p.m. on November 23. The largest of these, an M5.8 earthquake, struck at 5:54 p.m. on November 23, 1987.

In Figure 3.7 is shown the location of the November 23 and November 24 earthquakes as well as the locations of the plant and strong-motion recording accelerometers belonging to the California Strong Motion Instrumentation Program. CSMIP stations 335 and 336 are located within one and two miles respectively of the El Centro steam plant.

3.1.9 Loma Prieta Earthquake of 17 October 1989

On October 17, 1989 at 5:04 pm local time a Richter magnitude 7.1 earthquake struck in the Santa Cruz mountains about 10 miles east-northeast of the city of Santa Cruz and 18 miles north-north-west of the Moss Landing thermal power station. The epicenter was located at 37.033° N and 121.883° W. In Figure 3.8 is shown the location of the Loma Prieta earthquake.

3.2 Seismic Motions at Plant Sites

Table 3.2 identifies the earthquakes considered and plants surveyed. In Table 3.3 is a summary of seismic demand data relative to the power plant and the recording station used to define the plant seismic demand data for the earthquakes considered in this study.

Table 3.1 - Earthquake Data Summary

Earthquake a) Plant	Date/ Local Time	Epicentral Location	Magnitude (Richter)	Epicentral Intensity	Power Plant Intensity
1. Kern County	7/21/52/0452	35.00°N	7.7	VIII-XI	
a) Kern Valley		119.033°W			VIII+
2. San Fernando	2/9/71/0601	34.400°N	6.6	VIII-XI	
a) Burbank		118.395°W			
	VII+				
b) Glendale					VII+
c) Pasadena					VII+
d) Valley					VII+
3. Ferndale	6/7/75/0146	40.57°N	5.5	VII	
a) Humboldt Bay		124.14°W			VII
4. Imperial Valley	10/15/79/1616	32.63°N	6.6	VII[1]	
a) El Centro		115.33°W			VII
5. Eureka	11/8/80/0228	41.12°N	7.0	VII	
a) Humboldt Bay		124.66W			VII
6. Whittier Narrows	10/1/87/0742	34.050°N	5.9	VIII	
a) Pasadena		118.080°W			VII
7. Superstition Hills	11/24/87/0516	33.013°N	6.0	VII	
		115.838°W			
a) El Centro					VII
8. Loma Prieta	10/17/89/1704	37.037°N	7.1	VIII	
a) Moss Landing		121.883°W			VII

Note:
[1]The Imperial County Services Building in El Centro was badly damaged and demolished following the earthquake. Local to the building was an intensity IX.

Table 3.2 Summary of Data Base Power Plants and Relevant Earthquake Data

Earthquake Richter Magnitude	Power Plant(s) Affected	Electrical Generating Capacity Mwe	Power Plant Owner	Power Plant Location	Recording Instrument Location and Coordinates
Kern County (Taft) 1952	Kern Valley	157	PG&E	Bakersfield Green Acres & Coffee Rd.	Taft Lincoln School - 810 N. 6th Street 35.15 N 119.46 W
San Fernando 1971	Valley	513	LADWP	San Fernando Valley -Sun Valley	8244 Orion Blvd. L.A. 34.22 N 118.47 W
	Burbank Power	213	City of Burbank	Burbank 164 W. Magnolia Blvd.	633 E. Brodway Glendale 34.15 N 118.25 W
	Glendale Power	148	City of Glendale	Glendale 800 Air Way	633 E. Brodway Glendale 34.15 N 118.25 W
	Pasadena Power	206	City of Pasadena	Pasadena 130 Wallis	Millikan Lib. C.I.T, Pasadena 34.14 N 118.13 W
Ferndale 1975	Humboldt Bay	167	PG&E	Humboldt Bay King Salmon	On Site
Imperial Valley 1979	El Centro	174	Imperial Irrigation District	El Centro Villa & Dogwood	Main & Dogwood Sts., El Centro 32.796 N 115.535 W
Eureka 1980	Humboldt Bay	167	PG&E	Humboldt Bay King Salmon	On Site
Superstition Hills 1987	El Centro	174	Imperial Irrigation District	El Central Villa & Dogwood	Imperial County Center 9th & Main, El Centro 32.793 N 115.564 W
Whittier Narrows 1987	Pasadena	206	City of Pasadena	Pasadena 130 Wallis	2800 Monterey Rd., San Morino 34.109 N 118.130 W
Loma Prieta 1989	Moss Landing	2088[2]	PG&E	Moss Landing	Tele. Bldg. Watsonville 37.098° N 112.759° W

(1) Distance and Direction of Recording Station from Power Plant.

(2) A total 588 MWe for Units 1 - 5.

Table 3.3 Summary of Earthquake Record and Seismic Data Applicable to Plant Sites

Facility	Earthquake Record			Power Plant Site	
	Earthquake--- Name & Identification of Recording Station Closest to Plant	Epicentral Distance and Direction to Recording Station (Miles)	PGA[1] at Recording Station (g)	Epicentral Distance and Direction to Plant Site	Measured or Estimated PGA at Plant Site (g)
Valley	San Fernando-- 8244 Orion Blvd. Los Angeles	14.6 SSW	.27H_1 .14H_2 .17V	11.7 SSE	.30H_1 .15H_2 .18V
Burbank	San Fernando-- 633 E. Broadway Glendale	20.2 SSE	.28H_1 .23H_2 .14V	16.2 SSE	.35H_1 .29H_2 .18V
Glendale	San Fernando-- 633 E. Broadway Glendale	20.2 SSE	.28H_1 .23H_2 .14V	14.0 SSE	.30H_1 .25H_2 .15V
Pasadena	a) San Fernando-- CIT, Millikan Library Pasadena	24.4 SE	.18H_1 .22H_2 .12V	23.3 SE	.20H_1 .16H_2 .11V
	b) Whittier Narrows- 2800 Monterey Rd. San Marino	6.1 NNW	.22H	7.1 NNW	.20H
Kern	Kern Valley (Taft)-- Lincoln School 810 N. 6th Street Taft	26.7 WNW	.17H	26.9 N	.25H
El Centro	a) El Centro -1979-- Station 5165 Corner Main Street & Dogwood Road El Centro	17.5 NW	.51H_1[2] .37H_2 .93V	17.7 NW	.51H_1 .37H_2 .93V
	b) Superstition Hills CSMIP 335 Imperial County Center 9th & Main Street El Centro	23.5 SE	.27H_1 .13H_2 .36V	23.9 SE	.27H_1 .13H_2 .36V
Humboldt Bay	a) Ferndale-- Plant Site Humboldt Bay	11.8 NNW	.35H_1 .26H_2 .13V	11.8 NNW	.35H_1 .26H_2 .13V
	b) Eureka-- Plant Site Humboldt Bay	39.1 SSE	.40H_1 .20H_2 .16V	39.1 SSE	.40H_1 .20H_2 .16V
Moss Landing	Loma Pierta--	12.0 SSE	.36H_1 .26H_2 .56V	17.0 S	.24H_1 .16H_2 .34V

Note: Foundations at all Recording and Plant Sites are Allumvium

(1) H_1 is the maximum peak horizontal acceleration.
H_2 is the orthogonal peak horizontal acceleration.

(2) Measured on a small isolated approximately 5 ft. by 5 ft. pad. On a larger foundation, characteristic of recording instruments in large buildings, instrument accelerations would probably be lower in the range of about 0.3g.

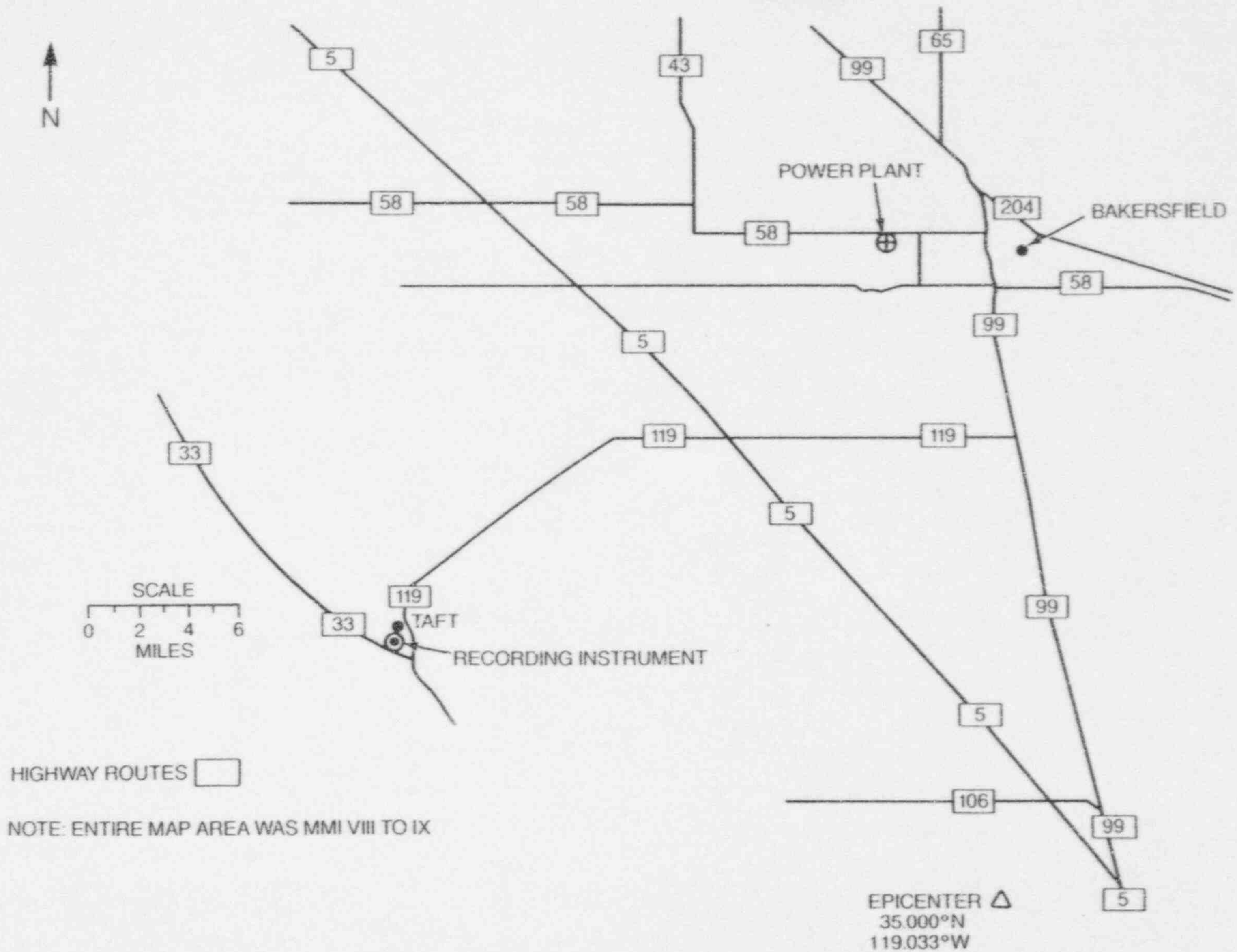

Figure 3.1 Epicentral, Recording Station & Power Plant Locations & Modified Mercalli Instensities from the Kern Country Earthquake of June 1952

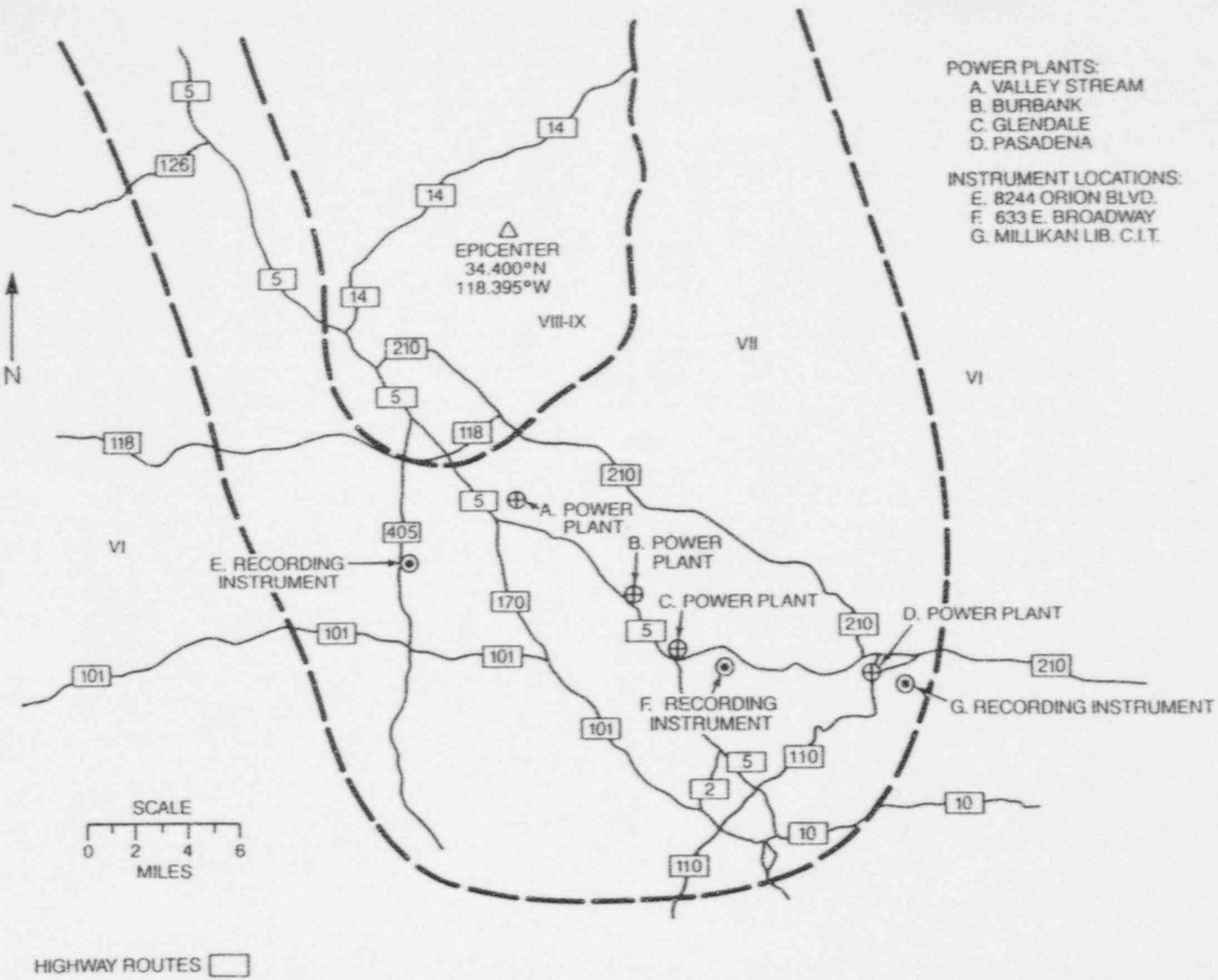

Figure 3.2 Epicentral, Recording Station and Power Plant Locations and Modified Mercalli Intensities from the San Fernando Earthquake 1971

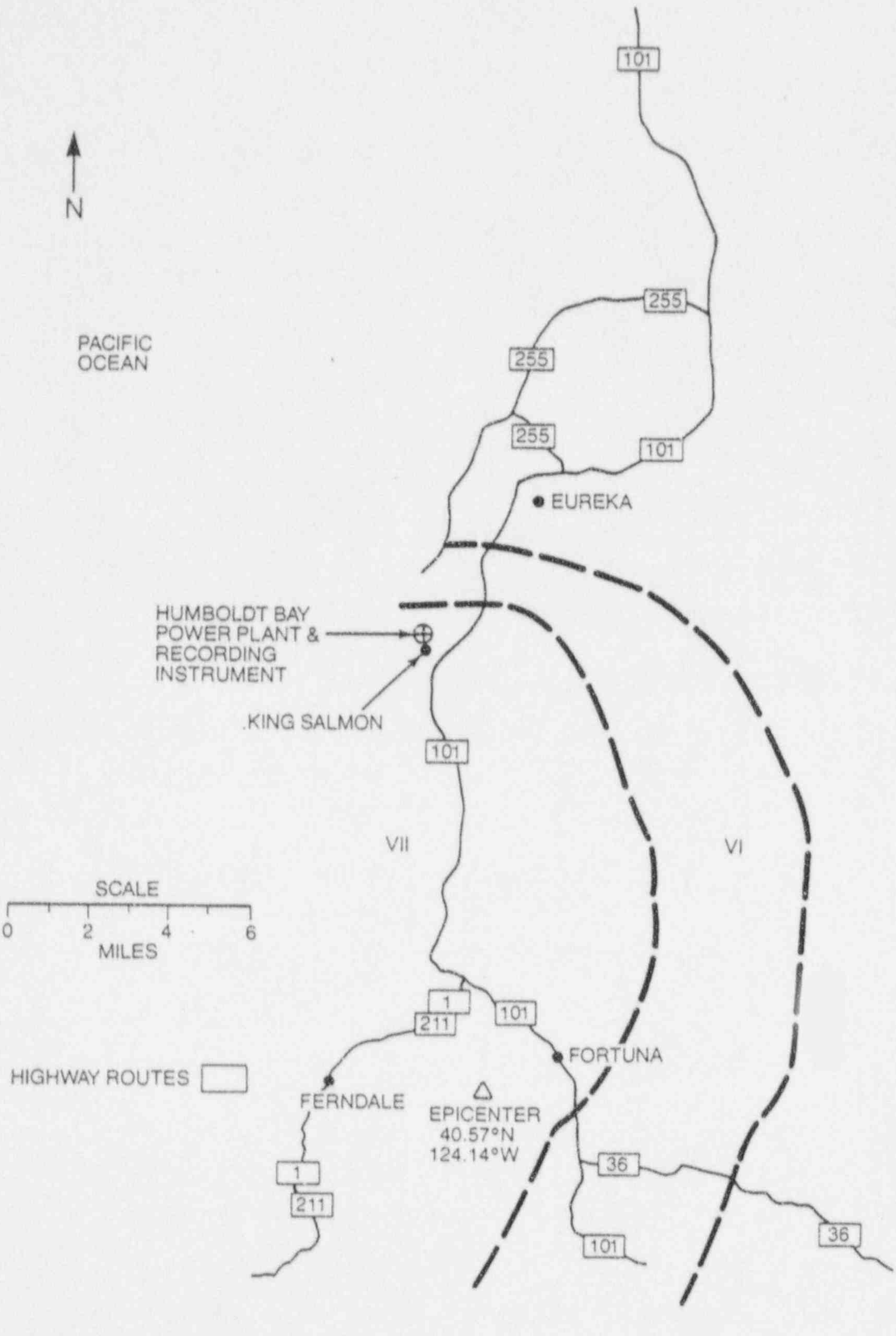

Figure 3.3 Epicentral, Recording Station and Power Plant Locations and Modified Mercalli Intensities from Ferndale June 1975 Earthquake

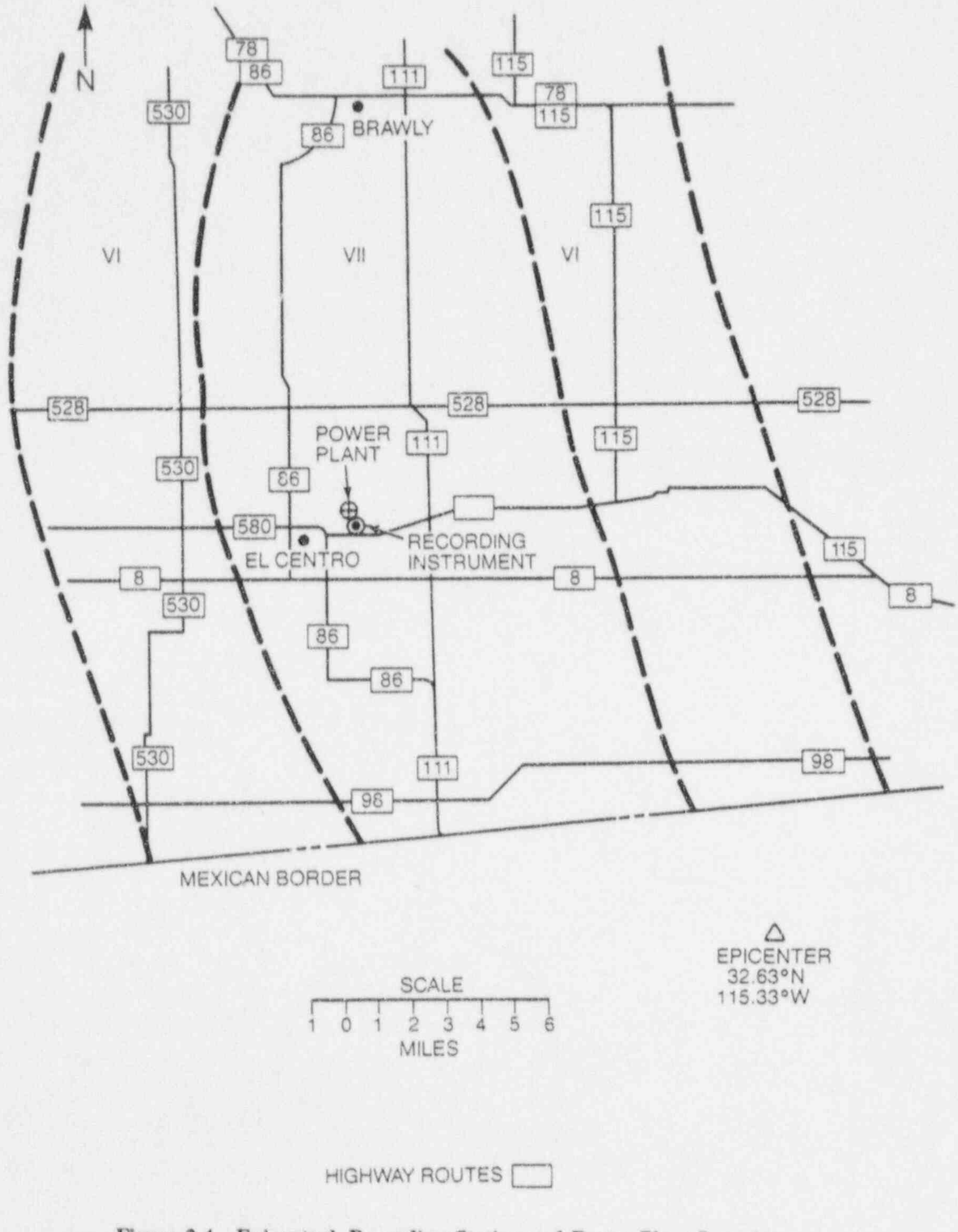

Figure 3.4 Epicentral, Recording Station and Power Plant Locations and Modified Mercalli Intensities from Imperial Valley 1979 Earthquake

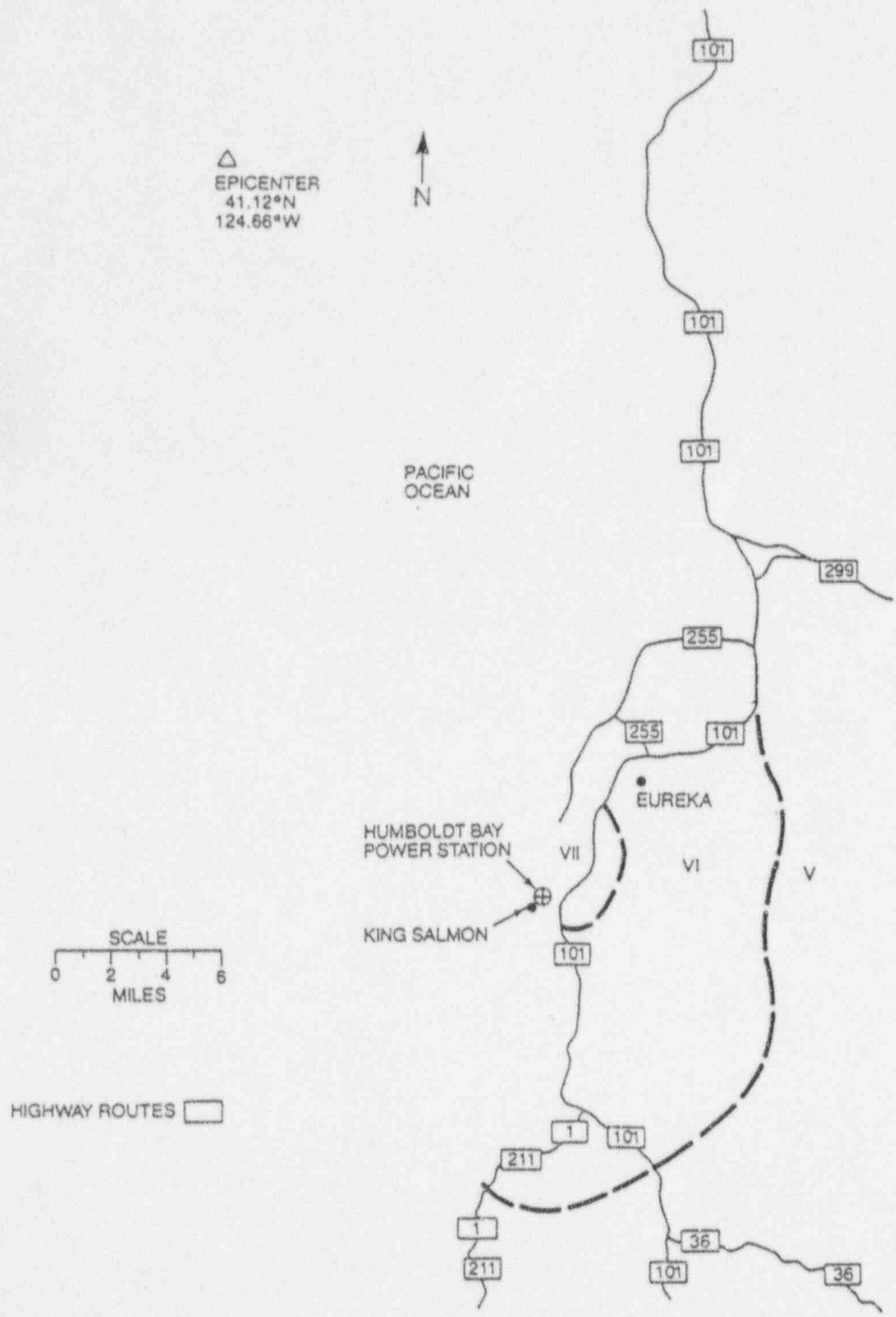

Figure 3.5 Epicentral, Recording Station and Power Plant Locations and Modified Mercalli Intensities from the Eureka November 1980 Earthquake

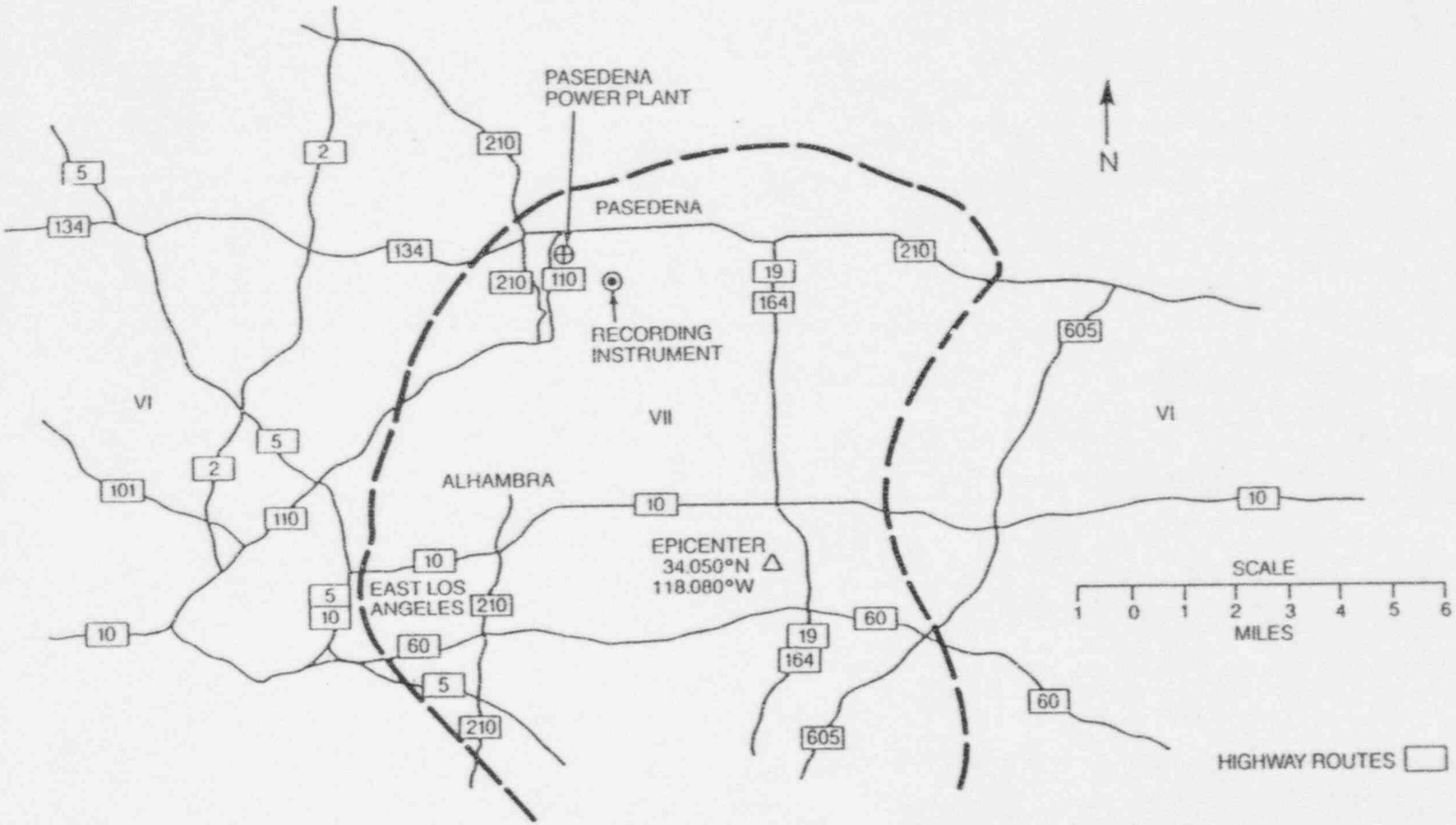

Figure 3.6 Epicentral, Recording Station and Power Plant Location and Modified Mercalli Intensities from the October 1987 Whittier Narrows Earthquake

