Report No. 42116-R-001

DUANE ARNOLD ENERGY CENTER
MAIN STEAM ISOLATION VALVE LEAKAGE CLOSURE
SEISMIC EVALUATION

August 9, 1994

Prepared for:

IES UTILITIES

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APPROVAL COVER SHEET

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TABLE OF REVISIONS

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DRAFT	For IES Review	June 10, 1994
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1	Minor editorial changes and additional Figures 4-1, 4-2 and Attachment I.	August 9, 1994

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SUMMARY

In order to justify the capability of the main steam piping and condenser as the alternate leakage treatment system, EQE has verified that the main steam lines, the steam drain line, the condenser, and interconnecting piping and equipment are seismically adequate to withstand a safe shutdown earthquake and maintain their integrity. The seismic adequacy of those piping and equipment systems at Duane Arnold Energy Center (DAEC) was confirmed by comparing them to a detailed earthquake experience database as discussed in Section 6.7 of NEDC-31858P, Revision 2, and performing engineering walkdowns and evaluations using qualified seismic capability engineers.

The earthquake experience database, which consists of the documentation of the performance of piping and equipment in power and industrial facilities during past earthquakes, is founded on extensive studies of over 100 industrial facilities and surveys of several hundred other facilities located in the vicinity of strong motion earthquakes that have occurred in California, Alaska, New Zealand, and Latin American countries since 1971. A detailed description of the database was provided to the NRC staff as part of the Georgia Power Company Plant Hatch Unit 2 supplemental information transmittal to the NRC dated January 6, 1994 (Docket No. 50-366). The database information was presented in an EQE document attached to the submittal entitled "Supplemental Piping Earthquake Performance Data," dated December, 1993.

The current standard practice for the seismic design of piping and equipment systems has not considered the real performance of such systems in strong motion earthquakes. This has resulted in excessive conservatism in the treatment of primary stresses when uncorrected linear elastic analyses are performed and the results are compared to stress limits based on static tests. The earthquake experience data provides the only available full-scale tests of designs and installations. The data, therefore, provides a realistic and practical method of verifying the seismic adequacy of piping and equipment.

Equipment and above ground piping at database facilities have exhibited excellent resistance to damage during and after earthquakes without the specific application of seismic design considerations and provisions. A large number of classes of equipment (pumps, valves, tanks, instrument cabinets, etc.) have proven seismically rugged when properly anchored. For welded steel piping designed and constructed to normal industrial practice (e.g., ANSI B31.1), past seismic experience has never shown a primary collapse mode of failure. A relatively small number of seismically induced piping failures have occurred due to excessive relative support movements or seismic interactions.

Consistent with the verification methodology, a plant specific seismic verification walkdown of all systems and components associated with the alternate MSIV leakage treatment was performed by qualified seismic engineers. The purpose of the walkdown was to physically verify that the components in the alternate leakage treatment system have attributes similar to those in the data bases that have good seismic performance and to identify potential seismic vulnerabilities. As a result of the walkdown and subsequent evaluations, EQE has determined that the plant features compare well with the database. The walkdown also includes an inspection for those structural details and causal factors that resulted in component damage at industrial sites contained in the database to ensure such conditions are evaluated to satisfaction or plant modifications are implemented to resolve the concern. As a result of the walkdown, EQE identified the need to implement minor modifications or repairs.

IES Utilities, Inc. has compared the DAEC piping and equipment necessary to utilize the alternate MSIV leakage control method with the earthquake experience data including a walkdown to identify and evaluate any of the characteristics associated with the limited failures that have occurred at the database facilities. An engineering analysis of selected critical supports was performed which showed that the supports exhibited substantial margin. As a result, IES Utilities, Inc. has concluded that the DAEC main steam line, main steam drain line, condenser, and applicable interconnecting piping and equipment, are well represented by the earthquake experience data demonstrating good seismic performance, are confirmed to exhibit excellent resistance to damage from a design basis earthquake, have been shown to have substantial margin for seismic capability, and are, therefore, seismically adequate to withstand the DAEC design basis earthquake and maintain pressure retaining integrity. This capability of the alternate MSIV leakage treatment system to with stand the effects of the safe shutdown earthquake and continue to perform its intended function (treatment of MSIV leakage) satisfies the intent of the seismic requirement of Appendix A to 10 CFR 100.

1.0 SCOPE OF REVIEW

The primary components to be relied upon for pressure boundary integrity in resolution of the BWR MSIV leakage issue are:

- The main turbine condenser.
- The main steam lines from the MSIV's to the turbine stop and bypass valves.
- The main steam turbine bypass and drain line piping to the condenser.

The BWROG MSIV Leakage Closure Committee has published guidelines for establishing the seismic verification boundary. The condenser forms the ultimate boundary of the leakage pathway. Boundaries may be established upstream of the condenser by utilizing a valve as a leakage boundary. The appropriate criteria used to select and justify a boundary valve are:

- Normally closed valve that will not open and can be assured to remain closed can be used as a seismic verification boundary.
- Normally open valves that can be assured to close and remain closed can be used as a seismic verification boundary.
- Manual actions may be utilized as a boundary valve if proceduralized and the use is justified.

The interacting systems boundaries are shown in Figure 1.1

A seismic verification walkdown was performed to assure that the main condenser and steam piping systems that are not seismically designed fall within the bounds of the design characteristics of the seismic experience database contained in Appendix D to the BWROG Report for Increasing MSIV Leakage Rate Limits and Elimination of Leakage Control Systems (NEDC-31858P, Rev. 2). An additional report, "Supplemental Piping Earthquake Performance Data," was prepared in support of the Georgia Power Hatch Unit 2 license request and is included as Attachment I to this report. The conclusions of this report also apply to Duane Arnold Energy Center (DAEC).

The seismic verification walkdown was performed by integrated IES/EQE teams. As a group, each team's members possessed the following qualifications:

- Knowledge of the failure modes and performance during strong earthquakes of components and structures in heavy industrial process plants and fossil fuel power plants including structures, tankage, piping, process and control equipment, and active electrical components.

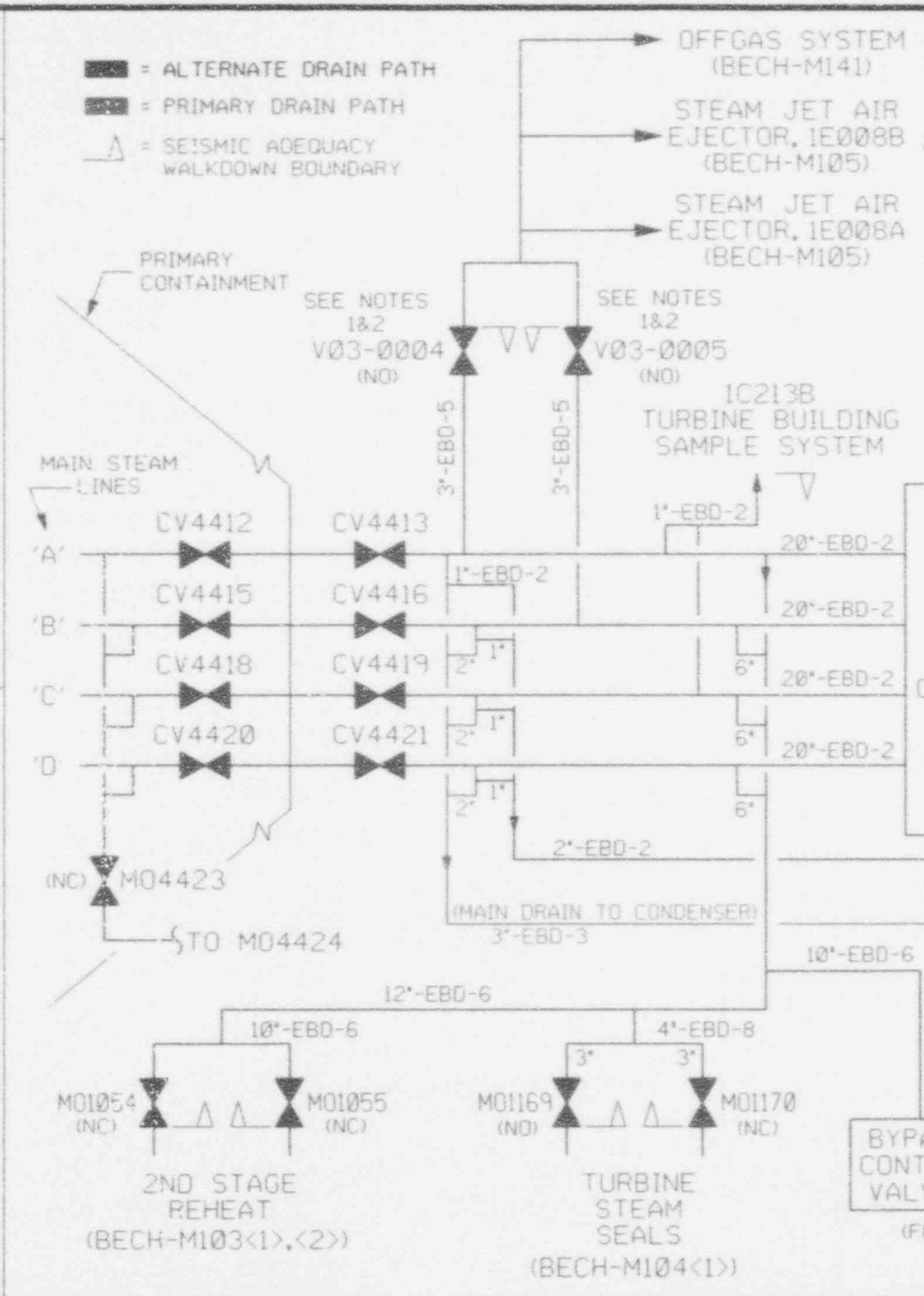
- Knowledge of nuclear design standards and seismic design practices for nuclear power plants including structures, tankage, piping, process and control equipment, and active electrical components.
- Ability to perform fragility/margins-type capability evaluations including structural/mechanical analyses of the above mentioned elements.
- Fundamental knowledge of the plant systems functions.

Each team contained at least two seismic capability engineers, one of whom was a licensed professional engineer. A detailed walkdown procedure was developed, and the EQE project manager conducted a training session at the site prior to initiation of the walkdown.

The seismic experience database piping and equipment designs have demonstrated good seismic performance, and the piping and equipment designs at Duane Arnold are equivalent to that contained in the seismic experience database. Conditions that might lead to piping configurations that are outside the bounds of this conventional piping were noted during the walkdown. Table 4-2 summarizes the identified conditions (termed "outliers"), and their resolution. Note that some outliers were resolved by demonstrating analytically that the outlier did not create hazards beyond the seismic inertial loading. These hazards include interaction, differential displacement, and failure/failing. Other outliers required corrective action as noted in the table.

Where analysis was used to resolve outliers, estimates of the realistic median-centered in-structure response spectra were employed. These estimated values are more representative of the actual response of the building during a seismic event than the original Design Basis Earthquake. Response spectra were generated using a mathematical model of the turbine building. Input time histories were generated to match the response spectra defined by the NUREG/CR-0098 one sigma response, anchored horizontally at 0.12g.

For analysis of pipe supports, the seismic demand was determined using a factor of 1.25 times the peak acceleration of median-centered floor response spectra. Anchorage capacity was determined using the methods and values provided in the SQUG Generic Implementation Procedure for Seismic Verification of Nuclear Power Plant Equipment.



NOTES:

1. V03-0004 AND V03-0005 WILL BE CONVERTED TO MOTOR OPERATED VALVES.
2. ESSENTIAL POWER WILL BE PROVIDED TO THE FOLLOWING VALVES: V03-0004, V03-0005 MO-1169, MO-1170, MO-1043, MO-1044
3. LINE UP DEPICTS A POST LOCA LINE UP. OPERATOR ACTION IS REQUIRED TO POSITION THE FOLLOWING VLV'S: V03-0004, V03-0005, MO-1169, MO-1043, MO-1044, CV-1064
4. MAIN STEAM LINES BETWEEN THE MSIV UP TO THE STOP VALVE, INCLUDING BRANCH LINES 3" AND LARGER HAVE BEEN SEISMICALLY ANALYZED.
5. ALL CONNECTIING BRANCH LINES SUCH AS HPCI, RCIC, EQUALIZING HEADER DRAIN, (2" AND UNDER), VENTS AND INSTRUMENTATION TAPS ARE NOT DEPICTED BUT WERE INCLUDED IN THE EQE SEISMIC ADEQUACY EVALUATION.
6. NO= NORMALLY OPEN
   NC= NORMALLY CLOSED
   FC= FAILED CLOSED

REFERENCE DRAWINGS:

1. BECH-M103<1>,<2>
2. BECH-M104<1>
3. BECH-M105<1>
4. BECH-M114
5. BECH-M122
6. BECH-M124
7. BECH-M141
8. BECH-M149
9. OI-646, 683, 692
10. IPOI-3

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MSIV LEAKAGE DRAIN PATH AND ISOLATION BOUNDARIES

DWG. NO. FIGURE 1.1

REV.

2.0 TURBINE BUILDING

Performance of the turbine building during a seismic event is of interest to the issue of MSIV leakage only to the extent that the building structure and its internal components should survive and not degrade the capabilities of the selected main steam and condenser pathways. A BWROG survey of this type of industrial structure has confirmed that excellent seismic capability exists. There are no known cases of structural collapse of either turbine buildings at power stations or structures of similar construction.

Based on DAEC FSAR Sections 3.8.4.1 and 3.8.4.3.3, the turbine building is classified as Nonseismic, however the criteria for Seismic Category I structures were used for the structural design of the entire building. A complete dynamic analysis was conducted for the turbine building. The same design procedures used for the reactor building were also used for the turbine building. Therefore the turbine building was specifically designed for seismic loading. Specific parameters involved in the evaluation follow.

2.1 Design Basis

2.1.1 Building Description

The turbine building is a three story structure consisting of a basement at elevation 734'-0", the ground floor at elevation 757'-6" and the operating floor at elevation 780'-0". The roof over the operating floor is at elevation 832'-7".

The basement story consists of a reinforced concrete base slab and reinforced concrete exterior walls. The remainder of the structure consists of rigid and braced steel framing with reinforced concrete floor slabs.

Above the operating floor there are 10 bays along the length and 5 across the ends of the building. The end frames are stiffened in the lateral (east-west) direction by cross bracing while the interior frames are of rigid frame construction. The last bay along the length of the turbine building is adjacent to the reactor building and framed by cross-brace construction tied into the rigid frames. The roof is supported by purlins which span between the rigid frames and which are tied by horizontal cross braces. Steel roof decking is welded to these members and designed as a horizontal shear diaphragm.

2.1.2 Lateral Force Resisting System Superstructure Type (above the operating floor).

The superstructure above the operating floor is a braced or rigid frame structure depending on the direction of lateral load consisting of the following:

a. Column lines K, L, and Q, contain vertical bays of cross bracing to resist N-S wind or seismic lateral loading conditions.

b., E-W lateral forces are resisted by rigid frames in column lines 5 through 13, and by braced frames in the end bays at column lines 4 and 14. Shear above the operating floor is carried by the frames in proportion to their stiffness.

c. The reinforced concrete operating floor, and roof above the operating floor serve as diaphragms to distribute lateral loads to the structural steel framing and to the substructure below the operating floor.

2.1.3 Lateral Force Resisting System Substructure Type (below operating floor)

a. The turbine pedestal is composed of a reinforced concrete slab at the operating floor level supported by a reinforced concrete shear wall and columns which are anchored to the foundation slab. Lateral forces from the turbine are transmitted to the base slab through these columns and shear wall. The turbine pedestal is isolated from the building floors with respect to horizontal motion.

b. Concrete walls serve as shear walls to transfer lateral forces to the foundation base slab.

c. The reinforced concrete ground floor slab at elevation 757'-6" also acts as a diaphragm to distribute lateral forces.

d. The K, Q, 4 and 14 column lines are cross-braced to the top of exterior shear walls at elevation 757'-6". The L column line is cross-braced to the foundation level at elevation 734'-0".

2.1.4 Seismic Design Codes

The turbine building was designed to conform with the following general codes:

a. American Institute of Steel Construction (AISC) Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings, 1963 and 1970.

b. American Concrete Institute (ACI) Building Code Requirements for Reinforced Concrete (ACI 318-63).

c. American Welding Society (AWS) Standard Code for Arc and Gas Welding in Building Construction (AWS D1.0-66 and AWS D2.0-66)

d. Official Linn County, Iowa, Building Code

2.1.5 Seismic Design Basis

a. The turbine building was analyzed and designed to the same seismic criteria as Seismic Category I structures. The load combination basis for Seismic Category I Structures is as follows:

Load Combination	Minimum Requirements for Seismic Category I Structural Components
Normal loads + operating-basis earthquake	Within code allowable stresses
Normal loads + design-basis earthquake	No functional failure
Normal loads + tornado loads	No functional failure

b. The turbine building was dynamically analyzed using the time history method. A maximum ground acceleration of 0.06 gravity was used for the Operating Basis Earthquake, and 0.12 gravity was used for the Design Basis Earthquake.

2.1.6 Wind Design Codes

a. American Society of Civil Engineers, Paper No. 3269, Wind Design Requirements, 1961.
b. Items a through d of Section 2.1.4.

2.1.7 Wind Design Basis

a. Wind Loads

The dynamic pressures used in the design of this plant are derived from ASCE Paper No. 3269 as it applies to the Duane Arnold Nuclear Plant.

$q = 0.002558V^2$

Where q is the velocity pressure in psf, and V is the wind velocity (mph). It was assumed that 90% of q is acting as pressure on windward side and 40% as suction on leeward side.

Suction on the roof was assumed as 60% of q. The total wind pressure p in psf is:

$p = 1.3\ q = 0.0033V^2$

Wind Loads:

Height (ft)	Basic Velocity (mph)	Dynamic Pressure (Including 1.1 Gust Factor) q (psf)	Wall Load Pressure 0.9q (psf)	Wall Load Suction 0.4q (psf)	Roof Load Suction 0.6 q (psf)
0-50	105	34	31	14	20
50-150	125	48	43	19	29
150-400	145	65	59	26	39

Whenever wind loads are combined with other loads, a 33% increase in allowable stresses is permitted in accordance with the AISC Code.

b. Tornado effects included in design consideration.

The design basis tornado consists of a tornado with a minimum tangential velocity of 300 mph traveling with a maximum transverse velocity of 60 mph. The loadings created by the design-basis tornado are reflected in the following two tornado design criteria used in the design of tornado-resistant structures:

(1) The velocity components are applied as a uniform 300 mph wind on the structure.
(2) The pressure differential is applied as a 3 psi positive (bursting) pressure occurring in 3 sec.

The design basis tornado velocity components are conservatively applied as a 300 mph wind on the structure using the applicable portions of the wind design methods described in ASCE 3269 particularly for shape factors. Variation of wind velocity with height is not used.

c. Load combinations allowable stresses

The load combinations are as defined in section 2.1.5 a.

Concrete buildings are designed using normal ACI code provisions and methods for ultimate strength design, including the appropriate capacity reduction factor (Φ). The load factors for the design equation are assigned as 1.0.

Steel structures are designed using traditional elastic methods of analyses and allowable stresses of 1.5 f_S with 0.9 F_Y as the upper limit. This is consistent with the design philosophy of structures under the DBE.

3.0 MAIN TURBINE CONDENSERS

The main condenser is a horizontal, twin shell, single pass, dual pressure, surface condenser. The two low pressure turbines exhaust to separate condenser shells. The high pressure condenser has a heat transfer surface area of 212,290 ft^2 and the low pressure condenser has a heat transfer surface area of 194,480 ft^2. In Table 3-1, the design attributes of the DAEC condensers are compared with the two sites in the earthquake experience database that have condensers most representative of the DAEC type condensers: Moss Landing Units 6 & 7, and Ormond Beach Units 1 & 2. Note that the DAEC condenser configuration is composed of two structurally independent shells, which may be independently compared to the earthquake experience condensers.

The shells of the DAEC condensers are constructed of 5/8" thick ASTM A-36 steel. The database condenser shells are 3/4" thick ASTM A-285C steel. The overall heat transfer area, weight, and footprint of the DAEC condenser are generally enveloped by the database condensers, as shown in Figures 3-1, 3-2, and 3-3.

In summary, the DAEC condenser design is typical of those at facilities in the earthquake experience database that have experienced earthquakes in excess of the DAEC design basis earthquake (See Figure 3-4). The DAEC condenser anchorage is comparable to the anchorage of earthquake experience database condensers. Appendix D, Section 4.1, of NEDC - 31858P, Rev. 2, contains details of the earthquake experience for condensers. Specific data used in the evaluation are as follows:

3.1 Design Basis

3.1.1 Design Code:

Heat Exchanger Institute (HEI) Standards

3.1.2 Hydrostatic Test Requirements

Shell - Completely filled with water

3.1.3 Anchorage

The existing condenser anchorage is shown schematically in Figure 3-5. Each condenser unit has four sliding plate supports with (4) 2 1/4" diameter A36 anchor bolts at each corner. These supports are designed to resist all uplift loads. Each anchor bolt has 3'-0" embedment in the turbine building foundation slab. Thermal growth of the condenser occurs from a fixed point near the center of the base. The sliding plate supports have oversized holes so these forces are not transmitted to the anchor bolts.

Additional uplift loads due to seismic considerations have been evaluated. Realistic median-center estimates of the in-structure response spectrum were used in the evaluation. The existing condenser anchorage system has the capacity to withstand the uplift forces during a seismic event.

Each condenser unit is also furnished with (2) flexible plate supports and (1) shear key anchor designed to resist lateral loads.

The 1" thick steel flexible plate supports resist lateral loads in the direction parallel to the turbine generator axis. They are welded to embedded steel wide flange sections, anchored in the foundation slab.

Table 3-1
Comparison of Data Base and DAEC Condensers (Page 1 of 3)

Facility	Units	Condenser Manufacturer	Flow Type	Condenser Dimensions	Condenser Tube Area Per Shell	Condenser Shell Material	Condenser Shell Thickness
Moss Landing	6 & 7	Ingersoll Rand	Single Pass	65 feet long 36 feet wide 47 feet high	435,000 sq ft	Cu Bearing ASTM A-285C	3/4 inch
Ormond Beach	1 & 2	Southwestern	Single Pass	52 feet long 27 feet wide 20 feet high	210,000 sq ft	Cu Bearing ASTM A-285C	3/4 inch
DAEC HP	1	Foster Wheeler	Single Pass	39 feet long 29 feet wide 39 feet high	212,290 sq ft	ASTM A-36	5/8 inch
DAEC LP	1	Foster Wheeler	Single Pass	36 feet long 29 feet wide 39 feet high	194,480 sq ft	ASTM A-36	5/8 inch

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Table 3-1

Comparison of Data Base and DAEC Condensers (Page 2 of 3)

Facility	Condenser Operating Weight	Tube Material	Tube Size	Tube Length	Tube Wall Thickness	Number of Tubes	Tube Sheet Material	Tube Sheet Thickness	No. of Tube Support Plates
Moss Landing	3,115,000	Al-brass	1 inch	65 feet	18 Bwg	25,590	Muntz	1.5 inch	15
Ormond Beach	1,767,000	90-10 Cu-Ni	1 inch	53 feet	20 Bwg	15,220	Muntz	1.25 inch	14
DAEC HP	1,960,000	Type 304 S.S.	1 inch	40 feet	22 Bwg	19,056	Muntz ASTM B-171	1.125 inch	11
DAEC LP	1,890,000	Type 304 S.S.	1 inch	37 feet	22 Bwg	19,056	Muntz ASTM B-171	1.125 inch	10

DAEC/TABLE3_1.DOC

Table 3-1

Comparison of Data Base and DAEC Condensers (Page 3 of 3)

Facility	Tube Support Plate Material	Tube Support Plate Thickness	Tube Support Plate Spacing	Waterbox Material	Waterbox Plate Thickness	Expansion Joint	Hot Well Capacity	Hot Well Hold Time
Moss Landing	Not Given	3/4 inch	48 inches	2% Ni cast iron ASTM A-48 CL 30	N/A	Rubber Belt	20,000	N/A
Ormond Beach	Cu Bearing ASTM A-285C	5/8 inch	36 to 36.5 inches	Cu Bearing ASTM A-285C	5/8 to 1 inch	Stainless Steel	34,338	N/A
DAEC HP	ASTM A-36	3/4 inch	40 inches	ASTM A-36	Not Given	Stainless Steel Shielded, Rubber Belt	72,500 (HP & LP combined)	5 min. (HP & LP combined)
DAEC LP	ASTM A-36	3/4 inch	41 inches	ASTM A-36	Not Given	Stainless Steel Shielded, Rubber Belt	72,500 (HP & LP combined)	5 min. (HP & LP combined)

The shear key anchor support, (2" x 5½" x 28" long shear key) resists lateral loads in the direction perpendicular to the turbine generator axis. It is welded to steel wide flange sections embedded in the foundation slab.

An evaluation of the condenser lateral load support arrangement was performed. It was determined that the horizontal shear capacity is sufficient to withstand the lateral forces that are present during an SSE event, based on estimated median centered earthquake demand and database comparison.

The shear area divided by the demand was used to compare DAEC condenser anchorage with condensers in the earthquake experience database (See Figures 3-6 and 3-7). Lateral load capacity for the side anchors was based on simplified assumptions on plate shear behavior, using the shear area of the plate attachment. The values for the DAEC condensers are as follows:

	Shear Area (in^2)/Seismic Demand	
	Lower Bound	Upper Bound
Parallel to Turbine Generator Axis	.0001777	.0002301
Perpendicular to Turbine Generator Axis	.0000922	.0001445

These values are comparable to other BWR condensers, and significantly higher than the selected database sites (see NEDC 31858P, Rev. 2, Figure 4-10 and 4-11).

3.1.4 Manufacturer: Foster Wheeler Corporation

3.1.5 Surface Area, Weight, Dimensions:

Surface Area: LP condenser has 194,480 ft^2 and the HP condenser has 212,290 ft^2.

Weight: LP condenser weighs 905,000 lbs empty, 1,890,000 lbs operating (no vacuum), 1,263,000 lbs operating (max vacuum), and 2,890,000 lbs flooded. HP condenser weighs 950,000 lbs empty, 1,960,000 lbs operating (no vacuum), 1,353,000 operating (max vacuum), and 3,089,000 lbs flooded.

Dimensions: LP condenser is 36'-5¼" long and the HP condenser is 39'-0½" long. Both condensers are 29'-0" wide and 39'-0" high.

3.1.6 Type: Base supported, rectangular, twin shell, single pass.

3.1.7 Shell Material and Thickness:

Material: ASTM A-36 steel

Thickness: 5/8"

3.1.8 Tube / Sheet Design:

Material: Inhibited Muntz Metal, ASTM B-171

Thickness: 1-1/8"

Tubes: Are of Type 304 stainless steel, are 1" in outside diameter, and are 0.028" thick. The effective tube length is 37'-4-3/4" in the LP shell and 40' in the HP shell.

Support Plate Spacing:

There are (10) tube support plates in the LP shell and (11) in the HP shell. This results in a support spacing of about 3'-5" in the LP shell and 3'-4" in the HP shell.

3.1.9 Hotwell Capacity:

The combined low pressure and high pressure hotwell storage capacity is 72,500 gallons.

