APPENDIX B

SEISMIC DESIGN

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

LIST OF TABLES

LIST OF TABLES (CONT'D)

LIST OF TABLES (CONT'D)

LIST OF FIGURES

LIST OF FIGURES (CONT'D)

APPENDIX B

SEISMIC DESIGN

B.1 SEISMIC DESIGN AND ANALYSIS OF STRUCTURES, SYSTEMS AND COMPONENTS

All structures, systems and components including instruments and controls where failure might cause or increase the severity of a loss-of-coolant accident or result in an uncontrolled release of excessive amounts of radioactivity, and those structures and components vital to safe shutdown of the reactor are defined as Seismic Category I. Note that the classification of Seismic Category I was previously designated as "Seismic Class I." These two terms are considered equivalent for which the above definition applies. Seismic Category I structures, systems and components are listed in Table B.1-1.

Those structures, systems and components which are important to reactor operation but not vital to safe shutdown of the reactor and whose failure could not result in the release of substantial amounts of radioactivity are defined as Seismic Category II. All other structures, systems or components not defined as either Seismic Category I or II are classified as nonseismic. The Nuclear Steam Supply System supplier also referred to this nonseismic category as Seismic Category III.

Seismic Category I structures are designed to resist seismic forces based on two ground response spectra which are described in Section 2.5:

1. The Operational Basis Earthquake (OBE)

2. The Design Basis Earthquake (DBE).

The OBE is based on 0.06 g maximum ground acceleration at zero period, and the DBE is based on 0.125 g maximum ground acceleration at zero period. Response spectra for each earthquake used for the analysis of Seismic Category I structures are given in Figures 2.5-1 and 2.5-2.

The response of the structure is obtained through modal analysis of a multi-mass dynamic model which closely approximates the physical and response characteristics of the structure. Masses are normally lumped at floor elevations and include the floor system, a portion of the walls above and the walls below the floor system, and major component and equipment loads. In addition, masses are located at elevations where any other response values are required. Spring elements between masses represent building structural characteristics and are based on equivalent structural flexibilities. These structural representations provide for the inclusion of torsional effects as a part of the dynamic output.

The soil springs which support the dynamic model are based on the subgrade shear modulus. A range of shear moduli values is used in the dynamic analysis to envelope the variation of peak floor response periods. In addition, the containment peak response spectra periods are further enveloped by considering containment wall and dome structural properties which are based on uncracked to partially cracked reinforced concrete sections to account for normal and pressurized conditions. The undamped model is analyzed to determine characteristic mode

shapes, natural frequencies, and modal participation factors. The appropriate damped ground response spectra provides the relationship between frequency and force-displacement.

Modal responses from the dynamic model are combined using the square root of the sum of the squares (SRSS) method to establish Seismic Category I structure seismic loads. This is used even when modes have closely spaced frequencies, since no well established criteria to combine modes under this condition was available.

The results of the seismic analysis provide the required information for structural component and equipment loading and interstructure "rattle-space." A 3-inch minimum width joint is provided between all structures not built integrally with each other. Components and equipment are generally designed to withstand the static application of the SRSS method of the force or deflection values of all participating modes. For certain critical equipment and piping (e.g., the Nuclear Steam Supply System), amplified response spectra generated from total system response are used for detailed dynamic analysis.

All inputs and responses required by all design organizations for all Category I structural systems, components, and equipment are derived from the lumped mass dynamic models.

The dynamic model is also used to determine base overturning moments. These are calculated by taking the sum of each mass times its height above the base times its square root of the sum of the squares acceleration value. Overturning moments are combined with vertical acceleration forces in order to check structure overturning stability and subgrade reactions.

B.1.1 Subgrade Properties

The properties of the subgrade are discussed in Section 2.5.3.

B.1.2 Damping

Structural damping is energy loss due to internal friction within the material and at connections between elements. The resulting damping forces are a function of the intensity of the motion and of the stress levels induced. The stress levels referred to are those resulting from the dynamic response only. However, structural makeup is also important in consideration of damping forces.

For the containment structure the major contribution to stress intensity is not from seismic loading but from other loading required by the load combination criteria. Loading due to internal pressure causes cracking of the concrete. The damping value of 2 percent for the structural components of response is considered valid because of high damping forces anticipated at the crack surfaces without consideration of the damping forces available from the internal equipment.

Damping for each significant mode of response is estimated by calculating the energy losses due to damping in each component of the mode. Component energy losses are summed and prorated to the total energy available in the mode with the system undamped.

This relationship establishes a damping value for the mode which is qualitatively correct and has some verification through test and observation.[(1)(2)(3)] Based upon the calculated damping values determined in this way, conservative damping coefficients are established for the significant modes of response. For the soil-structure system, 5 percent and 7 percent of critical damping has been established for the OBE and DBE respectively, for all significant modes.

These values are appropriately conservative as compared to the theoretical values obtained for this system.

A distribution of damping values calculated on a modal basis by the method described is outlined in Table B.1-2. A review of these values shows that total system damping is relatively insensitive to the values assumed for the structural components for the first two modes. Structural damping begins to dominate in the higher modes but this does not have much effect because the contribution to system response from the higher modes is not significant.

For the design of the containment structure, a value of 2 percent of critical is assumed for the concrete for both the OBE and DBE. A value of 5 percent is used for the total soil-containment structure in response to the OBE because of energy dissipation due to interaction with the soil. Because of a greater intensity of motion, a coefficient of 7 percent is used with the DBE for the total soil-containment structure system.

B.1.3 Containment Structure

Seismic response forces and stresses are determined for the containment structure from the simultaneous application of horizontal and vertical earthquake ground motions by the frequency response method (response spectrum technique). The motion of the containment structure in the vertical direction is uncoupled from the lateral motion. This necessitates two dynamic models. The earthquake ground motions are established in the form of frequency response spectra as the OBE and DBE for lateral loading. The derivation of these earthquakes and the response spectra are as shown in Section 2.5. The spectral intensity for vertical loading is assigned a value of 2/3 of the horizontal intensity for both earthquake loadings. The design loading conditions for combination with seismic loading and the allowable stress levels are stated in Section 5.2.1 and 5.2.2.

Originally, the containment structure was analyzed as a four-degree-of-freedom model. The cylindrical shell and dome and the internal structure were transformed to equivalent mass-spring systems mounted on the mat. A lumped mass model was later used to show the validity of the approach. This model incorporated the latest configuration and data and the results are used for seismic stress values.

The dynamic model of the containment structure for lateral motion is shown in Figure B.1-1. It consists of a system of spring-connected lumped masses coupled to the subgrade by soil springs. This multiple-degree-of-freedom model is established to determine the free, undamped vibrational characteristics of the structural system.

The dome is represented by one lumped mass. The cylindrical shell is modeled as 6 discrete mass points. Masses MI through M7 constitute the total real mass of the outer structure exclusive of a small tributary mass at the base of the shell which is lumped with the mass of the mat, M8.

Translational and rocking spring constants, K8 and K14 respectively, are included to represent the subgrade. These constants are for a rigid circular base resting on an elastic half space. Their values are given by:

$$K8(\text{translational}) = \frac{32(1-M_u)GR}{(7-8M_u)} \quad \text{(Bycroft 1956)}^{(4)} \qquad \text{(B.1-1)}$$

$$K14(\text{rocking}) = \frac{8GR^3}{3(1-M_u)} \quad \text{(Borowicka 1943)}^{(4)} \qquad \text{(B.1-2)}$$

where: G = Shear modulus of subgrade

R = Radius of foundation mat

M_u = Poisson's ratio of the subgrade

Beam Theory which accounts for distortion due to flexure and shear is used to establish the flexural characteristics of the cylinder and dome under inertial loading. Beam Theory is admissible since the shell cross-sections do not distort under inertial loading. The spring elements KI through K7 shown in Figure B.1-1 represent the outer structure. Spring KI represents the dome and K2 through K7 represent the cylinder.

The internal structure consists of the primary shield wall and the crane wall interconnected by floors and radial walls. The lumped masses (M9 through M13) representing the internal structure and equipment are also shown in Figure B.1-1. The stiffness elements K9 through K13 are determined from Beam Theory, accounting for flexure and shear distortion.

Torsional effects in the containment were studied and due to symmetry were found to contribute only a negligible amount to the entire containment motion.

In determining the free vibrational characteristics of the dynamic model, the modal equation for a multi-degree lumped-mass system, written using matrix notation is:

$$[F]\,[M]\,\{q\} = \frac{1}{W_n^2}\,\{q\} \qquad \text{(B.1-3)}$$

where: [F] = square flexibility matrix

[M] = a diagonal mass matrix containing the masses of the system

{q} = column matrix of displacement for the nth mode

W_n = natural frequency in radians per second for each mode

The solution of this equation determines the natural circular frequencies (W_n) for each mode and the associated coordinate displacements.

The modal participation factors are defined by the equation:

$$(Pr) = \frac{\sum_{i=1}^{j} (M_i q_{ir})}{\sum_{i=1}^{j} M_i (q_{ir})^2 + IMH (q_{ir})^2} \quad \text{(B.1-4)}$$

where: i = mass point

r = mode

IMH = rigid body mass moment of inertia due to lateral dimension only

Damped modal response is established for each mode from the following equation:

$$A_{ir} = (P_r)\,(q_{ir})\,(A_{sr}) \quad \text{(B.1-5)}$$

where: A_{ir} = ith coordinate response for the rth mode

A_{sr} = ith damped spectral response for the rth mode

The total response at any mass point is determined by taking the square root of the sum of the squares of the coordinate response for each mass for all significant modes:

$$A_i = \sqrt{(A_{i1})^2 + (A_{i2})^2 + \ldots + (A_{ir})^2} \quad \text{(B.1-6)}$$

where: A_i = total response for mass point i for all significant modes

The dynamic model of the containment structure for vertical motion is shown in Figure B.1-2. Masses MI, M2 and M3 represent the dome, M4 through M8 the containment, M9 the foundation mat, and M10 through M14 the internal structures and major equipment. The structural spring elements KI through K8 and K10 through K14 represent the vertical deformation characteristics of the structural elements. The soil stiffness K9 is determined by the following formula.[(5)]

$$K9 = \frac{4GR}{(1-M_u)} \quad \text{(B.1-7)}$$

Mode shapes, modal participation factors, and structural response are determined by the previously described method.

Earthquake-generated forces are applied statically to the structure and the results are combined with other loadings following the combinations and factors listed in Section 5.2.2.

B.1.4 Other Seismic Category I Structures

Seismic response forces and stresses are determined for Seismic Category I structures other than the containment by using the same approach described in Section B.1.3.

A lumped-mass, multiple-degree-of-freedom model is developed for each separate structure taking into account foundation conditions.

The free vibrational characteristics of the model are calculated. Acceleration and deflection values from the ground response spectra curves for the OBE and DBE (Section 2.5) are then combined to give the design loads. For the vertical model, ground response spectra values are taken as two-thirds of the horizontal. The resultant earthquake design load, depending upon the type and character of the structure or component, is either that resulting from horizontal acceleration, vertical acceleration, or a combination of both.

Earthquake-caused deflections are determined for both Seismic Category I structures and any abutting structures. The structures are then separated by a space sufficient to prevent unaccounted-for interaction between the structures. The Fuel Building (a Seismic Category 1 structure) and the Decontamination Building (an abutting structure) have separate foundations and an interconnected steel superstructure. The superstructure for these buildings has been analyzed as one structure, and the interconnected steel superstructure has been reinforced where necessary to meet the acceptance criteria.

Loading combinations for Seismic Category I structures other than the containment, have seismic loading combined with dead, live, and other static loads. Normal wind or tornado loadings are not assumed to occur simultaneously with the earthquake loading.

Concrete sections of Seismic Category I structures are designed using Working Stress Design according to "Building Code Requirements for Reinforced Concrete," ACI 318-63. The different loading combinations used are as follows:

D.L. + L.L.

D.L. + L.L. + OBE

D.L. + L.L. + DBE

D.L. + L.L. + TOR

D.L. + L.L. + F

where: D.L. = Dead Load

L.L. = Live Load

OBE = Operating Basis Earthquake Load

DBE = Design Basis Earthquake Load

TOR = Tornado Loads

F = Max possible flood loads

Allowable stresses are increased accordingly to the specific loading conditions as follows:

1. for OBE = 33% increase

2. for DBE = 50% increase

3. for TOR = 66.7% increase in allowable concrete compres-sive strength (reinforced steel at .9 fy)

4. for F = 50% increase

Structural steel sections of Seismic Category I structures are designed in accordance with the American Institute of Steel Construction (AISC) Manual of Steel Construction 1963 edition, Part 1 "Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings," except that the seismic loading referred to in paragraph 1.56 is considered as the OBE.