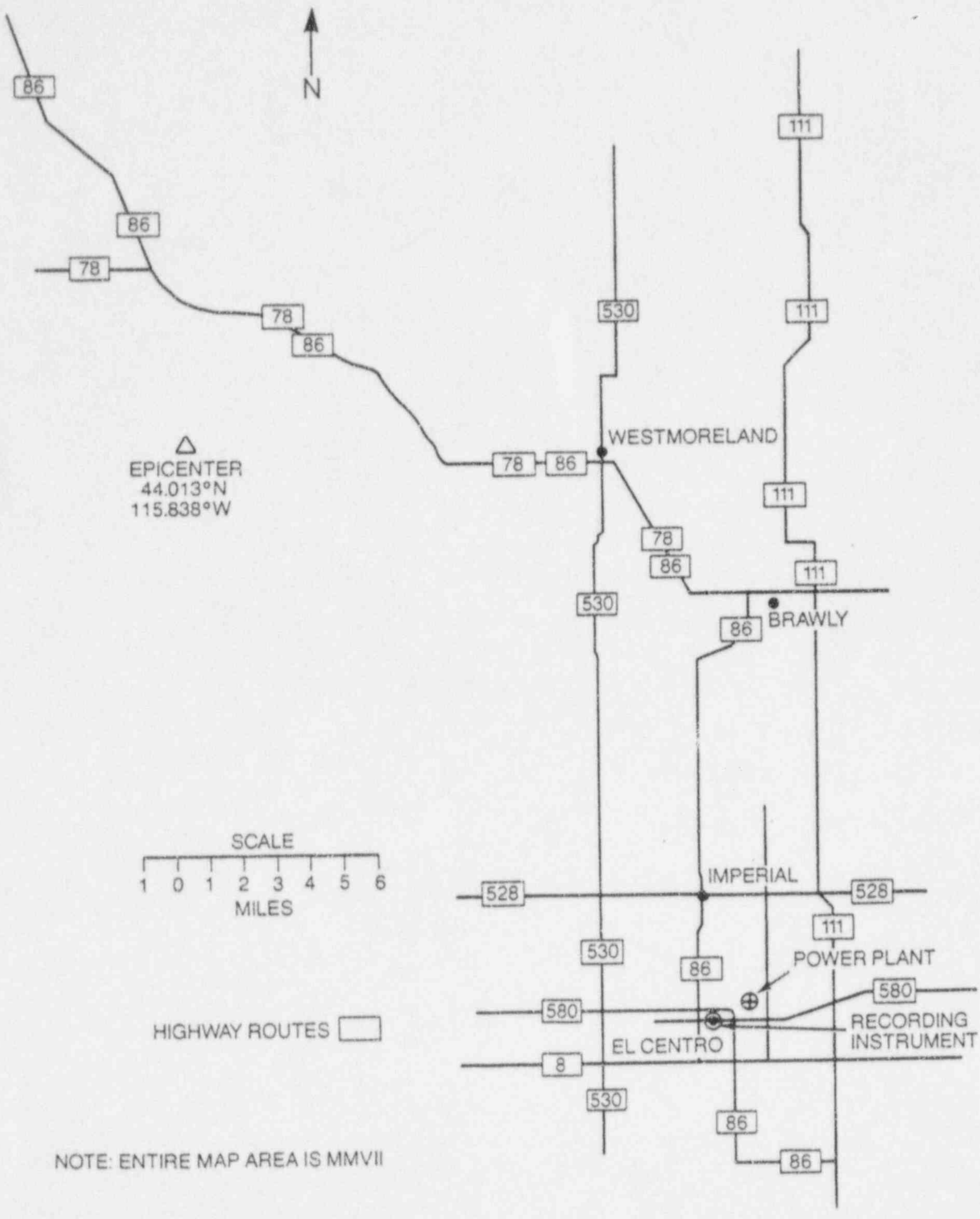

Figure 3.7 Epicentral, Recording Station and Power Plant Locations and Modified Mercalli Intensities from the Superstition Earthquake of 24 November 1987

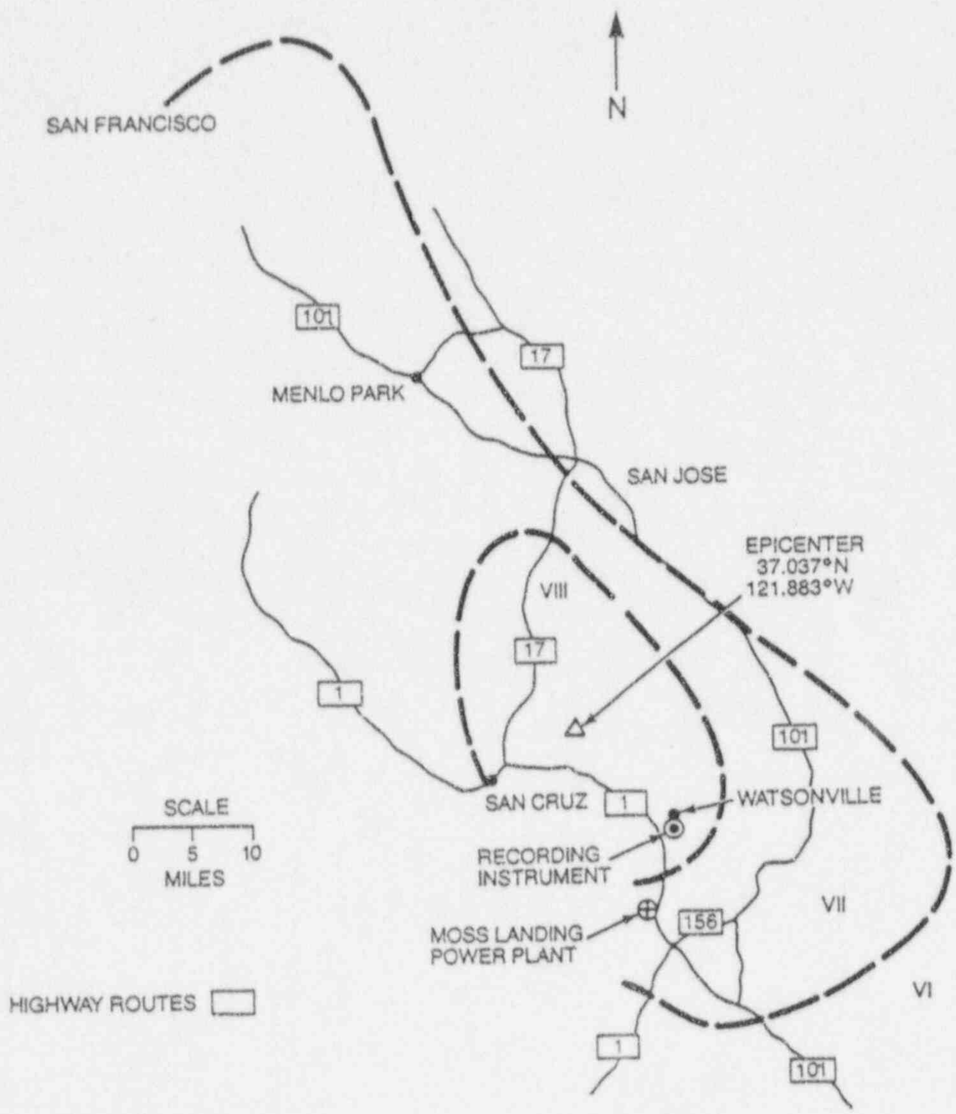

Figure 3.8 Epicentral, Recording Station and Power Plant Locations and Modified Mercalli Intensities from October 1989 Loma Prieta Earthquake

4 Typical Plant Parameters and Layout Considerations

4.1 General Description

The eight dual gas and oil fired power stations considered in detail in this study are similar in construction and layout. They consist primarily of a structural steel boiler house composed primarily of X-braced and moment resisting structural steel framing which supports and houses the boiler. The height of the boiler house structures considered vary from a total height of about 150 feet for the 157 Mwe Valley Steam Units 3 and 4 down to about 90 feet for the 20 and 28 Mwe Magnolia Units 3 and 4. The boiler heights are approximately 80 percent of the total boiler house building height. The foundations of the boiler houses are typically located at grade or within -15 feet of grade. The first floor of the boiler house up to a height of about 15 feet is typically reinforced concrete shear wall construction between and encasing the structural steel column lines. Above this elevation construction is structural steel framing, supporting steel grating floors. The boiler is typically, hung from the roof of the boiler house.

Fig. 4-1 shows a typical boiler arrangement installed in a central power station which employs natural gas or oil as a fuel (Valley Steam Plant Unit 1 or 2). There is a single furnace and the superheater stages are of the convection type. The boiler shown is designed to serve a 100 MWe turbine-generator and has a rated output of 850,000 lbs of steam per hour with superheater outlet conditions of 1500 psig, 1000° F. Either natural gas or oil may be burned in this boiler which is of the pressurized type. In Valley Steam Plant Units 3 and 4 the superheater outlet temperature is increased to 1850 psig at 1000° F.

Tubes between the upper headers and the drum transport the mixture of steam and water discharged from the waterwalls to the drum, where the steam is separated from the boiler water and passes on to the primary superheater. To insure uniform distribution of steam and water, the connecting tubes are arranged uniformly along the drum and headers. The lower sections of the front and rear waterwalls bend inward to form an almost flat furnace floor.

The primary superheater, is located in the vertical section at the rear of the furnace. Saturated steam from the drum passes through front and rear walls enclosing this section and then enters the lower superheater header. Leaving the primary superheater, the steam passes to the secondary superheater which is a platen section located in the gas outlet of the boiler furnace.

An economizer is located directly below the first stage superheater. Outlet tube ends of economizer sections extend vertically upward to form the sidewalls of the horizontal primary stage superheater and economizer enclosure. The entire boiler and air heater system are supported from building structural steel located at the roof elevation.

Reheat systems increase turbine efficiency by reheating steam which has passed through the high pressure section of the turbine to the initial temperature but at the same lower pressure the steam exited the high pressure section of the turbine and returning the reheated steam to the low pressure section of the turbine. Reheat has generally been employed on larger units built after about 1956 and is included in the Valley plant boiler Units 3 and 4.

A similar boiler for the much smaller Unit 1 of Humboldt Bay Power Plant is shown in Figure 4.2. This unit is capable of generating 475,000 lbs of steam per hour at 900 psig and 900°F. The unit does not have a reheat cycle but does employ hydrogen cooling of the turbine generator.

4.2 Typical Construction of the Boiler House

Typical boiler house framing construction is shown in Figures 4.3 to 4.6. The plants built prior to about 1954 were of all riveted connection construction. After about 1954 until 1956, shop connections tended to riveted and field connections were high strength bolts. After 1956, most joints were made with high strength bolts using beam seats and clip angles. There was little observed use of direct member to member weld connections.

In general, it is expected that the bolted construction would behave in a more ductile manner than would direct member to member welds or riveted construction. It is also thought that use of the ASTM A-7 structural grade steel with a specified minimum yield strength of 33 Ksi compared to the current Standard ASTM A-36 steel with a specified minimum yield of 36 Ksi and, in what appeared to be a somewhat more conservative detailing policy, resulted in somewhat heavier members and stronger construction in the plants surveyed than would be current practice for similar fossil fired power stations.

Structural steel has seen limited use in nuclear power plants because of the need for thick concrete wall sections to provide radiation shield or tornado missile protection. Because of the extensive use of shear wall sections and the use of concrete slabs as horizontal diaphragms in nuclear as apposed to fossil power plants, it is anticipated lateral deflections or story drifts and the potential for significant differential seismic anchor motions applied to supported pipe will be significantly greater in fossil as compared to nuclear power plants.

4.3 Piping

4.3.1 Quantity Sizes and Schedules

The quantity of piping per power station varies significantly as a function of the size of the unit, the degree and type of superheater and whether or not the unit has a reheat cycle or hydrogen cooling of the turbine.

Table 4.1 summarizes piping by sizes and schedule contained in the Valley Steam Plant Units 1 and 2 and common as determined by take offs from the piping procurement specifications. Valley Units 1 and 2 consist of two 100 MWe units. There is a total of 52,200 feet of large bore (> 2 1/2" OD) and 18,900 feet of small bore pipe shown in Table 4.1. Based on a total of 200 MWe this suggests 261 feet per MWe of large bore and 94.5 feet per MWe of small bore pipe. However, these quantities are not consistent with the quantity percentages shown in Tables 4.2 and 4.3 which were reproduced from the original plant P&ID's as summarized in Section 4.3.3. Section 4.3.3 suggests approximately 43 percent of piping is large bore while Table 4.1 suggests 74 percent is large bore. Experience in nuclear power plant piping quantities suggests that the total quantity of large bore piping in Table 4.1 of 52200 feet is reasonable while the percentage breakdown of 43 percentage of large bore versus 57 percent of small bore of Tables 4.2 and 4.3 appear more reasonable than the 74 percent large bore indicated by Table 4.1. For this study, the 52200 feet of large bore pipe indicated in Table 4.1 and the 43 percent large bore are considered correct. This suggests that the total quantity of piping for two 100 MWe units is 121395 ft of pipe. Using a 0.8 factor to compensate for the two unit configuration which permits sharing of systems suggests a total of 97116 ft of pipe for a 200 MWe plant. Based on a total of 97120 feet for 200 MWe and 43 percent of this is large bore suggests 208 feet per MWe of large bore and 276 MWe of small bore pipe.

However, there should be a minimum quantity of pipe regardless of the size of the station. It is suggested that a minimum value of 10,000 feet be selected for large bore and 15,000 for small bore pipe which represent the constant A in an equation of the form A + Bx where B is the quantity of pipe as a function of the plant size. On this basis, 10,000 + B x 200 = 41,762 and B = 159 ft/MWe for large bore pipe. Similarly, for small bore pipe with A taken as 15,000 ft. then B is 202 ft/ MWe.

The Valley Units 1 and 2 are fitted with a hydrogen cooling system for the turbine but do not have a reheat cycle system. It is suggested that a value of A = 13,500 ft and B = 180 feet/MWe be used for small bore pipe estimates and A = 9,000 ft and B = 140 feet/MWe for large bore pipe be used for base line estimates of piping quantities assuming no turbine reheat and no hydrogen cooling of the turbine. Additions of a reheat cycle and hydrogen cooling of the turbine should add an additional 10 and 5 percent respectively to these base line piping quantities.

Also, it should be understood that as the size of the boiler unit is reduced, the maximum size of high pressure pipe is also reduced. For a 100 MWe unit, the maximum diameter of a high pressure and temperature (1,000 psi, 900° F) steam line is about twelve inches. For a unit, less than 50 MWe the maximum diameter of a high pressure steam line would be reduced to about eight inches. Reheat lines which operate at the initial high temperature but lower pressure appear typically to be about fifty percent larger in diameter than the main steam lines.

4.3.2 Materials

For high pressure and high temperature service ($P_d \geq$ 1,000 psi; $T_d \geq$ 900°F) low alloy high strength steels schedule 80 to 160 are used, typically of the ASTM A-335 or equivalent type. For high pressure, but lower temperature service (P_d < 1000 psi T_d < 500° F) ASTM A-106 carbon steel pipe up to schedule 80 is used. For pressure service below 500 psi ASTM A-53 Carbon steel pipe schedule 40 and lower is typically used.

4.3.3 Temperature Service

In the report, all lines having a design temperature equal to or greater than 200° F are designated as hot, and all lines with a design temperature below 200° F are considered as cold lines. Alternatively, lines which are insulated or supported by spring hangers are considered hot. The lines having a nominal diameter of $D_o \leq$ 2 1/2 inches are considered small and lines 3 inches and larger are considered large. For the purpose of making this evaluation, the line list developed for the El Centro Unit 4 and Olive Unit 2 as shown in Table 4.2 and 4.3 are used. There are a total of 557 lines listed in Tables 4.2 and 4.3. A total of 87 lines are large and hot; a total of 149 lines are large and cold; a total of 113 lines are small and hot; and a total of 208 lines are small and cold. This gives rise to the following percentages:

1) 16% large and hot
2) 27% large and cold
3) 20% small and hot
4) 37% small and cold

It should be noted that it is not generally possible to obtain pipe line lengths and support spacing from a line list. In general this information can be determined only from stress isometrics or line walkdowns. In fossil plants it is common practice to develop stress isometrics only for the more important high pressure and temperature lines. Typical isometrics for the Pasadena, Brodway plant are shown in Section 5.0.

4.3.4 Distribution of Pipe Lines with Building Height

It should be noted that the distribution of piping with building height for a fossil power plant is to a considerable degree a function of boiler layout. Typically the steam drum where steam to drive the turbine generator is generated is located at the top of the boiler at an elevation of 75 to 135 feet above grade elevation. Steam lines from the stream drum typically run horizontally from the steam drum to the turbine side of the boiler house structure. It is estimated that approximately 20 percent of all plant piping and 30 percent of all hot piping is located in this elevation range. Piping runs from these high elevations typically drop vertically along the turbine side face of the boiler house to a height within about 30 to 40 feet of grade to connect with the turbine and auxiliary equipment. Approximately 20 percent of all hot piping is located between 30 and 40 feet above grade. The remaining 60 percent of all piping and 50 percent of hot piping is located within about 30 feet of grade.

4.3.5 Types of Pipe Connections

Most steel piping tends to be butt jointed, groove welded above about 3 inches in diameter. In a few cases for cold temperature and low pressure service, bolted flange connections were also observed. Below 3 inches, connections are typically either threaded, socket welded or bolted flange connected. In Table 4.2 can be found line list data giving the type of connection developed for the El Centro Steam plant Unit #4. A total of 134 lines above 2 1/2" were welded. A total of 34 lines below 2 1/2" were threaded and 148 lines socket welded. These data represent the following percentages:

1) 42% welded larger than 2 1/2" diameter
2) 47% socket welded less than or equal to 2 1/2" diameter
3) 11% threaded less than or equal to 2 1/2" diameter.

The perception developed through the walkdowns is that on small bore lines socket welded rather than threaded fittings tend to be used on high temperature (insulated) piping. In the older plants for small bore piping, the tendency is to use a higher percentage of threaded fittings as compared to socket welded fittings.

4.3.6 Typical Piping Layout

In Appendix E are shown photographs of typical piping and supports in the plants surveyed. In particular the photos highlight small bore pipe with relatively long unsupported spans. In several instances the spans are so long that there is visible sag in the lines. The photos in some instances also show a considerable amount of corrosion in the piping.

4.4 Types of Pipe Supports

Most large bore pipe supports are attached to structural steel that form part of peripheral and interior steel beams which support the floor grating. However, there are also instances where small bore pipe is supported off of auxiliary steel and other larger bore piping.

4.4.1 Distribution and Types of Vertical Supports

All plants, where piping support specifications are available as shown in Appendix D indicate that piping was to be installed in accordance with requirements of the ASME B 31.1 Code. This Code has recommended deadweight vertical support spacings as shown in Table 4.4. The site investigations indicated that the B 31.1 vertical support spacings were followed, for the most part, particularly for large bore piping $D_o > 2\ 1/2"$. For small bore piping, much of which appeared to be field run, the support spans relative to the B 31.1 recommended values appear to be somewhat greater. In Appendix F is presented a data base from a walkdown of randomly selected piping system support spacings for the Valley Steam, El Centro and Moss Landing Power Stations. These particular stations were selected because of their relative large or representative size. In Figure 4.7 and 4.8 are a histograms of horizontal span spacings between vertical supports normalized to the B 31.1 recommended spans for both large and small bore piping developed from a sampling of all the plants surveyed. These histograms were developed from the data given in Appendix F.

The types of vertical piping supports used range from those defined in typical industry standards[7] as shown in Figure 4.9 to typical plant specials, photographs of which are shown in Figures 4.10 and 4.11. Approximately 15 percent of the supports used in the plants are of the U-bolt or U-strap type which are of course capable of both lateral as well as vertical support. The use of U bolt or strap type supports appear in general to be limited to in small bore cold lines.

4.4.2 Distribution and Types of Horizontal Piping Supports

With two exceptions, the Valley and Pasadena Power Plants, there did not appear to be any significant or intentional use of lateral supports on piping in the eight fossil plants (25 units) surveyed. The 0.2g statically applied load typically used to design building structures and in some instances in seismic design of piping did not appear to significantly affect the location of lateral supports. Lateral supports appeared primarily in cold piping which were routed along or in the immediate proximity of building structural members and U bolts or straps were used to attached the piping directly to the members. Catalog type lateral pipe supports are shown in Figure 4.12. Some typical plant specials which provide lateral restraint are shown in Figure 4.13 to 4.16.

In Figures 4.17 and 4.18 can be found a histogram of typical horizontal spans between lateral or horizontal piping supports normalized to the appropriate B 31.1 span length for small and large bore piping as a function of nominal pipe diameters. These histograms are also based on the data base presented in Appendix F.

4.4.3 Typical Support Layout

In Appendix C are shown typical photographs of piping supports installed in the plants surveyed. As can be seen in the pictures a large variety of different supports have been used.

4.5 Damaged Piping and Supports in the Eight Plants Surveyed

Approximately 840,000 feet of large bore and 1,100,000 feet of small bore at the eight power stations surveyed were at risk to strong motion horizontal shaking in the range of 0.2 to 0.51g PGA. Two of the power plants were subjected to two different earthquake strong motions. In Table 4.5 is a summary of piping damage for the 8 plant surveyed.

In Figure 4.19 is shown the location of a small branch line rigidly attached (concrete wall to the pipe side wall) of a large cold water line in Glendale Unit 3. The branch line ruptured at the connection to the large line. The small line did not have the flexibility to accommodate the seismic motion of the large line or sufficient structural capacity to restrain the large line.

In Figures 4.20 to 4.22 are shown the location of a leak at a threaded joint in small bore boiler feed oil piping in Magnolia Unit 3. The cause of this leak was apparently a failure (rupture) in the threaded joint since the piping arrangement would appear to have sufficient flexibility to accommodate seismic motions of the boiler.

In Figures 4.23 to 4.25 are shown the location of a leak at a threaded joint at small bore pipe connection to a tank in El Centro Unit 2. Again the failure would appear to be in the threaded connection since the piping arrangement would appear to have sufficient flexibility to accommodate seismic motions of the tank.

In Figures 4.26 to 4.28 are shown the location of a leak at an apparent weld repair failure in a 3 inch turbine coolant line in El Centro Unit 4. The cause of the failure is thought to be poor welding aggravated by corrosion. The seismic anchor motions and inertia loads applicable to this piping are considered minimal.

In Figure 4.29 is shown cracking of a concrete abutment pipe support in the Kern Valley Plant, however, it could not be determined if this failure was caused by operating conditions or earthquake.

Table 4.1 Summary of Piping Quantities at the Valley Steam Plant Determined from Piping Procurement Specifications
Units 1 & 2 and Common[(1)]

SIZE	FEET	SCHEDULE
24"	1,000	20
20"	2,500	20
18"	1,100	30
16'"	1,050	30
14"	700	30
12"	8,000	40
12"	4,000	30
10"	650	160
8"	100	160
6"	9,500	40
4"	400	160
4"	12,500	40
3"	600	160
3"	100	80
3"	10,000	40
2"	300	160
2"	2,500	40
1 1/2"	100	160
1 1/2"	5,000	40
1"	9,000	40
3/4"	500	160
3/4"	1,500	40

Large Bore = 52,200'
Small Bore = 18,900'

Note:
[(1)]It is assumed that the large bore quantity estimate shown is correct for a two 100 MWe Units plant configuration and the actual small bore piping quantities used were supplemented by field purchase. Using large to small bore line percentage from line lists developed for EL Centro and Olive Plants a total of 69195 feet of small bore pipe would be estimated for this plant configuration rather than the 18,900 feet shown.