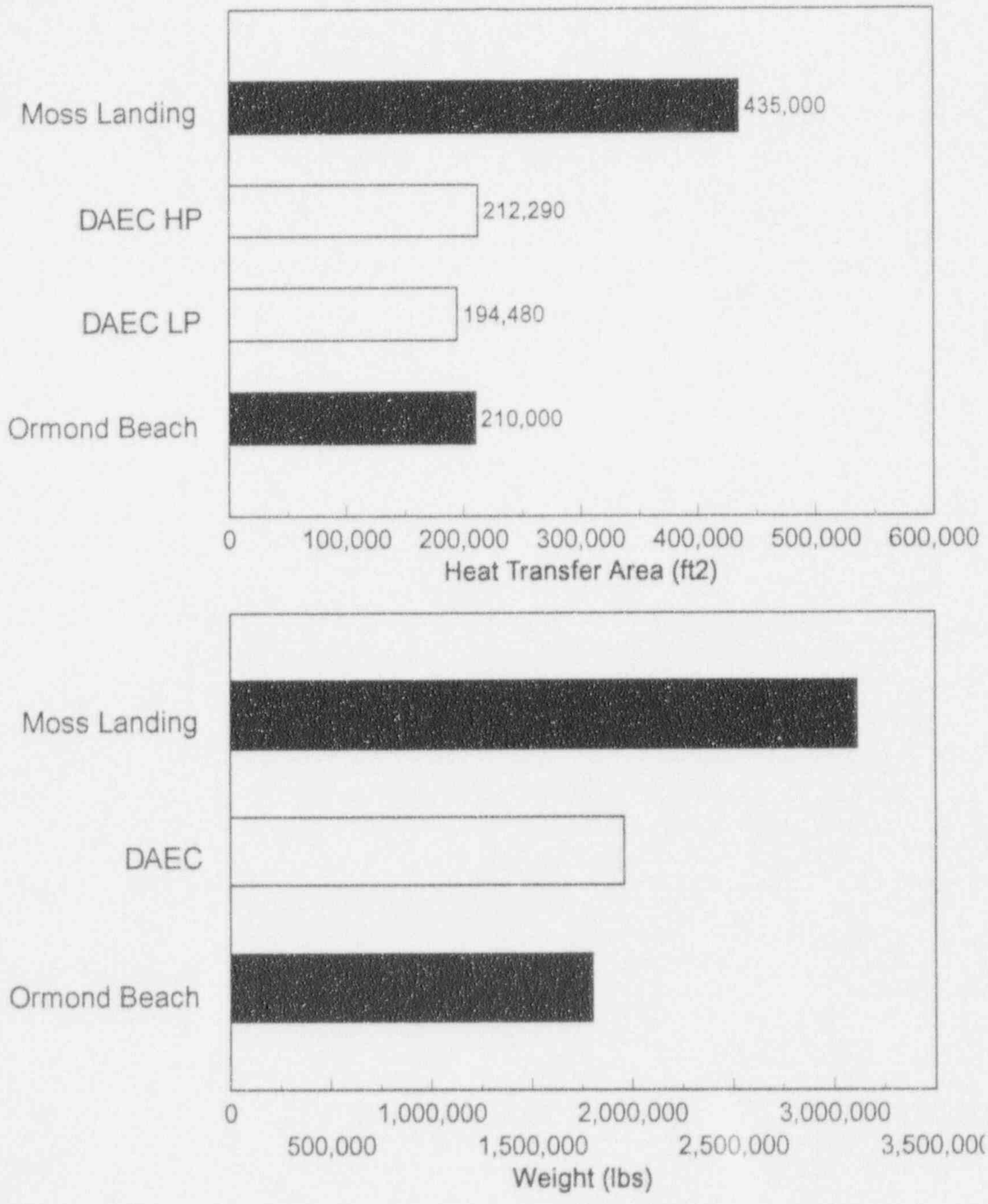


Figure 3-1: Size Comparison of the DAEC Condenser with Representative Condensers from the Earthquake Experience Database

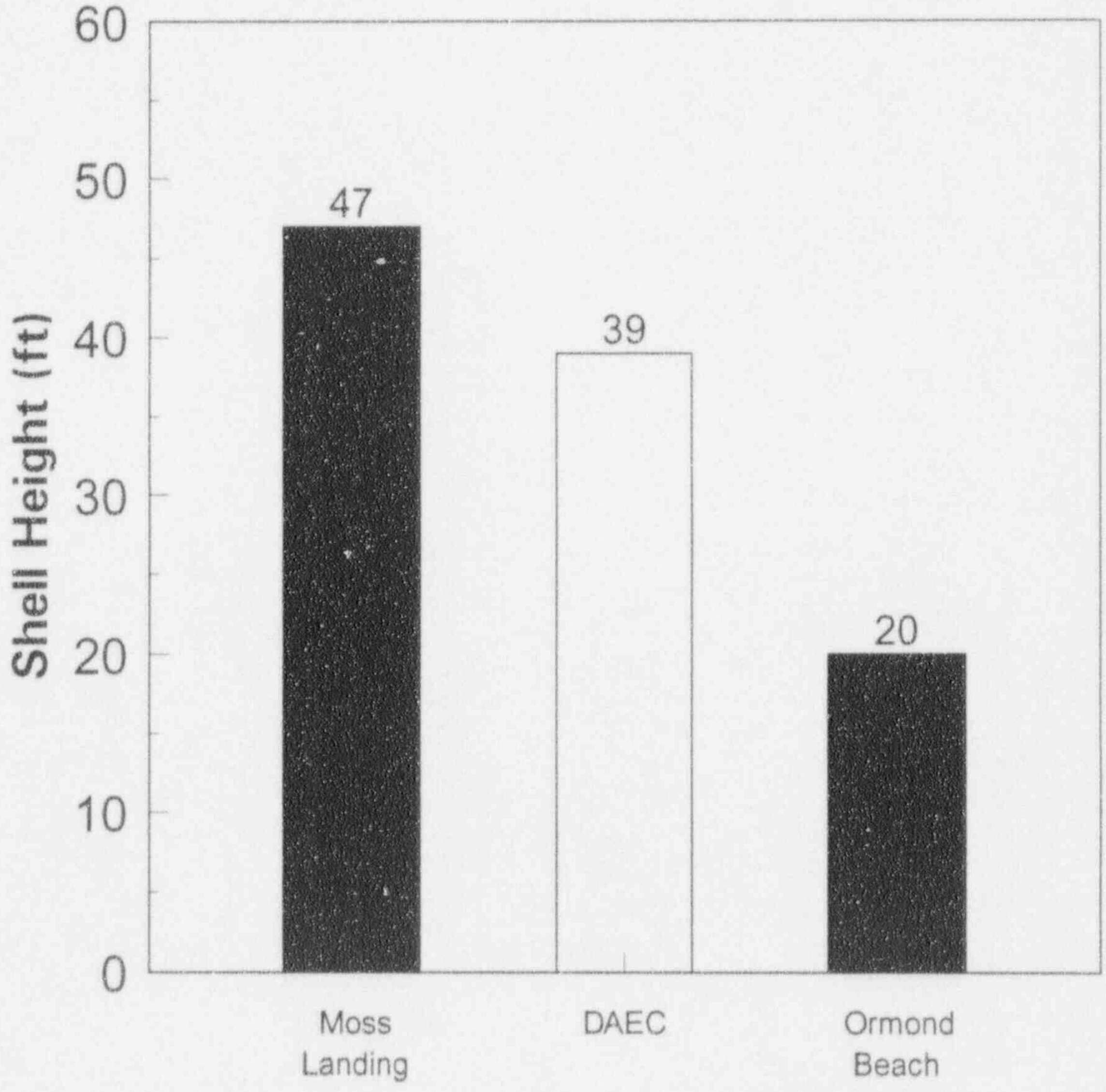
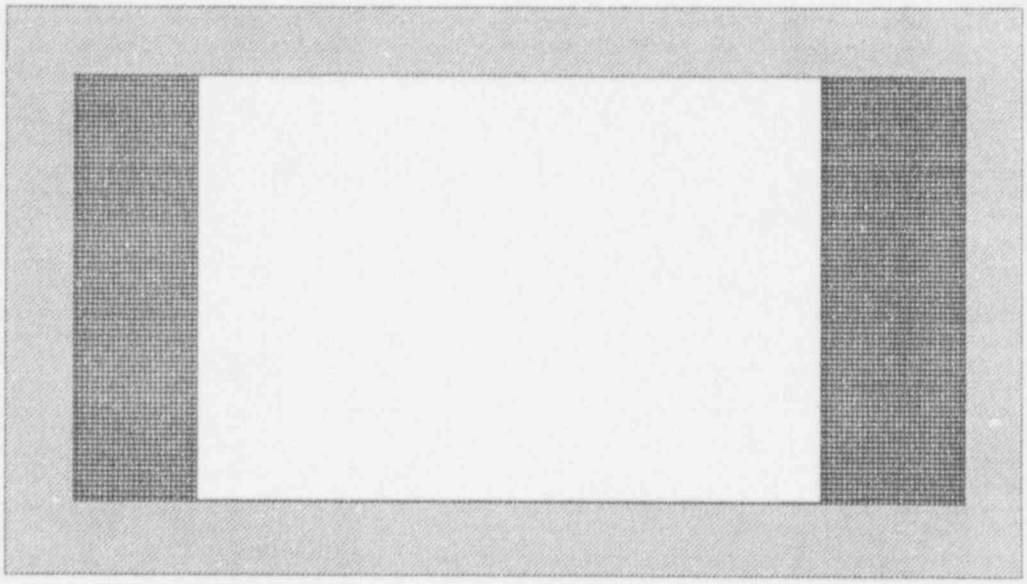


Figure 3-2: Size Comparison of the DAEC Condenser with Representative Condensers from the Earthquake Experience Database



(light shading)	Moss Landing 6 & 7	(65' x 36')
(dark shading)	Ormond Beach 1 & 2	(52' x 27')
(white)	DAEC LP & HP	(Approx. 39' x 29')

Figure 3-3 Condenser Shell Footprint Comparison

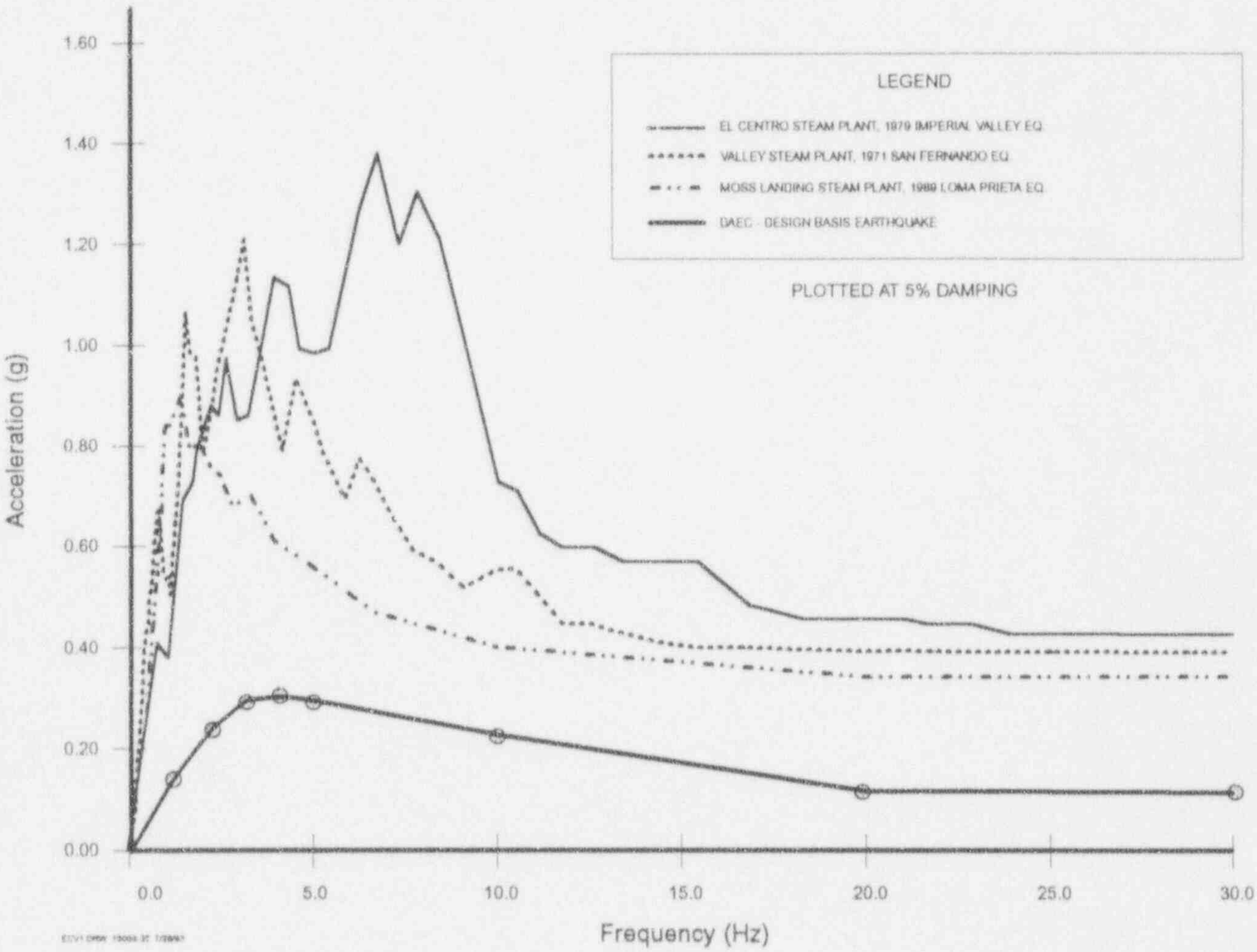
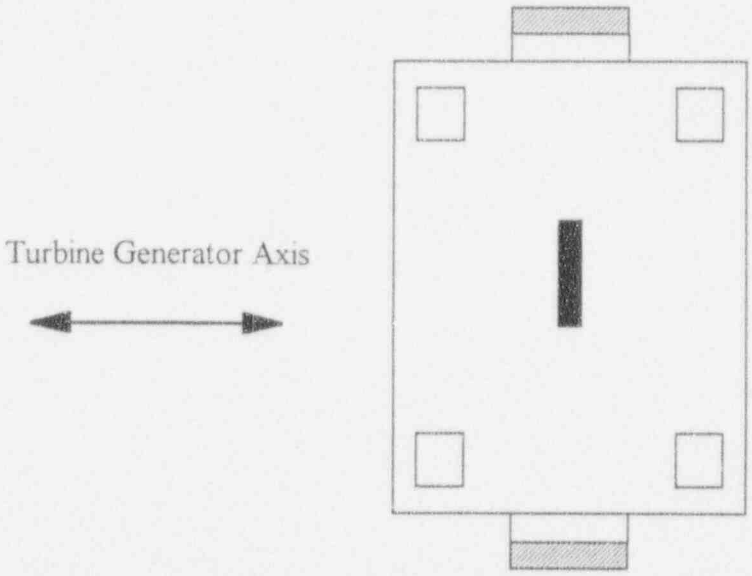


Figure 3-4: Comparison of DAEC Ground Response Spectrum to Data Base Spectra

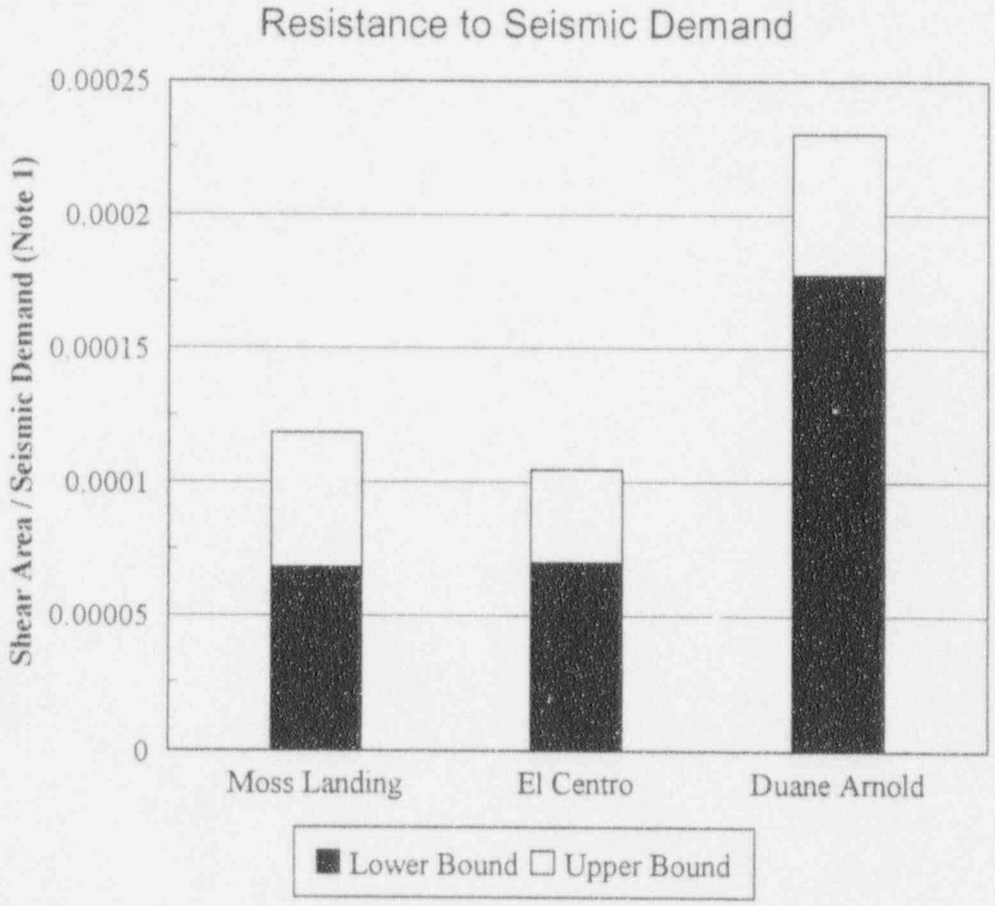


- Sliding Support with Anchor Bolts and Oversized Holes for Vertical Loads

- Fixed Point Considered Active Only in Perpendicular Horizontal Direction

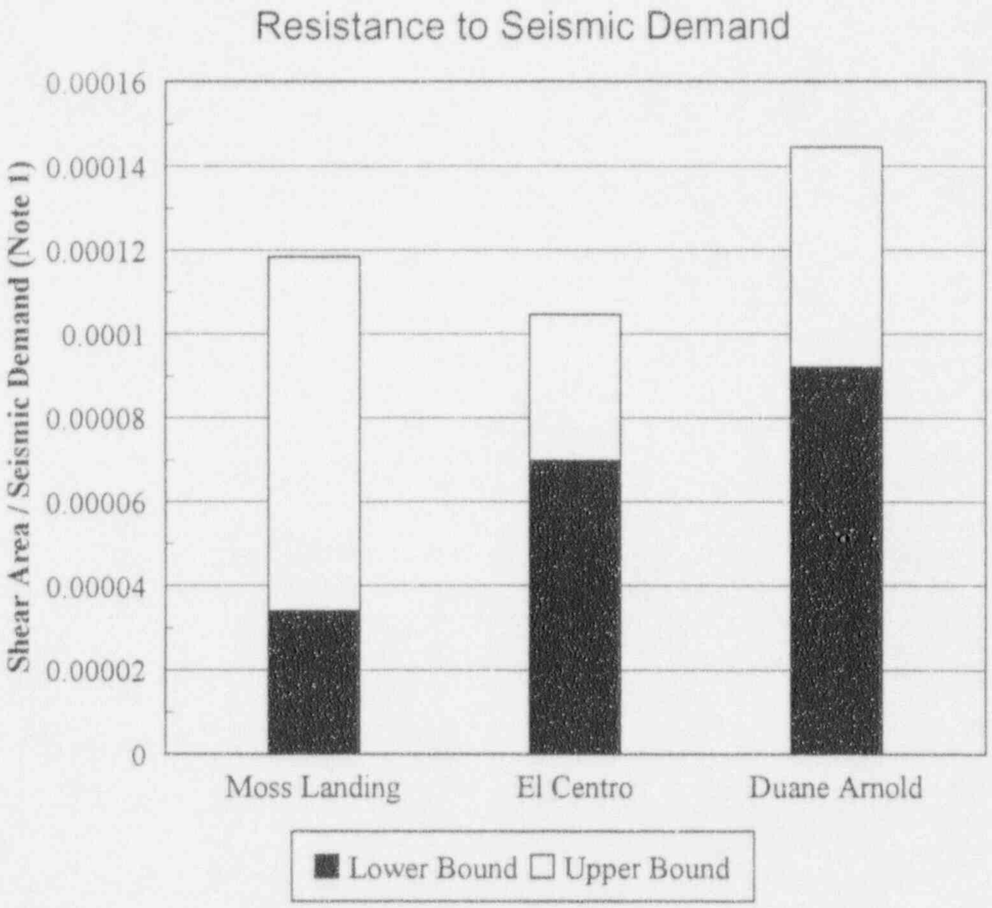
- Flexible Plate Perpendicular to Axis and Fixed in Parallel Horizontal Direction

Figure 3-5: HP and LP Condenser Anchorage Layout



Note 1: Shear Area (in2) / Seismic Demand (condenser weight * g level)

Figure 3-6 Anchorage Compared to Seismic Demand Parallel to the Turbine Generator Axis



Note 1: Shear Area (in2) / Seismic Demand (condenser weight * g level)

Figure 3-7 Anchorage Compared to Seismic Demand Perpendicular to the Turbine Generator Axis

4.0 MAIN STEAM AND DRAIN LINE/BYPASS PIPING

Those portions of main steam and drain line/bypass piping designs that were not seismically analyzed as part of the original plant design were evaluated to demonstrate that piping and supports fall within the bounds of design characteristics found in selected conventional power plant steam piping. These conventional power plant steam piping designs demonstrated good seismic performance and were shown to be comparable to the steam piping design for Duane Arnold. This included (1) a review of design codes and standards used to insure adequate dead load support margin and ductile support behavior where subject to lateral loads, (2) a review of capacity vs. demand for various critical supports, (3) a review of anchorage capacity vs. demand, and (4) a walkdown to verify that small diameter piping and instrumentation is free of impact interactions from falling and proximity or differential motion hazards.

Portions of the main steam piping that were seismically analyzed as part of the original plant design included the Main Steam Line (from the MSIV to the turbine stop valve) and the main steam bypass (to the bypass valves), and portions of various main steam branch connections to the seismic anchor downstream of the isolation valves for the branch. Design methods for these analyzed lines were consistent with seismic Category I qualification methods for Duane Arnold and design capacities are expected to be adequate to assure good seismic performance.

For lines designed by rule or by approximate methods such as the drain path and interfacing piping, it was demonstrated that these systems are composed of welded steel pipe and standard support components, well represented in conventional plants in the earthquake database. Further, it was demonstrated that adequate capacity exist for typical or bounding support anchorages.

In summary, the piping for the main steam and bypass was seismically analyzed and designed in accordance with ANSI B31.1.0. Thus, although it has thinner walls than most piping of its size in the earthquake experience database, its seismic capability is consistent with seismic Category I design requirements. The main drain and associated piping are similar to the piping found in commercial piping systems in the earthquake experience database that have experienced earthquakes in excess of the Duane Arnold design basis earthquake (see Figures 4-1, 4-2 and Attachment I). Minor interaction issues identified in the walkdown that could be potential sources of damage were evaluated, and, where necessary, action has been initiated to eliminate the potential (see Table 4-2). Specific data used in the evaluation is summarized below. For the main drain and interconnected piping, it was demonstrated that adequate capacity exists to provide reasonable assurance that piping position retention will be maintained by the system supports under normal and earthquake loading.

4.1 Main Steam and Turbine Bypass

These systems were analyzed in accordance with the ANSI B31.1 code, using response spectrum analysis techniques. The analysis model included the main steam (to the turbine), the bypass line, and significant branch piping up to the seismic anchor. Margin for the main steam and turbine bypass is basically the design margin inherent in the seismic design codes.

4.1.1 Design Basis

4.1.1.1 Piping Design Code: ANSI B31.1.0, 1967.

4.1.1.2 Piping Design:

a. Design Temperature: 563°F
Design Pressure: 1140 psi

b. Size, schedule and D/t

Pipe Size (NPS)	Schedule	Thickness (inch)	D/t
20	80	1.031	19
12	80	0.687	19
10	80	0.593	18
6	80	0.432	15
4	80	0.337	13
3	160	0.437	8

c. Typical Support Spacing: B31.1 suggested span.

d. Support Types: springs, struts, snubbers, box types, etc.

e. Design Loading: Weight, thermal expansion, seismic

f. Analysis Method: Linear elastic analysis, seismic spectrum analysis

g. Seismic and Dynamic Design Basis: Response spectrum analysis using floor response spectra based on the design basis earthquake (DBE) from the FSAR (0.12 g maximum ground motion - see Figure 3-4 for comparison to experience database ground motion)

4.1.1.3 Pipe Support Design Code: AISC, MSS SP58

4.1.1.4 Margin Assessment:

Design methods for these analyzed lines are consistent with seismic Category I qualification methods for Duane Arnold and Design margins are expected to be adequate to assure good seismic performance.

4.1.2 Main Steam and Turbine Bypass Supplemental Verification Walkdown Results

See Table 4-2.

4.2 Main Steam Drain to Condenser

The main steam drain to the condenser is of welded pipe, and was analyzed by rule and approximate methods. The main drain and associated piping are similar to the piping found in commercial piping systems in the earthquake experience database that have experienced earthquakes in excess of the Duane Arnold design bases earthquake (see Figure 3-4). Minor interaction issues identified in the walkdown that could be potential sources of damage were evaluated, and, where necessary , action has been recommended to eliminate the potential (see Table 4-2). Specific data used in the evaluation is summarized below. For these lines, it was demonstrated that adequate capacity exists to provide reasonable assurance that piping position retention will be maintained by the system supports under normal and earthquake loading.

4.2.1 Design Basis

4.2.1.1 Piping Design Code: ANSI B31.1.

4.2.1.2 Piping Design:

a. Design Temperature and Pressure: 563°F and 1140 psi
b. Size, schedule and D/t

Pipe Size (NPS)	Schedule	Thickness (inch)	D/t
6	80	0.432	15
3	160	0.437	8
2	160	0.343	7
1	160	0.250	5

c. Typical Support Spacing: B31.1 suggested span.
d. Support Types: Rigid struts, rods, stanchions, springs, snubbers
e. Design Loading: Weight, thermal expansion, seismic
f. Analysis Method: Linear elastic analysis
g. Seismic Basis: Linear elastic analysis - analyzed by rule and approximate methods

4.2.1.3 Pipe Support Design Code: AISC, MSS SP58

4.2.1.4 Support Capacity Assessment:

This assessment is to demonstrate the Main Steam Drain Line design provides adequate capacity when subject to weight and seismic load, thus providing reasonable assurance that the position retention of the line will be maintained during a seismic event. In conjunction with the field verification, this assessment has provided assurance that the supports will behave in a ductile manner and that the lines are free of known seismic hazards. Further, it demonstrates that the Duane Arnold designs will perform in a manner similar to piping and supports that have observed good seismic performance in past strong ground motion earthquakes.

All pipe supports on the Main Steam Drain Line were analyzed for weight and seismic loads using the Conservative Deterministic Failure Margins (CDFM) approach. The following summarizes the procedures used for the capacity vs. demand evaluation:

- The earthquake response spectrum is the estimated realistic median-centered amplified floor response spectrum including a 1.25 factor of conservatism.
- The estimated structural and piping response is median centered.
- The component support capacity is conservatively estimated.

Pipe support anchorage was evaluated using the philosophy of the SQUG Generic Implementation Procedure (GIP). Anchorage seismic capacity vs. demand was checked using the GIP Appendix C criteria.

This combination of conservatively defined seismic demand, median centered response to the seismic demand, and conservative estimate of capacity provides the desired assurance of adequate seismic performance.

4.2.1.4.1 Seismic Demand

Seismic demand is estimated based on median centered margins earthquake response spectra developed for the Duane Arnold turbine building. A mathematical model of the turbine building was analyzed to determine in-structure response spectra. The input time histories were generated to match the response spectra defined by NUREG/CR-0098 5% damped soil conditions and one sigma response, anchored horizontally at 0.12g. Seismic demand was conservatively determined using the peak of the appropriate in-structure floor response times a 1.25 factor of conservatism (GIP Section 4.4.3). This is consistent with the method for determining seismic demand for evaluating anchorage adequacy under the A-46 program. The estimated realistic median-centered amplified floor response spectrum peak values (5% damping) and the values used for support evaluation are summarized as follows:

Elevation (Ft.)	Direction	Median Centered FRS Peak (g)	Median Centered FRS Peak x 1.25 (for Support Evaluation) (g) (Note 1)
834	NS	2.00	-
	EW	2.00	-
	VERT	1.33	-
780	NS	.39	-
	EW	.39	-
	VERT	.26	-
757	NS	.38	.48
	EW	.38	.48
	VERT	.25	.31
734	NS	.33	-
	EW	.32	-
	VERT	.22	-

Note 1: all pipe supports are supported at or below elevation 757'-0".

4.2.1.4.2 Piping System Response Estimation

The system response estimation is a median centered best estimate of the appropriate loadings:

- Loadings combination:
  Operating Mechanical Loads + Dead Weight + Seismic
- Component Standard Supports Designed by Load Rating: $TL \times 0.7 \frac{S_u}{S_u^*}$

where,

TL = Support Test Load ≤ Load under which support fails to perform its intended function

S_u = Material ultimate strength at temperature

S_u^* = Material ultimate strength at test temperature

Operating mechanical loads for this system are thermal expansion loads. Thermal expansion loads identified in the support designs were only included if they added to the cumulative loading. Design dead weight support loads are consistent with tributary area weight procedures.

The seismic response of the line is median centered and utilizes a factored load coefficient methodology to determine seismic loads. The load coefficient utilized is a factor of one (1) times the peak spectral response acceleration in the direction of restraint.

4.2.1.4.3 Pipe Support Component Capacities

The supplemental field verification determined that the support types used are considered to have good seismic performance. The system is supported by a variety of seismic support types including rod hangers, vertical and lateral stanchions, and clamps. In addition, spring hangers are used for dead load support. Many of the support types are constructed from standard support catalog items and typically consist of clamps, threaded rod, weldless eye nuts, turnbuckles, clevis and welded lug attachments to either concrete or to steel structures. Design capacities are provided by manufacturers' ratings.

Load capacity ratings for component standard supports are typically based on test and utilize a factor of safety of 5 in accordance with MSSP-58. The load on which the load capacity data (LCD) is based is therefore a factor of five higher that the catalog load rating. The margins capacities for the component support items are taken as the LCD x 5 x 0.7.

4.2.1.4.4 Pipe Support Anchorage

Evaluation of bolted anchorages to concrete follows the procedures established for the Duane Arnold A-46 program. Concrete anchor bolt capacities are evaluated using Appendix C of the SQUG GIP.

4.2.1.4.5 Support Evaluation Results and Conclusions

All supports demonstrated adequate seismic capacity to resist the estimated demand. The minimum ratio of capacity to demand was found to be 2.3. On this basis it is concluded that the system design has adequate capacity to assure position retention. Furthermore, based on the supplemental field walkdown inspection, the piping systems and their supports are similar to piping systems and support designs that have experienced strong ground motion and demonstrated good seismic performance.

4.2.2 Main Steam Drain to Condenser Supplemental Verification Walkdown Results

See Table 4-2.