Loading combinations for these structures are the same as listed previously for concrete structures. Allowable stresses are increased as follows:

1. For OBE = 33% increase

2. For DBE or Tornado = 90% of the specified minimum yield strength for structural steel

B.1.5 Amplified Response Spectra for Equipment Loading

A response spectra modal analysis technique was initially used to design Seismic Category I equipment and piping for BVPS-1. Amendment 15 of the BVPS-1 PSAR and the Safety Evaluation by the Division of Reactor Licensing are cited for details regarding the matter. The frequency response method is described in Section B.1.5.1 below. A special report covering the validation of this method entitled "Empirical Method to Determine Amplified Response Spectra," is presented in Attachment "A" to Section B.1.

B.1.5.1 The Frequency Response Method

The response of a structural system, such as a nuclear containment building to seismic ground motion, is made up of harmonic components of frequencies equal to the natural frequencies of the structure. Components such as equipment and piping, mounted in the structure respond to the structural motion. The elastic behavior of the components is not considered in the analysis of the total structure. This does not, however, introduce a discernible inaccuracy in the dynamic analysis of the structure because the mass of the equipment is small as compared to the mass of the structure. Component mass is included in the analysis of the structure. The analysis of components must take into account the modification of the ground motion due to the response of the structure and the effects of the distortion of the structure itself.

Components mounted in the structure which are flexible as compared to the structure will respond essentially as though supported directly in the subgrade. Distortion of the structure is not considered important. On the other hand, components which are very stiff as compared to the structure experience seismic response which is the same as that of the structure at the point where the component is supported.

When components have natural periods close to the natural periods of the structure, resonance will occur and support motion will be greatly amplified. The extreme would be the classical situation of an elastic system responding to a sinusoidal support motion. Because of the irregular characteristics of earthquake motion and damping in the combined structure-sub-grade complex, a steady state of support motion does not exist and the harmonic components of support response are considered to decay. Component damping also has a significant effect on the magnitude of the component release.

Using the damped ground response spectra to determine modal responses at points of interest in the structure, structural motion is idealized as a decaying time-dependent sinusoidal motion for each mode of structural response. These discrete, time-dependent, modal structural motions are used as support motions for damped single-degree-of-freedom (SDF) oscillators to calculate approximate amplified response spectra.

This is accomplished by determining the maximum time-dependent oscillator response to each mode of the structural response and combining these results as the square root of the sum of the squares. Noting that the terms oscillator and component can be used interchangeably, a mathematical description of the frequency response method is summarized below. A computer program has been developed to carry out the procedure.

The equation of motion for a damped SDF oscillator subjected to time-dependent support motion described by F(t) is:

$$Mu'' + ku + cu' = -MF(t) \qquad \text{(B.1-8)}$$

where: M = mass

k = spring constant

c = oscillator damping constant

u = displacement of oscillator relative to the support

t = the time function

F(t) = the exponentially decaying sinusoidal support motion function which represents the idealized structural motion at equipment support point

For multiple-degree-of-freedom (MDF) oscillator systems such as piping and equipment:

$$F(t) = e^{(-rBst)} P_i A_i SIN(W_i t) \qquad \text{(B.1-9)}$$

where: P_I = modal participation factor for ith structural mode

A_i = amplitude of structural response acceleration for the ith structural mode

Bs = structural damping

r = an empirical factor which modifies the logarithmic decay of the forcing function to provide conservative results at resonance

t = time

W_i = natural frequency in radians per second for each mode

Dividing equation (B.1-8) by M and denoting f^2=k/M (where f = natural frequency of the oscillator) and c = 2MBe (where Be is a measure of oscillator damping):

$$u'' + 2Beu' + f^2u = -F(t) \quad \text{(B.1-10)}$$

The maximum response of the oscillator is determined for each mode of structural response. For each oscillator over the range of interest (1,2,..........n), the maximum responses to each structural mode of response are combined as the square root of the sum of the squares to generate the amplified response spectrum. Curves are developed for the required levels of equipment damping for both the OBE and DBE.

B.1.5.2 Validation of the Frequency Response Method for the Beaver Valley Power Station

To validate the method, amplified response spectra developed by the frequency response method are compared to spectra obtained by the theoretically more rigorous time history approach. This serves to establish the factor "r" which controls the rate of amplitude decay of the sinusoidal forcing function F(t).

In the time-history analysis method, seismic analysis is executed by an exact step-by-step integration of the modal equations of motion using as input an artificial time history (denoted by C) in Table B.1-4 whose response spectrum (denoted by B) envelopes the smoothed site design response spectrum (denoted by A) for five percent of critical damping. Time-history of the modal responses are combined algebraically to provide the time-history of total response, overturning moment and shear, at any elevation in the structure. In the analysis, a constant modal damping of 5 percent of critical is assumed. Maximum shears and moments predicted by this approach are summarized in Table B.1-4 under column III.

By the frequency response method, the peak response of each mode is computed directly from a response spectrum, curve B, obtained from the time-history curve. The peak modal responses are combined, usually by the SRSS or some modification thereof, to provide the estimated total peak response. Estimated maximum force and moments as predicted by the spectral analysis are shown in Table B.1-4 under column II.

The results of the above studies indicate that the base shear force computed from the time-history analysis is exceeded by the base shear values calculated from the response spectrum curves A and B. The base overturning moment calculated from the time history exceeds the base overturning moments calculated from the response spectrum curves A and B by only 9.2 and 3.0 percent, respectively.

A direct comparison can really only be made between values determined from curve B and the time history C. The time history shear values exceed the response curve B shear values by only 20 percent at the spring line and are exceeded by the response curve B shear values from 45 ft above the top of the mat to the top of the mat.

Comparisons were made of amplified response spectra determined by the frequency response method and the time history method for the containment structure. Three earthquake records were used, viz., Helena E.W. and Taft and El Centro. All three time histories were normalized to .125 g. The soil-structure system damping was 7 percent for all modes and oscillator damping was 0.5 percent. It was demonstrated that a value of r = 0.3 controlled the assumed logarithmic decay of the F(t) function to give conservative results in the resonant bands as compared to the time history method.

The BVPS-1 PSAR states that if the values of amplified response spectra obtained by the frequency response method fall below the appropriate spectra obtained by the time history method away from resonant peaks, the former values would be arbitrarily raised to envelop the time history spectra. The time history record used for this control is Helena E.W. in accordance with Amendment 15 of the BVPS-1 PSAR.

The containment structure dynamic model has been tested for possible variations in soil shear modulus.

Examination of results shows that reasonable variation of the soil shear modulus (±33.33 percent) would have a significant effect on the rocking and translational frequencies (-20 percent and +25 percent as measured against the nominal resonant periods). Accordingly, this is taken into account in the generation of amplified response spectra for components. For all other Seismic Category I structures the same value of "r" is used. Using the value of "r" calculated as outlined above, amplified response spectra were developed using the ground response spectra for the site. These were compared to the amplified spectra obtained directly from the time histories stated to ensure that the frequency response method gives acceptable results.

B.1.5.3 The Soil Structure Interaction Method

As part of the re-analysis of Seismic Category I piping systems performed in 1979, Amplified Response Spectra (ARS) was developed using Soil Structure Interaction (SSI) methodology. Section B.2.1.3 discusses the SSI-ARS. Figure 2.5-4 represents the response spectra for 0.125G DBE and Figure 2.5-5 represents the response spectra for 0.06 OBE. The licensee now considers that the SSI-ARS forms the present and future design basis for the plant.

B.1.5.4 Qualification of Frequency Response Method ARS to the Soil Structure Interaction Method ARS

Amplified response spectra using soil structure interaction (SSI) methodology was developed for the operational phase re-analysis of Seismic Category I piping systems. A review of the original plant ARS (Figures 2.5-1 and 2.5-2) on a building-by-building and elevation-by-elevation basis indicated that peak resonant responses occurred below 10 Hz and that amplification of ground motion principally occurred below 20 Hz for structures housing Seismic Category I equipment. For each building a "cutoff frequency" was selected (i.e., 10 to 20 Hz) in order to identify seismic acceleration levels above and below the cutoff frequency for calculational purposes. The "g" level identified below the cutoff frequency was a minimum of 1.3 times the peak ARS response. At the cutoff frequency the rigid range g value was conservatively selected.

A comparison of the ARS used for the original plant design with the SSI-ARS indicates that the original plant ARS are conservative based upon the above seismic specification of static g values for qualification by static analysis and testing.

It was noted that peaks of the SSI-ARS are significantly lower than the peaks of the original plant ARS. The SSI-ARS peaks occur in the 2 to 5 Hz region for all structures evaluated and there is little amplification of maximum floor acceleration above 10 Hz. In some isolated cases the SSI-ARS curves exceed the original plant ARS in the low frequency region (below 5 Hz) distant from peak original ARS responses. This breaching of the original ARS would only potentially affect equipment whose natural frequency is below 5 Hz. Further discussion of the SSI-ARS is presented in Section B.2.1.3. No re-analysis of Seismic Category I structures was necessary as a result of the development of the SSI-ARS curves.

B.1.6 Computer Programs Used for Structural Analysis

The following programs are used in the structural analysis of seismic Category I structures.

A Description of each program follows.

STRUDL II

STRUDL, an acronym for Structural Design Language, is a series of computer programs for solving problems in structural engineering. It is applicable to both framed and continuous mechanics problems, either static or dynamic in nature. In frame analysis, the member stiffness matrix is computed from beam theory, while in finite element analysis, the element stiffness matrix is computed from energy considerations.

STRUDL II[12] has been designed as a modified subsystem of the Integrated Civil Engineering System (ICES) which was designed and formulated at Massachusetts Institute of Technology, Department of Civil Engineering.

The finite element method[11] provides for the solution of a wide range of solids mechanics problems. Its implementation within the context of the STRUDL analysis facilities expands these for the treatment of plane stress, plane strain, plate bending, shallow shell, and three dimensional stress analysis problems. STRUDL II also provides a dynamic analysis capability for linear elastic structures undergoing small displacements. Either free or forced vibrational response may be obtained, and in the latter case the forcing function may be in the form of time histories or response spectra.

The three dimensional finite element capability of STRUDL II is used to analyze the primary containment at the region of the personnel and equipment hatches.

Seismic Category I structures are analyzed for seismic effect using the dynamic analysis capability of STRUDL II. The analysis yields frequencies of vibration, modes, shapes, displacements, velocities, accelerations, and forces. Category I structures additionally have been analyzed using the frame analysis capability of STRUDL II. The analysis provides twisting and bending moments, axial forces, shears, displacements, and joint rotations.

SHELL I

This computer program is a further development of a computer program written at AVCO Corporation. The program is based upon the general numerical procedure proposed by B. Budiansky and P. P. Radkowski(7)(8) to analyze a shell of revolution subjected to arbitrary loadings. The analysis is based upon the general first order linear theory of thin shells by J. L. Sanders, Jr.(9)

The program is used to obtain the membrane forces and bending moments in the primary containment walls and shield walls due to pressure and temperature loads. Discontinuity forces at the foundation mat are obtained from the computer program called MAT 5.

The results of pressure loads on a shell of revolution from SHELL I have been checked against hand calculations based upon "Theory of Plates and Shells" by Timoshenko and Woinowsky-Krieger (Second Edition, 1957). For these test problems actual containments were used. A plot of the meridional bending moment, meridional shear, and radial deflection of the containment wall showning the comparison between SHELL I and hand calculations based on "Theory of Plates and Shells" is given in Figures B.1-3 and B.1-4 for a containment structure subjected to uniform internal pressure.

MAT 5

This computer program analyzes a symmetrically loaded circular plate on an elastic foundation and maintains compatibility between:

1. The plate (foundation mat) and the subgrade

2. The plate and the circular walls supported thereon.

The program computes the discontinuity effects at the interface of the mat and circular walls and includes these effects in the analysis. The general method is described in "Practical Methods for Analysis of Beams and Plates on Elastic Foundations" by Boris N. Zhemochkin (Second Edition, 1962).

The program is used to analyze the foundation mat and to provide the contact pressure and the discontinuity forces at the junction of the mat and superstructure (i.e., primary and secondary containment walls, reactor support wall).

The solutions to test problems using MAT 5 are substantially identical to those obtained by hand calculations using Zhemochkin.(11) It is to be understood that the complexity of the hand calculations tend to limit their accuracy. The test problems have been actual containment structures.