Table 4.2 Line List for El Centro Steam Plant Unit 4

NUMBER	SIZE	SCHEDULE	MATERIAL	INSULAT.	CONT.	PRESS.	TEMP.	CONSTRUCTION
101SA-1	0.750	40	A-53	YES	LIQUID	25	249	WELDED
101SA-2	10.000	40	A-53	YES	LIQUID	25	249	WELDED
101SA-3	12.000	STD. WT.	A-53	YES	LIQUID	25	249	WELDED
102SH*-1	2.000	160	A-106	YES	LIQUID	1827	254	WELDED
102SH*-2	6.000	120	A-106	YES	LIQUID	1827	254	WELDED
102SH*-3	8.000	120	A-106	YES	LIQUID	1827	254	WELDED
103SH	8.000	120	A-106	YES	LIQUID	1815	290	WELDED
104SH	8.000	120	A-160	YES	LIQUID	1795	355	WELDED
105SH-1	2.000	160	A-106	YES	LIQUID	1760	436	WELDED
105SH-2	8.000	120	A-106	YES	LIQUID	1760	436	WELDED
106SJA*	8.000	160	A-335	YES	VAPOR	1405	1005	WELDED
107SD	18.000	STD. WT.	A-53	YES	VAPOR	365	479	WELDED
108SFA*-1	12.000	STD. WT	A-335	YES	VAPOR	333	1005	WELDED
108SFA*-2	18.000	EX. ST	A-335	YES	VAPOR	333	1005	WELDED
109SD	6.000	40	A-53	YES	VAPOR	359	679	WELDED
110SD*	8.000	40	A-53	YES	VAPOR	130	195	WELDED
111SC	10.000	40	A-53	YES	VAPOR	43	582	WELDED
112SC-1	8.000	SCH. 40	A-53	YES	VAPOR	15	448	WELDED
112SC-2	14.000	STD. WT.	A-53	YES	VAPOR	15	448	WELDED
1113SC-1	16.000	STD. WT.	A-53	YES	VAPOR	0	263	WELDED
1113SC-2	20.000	STD. WT.	A-53	YES	VAPOR	0	263	WELDED
114SH	3.000	160	A-106	YES	VAPOR	1600	604	WELDED
115SC	4.000	40	A-53	YES	VAPOR	100	338	WELDED
116SJA*-1	1.500	160	A-335	YES	VAPOR	1500	1005	WELDED
116SJA*-2	2.000	160	A-335	YES	VAPOR	1500	1005	WELDED
117SD	4.000	40	A-53	YES	VAPOR	275	415	WELDED
118SD	1.500	40	A-53	YES	LIQUID	35	254	WELDED
119SC-1	0.750	40	A-53	YES	LIQUID	15	190	WELDED

Table 4.2 Line List for El Centro Steam Plant Unit 4

NUMBER	SIZE	SCHEDULE	MATERIAL	INSULAT.	CONT.	PRESS.	TEMP.	CONSTRUCTION
119SC-2	1.000	40	A-53	YES	LIQUID	15	190	WELDED
121SD	6.000	40	A-53	YES	VAPOR	359	679	WELDED
122SC	10.000	40	A-53	YES	VAPOR	15	250	WELDED
123SC-1	0.750	40	A-53	YES	VAPOR	100	338	WELDED
123SC-2	1.500	40	A-53	YES	VAPOR	100	338	WELDED
123SC-3	2.000	40	A-53	YES	VAPOR	100	338	WELDED
123SC-4	3.000	40	A-53	YES	VAPOR	100	338	WELDED
124SC	3.000	40	A-53	YES	VAPOR	100	338	WELDED
125SD-1	2.000	40	A-53	YES	VAPOR	130	338	WELDED
125SD-2	4.000	40	A-53	YES	VAPOR	130	338	WELDED
125SD-3	6.000	40	A-53	YES	VAPOR	130	338	WELDED
126SC-1	2.000	40	A-53	YES	VAPOR	43	582	WELDED
126SC-2	6.000	40	A-53	YES	VAPOR	43	582	WELDED
129SA	6.000	40	A-53	NO	VAPOR/ LIQUID	15	100	WELDED
130SJA	1.500	160	A-335	YES	VAPOR	1505	1005	WELDED
131SD-1	2.000	40	A-53	YES	LIQUID	350	365	WELDED
131SD-2	3.000	40	A-53	YES	LIQUID	350	365	WELDED
132SC	3.000	40	A-53	YES	LIQUID	120	300	WELDED
133SC	4.000	40	A-53	YES	LIQUID	35	264	WELDED
134SA-1	2.000	40	A-53	NO	LIQUID	0	135	WELDED
134SA-2	4.000	40	A-53	NO	LIQUID	0	135	WELDED
135SA	10.000	40	A-53	NO	LIQUID	0	92	WELDED
136SA	10.000	40	A-53	NO	LIQUID	0	92	WELDED
137SA	8.000	40	A-53	NO	LIQUID	80	92	WELDED
138SA	8.000	40	A-53	NO	LIQUID	65	93	WELDED
139SA	8.000	40	A-53	NO	LIQUID	55	97	WELDED
140SA	3.000	40	A-53	NO	LIQUID	55	97	WELDED

Table 4.2 Line List for El Centro Steam Plant Unit 4

NUMBER	SIZE	SCHEDULE	MATERIAL	INSULAT.	CONT.	PRESS.	TEMP.	CONSTRUCTION
141SA	8.000	40	A-53	YES	LIQUID	45	186	WELDED
142SA-1	4.000	40	A-53	NO	LIQUID	60	93	WELDED
142SA-2	8.000	40	A-53	NO	LIQUID	60	93	WELDED
143SA-1	4.000	40	A-53	NO	LIQUID	15	90	WELDED
143SA-2	6.000	40	A-53	NO	LIQUID	15	90	WELDED
145SH	2.000	160	A-106	YES	LIQUID	600	254	WELDED
146F	36.000	40	A-120	NO	LIQUID	5	90	WELDED
147F	36.000	40	A-120	NO	LIQUID	5	90	WELDED
148F-1	36.000	40	A-120	NO	LIQUID	25	90	WELDED
148F-2	51.000	40	A-120	NO	LIQUID	25	90	WELDED
149F	51.000	40	A-120	NO	LIQUID	25	90	WELDED
150CWA	8.000	40	A-120	NO	LIQUID	5	80	WELDED
151WA	8.000	40	A-120	NO	LIQUID	5	80	WELDED
152WA-1	4.000	40	A-120	NO	LIQUID	120	80	WELDED
152WA-2	6.000	40	A-120	NO	LIQUID	120	80	WELDED
153WA-1	6.000	40	A-120	NO	LIQUID	30	90	WELDED
153WA-2	8.000	40	A-120	NO	LIQUID	30	90	WELDED
154WA	14.000	40	A-120	NO	LIQUID	10	80	WELDED
156WA-1	8.000	40	A-120	NO	LIQUID	10	80	WELDED
156WA-2	12.000	40	A-120	NO	LIQUID	10	30	WELDED
157WA	8.000	40	A-120	NO	LIQUID	30	110	WELDED
158WA-1	2.000	40	A-120	NO	LIQUID	30	80	WELDED
158WA-2	3.000	40	A-120	NO	LIQUID	30	80	WELDED
159WA-1	2.000	40	A-120	NO	LIQUID	30	90	WELDED
159WA-2	3.000	40	A-120	NO	LIQUID	30	90	WELDED
159WA-3	6.000	40	A-120	NO	LIQUID	30	90	WELDED
160WA-1	4.000	40	A-120	NO	LIQUID	30	80	WELDED
160WA-2	8.000	40	A-120	NO	LIQUID	30	80	WELDED

Table 4.2 Line List for El Centro Steam Plant Unit 4

NUMBER	SIZE	SCHEDULE	MATERIAL	INSULAT.	CONT.	PRESS.	TEMP.	CONSTRUCTION
161WA-1	4.000	40	A-120	NO	LIQUID	25	95	WELDED
161WA-2	8.000	40	A-120	NO	LIQUID	25	95	WELDED
162WA-1	0.750	40	A-120	NO	LIQUID	25	80	WELDED
162WA-2	2.000	40	A-120	NO	LIQUID	25	80	WELDED
163WA-1	0.750	40	A-120	NO	LIQUID	25	90	WELDED
163WA-2	1.500	40	A-120	NO	LIQUID	25	90	WELDED
163WA-3	2.000	40	A-120	NO	LIQUID	25	90	WELDED
163WA-4	4.000	40	A-120	NO	LIQUID	25	90	WELDED
164WA	0.750	40	A-120	NO	LIQUID	120	80	THREADED
165WA	6.000	40	A-139	NO	LIQUID	15	90	WELDED
166WA	1.500	40	A-120	NO	LIQUID	120	80	THREADED
167WA	4.000	40	A-120	NO	LIQUID	15	70	WELDED
168WA-1	0.750	40	A-120	NO	LIQUID	120	80	THREADED
168WA-2	1.500	40	A-120	NO	LIQUID	120	80	THREADED
169WA	4.000	40	A-120	NO	LIQUID	15	90	WELDED
170WA	3.000	40	A-120	NO	LIQUID	120	80	WELDED
172WA	1.000	40	A-120	NO	LIQUID	120	80	THREADED
174WA	1.000	40	A-120	NO	LIQUID	120	160	THREADED
175WA-1	0.750	40	A-120	NO	LIQUID	120	130	THREADED
175WA-2	1.000	40	A-120	NO	LIQUID	120	130	THREADED
176WA	1.000	40	A-120	NO	LIQUID	120	160	THRREADED
177WA	0.750	40	A-120	NO	LIQUID	120	80	THREADED
178WA	1.000	40	A-120	NO	LIQUID	15	90	THREADED
179WA-1	4.000	40-4	A-120	NO	LIQUID	10	80	WELDED
179WA-2	8.000	30-8	A-139	NO	LIQUID	10	80	WELDED
180WA	6.000	40	A-139	NO	LIQUID	10	80	WELDED
184PVC	0.500		PVC	NO	LIQUID	5	70	WELDED
186WA	1.000	40	A-120	NO	LIQUID	120	80	THREADED

Table 4.2 Line List for El Centro Steam Plant Unit 4

NUMBER	SIZE	SCHEDULE	MATERIAL	INSULAT.	CONT.	PRESS.	TEMP.	CONSTRUCTION
187PVC	1.000		--	NO	LIQUID	120	80	WELDED
188WA	1.000	40	A-120	NO	LIQUID	5	80	THREADED
190AA	6.000	40	A-53	NO	VAPOR	15	70	WELDED
191FC	8.000	40	A-53	NO	VAPOR	68	80	WELDED
192FA-1	10.000	30	A-53	NO	VAPOR	40	80	WELDED
192FA-2	12.000	30	A-53	NO	VAPOR	40	80	WELDED
193FA	1.000	40	A-53	NO	VAPOR	40	80	WELDED
194FA	6.000	40	A-53	YES	LIQUID	50	110	WELDED
195FA	8.000	40	A-53	YES	LIQUID	5	110	WELDED
196FA	8.000	40	A-53	YES	LIQUID	50	110	WELDED
197FA-1	0.750	40	A-53	YES	LIQUID	5	125	WELDED
197FA-2	2.000	40	A-53	YES	LIQUID	5	125	WELDED
197FA-3	6.000	40	A-53	YES	LIQUID	5	125	WELDED
198FE-1	2.000	80	A-106	YES	LIQUID	675	125	WELDED
198FE-2	4.000	80	A-106	YES	LIQUID	675	125	WELDED
199FE	3.000	80	A-106	YES	LIQUID	675	250	WELDED
200FE-1	1.000	80	A-106	YES	LIQUID	875	250	WELDED
200FE-2	3.000	80	A-106	YES	LIQUID	875	250	WELDED
201FC-1	1.000	40	A-53	YES	LIQUID	50	250	WELDED
201FC-2	2.000	40	A-53	YES	LIQUID	50	250	WELDED
201FC-3	4.000	40	A-53	YES	LIQUID	50	250	WELDED
202AA	1.000	40	A-53	NO	VAPOR	100	70	THREADED
203SC	1.000	40	A-53	YES	VAPOR	100	338	WELDED
204SC	3.000	40	A-53	NO	VAPOR	100	338	WELDED
205FA	6.000	40	A-53	NO	LIQUID	5	110	WELDED
206SA	2.000	40	A-53	YES	LIQUID	15	250	WELDED
207SA-1	0.750	40	A-53	YES	LIQUID	15	190	WELDED
207SA-2	2.000	40	A-53	YES	LIQUID	15	190	WELDED

Table 4.2 Line List for El Centro Steam Plant Unit 4

NUMBER	SIZE	SCHEDULE	MATERIAL	INSULAT.	CONT.	PRESS.	TEMP.	CONSTRUCTION
208SA	3.000	40	A-53	YES	LIQUID	15	190	WELDED
209SA-1	2.000	40	A-53	YES	VAPOR/ LIQUID	15	190	WELDED
209SA-2	4.000	40	A-53	YES	VAPOR/ LIQUID	15	190	WELDED
210SA-1	0.750	40	A-53	NO	LIQUID	15	100	WELDED
210SA-2	3.000	40	A-53	NO	LIQUID	15	100	WELDED
211SA-1	6.000	40	A-53	NO	VAPOR	15	100	WELDED
211SA-2	10.000	40	A-53	NO	VAPOR	15	100	WELDED
212SD-1	0.750	40	A-53	NO	VAPOR/ LIQUID	15	100	WELDED
212SD-2	6.000	40	A-53	NO	VAPOR/ LIQUID	15	100	WELDED
212SD-3	8.000	40	A-53	NO	VAPOR/ LIQUID	15	100	WELDED
213AA-1	0.750	40	A-53	NO	VAPOR	100	70	THREADED
213AA-2	1.000	40	A-53	NO	VAPOR	100	70	THREADED
214SA-1	1.500	40	A-53	YES	VAPOR/ LIQUID	25	249	WELDED
214SA-2	2.000	40	A-53	YES	VAPOR/ LIQUID	25	249	WELDED
214SA-3	3.000	40	A-53	YES	VAPOR/ LIQUID	25	249	WELDED
215SA	0.750	40	A-53	NO	VAPOR/ LIQUID	55	97	WELDED
216SA-1	0.750	40	A-53	YES	VAPOR/ LIQUID	55	135	WELDED
216SA-2	1.000	40	A-53	YES	VAPOR/ LIQUID	55	135	WELDED
216SA-3	3.000	40	A-53	YES	VAPOR/ LIQUID	55	135	WELDED
217SA-1	0.750	40	A-53	YES	VAPOR/ LIQUID	35	264	WELDED
217SA-2	1.000	40	A-53	YES	VAPOR/ LIQUID	35	264	WELDED

Table 4.2 Line List for El Centro Steam Plant Unit 4

NUMBER	SIZE	SCHEDULE	MATERIAL	INSULAT.	CONT.	PRESS.	TEMP.	CONSTRUCTION
217SA-3	1.500	40	A-53	YES	VAPOR/ LIQUID	35	264	WELDED
217SA-4	2.000	40	A-53	YES	VAPOR/ LIQUID	35	264	WELDED
217SA-5	3.000	40	A-53	YES	VAPOR/ LIQUID	35	264	WELDED
218SC-1	1.000	40	A-53	YES	VAPOR/ LIQUID	120	300	WELDED
218SC-2	1.500	40	A-53	YES	VAPOR/ LIQUID	120	300	WELDED
218SC-3	3.000	40	A-53	YES	VAPOR/ LIQUID	120	300	WELDED
219SD-1	1.000	40	A-53	YES	VAPOR/ LIQUID	350	365	WELDED
219SD-2	1.500	40	A-53	YES	VAPOR/ LIQUID	350	365	WELDED
219SD-3	3.000	40	A-53	YES	VAPOR/ LIQUID	350	365	WELDED
220SA-1	1.500	40	A-53	NO	VAPOR/ LIQUID	0	92	WELDED
220SA-2	2.000	40	A-53	NO	VAPOR/ LIQUID	0	92	WELDED
220SA-3	4.000	40	A-53	NO	VAPOR/ LIQUID	0	92	WELDED
221SH-1	0.750	80	A-106	YES	LIQUID	1600	604	WELDED
221SH-2	1.000	80	A-106	YES	LIQUID	1600	604	WELDED
223BD	2.000	80	A-106	YES	LIQUID	15	604	WELDED
224AA	6.000	40	A-53	NO	LIQUID	15	100	WELDED
231BD	2.000	80	A-106	YES	VAPOR/ LIQUID	15	190	WELDED
232SC-1	0.750	40	A-53	YES	VAPOR/ LIQUID	15	604	WELDED
232SC-2	12.000	STD. WT.	A-53	YES	VAPOR/ LIQUID	15	604	WELDED
233BD	1.000	80	A-106	YES	LIQUID	315	400	WELDED

Table 4.2 Line List for El Centro Steam Plant Unit 4

NUMBER	SIZE	SCHEDULE	MATERIAL	INSULAT.	CONT.	PRESS.	TEMP.	CONSTRUCTION
234SA	.1.000	40	A-53	YES	LIQUID	15	150	WELDED
235WA	2.000	40	A-120	NO	LIQUID	50	80	WELDED
236SC	1.500	40	A-53	YES	LIQUID	15	250	WELDED
237SC-1	0.750	40	A-53	YES	LIQUID	15	250	WELDED
237SC-2	1.000	40	A-53	YES	LIQUID	15	250	WELDED
237SC-3	1.500	40	A-53	YES	LIQUID	15	250	WELDED
237SC-4	3.000	40	A-53	YES	LIQUID	15	250	WELDED
237SC-6	6.000	40	A-53	YES	LIQUID	15	250	WELDED
238SA	6.000	40	A-53	YES	LIQUID	10	240	WELDED
239SA	2.000	40	A-53	YES	LIQUID	15	254	WELDED
240SA	2.000	40	A-53	YES	LIQUID	15	254	WELDED
241SA	2.000	40	A-53	YES	LIQUID	15	254	WELDED
242SA	1.500	40	A-53	YES	LIQUID	65	93	WELDED
243SA	10.000	40	A-53	YES	VAPOR/ LIQUID	15	90	WELDED
244SA-1	1.500	40	A-53	NO	LIQUID	60	93	WELDED
244SA-2	2.000	40	A-53	NO	LIQUID	60	93	WELDED
247SD	6.000	40	A-53	YES	VAPOR/ LIQUID	100	700	WELDED
248SA	6.000	40	A-53	YES	VAPOR/ LIQUID	25	100	WELDED
249SD	1.000	40	A-53	YES	VAPOR	350	600	WELDED
250SD	1.000	40	A-53	YES	VAPOR	350	600	WELDED
251SD-1	0.750			NO	LIQUID	60	93	WELDED
251SD-2	1.000			NO	LIQUID	60	93	WELDED
251SD-3	2.000			NO	LIQUID	60	93	WELDED
252CCD	1.000			NO	LIQUID	15	93	WELDED
253CCD	1.003			NO	LIQUID	15	93	WELDED
254CCD	1.000			NO	LIQUID	15	93	WELDED

Table 4.2 Line List for El Centro Steam Plant Unit 4

NUMBER	SIZE	SCHEDULE	MATERIAL	INSULAT.	CONT.	PRESS.	TEMP.	CONSTRUCTION
255CCD	1.000			NO	LIQUID	15	93	WELDED
256CP-1	0.750			NO	LIQUID	15	93	THREADED
256CP-2	1.000			NO	LIQUID	15	93	THREADED
257CCD	1.000			NO	LIQUID	15	93	WELDED
258CH-1	0.750			NO	LIQUID	2400	93	WELDED
258CH-2	1.000			NO	LIQUID	2400	93	WELDED
259CJP-1	0.500			NO	LIQUID	1900	93	WELDED
259CJP-2	0.750			NO	LIQUID	1900	93	WELDED
260CCD	0.750			NO	LIQUID	50	93	WELDED
261CCD-1	1.500			NO	LIQUID	15	93	WELDED
261CCD-2	[illegible].000			NO	LIQUID	15	93	WELDED
262CCD-1	0.750			NO	LIQUID	15	93	WELDED
262CCD-2	1.500			NO	LIQUID	15	93	WELDED
263CCD-1	0.750			NO	LIQUID	15	93	WELDED
263CCD-2	1.500			NO	LIQUID	15	93	WELDED
264CCD-1	0.750			NO	LIQUID	15	93	WELDED
264CCD-2	1.500			NO	LIQUID	15	93	WELDED
265CP-1	0.750			NO	LIQUID	15	93	THREADED
265CP-2	1.500			NO	LIQUID	15	93	THREADED
266CCD-1	0.750			NO	LIQUID	15	93	WELDED
266CCD-2	1.500			NO	LIQUID	15	93	WELDED
268FA	6.000	40	A-53	NO	LIQUID	5	125	WELDED
269SD	1.000	40	A-106	YES	VAPOR	130	790	WELDED
270SD	1.000	40	A-106	YES	VAPOR	130	790	WELDED
271SA	1.000	40	A-53	YES	VAPOR	0	263	WELDED
272SA	1.000	40	A-53	YES	VAPOR	0	263	WELDED
273SA	1.000	40	A-53	YES	VAPOR	15	443	WELDED
274SA	1.000	40	A-53	YES	VAPOR	15	443	WELDED

Table 4.2 Line List for El Centro Steam Plant Unit 4

NUMBER	SIZE	SCHEDULE	MATERIAL	INSULAT.	CONT.	PRESS.	TEMP.	CONSTRUCTION
275SA	1.000	40	A-53	NO	VAPOR	0	92	WELDED
276SA	1.000	40	A-53	NO	VAPOR	0	92	WELDED
277SA	4.000	40	A-53	NO	LIQUID	25	249	WELDED
278SC	2.000	40	A-53	YES	LIQUID	15	210	WELDED
279SA	2.000	40	A-53	YES	LIQUID	15	210	WELDED
280BD	2.000	80	A-106	NO	VAPOR/ LIQUID	150	604	WELDED
315LC	0.750	40	A-53	NO	LIQUID	15	120	WELDED
316LC-1	0.750	40	A-53	NO	VAPOR/ LIQUID	30	120	WELDED
316LC-2	1.000	40	A-53	NO	VAPOR/ LIQUID	30	120	WELDED
317LC-1	0.750	40	A-53	NO	VAPOR/ LIQUID	15	120	WELDED
317LC-2	0.750	40	A-53	NO	VAPOR/ LIQUID	15	120	WELDED
318LC	3.000	40	A-53	NO	VAPOR/ LIQUID	15	120	WELDED
319LC-1	0.750	40	A-53	NO	VAPOR/ LIQUID	15	120	WELDED
319LC-2	1.500	40	A-53	NO	VAPOR/ LIQUID	15	120	WELDED
319LC-3	2.000	40	A-53	NO	VAPOR/ LIQUID	15	120	WELDED
321LC	1.000	40	A-53	NO	LIQUID	15	120	WELDED
322LC-1	2.500	40	A-53	NO	VAPOR/ LIQUID	15	120	WELDED
322LC-2	4.000	40	A-53	NO	VAPOR/ LIQUID	15	120	WELDED
323LC-1	1.500	40	A-53	NO	VAPOR/ LIQUID	15	120	WELDED
323LC-2	4.000	40	A-53	NO	VAPOR/ LIQUID	15	120	WELDED
324AA-1	0.500	40	A-53	NO	VAPOR/ LIQUID	15	110	THREADED

Table 4.2 Line List for El Centro Steam Plant Unit 4

NUMBER	SIZE	SCHEDULE	MATERIAL	INSULAT.	CONT.	PRESS.	TEMP.	CONSTRUCTION
324AA-2	0.750	40	A-53	NO	VAPOR/ LIQUID	15	110	THREADED
324AA-3	0.625	40	A-53	NO	VAPOR/ LIQUID	15	110	THREADED
325AA	1.500	40	A-53	NO	VAPOR	0	0	THREADED
326AA	1.500	40	A-53	NO	VAPOR	15	70	THREADED
327AA	0.500	40	A-53	NO	VAPOR	0	0	THREADED
328AA-1	0.500	40	A-53	NO	VAPOR	30	70	THREADED
328AA-2	0.625	40	A-53	NO	VAPOR	30	70	THREADED
329AA	1.500	40	A-53	NO	VAPOR	15	70	THREADED
330SC	1.000	40	A-53	NO	--	15	70	THREADED
331SC	1.000	40	A-53	NO	LIQUID	15	90	WELDED
332WA-1	4.000	10-4"	A-120	NO	LIQUID	10	110	WELDED
332WA-2	6.000	40-6"	A-139	NO	LIQUID	10	110	WELDED
333WA	4.000	40-4"	A-120	NO	LIQUID	10	95	WELDED
334AA	0.750	40	A-53	NO	LIQUID	15	100	THREADED
335SA	1.500	40	A-53	YES	LIQUID	25	250	WELDED
336CCE	1.000	80	A-53	NO	LIQUID	15	70	WELDED
337CCE	2.000	80	A-53	NO	LIQUID	15	70	WELDED
338CCE	0.500	80	A-53	NO	LIQUID	15	70	WELDED
339CCE	0.500	80	A-53	NO	LIQUID	15	70	WELDED
340CCE	0.500	80	A-53	NO	LIQUID	15	70	WELDED
341CCE	2.000	80	A-53	NO	LIQUID	15	70	WELDED
343WA	30.000	--	--	NO	LIQUID	25	90	WELDED
344SA	0.500	40	A-53	NO	LIQUID	15	150	WELDED
345SA	0.750	40	A-53	NO	LIQUID	15	150	WELDED
346SA-1	0.750	40	A-53	NO	LIQUID	65	93	WELDED
346SA-2	1.000	40	A-53	NO	LIQUID	65	93	WELDED
347SD	4.000	40	A-53	YES	VAPOR	275	415	WELDED

Table 4.2 Line List for El Centro Steam Plant Unit 4

NUMBER	SIZE	SCHEDULE	MATERIAL	INSULAT.	CONT.	PRESS.	TEMP.	CONSTRUCTION
348WA	2.000	40	A-120	NO	LIQUID	100	90	WELDED
349SC-1	0.750	40	A-53	NO	VAPOR	15	70	WELDED
349SC-2	8.000	40	A-53	NO	VAPOR	15	70	WELDED
350SA-1	0.750	40	A-53	NO	VAPOR/ LIQUID	15	70	WELDED
350SA-2	8.000	40	A-53	NO	VAPOR/ LIQUID	15	70	WELDED
350SA-3	10.000	40	A-53	NO	VAPOR/ LIQUID	15	70	WELDED
351SA-1	0.750	40	A-53	NO	VAPOR	15	70	WELDED
351SA-2	6.000	40	A-53	NO	VAPOR	15	70	WELDED
351SA-3	8.000	40	A-53	NO	VAPOR	15	70	WELDED
352SAA	0.750	40	A-53	NO	VAPOR	30	70	THREADED
353SD-1	0.750	40	A-53	NO	VAPOR	15	70	WELDED
353SD-2	8.000	40	A-53	NO	VAPOR	15	70	WELDED
353SD-3	10.000	40	A-53	NO	VAPOR	15	70	WELDED
354WA	3.000	40	A-120	NO	LIQUID	15	70	WELDED
355SC-1	0.750	40	A-53	NO	VAPOR	15	70	WELDED
355SC-2	3.000	40	A-53	NO	VAPOR	15	70	WELDED
355SC-3	4.000	40	A-53	NO	VAPOR	15	70	WELDED
356WA	1.000	40	A-120	NO	LIQUID	120	80	THREADED
357WA	1.000	40	A-120	NO	LIQUID	120	80	THREADED
359SC	2.000	40	A-53	YES	VAPOR	100	338	WELDED
360SC	2.000	40	A-53	YES	VAPOR	100	338	WELDED
361FE-1	0.750	80	A-106	YES	LIQUID	700	250	WELDED
361FE-2	1.000	80	A-106	YES	LIQUID	700	250	WELDED
361FE-3	2.000	80	A-106	YES	LIQUID	700	250	WELDED
362SD	6.000	40	A-53	NO	VAPOR/ LIQUID	15	100	WELDED
363CCE	2.000	80	A-53	NO	LIQUID	15	70	WELDED

Table 4.2 Line List for El Centro Steam Plant Unit 4

NUMBER	SIZE	SCHEDULE	MATERIAL	INSULAT.	CONT.	PRESS.	TEMP.	CONSTRUCTION
364FC	8.000	40	A-53	YES	LIQUID	50	110	WELDED
365SA	0.750	40	A-53	YES	VAPOR/ LIQUID	15	210	WELDED
366SC	2.000	40	A-53	NO	VAPOR	100	338	WELDED
367SA	2.000	40	A-53	NO	VAPOR/ LIQUID	0	93	WELDED
368SD	6.000	40	A-53	NO	VAPOR/ LIQUID	15	100	WELDED
369SC	0.750	40	A-53	NO	VAPOR/ LIQUID	15	70	WELDED
370SC	6.000	40	A-53	NO	VAPOR/ LIQUID	15	70	WELDED
317SC	6.000	40	A-53	NO	VAPOR/ LIQUID	15	70	WELDED

Table 4.3 Line List for Olive Steam Plant Unit 2

NUMBER	SIZE	CONT.	PRESS.	TEMP.	DESCRIPTION
2001SA	8.000	LIQUID	0	85	COND.
2002SA	8.000	LIQUID	0	185	COND.
2003SA	6.000	LIQUID	65	110	COND.
2004SA	6.000	LIQUID	65	110	COND.
2005SA	6.000	LIQUID	65	110	COND.
2006SA	8.000	LIQUID	0	200	COND.
2007SA	8.000	LIQUID	0	200	COND.
2008SA	6.000	LIQUID	50	200	COND.
2009SA	8.000	LIQUID	15	250	COND.
2010SA	8.000	LIQUID	15	250	COND.
2011SA	6.000	LIQUID	125	250	COND.
2012SA	12.000	LIQUID	80	300	B.F.W.
2013SH	6.000	LIQUID	2105	300	B.F.W
2014SH	6.000	LIQUID	2105	370	B.F.W
2015SH	6.000	LIQUID	2105	475	B.F.W
2016SJA	10.000	VAPOR	1522	1000	MAIN STREAM
2017SF	12.000	VAPOR	550	736	COLD REHEAT STEAM
2018SFA	14.000	VAPOR	485	1000	HOT REHEAT STEAM
2019SF	6.000	VAPOR	550	736	EXTRACT. STEAM
2020SD	6.000	VAPOR	200	800	EXTRACT. STEAM
2021SC	10.000	VAPOR	75	600	EXTRACT STEAM
2022SC	12.000	VAPOR	25	400	EXTRACT. STEAM
2023SA	20.000	VAPOR	0	300	EXTRACT. STEAM
2024SH	4.000	LIQUID	2105	300	B.F.W.
2025SH	3.000	LIQUID	2105	475	B.F.W
2026SH	2.000	VAPOR	1700	630	AUX. STEAM
2027SD	3.000	VAPOR	425	462	AUX. STEAM
2028SC	6.000	VAPOR	135	358	AUX. STEAM

Table 4.3 Line List for Olive Steam Plant Unit 2

NUMBER	SIZE	CONT.	PRESS.	TEMP.	DESCRIPTION
2029SC	2.000	VAPOR	135	358	AUX. STEAM
2030SC	3.000	VAPOR	135	358	AUX. STEAM
2031SD	3.000	LIQUID	450	390	COND.
2032SD	4.000	LIQUID	450	390	COND.
2033SD	2.000	LIQUID	450	390	COND.
2034SJA	2.000	VAPOR/ LIUID	1522	1000	STEAM & COND.
2035SA	6.000	VAPOR/ LIUID	125	350	STEAM & COND.
2036SA	6.000	VAPOR/ LIUID	125	350	STEAM & COND.
2037SA	6.000	VAPOR	0	212	AIR
2038SA	1.500	LIQUID	0	212	COND.
2040BD	2.000	VAPOR/ LIUID	1400	590	STEAM & COND.
2041FA	10.000	VAPOR	50	100	FUEL GAS
2042FA-1	10.000	LIQUID	20	100	FUEL OIL
2042FA-2	6.000	LIQUID	20	100	FUEL OIL
2043FF-1	4.000	LIQUID	600	100	FUEL OIL
2043FF-2	3.000	LIQUID	600	100	FUEL OIL
2044FF	3.000	LIQUID	600	300	FUEL OIL
2045FF	3.000	LIQUID	900	300	FUEL OIL
2046FF	3.000	LIQUID	900	300	FUEL OIL
2047FA	3.000	LIQUID	20	100	FUEL OIL
2048WD	4.000	LIQUID	25	80	DEMIN. WTR.
2049SA	4.000	LIQUID	65	110	COND.
2050SA	4.000	LIQUID	25	80	WATER
2051WA	10.000	LIQUID	65	110	C.W.
2051WA	10.000	LIQUID	65	110	C.W.
2052WA	10.000	LIQUID	45	110	C.W.