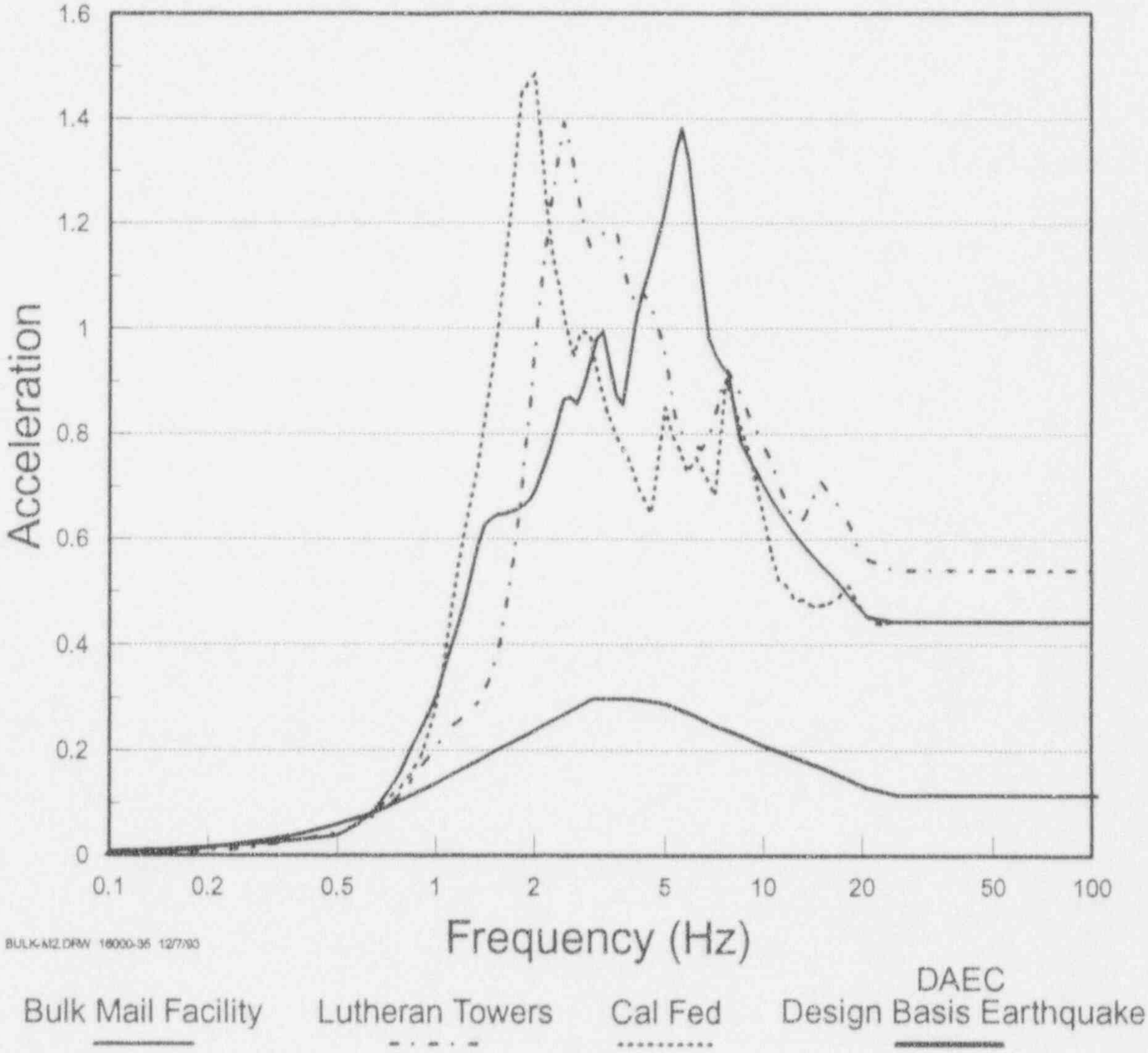


Figure 4-1: Comparison of Whittier database sites and DAEC design spectra (from Attachment I, Figure 27, and DAEC FSAR Figure 2.5-8, Sheet 4)

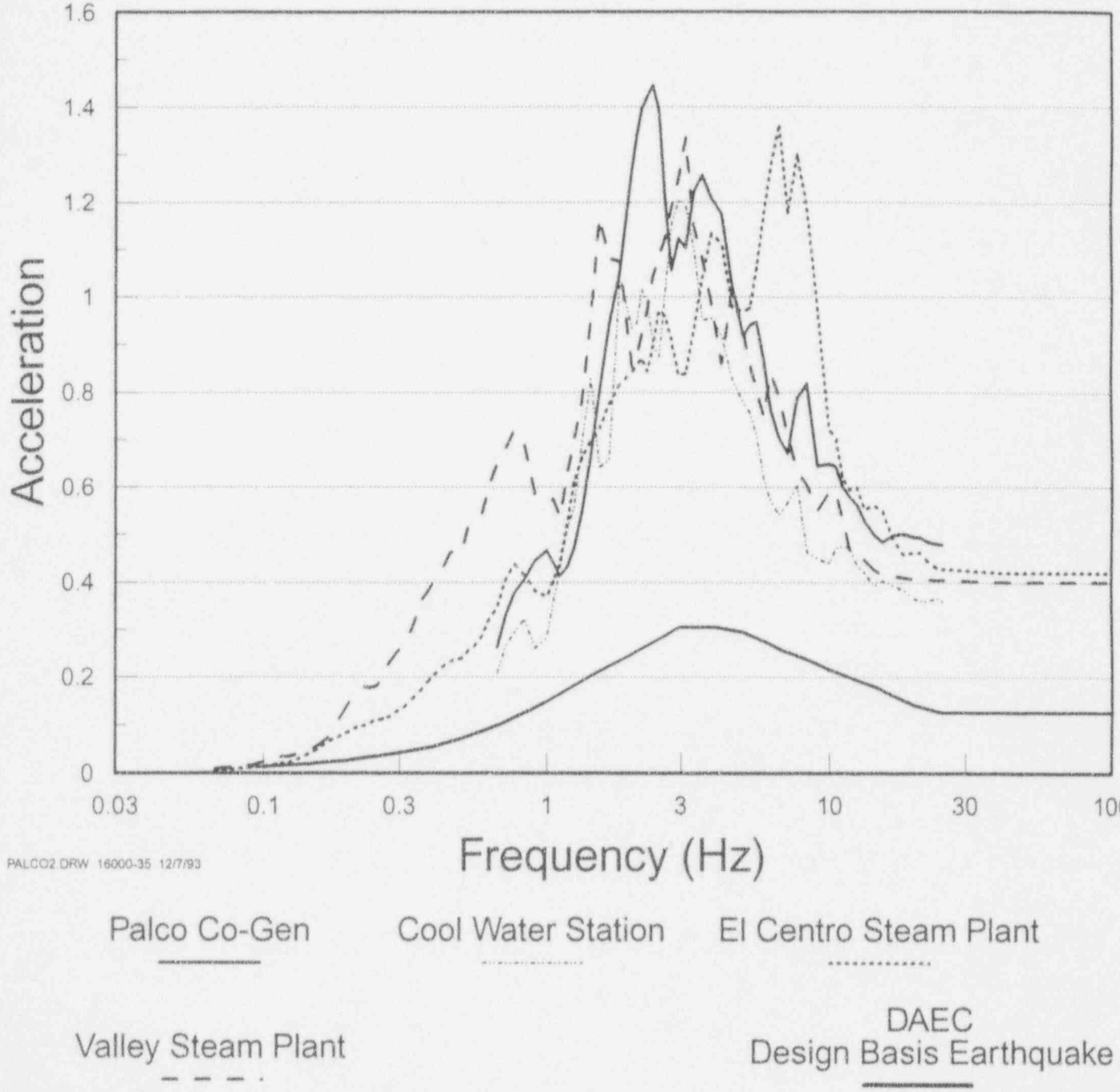


Figure 4-2: Comparison of database power plant sites and DAEC design spectra (from Attachment I, Figure 28, and DAEC FSAR Figure 2.5-8, Sheet 4)

5.0 INTERCONNECTED SYSTEMS

The interconnected systems are composed of welded steel piping and standard support components, well represented in the earthquake experience database. These systems, analyzed by rule and approximate methods, are similar to the piping found in commercial piping systems in the earthquake experience database that have experienced earthquakes in excess of the Duane Arnold design basis earthquake (see Figures 4-1, 4-2 and Attachment I). Minor interaction issues identified in the walkdown that could be potential sources of damage were evaluated, and, where necessary, action has been recommended to eliminate the potential (see Table 4-2). Specific data used in the evaluation is summarized below. For these lines, a sampling of the pipe supports which were judged to be representative of the worst case (lowest capacity vs. demand) were selected for analysis. Supports were analyzed using the same criteria used for the main steam drain line supports.

5.1 Design Basis

Table 4-1 shows the design parameters for the interconnected piping associated with the main steam, main steam bypass, main drain, and condenser.

5.1.1 Support Capacity Assessment for Interconnected Systems

A sampling of the pipe supports for the interconnected systems were reviewed using the same criteria used for the drain line supports. Seismic demand was the peak of the median centered in-structure response spectra times a factor of conservatism of 1.25. Conservative tributary piping spans were used to estimate seismic loading. All analyzed supports demonstrated adequate seismic capacity to resist the estimated demand. The minimum ratio of capacity to demand using conservative component capacity estimates was found to be 1.6. On this basis it is concluded the system design has adequate capacity to insure position retention.

These systems and their supports were also found to be similar to piping system and support design that have experienced strong ground motion and demonstrated good seismic performance.

5.1.2 Supplemental Verification Walkdown Results for Interconnected systems

See Table 4-2

Table 4-1: Interconnected System Design Parameters (Page 1 of 2)

System Designation	Piping Design	Design Temp (°F)	Design Press.(psig)	Size	Sch.	D\t	Support Spacing	Typical Spt. Types	Design Code	Loading	Analysis Method
Main Steam Sample Line	ANSI B31.1	563	1140	1" 3/8" Tubing	160 -	5 -	ANSI B31.1	Tubing Trays on Struts, Beam Clamps	AISC	Chart Method, Std. Spans	Linear Elastic Approximate Methods
Main Steam Instruments	ANSI B31.1	563	1140	3/4" 3/8" Tubing	160 -	5 -	ANSI B31.1	Tubing Trays on Struts & Angle, Beam Clamps	AISC	Chart Method, Std. Spans	Linear Elastic Approximate Methods
Main Steam to 2nd Stage Reheater Drain	ANSI B31.1	563	1140	3/4"	160	5	ANSI B31.1	Rod Hangers, U-Bolts, Stanchion	AISC MSS SP58	DW Thermal Hydro	Linear Elastic Approximate Methods
Main Steam to Offgas Recombiner	ANSI B31.1	563	1140	2" 3"	160 160	7 8	ANSI B31.1	Spring Hangers, Rod Hangers, Sleeves	AISC MSS SP58	DW Thermal Hydro	Linear Elastic Approximate Methods
SJAE Condensers to Main Condenser	ANSI B31.1	150	5 to 30	1 ½" 2" 3"	80 80 40	10 11 16	ANSI B31.1	Rigid U-Bolts, Rod Hangers	AISC MSS SP58	DW Thermal Hydro	Linear Elastic Approximate Methods
Offgas O_2 Injection to Steam Jet Air Ejector	ANSI B31.1	125 125 125	150 50 50	1/2" 3/4" 2"	40S 80 80	8 7 11	ANSI B31.1	Unstrut w/Pipe Straps	AISC MSS SP58	DW Thermal Hydro	Linear Elastic Approximate Methods
Condenser to Steam Jet Air Ejectors	ANSI B31.1	125	50	4 6 10 16	40 40 40 STD.	19 24 29 43	ANSI B31.1	Rod Hangers, Pipe Clamps, Spring Hangers	AISC MSS SP58	DW Thermal Hydro	Linear Elastic Approximate Methods

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Table 4-1: Interconnected System Design Parameters (Page 2 of 2)

System Designation	Piping Design	Design Temp (°F)	Design Press.(psig)	Size	Sch.	D\t	Support Spacing	Typical Spt. Types	Design Code	Loading	Analysis Method
Steam Bypass to Turbine Steam-Seal	ANSI B31.1	563	1140	1" 3" 4"	160 160 80	5 8 13	ANSI B31.1	Rod Hangers, Spring Hangers, Straps	AISC MSS SP58	DW Thermal Hydro	Linear Elastic Approximate Methods
Main Steam to Air Ejector	ANSI B31.1	563	1140	3/4" 1½" 3" 4"	160 160 160 80	5 7 8 13	ANSI B31.1	Rod Hangaers, Spring Hangers	AISC MSS SP58	DW Thermal Hydro	Linear Elastic Approximate Methods
Offgas Sampler to Condensate Return	ANSI B31.1	100	150	1" 3/8" & 1/2" Tubing	80 -	 -	ANSI B31.1	Rod Hangers, Unstrut w/Tube Clamps	AISC MSS SP58	DW Thermal Hydro	Linear Elastic Approximate Methods
Main Steam Vent to CRW	ANSI B31.1	563	1140	3/4"	160	5	ANSI B31.1	Rod Hangers	AISC MSS SP58	DW Thermal Hydro	Linear Elastic Approximate Methods
Miscellaneous Main Steam Drains & Branches	ANSI B31.1	563	1140	3/4" 1" 1½" 2"	160 160 160 160	5 5 7 7	ANSI B31.1	Rod Hangers, Rigid U-Bolts	AISC MSS SP58	DW Thermal Hydro	Linear Elastic Approximate Methods
Main Steam Vents	ANSI B31.1	563	1140	3/4"	160	5	ANSI B31.1	Rigid U-Bolts	AISC MSS SP58	DW Thermal Hydro	Linear Elastic Approximate Methods

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Table 4-2: Outlier Identification and Resolution (Page 1 of 5)

SYSTEM DESCRIPTION	OUTLIER NUMBER AND DESCRIPTION	OUTLIER TYPE (POTENTIAL FAILURE MODE)					RESOLUTION STATUS	REQUIRED ACTION
		A	F	P	D	V		
MAIN STEAM DRAINS (IN STEAM TUNNEL)	#1: PIPING SPAN EXCEEDS SCREENING CRITERIA		X				ACCEPTABLE AS-IS BY ANALYSIS	N/A
	#23: VALVE MOTOR OPERATOR HEIGHT AND WEIGHT EXCEED SCREENING CRITERIA					X	ACCEPTABLE AS-IS BY ANALYSIS	N/A
STEAM LINE DRAINS (IN TURBINE BLDG)	#5:PIPING SPAN EXCEEDS SCREENING CRITERIA		X				ACCEPTABLE AS-IS BY ANALYSIS	N/A
	#6: DISENGAGED PIPE SUPPORT EDB 3-H-44	X					NOT ACCEPTABLE AS-IS	MODIFY AND REINSTALL SUPPORT
	#18: VALVE MOTOR OPERATOR HEIGHT EXCEEDS SCREENING CRITERIA					X	ACCEPTABLE AS-IS BY ANALYSIS	N/A
MAIN STEAM LINE BRANCHES	#7: QUESTIONABLE SUPPORT FUNCTION MAY NOT ACCOMMODATE DIFFERENTIAL BUILDING MOVEMENT				X		NOT ACCEPTABLE AS-IS	FIELD VERIFICATION AND MODIFICATION OF AS-INSTALLED SUPPORT CLEARANCES (IF FOUND INSUFFICIENT)
MAIN STEAM LINE BRANCHES	#8: MASONRY WALL IS A POTIENTIAL INTERACTION HAZARD TO ADJACENT PIPING		X				ACCEPTABLE AS-IS BY ANALYSIS	N/A

KEY TO OUTLIER TYPES

A ANCHORAGE OR SUPPORT CAPACITY
F FAILURE AND FALLING
P PROXIMITY AND INPACT
D DIFFERENTIAL AND DISPLACEMENT
V VALVE OPERATOR SCREENING

DAEC/TABLE 4_2.DOC

Table 4-2: Outlier Identification and Resolution (Page 2 of 5)

SYSTEM DESCRIPTION	OUTLIER NUMBER AND DESCRIPTION	OUTLIER TYPE (POTENTIAL FAILURE MODE)					RESOLUTION STATUS	REQUIRED ACTION
		A	F	P	D	V		
MAIN STEAM TO STEAM JET AIR EJECTOR (SJAE)	#9: PIPING BRANCH LINE MAY NOT HAVE ADEQUATE FLEXABILITY TO ACCOMMODATE SEISMIC MOVEMENT				X		ACCEPTABLE AS-IS BY ANALYSIS	N/A
	#11: MASONRY WALL IS A POTENTIAL INTERACTION HAZARD TO ADJACENT PIPING		X				ACCEPTABLE AS-IS BY ANALYSIS	N/A
MAIN STEAM SAMPLE LINE	#4: MASONRY WALL IS A POTENTIAL INTERACTION HAZARD TO BRANCH LINES		X				ACCEPTABLE AS-IS BY ANALYSIS	N/A
	#22: POTENTIAL EXCESSIVE CABINET DEFLECTIONS DUE TO BASE DETAIL COULD AFFECT ATTACHED LINES				X		ACCEPTABLE AS-IS BY ANALYSIS	
	#24: TUBING SPAN EXCEEDS SCREENING CRITERIA		X				ACCEPTABLE AS-IS BY ANALYSIS	N/A

KEY TO OUTLIER TYPES

- A ANCHORAGE OR SUPPORT CAPACITY
- F FAILURE AND FALLING
- P PROXIMITY AND INPACT
- D DIFFERENTIAL AND DISPLACEMENT
- V VALVE OPERATOR SCREENING

DAEC/TABLE 4_2.DOC

Table 4-2: Outlier Identification and Resolution (Page 3 of 5)

SYSTEM DESCRIPTION	OUTLIER NUMBER AND DESCRIPTION	OUTLIER TYPE (POTENTIAL FAILURE MODE)					RESOLUTION STATUS	REQUIRED ACTION
		A	F	P	D	V		
MAIN STEAM TO 2ND STAGE REHEATER	#2: PIPING SPAN EXCEEDS SCREENING CRITERIA, PIPE IS SAGGING		X				NOT ACCEPTABLE AS-IS	ADD SUPPORTS
	#3: LOOSE ANCHOR BOLTS ON PIPE SUPPORT	X					NOT ACCEPTABLE AS-IS	REPAIR BY TIGHTENING ANCHOR BOLTS OR RE-LOCATING SUPPORT AND REPLACING BOLTS
MAIN STEAM BYPASS TO TURBINE STEAM SEAL	#12: PIPING SPAN EXCEEDS SCREENING CRITERIA AND SPRING SUPPORT OVERLOADED		X				SPRING SUPPORT NOT ACCEPTABLE AS-IS. PIPING SPAN ACCEPTABLE AS-IS BY ANALYSIS	RESET SPRING SUPPORT
	#13: BROKEN PIPE SUPPORT (U-BOLT)	X					NOT ACCEPTABLE AS-IS	REMOVE DAMAGED PIPE SUPPORT
	#14: VICTAULIC COUPLINGS ON FIRE PROTECTION PIPING SUSPENDED FROM RODS ATTACHED WITH FRICTION CLAMPS		X				NOT ACCEPTABLE AS-IS	MODIFY PIPING BY ADDING NEW SUPPORTS

KEY TO OUTLIER TYPES

A ANCHORAGE OR SUPPORT CAPACITY
F FAILURE AND FALLING
P PROXIMITY AND INPACT
D DIFFERENTIAL AND DISPLACEMENT
V VALVE OPERATOR SCREENING

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Table 4-2: Outlier Identification and Resolution (Page 4 of 5)

SYSTEM DESCRIPTION	OUTLIER NUMBER AND DESCRIPTION	OUTLIER TYPE (POTENTIAL FAILURE MODE)					RESOLUTION STATUS	REQUIRED ACTION
		A	F	P	D	V		
SJAE CONDENSERS TO MAIN CONDENSER	#15: MASONRY WALLS ADJACENT TO AIR EJECTOR CONDENSATE TANK ARE POTENTIAL INTERACTION HAZARDS		X				ACCEPTABLE AS-IS BY ANALYSIS	N/A
	REVIEW ANCHORAGE OF SJAE CONDENSATE RETURN TANK (IT-136)	X					ACCEPTABLE AS-IS BY ANALYSIS	N/A
CONDENSER TO SJAES	#17: MASONRY WALLS ADJACENT TO PIPING AND VALVE ARE POTENTIAL INTERACTION HAZARDS		X				ACCEPTABLE AS-IS BY ANALYSIS	N/A
	#20: VALVE AIR OPERATOR HEIGHT EXCEEDS SCREENING CRITERIA					X	ACCEPTABLE AS-IS BY ANALYSIS	N/A
	#21: VALVE AIR OPERATOR HEIGHT AND WEIGHT UNKNOWN					X	ACCEPTABLE AS-IS BY ANALYSIS	N/A
MAIN STEAM TO STEAM SEAL	#19: VALVE MOTOR OPERATOR HEIGHT EXCEEDS SCREENING CRITERIA AND WEIGHT IS UNKNOWN					X	ACCEPTABLE AS-IS BY ANALYSIS	N/A

KEY TO OUTLIER TYPES

A ANCHORAGE OR SUPPORT CAPACITY
F FAILURE AND FALLING
P PROXIMITY AND INPACT
D DIFFERENTIAL AND DISPLACEMENT
V VALVE OPERATOR SCREENING

DAEC/TABLE 4_2.DOC

Table 4-2: Outlier Identification and Resolution (Page 5 of 5)

SYSTEM DESCRIPTION	OUTLIER NUMBER AND DESCRIPTION	OUTLIER TYPE (POTENTIAL FAILURE MODE)					RESOLUTION STATUS	REQUIRED ACTION
		A	F	P	D	V		
MAIN STEAM INSTRUMENTATION LINES	#27: TUBING SPAN EXCEEDS SCREENING CRITERIA		X				ACCEPTABLE AS-IS BY ANALYSIS	N/A
	#28: MISSING U-BOLT FOR PIPE SUPPORT ON ADJACENT AIR LINE			X			NOT ACCEPTABLE AS-IS	INSTALL U-BOLT
MAIN STEAM INSTRUMENTATION LINES	#25: MASONRY WALL IS A POTENTIAL INTERACTION HAZARD TO ADJACENT TUBING AND INSTRUMENT RACKS IC-210A AND IC-210B		X				ACCEPTABLE AS-IS BY ANALYSIS	N/A
	#26: MASONRY WALL IS A POTENTIAL INTERACTION HAZARD TO INSTRUMENT RACKS FOR PS1014, 1015, 1016, 1017		X				ACCEPTABLE AS-IS BY ANALYSIS	N/A
	REVIEW ANCHORAGE FOR INSTRUMENT RACKS IC-210A,IC-210B,IC-212A	X					ACCEPTABLE AS-IS BY ANALYSIS	N/A
CONDENSER	REVIEW FOR ANCHORAGE AND EXPERIENCE BOUNDING	X					ANCHORAGE IS ADEQUATE AND CONDENSER IS WELL REPRESENTED IN THE DATABASE	N/A

KEY TO OUTLIER TYPES

A ANCHORAGE OR SUPPORT CAPACITY
F FAILURE AND FALLING
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V VALVE OPERATOR SCREENING

ATTACHMENT I

SUPPLEMENTAL PIPING EARTHQUAKE PERFORMANCE DATA

December 1993

INTERNATIONAL

SUPPLEMENTAL PIPING EARTHQUAKE PERFORMANCE DATA

December 1993

Prepared for:

GENERAL ELECTRIC NUCLEAR ENERGY

EQE INTERNATIONAL

INTRODUCTION

This report, submitted in support of the Hatch Unit 2 license change request for deletion of the MSIV Leakage Control System, provides supplemental piping seismic performance data to Appendix D of the Generic Electric NEDC - 31858 (Reference 1). The material presented for earthquake experience data base sites includes sites investigated since the initial work in Reference 1 as well as supplemental data covering a more comprehensive range of pipe sizes and design parameters. Specific supplements include:

- Piping performance data for both large and small bore piping covering a range from three quarters (3/4) inch to eight (8) inches in diameter.
- Seismic experience data on large and small diameter piping from power plant sites discussed in NEDC-31858.
- Seismic experience data and damage surveys from power plant and industrial sites not covered in NEDC-31858.
- Piping support design data for large and small diameter systems.
- Data base site ground motion data comparisons with the Hatch Unit 2 seismic design basis.

The supplemental data provided in support of Hatch Unit 2 supports the conclusions of NEDC-31858, that welded steel power piping of all sizes have substantial seismic ruggedness even when not designed to resist earthquakes.

BACKGROUND PIPING EXPERIENCE DATA BASE

A detailed seismic experience data base of the performance of power and industrial facilities during past earthquakes is founded on extensive studies of over 100 industrial facilities and surveys of several hundred other facilities located in the vicinity of over 60 strong motion earthquakes that have occurred in California, Alaska, New Zealand and Latin American countries since 1971. The earthquakes

and major facilities included in the data base are summarized in Table 1. Specific objectives of the experience data approach to seismic evaluation include:

- Documentation of the most common sources of seismic damage or operational difficulties in facilities that contain installations representative of critical nuclear plants systems;

- Identification of the threshold of seismic motion corresponding to various types of seismic damage;

- Determination of installations which are typically undamaged by earthquakes, regardless of the level of seismic motion;

- Identification of minimum standards in equipment installations that will ensure the seismic integrity of the system.

In general, data collection efforts focused on facilities located in the areas of strongest ground motion for each earthquake investigated. Facilities were sought that contained substantial inventories of piping, mechanical and electrical equipment.

Because of the number of earthquake-affected areas and types of facilities investigated, there is a wide diversity in the types of installations included in the data base. This wide diversity includes age, size, configuration, application, operating conditions, manufacturer, type of building, location within the building, local soil conditions, quality of maintenance, and quality of construction.

The detailed data base includes a total of 24 earthquakes, usually with several different sites investigated in each earthquake-affected area. The earthquakes investigated range in Richter magnitude from 5.4 to 8.1. Measured or estimated ground accelerations for data base sites range from 0.10g to up to 1.25g vertical acceleration. The duration of strong ground shaking (on the order of 0.10g or greater) ranges from 5 seconds to more than 50 seconds. Local soil conditions range from deep soft alluvia to rock. The buildings housing the piping of interest have a wide range in size, and type of construction. As a result, the data base covers a wide diversity of seismic input, in terms of seismic motion amplitude, duration, and frequency content.

Table 1 lists the average horizontal peak ground acceleration that was either measured, or estimated for selected data base sites. This ground acceleration represents the average of the peak accelerations in two orthogonal horizontal directions. With few exceptions, facilities were not investigated unless they experienced ground motion of 0.20g or greater.

PIPING IN THE EXPERIENCE DATA BASE

The experience data base for piping in the field consists of the following:

(1) Casual data from various, mostly older, reports on earthquakes pre-dating about 1979. These reports typically discuss only damage to piping, without elaborate discussions on the causes of damages and on the inventory of undamaged piping. Reports pre-dating the 1971 San Fernando earthquake usually have a few scattered observations offered by structural engineers who were not familiar with piping design.

(2) Specific data from various, mostly newer, reports on earthquakes since about 1971. These data are typically of two types -- damage reports by the operators of facilities and investigation reports by outside earthquake engineers who visited and studied the affected facilities. Typically, plant damage reports are written by plant engineers and tend to detail all significant damage to piping (and equipment), but often do not site the reasons for the damage, and do not discuss the performance of the remaining inventory of piping. Earthquake investigation reports on the performance of industrial and power facilities are sponsored by various organizations (EPRI, SQUG, NRC) in order to determine in detail the performance of facilities, the details of the known damage, the causes of the damage, and to obtain a general inventory of the piping that was affected.

(3) Detailed reports include detailed data on the piping itself for a given facility, its performance, and all damage, including the causes of the damage. Such a report would typically be based on a very detailed data collection effort at a specific facility. Such reports were initiated by the NRC for the El Centro plant for the 1979 M6.6 Imperial Valley (Reference 3) and 1980 Humboldt Bay (Reference 4). Many reports were also prepared principally by EQE for

SQUG, EPRI, the Earthquake Engineering Research Institute and other organizations since 1981 on numerous earthquakes and facilities.

The data base currently includes about 60 earthquakes, dating back to the 1933 Long Beach, California earthquake. Table 1 lists selected, more important earthquakes for which detailed data have ben collected. Damage and some inventory data have been collected for about 30 earthquakes. That includes about 200 industrial sites, and several hundred commercial structures that house piping. These facilities contain many millions of linear feet of pipe, over one million pipe supports and retainers (for lateral loads), many tens of thousands of piping components such as nozzles and elbows and thousands of valves.

The strength of the data base is in the quantity and variety of piping configurations, piping runs, and support and ground motions. Peak free field horizontal ground accelerations at affected data base facilities vary up to 1.0g, with durations of strong motion in excess of 60 seconds, as compared to a typical nuclear power plant SSE of less than 0.25g and a duration of motion of 15 seconds. The magnitudes of the data base events vary from about 5.0 to more than 8.0. The spectral shapes of the ground motion records vary from very broad band to narrow band and many envelope the broadest spectra used for design of nuclear facilities.

The foundation conditions of the data base facilities vary from very soft soils (some of which experienced liquefaction directly underneath data base piping) to highly competent rock. The data base includes a wide variety of ground conditions, including shallow overburdens. Further, a number of facilities are located very near the ruptured faults or in the uplifted or down dropped region of thrust faulting, resulting in high accelerations over a variety of ground conditions.

The data base piping is supported within a tremendous variety of structures, whose natural frequencies vary from very flexible (less than 1.0 Hz) to practically rigid. The structures include underground massive concrete structures to tall, slender structures, such as towers, over 300 feet tall. The taller structures include power plant and refinery structures, as well as conventional commercial structures. The structures include steel, masonry, and reinforced concrete structures of vintages from the 1940s through the late 1980s.

The thousands of housed piping systems include a wide variety of support conditions, geometrical configurations, size distributions and all other piping system variables. The natural frequencies of these systems vary from extremely flexible (less than 0.5 Hz) to rigid. Further, the quality of construction of many data base systems is much lower than the quality of typical nuclear plant systems -- that is particularly true of the data base from foreign facilities and older petrochemical facilities. The maintenance of the data base systems, on the average, is inferior to that of nuclear plant systems.

The large majority of data base piping systems was not specifically designed for seismic loads. A few systems were seismically designed using static approaches, a few systems were designed with snubbers (although it is not clear that the snubbers were specified for seismic reasons), and a large number of systems, particularly in California, were designed and supported, to resist earthquakes. That resistance is typically provided through motion limiters (such as gaps and friction connectors).

Several data base facilities have been subjected to multiple strong earthquakes. For example, the PALCO co-generation three boiler power plant, was subjected to three back to back earthquakes with magnitudes of 7.0, 6.0 and 6.5 on April 25 and 26, 1992. The peak horizontal ground accelerations near the plant, on better soil than that at the plant, were 0.55g, 0.55g, and 0.25g. Other sites with multiple earthquakes include Humboldt Bay and El Centro.

Many data base facilities are founded on soft, alluvial sites. The majority of their structures are flexible and the majority of the piping systems are also flexible. Therefore, numerous piping systems in a typical data base plant experienced large amplifications of the free-field ground motions.

This wide variety of piping configurations and dynamic excitations provides a data base that is representative of most piping systems found in power facilities. For example, Reference 6, contains a review of data in the literature from 29 earthquakes worldwide from 1923 to 1985. In addition, detailed site data were collected from 20 power plant units. The primary focus of the study was above-ground welded steel piping, but other types, such as buried and threaded piping, were also covered. The study reviewed the range of piping parameters covered by the experience data and concluded that those piping systems found in power plants, including nuclear power plants, would be covered by the data. Further, it concluded

that the sample size was sufficiently large that all credible failure modes for power piping would be revealed by the data.

<u>Analyses of Piping Experience Data</u>

Numerous analyses of the piping experience data have been conducted. Such analyses have typically addressed the failures in the data base piping and how these failures could be used, in conjunction with the inventory of undamaged pipes, to define design and review criteria.

Reference 6 summarizes all known damage and failures to piping form earthquakes included in that data base through the 1985 Chile earthquake. These data are shown in Table 2. Failures were defined as leaks, breaks, collapses, or loss of flow control. For above ground welded steel piping, failures were due to seismic anchor motion (caused by movement of terminal end equipment, header movements at small branch connections, or differential movements between buildings), deterioration of the wall thickness, progressive hanger failure, and seismic interaction. Failures resulting from seismic inertia forces were not observed.

Reference 5 summarizes examples of piping systems that were the subject of comparative analyses following strong earthquakes. The objective in all cases was to benchmark the analyses used in practice against observed results from earthquakes. It was shown in these comparative analyses that flexible piping is not necessarily highly stressed unless some undesirable design feature is present and that these undesirable features can be isolated without conducting analysis.

Other reviews of the above data have arrived at similar conclusions. In Reference 7, it is stated that: "Experience data collected by SQUG and others and high-level seismic tests on piping conducted in foreign countries and in the U.S. show that piping is not susceptible to failure resulting from seismic inertial loads. The only observed instances of piping failure during the SQUG program to collect seismic experience data were due to degraded pipe, support failures (where such supports were not designed to resist lateral loads), relative movement of anchor points and inadequate or nonexistent anchorage of tanks or equipment for sites with zero period acceleration between 0.25g and 0.60g."

Experience shows that earthquakes rarely cause failures in ductile, flexible piping systems. Studies such as those in NUREG-1061 (Reference 8), reveal that the only

important failure modes during earthquakes of piping equivalent to nuclear piping are the failure of the equipment to which the piping is connected or the very large relative motions of the piping anchor points. Failure of the piping system by collapse because of piping inertia loads has not occurred, even during earthquakes with ground accelerations as high as 0.90g."

For welded steel piping designed and constructed to normal industrial practice (e.g., ANSI B31.1), past seismic experience has never shown a primary collapse mode of failure as envisioned by the ASME Code. Seismic failures have been caused by either excessive relative support movements that failed the support or pulled the pipe apart, or rupture associated with an initial flaw, excessive erosion or corrosion. Failures due to differential support movement have usually resulted from lack of sufficient flexibility in the piping system.

A limited amount of nonlinear piping analyses (References 9 and 10) have also demonstrated that a primary collapse failure mode is highly unlikely. Current practice does not consider that piping systems are capable of absorbing and dissipating a considerable amount of energy when strained beyond their elastic limit, or that an earthquake is capable of inputting only a limited amount of energy into such systems.