Figure B.1-5 shows plots of the radial and tangential bending moments and the radial shear in the mat for a MAT 5 solution vs. hand calculations. Also shown are the discontinuity forces at the interface of the mat and circular walls. This particular mat is on soil.

Figure B.1-6 shows similar plots for a MAT 5 solution vs. a hand solution done in accordance with "Theory of Plates and Shells" by Timoshenko and Woinowsky-Krieger (Chapter 9) for a mat on rock. The comparison, particularly at the junction of the containment wall and mat is excellent. The hand calculations show a somewhat larger radial shear near the edge because the cantilever effect (5 ft) of the mat beyond the containment wall was not included. Other minor discrepancies occur at the lift-off point for the mat between the two solutions but these are due to the assumptions inherent in a Timoshenko solution (i.e., at the point of mat lift-off the radial moment, displacement, and slope of mat equal 0).

Time History

The Time History computer program computes time history response and amplified response spectra at any mass point location of a lumped mass spring connected system due to a synthetic earthquake time-motion record input. The responses are computed by integration of the modal equations of the system by the Exact Method.(10) The program's main application is the generation of Amplified Response Spectra used for design of Seismic Category I equipment and piping.

Time history program's solution to a test problem is substantially identical to the solution obtained using STRUDL II. The test problem utilizes an actual containment structure subjected to an earthquake time-motion record input of Helena East-West normalized to .06 g. The time history response of the structure was computed by the Time History program and STRUDL II. The results of these analyses are shown graphically in Figures B.1-7 and B.1-8 respectively, the results of the analysis using the Time history program agree extremely well with those obtained using STRUDL II.

ANSYS

ANSYS is a general purpose finite element analysis program with structural and heat transfer capabilities. ANSYS is used for engineering analysis of Seismic Category I structures, equipment, and piping. It has been used for several applications, including the structural and thermal analysis of the replacement steam generators. ANSYS is a recognized program in the public domain.

Verification of the ANSYS software has been completed by performing a series of test problems. Results were compared to verified solutions from alternate methods and hand calculations provided by the vendor.

References for Section B.1

1. N.M. Newmark, "Design Criteria for Nuclear Reactor Subject to Earthquake Hazards," Urbana, Illinois (1967).

2. N.M. Newmark, and E.Rosenblueth, Fundamentals of Earthquake Engineering, Prentice-Hill Inc. (1971).

3. R.V. Whitman, "Analysis of Foundation Vibration," Vibrations in Civil Engineering, Procedures of a Symposium Organized by the British National Section of the International Association of Earthquake Engineering.

4. R.V. Whitman and F.T. Richart, IP-765, University of Michigan (February 1967).

5. Timoshenko and Goodier, Theory of Elasticity, New York (1951).

6. Deleted by Revision 0, January 1982.

7. B. Budiansky and P. P. Radkowski, "Numerical Analysis of Unsymmetrical Bending of Shells of Revolution" AIAA Journal (August 1963).

8. G. A. Greenbaum, Comments of "Numerical Analysis of Unsymmetrical Bending of Shells of Revolution" AIAA Journal (October 1963).

9. J. L. Sanders, Jr., "An Improved First Approximation Theory for Thin Shells", National Aeronautics and Space Administration, Technical Report R-24.

10. C. Nigam and C. Jennings; "Digital Calculations of Response Spectrum from Strong-Motion Earthquake Records", National Science Foundation (June 1968).

11. 0. C. Zienkiewicz and Y. K. Cheung "The Finite Element Method".

12. "ICES STRUDL II, The Structural Design Language Engineering Users Manual" Volume I, Frame Analysis, November 1968; Volume II, Additional Design and Analysis Facilities (Chapters III and IV) (June 1971).

ATTACHMENT "A" TO SECTION B.1

EMPIRICAL METHOD TO DETERMINE AMPLIFIED RESPONSE SPECTRA

Introduction

In accordance with the procedures described in Amendment 15 of the BVPS-1 PSAR, amplified response spectra were developed for seismic design of equipment and piping by an empirical frequency response method. A mathematical development of this procedure is contained in Amendment 15 of the BVPS-1 PSAR and Section B.1.5 of the FSAR. Amendment 15 and the Safety Evaluation by the Division of Reactor Licensing concerned with validation of this method are cited for specific details.

This attachment contains the following information:

1. A comparison of amplified response spectra obtained by the frequency response method using the exact ground response spectra of the El Centro, Taft, and Helena E-W earthquakes, and amplified response spectra by the Time History Method using the same three earthquakes. These comparisons are shown in Figures B.1A-1A, B.1A-1B, and B.1A-1C.

2. A comparison of amplified response spectra obtained by the frequency response method using the site ground response spectra, and amplified response spectra obtained by the time history method using the Helena E-W earthquake. This comparison is for five locations in the containment structure. Three locations are on the internal structure and two are on the containment shell. These comparisons are shown in Figures B.1A-2A, B.1A-2B, B.1A-2C, B.1A-2D, and B.1A-2E.

3. Amplified response spectra showing the effects of reasonable variations in the soil shear modulus G on the magnitudes of the spectra and the variation in resonant periods for the containment building. This information is shown in Figures B.1A-3A and B.1A-3B. As stated in the PSAR and the FSAR, the soil shear modulus is established to be 18,000 psi. A realistic variation in this value is ±33-1/3 percent. The plots in Figures B.1A-3A and B.1A-3B were obtained by the frequency response method using the site ground response spectra.

Summary and Conclusions

A general study of the frequency response method using a six degree of freedom model of the containment was undertaken and documented in Amendment 15 of the BVPS-1 PSAR. The amendment also stipulated the following:

1. That the frequency response method would be validated for the actual dynamic model of the containment structure by comparisons with results obtained by the time history method for known earthquake records.

2. That the empirical value "r" which alters the structural damping and the logarithmic decrement of the modal sinusoidal forcing functions would be established to provide sufficient conservatism in the resonant sands.

3. Having established the value of "r", amplified response spectra would be developed by the frequency response method for all Seismic Category I structures using the site ground response spectra.

4. That values of amplified response spectra obtained by the frequency response method based upon the site ground response spectra would be used except where amplified spectra obtained from a known earthquake record by the time history method are greater. In such cases, the values obtained by the time history method was used.

In Amendment 15 of the BVPS-1 PSAR, it was shown that a value of r = .5 was sufficient to provide conservatism in the resonant peaks for the general study of the six degree of freedom model that was used. During the course of the validation procedure with the actual dynamic model of the Beaver Valley containment, several comparisons of results from the time history method and the frequency response method were made wherein the value of "r" was varied. It has been determined that the more conservative value of r = .3 yields reasonable results for the three earthquakes which were studied.

Referring to Figure B.1A-1A, it can be seen that the method is conservative at fundamental resonance and somewhat underconservative in the third structural mode for El Centro. Between the first and second modes and at periods longer than the first, the frequency response method yields results which are somewhat underconservative.

For the Taft earthquake, Figure B.1A-1B, the results are acceptable at fundamental resonance, the second mode, and very conservative for the third mode. Between the first and third modes and at periods beyond the first mode, results are underconservative.

As shown in Figure B.1A-1C, for the Helena E-W earthquake, the results are very conservative for the first, second, and third structural periods. The results are slightly underconservative at long periods and between periods of resonance.

Results of comparisons for other points in the containment show a similar degree of conservatism. The point for which these curves are made is at the top of the crane wall where maximum amplification would occur for the internal structure. All three comparisons show good agreement for short period oscillators which comprise the bulk of the equipment. It is emphasized that the major effort in this study and in the general study shown in the BVPS-1 PSAR, is to account for resonance effects.

In Figures B.1A-2A, B.1A-2B, B.1A-2C, B.1A-2D and B.1A-2E are shown comparisons of amplified response spectra for five locations on the containment. The comparisons are between amplified spectra calculated obtained by the frequency response method at r = .3 using the site ground response spectra and amplified response spectra obtained by the time history method using the Helena E-W earthquake. The DBE condition is used (.125g). Structural damping is .07 critical for all modes and oscillator damping is .005 critical for both methods. The Helena E-W record was normalized to .125g. The results from the frequency response method are conservative with the exception of a few oscillator periods between structural modes. At the oscillator periods where the frequency response results are under conservative, the time history results govern in accordance with paragraph 4 of this summary.

The plots in Figures B.1A-3A, and B.1A-3B show the difference in the amplified response spectra obtained by the frequency response method using the site ground response spectra due to a ±33.33 percent variation in the soil shear modulus G. In Figure B.1A-3A a plot is shown of amplified spectra for the charging floor for the established soil shear modulus G = 18,000 psi. The effects of variations in the established value of the shear modulus on the amplified spectra are shown in Figure B.1A-3B. The plots in Figure B.1A-3B should be compared to Figure B.1A-3A.

It can be concluded that a reasonable variation in the soil shear modulus (±33-1/3 percent) has a significant effect on the rocking and translational frequencies. Accordingly, a -20 percent and +25 percent variation (as measured against the nominal resonant periods at G = 18,000 psi) is accounted for in the calculation of amplified response spectra for seismic design of equipment and piping (reference Appendix B, Section 1.5.2).

B.2 STONE & WEBSTER

B.2.1 Analyses and Design Criteria of Seismic Category I Piping

B.2.1.1 Summary of Stone & Webster Piping Analysis Procedures

Seismic analysis of piping systems in nuclear plants has also undergone an evolution consistent with the growth and development of seismic methods for the plant as a whole. In the 1970's, several major changes in methods of nuclear plant seismic analysis were made. The key changes were a standardization of design ground spectra, a requirement for three-directional analysis and use of increased damping values. The net effect was a more rational approach to seismic analysis.

At the time of the design phase of BVPS-1, Seismic Category I piping analysis was done in accordance with the ANSI B31.1 code, 1967 edition including the Summer 1971 Addendum. The 1967 B31.1 code did not address seismic design in the sense of providing detailed rules for stress determination and load combinations. Further, the code did not deal with Normal, Upset, Emergency and Faulted Stress limits. Since that time, development of B31.7 and ASME III have addressed these rules and limits. The original seismic analysis was performed by the use of the SHOCK II computer code. The SHOCK II code, which combines intramodal responses algebraically, is no longer considered acceptable by the NRC. The PSTRESS computer code which developed input data for SHOCK II is also replaced by the NUPIPE computer code. The re-analysis performed in 1979, uses the NUPIPE computer code. NUPIPE incorporates a methodology which is currently acceptable to the NRC.

The NRC determined where design specifications and drawings are used to obtain input information for seismic analysis of safety-related piping systems, that it was essential for these documents to reflect the as-built configurations. All Seismic Category I piping 2 1/2 inches and greater were given a field verification of as-built conditions according to NRC IE Bulletin 79-14 requirements.

The new stress analysis of safety-related piping system did show some of the support stresses to exceed code allowable levels. These supports were corrected by physical hardware additions. Generally, this was done by the addition of restraints or snubbers, or minor modifications to existing supports.

B.2.1.2 General Analytical Procedure

Analysis of Seismic Category I piping 2-1/2 inches and larger is performed by the use of the NUPIPE computer code. Both the commercial version, NUPIPE-II, and the Stone & Webster version, NUPIPE-SW, are used. Each piping system is mathematically modeled as linearly elastic structural model in three- dimensional space. Inertial characters of the piping systems are modeled by lumping the mass at various nodes through-out the piping included in each computer analysis. The stiffness matrix used in each analysis is computed based upon the structural behavior of piping elements in NUPIPE.

The seismic inertial response within each mode is computed as the square root of the sum of squares of the response due to the seismic excitation in each of the three orthogonal directions. The seismic inertial response among modes is computed as the square root of the sum of squares of responses due to each mode computed, except that the responses of all modes within a natural frequency band of 10 percent are added absolutely, and this sum is added by the square root of the sum of squares with the remaining computed nodes. This approach is in full compliance with Regulatory Guide 1.92 entitled "Combining Modal Responses and Spatial Components in Seismic Response Analysis".

The development of amplified response spectra used in the analysis of piping systems is described in Section B.2.1.3. Damping factors used for seismically designed piping and components are 0.5 percent for the OBE and 1.0 percent for the DBE. Refer to Section B.2.1.12 regarding the use of alternate damping values in ASME Code Case N-411.

Where a piping system is subjected to more than one amplified response spectrum as when support points are located in different parts of the structure or different structures, the amplified response spectrum which is closest to and higher in elevation than the highest support on the piping system is applied to this system or multi ARS are used simultaneously in the analysis.