Table 4.3 Line List for Olive Steam Plant Unit 2

NUMBER	SIZE	CONT.	PRESS.	TEMP.	DESCRIPTION
2053WA	10.000	LIQUID	45	115	C.W.
2054WA	8.000	LIQUID	0	95	C.W.
2055WA	4.000	LIQUID	150	100	SERVICE WATER
2056WA	4.000	LIQUID	45	115	C.W.
2057WA	8.000		150	100	C.W.
2058WA	10.000	LIQUID	65	110	B.C.W
2060WA	10.000	LIQUID	65	90	B.C.W
2061WA	10.000	LIQUID	60	100	B.C.W
2062WA	6.000	LIQUID	65	90	B.C.W
2063WA	6.000	LIQUID	60	100	B.C.W
2064WA	4.000	LIQUID	65	90	B.C.W
2065WA	4.000	LIQUID	60	100	B.C.W.
2066WA	4.000	LIQUID	60	100	B.C.W
2067WA	4.000	LIQUID	150	100	SERVICE WATER
2068SH-1	1.000	LIQUID	1700	630	CONTIN. BLOW.
2068SH-2	1.500	LIQUID	1700	630	CONTIN. BLOW.
2069BD	2.000	LIQUID	1400	590	DRAINS & CONTIN BLOW
2070SC	12.000	VAPOR	25	590	EXHAUST STEAM
2071SC	4.000	LIQUID	0	210	COND.
2072SA	0.750	LIQUID	150	365	COND.
2073BD	2.000	VAPOR/ LIUID	1400	590	WATER
2074SC	2.000	VAPOR	135	358	STEAM
2075SC	3.000	VAPOR	100	480	STEAM
2076SA-1	1.000	LIQUID	65	110	COND.
2076SA-2	1.500	LIQUID	65	110	COND.
2077	1.000	LIQUID	0	100	MORPHOLINE SOL.
2078SH	1.000	LIQUID	2105	370	FEED WATER

Table 4.3 Line List for Olive Steam Plant Unit 2

NUMBER	SIZE	CONT.	PRESS.	TEMP.	DESCRIPTION
2079SH	1.000	LIQUID	2105	370	PHOSPH. SOL.
2080SC	1.000	VAPOR	0	100	VENT
2081SC	1.000	LIQUID	0	100	PHOSPH. SOL.
2082SC	1.000	LIQUID	0	100	PHOSPH. SOL.
2083	0.500	LIQUID	0	100	HYDRAZINE SOL.
2084	0.500	LIQUID	0	100	HYDRAZINE SOL.
2085WA	8.000	LIQUID	150	100	C.W.
2086WD	3.000	LIQUID	0	0	COND.
2087WD	4.000	LIQUID	25	80	DEMIN. WATER
2088FC	2.000	LIQUID	200	300	FUEL OIL
2089SA	2.000	LIQUID	100	338	COND.
2090FA-1	0.750	LIQUID	0	100	FUEL OIL
2090FA-2	1.000	LIQUID	0	100	FUEL OIL
2091SD	2.000	VAPOR/ LIUID	450	390	STEAM & COND.
2092SD	1.500	VAPOR	425	462	AIR & STEAM
2093SD	2.000	VAPOR/ LIUID	200	385	STEAM & COND.
2094SD	3.000	VAPOR	200	650	STEAM
2095SH	2.000	LIQUID	2105	300	B.F.W.
2097SA	1.500	LIQUID	80	300	B.D.
2098SA	1.000	VAPOR	65	300	VENT
2099SC	4.000	VAPOR	135	358	AUX.
2100SA	2.000	LIQUID	30	250	COND.
2101SH	1.000	LIQUID	0	0	B.F.W.
2102SC	1.500	VAPOR	135	358	AUX. STEAM
2103WA	1.500	LIQUID	150	100	SERVICE
2104SC	12.000	VAPOR	135	358	AUX. STEAM
2105SH	1.000	LIQUID	0	0	PHOSPH. SOL.

Table 4.3 Line List for Olive Steam Plant Unit 2

NUMBER	SIZE	CONT.	PRESS.	TEMP.	DESCRIPTION
2106SA	6.000	LIQUID	125	250	COND.
2107SA	3.000	LIQUID	125	250	COND.
2108SA	1.000	VAPOR	15	250	VENT
2109SA	1.000	VAPOR	0	200	VENT
2110SA	2.000	VAPOR/ LIUID	15	250	COND.
2111SA	2.000	VAPOR/ LIUID	0	200	COND.
2112SA	1.000	VAPOR	15	250	VENT.
2113SA	1.000	LIQUID	65	110	COND.
2114SA	1.000	LIQUID	65	110	COND.
2115SA	1.500	VAPOR	0	212	VENT
2116SA	0.750	LIQUID	65	110	COND.
2117SA	2.000	VAPOR/ LIUID	0	185	COND.
2118SA	1.000	LIQUID	125	250	COND.
2119WD	3.000	LIQUID	0	80	VENT.
2120BD	1.000	VAPOR/ LIUID	150	600	STEAM COND.
2121	0.500	LIQUID	0	0	SULFITE SOL.
2122BD	2.000	LIQUID	0	0	DRAINS, INTERS. CONT. B.D.
2123WA	3.000	LIQUID	25	90	COND.
2124BD	1.000	VAPOR/ LIUID	50	600	STEAM & COND.
2125BD	1.000	VAPOR/ LIUID	50	600	STEAM & COND.
2126SA	1.000	VAPOR/ LIUID	25	350	STEAM & COND.
2127SA	1.000	VAPOR/ LIUID	25	350	STEAM & COND.
2128SA	1.000	VAPOR	25	350	VENT
2129SA	1.000	VAPOR	0	185	VENT

Table 4.3 Line List for Olive Steam Plant Unit 2

NUMBER	SIZE	CONT.	PRESS.	TEMP.	DESCRIPTION
2130WA-1	2.000	VAPOR/ LIUID	45	115	VENT & DRAIN
2130WA-2	4.000	VAPOR/ LIUID	45	115	VENT & DRAIN
2131WA	1.500	LIQUID	150	100	SERVICE WATER
2132WA	1.500	LIQUID	150	100	SERVICE WATER
2133SA	2.000	LIQUID	125	250	COND.
2134SA	3.000	VAPOR/ LIUID	5	140	VABORS
2135WA	2.000	LIQUID	65	90	B.C.W.
2136WA	3.000	LIQUID	60	100	B.C.W.
2137WA	2.000	LIQUID	65	90	B.C.W
2138WA	2.000	LIQUID	60	100	B.C.W.
2139WA	2.000	LIQUID	65	90	B.C.W.
2140WA	2.000	LIQUID	60	100	B.C.W.
2141WA	1.000	LIQUID	65	90	B.C.W.
2142WA	1.000	LIQUID	60	100	B.C.W.
2143WA	0.750	LIQUID	65	90	B.C.W.
2144WA	0.750	LIQUID	60	100	B.C.W.
2145WA	1.000	LIQUID	65	90	B.C.W.
2146WA	0.750	LIQUID	60	100	B.C.W.
2148	12.000	VAPOR	600	600	STEAM
2149	12.000	VAPOR	600	600	STEAM
2150	12.000	VAPOR	600	600	STEAM
2151SA	1.000	LIQUID	65	110	COND.
2152SD	1.000	VAPOR	425	462	AIR & STEAM
2153SC	1.000	VAPOR	0	100	VENT
2154LC	1.000	LIQUID	10	150	LUBE OIL
2155LC	1.000	LIQUID	0	100	LUBE OIL

Table 4.3 Line List for Olive Steam Plant Unit 2

NUMBER	SIZE	CONT.	PRESS.	TEMP.	DESCRIPTION
2156LC	1.500	LIQUID	0	100	LUBE OIL
2157LC	1.500	LIQUID	0	100	LUBE OIL
2158SA	2.000	VAPOR	0	100	HZ
2159SA	3.000	VAPOR	0	100	HZ
2160SA	3.000	VAPOR	0	100	HZ
2161SA	0.500	LIQUID	0	100	WATER
2162AA	1.000	VAPOR	125	130	AIR
2163AA	3.000	VAPOR	125	130	AIR
2164AA	1.000	VAPOR	125	130	AIR
2165AA	1.500	VAPOR	125	130	AIR
2166AA	1.500	VAPOR	125	130	AIR
2167AA	2.000	VAPOR	125	130	INSTR.
2169AA	1.000	VAPOR	125	130	INSTR. AIR
2170AA	1.500	VAPOR	125	130	AIR
2171FC	1.500	LIQUID	200	300	FUEL OIL
2172SC	8.000	VAPOR	195	300	EXH. SSTEAM
2173SJA	0.750	VAPOR	1522	1000	STEAM
2174SA	0.500	LIQUID	0	212	DRAIN
2175SA	1.000	LIQUID	0	212	DRAIN
2176SA	1.000	LIQUID	0	212	DRAIN
2177AA	1.000	VAPOR	60	100	AIR
2178DA	4.000	LIQUID	0	80	ROOF DOWNSPOUT
2179SC	3.000	VAPOR	135	358	STEAM
2180SA	1.000	LIQUID	30	250	COND.
2181WA	3.000	LIQUID	65	90	B.C.W.
2182WA	2.000	LIQUID	60	100	B.C.W.
2183SC	1.000	LIQUID	0	100	DRAIN
2184WD	3.000	LIQUID	0	0	DEMIN WATER

Table 4.3 Line List for Olive Steam Plant Unit 2

NUMBER	SIZE	CONT.	PRESS.	TEMP.	DESCRIPTION
2185WA	30.000	LIQUID	45	115	C.W.
2186WA	48.000	LIQUID	45	115	C.W.
2187WA	0.750	LIQUID	65	90	B.C.W.
2188WA	0.750	LIQUID	60	100	B.C.W.
2189SJA	1.500	VAPOR/ LIUID	1522	1000	DRAIN
2190SFA	1.500	VAPOR/ LIUID	485	1000	DRAIN
2191SA	1.500	VAPOR/ LIUID	1522	1000	DRAIN
2192SH	1.500	VAPOR/ LIUID	1700	630	DRAIN
2193WA	0.750	VAPOR/ LIUID	60	100	VENT
2194WA	1.000	LIQUID	60	100	DRAIN
2195SF	1.500	VAPOR/ LIUID	550	736	DRAIN
2196WD	6.000	LIQUID	0	0	DEMIN WATER
2198SC	2.000	VAPOR	135	558	AUX.STEAM
2199SA	0.500	LIQUID	125	250	COND.
2200SA	4.000	LIQUID	125	250	COND.
2201FA	3.000	VAPOR	5	70	PILOT GAS
2202BD	0.750	LIQUID	3	1000	STEAM & COND.
2203SA	0.500	LIQUID	0	200	WASTE WATER & OIL
2204SF	0.500	LIQUID	0	200	WASTE WATER & OIL
2205SJA	1.500	VAPOR	1522	1000	STEAM
2206SD	1.000	VAPOR	300	850	VENT
2207DA	0.750	LIQUID	0	80	DRAIN
2208DA	0.750	LIQUID	0	80	DRAIN
2209SH	3.000	LIQUID	0	0	B.F.W.
2210SH	1.000	LIQUID	0	0	B.F.W.

Table 4.3 Line List for Olive Steam Plant Unit 2

NUMBER	SIZE	CONT.	PRESS.	TEMP.	DESCRIPTION
2213SH	0.500	LIQUID	0	0	B.F.W.
2217SH	3.000	LIQUID	0	0	B.F.W.
2218SF	1.500	LIQUID	0	0	DRAIN
2219BD	1.000	NO	0	0	BLOW DOWN
2220BD	1.500	LIQUID	0	0	BLOW DOWN
2221DA	2.000	LIQUID	0	0	DRAIN
2222SF	0.750	LIQUID	0	0	DRAIN
2223SF	2.000		0	0	VENT
2224SF	6.000		0	0	COLD REHEAT
2225SH	0.375	LIQUID	0	0	DRAIN
2226SH	0.750	LIQUID	0	0	DRAIN
2227SH	0.375	LIQUID	0	0	DRAIN
2228SH	3.000	LIQUID	0	0	B.F.W.
2229SH	2.000	LIQUID	0	0	B.F.W.
2230SH	3.000	LIQUID	0	0	B.F.W.
2231SH	8.000	LIQUID	0	0	B.F.W.
223[illegible]WD	3.000	LIQUID	0	0	DEMIN WATER
2233WD	2.000	LIQUID	0	0	DEMIN WATER
2234WD	1.500	LIQUID	0	0	DEMIN WATER
2235WD	0.750	LIQUID	0	0	DEMIN WATER
2236SA	0.750	LIQUID	0	0	B.F.W.
2237BD	1.000		0	0	BLOW DOWN
2238WA	1.500	LIQUID	0	0	WATER
2239WA	0.500	LIQUID	0	0	WATER
2240FC	0.500	G	0	0	FUEL GAS
2241FC	0.500	G	0	0	FUEL GAS
2242	2.000	LIQUID	0	0	COND.
2243WD	4.000	LIQUID	0	0	COND.

Table 4.3 Line List for Olive Steam Plant Unit 2

NUMBER	SIZE	CONT.	PRESS.	TEMP.	DESCRIPTION
2250SC	2.000	VAPOR	0	0	AUX. STEAM

Table 4.4

Suggested Deadweight Pipe Support Spacing

Nominal Pipe Size Inches	Suggest Maximum Span in Feet	
	Water Service	Steam, Gas, or Air Service
3/4	5	7
1	7	9
2	10	13
3	12	15
4	14	17
6	17	21
8	19	24
12	23	30
16	27	35
20	30	39
24	32	42

Note 1. Suggested maximum spacing between pipe supports for horizontal straight runs of standard and heavier pipe at maximum operating temperature of 750 F.

Note 2. Does not apply where span calculations are made or where there are concentrated loads between supports such as flanges, valves, specialties, etc.

Note 3. The spacing is based on a maximum combined bending and shear stress of 1500 psi and insulated pipe filled with water or the equivalent weight of steel pipe for steam, gas or air service, and the pitch of the line is such that a sag of 0.1 in. between supports is permissible.

Table 4.5 Summary Description of Behavior, Damage and Failures of California Above Ground Power Plant Piping and Supports Due to Strong Motion Earthquakes[1]

Earthquake	Mag. Site MMI	Date	Facility	Facility Des.	Estm. PGA @ Site g	Location Nearest Ground Motion Record	Damage Cat.	Damage Location	Pipe Size	Damage Description	Seismic Design Basis of Pipe
1. Long Beach	6.3	1933									
a)	VII		Terminal Island Station	Station consisted of 6 fossil fired steam units which were built between 1911 & 1928	0.25	None	NONE	-	-	None	None to 0.2g Static
2. Kern County (Taft)	7.7	1952									
a)	VIII-XI		Kern County Plant	Oil fired 60 WMe built in 1947-81	0.25	Lincoln, Sch. Taft, CA	NONE	-	-	None to Piping but there was significant damage to flat bottom ground mounted tanks	Dynamic analysis using Biot-Smoothed Response Spectrum) Normalized to 0.1 at grade & 0.3g top floor of Bldg.

Earthquake	Mag. Site MMI	Date	Facility	Facility Des.	Estm. PGA @ Site g	Location Nearest Ground Motion Record	Damage Cat.	Damage Location	Pipe Size	Damage Description	Seismic Design Basis of Pipe
3. San Fernando a) (1)	6.5 VII	1971	Burbank Power Facility	2 plants: 2 unit Olive & 5 unit Magnolia; Both fossil fueled. Total generating capacity of 200 MW.	0.35g (H_1) 0.29g (H_2) 0.18g (Vert.)	Municipal services Building; 533 East Broadway Glendale	SAM	Grade elevation on ground	NA	An unanchored demineralizer water tank in the Magnolia Plant yard shifted, breaking attached pipe at base of tank.	Olive and Magnolia Plant structures 0.20g static; equipment generally anchored, no other seismic design; Piping-rod hung for gravity only.
(2)							SAM	Grade	2"	A 2" diameter cooling water line connect-ng to the Magnolia Unit 3 main cooling water line cracked.	-
(3)							CONNECT Threaded	Tank located at grade in Plant yard	NA	One valve & pipe broke at the Olive Plant demineralizer tank connection	-

Earthquake	Mag. Site MMI	Date	Facility	Facility Des.	Estm. PGA @ Site g	Location Nearest Ground Motion Record	Damage Cat.	Damage Location	Pipe Size	Damage Description	Seismic Design Basis of Pipe
b) (1)			Glendale Power Plant	Five Generating Units with individual generating capacities of 5,20,20,20 and 4-MWe were built in the period 1941-1964. See descrip. B-16.	0.3g (H_1) 0.25g (H_2) 0.15g (Vert.)	Munc. Services Bldg. 533 E. Broadway Glendale	CONNECT Threaded			Two water lines broke, one cooling water line to the induced draft fan and air preheater on the Unit 3 boiler and the other on the No. 2 influent water line to deminalizer tank.	Same as for Olive and Magnolia Plants
(2)							SAM	Main coolant line connection	SB	Small bore connected to main coolant line of Unit 3	
c)	VII		Pasadena Power Plant	The plant has four units with capacities of 45, 45, 71 and 45 MWe. All four units are in separate braced steel frame structures.	0.2g (H_1) 0.16g (H_2) 0.11 (Vert.)	Millikan Library C.I.T. Pasadena	None	None to piping None to piping condenser	Small tubes	None	Some seismic stop provided on long runs of pipe.
d)	VII		Valley Steam Plant	Four Generating Units with individual generating capacities of 100, 100, 157 and 157 MWe were built in the period 1954-1956. All four units	0.3g (H_1) 0.15g (H_2) 0.18g (Vert.)	8244 Orion Blvd. Los Angeles, CA	UK			A few circulating water tubes in condenser were ruptured.	

Earthquake	Mag. Site MMI	Date	Facility	Facility Des.	Estm. PGA @ Site g	Location Nearest Ground Motion Record	Damage Cat.	Damage Location	Pipe Size	Damage Description	Seismic Design Basis of Pipe
4. Point Mugu	5.9	1973									
a) (1)	VII		Ormond Power Plant	2 unit fossil fueled power plant; total generating capacity of 1500 MWe.	0.20g	11 miles from the epicenter.	INTER	Various	NA	Various insulation was dented. Four 75 ft. vertical run steam pipes in Units 1 & 2 collided with nearby catwalks & structural steel members. Deflections of up to 13" were noted at impact points.	Structures-0.20g static Equipment-anchored for 0.20 g static overturning forces. Piping-most piping designed for gravity loads only. A few braces and snubbers exist on large diameter pipes.
(2)							LOAD	-	-	One snubber buckled its support rod to 20° angle.	-

Earthquake	Mag. Site MMI	Date	Facility	Facility Des.	Estm. PGA @ Site g	Location Nearest Ground Motion Record	Damage Cat.	Damage Location	Pipe Size	Damage Description	Seismic Design Basis of Pipe
.. Ferndale a)	5.5 VII		Humboldt Bay	2- Units are fossil fueled; one unit is nuclear; total generating capacity up 167 MWe	0.35g (H_1) 0.26g (H_2) 0.16 (Vert.)	On site	NONE	-	-	None	Units 1 and 2 structures and selected large bore pipe - 0.2g static; Unit 3 - 0.25g OBE, 0.50g SSE dynamic (Housner Spectra)

Earthquake	Mag. Site MMI	Date	Facility	Facility Des.	Estm. PGA @ Site g	Location Nearest Ground Motion Record	Damage Cat.	Damage Location	Pipe Size	Damage Description	Seismic Design Basis of Pipe
6. Imperial Valley	6.6	1979									
a) (1)	VII		El Centro Steam Plant	4 unit fossil fueled power plant; total generating capacity of 182 MWe.	0.51g (H_1) 0.37g (H_2) 0.93g (Vert.)	On site from 0.2 miles from units.	SAM at threaded connect	Grade Elevation in pump-house	Small bore	An unanchored filter slid, causing the failure of a small attached line.	Unit 4-0.2g static; other units probably similar. Some snubbers and seismic stops exist on the main steam lines.
(2)							SAM	Grade Elevation on Ground	NA	A steel storage tank rocked, causing failure to an unattached pipe.	
(3)							CORR	Generator Cooling Water	3" & 4"	Some 3"-& 4" generator exciter cooling & hydrogen cooling water lines cracked apparently at corroded or previously weld-repaired areas in Units 3 to 4 leakage was minor	

Earthquake	Mag. Site MMI	Date	Facility	Facility Des.	Estm. PGA @ Site g	Location Nearest Ground Motion Record	Damage Cat.	Damage Location	Pipe Size	Damage Description	Seismic Design Basis of Pipe
(4)							INTER	This flexible line was on the mezzanine level just above the turbine deck.	4"	The cast iron yoke of an AOV operator on a 4" steam supply line to the evaporator failed due to impact with a steel column 2" away.	
(5)							INTER	Various	8" & 12"	Unit 4 main steam lines were dented due to impact with building structure.	

Earthquake	Mag. Site MMI	Date	Facility	Facility Des.	Estm. PGA @ Site g	Location Nearest Ground Motion Record	Damage Cat.	Damage Location	Pipe Size	Damage Description	Seismic Design Basis of Pipe
(6)							CONNECT	NA	2"	A two inch component cooling water lined cracked at Victaulic coupling at Unit #4	
7. Humboldt County a) (1)	7.0 VII	1980	Humboldt Bay Power Plant	2-units are fossil fueled; one unit is nuclear; total generating capacity of 167 MWe	0.35g (H_1) 0.26g (H_2) 0.13g (Vert.)	Ground Floor of Unit 3 refueling building	CORR	Welded Connectio n	2"	A pinhole occurred on a boiler feedwater line. Substantial prior wall erosion was evident	Units 1 & 2 Structures and selected large bore pipe - 0.2g .Static. Unit 3-0.25g OBE, 0.5g SSE dynamic (Housner Spectra) Seismic upgrade performed on Units 1, 2, & 3 prior to 1980 Earthquake (R.G.1.60 Spectra)

Earthquake	Mag. Site MMI	Date	Facility	Facility Des.	Estm. PGA @ Site g	Location Nearest Ground Motion Record	Damage Cat.	Damage Location	Pipe Size	Damage Description	Seismic Design Basis of Pipe
8. Whittier a) (1)	5.9 VII	1987	Pasadena Power Plant	4 Unit Gas Fired Power Station. Each Unit has approx. 40 MWe capacity	0.20	Munc. Service Bldg. 533 E. Broadway Glendale	None	-	-	None	-
b) (1)			Glendale Power Plant	4 Unit Gas Fired Power Station. Each Unit has approx. 40 MWe	0.20	Munc. Service Bldg. 533 E. Broadway Glendale	UNK	Circulating Water	Small Bore	Damage of Small pipe in Circulating Water System	-
9. Superstition Hills a) (1)	6.0 VII	1987	El Centro Steam Plant	4 unit fossil fueled power plant; total generating capacity of 182 MWe.	0.27g (H_1) 0.13g (H_2) 0.36 (Vert.)	Imperial County Center 9th & Main El Centro	CORR	Unit 2 Deaerator Threaded Connect-ion	1"	Leakage of 1 inch threaded pipe connection to Unit 2	Unit 4-0.2g static; other units probably similar. Some snubbers and seismic stops exist on the main steam lines
(2)							INTER	Steam Line	12"	Dearator Tank Denting of Insulation on Unit 4 Steam Line	

(1)Strong motion earthquakes are those earthquakes which resulted in a 0.2g or larger PGA at the site.

Notes:

CORR	-	Primary cause of piping or support failure or damage is due to corrosion.
CONNECT	-	Primary cause of failure of piping is loading at a non-ductile piping connection.
INTER	-	Primary cause of piping or support failure or damage is due to spatial interaction (impact or banging) with other piping, structures or equipment.
SAM	-	Primary cause of piping or support failure or damage is due to seismic motion of support or nozzle anchor points of piping.
OTHER	-	Primary cause of piping or support failure is due to causes other than those listed above.
LOAD	-	Primary cause of support failure or damage is load on the support.
UNK	-	Unknown mechanism caused failure or damage.
NONE	-	There was no piping support failure or significant damage due to the earthquake identified.
NA	-	Not available.