Earthquake experience data present us with the only available full-scale tests of our designs and installations. In effect, the current practice for the seismic design of piping has not considered the real performance of piping systems in strong motion earthquakes. The net result is excessive conservatism in the treatment of primary stresses when uncorrected linear elastic analyses are performed and the results are compared to stress limits based on static tests. This conservatism, in the treatment of primary stresses, leads to the use of pipe supports in excess of what is needed to provide acceptable margins against failure for the dynamic loads that may occur.

Above ground piping at data base facilities exhibited excellent resistance to damage during and after earthquakes in spite of a general lack of seismic design considerations and provisions. A limited number of piping failures at data base facilities have been reported.

Damage to piping in the data base seldom results in falling. When falling does occur, it is due to multiple support failure, not pipe breakage. Figure 1 shows a

building which was extensively damaged during the 1971 San Fernando earthquake with rod supported piping intact. Figure 2 shows a piping system which did collapse in a heavily damaged building at the Tasman Paper Mill affected by the 1987 New Zealand Bay of Plenty earthquake. Figure 3 shows a line at the Bata Shoe Factory affected by the 1985 Chile earthquake which remained in place even though its supports failed. Failures shown in Figures 2 and 3 are attributed to poor support details.

Seismic anchor movement is the most common cause attributed to the failure of above ground piping. These failures are typically caused by equipment anchorage failure (due to sliding, rocking, etc.) and differential displacement. Inadequately anchored or unanchored equipment such as chillers, heat exchangers, and tanks have caused piping failures when the attached piping was not flexible enough to accommodate the seismic displacement. Small diameter branch piping connected to large diameter main lines have failed due to lack of sufficient flexibility to accommodate the motion of the larger line. Piping failures due to differential building displacement result primarily from designs that fail to provide adequate flexibility for the relative movement of two structural systems.

Several cases of corroded piping failures have been noted in the data base. The predominant failure mode consists of cracks and leakage at points where a significant decrease in wall thickness had occurred.

Piping component failures have also been reported due to seismic impact. These failures were confined to cast iron and steel yokes on air operated valves. The yokes of the air operated valves fractured due to repeated impact with adjacent structures. Each of the valves was located on a flexibly supported line where estimated displacements of 6 to 12 inches occurred.

DATA BASE SITES SELECTED FOR PARAMETRIC STUDIES

Piping data from the El Centro Steam Plant, the Valley Steam Plant, PALCO Co-generation Plant, Cool Water Plant, and various facilities affected by the 1987 Whittier Earthquake were selected for presentation and detailed comparison of various piping design parameters and attributes. The El Centro Steam and Valley Steam plants affected by earlier earthquakes, and the PALCO and Cool Water plants, affected by the more recent earthquakes, were selected for parametric studies

because substantial documentation on the earthquake input and piping configuration are available.

El Centro Steam Plant

The four unit El Centro Steam Plant (Figure 4), located on a flat, alluvial site, experienced the Magnitude 6.6 Imperial Valley, California earthquake of 1979 and Magnitude 6.3 Superstition Hills, California earthquake of 1987.

Seismic design criteria for the braced steel-frame structures specified a lateral static force equivalent to 20% of the dead and live loads. Equipment was typically anchored. Piping was generally designed in conformance with ANSI B31.1 for dead load, pressure, and thermal loads. Generally, earthquake loads were not considered in the design of the piping except for a few of the high temperature, high pressure large bore lines such as the main steam and reheat lines. Piping at El Centro is primarily rod hung and is more flexible than comparable size nuclear systems. However there is a wide range of flexibilities for specific piping systems. In particular, large diameter lines are supported using a combination of rod hangers, U-bolts and structural sections. A few snubbers were used on the main steam and reheat lines. Examples of large and small bore piping configurations at the facility are shown in Figure 5.

The El Centro plant includes a variety of welded and threaded piping extending up to about 100 feet above grade. Most of the piping is constructed of ASTM A-53 carbon steel. Some stainless steel lines associated with the water demineralization systems are present. The high pressure steam and feedwater piping systems are of butt welded construction. Line sizes range from 1/2 inch to 30 inches in diameter.

Pressures range up to 3,000 psi. Pipe schedules 10 to 40 are used primarily for the lower operating pressures. Schedules 80 to 160 are used for systems operating at pressures greater than 1,200 psi. Maximum operating temperatures are 1,000°F. Most of the piping systems operate at temperatures less than 400°F.

During 1979, the plant experienced the Imperial Valley earthquake with a Richter magnitude of 6.6 with an epicenter about 27 km from the plant. The average of two horizontal peak ground accelerations measured 0.6 miles from the plant was 0.42g. The vertical acceleration was 0.66g. At the time of the Imperial Valley

earthquake, Unit 4 was in operation so that piping was subjected to normal operating loads in addition to the seismic induced loading.

Reported piping failures included the following:

- Several cracked 3 and 4 inch diameter generator exciter cooling lines at previously repaired and corroded points,

- A broken pipe attached to an unanchored filter in the pumphouse,

- A cracked mechanical (Victualic) coupling on a 2" diameter component cooling line,

- A broken cast iron yoke on a steam supply line air operated valve caused by impact with an adjacent structural column.

None of the reported failures resulted in gross structural collapse or falling of piping or piping components.

In 1987, the plant experienced the Superstition Hills earthquake with a Richter magnitude of 6.3 with an epicenter approximately 20 miles North-West of El Centro and faulting just 3 miles from the plant. The average of two horizontal peak ground accelerations measured at El Centro was 0.25g.

One instance of piping damage occurred as a result of the Superstition Hills earthquake. A minor leak occurred on a low flow line installed in the early 1950s which did not affect plant operation. A one inch diameter carbon steel threaded line on Unit 3 developed a leak at the deareator tank. The leak is believed to be inertially generated based on the long unsupported length of pipe.

Valley Steam Power Plant

The Valley Steam Power Plant is located about 10 miles from the epicenter of the 1971 San Fernando earthquake and four miles from a fault rupture. It is located on a flat, alluvial site. The Richter magnitude of the earthquake was 6.6 with an estimated peak ground acceleration of 0.40g in the two horizontal directions.

The braced steel-frame boiler structures were designed for a lateral shear force of 0.20 times the weight of the structure as required by the Los Angeles Department of Water and Power. Most of the equipment is anchored. Although some piping was designed to accommodate the differential movement of the pendulum-hung boiler with respect to the steel frame, piping was not specifically designed for seismic loads.

The Valley Steam plant piping extends up to about 150 feet above grade. Threaded and mechanically coupled piping are supported by rod hangers and U-bolts to structural steel sections. Figure 6 illustrates typical piping and supports at the Valley Steam Plant. The lower photo shows a typical fire protection header that is bolted to the structure with branch lines rod hung with expansion anchors from concrete deck.

Most of the piping is constructed of ASTM A-53 carbon steel. High energy lines operate at pressures up to 2,250 psi and at temperatures as high as 1,000°F. Line sizes range from 3/8 inch to 42 inches. Piping schedules vary from Schedule 10 to Schedule 160.

Damage to piping was limited to several corroded circulating water tubes which ruptured in the Unit 4 condenser. No instances of gross structural collapse, or falling of piping components were reported.

Whittier Facilities

Various Whittier facilities affected by the 1987 Richter Magnitude 5.5 (Reference 11) earthquake were investigated to document the performance and instances of damage to large bore piping systems. A brief description of the investigated facilities, the average of two horizontal peak ground accelerations, the types of large and small bore piping systems documented and instances of seismic induced damage to piping systems are given below:

Nekoosa Packaging (pga = 0.40g)

The Nekoosa Packaging manufacturing facility in Vernon was built in three stages from 1950 to 1959. The building is a single level 350,000 square foot precast concrete, concrete block and wood frame structure that is located approximately 6 miles from the epicenter. This region experienced strong vertical seismic motion in

excess of 0.5g. Moderate seismic damage occurred in the fire protection sprinkler system at threaded connections and mechanical couplings due to header displacement. The cause of failures is attributed to inadequate lateral support of headers and inadvertent sprinkler head interaction with ceiling beams. Figure 7 shows large diameter fire protection piping located on top of a water storage tank at Nekoosa Packaging. Although the tank experienced movement during the earthquake and ruptured, no damage occurred to attached piping.

The Clorox Company (pga = 0.40g)

The Clorox Company, also in Vernon, includes two large warehouse facilities that were investigated due to reports of piping damage. Damaged piping, however, was localized to one small bore threaded sprinkler line. Differential motion of the cross main imposed displacement on a small anchored branch line.

Piping surveyed included threaded and Victualic type mechanical connections that spanned the two warehouses. Figure 8 shows typical piping installations. Despite the large vertical motion in excess of 0.5g as recorded in the nearby U.S. Bulk Mail Facility, piping damage and leaking did not occur except for the one instance noted above.

International Paper (pga = 0.40g)

International Paper located in Commerce is a 40 year old, single level structure with a steel frame roof structure that covers approximately 300,000 square feet of manufacturing and storage space. The building includes a vast quantity of threaded and mechanically coupled large bore pipe that experienced no damage during the earthquake. The piping is primarily rod hung with an occasional lateral brace. Piping was installed in 1953. Figure 9 shows typical configurations of fire protection sprinkler lines in the loading area. No damage to large bore piping was found or reported by facility personnel.

Lutheran Tower (pga = 0.51g)

Lutheran Tower is a 10 story reinforced concrete residence home located in Whittier. USGS instruments recorded horizontal peak ground accelerations of 0.63g and 0.40g in the basement. (Note: The 0.51g pga above is the average of the two horizontal 0.4g and 0.63g pga's).

Piping systems include carbon steel threaded fire protection piping located in the building basement, and brazed copper and carbon steel lines with threaded and welded joints throughout the building. Supports for piping systems were primarily rod hangers with lateral restraints for fire protection headers. No damage to piping systems occurred. Figure 10 includes a photograph of the 10 story building. Figure 11 illustrates examples of large and small bore piping systems found in the building.

Cal Fed Facility (pga = 0.42g)

The Cal Fed data processing facility is a new 3 story steel frame building containing computers, support equipment and diesel generators. The building sustained extensive architectural damage including fire protection sprinkler system failures. Figure 12 illustrates piping movement at Cal Fed.

Threaded piping failures attributed to header displacement occurred in the raised ceiling on the fourth floor. The cause of failures is attributed to inadequate lateral support of headers and inadvertent restraint of branch lines due to sprinkler head interaction with the ceiling.

Cal State Los Angeles (pga = 0.40g)

The State University Campus located in East L.A. includes a 10 story building and adjacent 3 story parking structure which were investigated due to reports of piping damage. Damaged piping was large bore mechanical coupled rod hung cooling water lines. One piping system fell. The failure was attributed to poor installation of pipe anchors.

Small bore piping surveyed included welded and threaded carbon steel lines located on the 10 story building roof. No damage to small bore piping was found or reported by facilities personnel. A larger fire protection pipe header fell in a parking structure due to unzipping of the rod hanger supports. Post earthquake investigation revealed that the rod hanger supports were attached to cast-in-place channel inserts installed in lightweight concrete.

Sanwa Bank Building (pga = 0.38g)

The Sanwa data processing facility is a new 2 story steel frame structure containing computers and support equipment. Small bore piping systems included threaded

carbon steel fire protection systems, threaded and welded carbon steel piping and brazed copper piping. Figure 13 shows a beam clamp rod hanger supporting Sanwa fire protection piping, no support failures occurred. Two instances of damage to small bore piping were reported.

Two copper lines attached to a hot water heater failed due to overturning of the unanchored component. Sprinkler heads located in the building seismic joint above the atrium failed due to impact with the structure.

Pacific Manor (pga = 0.26g)

Pacific Manor is a 10 story residence home located in Burbank with precast and poured-in-place concrete floor slabs supported by precast concrete bearing walls with shear walls in both directions. Small bore piping systems surveyed include brazed copper, threaded carbon steel and welded carbon steel lines located on the building roof. No damage to piping systems occurred.

SCE Headquarters (pga = 0.44g)

SCE Headquarters is a large office complex including 3 buildings, a 4 story, 1970 vintage, concrete structure with interior shear walls, a 1975 vintage one story concrete structure with a two story section housing an equipment penthouse and a 3 story concrete shear wall building of 1980 vintage. Small bore piping systems surveyed include brazed copper, welded carbon steel and threaded carbon steel. Several instances of damage or failure in copper lines were identified. All are attributed to movement of inadequately anchored or unanchored equipment.

<u>Mesquite Lake Resource Recovery Plant</u>

During the 1987 Superstition Hills earthquake the Mesquite Lake plant was essentially complete and undergoing startup testing. The Richter Magnitude was 6.3 with an estimated average of the two horizontal peak ground accelerations of 0.30g at the site.

The 16.5 MW power plant is similar to a conventional fossil fueled facility with manure from local dairies and beef suppliers used as fuel. The plant includes one steam turbine/generator and two boiler/economizer/combuster trains which are 80-90 feet tall steel frame structures. Small bore piping systems include welded and

threaded carbon steel and stainless steel. Support configurations include rod hangers and U-bolts attached to steel members or structures. Frequently, gang supports are used for both large and small bore piping.

Impacting of pipes and insulation with buildings and equipment occurred due to differential displacement. No instances of damage or failure to piping were reported. Figure 14 includes examples of small bore piping at Mesquite Lake.

PALCO Co-generation Plant

The Cape Mendocino earthquakes occurred on April 25, 1992 at 11:06 A.M. with aftershocks at 12:41 A.M. and 4:18 A.M. the following morning. The initial and subsequent large events registered at Richter magnitudes (M) of 7.1, 6.6, and 6.7, respectively. Epicenters are located within the general vicinity of Cape Mendocino in northern California. Average peak ground accelerations of 0.47g, 0.42 and 0.22 from the three events were recorded near the cogen plant location.

The Pacific Lumber Company (PALCO) Co-generation Plant, Figure 15, is located in the town of Scotia in northern California. The plant operates from three boilers that burn wood waste from nearby mill operations. The three wood-fired boilers produce steam at about 600 psi that is routed through a common header into the adjacent turbine generator building. The plant contains two steam turbine generators, each capable of producing about 18 MW at 13.8 kV.

The plant was brought on line in 1989 and included a diversity of recent vintage equipment, mounted in steel-frame structures designed to the current Uniform Building Code, Seismic Zone IV. Piping was generally designed in accordance with ANSI B31.1 for dead load, pressure, and thermal loads, with minimal to no considerations of seismic loads except for a few of the high temperature, high pressure large bore lines. Typical pipe supports consisted of a combination of rod hangers, U-bolts and structural steel sections. Equipment were typically anchored.

The PALCO cogen plant includes a variety of welded and threaded piping extending up to 100 feet above grade. Most of the piping are constructed of ASTM A-53 carbon steel. Some stainless steel piping are noted. Low pressure fire protection lines are typically constructed with threaded and/or mechanical connections. The high pressure systems such as steam piping are of butt welded construction.

Pressures range up to 1,000 psi. Pipe schedules 10 to 40 are used primarily for the lower operating pressures. Schedules 80 to 160 are used for systems operating at pressures of 700 psi or greater. Maximum operating temperatures are 1,000 °F with most of the piping systems operate at temperatures of 200°F or less. Typical piping and support configurations are shown in Figure 16.

At the time of the initial earthquake, Unit A turbine generator was on line near full capacity with steam supplied from all three boilers. Turbine Generator B was down for overhaul with the generator rotor removed to the shop.

Actuation of a generator overload relay in the control room tripped Unit A off line and initiated shut down of the boilers. In spite of the intense level of shaking, the offsite power transmission system remained energized into the plant area. The supply of 60 kV power from the offsite power system was retained into the cogen plant substation. The source of 13.8 kV station power automatically transferred from Turbine Generator A to the substation's 60/13.8 kV transformer. This retained power within the cogen plant to all operating equipment.

Both mechanical and electrical power supply systems within the cogen plant survived the earthquakes with minimal effects. No problems were encountered in mechanical equipment such as fans, pumps, or control valves in the process of restarting the plant. Although buried piping fractured in many locations around the mill site and near the town, there were no serious instances of rupture in above-ground piping within the cogen plant. Slight increases appeared to occur in slow leaks at flanged connections in steam piping. A few leaks were found in low pressure small bore piping, such as from cracked sight glasses. Pneumatic tubing within the plant instrument and service air systems remained intact, except for several locations where sway of the boilers buckled or crimped the instrument tubing (Figure 17). The only damage to piping support was the broken shaft of a mechanical snubber for main steam riser (Figure 18).

Cool Water Generation Plant

The Southern California Edison (SCE) Cool Water Generation Plant, Figure 19, is located in the town of Dagget, less than 10 miles east of Barstow, California. The plant includes two conventional gas/oil-fired steam turbine generators (Units 1 & 2)

of late 1950s to early 1960s vintage, respectively, and two Westinghouse 260 PACE combined cycle units (Units 3 & 4) of late 1970s vintage.

Units 1 & 2 are housed in typical open steel-frame boiler towers adjoining a common open turbine deck and have a combined generating capacity of about 143 MW. Each of the two PACE units (Units 3 & 4) consists of two ground-mounted packaged gas turbine generators with exhaust gases making steam in a heat recovery steam generator (HRSG) which supplies a single steam turbine. Total generation output for the two combined cycle units is about 500 MW.

Design documents for the older units (Units 1 & 2) specified that all pressure piping to be in accordance with applicable ASA Code for Pressure Piping (i.e., ASA-B-31.1-1955 and ASA-B-16.5-1953), as well as ASME Code for Power Boilers. In addition, a 2" clearance between piping and any equipment or other plant commodities was also specified. The balance of plant and/or utility piping were generally field routed using field installation procedure and typical support details.

Similarly, piping design for Units 3 & 4 were in accordance with the code for pressure piping, ANSI B31.1, "Power Piping," for piping appropriate to the scope of the code except as otherwise specified.

The Cool Water plant includes a variety of welded and threaded piping extending up to 100 feet above grade. All piping are constructed of ASTM A-53 carbon steel. Low pressure systems including fire protection are typically constructed with threaded connections. The high pressure steam and feedwater piping systems are of butt welded construction. Line sizes range from 1/2 inch to 30 inches in diameter. Typical piping and support configurations are shown in Figures 20 and 21 for Units 1 & 2, and Figures 22 and 23 for Units 3 & 4. Note that the later vintage units (3 & 4) utilized more rigid pipe supports than the older units (1 & 2).

Pressures range up to 1,000 psi. Pipe schedules 10 to 40 are used primarily for the lower operating pressures. Schedules 80 to 160 are used for systems operating at pressures of 700 psi or greater. Maximum operating temperatures are 1,000 °F with most of the piping systems operate at temperatures of 200°F or less.

The Landers and Big Bear earthquakes occurred on June 28, 1992 at 4:58 A.M. and 8:04 A.M. with Richter magnitude (M) of 7.5 and 6.5, respectively. Both epicenters are located at about 40 miles south of the SCE Cool Water Plant. Peak ground

accelerations of 0.43g in the transverse direction, 0.28g in the longitudinal direction, and 0.16g in the vertical direction were recorded at the site.

At the time of the initial event, one gas turbine (C.T. - 31) was on line, and the Unit 3 steam turbine was in the process of being brought on line. All other turbine generators were down. The gas turbine tripped off line and shut down due to its vibration trip system. The older Unit 1 & 2 side of the plant retained station power in both earthquakes through its 115 kV/4 kV autotransformer (in the adjacent switchyard) which retained its supply from El Dorado Substation. Most circuit breakers in the 115 kV and 230 kV switchyards opened, presumably due to vibration-induced relay actuation on the control panels. The Unit 3 & 4 side of the plant lost station power for a brief time period in the initial earthquake.

Piping systems at all four units of the Cool Water Plant performed extremely well during both earthquakes. No major piping damage, either above- or below-ground, was reported following the events. Minor instances of piping damage were noted in Units 1 & 2, and described as follows:

- A 1" line fractured near its attachment to one of the tank drains due to differential displacement. The unanchored tank (Demineralized Water Test Tank No. 1) suffered slight buckling at the base of its wall where it apparently slapped down on the concrete foundation enclosing its drain line (Figure 24).

- At several locations, particularly in the Unit 2 boiler tower, instrument tubing or small air lines were fractured due to differential displacement between the attachment points on the tower and the swaying boiler. Buckling of steel grating was found at several locations due to the extent of boiler movement and impact (Figure 25).

- Several instances of proximity interaction between rod-hung large bore piping (insulated) and other plant features were noted. Damage consisted of dented pipe insulation only (Figure 26).

COMPARISON OF DATA BASE PIPING

Seismic ruggedness of large and small bore piping systems at the data base sites is demonstrated by the following qualitative and quantitative comparisons:

- Data base piping are typically installed with minimal to no seismic considerations and yet have survived earthquakes much more severe than the Hatch Unit 2 design basis (0.15g).
- Data base power plant piping and BWR steam piping are constructed to comparable codes, standards, and installation practices.

To demonstrate these points a comparison is made of parameters associated with earthquake input and systems seismic integrity. To facilitate the comparisons, critical parameters are grouped into the categories outlined below.

Seismic Input Parameters

This parametric category is associated with the transfer of seismic motion from the ground through the building structure to the location of the piping installations. These parameters include aspects of earthquake ground motion as follows:

- Peak ground acceleration
- Duration of strong ground motion
- Frequency content of ground motion

Parameters also include aspects of the amplification and filtration of the ground motion by:

- Soil conditions
- Building type and size
- Elevation of the piping in the building.

Parameters associated with the seismic ground motion are illustrated by a free-field ground motion response spectrum and by peak ground acceleration.

Figure 29 shows the averag of the two horizontal peak ground accelerations from data base sites selected for this parametric study. Free-field ground response

spectra applicable for Cal Fed, Lutheran Tower and the Bulk Mail facility, which was in close proximity to Nekoosa Packaging, Clorox, and International Paper facilities, are presented in Figure 27, along with the design basis spectrum for Hatch Unit 2 with a 0.15g PGA. Similarly, free-field ground response spectra applicable for El Centro, Valley, PALCO, and Cool Water plants are presented in Figure 28, along with the design basis spectrum for Hatch Unit 2 with a 0.15g PGA.

The various power stations and industrial facilities surveyed in compiling the experience data base offer a wide diversity of building sizes, flexibility and ground compositions. In turn, this represents a wide diversity in the amplification, distortion and filtration of ground motion experienced at the various sites.

Much of the data base piping is contained in multi-story, steel-frame buildings. Typical fundamental response frequencies for this type of building range from 1 to 5 Hz, which corresponds to the frequency range of maximum energy content for most earthquake ground motion.

Typical nuclear plant turbine building structures are somewhat stiffer in comparison. The frequency range of these structures would lie at the end or above the range of maximum energy content for typical seismic ground motion. This in turn suggests that the intensity of typical commercial nuclear plant response (or piping system seismic input) to an earthquake would be lower than that experienced at the data base sites.

System Integrity Parameters

This category addresses the local details of piping installations that influence the inertial seismic loads, and the structural elements that would be most likely to fail in an earthquake. These parameters include the following:

- Support type
- System weight per linear foot
- Construction details
- Span between supports

Piping is typically similar in design at the data base sites. Construction details, including welds and joints are also standard at these sites. Pipe supports typically consist of individual or gang trapeze rod and clevis-type dead load supports, light

structural sections with U-bolt attachment or Unistrut channel with bolted pipe straps. Structural attachments are provided by welds to building structural members or by expansion anchor bolts.

Standard pipe diameters and schedules are used for the data base piping. Data base facilities typically include steam, liquid, and dry systems. Pipe operating at high temperature is generally insulated. System weights among the data base piping are typically comparable.

Piping interactions are influenced by system complexity and flexibility. Complexity addresses the layout of pipe runs and their proximity to adjacent installations. Pipe flexibility is determined by support types, spans, and interfaces with equipment and penetrations. Highly flexible piping will undergo greater displacement relative to the building during an earthquake. Due to the flexible nature of much of the data base piping routed in congested areas of the plants, impacts between adjacent structural steel, HVAC equipment, light fixtures, and other piping are common. Scratch marks and dented insulation indicate that large displacements have occurred at these data base sites. Lift-off from dead weight supports has undoubtedly occurred in data base piping systems without adverse effects on the supports.

Support spans for large and small bore piping systems were compiled from field investigations and/or design documents at the above data base facilities. These spans represent the distance between horizontal or vertical supports for piping runs or the distance to the first horizontal and vertical support from nozzles or tees. These spans represent a diversity of pipe runs which have performed successfully during earthquakes.

Spacing between supports and number of samples for the surveyed data base piping are presented in Figures 30 through 33 for both large and small bore piping.

SUMMARY OF DATA BASE COMPARISON

A review of large and small bore piping configurations and performance in the earthquake experience data base resulted in the following observations:

- Data base piping are typically installed with minimal or no seismic considerations and exhibit a wide range of system flexibility.

- Support details well represented in the data base piping include rod hangers, U-bolts to light structural members, unistrut supports and many gapped seismic stops.

- Data base sites have experienced seismic input significantly greater than the Hatch Unit 2 design basis.

- Welded steel piping systems designed and installed to commercial power piping codes and standards have exhibited successful seismic performance.

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Table 1

SUMMARY OF SITES REVIEWED IN COMPILING THE SEISMIC EXPERIENCE DATA BASE

Earthquake (Magnitude)	Facility	Type of Facility	Estimated Horizontal Peak Ground Acceleration (g)**
San Fernando, CA Earthquake 1971 (M6.5)	Sylmar Converter Station	Large electrical substation	0.50-0.75
	Rinaldi Receiving Station	Large electrical substation	0.50-0.75
	Valley Steam Plant	Four-unit gas-fired power plant	0.40
	Burbank Power Plant	Six-unit gas-fired power plant	0.30
	Glendale Power Plant	Five-unit gas-fired power plant	0.30
	Pasadena Power Plant	Five-unit gas-fired power plant	0.20
Point Mugu, CA Earthquake 1973 (M5.7)	Ormond Beach Power Plant	Large two-unit oil-fired power plant	0.20
Ferndale, CA Earthquake 1975 (M5.5)	Humboldt Bay Power Plant	Two gas-fired units, one nuclear unit	0.30*
Santa Barbara, CA Earthquake 1978 (M5.7)	Goleta Substation	Electrical substation	0.26*

* Ground acceleration measured by an instrument at the site

** Average of two horizontal components

Table 1 (Continued)

SUMMARY OF SITES REVIEWED IN COMPILING THE SEISMIC EXPERIENCE DATA BASE

Earthquake (Magnitude)	Facility	Type of Facility	Estimated Horizontal Peak Ground Acceleration (g)**
Imperial Valley, CA Earthquake 1979 (M6.6)	El Centro Steam Plant	Four-unit gas-fired power plant	0.42*
	Drop IV Hydro. Plant	Two-unit hydroelectric plant	0.30
Humboldt, CA Earthquake 1980 (M7.0)	Humboldt Bay Power Plant	Two gas-fired units one nuclear unit	0.25
Coalinga, CA Earthquake 1983 (M6.7)	Main Oil Pumping Plant	Pumping station feeding oil pipeline from Coalinga area	0.60
	Union Oil Butane Plant	Petrochemical facility to extract butane and propane from well waste gas	0.60
	Shell Water Treatment Plant	Petrochemical facility to demineralize water prior to steam injection into oil wells	0.60
	Coalinga Water Treatment Plant	Potable water purification facility	0.60
	Coalinga Substation No.2	Electrical substation	0.60
	Shell Tank Farm No.29	Oil storage tank farm	0.60
	Pleasant Valley Pumping Plant	Pumping station to supply water from the San Luis Canal to the Coalinga Canal	0.56*
	San Luis Canal Pumping Stations (29)	Agricultural pumping stations taking water from the San Luis Canal	0.20-0.60

* Ground acceleration measured by an instrument at the site

** Average of two horizontal components

Table 1 (Continued)

SUMMARY OF SITES REVIEWED IN COMPILING THE SEISMIC EXPERIENCE DATA BASE

Earthquake (Magnitude)	Facility	Type of Facility	Estimated Horizontal Peak Ground Acceleration (g)**
Coalinga, CA Earthquake (Cont.)	Gates Substation	Large electrical substation	0.25
	Kettleman Compressor Station	Natural gas pipeline booster station	0.20
Morgan Hill, CA Earthquake 1984 (M6.2)	United Tech. Chemical Plant	Large research facility for missile systems development	0.50
	IBM/Santa Teresa Facility	Large computer facility for software development	0.37*
	San Martin Winery	Winery	0.35
	Wiltron Electronics Plant	Electronics manufacturing facility	0.35
	Metcalf Substation	Large electrical substation	0.40
	Evergreen Community College	Large college complex with self-contained HVAC power plant	0.20
	Mirassou Winery	Winery	0.20
Chile Earthquake 1985 (M7.8)	Bata Shoe Factory	Four-building factory and tannery	0.64
	San Isidro Substation	Electrical substation	0.58*

* Ground acceleration measured by an instrument at the site

** Average of two horizontal components

Table 1 (Continued)

SUMMARY OF SITES REVIEWED IN COMPILING THE SEISMIC EXPERIENCE DATA BASE

Earthquake (Magnitude)	Facility	Type of Facility	Estimated Horizontal Peak Ground Acceleration (g)**
Chile Earthquake 1985 (Cont.)	Llolleo Water Pumping Plant	Water pumping station	0.55
	Terquim Tank Farm	Oil/acetate/acid storage tank farm	0.55
	Vicuna Hospital	Four-story hospital	0.55
	Rapel Hydroelectric Plant	Five-unit hydroelectric plant	0.40*
	San Sebastian Substation	Electrical substation	0.35
	Concon Petroleum Refinery	Petrochemical facility producing fuel oil, asphalt, gasoline, and other petroleum products	0.30
	Oxiquim Chemical Plant	Chemical facility producing various chemicals, including feed stock for paint ingredients	0.30
	Concon Water Pumping Station	Water pumping station	0.30
	Renca Power Plant	Two-unit coal-fired power plant	0.30
	Laguna Verde Power Plant	Two-unit coal-fired peaking plant	0.25
	Las Ventanas Copper Refinery	Copper refinery/foundry/power plant	0.25
	Las Ventanas Power Plant	Two-unit gas-fired power plant	0.25*

* Ground acceleration measured by an instrument at the site

** Average of two horizontal components

Table 1 (Continued)

SUMMARY OF SITES REVIEWED IN COMPILING THE SEISMIC EXPERIENCE DATA BASE

Earthquake (Magnitude)	Facility	Type of Facility	Estimated Horizontal Peak Ground Acceleration (g)**
Chile Earthquake 1985 (Cont.)	San Cristobal Substation	Electrical substation	0.25
	Las Condes Hospital	Four-story hospital	0.20
Mexico Earthquake 1985 (M8.1)	Infiernillo Dam	Six-unit hydroelectric plant	0.15
	La Villita Power Plant	Four-unit hydroelectric plant	0.14
	SICARTSA Steel Mill	Large, modern steel mill	0.25-0.50
	Fertimex Fertilizer Plant	Fertilizer plant	0.25-0.50
Adak, Alaska Earthquake 1986 (M7.5)	Adak Naval Base	Diesel-electric power plants, electrical substations, sewage lift stations, water treatment plant, steam plants	0.25
North Palm Springs, CA Earthquake 1986 (M6.0)	Devers Substation	Large electrical distribution substation	0.85*
	Whitewater Hydro. Plant	Small hydroelectric power plant	0.50
Chalfant Valley, CA Earthquake 1986 (M6.0)	Control Gorge Hydro Plant	Two-unit hydroelectric plant	0.25
	Hi-Head Hydro Plant	Small one-unit unmanned hydroelectric plant	0.25

