3.7 SEISMIC DESIGN

Plant structures and components are designed according to the criteria described herein to resist the dynamic forces resulting from the earthquake conditions postulated for the site. These structures and components are analyzed either dynamically or statically for the respective equivalent loadings according to their classification.

Two types of seismic loadings are considered: Operational Basis Earthquake (OBE) and Design Basis Earthquake (DBE).

For the OBE loading condition, the nuclear steam supply system is designed to be capable of continued safe operation. Therefore, for this loading condition critical structures and equipment needed for this purpose are required to operate within design limits. The seismic design for the DBE is intended to provide a margin in design that assures capability to shut down and maintain the nuclear facility in a safe condition. In this case, it is only necessary to ensure that required critical structures and components do not lose their capability to perform their safety function. This has come to be referred to as the "no-loss-of-function" criteria and the loading condition as the "design basis earthquake" loading condition.

Not all critical components have the same functional requirements for safety. For example, the reactor containment must retain capability to restrict leakage to an acceptable level. Therefore, based on present practice, general elastic behavior of this structure under the "Design Basis Earthquake" loading condition must be ensured. On the other hand, many components can experience significant permanent deformation without loss of function. Piping and vessels are examples of the latter where the principal requirement is that they retain their contents and allow fluid flow.

What follows in Section 3.7 is a description of the original design basis seismic analyses performed for Salem Units 1 and 2. The reanalysis of the Unit 1 and Unit 2 reactor coolant loops, which addresses the elimination of snubbers from the steam generator upper supports, is described in Section 3.9.1.8.

3.7.1 Seismic Input

3.7.1.1 Design Response Spectra

The El Centro ground motion of May 18, 1940, was recommended by Dames and Moore as the most appropriate motion for the site. Its peak horizontal acceleration was normalized to 0.10g and 0.20g for Operating and Design Basis Earthquake, respectively. Two-thirds of the above mentioned values are used for vertical ground motions, and they are considered to be acting simultaneously with the horizontal ground motion.

Modified Housner's average response spectra as shown on Figures 3.7-1 and 3.7-2 are used for manual modal analysis.

The Salem ground response spectra are generally lower than those normalized from Regulatory Guide 1.60. However, the conservative damping values used in the Salem analyses compensate for the differences. Furthermore, time history input was used for Category I structure seismic analyses. The normalized El Centro 1940 ground response N-S components, as shown on Figures 3.7-1 and 3.7-2, are considerably higher than the Salem ground response spectra.

3.7.1.2 Design Response Spectra Derivation

The tabulation which follows provides a comparison of the damping values used in the seismic analysis with those identified in Regulatory Guide (RG) 1.61. It can be seen that the damping values used in the Salem analysis are consistently more conservative than the Regulatory Guide recommended values.

Component	Damping Values			
	SSE		OBE	
	Salem	RG 1.61	Salem	RG 1.61
Large Diameter Piping Systems Greater than 12"	1.0	3.0	0.5	2.0
Small Diameter Piping Systems 12" or less	0.5	2.0	0.5	1.0
Concrete Structures	5.0	7.0	2.0	4.0
Bolted or Riveted Steel	5.0	8.0	2.5	4.0
Welded Steel	3.0	4.0	1.0	2.0

In the seismic analysis of mechanical equipment (Westinghouse supplied) and Category I structures the method of combining responses is to add absolutely the results of the vertical and the worst of the two horizontal earthquake components.

3.7.1.3 Critical Damping Values

The following damping values are used in the design:

Component	Percent of Critical Damping
1. Concrete Structures	2 (OBE)
	5 (DBE)

2. Structural Steel				
Bolted or Riveted	2.5	(OBE)	5	(DBE)
Welded	1.0	(OBE)	3	(DBE)
3. Vital Piping System	0.5	(OBE)	0.5	(DBE)

For the DBE, a damping factor of 5 percent of critical damping is used for analysis for structure and soil. Similarly, for the OBE, a damping factor of 2 percent is applied for both structure and soil.

3.7.1.4 Bases for Site Dependent Analysis

The soft soil properties, as determined by Dames and Moore, used in the finite element seismic analysis will filter out some high frequency waves. However, the input response spectra, as shown on Figure 3.7-2, indicate that the structure will experience very little or no amplification in the high frequency range. Various modal analyses, both with or without soil interaction, indicate that the fundamental mode and other modes with large participation factors are not in the high frequency range. Thus high frequency filtering will not significantly affect the structural response.

Conrad Associates has also performed two separate studies, with and without soil backfill around the Containment Building, to find the most critical building response. They have concluded that the inclusion of the soil backfill in the finite element model yields a more critical condition for the Containment Building. The result of the plots is shown on Figure 2-63 of the Conrad Associates Report (1).