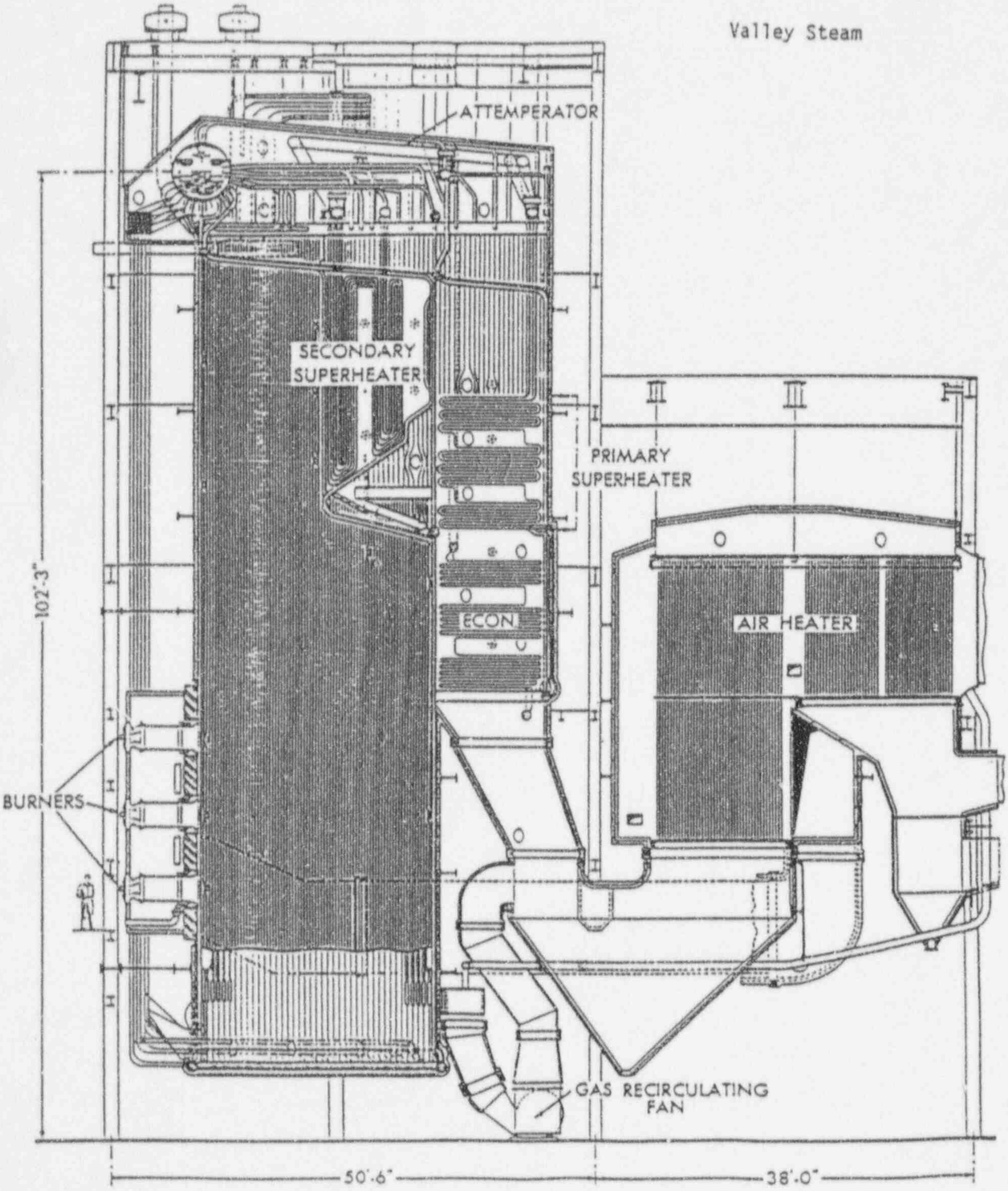

Figure 4.1 Steam Boiler - Units 1 and 2

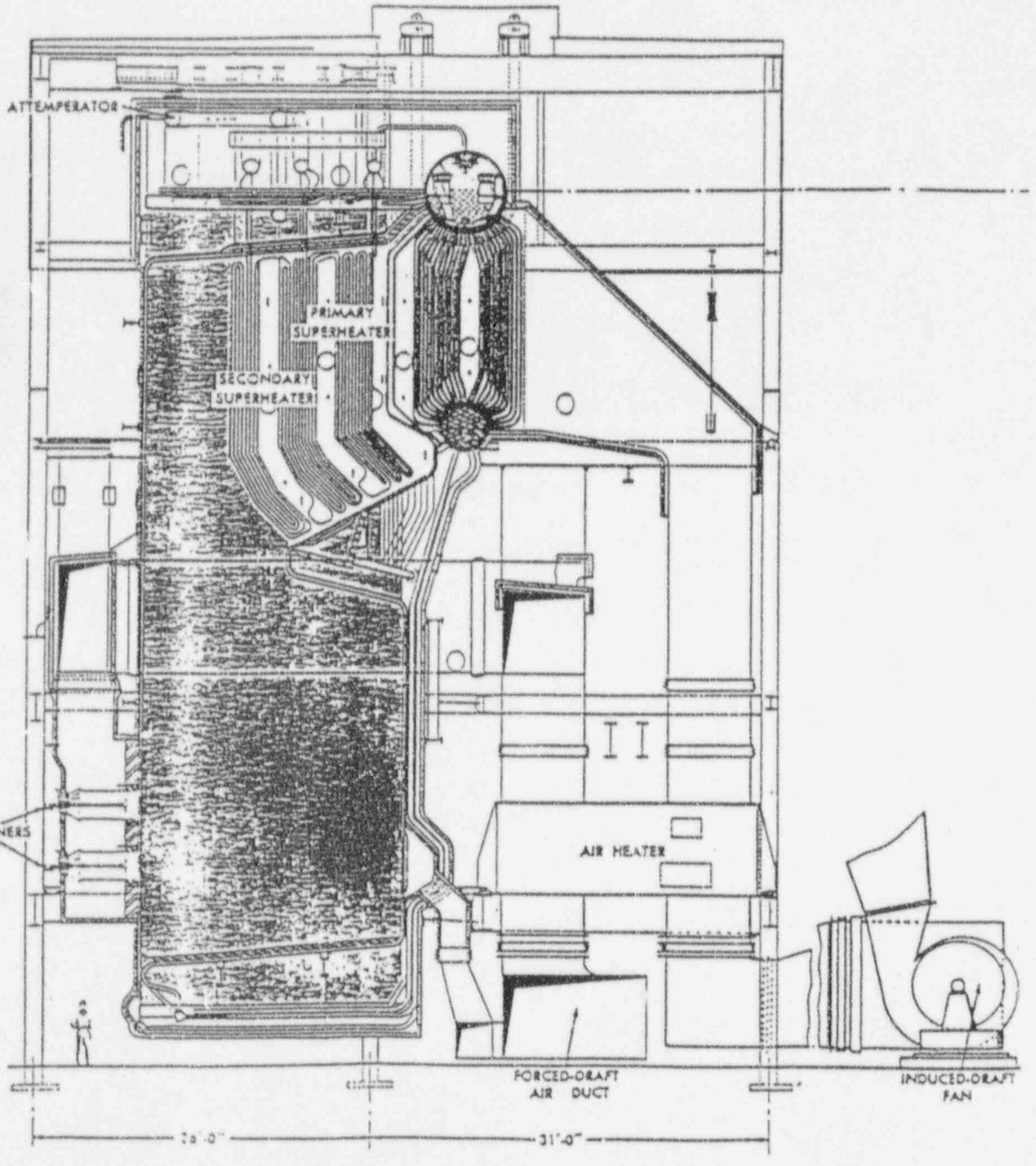

Figure 4.2 Pacific Gas & Electric Company, Humbolt Bay Steam Plant, Buhne Point, Eureka, California B & W Contract No. S-9891

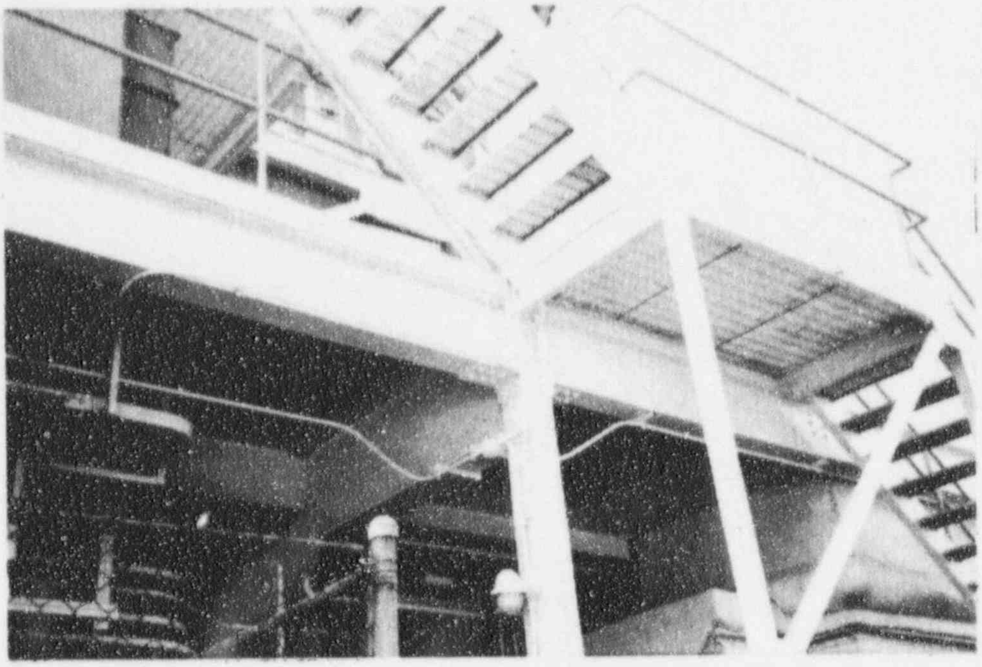

Figure 4.3 Typical Moment Connectors for Building Structural Steel

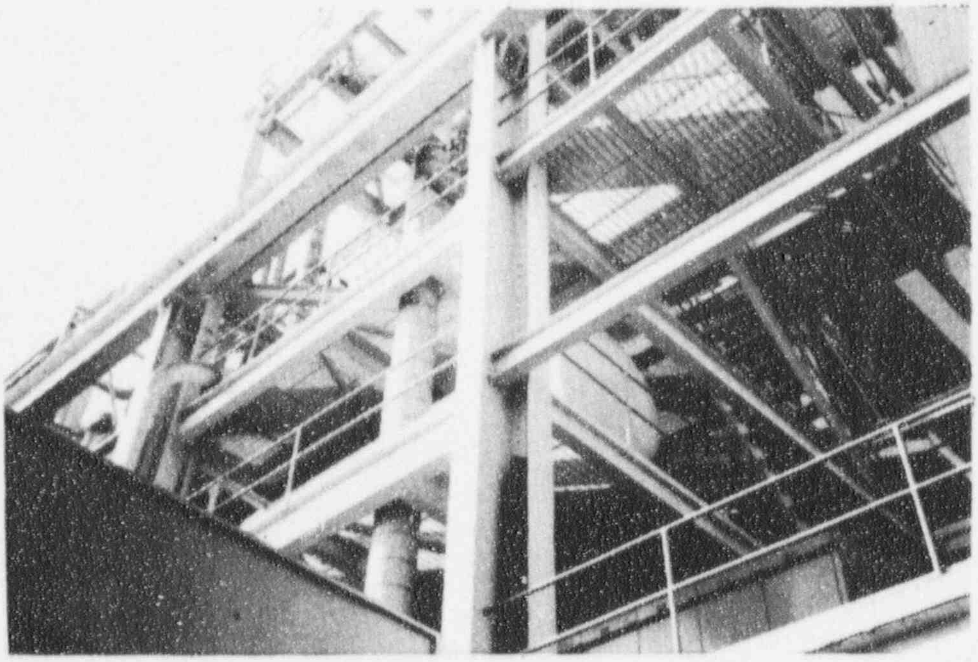

Figure 4.4 Typical Building Framing and Shear Connectors

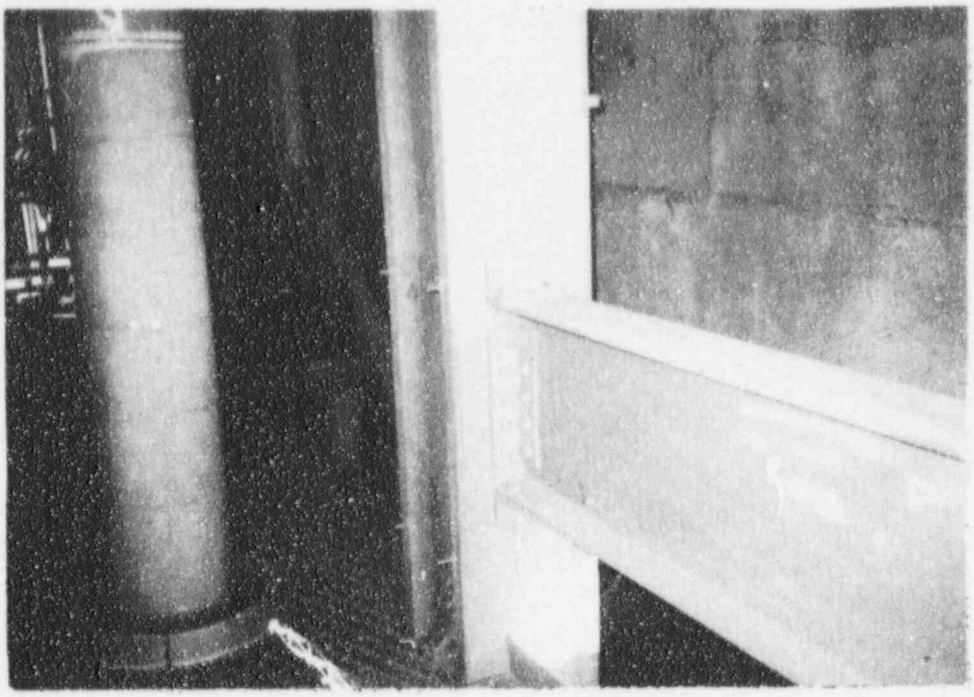

Figure 4.5 Simple Moment Connection for Building Structural Steel

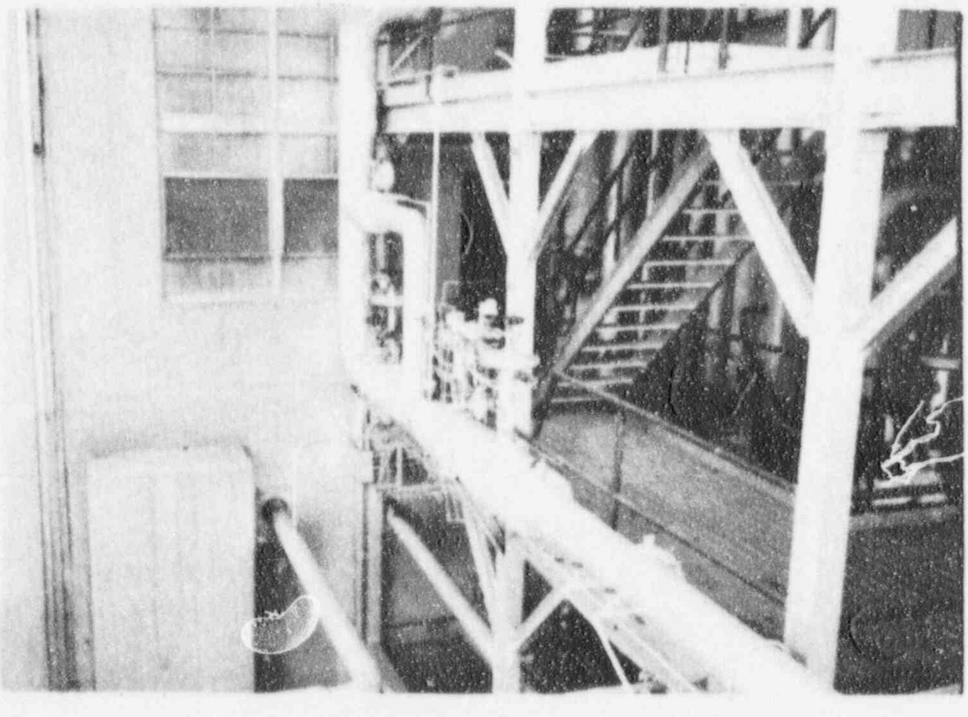

Figure 4.6 Interior Building Structural Steel with Knee Braces

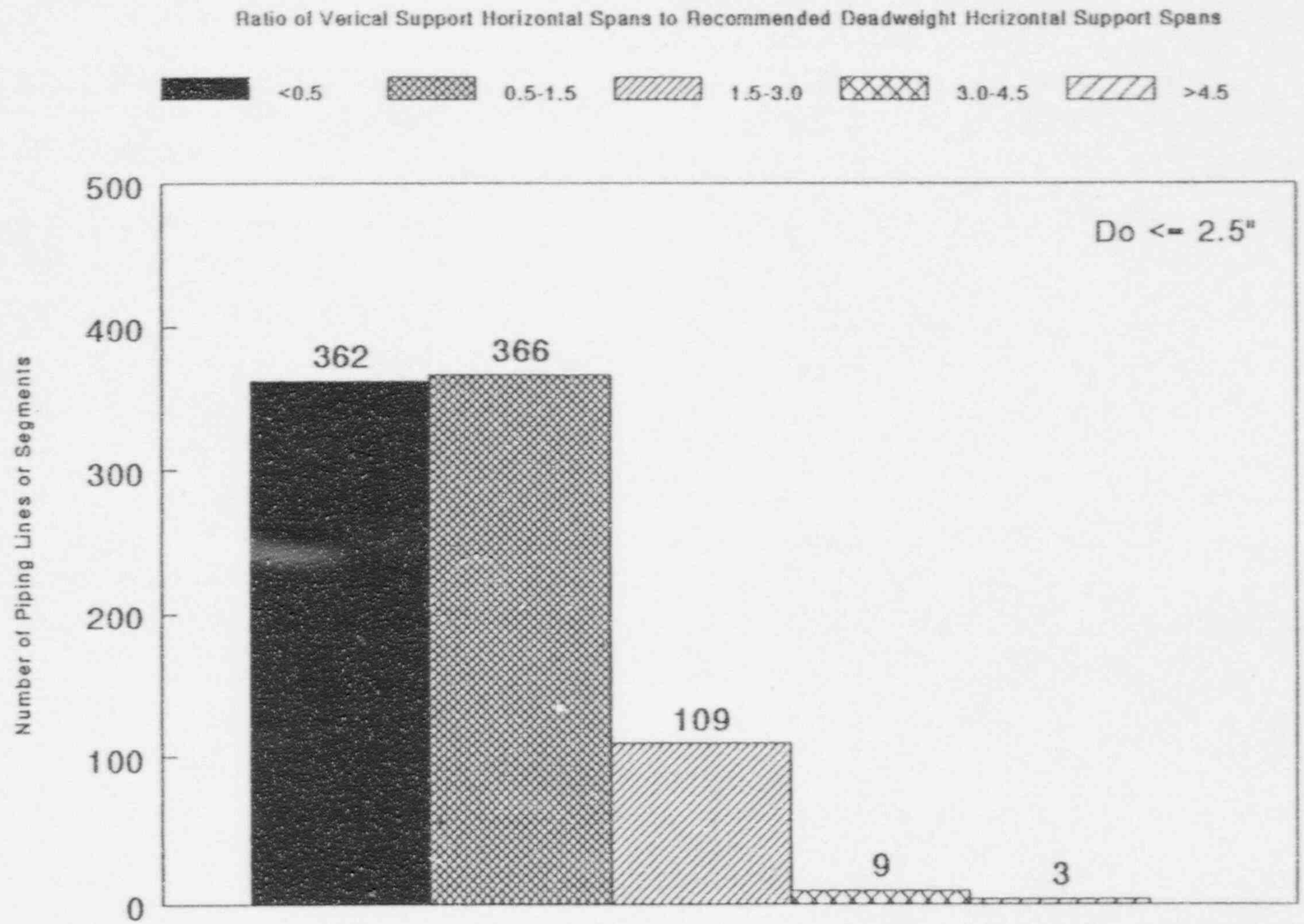

Figure 4.7 Summary of Data Base Experience for Small Bore Piping Horizontal Deadweight Span Ratios Between Vertical Supports

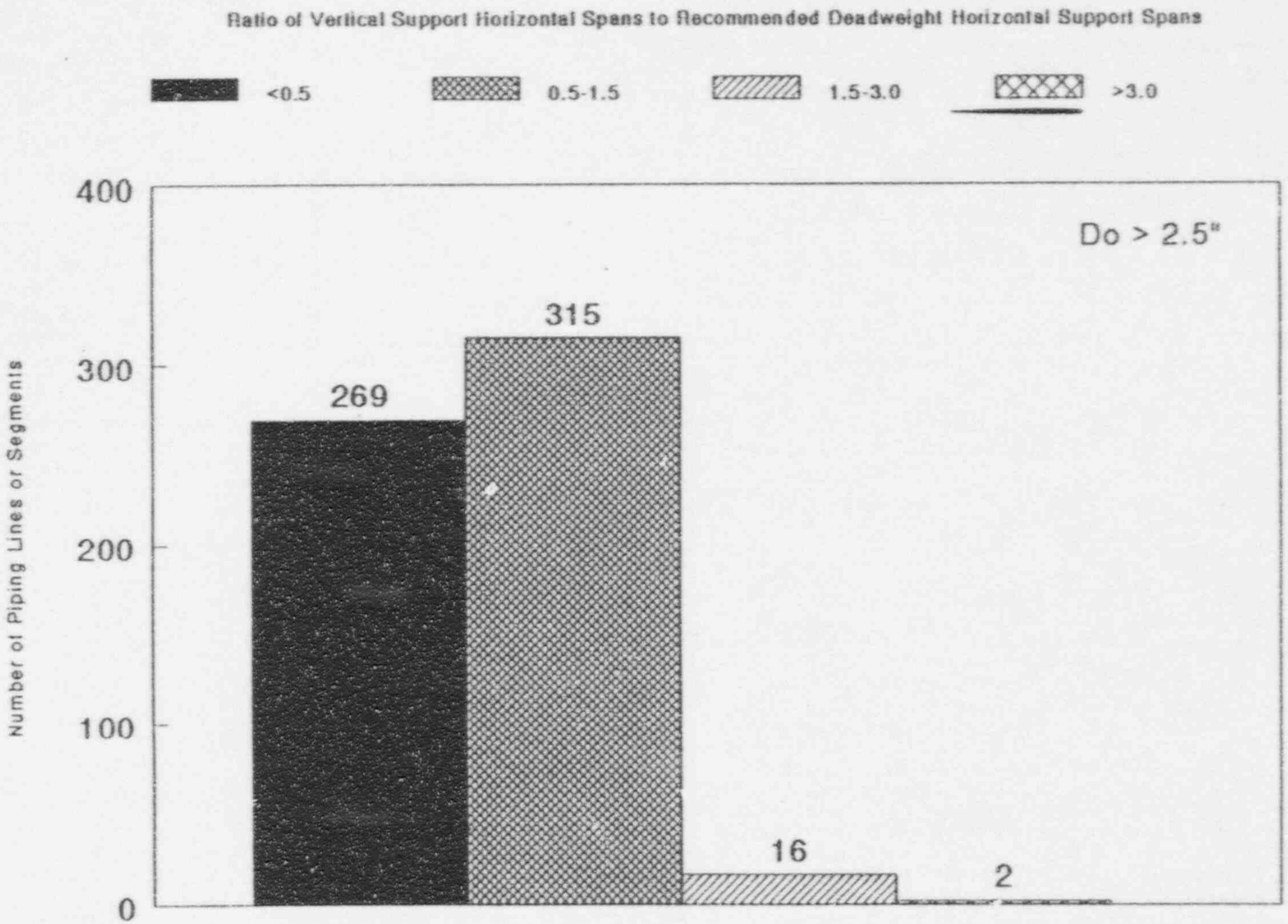

Figure 4.8 Summary of Data Base Experience for Large Bore Piping Horizontal Deadweight Span Ratios Between Vertical Supports