Relative seismic structural displacements between the piping supports and anchor points, that is, between floor penetrations and equipment supports at different elevations within a building and between the buildings, are used as inputs of equivalent static boundary displacement conditions in the computations. Relative seismic displacements between the pipe support points at different buildings are always considered to be out of phase in order to obtain the most conservative piping responses.

For the analysis effort, the effects of the seismic anchor displacements have been evaluated statically and separately from the inertia effect. Static analysis is performed for each direction of relative displacement and for each earthquake, leading to a total of six evaluations. Internal moments resulting from the three evaluations for each earthquake are combined by SRSS on a component level and are then combined with the inertia effects by absolute summation, also on a component level.

B.2.1.3 Amplified Response Spectra

The NUPIPE computer code uses an amplified response spectra (ARS) based on soil-structure interaction (SSI). The methodology used in SSI-ARS is based upon a layered elastic media model for soil and a lumped mass model for the structure. Analysis using these models involves:

1. The calculation of frequency-dependent stiffness at the surface of a layered medium using the program REFUND

2. Modification of a specified surface motion to account for embedment of the structure

3. The application of kinematic interaction principles to modify translational input specified at the surface to both a translational and rotational motion at the base of the rigid structure foundation using the program KINACT

4. Analysis of the structural model supported on frequency-dependent springs using the program FRIDAY.

The resulting ARS developed from this methodology were compared with ARS developed using a detailed finite element representation of the underlying soil medium with a lumped mass representation of the containment structure using the program PLAXLY. The amplified values of acceleration computed using the REFUND/KINACT/FRIDAY method are generally 30 to 100 percent larger than values computed using the more rigorous PLAXLY approach.

Variations in soil properties have generally been accounted for by developing ARS using mean values of soil moduli and damping ratio values adjusted for strain levels associated with earthquakes, and peak spreading the resulting ARS.

The soil properties are developed from subsurface data into a soil profile, in which each stratum has its own soil parameters. The required dynamic properties in each layer are described first by the small strain values of shear modulus, and then site response analysis is used to develop values of damping and shear modulus that are compatible with the strains to be expected during an earthquake.

Subsurface information was obtained from several sources, which include the BVPS-1 FSAR, the Geotechnical Design Criteria for BVPS-2, and the report on the Soil Densification Program for BVPS-2. The pre-construction boring logs for BVPS-1 under the Category 1 structures are found in Appendix 2F. Two seismic cross-hole surveys were performed by Weston Geophysical Laboratory, the first in 1968 and the second in 1977, in conjunction with the BVPS-2 Soil Densification Program.

The computer program SHAKE developed by Schnabel, Lysmer, and Seed[6] was used to calculate strain compatible shear moduli and damping from low strain values was determined from field testing and empirical formulae based on laboratory test data.

The amplified response spectra used in the analysis are based on the methodology described in the report entitled "Soil-Structure Interaction in the Development of Amplified Response Spectra for Beaver Valley Power Station, Unit No. 1." This report was submitted to the NRC by Duquesne Light Company on June 11, 1979.

The licensee now considers that the SSI-ARS forms the present and future design basis for the plant.

The original ARS is the design basis for work performed prior to NRC approval of the use of the SSI-ARS.

B.2.1.4 Dynamic Analysis

B.2.1.4.1 Mathematical Model

For dynamic analysis, the mathematical model is described as a lumped mass, multi-degree of freedom model. The distributed piping mass is lumped at the system nodal points. The equation of equilibrium for the system is:

$$Mu'' + Cu' + Ku = F \qquad \text{(B.2-1)}$$

where:

M = Mass matrix for assembled system

C = Damping matrix for assembled system

u'' = Nodal acceleration vector = $u''(t)$

u' = Nodal velocity vector = $u'(t)$

u = Nodal displacement vector = $u(t)$

F = Applied dynamic forces = $F(t) - Mu_g$ for earthquake

u_g = Ground acceleration = $u_g(t)$

This equation is solved for the system dynamic response as follows. First, the frequency, obtained by removing the forcing and damping terms from equation (B.2-1), is solved for the system natural frequencies and mode shapes. Next, the natural mode shapes are used to affect an orthogonal transformation of equation (B.2-1), yielding a series of independent equations of motion uncoupled in the system modes. Then, the uncoupled equations are solved by either the step-by-step integration or the response spectrum method to obtain system response in each mode, and the individual modal results are combined to determine the total system dynamic response. The mathematical formulation of these steps is discussed below.

B.2.1.4.2 Natural Frequencies and Mode Shapes

The eigenvalues (natural angular frequencies W_n) and the eigenvectors (mode shapes ϕ_n) for each of the natural modes are calculated by solving the frequency equation

$$[K - W_n^2 M] \{\phi_n\} = \{0\} \qquad \text{(B.2-2)}$$

where: W_n = Natural frequency in n^{th} mode

K = Stiffness matrix

M = Mass matrix

ϕ_n = Mode shape vector in n^{th} mode

0 = Null vector

The eigenvalues and eigenvectors are obtained in NUPIPE using the Householder-QR algorithm (NUPIPE-11M) or subspace iteration (NUPIPE-11L).

B.2.1.4.3 Dynamic Response

Pre- and post-multiplication of equation (B.2-1) by $[\phi]$, the square matrix of mode shape vectors, constitutes an orthogonal transformation, from which the uncoupled equations of motion shown below are obtained.

$$Y_n + 2W_n\lambda_n Y + W_n^2 Y_2 = P_n \qquad \text{(B.2-3)}$$

where:

Y_n = Generalized (model) displacement coordinate for the n[th] mode ($U_n = \phi_n Y_n$)

λ_n = Damping ratio for the n[th] mode expressed as percent of critical damping

P_n = Generalized force for the n[th] mode = $\phi_n^T F$

Solution to these differential equations may be obtained by direct integration, or, for seismic ground motions, by the method of response spectrum superposition.

B.2.1.5 Piping Stress Limits

The calculated stress of computer analyzed piping are governed by the following allowables:

$$S_{LP} + S_{DL} \leq S_h \qquad \text{(B.2-4)}$$

$$S_{LP} + S_{DL} + (S_{OL}^2 + S_{OBET}^2)^{0.5} \leq 1.2S_h \qquad \text{(B.2-5)}$$

$$S_{LP} + S_{DL} + (S_{OL}^2 + S_{DBEI}^2)^{0.5} \leq 1.8S_h \qquad \text{(B.2-6)}$$

$$S_E \leq [(1.25S_c + 0.25S_h) + (S_h - |S_{LP} + S_{DL}|)]f \qquad \text{(B.2-7)}$$

where:

S_{LP} = Stress due to longitudinal pressure

S_{DL} = Stress due to moments caused by deadload

S_h = Allowable stress of material at maximum and/or minimum operating temperature

S_C = Allowable stress of material at 70°F

S_{OL} = Stress due to moments caused by occasional loads such as are due to valve actuation, etc.

S_{OBET} = Stress due to moments (half range) caused by the operating basis earthquake. The inertial effects and anchor movement effects are summed absolutely.

S_{DBEI} = Stress due to moments caused by the inertial effects of the Design Basis Earthquake.

S_E = Maximum stress due to all moments induced by the constraint of free thermal expansion.

f = Fatigue factor based upon the number of thermal cycles. This factor is determined from ANSI B31.1.

For the River Water System, a special 4-way fitting (piping cross) was evaluated seismically by combining the seismic anchor movements with S_E. This is allowed per ANSI B31.1, 1973.

For load combination and stress limits applicable to the pressurizer safety and relief valve piping from the pressurizer to the pressurizer relief tank see Tables B.2-24, B.2-25 and B.2-26. For additional information concerning the use of these equations see Reference 18.

Load combinations and stress limits associated with the Reactor Coolant Gas Vent System (RCGVS) piping are in accordance with ASME III, 1989.

For load combinations and stress limits applicable to QA Category I piping 2" diameter and smaller, see Tables B.2-27, B.2-28, B.2-29, B.2-30 and B.2-31.

B.2.1.6 Buried Seismic Category I Piping

Responses of buried Seismic Category I piping to differential ground motion, due to particle motions caused by seismic wave propagations, are calculated by a method developed by N. M. Newmark.[4]

Reactions and bending moments of buried Seismic Category I piping, due to differential motion at structural penetrations, are calculated by considering buried pipe as a semi-infinite beam on elastic soil foundation with full restraint at structural penetrations. Using the maximum expected seismic displacements at structural penetration and the modulus of soil foundation, the stress thus calculated is superimposed with axial tension-compression stress meet the requirements defined in ANSI-B31.1 Code for Pressure Piping. If these stresses are found to be excessive, a seismic design of the underground piping within concrete or steel conduits (unattached to structure) combined with or without expansion joints has been incorporated in the system.

B.2.1.7 Interface Between Seismic Category I Piping and Non-Seismic Piping

The interface between seismic and non-seismic piping has been addressed in several ways. In general, large non-seismic piping has been routed so as not to create a hazard to smaller seismic piping. In certain cases where this approach was not possible, the normally non-seismic piping was redesignated as seismic and supported as such, e.g. raw water pump discharge piping in the intake structure. Where a seismic/non-seismic break occurs within a piping system, an interface anchor was normally provided to effect separation. Another method utilized was the imposition of building structure or rack steel as barriers between piping systems.

B.2.1.8 Pressure Relief Devices

The design criteria for most safety/relief valves are in accordance with the rules in paragraph 122.6 of ANSI-B31.1. Maximum stresses on each valve nozzle is calculated based upon its full discharge loads (i.e., thrust and bending) and internal design pressure is also computed by Stone and Webster "PITRUST" computer program. The "PITRUST" computer program is based on Bijlaard's method of calculating local stresses and experimental results.[5]

For Open Relief System

The total steady state discharge thrust load for an open system discharge will be expressed as the sum of the pressure and momentum forces as follows:

$$\frac{F}{A} = 144P + \frac{\rho V^2}{2g} \qquad \text{(B.2-8)}$$

where: F = total reaction force (lb)

A = exit flow area (ft^2)

P = exit pressure (psig)

V = exit fluid velocity (ft/sec)

ρ = exit fluid density (lb/ft^3)

g = 32.2 ft/sec^2

To ensure consideration of the effects of the suddenly applied load, a dynamic load factor is computed by dynamic analysis. The dynamic load factor is based on the relief/safety valve opening time and system characteristics in the absence of slug flow, to be applied to the forces and moments due to the reaction force (F). In the case of open safety or relief valve(s) mounted on a common header and full discharge occurring concurrently, the additional stresses induced in the header is combined with the previously computed local and primary membrane stresses to obtain the maximum stress intensity.

For Closed Relief System

For relief valve discharging into closed system, an analytical model of one-dimensional transient flow characteristics following the blow-off of the upstream safety/relief valve into the discharging piping system is established. The time-dependent pressure, temperature, density, velocity, and hence the momentum of the downstream pipe flow, is computed from this conservative hydrodynamic/thermodynamic flow model. Because of the complexity in the valve body structure, such phenomena as flow restrictions and frictional resistance, are considered. This model also considers the influence of valve opening time and the effect of loop seal water contained in the upstream valve seat. The Westinghouse proprietary computer codes ITCHVALVE and FORFUN were used to develop the hydraulic forcing function. This computer code is described in Section B.2.1.11. See Reference 18 for a more detailed description of this analysis.

The unbalanced transient hydraulic forcing function acting on the piping system computed from the flow model is used to determine the transient dynamic responses of the piping structural model. Adapting the lumped-parameter method incorporated with the modal analysis of piping system, the time history modal response is computed.

B.2.1.9 Simplified Seismic Analysis of Small Size Seismic Category I Piping (Generally less than or equal to 6 inches)

Code Requirements

BVPS-1 is designed to the USAS B31.1 Code for Power Piping (ANSI B31.1.0-1967 including Addenda through and including June 30, 1971). The Code, at that time, contained few specific seismic design rules, essentially requiring that the designer consider the effects of earthquake but falling short of supplying any significant guidance for detailed design.

The Code recognizes the existence of simplified methods within the thermal expansion and flexibility section, and specifically allows their use as follows: approximate or simplified methods may be applied only if they are used for the range of configurations for which their adequate accuracy has been demonstrated. The Code also allows that systems can be qualified without analysis if the system duplicates a successfully operating installation or can be adjudged adequate by comparison with previously analyzed systems.

Development of Simplified Methods for Seismic Category I Piping

This section is being maintained in the UFSAR to provide a historical record of the simplified methods performed by Stone and Webster during original plant design and construction.