A nonlinear stress-strain relationship for soil properties has been recognized in our modal analyses. Due to the different strain levels in the soil under the OBE and DBE, the secant modulus of the soil has different values. Our soils' consultant, Dames and Moore, established the values for the secant modulus through dynamic triaxial tests of soil samples which imposed strain levels on the soil equivalent to those levels which are predicted to develop in the soil at the Salem site under the two different earthquake magnitudes. The range of the secant modulus of the different layers of soil at the Salem site under OBE and DBE motions is listed in Table 2-3 of Reference 1.

The free field response spectra at Elevation 30 feet, scaled down from El Centro N-S components, are shown on Figures 3.7-1 and 3.7-2. Both of the free field response spectra envelop the smooth curve site design spectra except at frequencies smaller than 0.25 cps, which is beyond the range of all structural modal frequencies.

Although the soil properties were not varied in their courses of motion under varying strains for each separate OBE and DBE seismic analysis, this effect has been taken into account in the parametric studies for establishing the most severe design load. The analytical model for the most critical case is that which has compacted fill completely surrounding the Containment Building, while in the actual case, the compacted sand encompasses only a portion of the periphery of the containment wall. In this conservative model, the soil rocking spring was increased more than the equivalent rise of the soil property by 30 percent. Reduction of the soil modulus of elasticity, or neglecting the backfill completely, results in a less critical case in the structural response. Thus, the most conservative response from soil interaction has been used in the design of the Category I (seismic) structures.

3.7.2 Seismic System Analysis

This information is printed in detail in Reference 1.

3.7.2.1. Seismic Analysis for Structures

3.7.2.1.1 Seismic Analysis for Category I Structures

For seismic analysis of structures, two separate model analyses, horizontal and vertical motions, were performed and their results superimposed.

The acceleration time histories from the result of the structural seismic analysis were used for the generation of horizontal and vertical response spectra at specified floors or locations for equipment of seismic design. They are kept on file by Public Service Electric & Gas (PSE&G) (1 and 3).

Total accelerations, peak displacements, and the envelope of forces in the containment structure under DBE and OBE conditions are shown on Figures 3.7-3 through 3.7-12.

Clearances between Category I buildings and adjacent structures were checked based on the relative displacements at various building elevations under seismic and design basis accident loadings to assure that the required separations are maintained.

Seismic design for Category I structures is based on dynamic analysis. The mathematical model of an equivalent system has been used to simulate the response. The system consists of lumped masses at floor levels supported by weightless springs. Floor rotations are neglected. Both shear stiffness and flexure stiffness are included in the spring constants. The lumped mass system is considered resting on the rigid base mat.

To solve the modal frequencies and mode shapes, the Stodola-Vianello Procedure and the Modified Rayleigh Method were used in manual analysis. The independent computer analysis sets up the dynamic equilibrium equations in the matrix form and uncouples the response of the structure through the computer program.

Average response spectra were used in the manual analysis while time history inputs were used in the computer analysis.

Rocking of a structure due to yielding of the subgrade under the lean concrete fill was considered. Response of the structure under the combined rocking and translational modes as well as the separated independent modes were evaluated. For soil structure interaction in the computer analysis, a series of studies were conducted in order to establish the free field soil boundaries. With the boundaries established, the finite element model, including the surrounding soil mass, can be set up more accurately.

With the exception of Auxiliary Building horizontal seismic responses, the containment structure seismic analysis was performed through (1) lumped mass model manual analysis, using average response spectra ground input, and (2) a finite element model analysis, using time history ground input. The detailed report from Conrad Associates (1) and the independent manual calculations are kept on file by PSE&G.

The computer analysis yielded a slightly higher result in accelerations, shears, and moments in comparison with the manual analysis. The most conservative results were used in design.

The seismic analysis of the containment structure by the finite element method was performed by computer using a step-by-step direct integration procedure. Studies were made to establish free field soil boundary condition. The model used in the analysis is shown on Figure 3.7-13.

3.7.2.1.2 Seismic Analysis for Category II and Category III Structures

There are no Category II structures at the Salem Generating Station.

Category III structures are designed for loadings commonly used in the design of conventional power plants. In the State of New Jersey, no seismic analysis is required for conventional power plants, or non-nuclear elements of nuclear power plants.

Extra precautions have been taken to brace the Category III structures in the direction of Category I structures so that the possibility of failure of the Category III structure affecting the integrity of the Category I structure is eliminated.