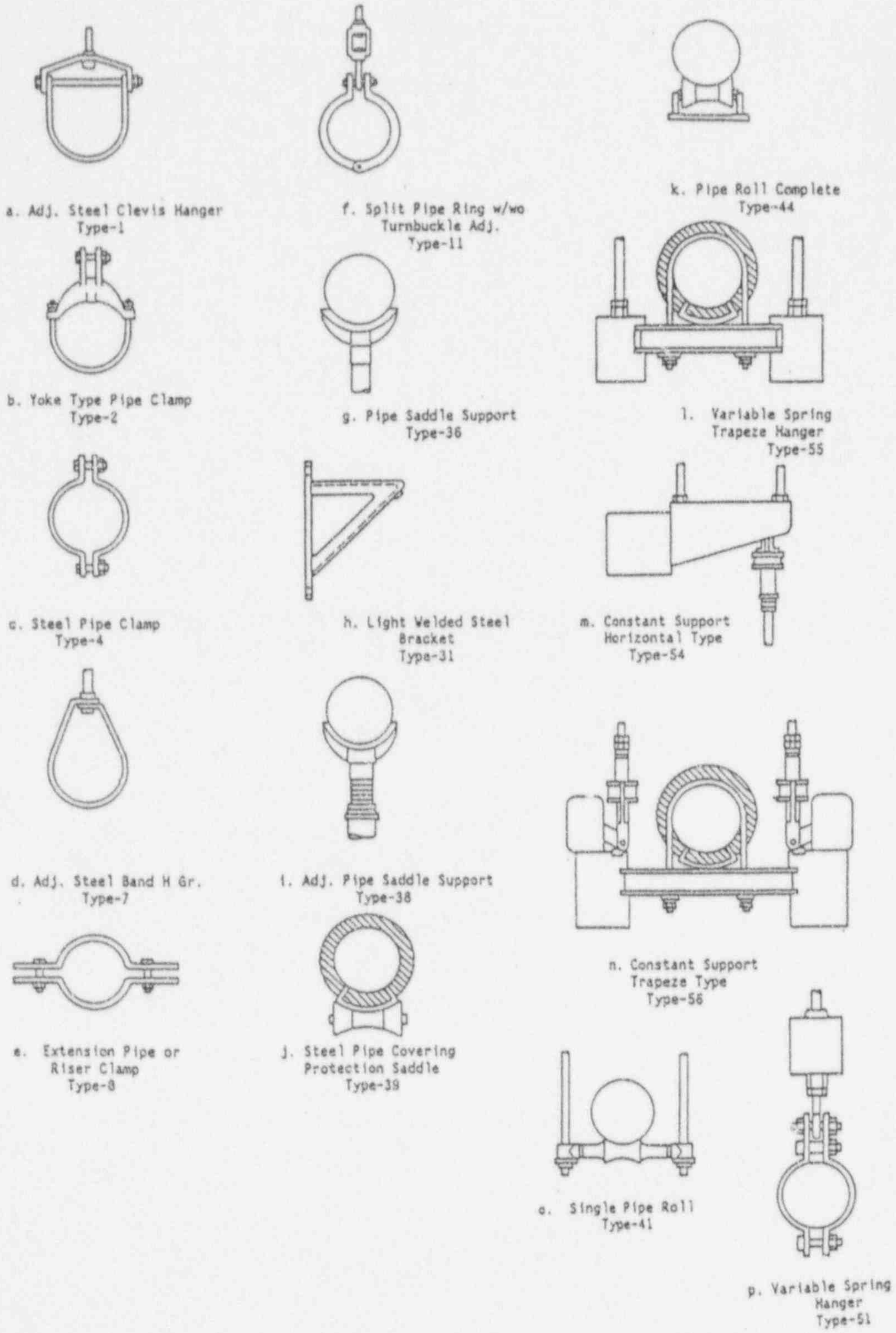

Figure 4.9 Typical Standard Vertical Pipe Supports

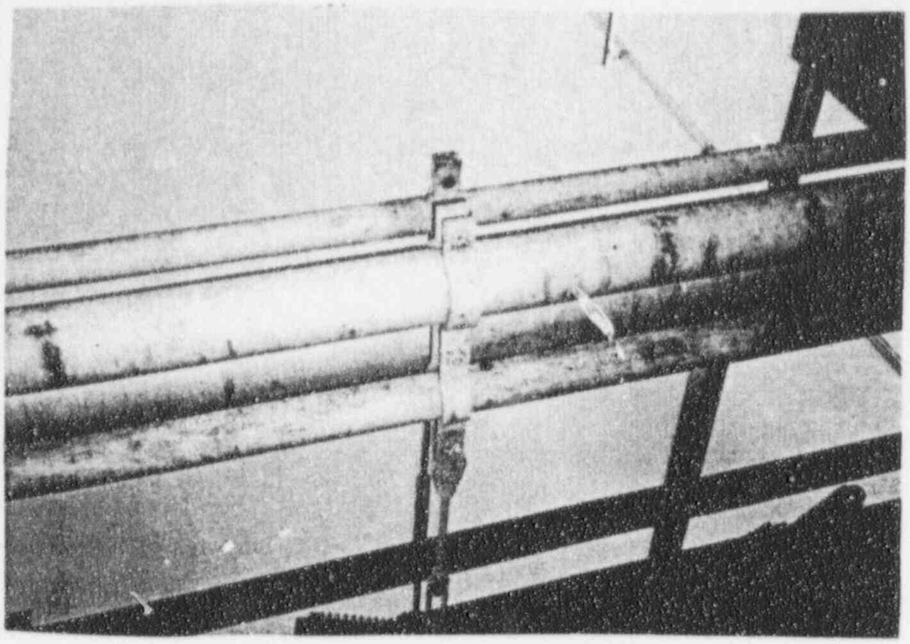

Figure 4.10 Multiple Pipe Supports off the Same Pipe Hanger

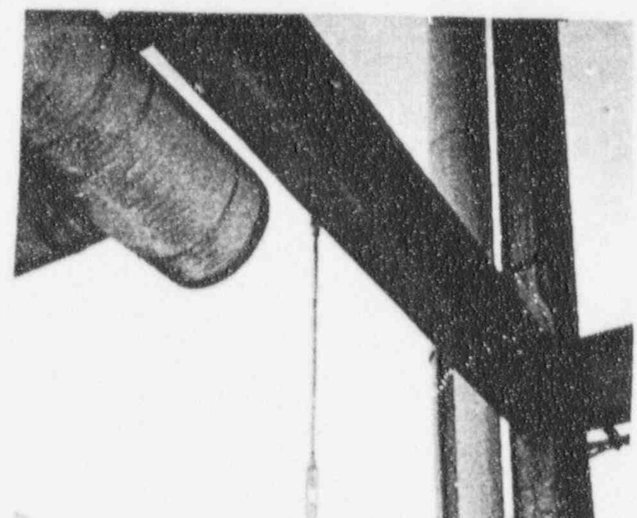

Figure 4.11 Pipe Used to Support Pipe

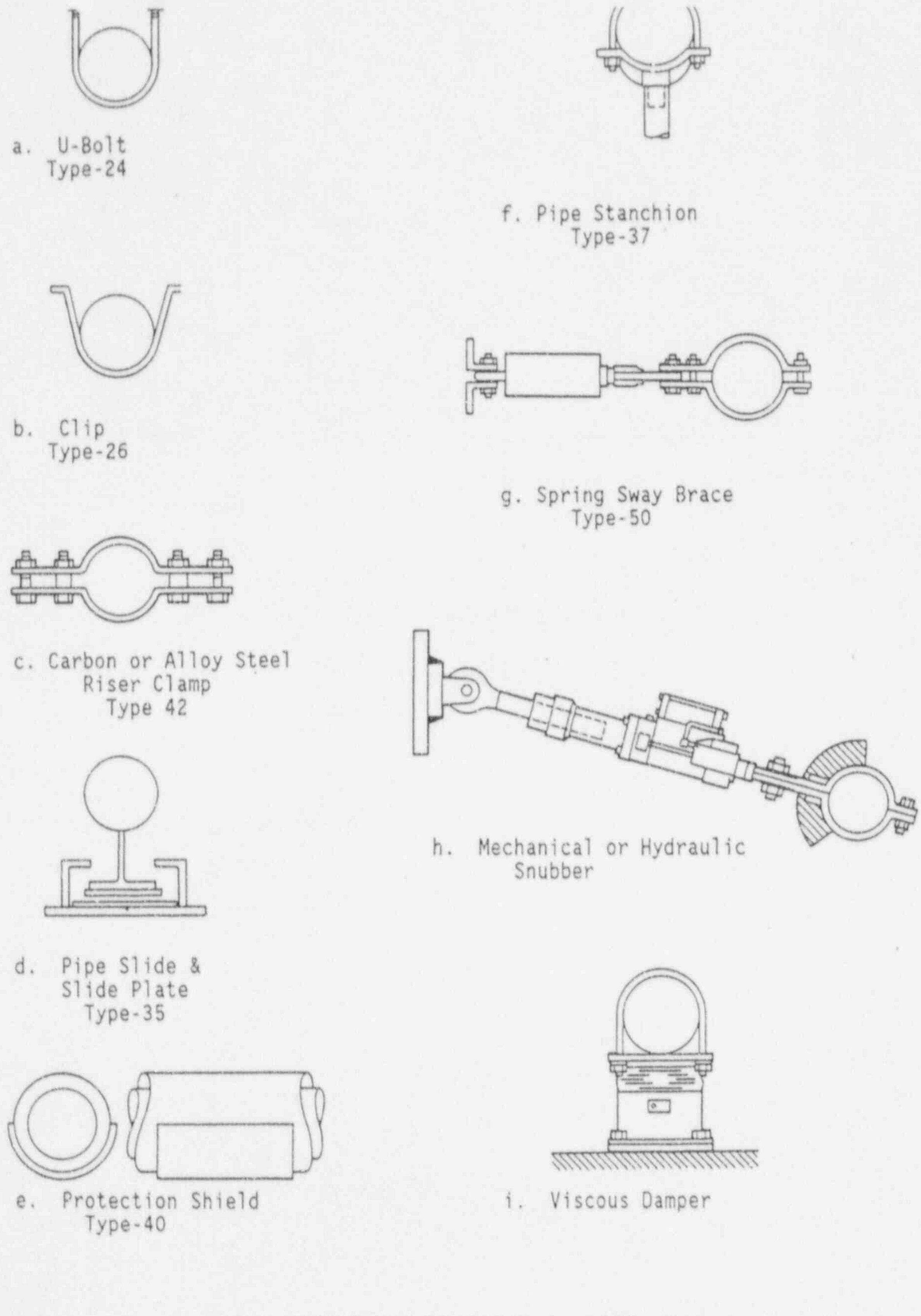

Figure 4.12 Typical Standard Horizontal Pipe Supports

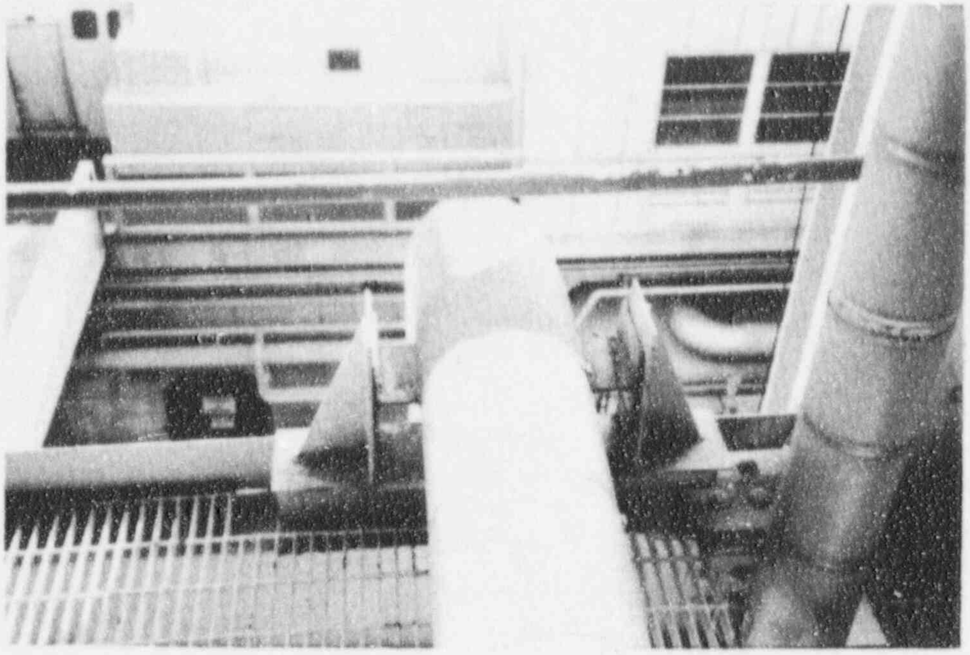

Figure 4.13 Guided Lateral Support (snug)

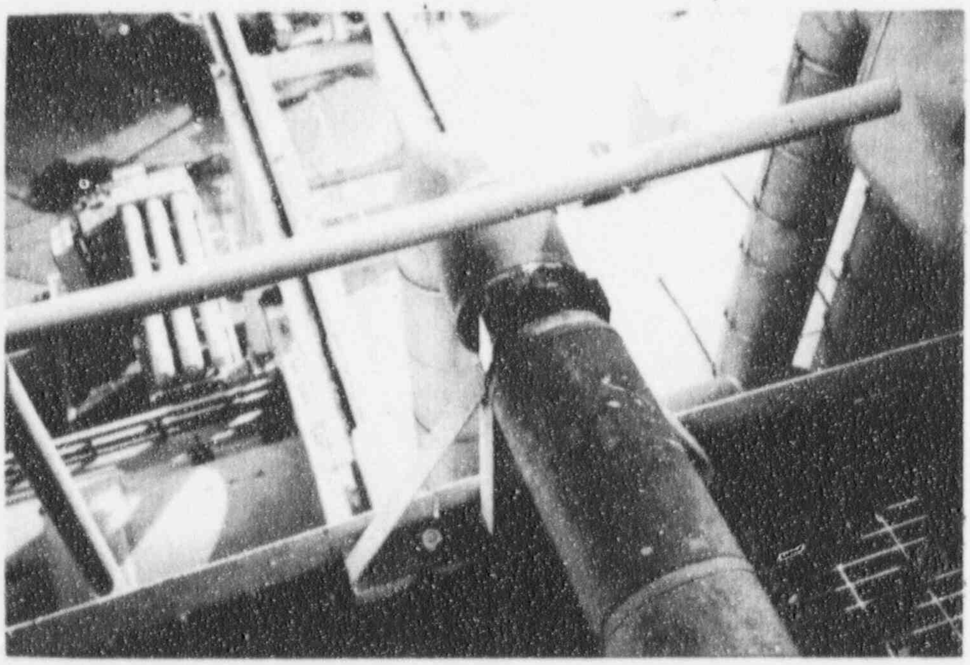

Figure 4.14 Hot Line Guide Support

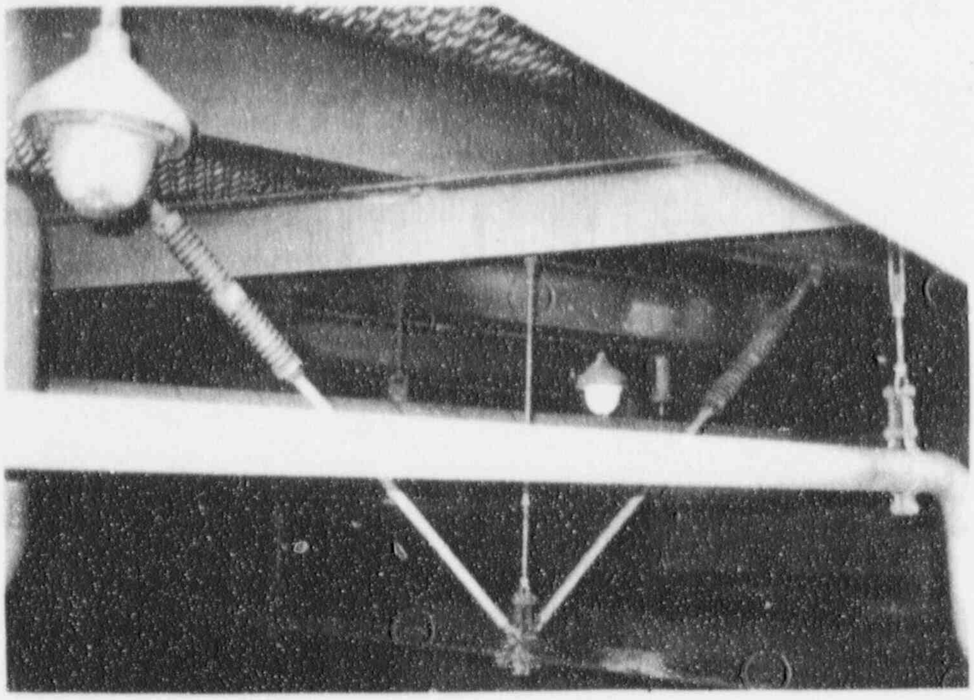

Figure 4.15 Combined Vertical Support and 45 Degree Angle Sway Brace

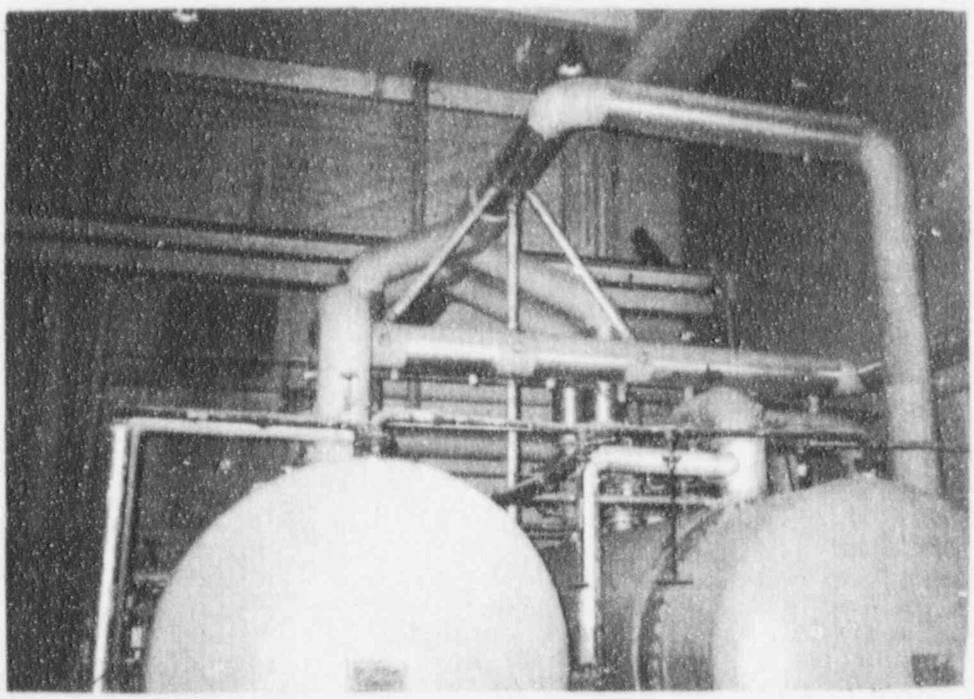

Figure 4.16 Lateral Support of Pipe Off Another Pipe

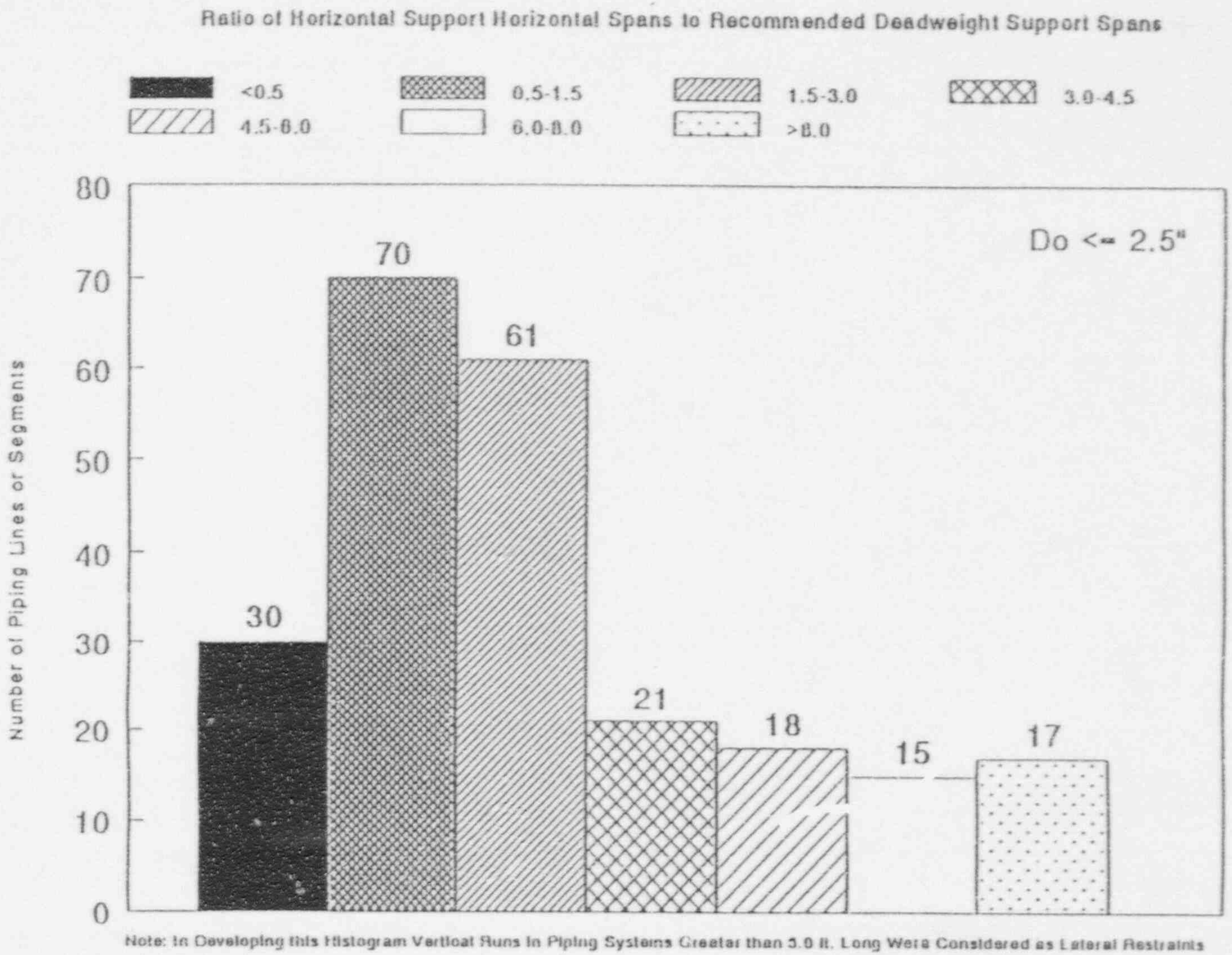

Figure 4.17 Summary of Data Base Experience for Small Bore Piping Horizontal Deadweight Span Ratios Between Lateral Supports

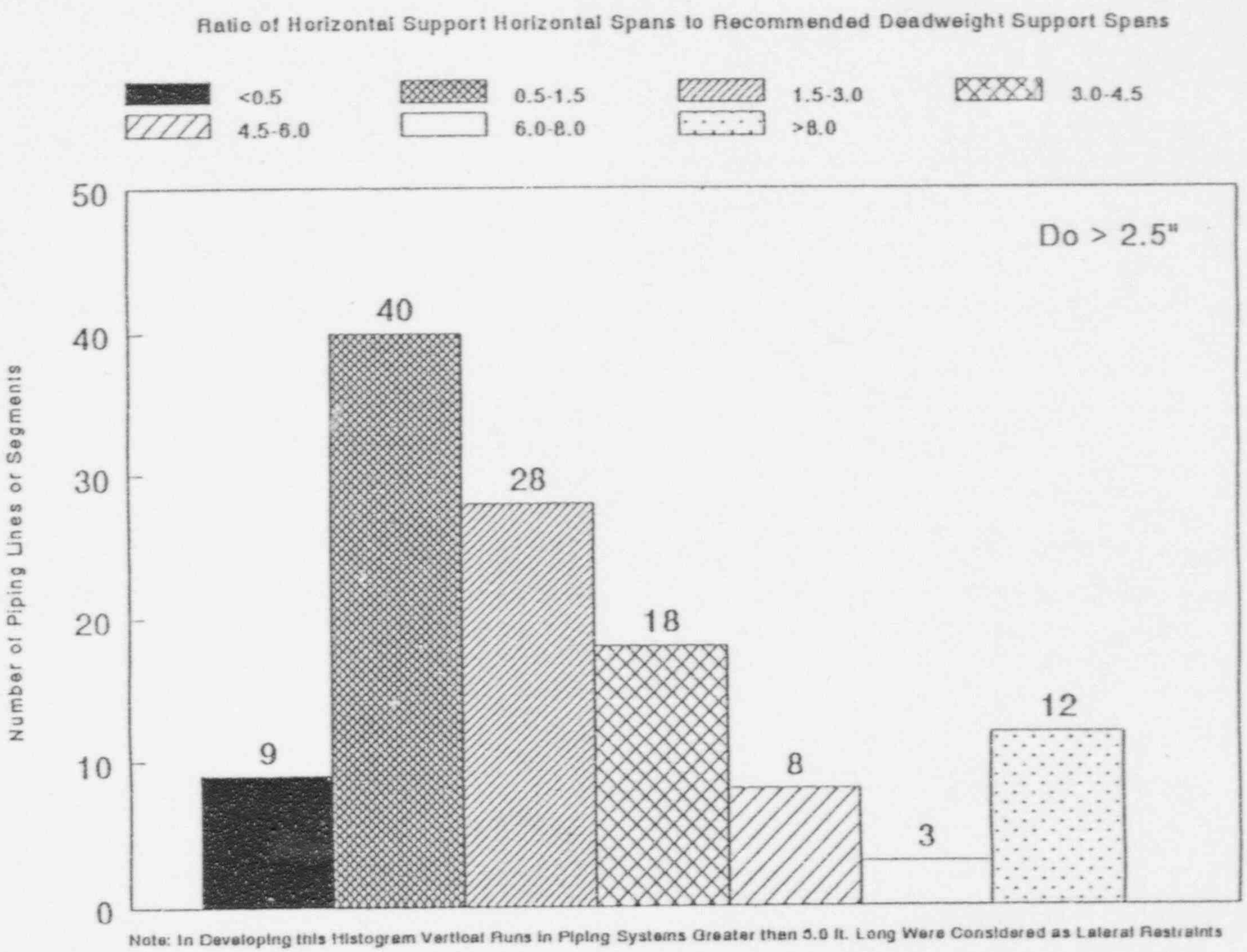

Figure 4.18 Summary of Data Base Experience for Large Bore Piping Horizontal Deadweight Span Ratios Between Lateral Supports

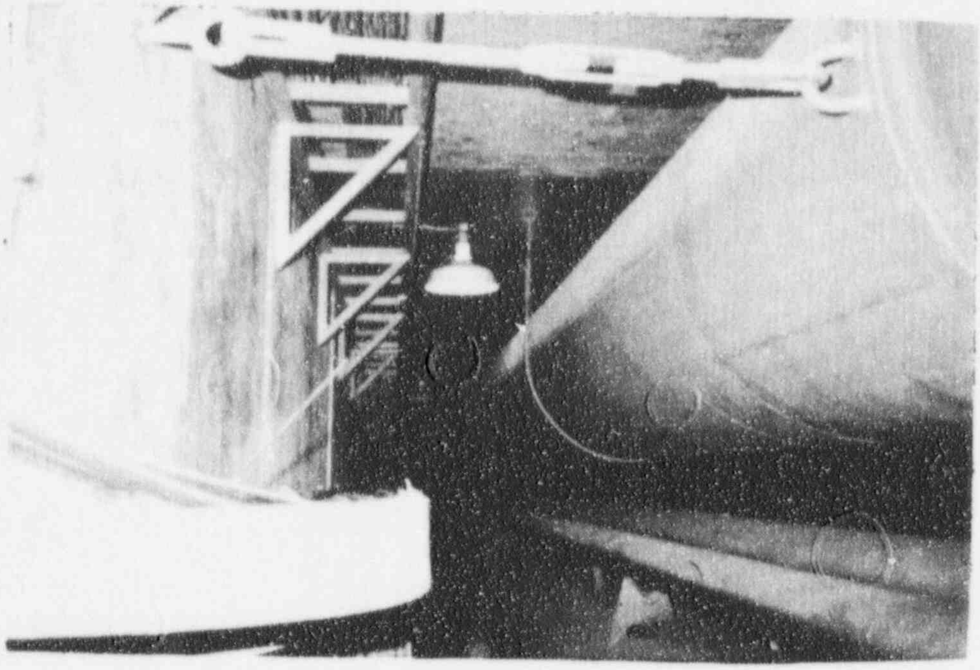

Figure 4.19 Small Branch Line Rigidly Connected to Main Coolant Pipe Which Ruptured at Connection to Pipe