During the 1979 re-analysis, Seismic Category I piping 2-1/2" diameter to 6" diameter was analyzed in accordance with Section B.2.1.2.

Stone & Webster, largely for economic reasons, initiated during the period 1968-1969, development of simplified piping analysis methods for application to 6 inch and smaller Seismic Category I systems. These rules consisted of (a) seismic methods and (b) flexibility methods.

Seismic methods were based on Kellogg, and were intended to keep seismic loads felt by the system low by keeping the fundamental piping frequencies out of the range of the fundamental structural (building) frequency, avoiding the possibility of resonance. Calculations were based on simple beam formulations and control of the piping fundamental frequency was effected by establishing the span length (between supports) of the piping during application of the method.

Flexibility methods were similarly based on simple cantilever beam methods, and provided the length of pipe necessary to absorb a given deflection at the free end.

The formulations of both methods were available to the analyst in "chart" form (actually nomographs), and were also available in tabular form.

Calculation of stress in the pipe was slightly different for each case in that the methodology of application followed a slightly different procedure.

For seismic, if the nomograph indicated that the piping was out of the resonance band of the structure, a "g" value equal to one-half the peak acceleration of the appropriate spectra was applied statically to the system. Tabulations relating various spans, nominal pipe sizes, and acceleration levels to actual pipe stress levels were provided for use by the analyst. The "resonant band" was defined as plus or minus 50 percent of the fundamental structural frequency. In 1971 the "resonant" band concept was revised to address the piping fundamental frequency for a simply supported beam model. Pipe span frequency, taken from nomograph or manually calculated, was compared to structural frequency. The desired piping frequency was greater than or equal to one and one-half the structural frequency, where a piping acceleration of one-half the peak acceleration was applied. Where this proved impractical or not feasible, the pipe frequency was allowed to fall in the area less than one and one-half the structural frequency but the peak acceleration from the appropriate spectra was applied. Calculated seismic stress was based on an assumed 3 component earthquake. Still later in the design of BVPS-1, a further refinement of the simplified procedure specified the use of a piping span based on deadweight support spans (in accordance with B31.1 Code) and utilized an applied acceleration equal to one and one-half times the peak spectral acceleration if pipe frequency fell into the area below one and one-half times the structural frequency.

For flexibility the nomograph was based on an allowable stress range of 15,000 psi, derived from B31.1 material allowables at temperature, so that the resulting span lengths were "prequalified" for stress.

Support and restraint loadings were based on standardized loadings enveloping the various loading conditions. Equipment nozzle loads were calculated based on similar, simplified methods.

When it is judged practical, computer methods will be used in place of the simplified techniques.

Detailed Application

This section is being maintained in the UFSAR to provide a historical record of the stress analysis methods performed by Stone and Webster during original plant design and construction. During the 1979 re-analysis, Seismic Category I piping 2-1/2" diameter to 6" diameter was computer analyzed in accordance with Section B.2.1.2.

For BVPS-1, piping was typically analyzed as follows, with the option of utilizing more rigorous methods available to the analyst.

Nominal Pipe Size	Method	Where Performed
8 inches and above	Rigorous (Computer)	Engineering Office
2 1/2 to 6 inches	Simplified	Engineering Office
2 inches and below	Simplified	Field

Piping 2 inches and below was shown on the piping drawings "diagrammatically" (i.e., without detailed dimensions). The stress engineers located supports during the installation process working at the site with erection isometric sketches. The piping dimensions, including pipe support locations, were added to the piping isometrics.

Simplified Method for QA Category I Piping 2" Diameter and Smaller

Simplified methods are used for the evaluation of QA Category I piping 2" diameter and smaller. The methods are similar to those used during original plant design. The methods consist of determining piping span requirements based on deadweight spans as well as seismic spans. Tables are developed utilizing beam formulas and static analysis which define the span requirements. The seismic span criteria for static analysis considers an applied acceleration equal to one and one-half times the peak spectral acceleration for that building and elevation. If a piping frequency check is performed, and the piping frequency falls above the structure frequency experiencing the peak acceleration, the static evaluation can be performed based on one and one-half times the actual acceleration at that frequency. If the piping is determined to be rigid, (frequency > 33 Hz) the evaluation can be performed based on the actual acceleration at that frequency. The static 1.5 factor does not have to be applied where it can be shown that the entire frequency content and modal participation has been adequately accounted for.

Flexibility methods determine the length of piping offset necessary to absorb a given amount of expansion or deflection. The flexibility tables are based on an allowable stress range derived from material allowables at the operating temperature. The tables follow the expansion stress equation from the 1967 ANSI B 31.1 Code.

Support and equipment loadings are conservatively calculated for use in the support evaluations.

It is also permissible to perform computerized analysis on QA Category I piping 2" diameter and smaller. Both simplified methods and computerized analysis will utilize the load combinations presented in Tables B.2-27, B.2-28, B.2-29, B.2-30 and B.2-31.

B.2.1.10 Field Run Piping

This section is being maintained in the UFSAR to provide a historical record of the field run piping installed during original plant construction. Portions of the piping systems listed below are analyzed using the criteria of Tables B.2-27, B.2-28, B.2-29, B.2-30 and B.2-31.

All piping in nominal pipe sizes 2 inch and smaller are field run, with exception of Seismic Category I stainless steel piping in sizes 2 inch and 1 1/2 inch with wall thickness schedule 80 and heavier, which are shop fabricated. Materials for all other 2 inch and smaller piping are designed, fabricated, welded, tested, inspected, and erected at the jobsite in accordance with the requirements of ANSI B31.1-1967 and addenda through and including June 30, 1971. The simplified design analysis procedure for field run piping are described in Section B.2.1.9. None of the Seismic Category I systems are completely field run because each system consists of various pipe sizes. Portions of the following Seismic Category I piping systems that are 2 inch NPS and smaller which are field run are listed below:

1. Reactor Coolant
2. Safety Injection
3. Containment Depressurization
4. Containment Vacuum
5. Charging and Volume Control
6. Residual Heat Removal
7. Boron Recovery
8. Component Cooling
9. River Water
10. Sample System
11. Fuel Pool Cooling and Purification
12. Process Radiation Monitoring
13. Area Radiation Monitoring
14. Fire Protection
15. Fuel Handling
16. Auxiliary Steam and Air Removal
17. Compressed Air

18. Vent and Drain System

19. Steam Generator Blowdown

20. Main Steam

21. Feedwater

22. Gaseous Waste.

The stress analysis design of field run piping has been initially performed by engineers and designers located at the site and subsequently independently verified by engineering at Stone & Webster project headquarters in Boston.

B.2.1.11 Computer Programs for Seismic Category I Piping Systems

The following computer programs were used by Stone and Webster in dynamic and static stress analyses of Seismic Category I piping systems.

A description of each program follows:

<u>NUPIPE</u>

NUPIPE-SW, the Stone & Webster version of NUPIPE, was used to re-analyze the Seismic Category I piping systems. NUPIPE-SW performs linear elastic analysis of three-dimensional piping systems subject to thermal, seismic, and dynamic time-history loads. The basic method of analysis used in NUPIPE-SW is the finite element stiffness method. In accordance with this method, the continuous piping is mathematically idealized as an assembly of elastic structural members connecting discrete nodal points.

Nodal points are placed in such a manner as to isolate particular types of piping elements, such as straight runs of pipe, elbows, valves, etc., for which force-deformation characteristics can be categorized. Nodal points are also placed at all discontinuities, such as piping supports, concentrated weights, branch lines, and changes in cross-section. System loads such as weights, equivalent thermal forces, and earthquake inertia forces are applied at the nodal points. Stiffness characteristics of the interconnecting members are related to the effective shear area and moment of inertia of the pipe. The stiffness of piping elbows and certain branch connectors is modified to account for local deformation effects by the flexibility factors suggested in the ASME Section III Code, Articles NB-3600 (Class 1 piping analysis), NC-3600 (Class 2 piping analysis), and ND-3600 (Class 3 piping analysis), and the ANSI B31.1 - 1967 and 1973 Code version piping.

The program NUPIPE has been verified for flexibility and stress analysis of nuclear piping by comparison with hand calculations and other computer program analytical solutions. A complete report on the verification was prepared by the Nuclear Services Corporation.[7]

PITRUST

PITRUST is a program to calculate local stresses in the pipe caused by cylindrical welded attachments under external loadings. This program uses the Bijlaard method as published in WRC-107[5] to calculate local stresses in the pipe wall caused by cylindrical welded attachments under external loadings, including pressure, dead load, and combinations of maximum seismic reactions.

Program PITRUST has been verified by comparing its solution of a test problem to the solution of the same problem by an independently written piping local stress program, CYLNOZ, in the public domain. The CYLNOZ piping local stress program was written by Franklin Institute (Philadelphia, PA), and is presently used by engineering companies. The test problem is of a 72.375 inch O.D. x .375 inch thick run pipe, reacting under an external in-lbs. bending and torsional moments transmitted by a 16 inch O.D. nozzle. A comparison of results is tabulated in Table B.2-4 solution of a test problem to the experimental results obtained in Reference 10. A comparison of these results is tabulated in Table B.2-5.

PILUG

PILUG is a program to calculate local stresses in the pipe wall caused by rectangular welded attachments under external loadings. This program uses the Bijlaard method as described in Reference 5 to calculate local stresses in pipe wall caused by rectangular welded attachments under external loadings, including pressure, dead load and combinations of maximum seismic reactions.

Program PILUG has been verified by comparing its solution to a test problem, to results obtained by hand calculations using the formulations specified in Reference 5. A comparison of results is tabulated in Table B.2-6.

SAVAL

SAVAL is a program to calculate stress levels at the junction of a run pipe and safety/relief valve nozzle during discharge of the valve. This program incorporates a subroutine to compute the dynamic load factor for each problem. The combined primary local stresses in the run pipe are obtained from Equation 9 of ANSI-B31.1 Power Piping Code (1973 proposed Summer Addendum). A design option is available which adds reinforcement, if necessary, to reduce stresses to allowable levels.

Program SAVAL has been verified by comparing its solution of a test problem to results obtained by hand calculations. The test problem is illustrated in Figure B.2-7. A comparison of results is tabulated in Table B.2-7 and B.2-8.

GAPPIPE

The GAPPIPE computer program is a general purpose piping analysis program. GAPPIPE performs both linear and nonlinear elastic analyses of three-dimensional piping systems subject to thermal expansion, imposed displacements, internal pressure, externally applied loads, seismic and fluid transient loads or motions.

GAPPIPE includes the capability to analyze piping systems containing gaps. Two analysis methods are included to compute the dynamic responses of such systems. The first method is nonlinear time history analysis by modal superposition and pseudoforce representation of gap responses. This method is most suitable for the simulation of piping responses induced by fluid transient loads or excitations where the input cannot be easily or adequately characterized by response spectra.

For excitations defined by response spectra, GAPPIPE offers a second analysis method that uses the response spectrum analysis technique and the method of equivalent linearization to account for the nonlinear behavior of gaps. In this method, GAPPIPE can use either uniform enveloped response spectra or different spectra at different supports using the independent support motion technique.

The program GAPPIPE has been verified for stress analysis of nuclear piping. The verification process included comparison to NRC benchmark problems (NUREG/CR-1677) as well as comparison to test data.

RELAP5/MOD

RELAP5/MOD was used to develop the forcing functions for analysis of the piping associated with the pressurizer safety valves and power operated relief valves in event of pressurizer overfill due to spurious operation of the Safety Injection System at power (refer to Section 14.1.16).

The light water reactor (LWR) transient analysis code, RELAP5, was developed at the Idaho National Engineering Laboratory (INEL) for the U.S. Nuclear Regulatory Commission (NRC). The Code uses include analyses required to support rulemaking, licensing audit calculations, evaluation of accident mitigation strategies, evaluation of operator guidelines, and experiment planning analysis. RELAP5 has also been used as the basis for a nuclear plant analyzer. Specific applications have included simulations of transients in LWR systems such as loss of coolant, anticipated transients without scram (ATWS), and operational transients such as loss of feedwater, loss of offsite power, station blackout, and turbine trip. RELAP5 is a highly generic code that, in addition to calculating the behavior of a reactor coolant system during a transient, can be used for simulation of a wide variety of hydraulic and thermal transients in both nuclear and non-nuclear systems involving mixtures of steam, water, noncondensables, and solute.