3.7.2.2 Natural Frequencies and Response Loads

Containment Building mode frequencies, shapes, and participation factors are shown on Figures 2-29 through 2-46 in the Conrad Associates' report. The floor response spectra are shown on Figures 2-68 through 2-91 in that report.

3.7.2.3 Procedures Used to Lump Masses

Masses were lumped at points of mass concentration, such as building floors, or selected points so that the displacement of these points gave a good representation of the distortion of the structure. The ratio of floor mass to the supported equipment is indeed very large. Thus, the equipment compliance will not alter the building of floor response. A finite element model was used for seismic analysis containment structures at the Salem station. A total of 190 elements were used in discretizing the structure.

Lumped mass models were used for the seismic analysis of the Auxiliary Building and Fuel Handling Building. The points of mass concentration of these buildings are most apparent at the roof, floor, and foundations. Heavy equipment and subsystems in the buildings are rigidly attached to the floors. Therefore, the masses of the analytical models were logically lumped at these levels.

Analytical models have been reviewed and it is concluded that the degrees of freedom used are adequate. Additional degrees of freedom in these models will not result in more than 10 percent increase in structural responses.

The mass ratios of subsystems to the supporting structures are less than 0.1 and, therefore, the subsystems are not included in the structural model.

Based on the above, the Salem design is in compliance with the modeling criteria defined in Section 3.7.2 of the Standard Review Plan.

3.7.2.4 Methods Used to Couple Soil with Seismic-System Structures

Studies were undertaken to examine the influence of the soil boundary location on the dynamic behavior of the Containment Building. The soil-structure continuum boundary was established through five finite elementary models. With the free field soil boundary determined, the finite element model was set up for seismic analysis. The seismic analysis of the Containment Building by the finite element method was performed by computer using a step-by-step direct integration procedure.

3.7.2.5 Development of Floor Response Spectra

Response spectra at different floors in the structures were derived for use in the design of Category I (seismic) mechanical and electrical equipment, piping, and their supports. These spectra were obtained as follows: The building was subjected to the input ground acceleration time history and the corresponding output acceleration time histories at the floors of interest were determined. The acceleration time histories were then used to derive single-degree-of-freedom system response spectra, which are the floor response spectra, for each floor of interest.

3.7.2.6 Differential Seismic Movement of Interconnected Components

In most cases, the seismic analysis of Category I (seismic) piping systems was performed using the modal response spectrum method. In order to account for the effects of the relative displacement between piping support points in this analysis, the following procedures were used:

1. For any given system under analysis, define piping support locations which could transmit significant forces to piping due to relative building and/or equipment displacements.

2. For analysis of building and/or equipment vibrational characteristics, establish an upper bound on the magnitude of relative displacements for locations defined in 1., above.

3. Apply significant relative displacements found in 2., above to the piping system as static anchor (or support) displacements.

3.7.2.7 Combination of Modal Responses

In the response spectra analysis, the total response for the structures and components is the square root of the sum of the square of all maximum values from all modes, provided there are three modes or more. In cases where there are only two modes contributing significantly or when there are three contributing modes with only one dominant, the absolute sum of the maximum values was used for design.

In the time history analysis, the corresponding response in each vibrating mode is calculated as a function of time. The total response for any desired instant is evaluated by summing the response of all significant modes.

If modal frequencies are closely spaced, the total response for structural items is computed as the absolute of the modal responses.

3.7.2.8 Effects of Variations on Floor Response Spectra

In equipment seismic design using floor response spectra as input, PSE&G requested that suppliers ensure that the period falls outside of the peak regions in order to avoid a resonance effect and sensitive variation in response under a small shifting of period. On other steep portions of curves, conservative response readings were made to account for the inaccuracy of periods of vibration due to various unaccountable effects in the modal analysis.

A minimum of ± 10 percent shifting of period coordinates was provided in obtaining the system's conservative response from the floor response spectra. This allows for the possible period inaccuracy due to the variation of structural properties, damping values, soil properties, and soil structural interaction.

The intent in qualifying component seismic capability was that the component should be analyzed with mode frequencies apart from the floor response peaks to avoid the effect of damaging resonance. Vendors were instructed to stiffen the component to shift its model frequencies outside the spike area. In other more flat areas of the response spectra, a 10 percent shifting of period coordination has been provided in obtaining the system's conservative response.

Regulatory Guide 1.122 (issued on September 1976) requires that the peaks of the response spectra be broadened by ± 10 percent fj if computed value is less than that amount ± 15 percent fj if the variation value is not computed. The Salem floor response spectra was developed before the issuance of this Regulatory Guide. At the time of the Salem design, 10 percent shifting was considered sufficient.