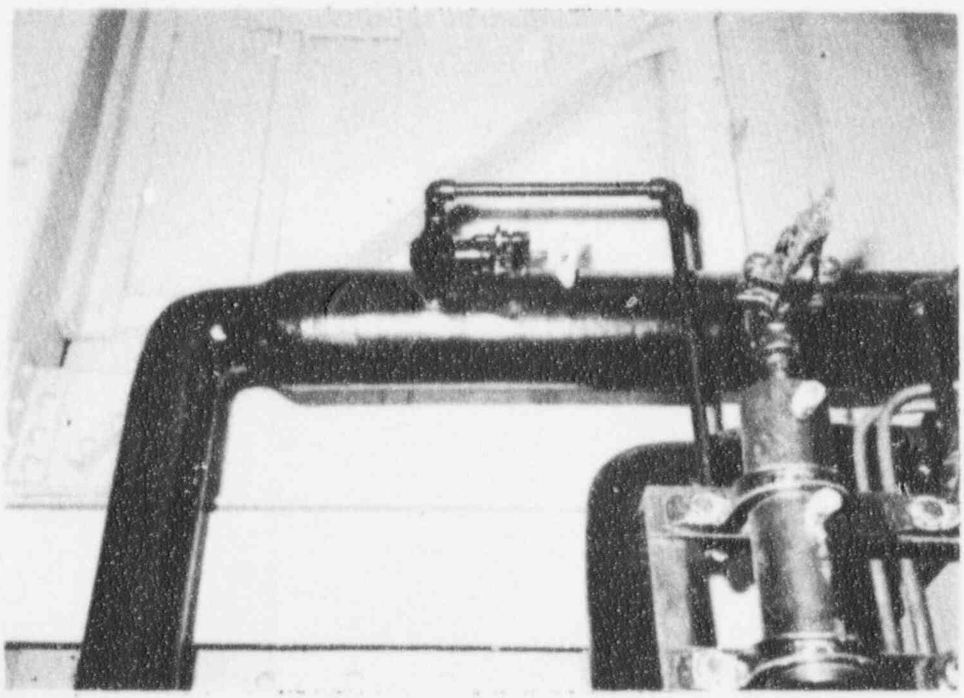

Figure 4.20 Broken Branch Oil Line at Connection to Main

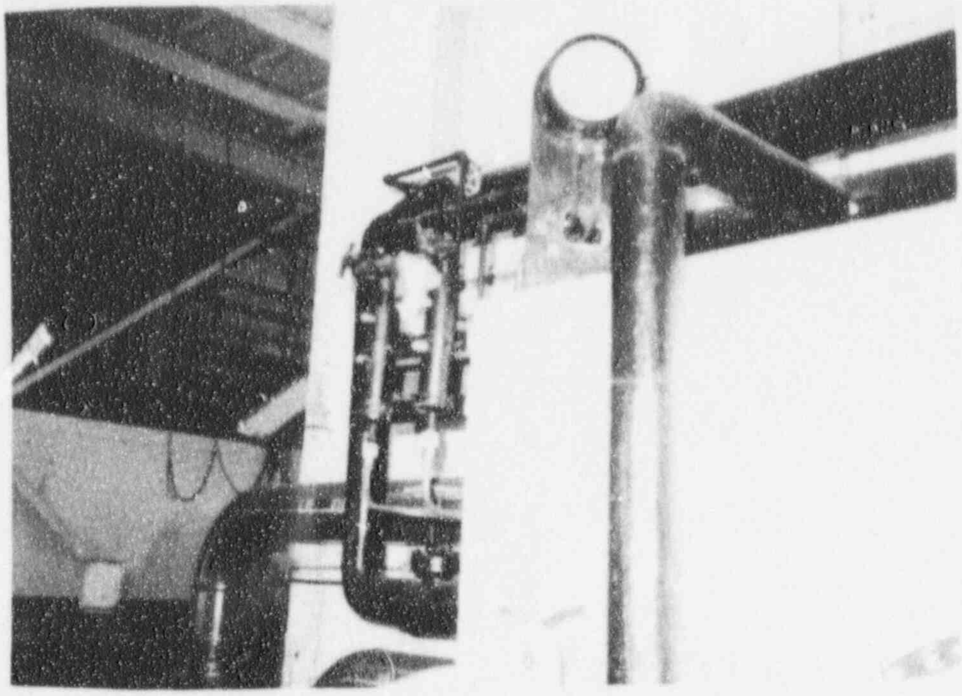

Figure 4.21 Broken Branch Oil Line at Connection to Main

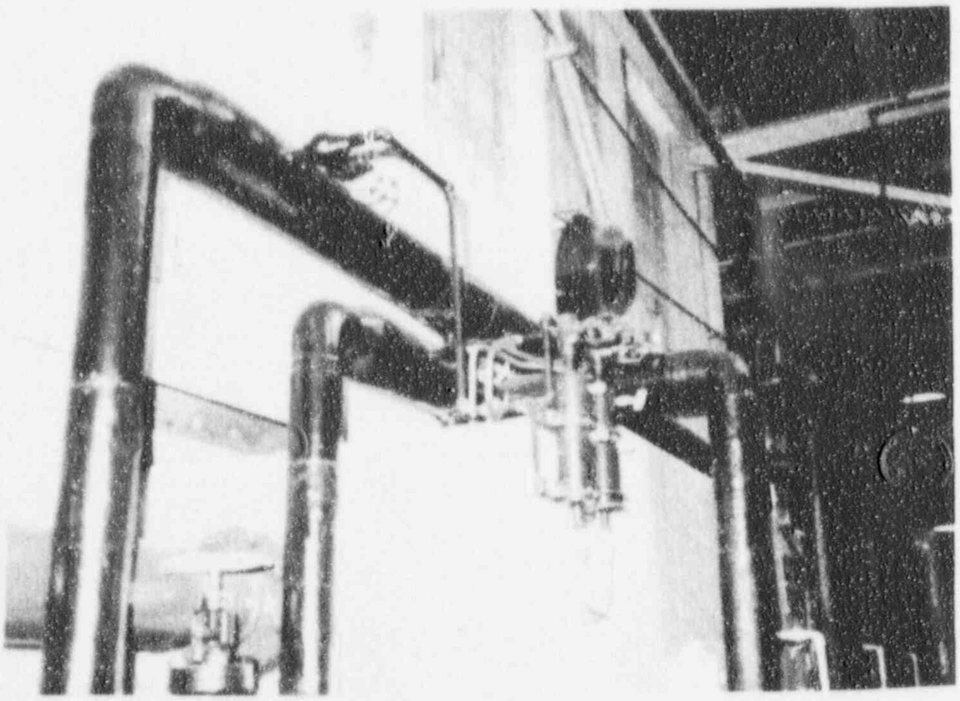

Figure 4.22 Broken Branch Oil Line at Connection to Main

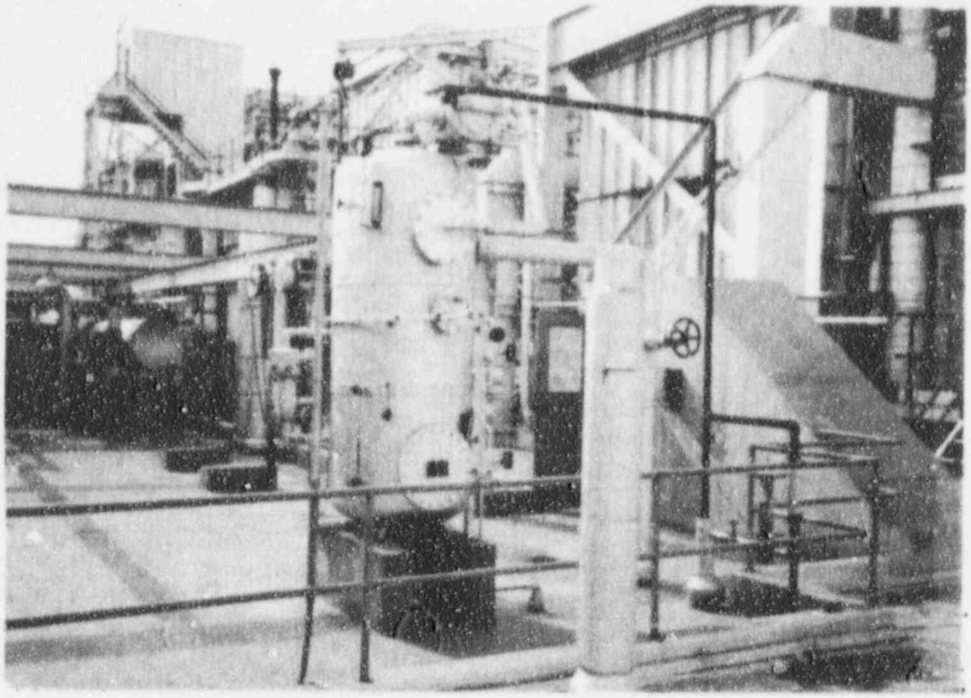

Figure 4.23 Broken Connection of Threaded Line to Tank

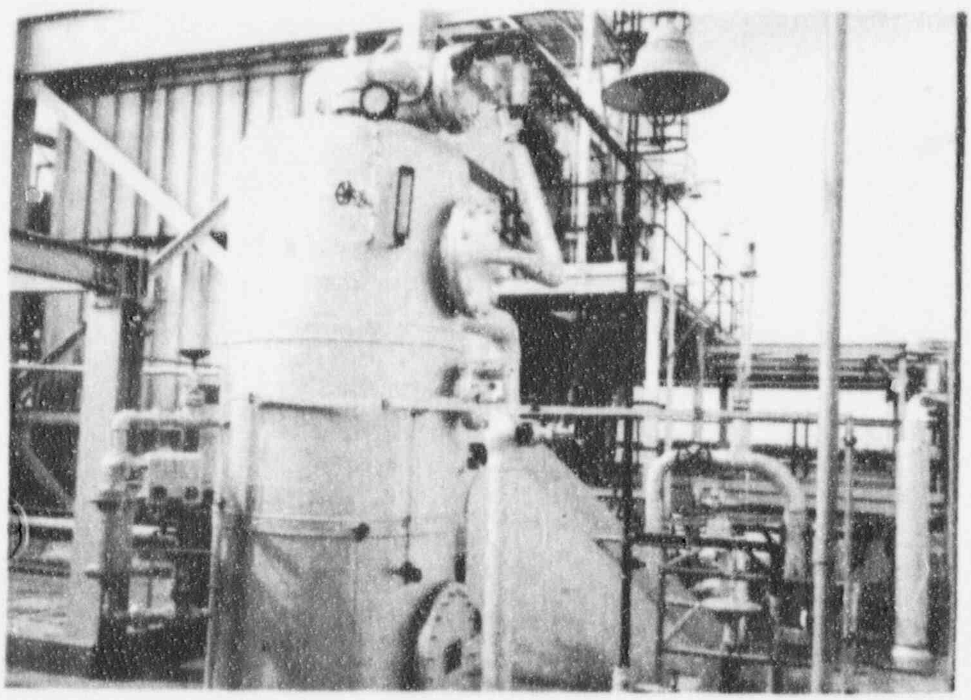

Figure 4.24 Broken Connection of Threaded Line to Tank

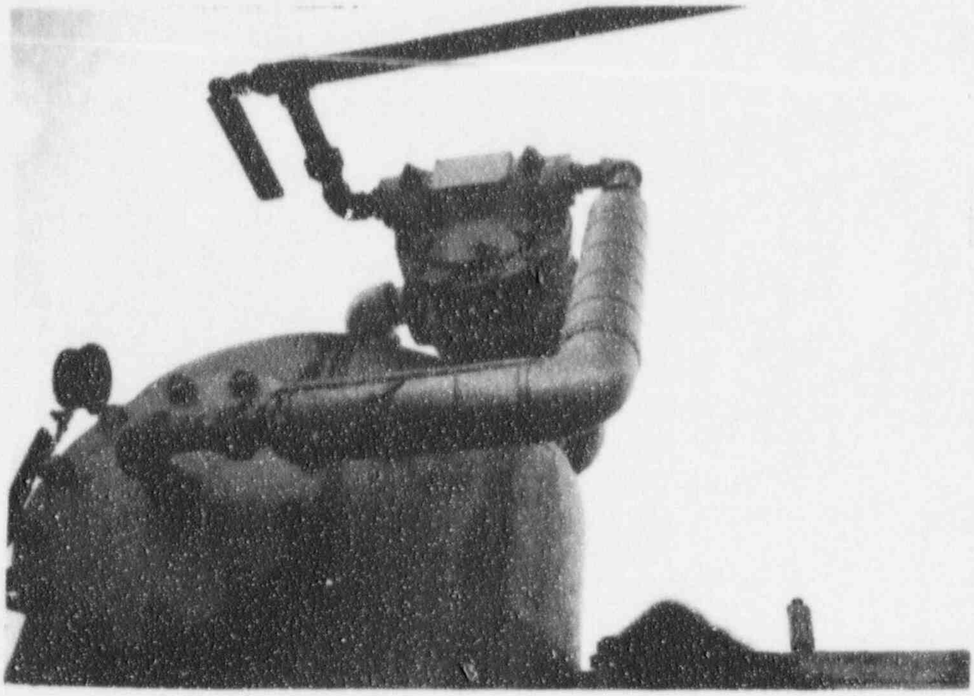

Figure 4.25 Broken Connection of Threaded Line to Tank

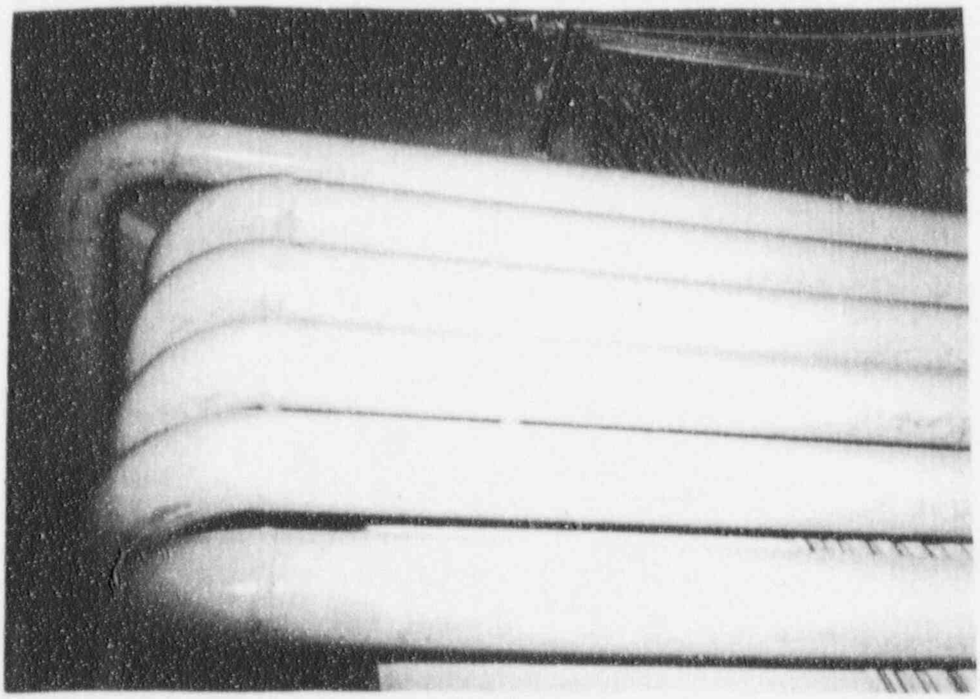

Figure 4.26 Broken Hydrogen Cooling Line in Region of Weld Repair

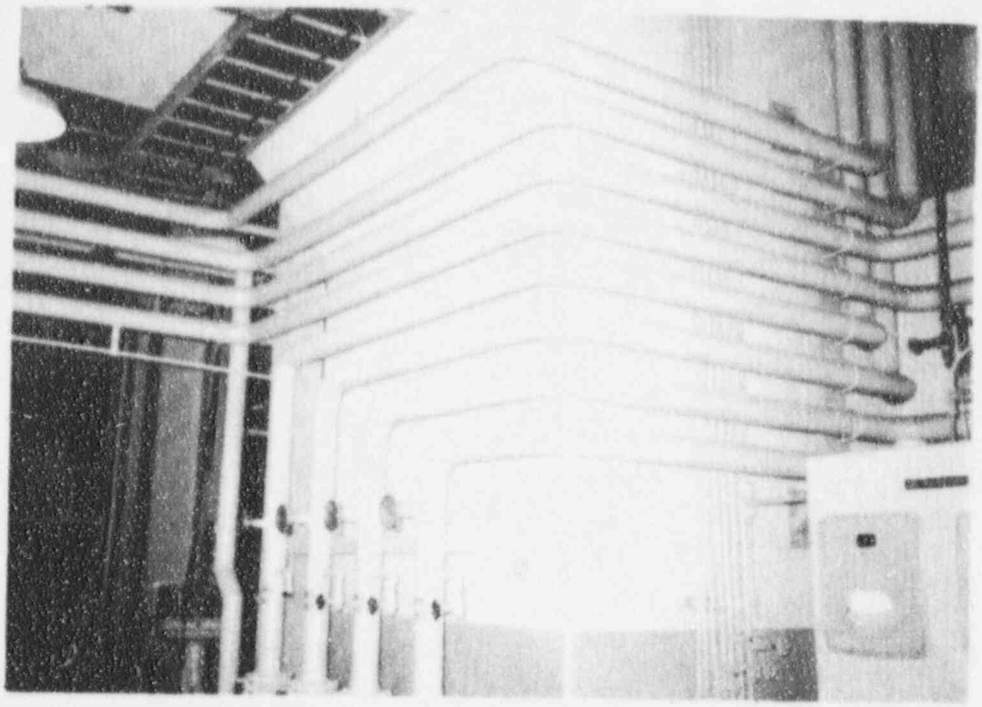

Figure 4.27 Broken Hydrogen Cooling Line

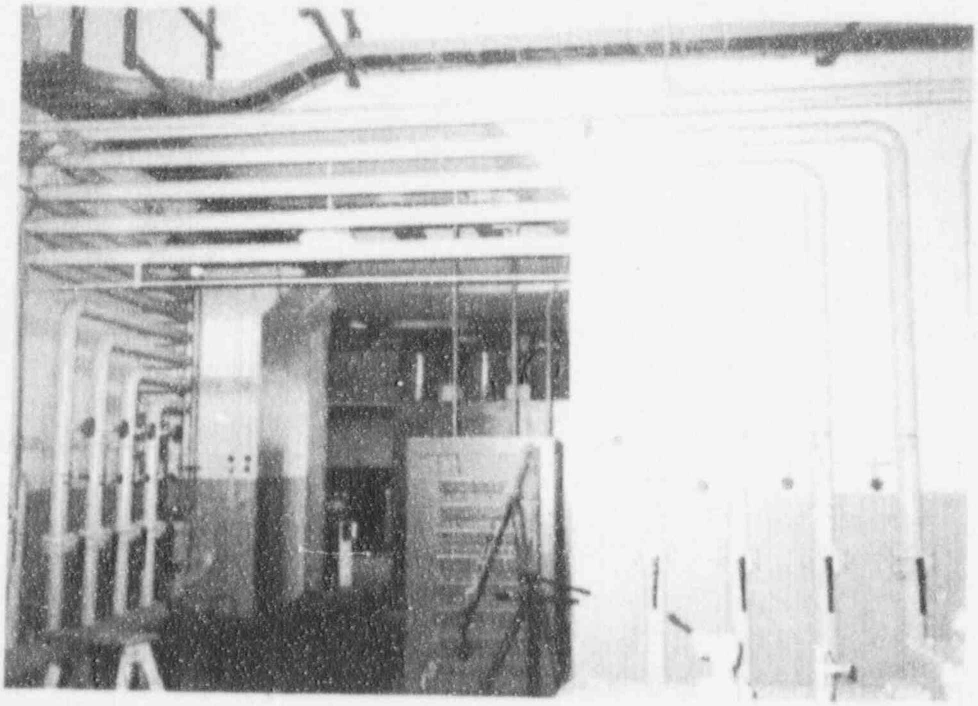

Figure 4.28 Broken Hydrogen Cooling Line

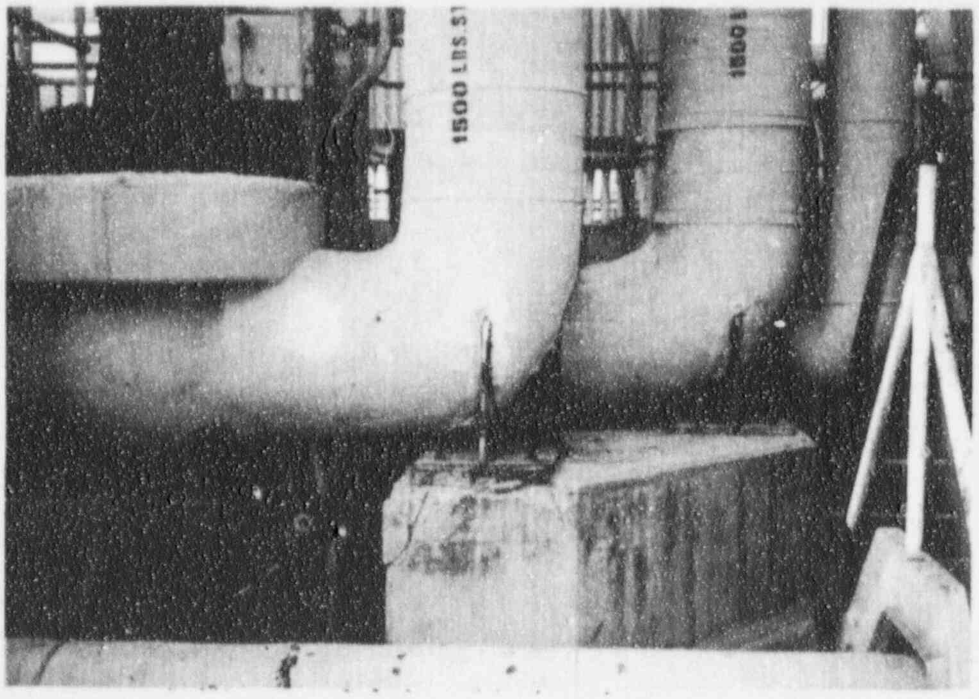

Figure 4.29 Damage Pipe Support Concrete Block at Elbow

5 Summary of Plant Specific Earthquake Response of Piping

5.1 Burbank Power Plant

5.1.1 Plant Description

The Burbank Public Service Department presently operates two steam power plants designated the Magnolia and Olive plants with four operating units each. The plants are located on the eastern edge of the central San Fernando Valley on a flat alluvial site as discussed in more detail in Appendix G.

The total continuous net capability for both plants is currently 226 MWe on oil and 233 MWe on gas. Operable generating units on the Magnolia-Olive site are:

Table 5.1 Burbank Power Plant Operating Characteristics

Unit	Type	Net Continuous Capability Oil	Net Continuous Capability Gas	Installed
Magnolia Plant				
M-2	Steam Turbine (Combined Cycle)	-	-	1943
M-3	Steam Turbine	20 MW	20 MW	1949
M-4	Steam Turbine	28 MW	30 MW	1953
M-5	Combustion Turbine	17 MW	17 MW	1969
		76 MW*	78 MW	
Olive Plant				
0-1	Steam Turbine	42 MW	42 MW	1959
0-2	Steam Turbine	58 MW**	60 MW**	1964
0-3	Combustion Turbine	19 MW	22 MW	1972
0-4	Combustion Turbine	31 MW	31 MW	1975
		150 MW	155 MW	

**Includes 5 MW available from the Olive 3 heat recovery steam generator. The M-3, M-4 and 0-1 and 0-2 units are of particular interest because they are steam turbine units having piping which is more characteristic of nuclear power plants and 0-3 and 0-4 were not in existence at the time of the San Fernando earthquake. The 0-2 unit includes a 55 KW turbine generator with reheat. The initial steam design pressure and temperature is 1450 psig and 1000° F with the reheat temperature also 1000° F. The boiler has a maximum steam capacity of 440,000 Lbs/hr.

The Magnolia and Olive Units consist of steel-framed boiler structures, concrete turbine- steam generator pedestals, and a two-story concrete masonry control building that houses the switchgear and control rooms.

5.1.2 Seismic Design Basis of Piping

The Olive and Magnolia Units plant structures were designed for an equivalent static horizontal force of 0.20g. The design of equipment in the plant included no particular seismic design considerations other than normal floor anchorage based on operating requirements.[4] Piping is primarily rod-hung for dead-weight support only. Generally, no provision for lateral restraint of piping was found.

The technical specification used for procurement of piping for the most recent steam turbine plant (Olive 2, 1964) is shown in Appendix C. It should be noted that the piping contractor was to supply all hangers, supports etc. to B31.1, MSS-58, and AISC requirements. No mention was made of seismic requirements. The line list for the Olive 2 Unit is shown in Table 4.3 of this report.

5.1.3 Earthquake Induced Damage to Piping

5.1.3.1 Olive Plant

The following piping and related damage was noted at the Olive Plant:

1. A broken valve and pipe at the demineralizer tank

5.1.3.2 Magnolia Plant

The following piping and related damage was noted at the Magnolia Plant.

1. A demineralized-water tank in the plant yard was not anchored and shifted, breaking attached piping connections near the base of the tank.

2. A fuel-oil gage line in Unit 3 broke.

3. A 2-inch-diameter pipe connecting to the Unit 3 main cooling-water line cracked. (The plant operators though this crack resulted in a minor leak since it did not impair restarting the plant.)

5.2 El Centro Power Plant

[4]Normally any rotating or reciprocal operating equipment would be bolted down in order to resist starting torques or reactions during normal operation. Such positive anchorage would normally be sufficient to resist earthquake effects up to a level to cause significant structural damage and failure of the building structure supporting and housing the equipment.

5.2.1 Plant Description

The El Centro Power Plant is the principal electric power generating facility of the Imperial Irrigation District. The facility consists of four units that burn oil or natural gas. Units 1, 2, and 3 which are 20 MWe, 30 MWE and 44 MWe size units respectively were designed by Gibbs and Hill, and were built in 1949, 1952, and 1957. Unit 4 an 80-MW facility designed by The Fluor Corporation, Ltd. was built in 1968. A more detailed description of the El Centro Plant and its general response to the El Centro - 1979 and Superstition Hills - 1987 can be found in Appendix H.

5.2.2 Seismic Design Basis of Piping

According to the engineering-design and construction completion report by Fluor Corporation, the original seismic design of Unit 4 as follows:

> "The architectural and structural treatment of the building, with minor modifications dictated by variations in size and arrangement of equipment, was carried out in general conformity with criteria established for the previous three units. The building frame was of the rigid frame structural steel type of design. The framing was designed to handle specified loads and to resist stresses from earthquake shocks equivalent to a horizontal force of 0.2 of live and dead weights supported."

It was assumed that this force was applied to the center of gravity of the live and dead weights, and then transferred to the structure and foundation.

The equipment procurement specifications read:

> "The area is also subject to seismic disturbances, and all equipment supplied shall be designed to resist seismic forces of 0.2 magnitude."

This suggests the piping may have been designed for a 0.2g static lateral load. However, in general there are few lateral restraints provided on installed piping.

5.2.3 Earthquake Induced Damage to Piping - El Centro 1979

No high temperature or high pressure piping failed during the earthquake. However, a Victaulic coupling on a straight section of a 2 inch diameter cooling water line was damaged. Additionally, 3 and 4 inch diameter water treatment and hydrogen cooling water lines in Units 3 and 4 failed in straight runs in areas which had been either weld repaired or excessively corroded. Circumferential cracks were observed in these corroded lines, which were apparently caused by the earthquake.

Another piping failure resulted from movement of an unanchored pumphouse filter in Units 1 and 2. Movement of the filter caused failure of a small threaded pipe.

The yoke of an air-operated valve on a steam-supply line to the evaporator failed. It was located on the mezzanine, above the turbine deck. The yoke failure was attributed to repeated impact of the valve operator with an adjacent building girder.

5.2.4 Earthquake Induced Damage to Piping - Superstition Hills -1987

A minor leak opened in a 1 inch pipe line where a threaded joint connected to the Unit 2 deaerator tank. This failure was probably caused by the effects of corrosion at the threaded joint connection. Insulation on a steam line in Unit 4 was dented by an adjacent pipe. The unit had been in operation during the 1979 earthquake when interaction of the same two lines had caused a similar dent in the insulation.

5.3 Glendale Power Plant

5.3.1 General Description

The Glendale Power Station is owned and operated by the City of Glendale. It is located on the southern edge of the San Fernando valley on the west side of Interstate Highway 5 in a flat area of recent alluvia on the north bank of the Los Angeles River. The plant currently consists of 8 units, 5 of which were installed at the time of the San Fernando earthquake in 1971. The basic data for these 5 stations is summarized as follows:

Dual Fired Gas and Oil Steam Turbine Generators

	No. 1 Unit	No. 2 Unit	No. 3 Unit	No. 4 Unit	No. 5 Unit
Date Installed	1941	1947	1953	1959	1964
Name Plate Mwe	20	20	20	44	44
Steam Pressure	600 lb.	600 Lb.	850 lb.	1250 lb.	1250 lb.
Turbine Manuf.	G.E.	G.E.	G.E.	G.E.	G.E.
Steam Boiler Manuf.	Combustion Engineering	Combustion Engineering	Babcock & Wilcox	Riley Stoker	Riley Stoker

All five units of the plant are housed in a continuous building, which consists of a large concrete basement and operating floor that supports steel-framed boiler structures similar in layout and appearance. None of the units employ reheat. The turbine operating floor is located about 6 feet above grade which is closer to grade than the other power stations surveyed. More details of the plant description and response to the San Fernando earthquake can be found in Appendix I.

5.3.2 Earthquake Induced Damage to Piping

The reported damage in the San Fernando Earthquake consisted of two broken water lines, one in the cooling-water line to the induced-draft fan and air preheater of the Unit 3 boiler, and the other on the Unit No. 2 influent water line to the demineralizer tank. During the survey, it was also indicated by plant personnel that there had been a small branch line break to the main coolant pipe of Unit G-3.

5.3.3 Seismic Design Basis for Piping

There is no mention made in any of the piping and piping support specifications as to any earthquake design requirements. Specific references in the specifications were made to the ANSI B31.1 Piping Code. However, it should be understood that the ANSI B31.1 Code provides seismic design at the option of the engineer. A plant walkdown disclosed that there was no explicit seismic design of piping for any of the Glendale Units.

5.4 Humboldt Bay Power Plant

5.4.1 Plant Description

The Humboldt Bay power plant is located on Humboldt Bay, California, just northeast of the town of King Salmon and about 5 miles southwest of Eureka, California. The facility, owned and operated by Pacific Gas and Electric Company (PG&E), consists of three units. The nuclear plant (unit 3) is a 63 MW plant. The other two units (unit 1 and 2) are older, 52 Mwe dual oil and gas fired boilers which drive steam turbine generators. Unit 1 began operation in 1956. Units 2 and 3 began operation in 1958 and 1962 respectively. Unit 3 is at the eastern end of the facility. The soil in the vicinity of the plant at grade consists of about 40 feet of clay overlain by several feet of fill. The Unit 3 reactor is housed in a steel dry well vessel surrounded by a reinforced concrete caisson beneath the structural steel refueling building. About 300 feet south of the refueling building is the light, shallowly embedded storage building. In Appendices J is a more detailed descriptions of the plant units.

Units 1 and 2 are conventional steam boilers supported by a structural steel frame metal sided structure.

5.4.2 Seismic Design Basis of Piping

It was PG&E policy at the time of construction of the Humboldt Bay fossil Units 1 & 2 to design all major structures for an 0.2g static lateral load factor applied to dead and 50 percent of live load. Their is no evidence that this criteria resulted in any requirement to laterally restrain any piping or use snubbers.

The building structure of Unit 2 adjacent to Unit 3 was modified and strengthened as part of the seismic upgrade of Unit 3 performed in the 1975 - 1976 time frame.

The Unit 3 nuclear unit was originally (1962) designed for a 0.25g horizontal static seismic load. In 1975 - 1976 the nuclear safety related building structures and piping were upgraded to meet a modern seismic Operational Basis Earthquake, OBE, load of 0.25g horizontal and 0.17g vertical zero period ground acceleration, defined dynamically by Regulatory Guide 1.60 ground response spectra and compatible floor spectra. A Safe Shutdown Earthquake, SSE, load of 0.5g horizontal and 0.33 vertical zero period ground acceleration defined by the R.G. 1.60 ground response spectrum were also established in 1975 - 1976. This seismic design change from the original static 0.25g load leads to significant modifications of Unit 3 structural steel and the addition of a large number of lateral restraints to piping systems.

5.4.3 Damage to Piping - Ferndale - 1975

None Reported

5.4.4 Damage to Piping - Eureka - 1980

One piping failure and one support failure in above ground piping were noted for the fossil plant piping of Units 1 and 2. The two failures appeared to be the result of severe deterioration. The pipe failure was a pinhole leak in a weld joint for a 2-in. boiler feedwater line for Unit 1. Reportedly, examination during repair revealed substantial wall erosion, necessitating the replacement of a complete spool piece. Given the chipped grout and the piping configuration, it is obvious that the area where the leak occurred was highly stressed. The coupling of this stress with the pipe wall erosion apparently led to the development of the leak.

The second failure was a sheared bolt on a Grinnell vertical spring hanger for the Unit 1 main steam line. The support was exposed to the weather and badly corroded. Examination of the sheared bolt indicated that the corrosion had frozen the bolt to the slot in which it was intended to slide. Only about two-thirds of the fracture appeared to be attributable to the earthquake; about one-third of the surface appeared to have been cracked before the event. An identical hanger on the opposite side of the line (which appeared to have moved properly) appeared to be undamaged. Failure appeared to be the result of the locking of a partially failed bolt, which caused its overload.

The only effect noted in the Unit 3 safety-related piping was a deformed expansion bellows on the shutdown system discharge line in the shutdown room near the line's containment penetration into the valve gallery.

5.5 Kern Valley Power Plant

5.5.1 General Description

The Kern Steam Power Plant is owned by the Pacific Gas and Electric Company and is located in the southern end of the San Joaquin Valley, approximately four miles west of the City of Bakersfield, Kern County, California. Construction work started on Units 1 and 2 in September 1946 and was completed in March 1950.

The plant site consists of a 77.5 acre plot of level sandy soil, bordered on the north by Rosedale Highway, on the east by Coffee Road, and on the south by the A.T. & S.F. Railroad. This description covers the design and construction for Units Nos. 1 and 2. The power plant was designed to have a rated output of 173,500 kilowatts. Currently the plant is in a cold standby condition and has been since 1985. A more detailed description of the plant can be found in Appendix K.

5.5.2 Seismic Design Basis for Piping

This is one of the first electric power plants to have piping designed by dynamic analysis.[4] The Biot smoothed response spectrum was used by the Stone and Webster Engineering Corp. for the design of the main steam and boiler feedwater piping. The response spectrum was normalized to 0.1 g at ground level and 0.3 g at the top floor of the buildings, with linear interpolation at other levels. In this way an amplified response spectra was available at every floor, even though it was of narrow band and heavily damped compared to spectra typically used for nuclear power plants. The spectra was applied for the steam and feed lines by calculating the first natural frequency of each span of pipe considered as a simply supported beam, then applying the appropriate lateral g force. Based on the dynamic analysis of the main piping, pseudo-static g loads were developed for other piping systems. These loads were also used to design guides and stops and to find loads acting on the supporting structure. It is of interest to note that some guides and stops on the main steam line had gaps or rattle space of as much as two inches.

The dynamic analysis was limited to major heat transport piping (main steam and feedwater). Some other piping systems were apparently designed for lateral seismic loads based on static coefficients developed from the dynamic analysis. However, it should also be noted that no mention was made in the pipe hanger specification regarding lateral loads or seismic supports so it can be surmised that no lateral or seismic supports were supplied except as shown on the Engineer's drawings. A walkdown of the plant did not show any significant use of lateral or seismic pipe supports. A few sway braces (estimated less than 20) were observed in the plant. Therefore, it can be concluded seismic design of piping was limited to a few major or critical piping systems.