RELAP5/MOD3.3 has been developed jointly by the NRC and a consortium consisting of several countries and domestic organizations that were members of the International Code Assessment and Applications Program (ICAP) and its successor organization, Code Applications and Maintenance Program (CAMP). Credit also needs to be given to various Department of Energy sponsors, including the INEL laboratory-directed discretionary funding program. The mission of the RELAP5/MOD3.3 development program was to develop a code version suitable for the analysis of all transients and postulated accidents in LWR systems, including both large-break and small-break loss of coolant accidents (LOCAs), as well as the full range of operational transients.

The code includes many generic component models from which general systems can be simulated. The component models include pumps, valves, pipes, heat releasing or absorbing structures, reactor point kinetics, electric heaters, jet pumps, turbines, separators, accumulators, and control system components. In addition, special process models are included for effects such as form loss, flow at an abrupt area change, branching, choked flow, boron tracking, and noncondensable gas transport.

B.2.1.12 Use of ASME Code Case N-411

As stated in Section B.2.1.2, the initial design damping values used at Beaver Valley Power Station Unit No. 1 for seismically designed piping and components are 0.5 percent for the operating-basis earthquake (OBE) and 1.0 percent for the design-basis earthquake (DBE). NUREG 1061, "Report to the USNRC Piping Review Committee" has shown that the use of such low damping values for seismic piping analysis are overly conservative, and recommended the damping values given in ASME Code Case N-411 "Alternative Damping Values for Seismic Analysis of Classes 1, 2 and 3 Piping Sections". These damping values are: five percent below a frequency of 10 Hz; linear reduction from five percent to two percent between 10 Hz and 20 Hz; and two percent above 20 Hz. These damping values would apply for both OBE and DBE cases. The NRC staff has conditionally approved the use of the damping values in ASME Code Case N-411 for piping modifications and future piping stress analyses at Beaver Valley, Unit 1 by letter dated April 8, 1987.

The alternate damping values in ASME Code Case N-411 may be used at Beaver Valley, Unit 1 provided the following conditions are met:

1. The alternate damping criteria of this Code Case will be used for seismic analysis in cases where new piping is added, existing systems are modified, existing systems are re-evaluated for new requirements and where existing numbers of snubbers are to be reduced provided that the response mode frequencies are limited to 33 Hz and below.

2. When these alternate damping values are used, they will be used in a given analysis completely and consistently in which current seismic spectra and procedures are employed.

3. The damping values will be used in seismic analysis using response spectrum methods and not for seismic analysis using time-history analysis methods.

4. When used for reconciliation work or for support optimization of existing designs, the effects of increased motion on existing clearances and on line mounted equipment will be reviewed.

5. The alternate damping values will not be used in seismic analyses of piping systems using supports designed to dissipate energy by yielding or piping in which stress corrosion cracking has occurred.

6. When these alternate damping values are used, the ±15 percent peak broadening criteria of Regulatory Guide 1.122, "Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components" will be used.

7. When the damping values of Code Case N-411 are used, they will be used in their entirety in a given analysis and shall not be a mixture of Regulatory Guide 1.61 criteria and the alternate criteria of this Code Case.

8. For equipment other than piping, the damping values specified in Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants," should be used.

9. The damping values specified in Code Case N-411 may be used only in analyses which assume an upper bound envelope of the individual response spectra for all support locations to calculate maximum inertial responses of multiply-supported items.

10. Where predicted maximum piping displacements using Code Case N-411 criteria exceed the current design calculations by an amount greater than acceptable tolerance levels, a physical verification of the availability of adequate clearance with adjacent structures, equipment and components must be performed. For equipment mounted on piping, such as valves with extended structures, proper account must be taken for both rotation and translation in arriving at the predicted maximum displacement at the extreme ends of the pipe mounted equipment.

11. It must be verified that the operability qualification level of pipe mounted equipment is not exceeded by the predicted response using Code Case N-411.

12. Where the existing design loads of piping supports are exceeded by the new loads predicted by the use of Code Case N-411, it must be verified that the new loads do not exceed the design capacity of the supports.

13. It must be verified that the cumulative effect of the changes of loads on piping supports that are in turn supported by a structural element of a building, such as walls, slabs, beams and columns does not exceed the load carrying capacity of the affected structural element.

14. A listing of all applications of Code Case N-411 will be maintained by engineering, and the individual files of pipe stress packages re-analyzed using Code Case N-411 will be maintained with its respective Design Change Package (DCP) or Technical Evaluation Report (TER) records.

B.2.2 Summary of Stone & Webster Equipment Design Procedures

The seismic adequacy of Seismic Category I equipment has been documented. Depending upon equipment location, the basic source of seismic design data will be either the ground response spectra or the amplified response spectra to be derived through a dynamic analysis of the relevant structure (subparagraph B.1.5). New analysis will use the SSI ARS.

These spectra are developed and used for equipment consistent with the damping factors tabulated in Table B.1-3 or as justified by test. The uncertainties in the calculated values of fundamental structural frequencies due to reasonable variations in subgrade and structural properties are taken into account. The peak resonant period value(s) in the amplified response spectra developed as described in Subsection B.1.5 are subject to variations of plus 25 percent and minus 20 percent for this plant and site. Accordingly, equipment designed using these amplified response spectra having modal periods within plus 25 percent and minus 20 percent of the peak resonant period(s) are assigned the peak resonant response value(s). Beyond this range, the amplified response spectra are utilized exactly as shown.

As was discussed in Section B.1.5.3, a review of the original plant ARS with the SSI-ARS indicated that the original plant ARS are conservative based upon the seismic specification of static g values for qualification by static analysis and testing. The review of the original plant ARS indicated that peak resonant responses occurred below 10 Hz and that amplification of ground motion primarily occurred below 20 Hz for structures housing Seismic Category I equipment. For each building a "cutoff frequency" was selected (i.e., 10 or 20 Hz) in order to identify seismic acceleration levels above and below the cutoff frequency for calculational purposes. The "g" level identified below the cutoff frequency was a minimum of 1.3 times the peak ARS response.

Equipment having a natural frequency below the cutoff frequency was qualified to an equivalent static acceleration of 1.3 times the peak ARS response. When equipment frequency characteristics were rigid (above the cutoff frequency) the maximum rigid range g values were used. For tested equipment, the maximum rigid range g levels were conservatively used for qualification.

These requirements pertain to all Seismic Category I equipment regardless of industry code. The requirements for seismic qualification are intended to either supplement existing industry analytical requirements where applicable, or to provide documentation of component adequacy to combined normal plus earthquake loads where no documentation requirements existed at the time of the qualification.

All acceleration ("g") factors and analyses are based on elastic analysis exclusively.

Stress limits for Stone & Webster supplied Seismic Category I piping systems are specified in B.2.1.5.

Stress limits as outlined above were utilized in the qualification of all Seismic Category I components. No limits were imposed which allowed inelastic deformation on any Code Class A or B component.

Generally, no distinction is made for normal, upset, emergency, and faulted plant conditions in accordance with ASME III requirements for Class A, B, and C components. The combination of normal operating loads and Operating Basis Earthquake loads, which may be considered analogous to the normal and upset plant conditions, were kept within applicable code limits. Specification requirements for the combination of normal operating loads and Design Basis Earthquake loads, which may be considered analogous to the emergency and faulted plant conditions, allowed stress level to reach 90 percent of the minimum yield strength of the material as an upper limit.

The three principal categories of documentation considered are:

1. Static Analysis

2. Dynamic Analysis

3. Testing

B.2.2.1 Static Analysis

Static analysis is utilized for equipment that can be characterized as a relatively simple structure. This type of analysis involves the multiplication of the equipment or component total weight by the specified seismic acceleration component (direction dependent loading) to produce forces that are applied at the center of gravity in the horizontal and vertical directions. A stress analysis of equipment components such as feet, hold-down bolts, and other structural members, is performed to determine their adequacy.

In the specification of equipment for static analysis, two or more sets of acceleration data are provided, the choice of which set to use being dependent upon the fundamental equipment natural frequency. For the particular or "worst" equipment location, the relevant response curves are reviewed to determine a "cutoff frequency" which bounds the rigid range from the resonance range of the response curves. Components having fundamental natural frequencies above the cutoff frequency are analyzed to rigid range response accelerations. For components having a fundamental natural frequency below the cutoff frequency, analysis is based on response accelerations that are not less than those indicated by the curves over the full frequency range of the component. If the fundamental mode of the component falls within any of the "broadened" resonant response peaks existing in the component frequency range, the resonant response acceleration is increased by 30 percent as an arbitrary factor for conservatism in order to account for all significant dynamic modes under a resonant situation.

Method of Analysis

Those components which are considered relatively simple or rigid are designed, by virtue of natural frequency calculations, to withstand the effects of amplified seismic acceleration values dependent upon frequency and amplitude ranges associated with the relevant amplified response spectrum. Analysis of components to the peak value of resonant response is considered conservative since fundamental natural frequencies do not generally coincide with the frequency at resonance of the relevant response curve. Components having fundamental natural frequencies within the broadened response peak are designed to peak acceleration values, increased by a factor of 1.3, or as justified to account for the contribution of all significant dynamic modes under a resonant condition. Generally, the vibratory characteristics of the components qualified by "resonant static analysis" (relatively simple) is such that no possibility

exists for adjacent or multiple modes to exist within the relatively narrow peak of the response spectrum.

Peak broadening is intended to reflect a range of uncertainty in the precise location of the resonant peak of the response curve and not to indicate that the multiple peak resonant response is possible within this broadened range. What is concluded is that there is a fairly equal chance that the peak of the curve (singular) would fall in the specified range and thus what, in fact, exists is a "family" of resonant response curves, each having only one point of peak resonant response (Figure B.2-1). If more than one system or component mode of vibration falls within the broadened peak, one and only one mode (a presumed "worst case") can be presumed at an actual response peak value (Figure B.2-2). All other possible modes would realistically respond to lower values. Using the simple vibration theory and some simplifying assumption, it is shown that a factor of 1.3 is conservative.

A simple damped oscillator responds with a transmissibility:

$$TR = \frac{\sqrt{1 + (2\beta \quad W/W_n)^2}}{\sqrt{[1-(W/W_n)^2]^2 + [2\beta \quad W/W_n]^2}} \qquad \text{(B.2-9)}$$

The value of TR is sensitive to both the damping value and the assumed placement and spacing of the number of modes around the peak considered.

For instance, if only one mode is considered, the value of TR is as defined above and is equal to the value of the peak of the amplified response spectrum curve (single degree of freedom system).

As more modes are added around the nominal W_n mode K will increase. It is easily concluded that the most conservative placement of assumed modes is with one mode on the "peak" and others centered around this peak.

Data is presented in Figure B.2-3 which proves that the factor 1.3 is conservative for all potential equipment applications. The curves are developed for two "planes" representing five modes, and nine modes assumed acting within broadening resonant peak. These numbers are intended to show an upper bound for general equipment application. Equipment damping values of 0.5 percent and 1.0 percent are used for static analyses. Higher damping is shown to indicate the trend and the full conservatism of this approach.

As further conservatism, all modes are considered equally participating. This is never the case in dynamic analysis. The higher frequencies of the component are given equal weight to the fundamental resonant frequency and the modes are centered on the "nominal" response curve. If the fundamental frequency were placed on the peak of the nominal curve, the results would show even lower transmissibilities.

As has been stated, the factor 1.3 is applicable only for those components whose fundamental natural frequency falls within the broadened response peak. Broadening generally spans ranges from $\pm$10 percent to $\pm$25 percent. A sample calculation of this method is given in Table B.2-10.

It is shown that for the range of values associated with component and system static analysis, use of the 1.3 factor is conservative. In fact for a predominant number of likely cases a value far less than this can and should be justified on the bases of this data. For example, a value of 1.1 could easily be justified for most components which present only a few significant modes of vibration within the broadened response peak. It is further emphasized that, in reaching these conclusions, the most conservative (and generally improbable) assumptions regarding the location of the nominal response curve and the placement of response modes for the arbitrary component, have been made.

Verification of Analysis

As a conclusive supplement to the discussion above a study was performed utilizing rigorous dynamic analysis of models closely representative of typical components. This investigation consisted of computing the ratio of maximum dynamic stress to maximum static stress; i.e., the factor denoted by K for several model beams subject to a flat response and typical amplified response spectra. Since bending stress is dominant for frame/equipment constructions, the actual ratio employed equals

$$K = \frac{\text{Max dynamic moment}}{\text{Max static moment}}$$

Both the square root of the sum of the squares (SRSS) and absolute (ABS) moments are computed for comparison purposes, but conclusions are based solely on SRSS moments because they most closely represent actual dynamic stress.