As noted above, the containment floor response spectra were broadened by ± 10 percent. The prominent spike, however, is at 1 cps, a very flexible frequency. None of the equipment falls in this area. In the other Category I buildings, there is more than one spike in the floor response spectra. In order to avoid undesirable resonance effects, components were stiffened and frequencies shifted outside the sharp spiked areas, thereby eliminating the broadening considerations. In other flat areas of the response spectra, a 10 percent shifting of frequency coordinates was applied to obtain the equipment response. Since these areas are flat, an additional 5 percent shifting would not cause an appreciable change to equipment response.

3.7.2.9 Method Used to Account for Torsional Effects

PSE&G's evaluation in response to the Nuclear Regulatory Commission (NRC) request to add a 5 percent accidental eccentricity in the containment seismic design is as follows:

1. Torsional shears as a result of 5 percent eccentricity in the thick containment shell wall and interior crane wall are very small. Under DBE loading, the containment shell wall will have torsional shear of 7 psi while in the crane wall, only 3 psi.

2. Designed to be resisted solely by the 45° diagonal reinforcement. The concrete and liner plate were neglected in taking any portion of the shear load. The reserve capacities in the concrete and liner can easily handle the extremely small torsional shear stress.

3. If one attempts to avoid seismic shear in the concrete and liner, then the hoop reinforcement in the cylinder will act as torsional stirrups. The torsional shear will merely increase the rebar stress by 0.7 ksi. In our loading combinations (B), (C), and (E) when the

torsional moment is present, the stresses in the hoop reinforcement in the lower portion of the cylinder are under 50 percent of their capacity.

4. The reserve capacity of the concrete in the crane wall, assisted by the many interior walls framed into the crane wall, will easily take care of the even smaller torsional shear.

The Containment Building is basically axisymmetric; therefore the torsional mode is not prominent. In designing the Auxiliary and Fuel Handling Buildings, the torsional moments at each floor level due to the distance between the center of rigidity and the center of mass were taken into account. The floors are very strong and rigid and the supporting walls would deflect equally, provided the center of mass coincides with the center of rigidity. The horizontal shear would be distributed to the cross walls in proportion to their stiffness. However, since the lateral shear is applied not at the center of rigidity, but at the center of mass, an adjustment for shear distribution must be made to compensate for the torsional effect. The shear resisting capacity of walls which resist the torsional moment have therefore been increased. For conservatism, other wall shears were not reduced where the torsional moment becomes beneficial to them.

3.7.2.10 Comparison of Responses

The finite-element model was only applied to the seismic analysis of the containment structure. The Auxiliary Building and the Fuel Handling Building modal analyses were based on lumped mass models.

Two independent seismic analyses were performed for the containment structure, namely a finite-element time history analysis and a lumped mass response spectrum analysis. The comparison of response at selected points in the containment structure from these two analyses is as follows:

	Top of Dome		El. 130 Feet	
	Acceleration	Displacement	Acceleration	Displacement
Time History	0.60g	1.88 inches	0.28g	0.53 inch
Response Spectrum	0.59g	1.96 inches	0.29g	0.69 inch

3.7.2.11 Methods to Determine Category I Structure Overturning

Linear modal analysis was performed using time history and ground response spectra as input. Modal response was determined through both computer and manual analyses. From the displacement responses, the maximum values of the shear and overturning moment were determined by applying the proper spring constant and lever arms at different floor levels.

As part of the seismic analysis of the finite element model by Conrad Associates, soil reactions in the compacted sand fills were computed for both the DBE and OBE conditions.

Vertical seismic analysis for the Containment Building was also performed. The vertical response was considered to be either upward or downward so that it would increase the soil pressure when it was downward and decrease the stability factor against overturning when it was upward.

3.7.2.12 Analysis Procedure for Damping

Major Category I structures are essentially concrete. Steel equipment supports and platforms represent a very small percentage of the total mass of the entire structure. In the building modal analysis, the equipment and platform masses were included in the lumped mass system and a uniform damping value was used. The floor response spectra were thus developed to be used as the input loading to the equipment and support structures, where the appropriate damping value for the material was assigned in the analysis.

3.7.3 Seismic Subsystem Analysis

3.7.3.1 Determination of Number of Earthquake Cycles

The containment liner is the most critical structural component that may be subjected to fatigue stress under cyclic loading. Tests* have indicated that plates stressed under reverse stresses of 20 ksi tension and compression produced failure after 180,000 cycles. The containment liner plate stresses under seismic load alone are below that range. Thus, the number of seismic loading cycles indicated above is not at all damaging.