* Ground acceleration measured by an instrument at the site

** Average of two horizontal components

Table 1 (Continued)

SUMMARY OF SITES REVIEWED IN COMPILING THE SEISMIC EXPERIENCE DATA BASE

Earthquake (Magnitude)	Facility	Type of Facility	Estimated Horizontal Peak Ground Acceleration (g)**
San Salvador Earthquake 1986 (M5.4)	Soyapango Substation	Electrical substation	0.50
	San Antonio Substation	Electrical substation	0.40
Cerro Prieto, Mexico Earthquake 1987 (M5.4)	Power Plant 1	Geothermal power plant	0.20-0.30
	Power Plant 3	Geothermal power plant	0.20-0.30
Bay of Plenty, New Zealand Earthquake 1987 (M6.25)	Edgecumbe Substation	230/115 kV substation	0.50-1.0
	New Zealand Distillery	Liquor distillery	0.50-1.0
	Caxton Paper Mill	Paper and pulp mill	0.40-0.55
	Kawerau Substation	230/115 kV substation	0.40-0.55
	Whakatane Board Mill	Paper mill producing cardboard	0.25
	Matahina Dam	Two-unit hydroelectric plant	0.26*
Whittier, CA Earthquake 1987 (M5.9)	Olinda Substation	Electrical substation	0.65*
	SCE Central Dispatch Headquarters	Data Processing Center	0.56*
	SCE Headquarters	Large office complex	0.42*

* Ground acceleration measured by an instrument at the site

** Average of two horizontal components

Table 1 (Continued)

SUMMARY OF SITES REVIEWED IN COMPILING THE SEISMIC EXPERIENCE DATA BASE

Earthquake (Magnitude)	Facility	Type of Facility	Estimated Horizontal Peak Ground Acceleration (g)**
Whittier, CA Earthquake 1987 (Cont.)	California Federal Bank Facility	Data processing facility	0.40
	Ticor Facility	Data processing facility	0.40
	Mesa Substation	Electrical substation	0.35
	Sanwa Bank Facility	Data processing facility	0.40
	Alhambra Telephone Station	Three-story concrete-frame building	0.40
	Rosemead Telephone Station	Two-story steel-frame building	0.40
	Central Telephone Station	Three steel-frame high-rise buildings	0.15
	Wells Fargo Bank Facility	Data processing facility	0.30
	Center Substation	Electrical Substation	0.30
	Lighthype Substation	Electrical Substation	0.26*
	Del Amo Substation	Electrical Substation	0.20
	Pasadena Power Plant	Five-unit gas-fired power plant	0.25
	Glendale Power Plant	Five-unit gas-fired power plant	0.20g

* Ground acceleration measured by an instrument at the site

** Average of two horizontal components

Table 1 (Continued)

SUMMARY OF SITES REVIEWED IN COMPILING THE SEISMIC EXPERIENCE DATA BASE

Earthquake (Magnitude)	Facility	Type of Facility	Estimated Horizontal Peak Ground Acceleration (g)**
Whittier, CA Earthquake (Cont.)	Commerce Refuse-to-Energy Plant	One-unit gas-fired power plant	0.30
	Puente Hills Landfill Gas & Energy Recovery Plant	One-unit gas-fired power plant	0.20
Superstition Hills (El Centro), CA 1987 (M6.3)	Mesquite Lake Resource Recovery Plant	16 MW gas-fired power plant	0.20
	El Centro Steam Plant	Four-unit gas-fired power plant	0.26*
Loma Prieta Earthquake 1989 (M7.1)	Moss Landing Power Plant	Seven-unit gas-fired power plant	0.30
	Gilroy Energy Cogen Plant	One-unit combined gas turbine and steam turbine plant	0.32
	Cardinal Cogen Plant	One-unit combined gas turbine and steam turbine plant	0.25
	UCSC Cogen Plant	One-unit diesel cogeneration plant	0.40
	Hunter's Point Plant	Three-unit gas-fired power plant	0.15
	Portrero Plant	One-unit gas-fired plant	0.15
	Metcalf Substation	500 kV substation	0.30
	San Mateo Substation	230 kV substation	0.20

* Ground acceleration measured by an instrument at the site

** Average of two horizontal components

Table 1 (Continued)

SUMMARY OF SITES REVIEWED IN COMPILING THE SEISMIC EXPERIENCE DATA BASE

Earthquake (Magnitude)	Facility	Type of Facility	Estimated Horizontal Peak Ground Acceleration (g)**
Loma Prieta Earthquake (Cont.)	Monte Vista Substation	230 kV substation	0.20
	National Refractory	Large brick & magnesia extraction plant	0.30
	Green Giant Foods	Concrete tilt-up food processing plant	0.33
	Watsonville Wastewater Treatment	Sewage treatment plant	0.40
	Santa Cruz Telephone Station	Three-story concrete shear wall switching station	0.50
	Watsonville Telephone Station	Four-story concrete shear wall switching station	0.33*
	Seagate Technology Watsonville	Concrete tilt-up manufacturing facility	0.40
	Santa Cruz Water Treatment	Potable water purification facility	0.40
	Soquel Water District Headquarters	One-story wood-frame office complex with small pumping station & storage tanks	0.50
	Lipton Foods	Concrete tilt-up food processing and packaging facility	0.30
	Lone Star Cement	Large cement factory	0.25

* Ground acceleration measured by an instrument at the site

** Average of two horizontal components

Table 1 (Continued)

SUMMARY OF SITES REVIEWED IN COMPILING THE SEISMIC EXPERIENCE DATA BASE

Earthquake (Magnitude)	Facility	Type of Facility	Estimated Horizontal Peak Ground Acceleration (g)**
Loma Prieta Earthquake (Cont.)	Watkins-Johnson Instruments	One-, two-, and three-story concrete & steel-frame buildings for light manufacturing	0.35
	Rinconada Water Treatment Plant	Potable water processing facility	0.30
	IBM/Santa Teresa Facility	Steel-frame high-rise complex for software development	0.20
	EPRI Headquarters	Two- and three-story concrete-frame office	0.25
	San Martin Winery	Winery	0.30
Central Luzon Philippines Earthquake 1990 (M7.7)	Baguio Telephone	Telephone switching station	--
	Cabanatuan Substation	230 kV substation	--
	La Trinidad Substation	230 kV substation	--
	San Manuel Substation	230 kV substation	--
	Moog Manufacturing Plant	Manufacturing plant	--

* Ground acceleration measured by an instrument at the site

** Average of two horizontal components

Table 1 (Continued)

SUMMARY OF SITES REVIEWED IN COMPILING THE SEISMIC EXPERIENCE DATA BASE

Earthquake (Magnitude)	Facility	Type of Facility	Estimated Horizontal Peak Ground Acceleration (g)**
Valle de Estrella, Costa Rica Earthquake 1991 (M7.4)	Bomba Water Treatment Plant	Water treatment plant	--
	Cachi Dam	1,000 MW hydroelectric plant	0.12*
	Changuinola Power Plant	Diesel power plant	--
	Limon Telephone	Telephone switching station	--
	Moin Power Plant	140 MW thermoelectric power plant	--
	RECOPE Refinery	Oil refinery	
Sierra Madre, California Earthquake 1991 (M5.8)	Pasadena Power Plant	Five-unit gas-fired power plant	0.20
	Goodrich Substation	230 kV substation	0.30
Cape Mendocino, California Earthquake 1992 (M7.0)	PALCO Co-generation Plant	Two-unit power plant	0.47
	Humboldt Bay Power Plant	Two gas-fired units, one nuclear unit	--
	Centerville Beach Station	Naval facility	0.40*

* Ground acceleration measured by an instrument at the site

** Average of two horizontal components

Table 1 (Continued)

SUMMARY OF SITES REVIEWED IN COMPILING THE SEISMIC EXPERIENCE DATA BASE

Earthquake (Magnitude)	Facility	Type of Facility	Estimated Horizontal Peak Ground Acceleration (g)**
Landers and Big Bear, California Earthquake 1992 (M7.4)	Cool Water Generation Plant	Four-unit power plant two gas/oil-fired and two combined cycle units	0.35*
	Mitsubishi Cement Plant	Cement plant	--
	LUZ Projects	Solar electric generating station	0.35

* Ground acceleration measured by an instrument at the site

** Average of two horizontal components

Table A-2

PIPING DAMAGE IN POWER PLANTS AND OTHER FACILITIES

Category	Total Pipe Damage Cases	Power Plants	Other Facilities
Seismic Anchor Movement	142	15	127
Corrosion	8	7	1
System Interaction	72	62	10
Non-Welded Joints	153	46	107
Supports	74	40	34
Internal Equipment	34	34	0
Buried	450	5	445
Miscellaneous	87	10	77
TOTAL	1,020	219	801

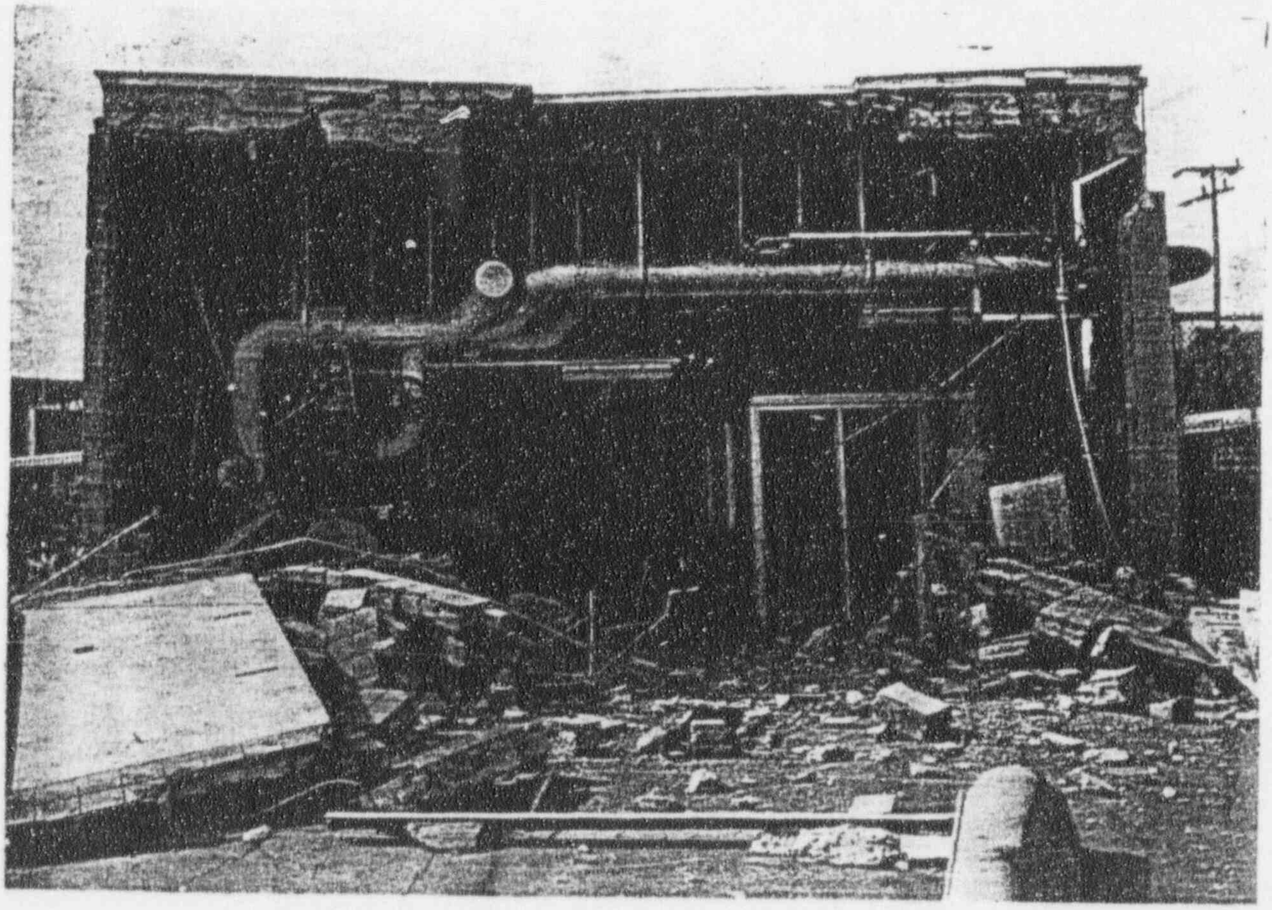


Figure 1: This structure was severely damaged during the 1971 San Fernando earthquake, the rod supported piping did not fall down.

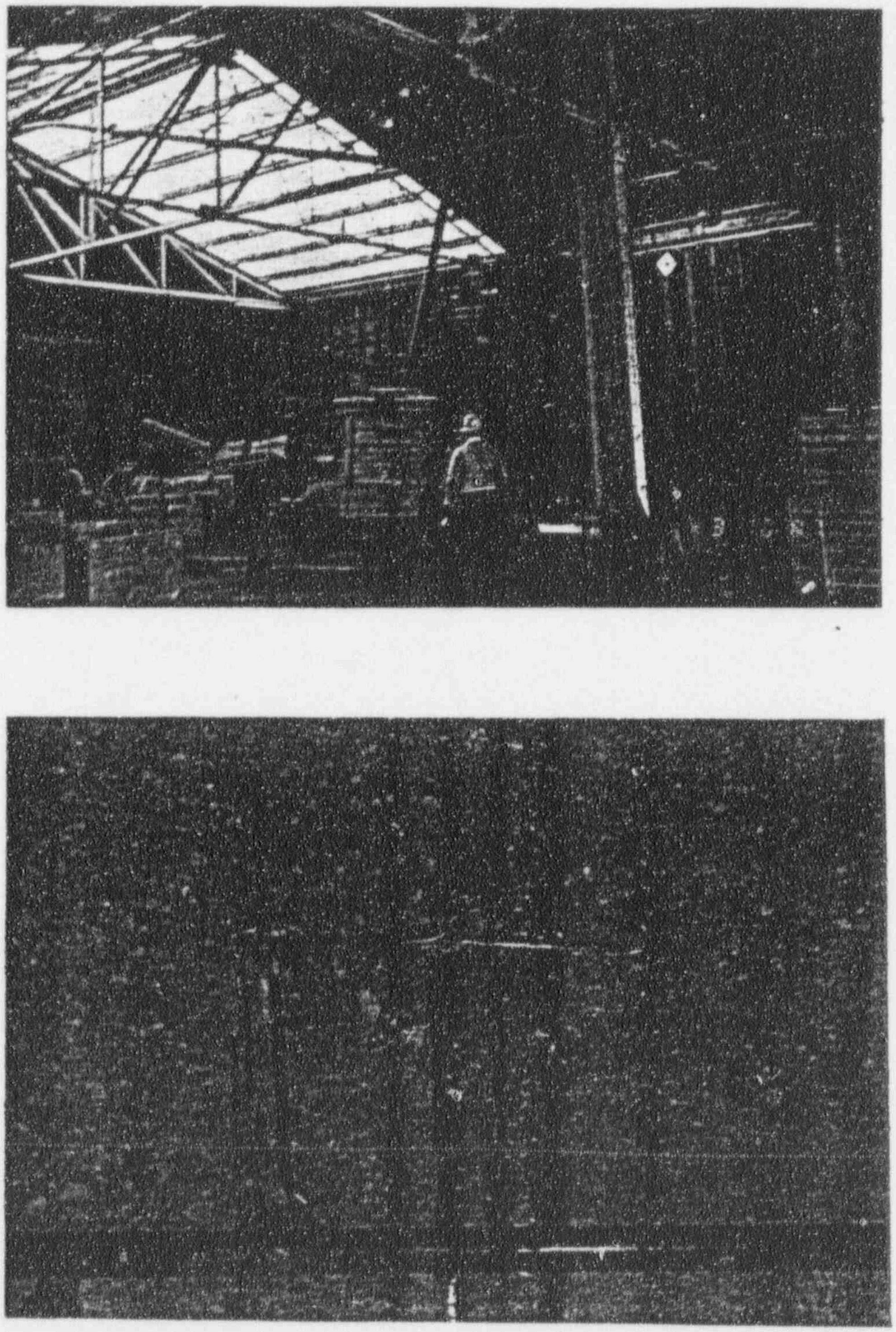


Figure 2: Example of piping system collapse caused by poor support detail at the Tasman Paper Mill in New Zealand. Eccentrically loaded clamp connection is shown in lower photograph.

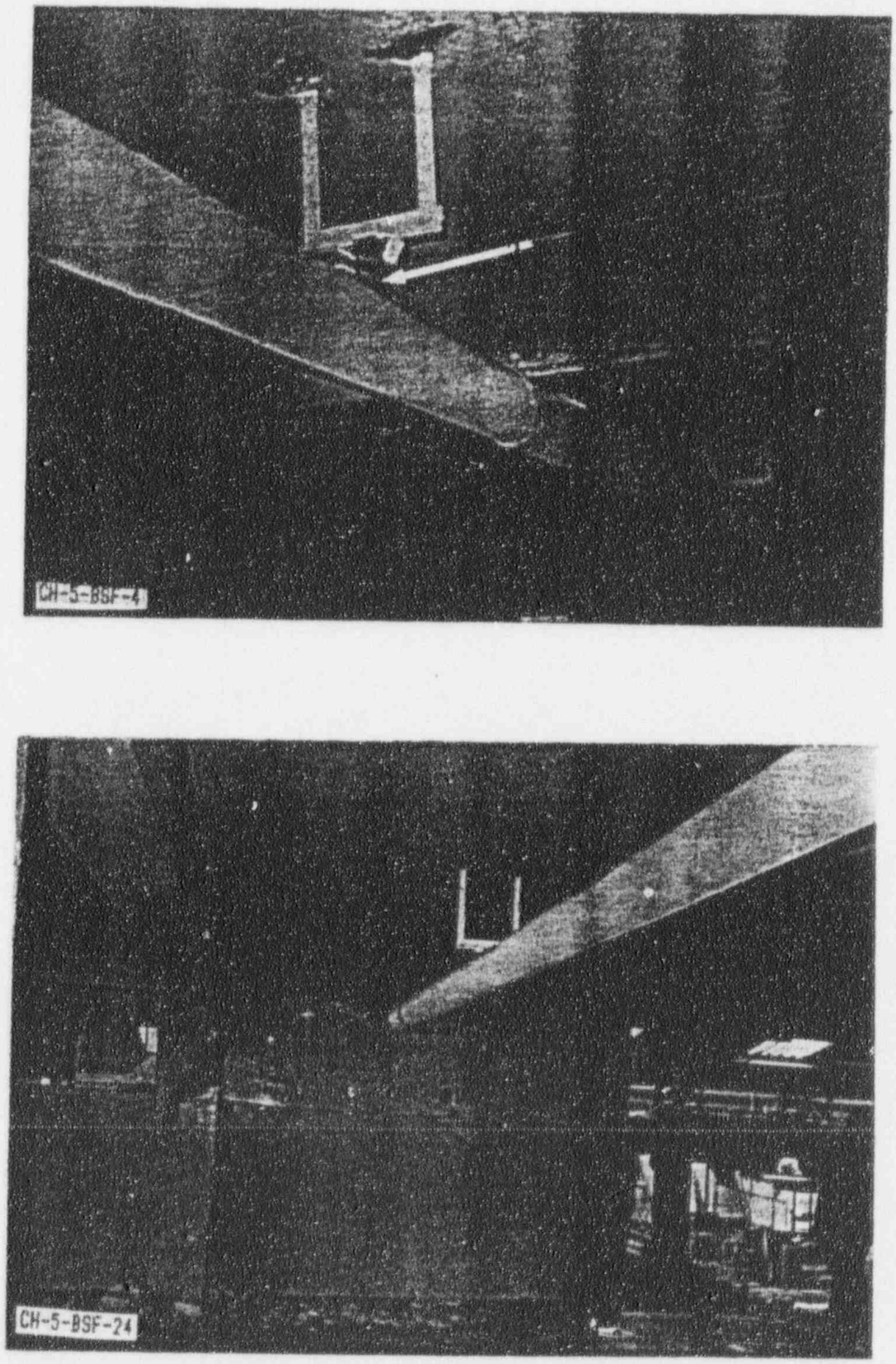


Figure 3: This line at the Bata Shoe Factory affected by the 1985 Chile earthquake remained in place even though its supports failed.

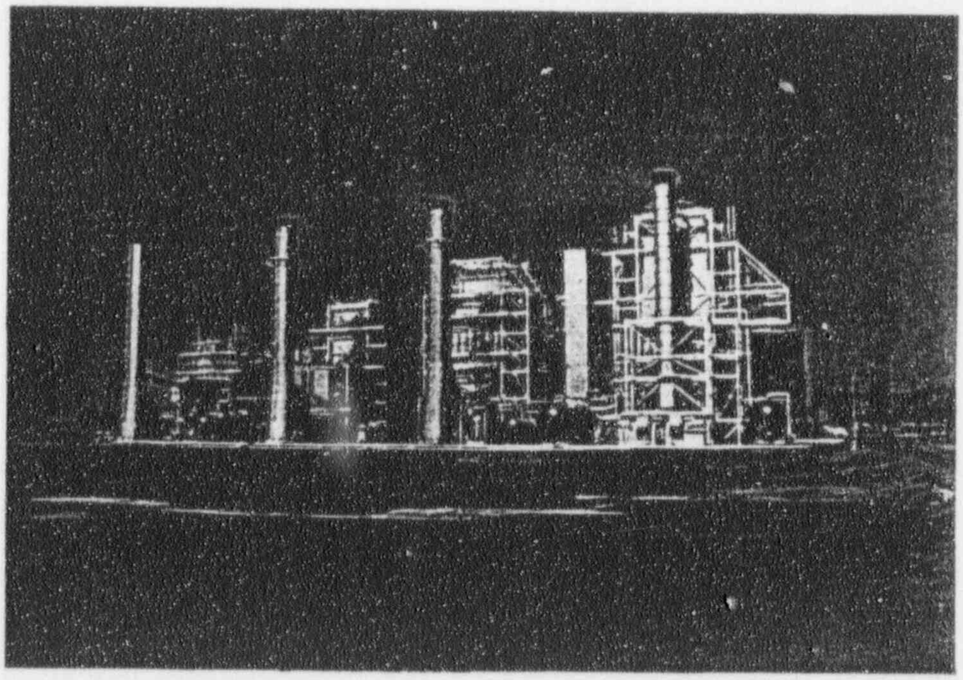


Figure 4: Four Unit El Centro Steam Plant.

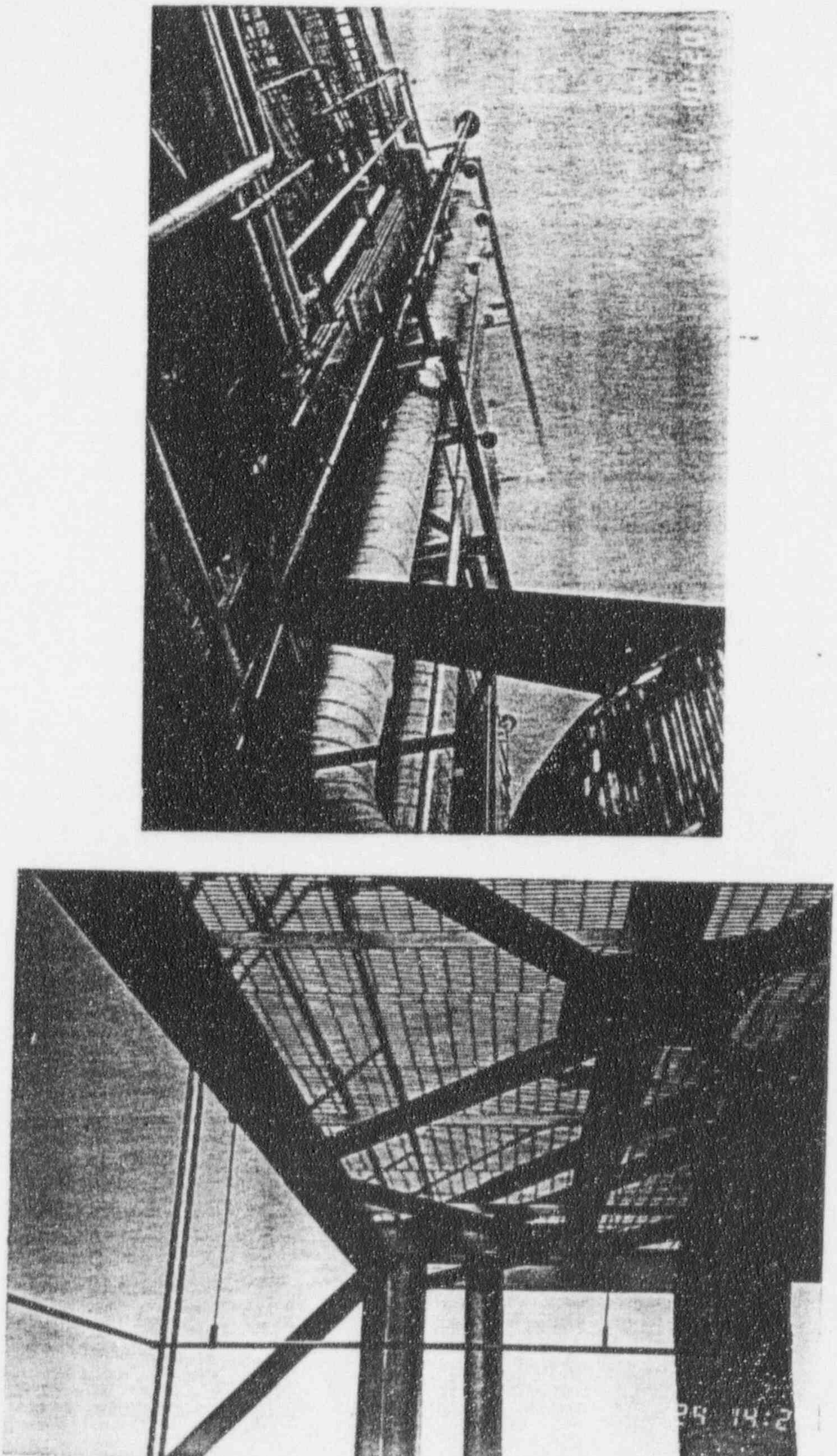


Figure 5: Examples of large bore piping (upper photo) and small bore piping (lower photo) at the El Centro Steam Plant.

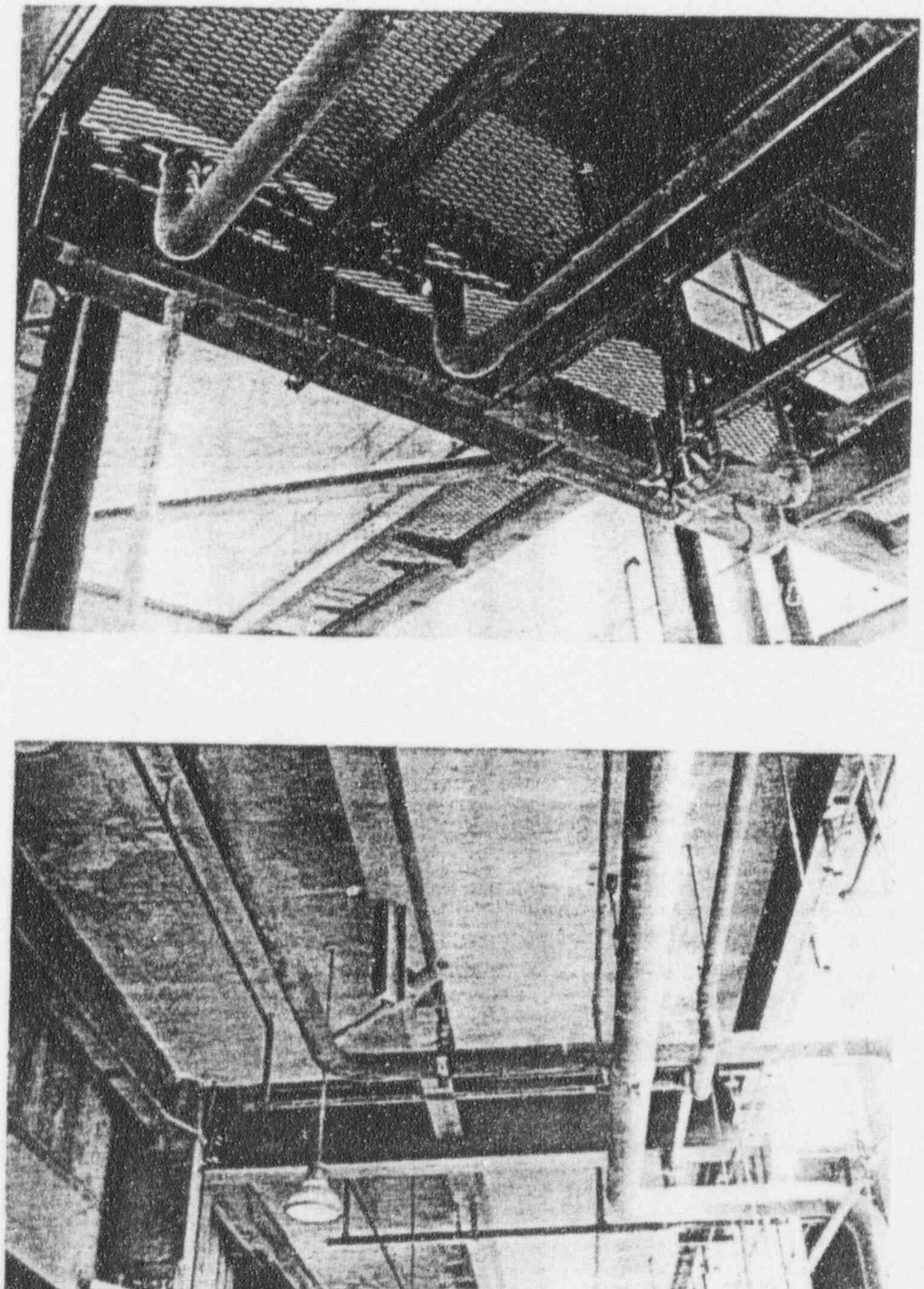


Figure 6: Typical piping and support configurations at Valley Steam Plant.