5.5.3 Extracts from Text of Piping Specification for the Kern Valley Steam Plant

All piping is fabricated and erected in accordance with the latest issue of the American Standard Code ASA B-31 for Pressure Piping. The specified piping schedule numbers are the minimum permissible. If piping, in accordance with this schedule is not readily obtainable, the Contractor may, unless otherwise specified, furnish heavier pipe upon approval of the Engineer.

"Maximum working pressures and temperatures for each piping system are stated in this schedule. All materials and fabrication details shall be suitable for the service conditions of the system in which they are installed."

No mention was made of seismic design requirements.

5.5.4 Earthquake Induced Damage to Piping

None reported

5.6 Pasadena Power Plant

5.6.1 Plant Description

The Pasadena power plant is owned and operated by the city of Pasadena. It is located on the southern edge of the city of Pasadena, in the Los Angeles Basin adjacent to the San Fernando Valley. The plant at the time of the San Fernando earthquake had four generating units with a total capacity of 206 MWe. Broadway Units B1 and B2, each having a capacity of 45 MWe, were built in 1955 and 1957, respectively. Broadway Unit B3 is a 71 MWe unit and was built in 1965. Unit 4, the Glenarm Plant, was built in 1933 and has a capacity of 45 MWe.

All four units are in separate structures, and all the Broadway Units 1 to 3 except for the reinforced concrete turbine-generator pedestals are braced steel-framed buildings. The Glenarm plant is enclosed primarily by a masonry structure with the boiler supported by structural steel. A more detailed description of the plant and overall earthquake effects are contained in Appendix L.

5.6.2 Seismic Design Basis for Piping

Units B1 and B2 structures were probably designed to Los Angeles City Building Code which is equivalent to the then current (1955 - 1957) Uniform Building Code. Main heat transport piping for Units B1 and B2 were probably designed to a 0.2g static load. However, there is no evidence during a walkdown that Units B1 and B2 piping support was affected by seismic considerations.

Unit B3 structure also appears to have been designed for the then current Los Angeles or Uniform Building Code (1965). There was however explicit seismic design of main heat transport piping to resist seismic effects. Piping Isometrics are as shown in Figures 5.1 - 5.6. The seismic analysis on the lines shown was performed by Basic Engineers, Pittsburgh, Pa. during August - December 1963. The seismic analysis was performed by applying a static 0.2g acceleration times mass in two orthogonal horizontal directions simultaneously and computing resultant stresses. Resultant stresses were required to meet the provisions of the ASA B.31.1.0-1955 Code. One result of this analysis was to require one main steam line snubber.

There is no indication that the Glenarm Unit structure or piping was seismically designed.

5.6.3 Damage to Piping - San Fernando - 1971

None Reported

5.6.4 Damage to Piping - Whittier's Narrow - 1985

None Reported

5.7 Valley Power Plant

5.7.1 Plant Description

The Valley Steam Plant is located on a 150-acre site in the central San Fernando Valley and is owned and operated by the Los Angeles Department of Water and Power. The plant has four generating units with a total capacity of 513 MW. Units 1 through 4 were constructed in 1954, 1954, 1955, and 1956, respectively; and their individual capacities are 100, 100, 157, and 157 MW, respectively. Because of the area's mild climate, much of the plant piping and equipment is located outdoors.

The main structures consist of braced steel frames supporting the boilers, concrete foundations for the turbine-generator units, and concrete-surfaced decks in the steel-framed turbine building. The plant is located in a flat, alluvial area, on sand, gravel, and boulders that extend to a depth of more than 500 feet. The permanent water table is about 200 feet below the surface. A more detailed description of the plant and its response to the San Fernando earthquake can be found in Appendix M.

5.7.2 Seismic Design Basis for Piping

The major pipe system in the plant also appears to have been designed for a 0.2g static load. However, after the San Fernando earthquake there was a seismic upgrade program instituted for all LADWAP facilities. This program resulted in the addition of 45 degree sway braces on some piping systems. In total approximately 50 such sway braces were observed on Units 1-4 piping. However, there appears to be no uniform sway brace policy having been followed. Several small bore pipe were braced while adjacent large bore pipe were not.

5.7.3 Piping Damage Summary

In Unit 4, a few circulating water tubes in the condenser were ruptured. The damage was noticed when contamination began to appear in the boiler feedwater. This was the only reported failure of piping and tubing at the plant as a result of the earthquake.

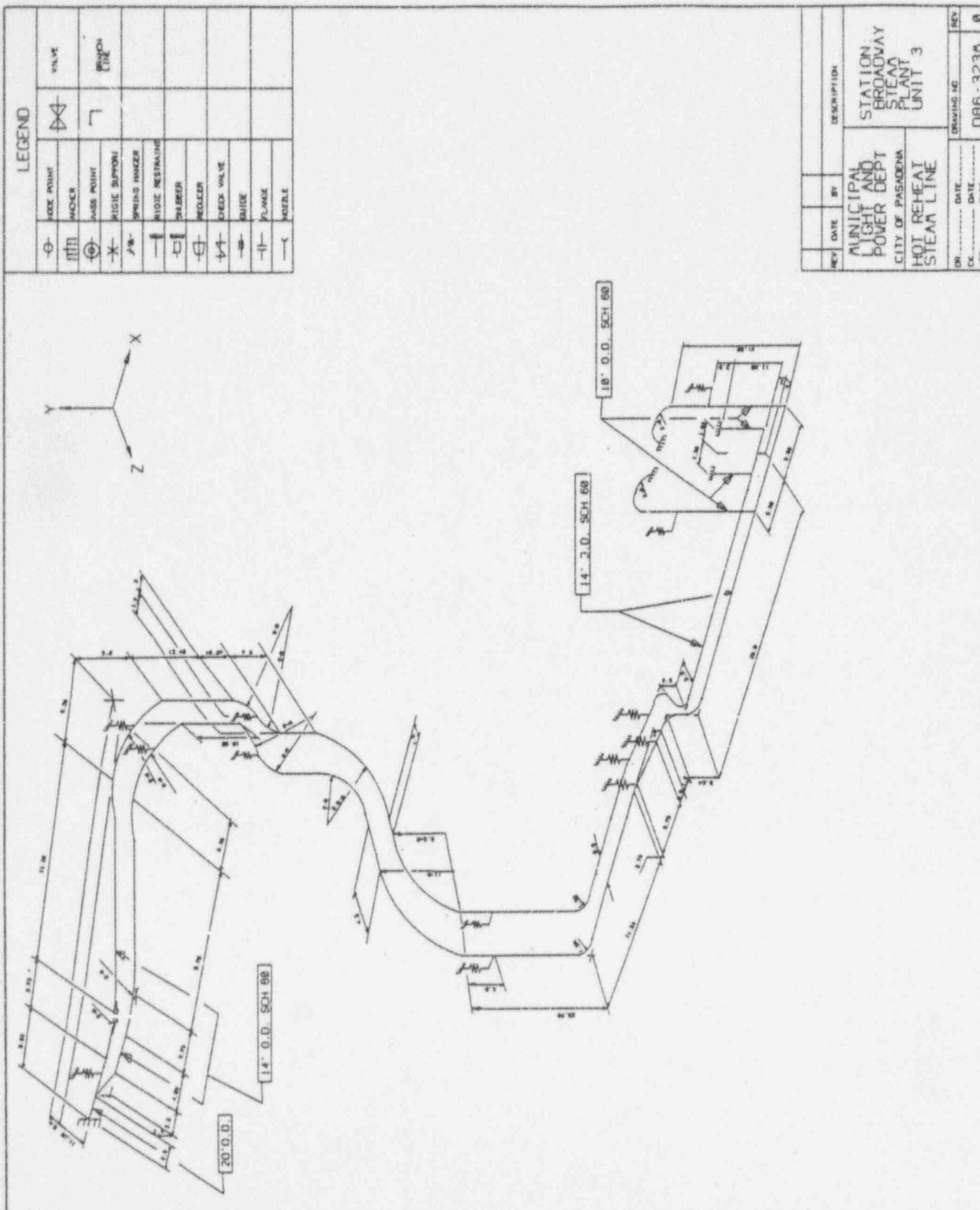

Figure 5.1 Typical Large Hot Line Isometric Broadway Unit 3

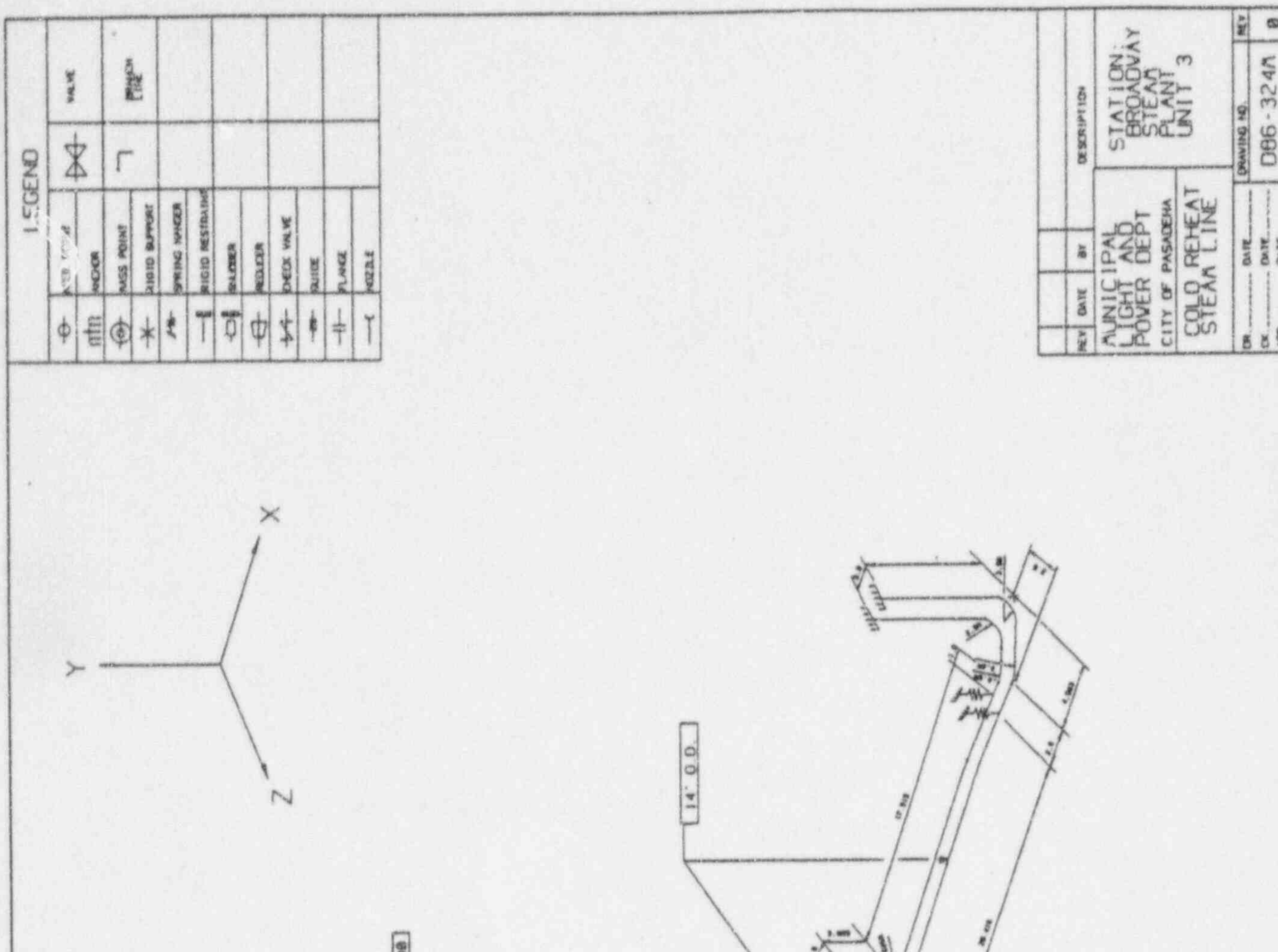

Figure 5.2 Typical Large Hot Line Isometric Broadway Unit 3

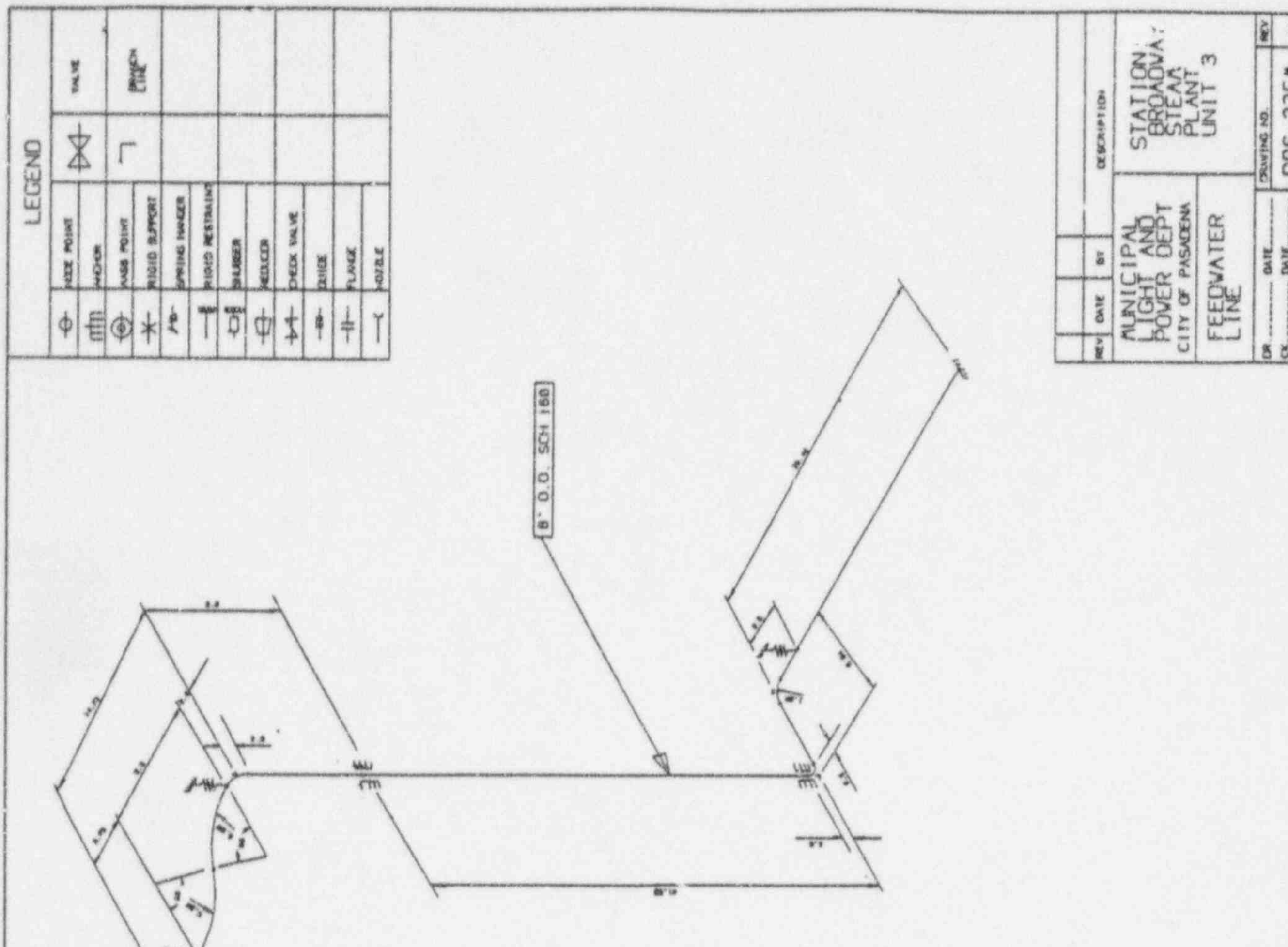

Figure 5.3 Typical Large Hot Line Isometric Broadway Unit 3

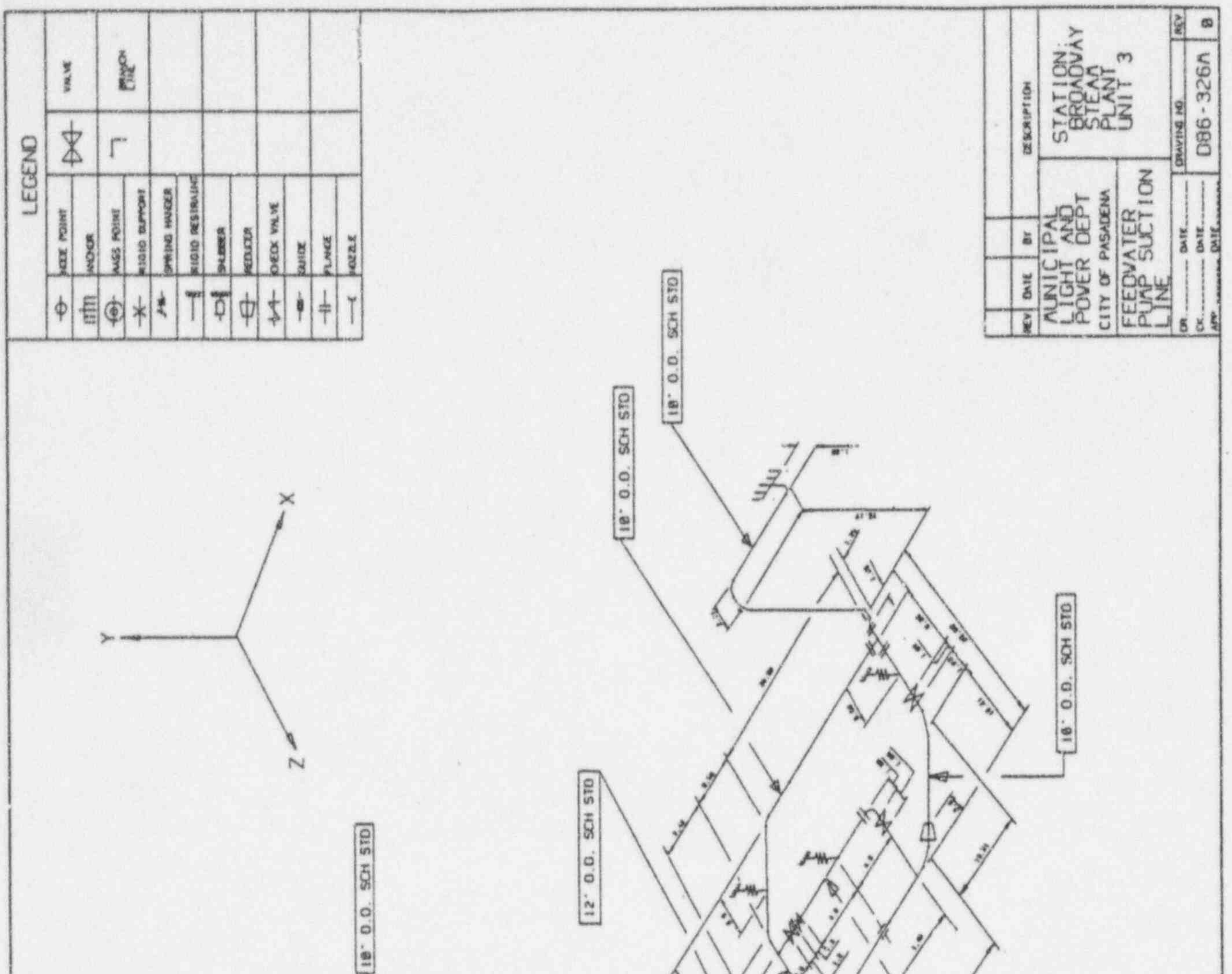

Figure 5.4 Typical Large Hot Line Isometric Broadway Unit 3

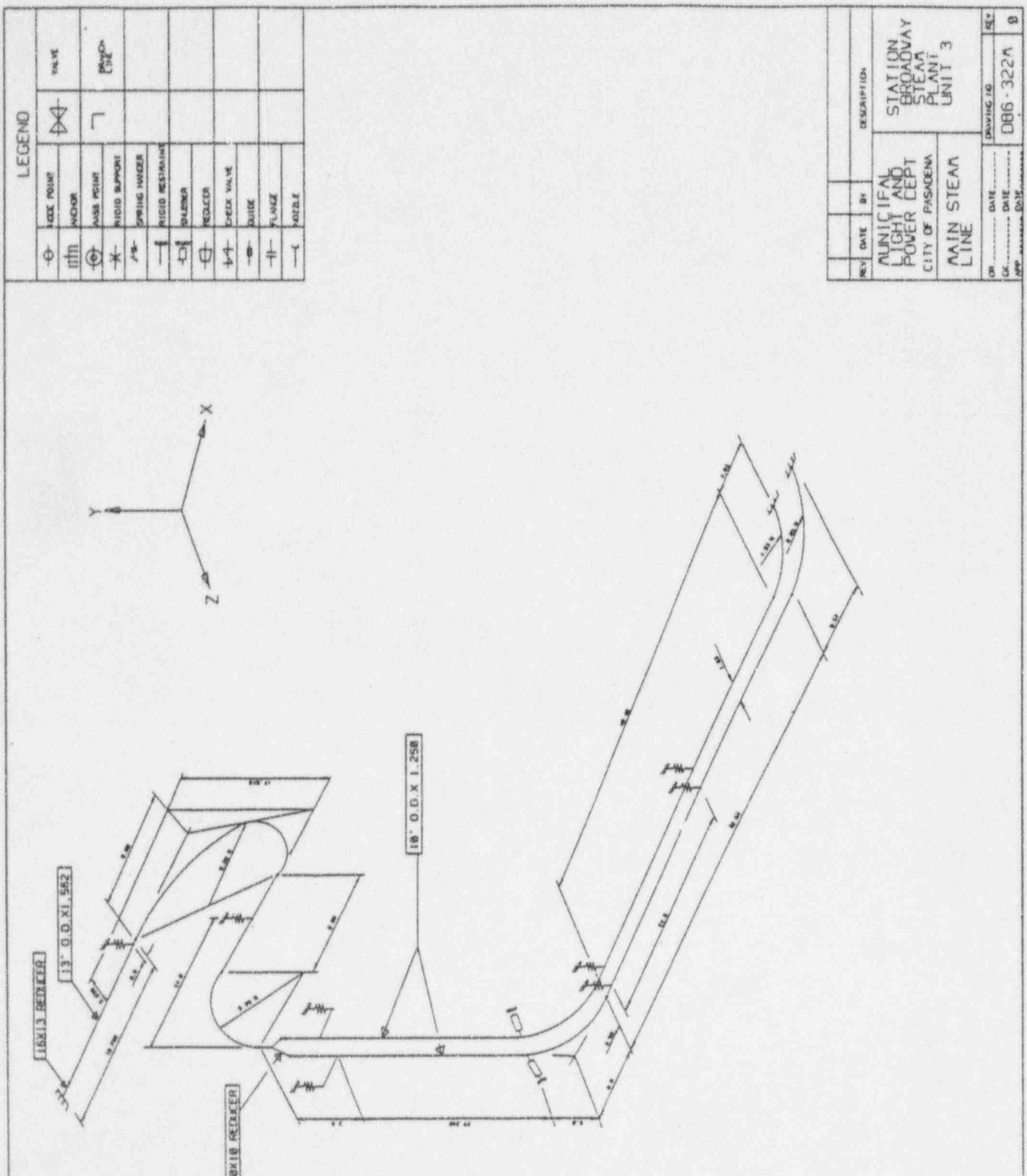

Figure 5.5 Typical Large Hot Line Isometric Broadway Unit 3

6 Summary, Recommendations, and Conclusions

6.1 Summary

In Appendix E are a series of photographs which show the general layout, arrangement and condition of piping and piping supports which have undergone Zero Period Ground Acceleration, ZPGA, equal to or greater than 0.2g (up to 0.5g) in the power plants surveyed. In Figures 4.19 to 4.29 are shown seismic induced failures of piping and supports in the plants surveyed. Three additional failures for these plants are reported in the literature[2] but were not available to be photographed during the site visits.

6.2 Recommendations

Based on the results of the survey the following recommendation or caveats are considered applicable to the construction of seismically qualified piping in plants with ZPGA equal to or less than about 0.2g.

- o Building structures should be designed and detailed with ductile (earthquake resistant) structural connections in accordance with current applicable codes and standards. (This is not currently a requirement for design of safety related nuclear power plant structures.)

- o Seismically qualified piping should not use threaded connections except as specifically exempted by applicable earthquake standards (ie., threaded fire protection piping)

6.3 Conclusions

- o Except for the very limited use of sway braces in the Kern and Valley Power Stations there is almost no evidence of earthquake resistant design in the form of lateral restraints being applied to piping systems in the power plants surveyed.

- o Deadweight (vertical) support spacing were generally in line with ASME/ANSI B31.1 recommendations except for small bore piping ($D_o \leq 2½$ inch). As shown in Figures 4.7 and 4.8, there are many instances where small bore pipe dead weight support spacing exceed by factors of two or three the recommended spacing.

- o Piping spans (including nozzles, anchors and vertical legs more than 5.0 feet long acting as horizontal restraints) have horizontal restraint spans which are typically 3 to 4 times the dead weight spans and often exceed 8 times dead weight support spans.

- o There was less than one pipe failure per unit per strong motion (ZPGA $\geq$ 0.2g) earthquake observed in the plants surveyed. The failures that did occur were associated with types of pipe connections (threaded joints), rigid connection of branch piping to main piping runs and maintenance condition of the pipe associated with erosion and corrosion rather than any systematic design deficiency.

- o Piping and support systems constructed to the requirements of the ASME/ANSI B31.1 piping code employing ductile standard support hangers with no or little consideration for seismic loads sustained essentially no damage up to 0.3g PGA.

- o The experience gained from this survey suggests that the elaborate, rigorous piping design and lateral support hardware rigidity requirements placed on nuclear power plant piping and supports to resist seismic loads up to at least 0.3g PGA could be simplified.

- o Socket welded connections appear to perform as well as butt joined, groove welded connections.

- o Threaded connections have failure ratios approximately three times that of welded connections.

- o Buildings supporting or housing seismically qualified piping in general have seismic design margins less than the piping they house or support.

- o Given the relatively few failures (less than one tenth of one percent of piping at risk) of above ground industrial piping due to strong motion earthquakes with PGA between 0.2g and 0.5g consideration should be given to development of simplified piping seismic design by rule rather than analysis for plant sites where the Design Basis Earthquake is defined at or less than 0.3g.

The resources available for this study were somewhat limited so it was not possible to record piping span connection and support characteristics except on a limited sample basis. It is strongly recommended that this study be expanded to include the development of a much larger sample of vertical and lateral support spacings and types of pipe connections in order to demonstrate their sensitivity to actual strong motion earthquake effects. Also the review of detailed design information at the engineering offices of designers may permit a better definition of the original seismic design criteria and procedures.

7 References

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(2) EQE Incorporated, "Program for Development of an Alternative Approach to Seismic Equipment Qualification," Vol. 1 Pilot Program Report, Prepared for Seismic Qualification Equipment Qualification Group.

(3) Stevenson and Associates, Report of the U.S. Nuclear Regulatory Commission Piping Review Committee, Summary and Evaluation of Historical Strong - Motion Earthquake Seismic Response and Damage to Above Ground Industrial Piping," NUREG-1061 Vol. 2 Addendum Prepared for the Seismic Design Task Group, U.S. Nuclear Regulatory Commission, April 1985.

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(6) (not used)

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10. SUPPLEMENTARY NOTES
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11. ABSTRACT (200 words or less)

Since 1982, there has been a major effort expended to evaluate the susceptibility of nuclear power plant equipment to failure and significant damage during seismic events. This was done by making use of data on the performance of electrical and mechanical equipment in conventional power plants and other similar industrial facilities during strong motion earthquakes. This report is intended as an extension of the seismic experience data collection effort and a compilation of experience data specific to power plant piping and supports designed and constructed to U.S. power piping code requirements which have experienced strong motion earthquakes.

Eight damaging (Richter Magnitude 7.7 to 5.5) California earthquakes and their effects on 8 power generating facilities in California were reviewed. All of these facilities were visited and evaluated. Seven fossil-fueled (dual use natural gas and oil) and one nuclear fueled plants consisting of a total of 36 individual boiler or reactor units were investigated. Peak horizontal ground accelerations that either had been recorded on site at these facilities or were considered applicable to these power plants on the basis of nearby recordings ranged between 0.20g and 0.51g with strong motion durations which varied from 3.5 to 15 seconds. Most U.S. nuclear power plants are designed for a safe shutdown earthquake peak ground acceleration equal to 0.20g or less with strong motion durations which vary from 10 to 15 seconds.

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