Category I (seismic) piping, with the exception of the primary coolant loop, has been designed to the stress criteria indicated in Section 3.9.2. The number of maximum amplitude loading cycles due to seismic events has been considered in the design criteria; however, it has been found unnecessary to apply correction to allowable stresses to account for fatigue phenomena in the design of this piping.

Experience dictates that the fundamental mode of vibration of piping systems varies between 0.1 and 1 second. Earthquake strong motion can be conservatively estimated as 10 seconds in duration. Postulating five OBE events and one DBE event over the life of the plant, the number of seismically induced stress cycles can be calculated as

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*Highway Research Record No. 176, "Fatigue Tests of Plates and Beams"

$$N_s = \frac{N_{ea} \text{ x Seismic Strong Motion Duration}}{T}$$

where:

N_s = number of seismically induced stress cycles

N_{ea} = number of seismic events

T = fundamental piping period, seconds

Therefore, for the OBE:

$$N_s = \frac{\text{(5 events)(10 seconds/event)}}{\text{(0.1 seconds/cycle)}}$$

$$= 500 \text{ cycles}$$

and, for the DBE:

$$N_s = \frac{\text{(1 event)(10 seconds/event)}}{\text{(0.1 seconds/cycle)}}$$

$$= 100 \text{ cycles}$$

Although the allowable design stresses are greater than the endurance limits of the materials used, it can be shown that the usage factor, U, defined as:

$$U = \frac{\text{Number of Specified Stress Cycles}}{\text{Number of Permitted Stress Cycles}}$$

is sufficiently small to provide an adequate margin of safety.

Westinghouse supplied Category I (seismic) systems, components, and equipment requiring a fatigue evaluation by the appropriate codes and standards are evaluated according to a criteria somewhat different than that used by PSE&G.

Five OBE events and one DBE event are postulated during the life of the plant. The actual number of maximum response cycles in a response history varies with several parameters such as damping of the equipment and the support structure, ground time history, etc. The response cycles of a magnitude less than the maximum response may be converted to an equivalent number of maximum response cycles by using the fatigue curves given in the ASME Boiler and Pressure Vessel Code, Section III.

The Areva NP Unit 2 RSG and Westinghouse supplied Category I (seismic) systems, components, and equipment analyzed for fatigue are evaluated for an equivalent of 10 maximum response cycles per event.

3.7.3.2 Basis for Selection of Forcing Frequencies

Components and equipment supports are required to have their fundamental frequency apart from the building frequencies to avoid resonance. When their fundamental frequencies were found to be in the range of the resonance peak area, they were stiffened or otherwise modified to shift their mode frequencies outside of that region.

3.7.3.3 Procedure for Combining Modal Responses

If modal frequencies are closely spaced, the total response for structural items is computed as the absolute sum of the modal responses.

For Category I (seismic) piping (except the primary coolant loop), where the modal response spectrum technique is utilized, the combined total response for each earthquake is taken as the square-root-of-the-sum-of-the-squares of the modal responses for any response parameter considered. The use of this criterion for combining modal responses in the response spectrum method of analysis may not be valid, however, in combining closely-spaced in-phase modes of vibration. This is accomplished by computing modal responses and then using both the square-root-of-the-sum-of-the-squares criteria and the absolute sum criteria in combining modes. In many locations in a complex model, both criteria give nearly equal results, which means a single mode is contributing to the response. If the absolute sum and the square-root-of-the-sum-of-the-squares combinations are different, the modes which contribute are checked. If contributing modes are closely-spaced in-phase modes, they are combined using the absolute sum criteria and treated as a single mode when combined with the rest of the modes using the "root-mean-square (RMS)" criteria.

For Westinghouse-supplied equipment, the combined total seismic response is also obtained by adding the individual modal responses, utilizing the square-root-of-the-sum-of-the-squares method. Combined total response for closely spaced modal frequencies whose eigenvectors are perpendicular are handled in the above mentioned manner. In the rare event when two significantly closely spaced in-phase modes occur, the combined total response is obtained by adding the square-root-of-the-sum-of the-squares of all other modes to the absolute value of one of the closely spaced modes.

3.7.3.4 <u>Bases for Computing Combined Response</u>

For Seismic Category I piping (except primary coolant loop piping) receiving modal analyses, the combined responses to horizontal and vertical seismic excitation are computed as follows:

1. The moments (and forces) in each of three orthogonal directions e.g. (F_x, F_y, and F_z) are computed separately for each mode and for both horizontal and vertical excitation.

2. The algebraic sum of moments and forces generated by the vertical and horizontal excitations is computed in each axial direction for each mode.