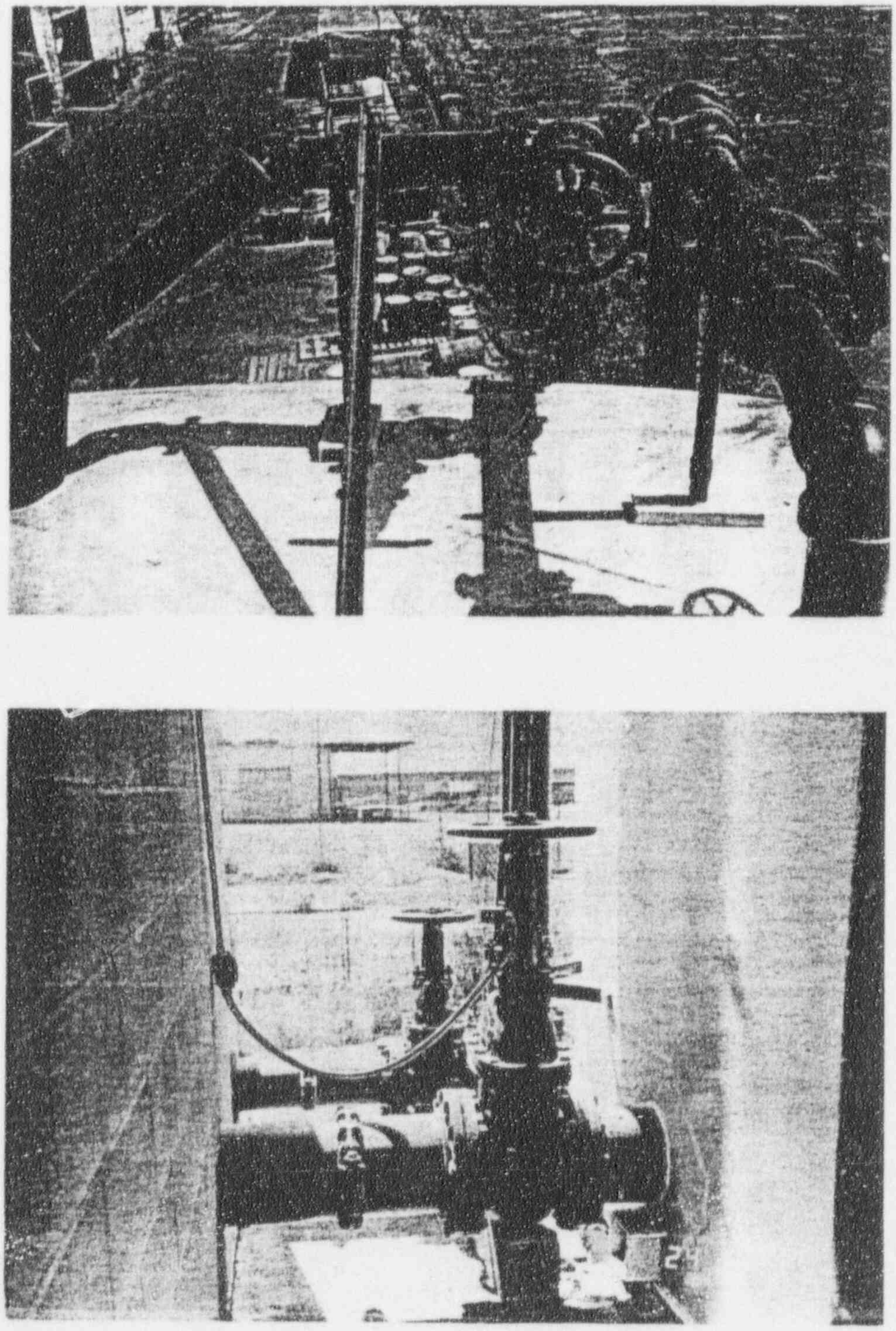


Figure 7: Large diameter fire protection piping located on top of water storage tank (upper photo) at Nekoosa packaging. Tank experienced movement during the earthquake and ruptured causing no damage to attached pipe (lower photo).

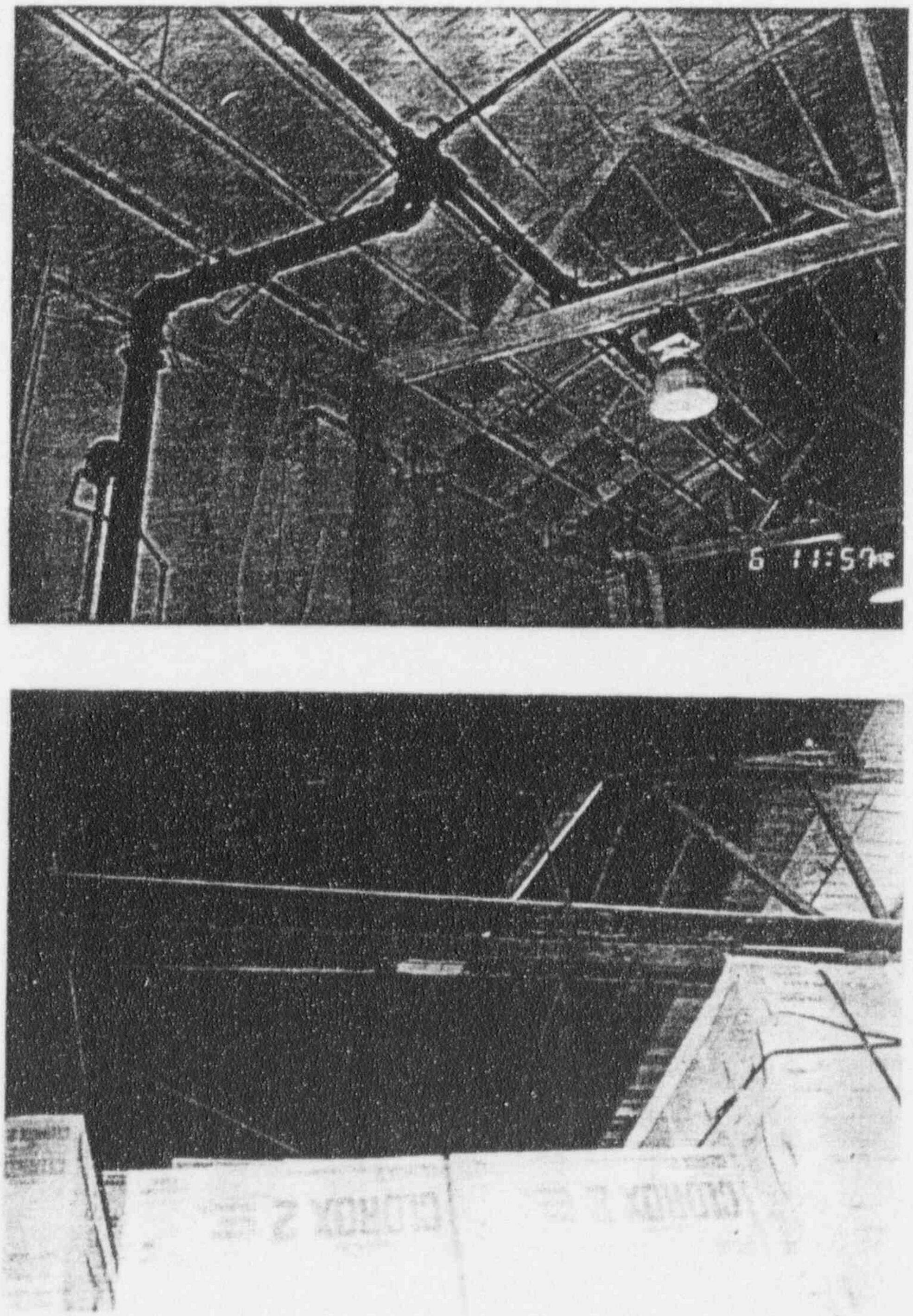
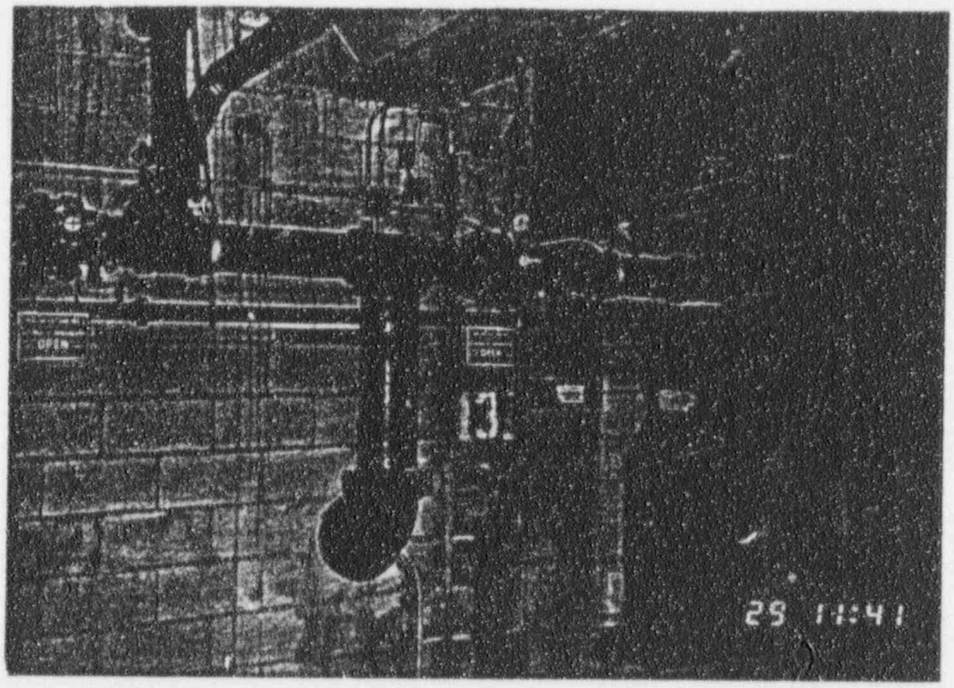


Figure 8: Fire protection line at the Clorox Company. Header is U-bolted to structure and cross main is rod hung from wood truss ceiling. Lower photograph shows a 6" diameter rod hung threaded pipe. There was approximately 5" of displacement of the pipe relative to the structure.

Figure 9: Typical mechanically coupled piping at International Paper. View of fire sprinkler line in loading bay area.

EQE

Figure 10: View of Lutheran Tower showing temporary trailers for damaged buildings in downtown Whittier.



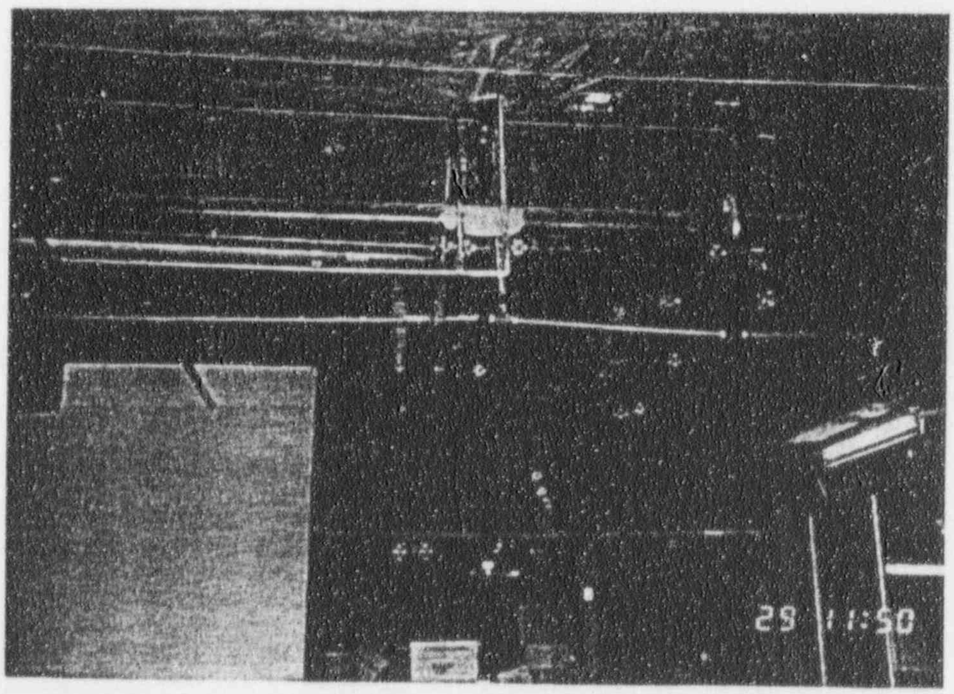


Figure 11: Examples of undamaged large bore piping (upper photo) and small bore piping (lower photo) inside the Lutheran Tower.

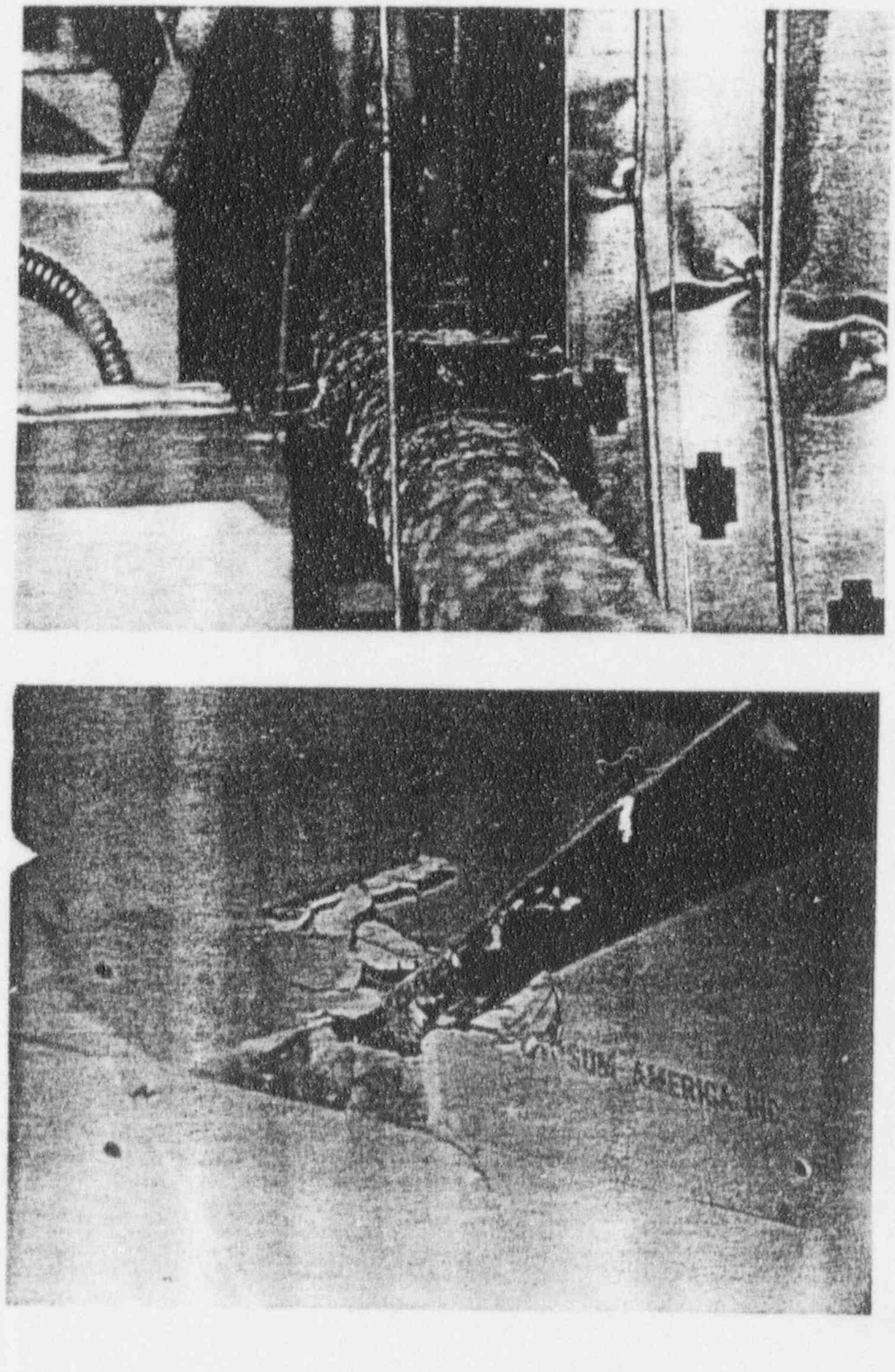


Figure 12: Pipe movement at the California Federal Data Center bent light gauge structural metal framing (upper photo) and damaged wallboard (lower photo).

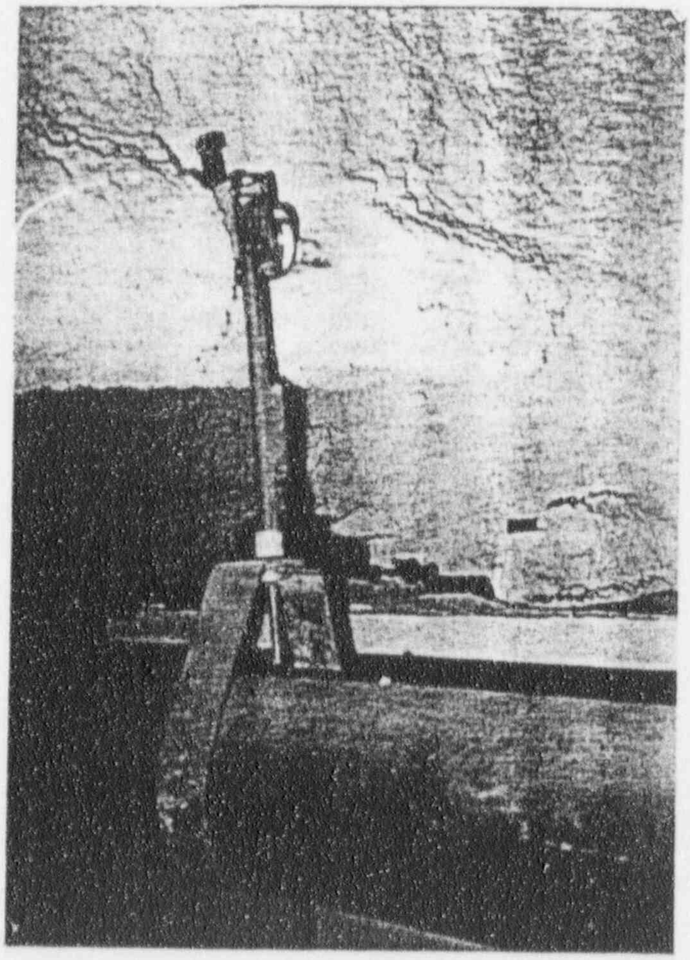


Figure 13: Example of rod hanger for Sanwa fire protection piping. Support is anchored to structure with a beam clamp.

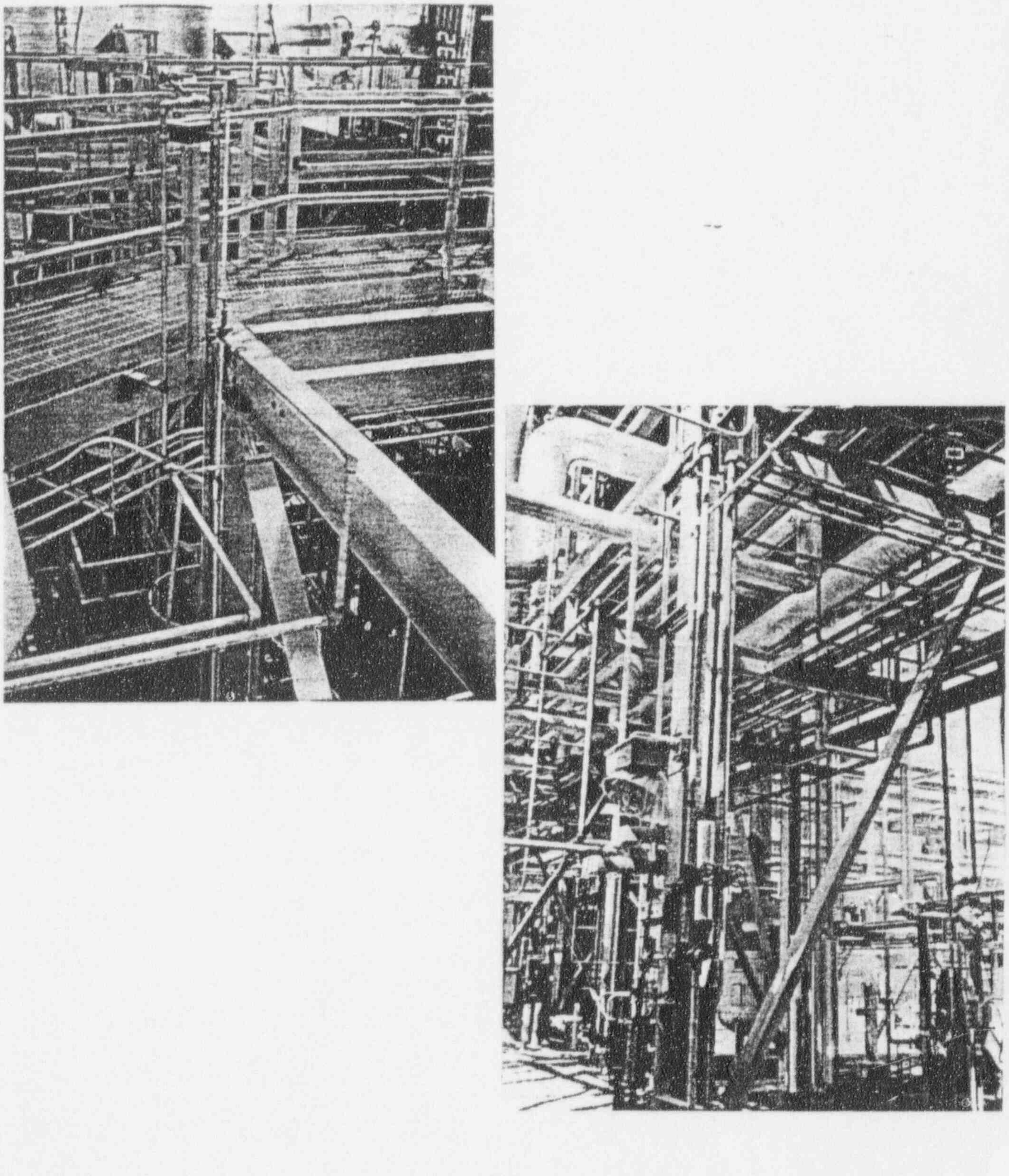


Figure 14: Examples of small bore piping at Mesquite Lake Resource Recovery Plant.

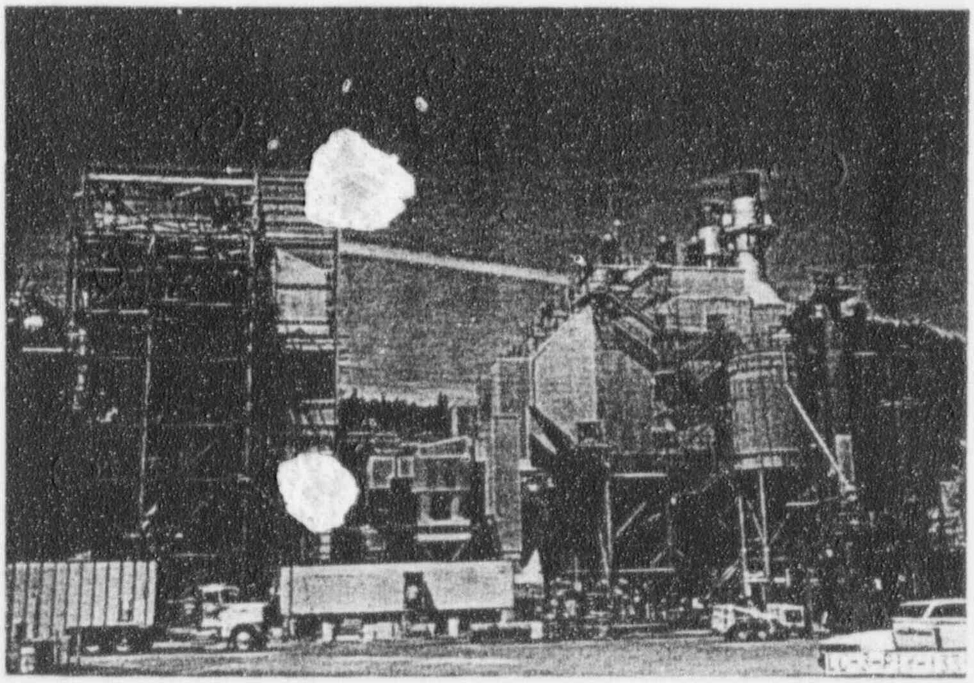


Figure 15: PALCO Co-generation Plant located in Scotia, California.

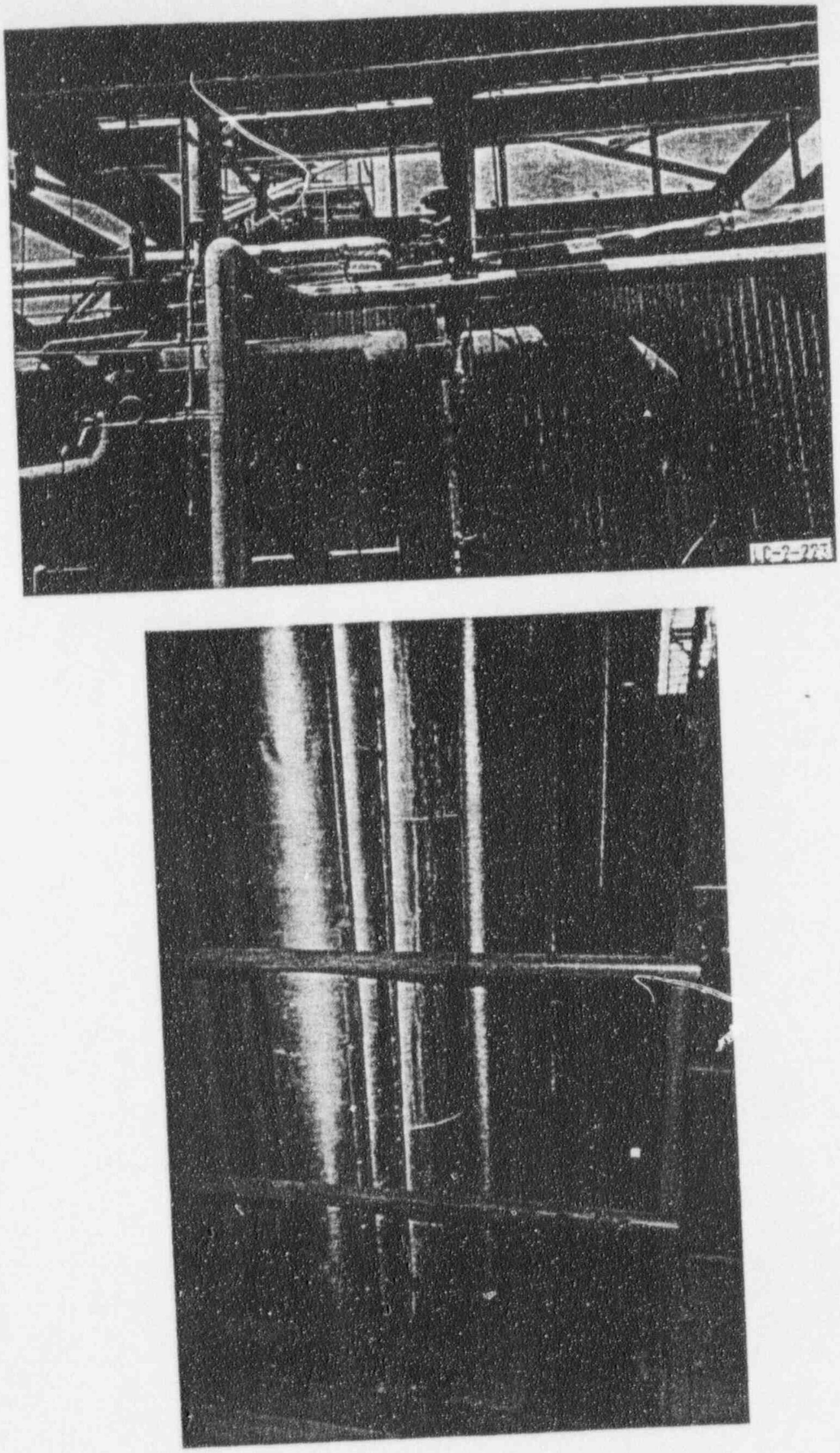


Figure 16: Typical piping and pipe support configurations at PALCO Co-generation Plant.

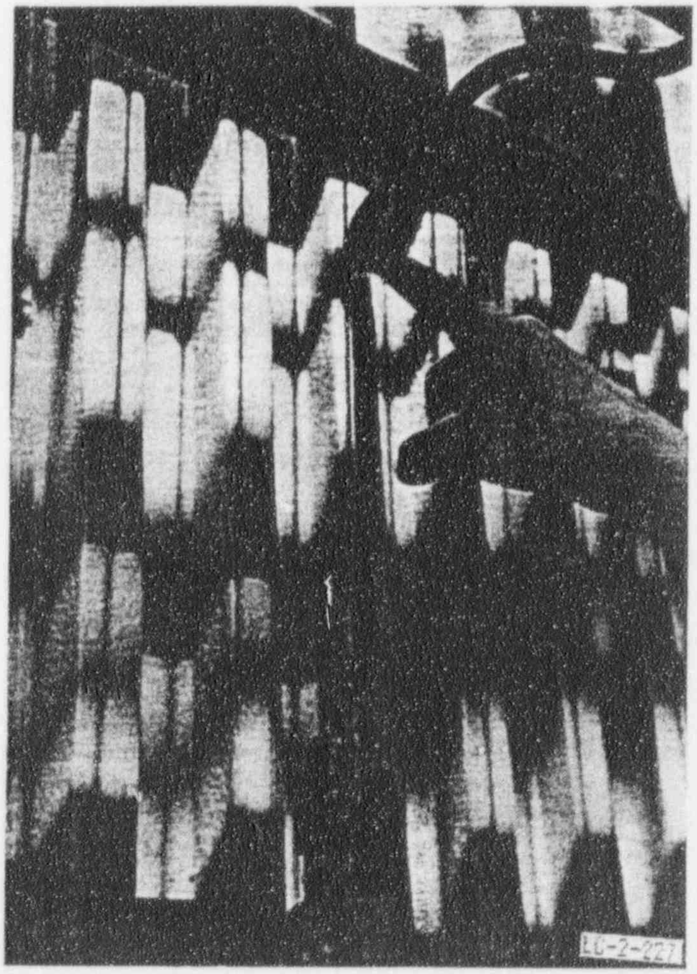


Figure 17: Pneumatic tubing within the plant instrument and service air systems remained intact, except for several locations where sway of the boilers buckled or crimped the instrument tubing as shown.