Maximum static moment corresponds in the case of the l "g" flat response, to a l "g" static load. In the case of a typical amplified response, the maximum static load is based upon the following frequency relationships (refer to Figure B.2-4).

$f_o \leq f_p$, g = max (peak acceleration) (B.2-11)

$f_o > f_p$, g = acceleration at f_o (B.2-12)

where: f_o = the fundamental frequency of the model beam

f_p = the peak frequency; i.e., the frequency at which the peak acceleration occurs.

The effect of "peaking spreading" is investigated by using a flat response, thus giving all modes the same acceleration. This is equivalent to infinite peak spreading. The importance of the uncertainty in the location of the peak acceleration with respect to the fundamental mode of the model beams is examined by adjusting the fundamental frequency from well below to well above the peak resonant frequency of a typical response spectrum.

The model beams selected for this verification are shown in Figure B.2-5. These beams are typical of the frames and equipment combinations used in nuclear power plants. All dynamic analyses were conducted using the STRUDL computer program. Static analyses were carried out by hand, except for the simple/fixed beam with overhang. Consistent with design practice, all mountings are assumed rigid.

Table B.2-11 summarizes the results for l "g" flat response applied to the model beams of Figure B.2-5. Three K factors were computed for comparison purposes:

$$K\ s/c = \frac{\text{Max SRSS dynamic moment}}{\text{Max static moment from concentrated load}} \qquad \text{(B.2-13)}$$

$$K\ s/u = \frac{\text{Max SRSS dynamic moment}}{\text{Max static moment from uniform load}} \qquad \text{(B.2-14)}$$

$$K\ a/u = \frac{\text{Max ABS dynamic moment}}{\text{Max static moment from uniform load}} \qquad \text{(B.2-15)}$$

All conclusions are based on K s/u because it most closely represents the actual ration of dynamic moment to static moment. K a/u was not so chosen because, as can be seen in Table B.2-12 modes are so widely spaced that no more than one modal frequency lies within a $\pm$10 percent frequency band. K s/c is shown since this is the K factor which represents a typical simplification used in component analysis (concentrated static loads at component center of gravity).

The 1 "g" flat response was selected to give infinite peak spreading. As can be seen, K s/u was never significantly greater than unity.

Table B.2-13 presents the results for the simply supported/fixed model beam with 33 percent overhang subjected to the response spectra of Figure B.2-4. The column entitled 1st Mode in Table B.2-13 gives the fundamental frequency (f_o) and response acceleration (g_o) at f_o. Note that f_o was adjusted (by density variation) from well below to well above the peak frequency (f_p) of the response spectra to determine the effect on K of the uncertainty in the location of the peak frequency with respect to the fundamental frequency of the model beam. Since all values of K s/u were less than equity, it is concluded that this uncertainty has no important effects on the K factor.

It was concluded from the verification study that:

1. Peak acceleration times 1.3 applied as a static load to equipment whose fundamental natural frequency is within the broadened peak of the amplified response spectra curve is conservative.

2. No amount of peak spreading can itself result in a K s/u factor significantly greater than unity.

3. Uncertainty in the frequency at which the peak response acceleration occurs itself has no important effects on the K factor.

4. Multiple supported continuous spans are not included in the scope of this study. Components or equipment which make up a system of continuous multiple span supports will utilize a factor no less than 1.5 times peak acceleration as in Item 1 above, if applicable.

B.2.2.2 Dynamic Analysis

A detailed dynamic analysis is performed when component complexity or dynamic interaction precludes static analysis, or when static analysis is too conservative.

Modeling

To describe fully the behavior of a component subjected to dynamic loads, infinite number of coordinates would be required. Since calculation at every point of a complex model is impractical, the analysis is simplified by a judicious selection of a limited number of mass points. The "lumped mass" of the "consistent mass" approach is employed in the dynamic analysis. In the lumped and in the consistent mass idealization, the main structure is divided into substructures and the masses of these substructures are concentrated at a number of discrete points. The nature of these substructures and the stiffness properties of the corresponding modeling elements determine the minimum spacing of the mass points and the degrees of freedom to associate to each point. In accordance with the minimum spacing requirements, the analyst can then choose for the model, particular mass points which reflect predominant masses of components which are believed to give significant contribution to the total response.

In cases for which some dynamic degrees of freedom do not contribute to the total response, static or kinematic condensation is employed in the analysis.

Method of Analysis

The normal mode approach is employed for seismic analysis of components. Natural frequencies, eigenvectors, participation factors, and model member-end forces and moments of the undamped structure are calculated. The system of equations which describe the free vibrations of an n-degree of freedom, undamped structure is

$$[M]\ \{x''\} + [K]\ \{x\} = 0 \qquad \text{(B.2-16)}$$

where: [M] = mass matrix

[K] = stiffness matrix

{x}, {x"} = displacement, acceleration vectors

The mode shapes and frequencies are solved in accordance with:

$$[K - W_n^2 M]\ \{\phi\}_n = 0 \qquad \text{(B.2-17)}$$

W_n = frequency of the n^{th} mode

$\{\phi\}_n$ = mode shape vector for the n^{th} mode

Eigenvector, eigenvalue extraction routines such as Householder-QR, Jacobi Reduction and Inverse Iteration are used depending upon the total number of dynamic degrees of freedom and the number of modes desired.

For each mode, the participation factor for the specific direction is defined by:

$$n_i = \frac{\{\phi\}^T \quad [M] \quad \{D\}i}{\{\phi\}^T \quad [M] \quad \{\phi\}} \qquad \text{(B.2-18)}$$

where: $\{\phi\}^T$ = transpose of mode shape vector for the n^{th} mode

$\{D\}$ = earthquake direction vector referring to direction i

The modal member-end forces and moments are determined by:

$$\{F_M\}_n = [KM]\ \{\phi\}_n \qquad \text{(B.2-19)}$$

where: [KM] = member stiffness matrix

For each modal frequency, the corresponding response acceleration is determined for a given level of equipment damping from the applicable response curve.

The maximum response for each mode is found by computing:

$$\{x''\} = n_i\ Rn_i\ \{\phi\}_n \qquad \text{(B.2-20)}$$

$$\{x'\} = \frac{1}{W_n}\ \{x''\}_n \qquad \text{(B.2-21)}$$

$$\{x\} = \frac{1}{W_n^2}\ \{x''\}_n \qquad \text{(B.2-22)}$$

$$\{F\}_n = \frac{{}_n Rn_i}{W_n^2}\ \{F_m\}_n \qquad \text{(B.2-23)}$$

where: $\{x''\}_n$ 1 $\{x'\}_n$ 1 $\{x\}_n$ $\{F\}_n$

are the modal acceleration, velocity, displacement and member-end force and moment vectors respectively. Rn is the spectral acceleration for the nth mode in the i direction.

Before combining seismic response, a search is made for modes with adjacent closely spaced frequencies.

If no such modes are found, the total combined seismic results are obtained by taking the square root of the sum of the squares (SRSS) of each parameter under consideration.

$$\{x\}_{SRSS} = \sqrt{\sum_n \{x\}_n^2} \quad \text{(B.2-24)}$$

$$\{x'\}_{SRSS} = \sqrt{\sum_n \{x'\}_n^2} \quad \text{(B.2-25)}$$

$$\{x''\}_{SRSS} = \sqrt{\sum_n \{x''\}_n^2} \quad \text{(B.2-26)}$$

$$\{F\}_{SRSS} = \sqrt{\sum_n \{F\}_n^2} \quad \text{(B.2-27)}$$

where the summation $\sum_n$ includes all significant modes.

B.2.2.3 Testing

Equipment that is tested is qualified in accordance with Stone & Webster general instructions for Earthquake Requirements. For tested equipment these S&W Requirements either supplement other applicable industry standards (such as "IEEE Guide for Seismic Qualification of Class I Electric Equipment for Nuclear Power Generation Stations," STD-344-1971) or provide guidance for testing where no such codes are available. Equipment packages or components are shown adequate either by being tested individually, as part of a simulated structural section, or as part of an assembled module or unit. In any case, the minimum acceptance criterion must include:

1. No loss of function, or ability to function, before, during, or after the proposed test

2. No structural/electrical failure (i.e., connections and anchorages) which would compromise component integrity

3. No adverse, or dysfunctional, operation before, during or after the proposed test that could result in an improper safety action.

Equipment vendors and suppliers are required to formulate a program for qualifying the equipment in accordance with the conditions specified in Stone & Webster's general instructions for Earthquake Requirements. The vendor must submit a summary of the proposed effort to Stone & Webster for approval.

General testing guidance criteria specified for components include the following:

1. A frequency scan (standard logarithmic sweep) at a constant acceleration level is performed for as much of the range between 2 and 100 Hz as practicable or justified. The objective of this test is to determine the natural frequencies and amplification factors of the tested equipment and its critical components or appurtenances and to assure general seismic adequacy over the full frequency range of interest. The acceleration inputs used are the maximum rigid range accelerations indicated by the relevant response spectrum curves (damping) independent.

2. A "dwell test" of the equipment at its fundamental natural frequency is included at the acceleration values specified in Item 1 above. Additionally, other frequencies are selected if amplification factors of 2.0 or more are indicated. A 20 to 60 second duration is considered acceptable for each "dwell."

3. The test is conducted in three orthogonal directions individual or in a manner that adequately represents vertical and horizontal forcing simultaneously for each of two orthogonal horizontal directions.

Qualification programs for random or sinusoidal beat excitation are considered acceptable alternatives to the sinusoidal vibration test criteria outlined above. Also given consideration are laboratory shock results, in-shipment shock data, or adequate historical dynamic adequacy data (i.e., previous relevant test or environmental data). The method of test selected must demonstrate the adequacy of principal structural and functional components of the equipment.

B.2.2.4 Specification Requirements

Within these three general categories, all Seismic Category I equipment furnished will be shown to meet the requirements for the Operational Basis Earthquake and Design Basis Earthquake. There is no requirement that a Design Basis Earthquake (DBE) and a Design Basis Accident (DBA) be considered simultaneously for accident analysis purposes. The following discussion applies to safety-related SSC design considerations only.

Operating Basis Earthquake (OBE)

Equipment is designed to be capable of continued operation with the normal operating loads acting simultaneously with both horizontal and vertical components of the Operating Basis seismic loadings. Horizontal and vertical seismic loads are added considering a horizontal direction earthquake acting concurrently with the vertical direction earthquake. One more direction of the horizontal earthquake is considered on a "most severe basis." The stress levels due to these combined loading conditions are kept within maximum working stress limits permitted under applicable design standards, AISC Manual of Steel Construction, ASME Boiler and Pressure Vessel Code, AWWA Standards, or other codes or specifications. If no codes are used, the stress level under the combined loading is limited to 90 percent of the minimum yield strength of the material per the ASTM relevant Specification.

Design Basis Earthquake (DBE)

The equipment is designed to withstand the combined effects of the normal operating loads acting simultaneously with DBE loads without loss of function or structural integrity. Horizontal and vertical seismic loads are added considering a horizontal direction earthquake, again on the "most severe basis." It is permissible to allow strain limits in excess of yield strain in safety-related components during the DBE and under postulated concurrent conditions, provided the necessary safety functions are maintained. These limits would be defined and utilized only with reference to specific design codes, such as ASME Section III, which allow such limits for this loading.

Coupled Items

In the course of analysis, a comparison of relative mass and stiffness properties between connected components is performed. If this comparison indicates that the possibility of dynamic interaction is small, the interface is assumed to be an anchor. In order for this to be valid, the natural frequencies of connected components must be separated by a factor equal to or greater than 2, and the floor connected component (related to amplified response curve) be nonresonant.

If, however, adverse dynamic coupling is concluded to be possible, the problem is resolved by two general methods. Either additional restraints are provided to suitably alter stiffness parameters, and thus dynamically uncouple the system, or the analytical model is formulated to include the connected components interface loads (specifically nozzle loads) for inclusion in component adequacy documentation.

Seismic Design of Category I Instrumentation and Electrical Equipment

Seismic Category I instrumentation and electrical equipment are designed to maintain their capability to:

1. Initiate a protective action during the DBE and the OBE

2. Withstand seismic disturbances during post accident operation

Instruments and electrical equipment are seismically qualified in accordance with Stone & Webster's general instructions for Earthquake Requirements. These Stone & Webster Requirements generally impose the requirements of the IEEE Codes, such as IEEE STD-344-1971 even though this code was nonexistent during the purchase cycle of most Seismic Category I electrical equipment. Equipment of this type may be tested as an individual component, as part of a simulated structural section, or as part of a completely assembled module or unit.