3. The square-root-of-the-sum-of-the-squares of each modal algebraic sum (from 2., above) is found for each orthogonal direction. This results in "RMS" values for F_x, F_y, and F_z due to the simultaneous action of vertical and horizontal excitations.

In the seismic analysis of primary loop piping, the results for the vertical direction are added absolutely to the results of the worst of those for the north-south and east-west directions.

Safety-related instrumentation, except for the trip breakers, is tested by the methods recommended in IEEE Standard 344-1971, "IEEE Guide for Seismic Qualification of Class I Electric Equipment for Nuclear Power Generating Stations."

The trip breakers have been shock tested instead of sine beat tested because IEEE Standard 344-1971 was not applicable at the time the equipment was purchased.

3.7.3.5 Use of Simplified Dynamic Analysis

Most components and systems can be simplified as a single degree of freedom system for which the period of vibration can be readily obtained. Even in a multi-degree system the fundamental period can be arrived at by the Modified Rayleigh Method with relative ease. From the resulting period of the component, we can compare that with the input period to assure there will be no resonance effect.

Seismic Category I piping is divided into two categories: rigid and flexible. Rigid category piping is defined as that piping whose lowest natural mode of vibration has a frequency over 20 Hz, while flexible category piping has a frequency less than 20 Hz.

Seismic Category I piping which falls into the flexible category generally receives a modal dynamic analysis (with either response spectra or time history inputs).

Seismic Category I piping which falls into the rigid category generally receives a simplified or "static equivalent" analysis. This procedure is justifiable because, for rigid systems, essentially no amplification of support accelerations occurs. In these cases, horizontal and vertical support accelerations are imposed upon the piping as static loads and the resulting stresses computed.

The "cutoff frequency" (or "cutoff point") is defined as that frequency at which the spectral response curve at a given location in a given building or structure "flattens-out"; i.e., that frequency above which the response of a single degree of freedom oscillator is independent of its natural frequency and only a function of location (elevation) in the building.

Elastic vibration theory predicts that if a modal analysis is conducted on a system subjected to an excitation which produces a flat response curve, the resultant loadings will be the same as those obtained by applying a "static" loading equivalent in magnitude to the flat portion of the response curve. Thus, for vibrating systems whose first or lowest normal mode of vibration is above the "cutoff frequency" described above, it is justifiable to perform a "static equivalent" or "simplified" analysis.

The fundamental frequencies of key subsystems were considered in relation to the dominant frequencies of their supporting systems. The key subsystems have been determined to be adequately designed for the applicable loads.

Elimination of resonance was one of the principles of design. Various methods for seismic qualification were employed for key subsystems. In most cases, the key subsystems were considered to be very flexible and were analyzed/tested as a decoupled system from the supporting system. Additional information is contained in Sections 3.7.3.3, 3.7.3.4, 3.9.1.2, and 3.10.

These subsystems were analyzed/tested as a decoupled system from the supporting system, because the mass ratio of the subsystem to that of the supporting system is less than 1 percent.

3.7.3.6 Modal Period Variation

The mass and spring constants due to variation in materials have been properly accounted for in the dynamic equations. The damping factor is the only remaining factor. Refer also to Section 3.7.2.9.

The fundamental equation of motion is:

$$M x'' + C x' + Kx = F(t)$$

In which the spring constant, K, is a function of the modulus of elasticity, E, and the modulus of rigidity, G, of the material of the structural component. The proper E and G, with respect to various materials, are used for the stiffness of the weightless spring in the dynamic equations. A mass matrix in the above equation is also established by applying the proper mass density for the various materials. A conservative damping coefficient, C, is used in the input spectrum of time history. Modal periods are obtained by solving the dynamic equations.

3.7.3.7 Torsional Effects of Eccentric Masses

The torsional effects of valves and other eccentric masses are accounted for in the seismic piping analysis.

For rigid components (Section 3.7.3.5), this is accomplished by modeling these components as a concentrated (point) mass, equal in magnitude to the component mass, located at the center of gravity of the component. The mass is then modeled as being connected to the piping model by a massless rigid member.

For flexible components, the torsional effects are included by modeling as a lumped mass-massless spring system coupled to the piping system model.

3.7.3.8 Piping Outside Containment Structure

Seismic Category I piping located outside the containment structure is either located in (or supported from) Seismic Category I buildings or structures, or is buried in the ground.

For that Seismic Category I piping supported from Seismic Category I structures, analytical procedures and design criteria are the same as for piping within the containment.

For buried steel piping outside the containment, flexible joints have been provided at wall sleeves where necessary to accommodate the maximum expected differential ground motion without over stressing piping or structural components. Also, some piping has been surrounded by friable material to reduce bearing stresses due to differential motion at points of entrance to buildings.