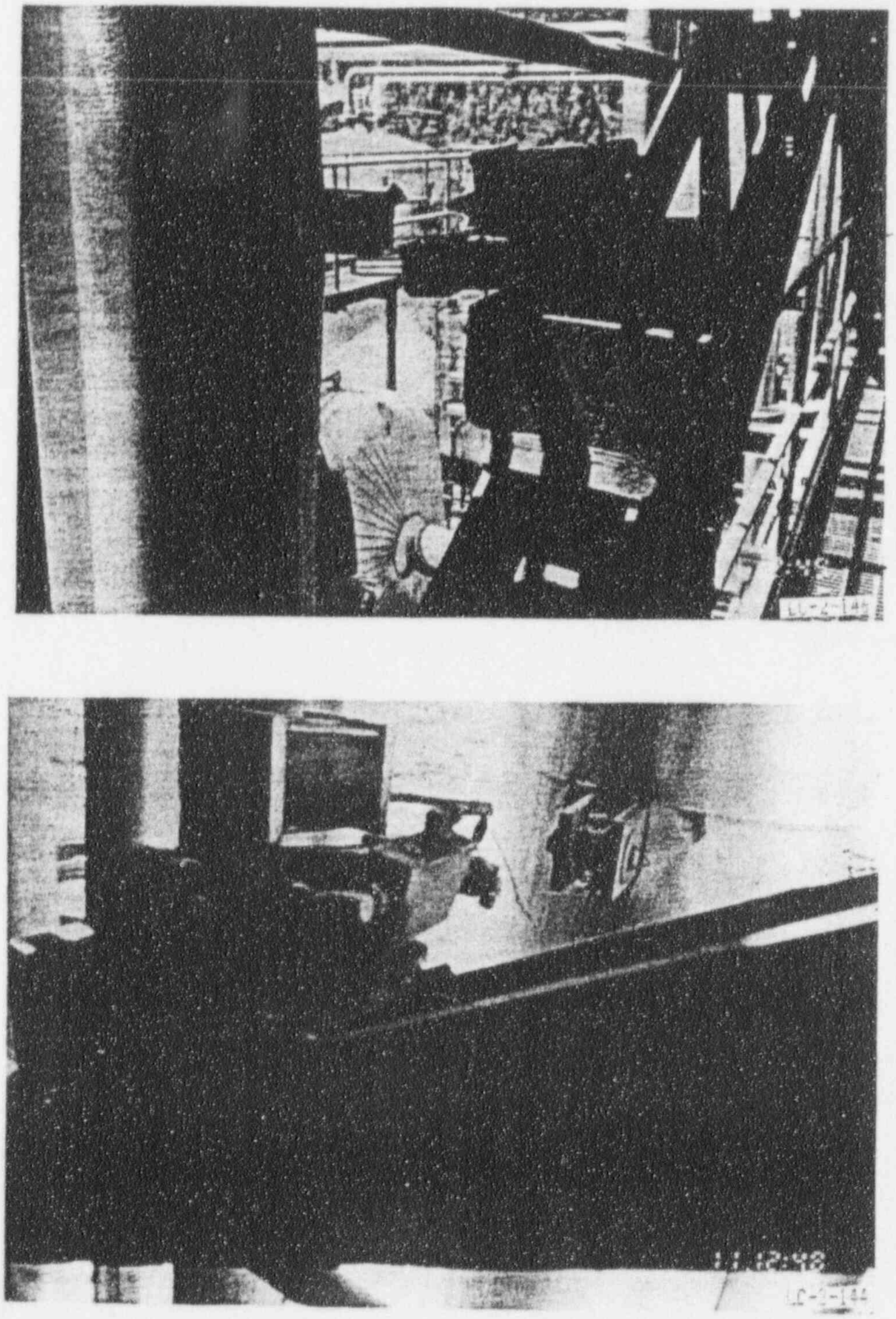
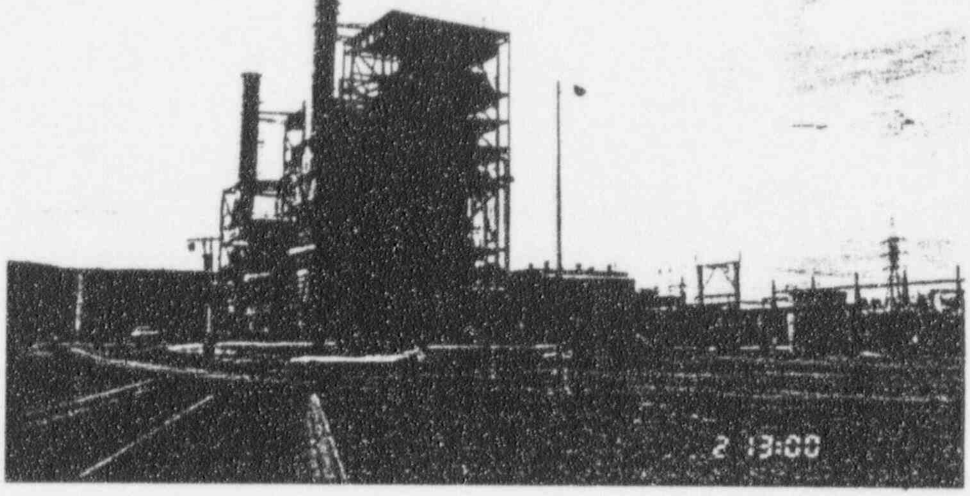


Figure 18: The only damage to piping support was the broken shaft of a mechanical snubber for main steam riser.



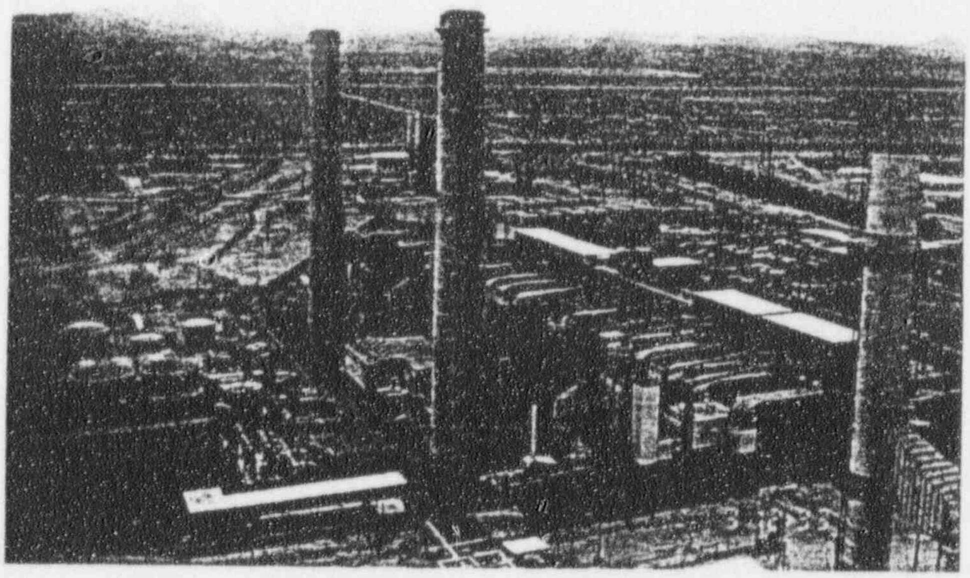
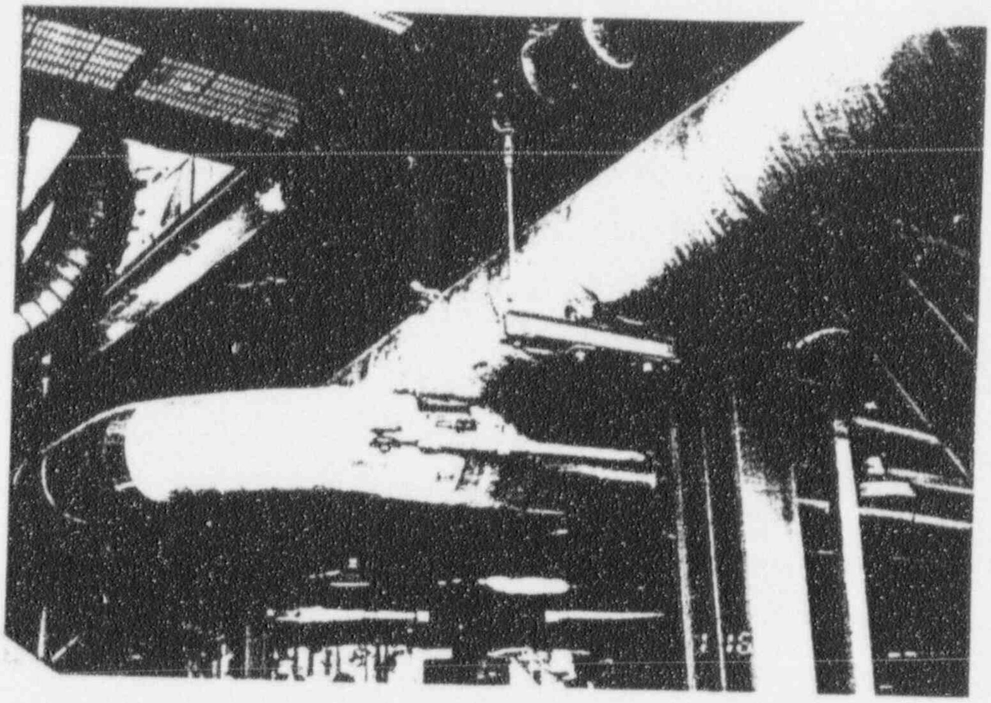


Figure 19: Cool Water Generation Plant, Units 1 & 2 (upper photo) and Units 3 & 4 (lower photo) located in Dagget, California.



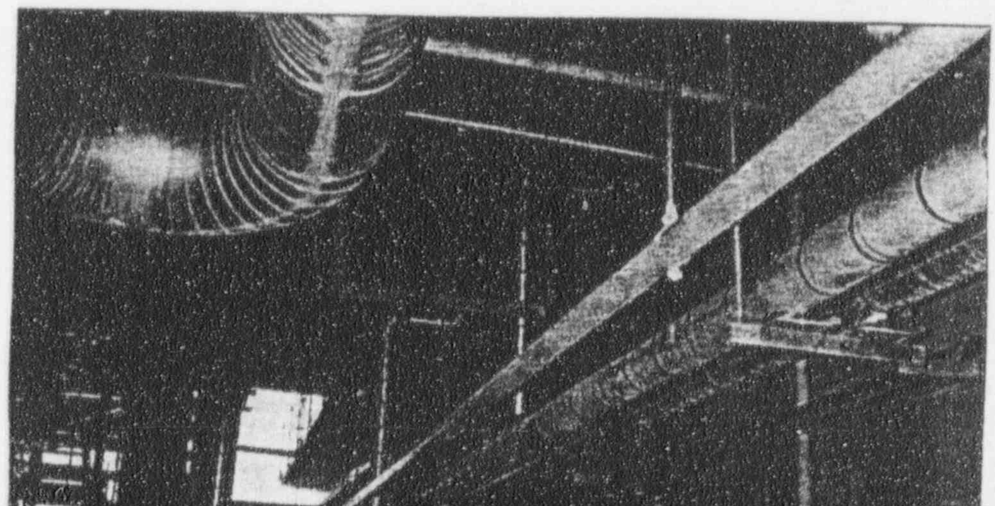


Figure 20: Typical pipe supports in Cool Water Units 1 & 2. Engineered supports for high energy, large bore piping (upper photo) and field-routed supports for low energy piping (lower photo).

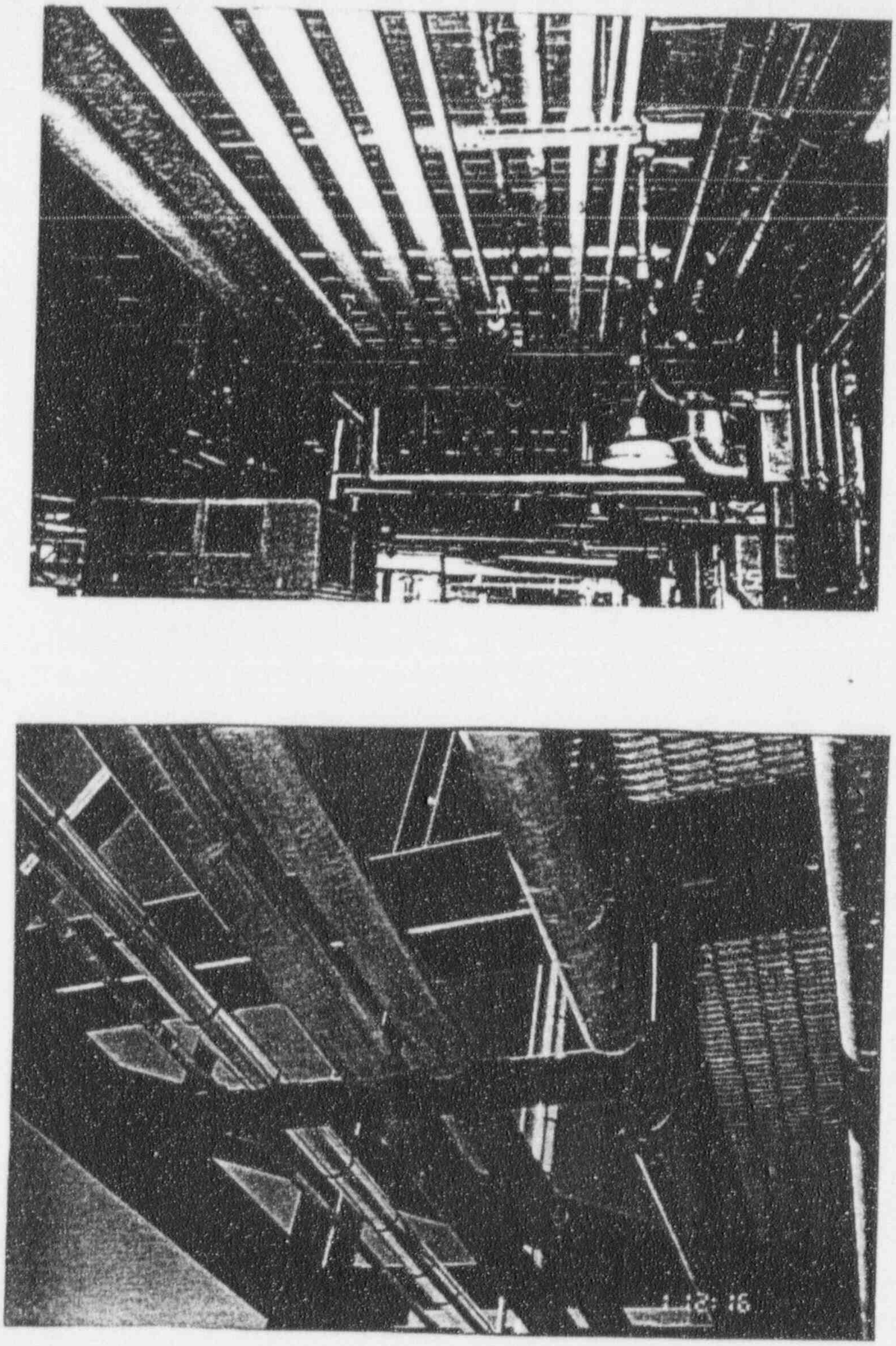
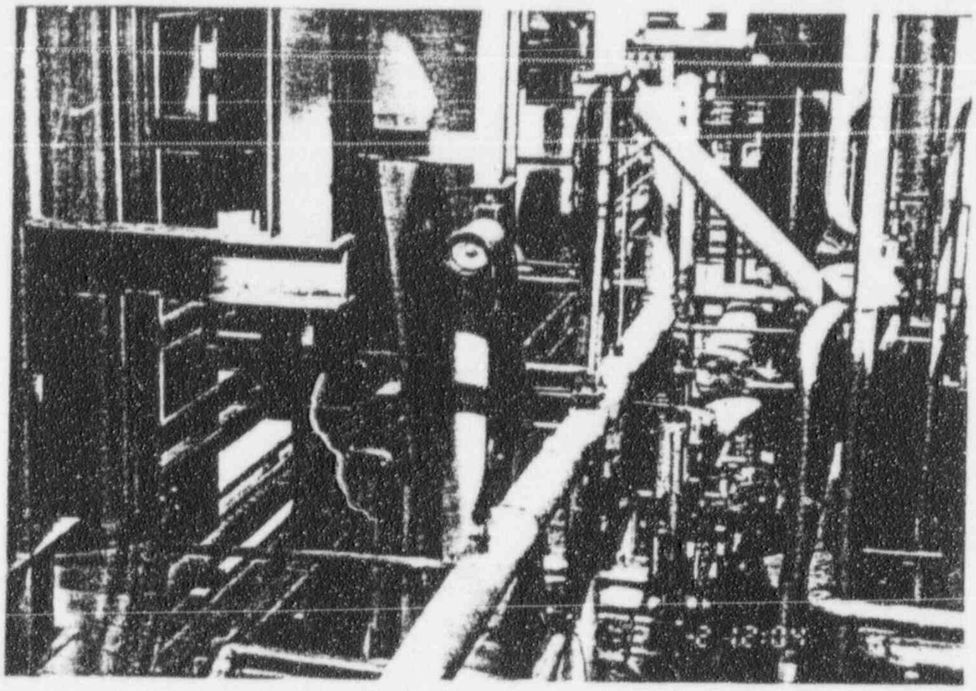


Figure 21: Typical trapeze frame supports in Cool Water Units 1 & 2.



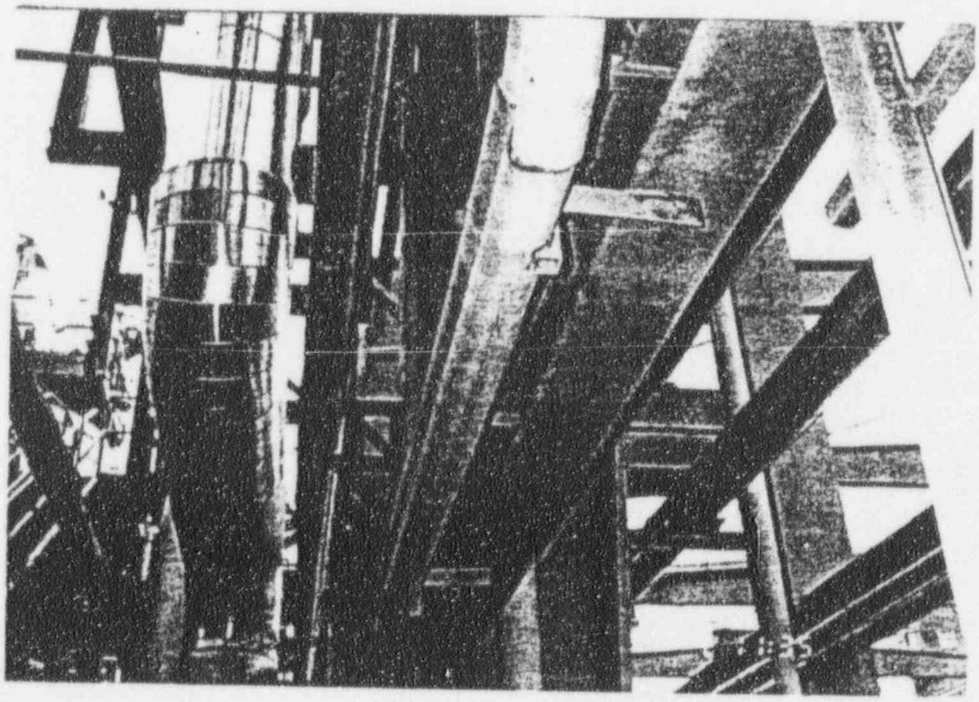


Figure 22: Typical pipe supports in Cool Water Units 3 & 4. Combination of rod hangers, U-bolts, and structural sections is widely used in the plant.

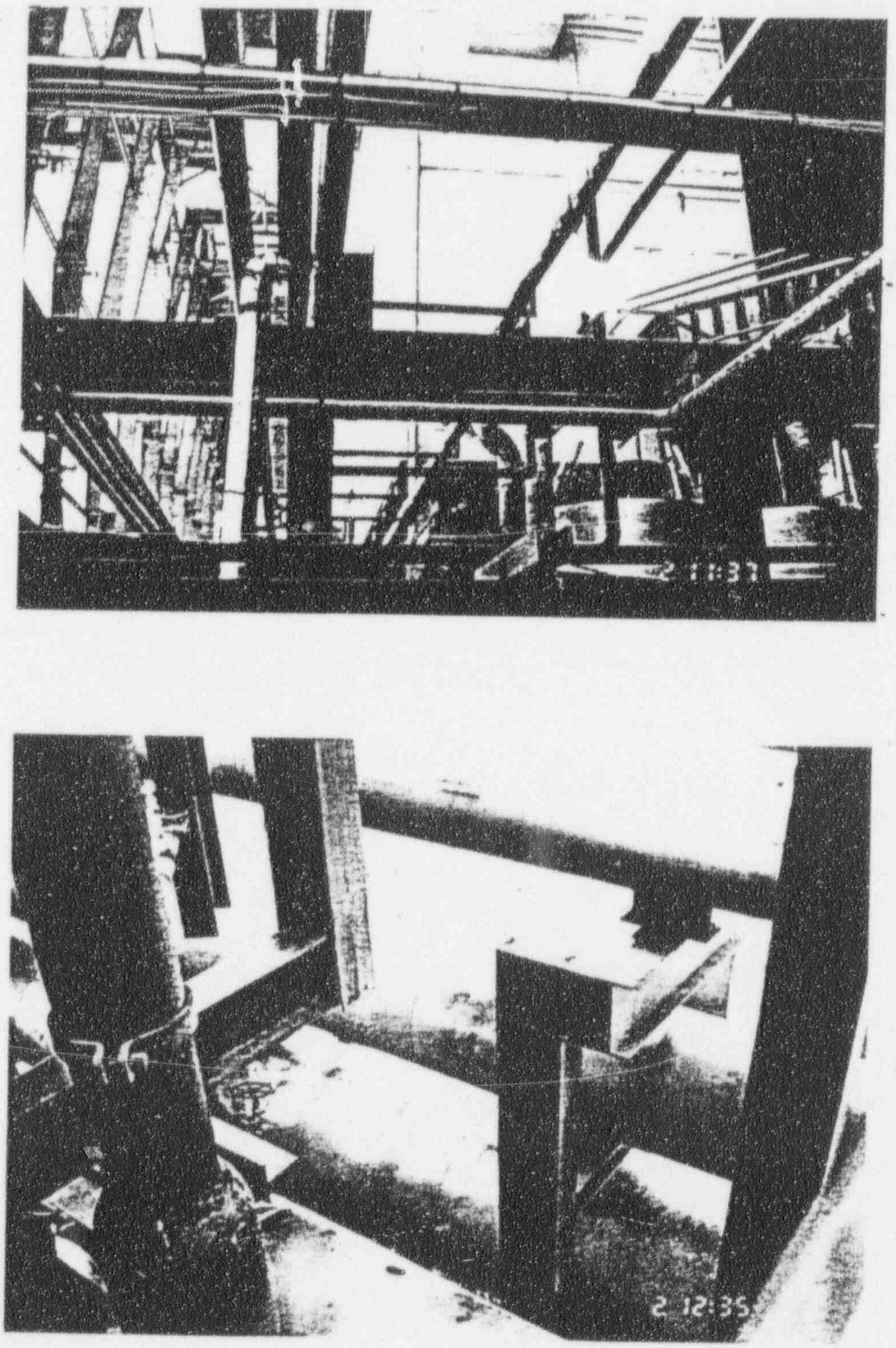
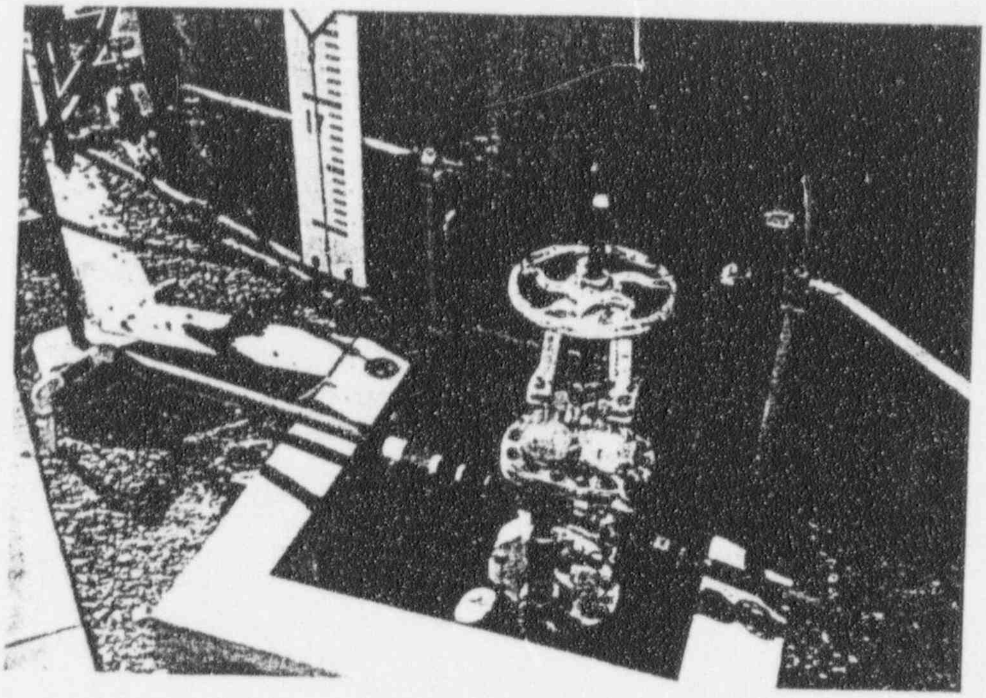


Figure 23: Typical structural steel section pipe supports found in Cool Water Units 3 & 4.



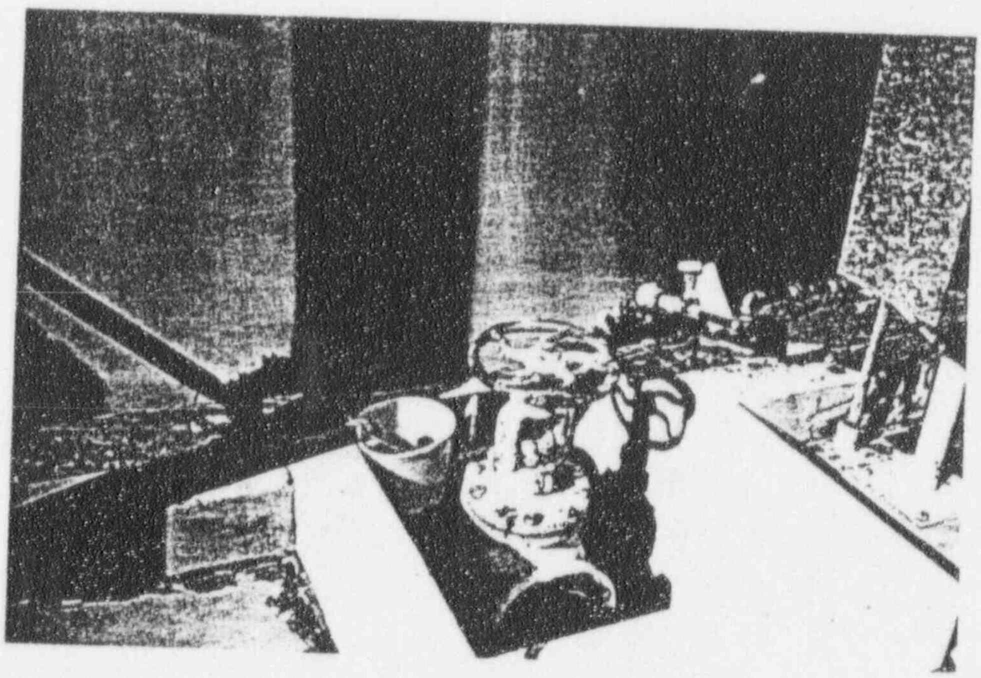


Figure 24: A one-inch diameter line fractured near its attachment to one of the tank drains at Cool Water Unit 1 due to differential displacement.

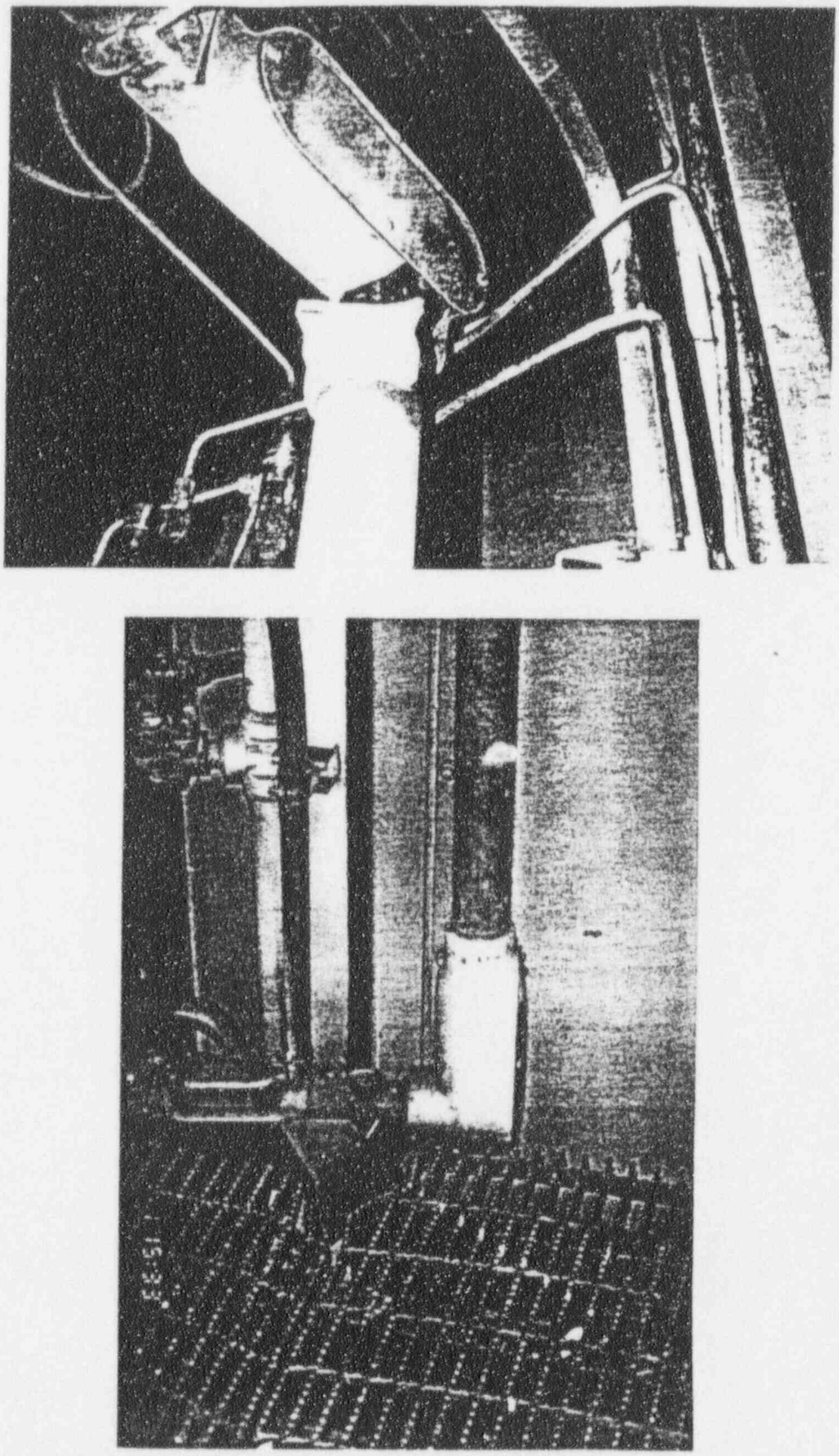


Figure 25: Instrument tubing or small air lines were fractured due to differential displacement between the attachment points at the Cool Water Unit 2 boiler tower and the swaying boiler (upper photo). Buckling of steel grating (lower photo) due to boiler movement and impact was found at several locations.

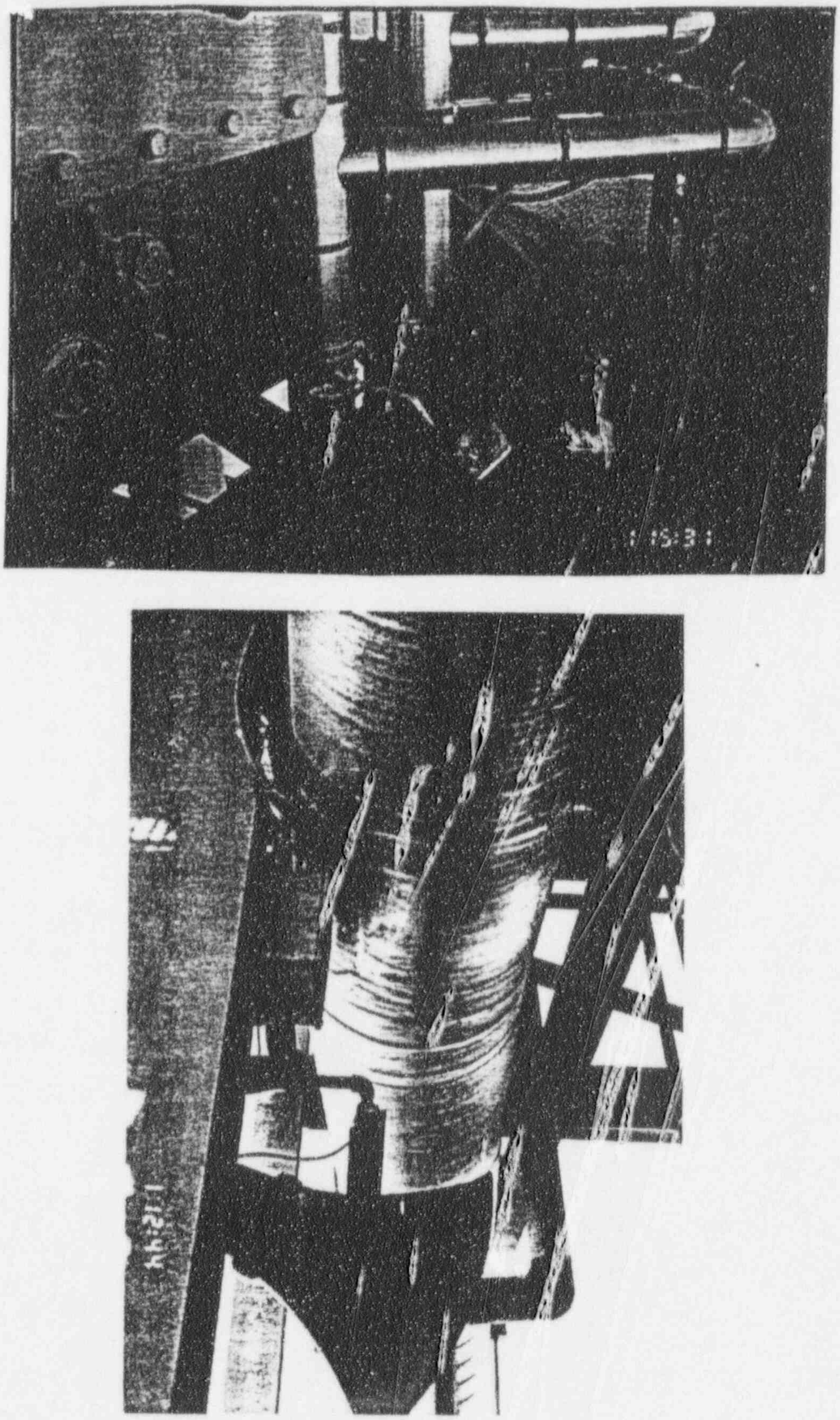


Figure 26: Several instances of proximity interactions noted at Cool Water Units 1 & 2.

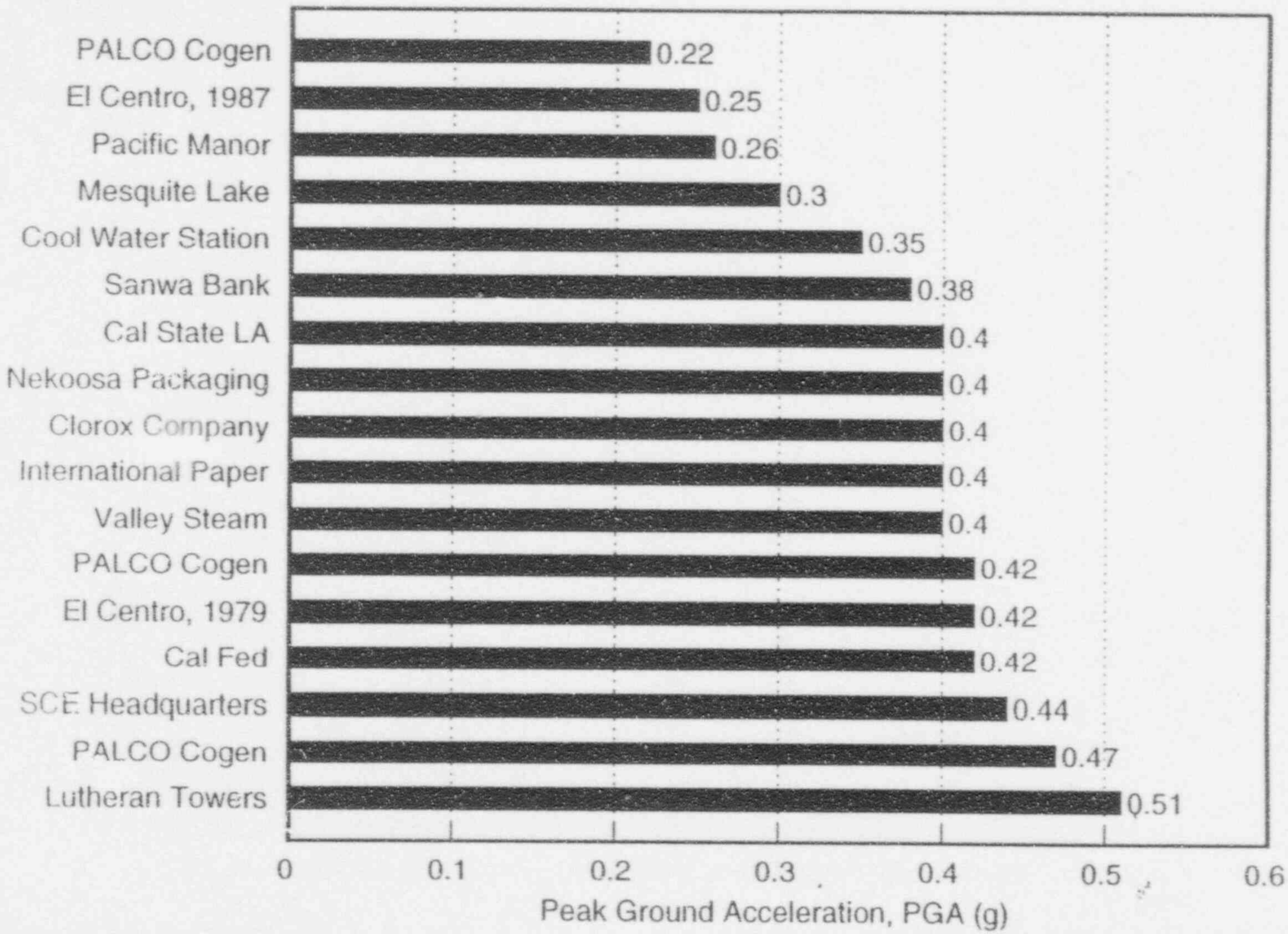


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Figure 29: Comparison of data base average horizontal peak ground acceleration.

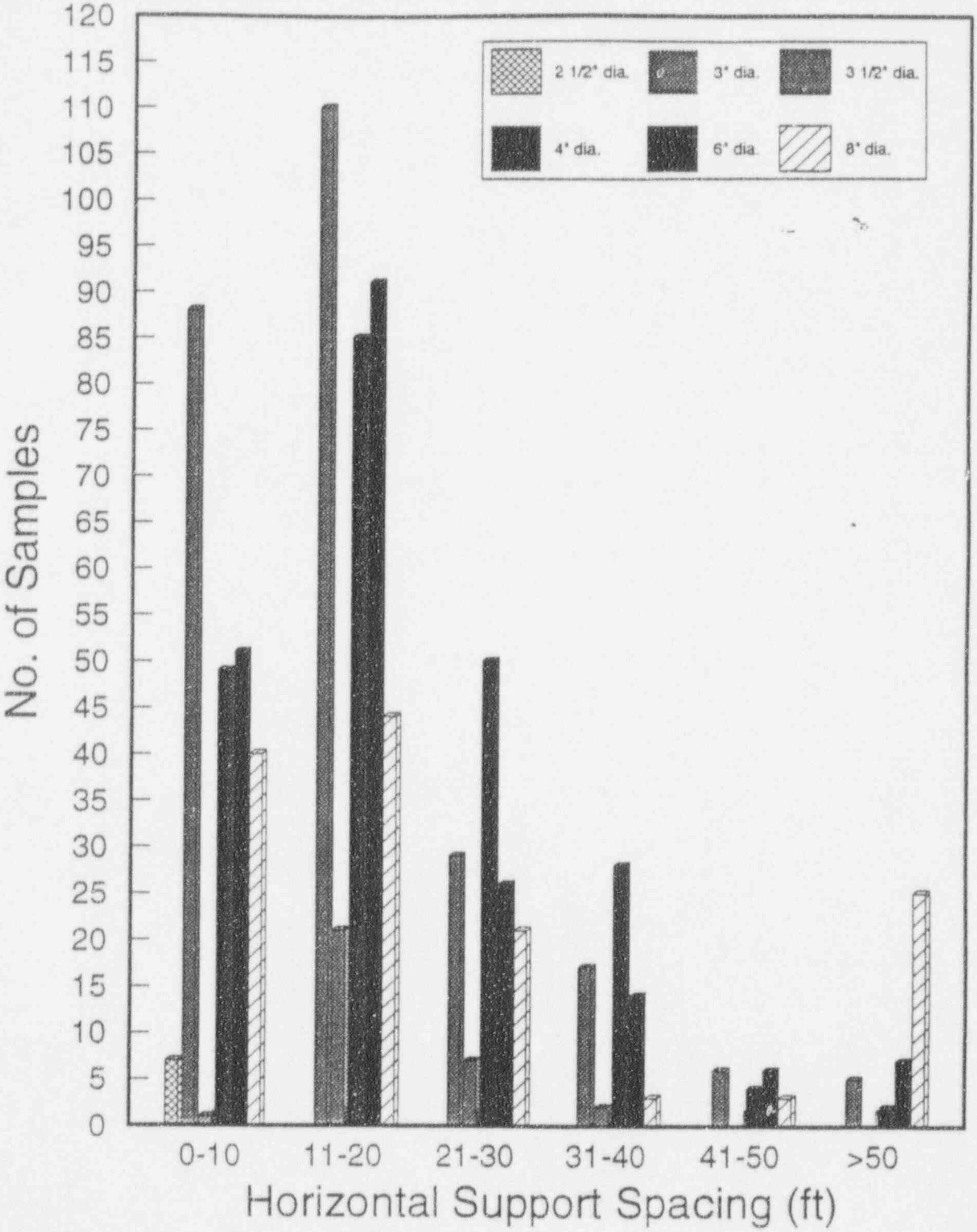

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Figure 30: Spacing between horizontal supports and number of samples for data base large bore piping.

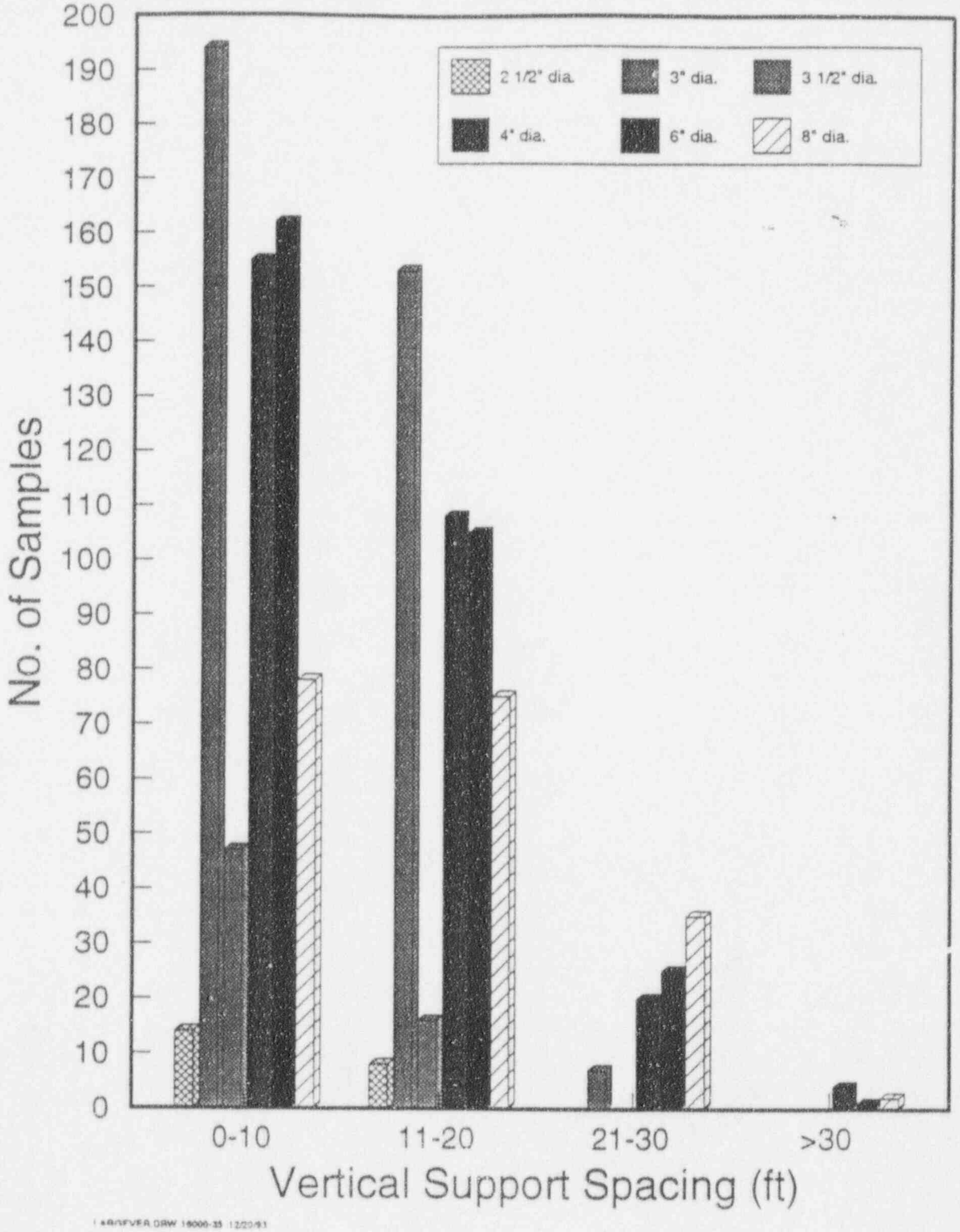

Figure 31: Spacing between vertical supports and number of samples for data base large bore piping.

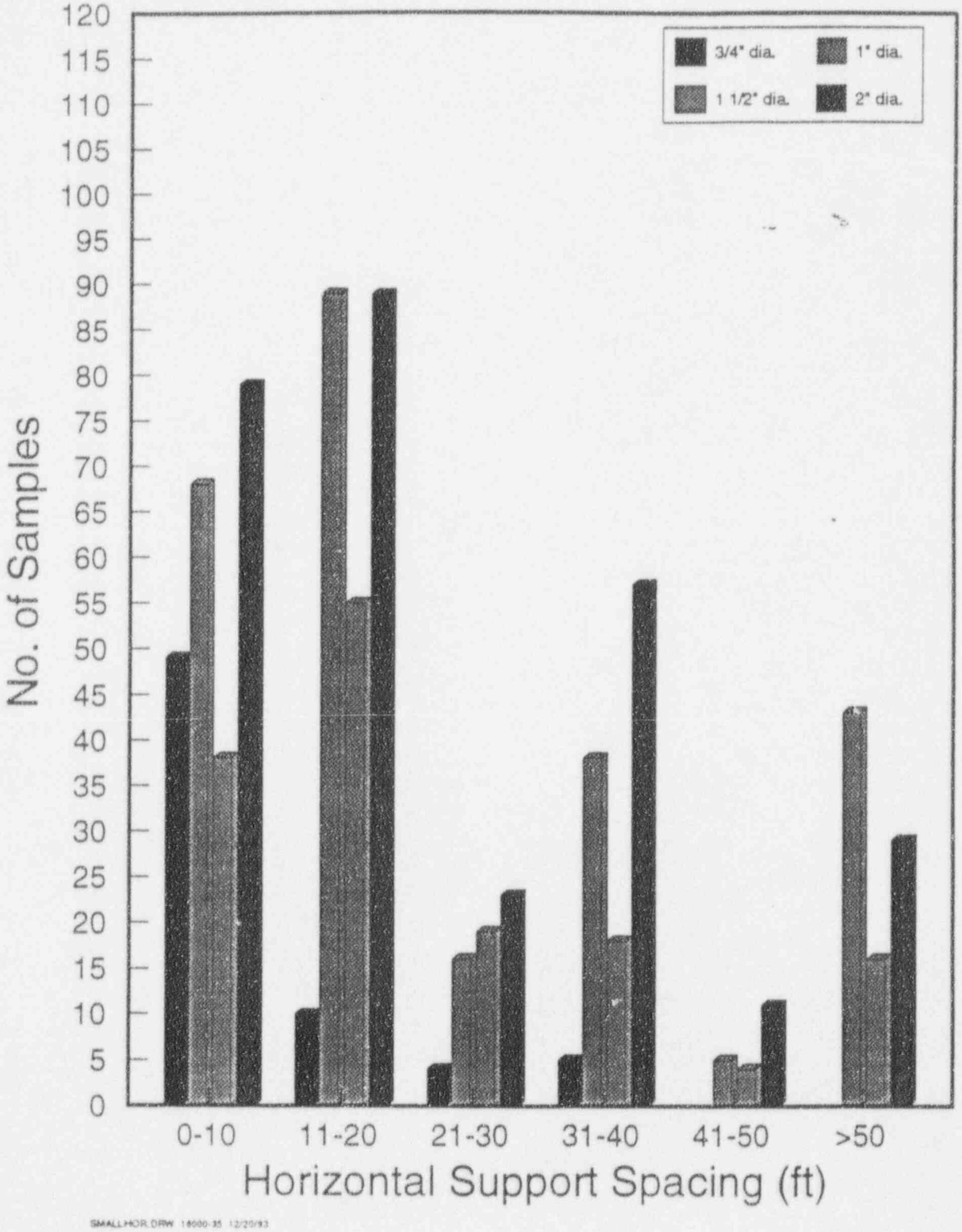

Figure 32: Spacing between horizontal supports and number of samples for data base small bore piping.

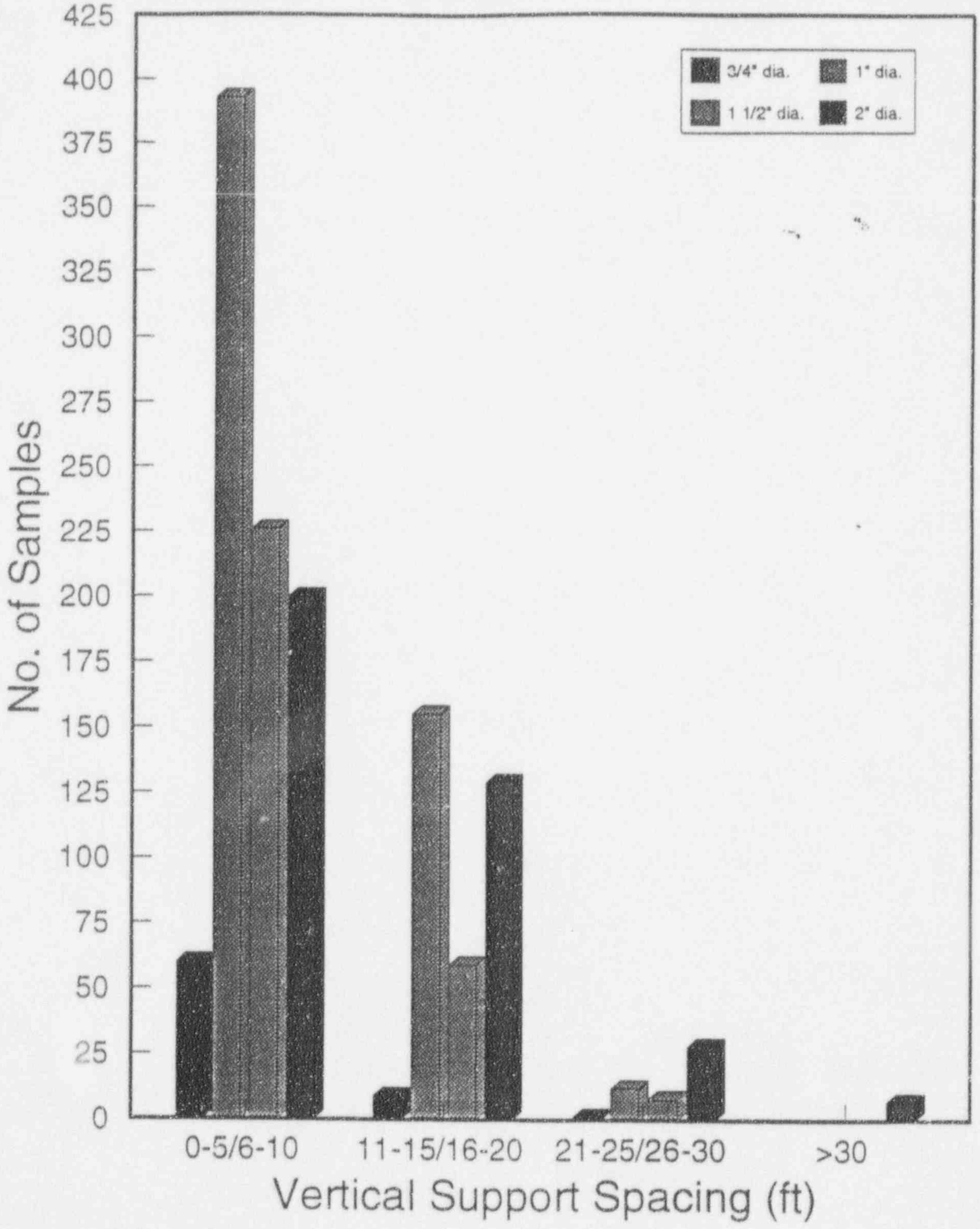

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Figure 33: Spacing between vertical supports and number of samples for data base small bore piping.

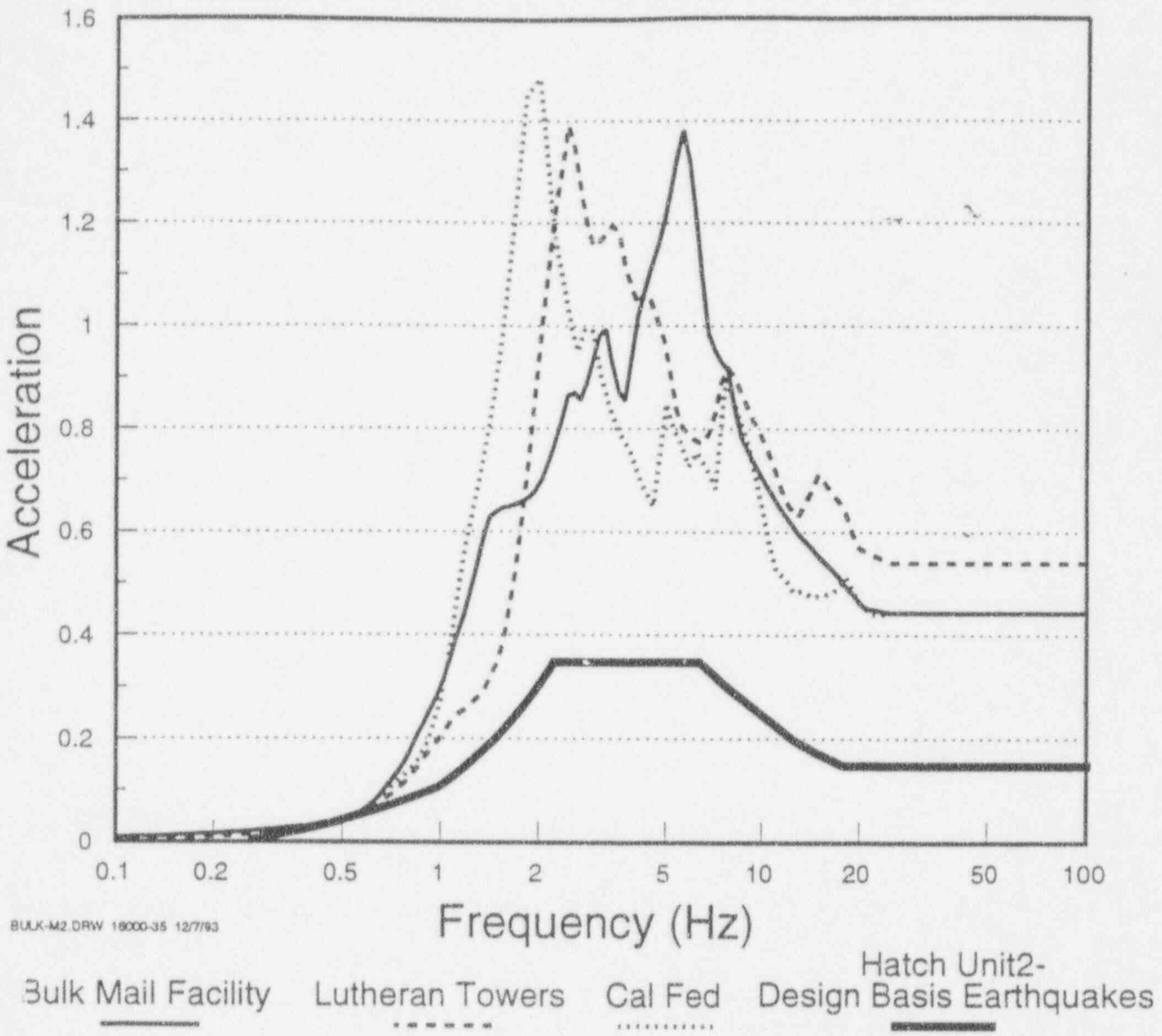

Figure 27: Comparison of Whittier data base sites and Hatch Unit 2 design spectra.

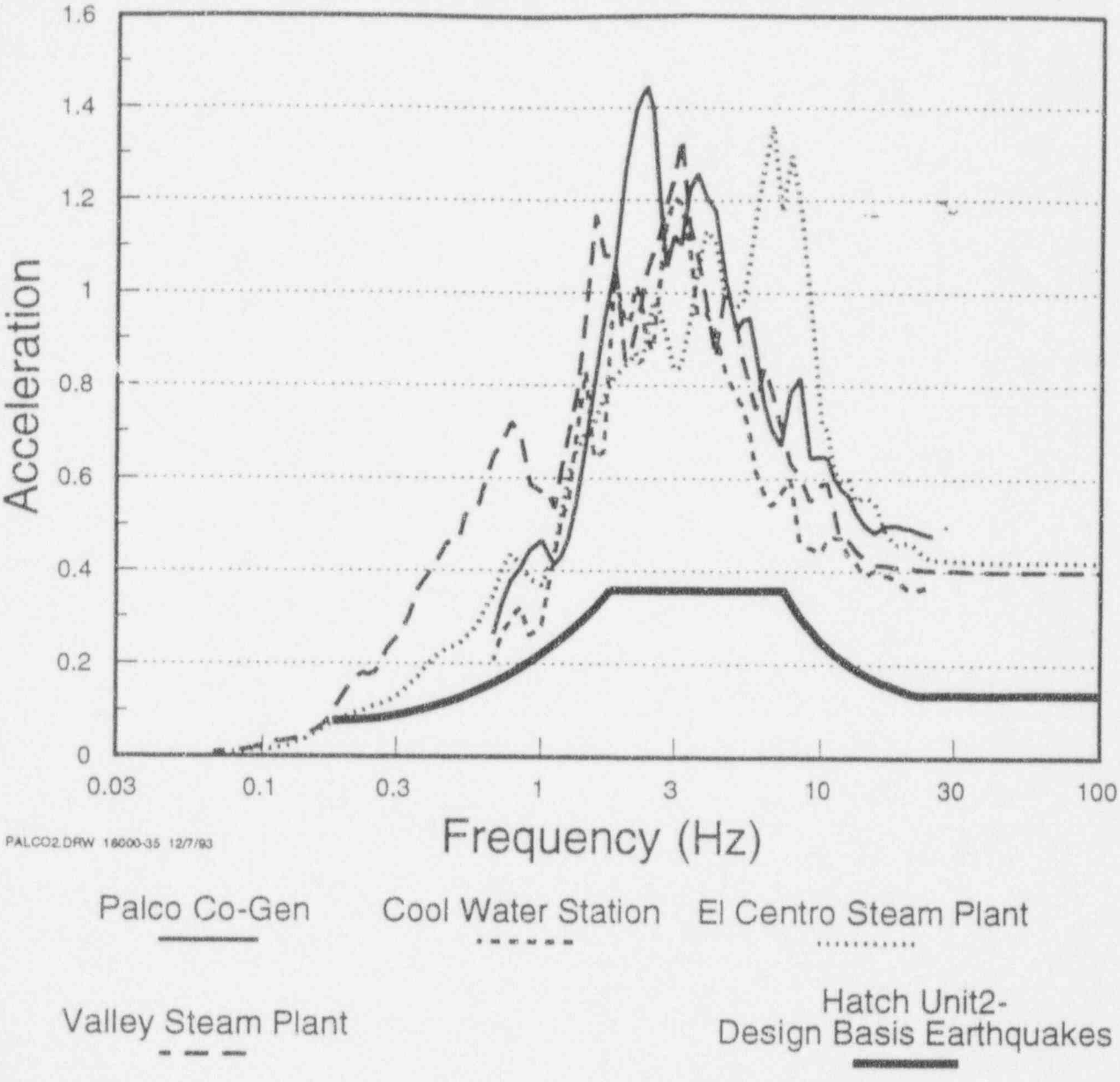

Figure 28: Comparison of data base power plant sites and Hatch Unit 2 design spectra.