Seismic Category I buried concrete piping sections have been provided with specially designed slip joints. These joints permit seismically induced angular deflections and axial strains without overstress or loss of system integrity.

An access manway for personnel egress and isolation valve will be installed in the SW discharge headers near the tie-in to the CW piping allowing for the headers to be dewatered for inspections. During this evolution it is acceptable to use interim structural pipe supports that are designed to address angular deflection and axial movement capabilities under seismic loads. In addition, interim concrete missile shields are provided for any time the header is excavated. These missile shields meet the requirements to withstand applicable tornado missiles as defined in Section 3.5.2.1 of the UFSAR.

3.7.3.9 Field Location of Supports and Restraints

The locations of seismic supports for Seismic Category I piping is determined by analysis during the design of a system. These locations and orientations are then shown on detailed piping arrangement drawings and "hanger detail" drawings. The seismic supports are then installed according to the above drawings, i.e., their location is not a field decision.

3.7.3.9.1 General Procedure

During the erection of piping systems for Unit 1, a Stress Analysis Task Force was formed whose function was to assure, by inspection, that safety-related piping conformed to stress isometric drawings. This included incorporating the "as-built" conditions.

These "as-built" conditions were reviewed by Stress Engineering. If the Stress Engineer determined that the revision was questionable, the calculation was rerun and the stress isometric updated. If the condition was a minor deviation and no adverse effect would occur to the stress levels, this condition was accepted "as-built" and noted on the stress isometric.

3.7.3.9.2 Safety-Related Piping

Safety-Related Systems

There are 15 systems involved in the safety-related piping investigation to confirm conditions of actual configuration.

The following is a list of the systems which are inspected:

1. Reactor Coolant System
2. Safety Injection System
3. Steam Generator Feed System
4. Component Cooling System
5. Service Water - Nuclear System
6. Auxiliary Feedwater System
7. Containment Spray
8. Main Steam System
9. Chilled Water System
10. Chemical and Volume Control System
11. Control Air System
12. Diesel Generator Starting Air and Fuel System
13. Steam Generator Blowdown System
14. Spent Fuel Cooling System
15. Residual Heat Removal System

The stress analysis calculation numbers for each system for all safety-related piping and the calculations that have been stress walked are given in Reference 2. The completed field walk covered the inaccessible and the reactor coolant pressure boundary calculations.

The results of the field walk were evaluated by PSE&G Stress engineers. The inspection walk results obtained can be examined at PSE&G Newark and Salem offices.

Field Procedure for Verifying As-Built Conditions

As requested by NRC IE Bulletin 79-14, the safety-related piping systems were field walked. This added assurance to identify nonconformances and confirm that seismic input information conforms to the "as-built" conditions.

In each system PSE&G identified the analytical isometrics which represent the calculated piping. The isometrics incorporate the following information:

1. Arrangement drawing numbers - to obtain piping geometry.

2. Insulation drawing numbers - type, weight, and location of insulation.

3. Hanger detail drawing numbers - specific location and type of support.

4. Equipment manufacturer's print numbers - the location of nozzles, weights of valves, centers of gravity, and dimensions.

In responding to NRC Bulletin 79-07, PSE&G agreed to perform a stress walk with the NRC. That sample walk took place in the inaccessible areas of the containment by the Resident NRC Inspector, together with the PSE&G Stress Engineer. The procedure that was followed is described below. This same procedure was followed during the implementation of Item No. 2 of the subject Bulletin 79-14. The results of these walks confirmed our previous assertions that the actual configuration conforms to the stress isometric drawings.

Procedure for Stress Isometric Verification

The purpose of the stress walk was to give reasonable assurance that Unit 1, Salem Generating Station, as constructed, was represented on the isometric drawings (ISO) and, therefore, our stress calculations are valid.

The Stress ISO Verification Program was initiated prior to Unit 1 "Hot Functional Testing." The stress isometric was used to perform this function because it incorporates other drawings into one composite. It is not drawn to scale, but shows dimensional piping configuration. It also includes:

1. Pipe material, size, and wall thickness

2. Allowable S_A values

3. Operating temperature

4. Specifications

5. Support location and type

6. Insulation information

Verification of the stress isometrics involved in "Hot Functional Testing" was done by checking the following:

1. Piping conforms to isometric configuration.

2. No obstruction impedes thermal pipe growth:

   a. Engineering thermal calculations were used to determine necessary clearance in sleeves.

   b. Carefully checked location of first guide after a change in direction of pipe run.

c. Supports were described correctly on ISO and erected accordingly.

d. Supports found to restrict or allow growth in the proper direction.

3. Verified that a movement chart existed on the isometric where pipe was connected to equipment.

4. Verified that bends and fittings were properly defined. On 2-inch diameter and smaller pipe, verified socket welded fittings.

5. Control valves noted for center of gravity and if valve was tilted, it was noted as such.

Upon completion of the "Hot Functional Testing" Stress Isometric Verification Field Walk, all discrepancies were reviewed and the following steps were taken for achieving corrective status:

1. Calculations were rerun as necessary, using "as-built" information on the ISO.

2. Unacceptable calculations which occurred due to "as-built" revisions necessitated revisions by the field forces to correct "as-built" conditions to agree with the original acceptable stress isometric.

3. These stress isometrics were then rewalked to verify corrections.

Field Procedures 719 and 720 used by United Engineers and Constructors, Inc. for "Hanger and Hanger Support Shop Fabrication - Mechanical" and "Mechanical Pipe Hanger Fabrication and Installation" are contained in Reference 2. These procedures were also used when verifying the "as-built" conditions.

3.7.4 Seismic Instrumentation Program

3.7.4.1 Comparison with Regulatory Guide 1.12

The seismic instrumentation provided follows closely the guidelines of Regulatory Guide 1.12. It is comprised of the following:

1. A strong motion accelerograph system of a centrally located recording and printout device and three triaxial sensors with triggers. One of the triaxial sensors will be on the mat of the containment foundation and one each of the remaining two triaxial sensors will be at a higher elevation in the Containment Building (approximately Elevation 130 feet) and the Auxiliary Building (approximately Elevation 122 feet). Installation of the triaxial sensors will be according to Item C.2 in Regulatory Guide 1.12.

2. Peak recording accelerographs will be located on selected Category I (seismic) structures and components in the Containment, the Fuel Handling, and the Auxiliary Buildings.

3.7.4.2 Location and Description of Instrumentation

The number and location of peak recording accelerographs to be installed on Category I (seismic) components is under development. It is planned to locate these devices such that readings from the peaking recording instruments can be used to verify the seismic results derived analytically from the traces recorded in the strong motion accelerographs and also the dynamic model analysis.

3.7.4.3 Control Room Operator Notification

Whenever the accelerograph recorder is triggered to record in any or all the channels, an alarm will be initiated in the control room so as to enable the operator to collect the traces from the accelerograph. The recording for the printout device is located near the control room area for immediate access. Starting of the recording device can be initiated for all nine channels of the three triaxial sensors by the triaxial starter unit. The signal from each axis of each triaxial sensor is recorded in one channel of the recorder. Peak level indication will be available to the operator within a few minutes.

3.7.4.4 Comparison of Measured and Predicted Responses

The DBE level is 20 percent 'g', and the triggering level is set at 2 percent 'g'.

The Salem site possesses a common underlying soil condition, and the previously described design provides adequate measures to include all the pertinent considerations of different dynamic response of different Category I structures.

Four peak recording accelerographs will be installed on selected Category I (seismic) structures. They will be located so that the recorded accelerations can be used to verify the analytically derived seismic response. Two accelerographs will be located in the Containment Building, one at Elevation 81 feet and the other at Elevation 130 feet. One will be in the Auxiliary Building at Elevation 122 feet and the remaining one in the Fuel Handling Building at Elevation 130 feet. The instruments are designed to perform their function over the normal range of environmental conditions such as temperature, humidity, pressure, and vibration.

Measured responses at various locations in Category I (seismic) structures or components are collected to ascertain that the severity of the peak responses does not equal or exceed the maximum OBE response for the various locations. In the event that the maximum OBE responses are equaled or exceeded, a detailed inspection will be conducted to determine whether there are any major cracks in the structural components or any equipment has undergone permanent deformation resulting from the earthquake motion. Additionally, the time history record from the accelerograph that has equaled or exceeded the OBE response will be analyzed to determine the ground motion response spectrum so that a comparison with the input design spectrum can be made. The effect of the earthquake on plant operation may thus be determined and any necessary steps can be taken to assure the continued safe operation of the plant.

3.7.5 References for Section 3.7

1. "Structural Analysis of Containment Vessel, Salem Nuclear Generating Station," Conrad Associates (submitted with FSAR Amendment 13, July 31, 1972).

2. Letter dated 9/14/79 Schneider to Grier, "NRC, IE Bulletin No. 79-14, Revision 1, Salem Generation Station," Unit No. 1.

3. VTD 320237-01, "Design Basis Response Analysis of the Salem Nuclear Generating Station Structures," EQE Final Report, January, 1995.