The response of racks, panels, cabinets, and consoles is considered in assessing the capability of instrumentation and electrical equipment. Mounted components are tested, as a minimum, to acceleration levels consistent with those transmitted by their supporting structure. A design objective is to minimize amplification of floor acceleration by supporting members to mounted components.

Determination of amplification and seismic adequacy of instruments and electrical equipment is implemented by the analysis and testing methods outlined previously.

Dynamic System Analysis and Testing

All Seismic Category I mechanical equipment such as fans, pumps, and heat exchangers are qualified as seismically adequate in accordance with the criteria and procedures outlined previously. Generally all equipment is specified for qualification in the operating mode unless it can be shown that an alternative condition is a more severe case. Compliance with these criteria is intended to assure that the equipment will function when subjected to seismic loading.

In Generic Letter 87-02[19], the NRC staff set forth the process for resolution of Unresolved Safety Issue (USI) A-46 and encouraged licensees to participate in a generic program to resolve the seismic verification issues associated with USI A-46. As a result, the Seismic Qualification Utility Group (SQUG) developed the "Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment," Revision 2. Beaver Valley Unit 1 committed (Reference 21) to follow the SQUG commitments set forth in GIP-2, including clarifications, interpretations and exceptions identified in the NRC Supplemental Safety Evaluation Report.[20] Reference 22 provided a summary report of the implementation results of the USI A-46 program at BVPS-1. The NRC concluded (Reference 23) that the Beaver Valley Unit 1 USI A-46 Implementation Program, in general, met the purpose and intent of the criteria in GIP-2 and the NRC SSER[20] for the resolution of USI A-46.

Air handling cooling units are specified to be furnished in accordance with ARI and AMCA Codes and Standards. Fans are specified to be furnished in accordance with AMCA Standards. Damper assemblies are not furnished in accordance with any code or standard.

Safety related cooling units, fans, and damper assemblies are analyzed or tested to specified seismic criteria to confirm structural integrity and functional capability during earthquake conditions. Electrical components are subject to ambient temperature limited to 104°F.

This type of equipment is of standard industrial design and has proven reliable over many years of use. Operating conditions for the equipment will not exceed past performance criteria as there are no safety related cooling units, fans, or dampers assemblies located within the containment.

Seismic Category I cranes have been dynamically analyzed to ensure structural adequacy. In addition, restraints have been designed and installed to prevent cranes from becoming dislodged during an earthquake.

Seismic Design Control

Components and equipment requiring seismic input are specified in Table B.1-1. When equipment specifications are prepared a check is made to ensure that they are in full compliance with the FSAR. All designers and vendors of Seismic Category I equipment are provided with the necessary seismic information for the design and verification of components and equipment. This information is either amplified (floor) acceleration data (in the form of either response spectra or acceleration "g" constants) or dynamic model data necessary to incorporate coupling effects.

Stone & Webster designed and purchased components not specifically affecting structural response are specified in accordance with these Stone & Webster procedures. All vendor-supplied documentation is reviewed by Stone & Webster to insure component adequacy with respect to current criteria. The vendors proposed methods for documenting seismic adequacy are reviewed prior to implementation and reviewed in detail for approval upon submittal of completed documentation.

B.2.2.5 Computer Programs for Seismic Category I Equipment

The following computer programs were used by Stone & Webster in dynamic and stress analyses for Seismic Category I Stone & Webster designed equipment:

A description of each program follows.

TAC2D

TAC2D is a general purpose two-dimensional heat transfer computer code. It is a finite difference computer code. It can be used to determine steady-state and transient temperatures in two-dimensional problems. The configuration of the body to be analyzed is described in the rectangular, cylindrical, or circular (polar) coordinate system by orthogonal lines of constant coordinate called grid lines. These grid lines specify an array of nodal elements. Nodal points are defined as lying midway between the bounding grid lines of these elements. A finite-difference equation is formulated for each nodal point in terms of its capacitance heat generation, and heat flow paths to neighboring nodal points. The equations for all the nodal points are assembled and solved using an implicit alternating gradient algorithm. TAC2D(11) is a recognized program in the public domain.

A sample problem is presented to compare the results from TAC2D with an analytical solution in Table B.2-15. The objective is to show that the TAC2D program yields the correct solution.

A comparison of the output from the code with the series solution is shown in Figure B.2-9. The temperature versus time function is plotted at three representative points within the cylinder. It can be seen that the results from TAC2D are almost identical to the series solution results. The maximum difference between the two sets of results is about 2°F out of a mean magnitude of 100°F.

ASAAS

This is a finite element computer code. It can be used to determine stresses and displacements in arbitrary axisymmetric solids, including problems involving asymmetric mechanical and thermal loads and asymmetric temperature-dependent mechanical properties. All dependent variables, including the mechanical properties, are input by "Fourier Series" expansions of the circumferential coordinate. The mechanical loads can be surface pressures, surface shears, and nodal point forces.

The explicitly defined stiffness relations for the axisymmetric solid ring elements of triangular cross section are based on the classical theorem of potential energy and the assumption that within any element the displacement variation in the R-Z plane is linear. All dependent variables, including the material properties, are expanded into "Fourier Series." The harmonics are coupled and all the equilibrium equations are solved simultaneously. The algorithm used to solve the equations is a block modified square root "Cholesky Method with Iterative Refinement." ASAAS(12) is a recognized program in the public domain.

A sample problem is presented in Table B.2-16. The computer results are very close to the exact results. Therefore, this problem serves to verify that the accuracy of ASAAS for mechanical loading problems where material properties are not variable.

Vessel Penetration Analysis

This computer code performs various analyses on tanks and pressure vessels. All of the analyses are concerned with local stresses at penetrations. Typical problems which can be handled include the following:

1. Applied load stresses at vessel-nozzle junction for:

    a. Rigid attachment to cylinder

    b. Rigid attachment to sphere

    c. Hollow attachment to sphere

2. Pressure discontinuity analysis for thin shell interaction

3. Allowable load functions on nozzles for each case

4. Area compensation analysis in accordance with ASME Code

5. Maximum forces on supports of vessel based on allowable loads on nozzles.

Local stresses due to nozzle loads are found by the method of P.P. Bijlaard.(5) The method of "Johns and Orange" is used for pressure discontinuity stresses.

A sample problem, described in Table B.2-17, consists of a thin-walled cylindrical vessel subjected to applied loads from a rigid cylindrical attachment. A solution of this problem may be obtained by the use of Reference 5. A summary of the manual calculations is presented in Table B.2-18. The computer calculations are summarized in Table B.2-19. As can be seen, the computer results are very close to the exact results. Therefore, this problem serves to verify the accuracy of "Vessel Penetration Analysis."

SHELL 1

This is a finite-difference stress analysis computer code. It can be used to determine the forces, moments, shears, displacements, rotations, and stresses in a thin shell of revolution subject to arbitrary loads expanded in "Fourier Series" of up to 150 terms. Single-layer shells with up to 30 simply connected branches may be analyzed. Poisson's Ratio may change at discontinuity points, and Young's Modulus and the thermal coefficient of expansion may be different at each point. The allowed types of loading include elastic restraints, pressures in three orthogonal directions, temperature changes which may have a gradient through the shell thickness, and simplified input for weight of the shell or earthquake forces.

The equilibrium equations for a thin shell are based on the linear theory of Sanders. Sanders' equations are expanded and modified slightly to handle a broader range of problems. All pertinent load, stresses, and deformation variables are expanded into Fourier Series. The individual Fourier components of stress and deflection are found separately by solution of the finite-difference forms of the appropriate differential equations. The algorithm used to solve these equations is a minor modification of the Gaussian elimination method.

A sample problem is described in Table B.2-20. The cylinder is idealized by 10 elements as shown in Figure B.2-12. The computer results compared to exact calculations in Table B.2-20 were favorable. As can be seen, the problem serves to verify the accuracy of SHELL 1.

Stress Analysis of Shells of Revolution

This is a finite element computer code. It can be used to determine the forces, moments, shears, displacements, rotations and stresses in a thin shell of revolution subject to axisymmetric loads. Different orthotropic material properties may be input for each element in a model. The allowed types of loading include internal pressure, temperature changes which may have a gradient through the shell thickness, and simplified input for weight of the shell.

The explicit stiffness relations for the axisymmetric shell elements are based on the classical theory of potential energy and the usual approximations of thin shell theory. The direct stiffness method (a simple modification of the displacement method) is employed to assemble the equilibrium equations. The algorithm used to solve these equations is derived by applying the "Gauss-Jordan" method of elimination to a Tri-diagonal System of equations.

A sample problem is described in Table B.2-21. The cylinder is idealized by 10 elements as shown in Figure B.2-12. The computer results compared to hand calculations in Table B.2-21 were favorable.

SAAS III

This is a finite element computer code. It can be used to determine displacements, stresses, and strains in axisymmetric and plane solids with different orthotropic, temperature-dependent material properties in tension and compression including the effects of internal pore fluid pressures and thermal stresses. The mechanical loads can be surface pressures, surface shears, and nodal point forces, as well as acceleration or angular velocity.

The explicit stiffness relations for the two-dimensional solid elements of triangular cross section are based on the classical theorem of potential energy and the assumption that within any element the displacement variation in the place is linear. The stiffness matrix is assembled in a band form. A simplified "Gaussian Elimination Method," which takes advantage of the concentration of the elements of the stiffness matrix along the main diagonal, is the algorithm used to solve the equilibrium equations. SAAS III(14) is a recognized program in the public domain.

The well-known Lame cylinder solution for an elastic isotropic material is used to check the answers obtained by use of the SAAS III program. The cylinder is idealized by four elements as shown in Figure B.2-13. The computer results are shown on Table B.2-22 along with the exact results obtained by the use of Reference 15. As can be noted from the table, the computer results are very close to the exact results. Even better results, however, can be obtained by the use of more elements in the radial direction.

STARDYNE

The STARDYNE Structural Analysis System, written by Mechanics Research, Inc., of Los Angeles, California, is a fully warranted and documented computer program available at Control Data Corporation's 600 data centers. The latest version of this program became available September 1, 1972.

The MRI STARDYNE Analysis System consists of a series of compatible digital computer programs designed to analyze linear elastic structural models. The system encompasses the full range of static and dynamic analyses. The static capability includes the computation of structural deformations and member loads and stresses caused by an arbitrary set of thermal, modal applied loads, and prescribed displacements. Utilizing the normal mode technique, dynamic response analyses can be performed for a wide range of loading conditions, including transient, steady-state harmonic, random and shock spectra excitation types. Dynamic response results can be presented as structural deformations and internal member loads.

PISCES

The PISCES, written by Physics International Scientific Codes and Engineering Services of San Diego, California, is a fully supported and well-documented computer code available at Control Data Corporation.

Physics International's PISCES computer program utilizes state-of-art techniques to solve complex problems in fluid-structure interaction, explosion effects, gas and fluid dynamics, and impact and penetration. The unique and powerful feature of the PISCES is the ability to apply the most accurate and efficient numerical schemes to the different regimes of a given problem and then couple them together in space and time.

ST-167 Free Vibration Analysis of Undamped Systems

This computer program, written at Stone & Webster Engineering Corporation, is designed to calculate eigenvectors, eigenvalues, and participation factors of vibrating systems whose mass matrix contains off-diagonal terms.

Free vibration analysis of undamped systems is represented by the following system of equations:

$$[M] \{\phi(t)\} + [K] \{\phi(t)\} = 0 \qquad \text{(B.2-28)}$$

Assuming that $\phi(t) = e^{iwt}$, the above equation can be written as

$$[M]^{-1} [K] \{\phi\} = W^2 \{\phi\} \qquad \text{(B.2-29)}$$

which is in the form of the classical characteristic value problem. However, if [M] contains off-diagonal elements, the matrix $[M]^{-1}$ [K] is, in general, a nonsymmetric matrix.

Eigenvalues are extracted by transforming matrices to the upper Hessenberg form and using the QR transformation by Francis. Eigenvectors are extracted using J. H. Wilkinson's approach. Participation factors are calculated using eigenvectors and the mass matrix as shown by J. M. Biggs in his book "Introduction to Structural Dynamics."

A sample problem comparing the results of hand calculations and the ST-167 output is presented in Table B.2-23.

References for Section B.2

1. American National Standard Code for Pressure Piping ANSI-B31.1 American Society of Mechanical Engineers (1971).

2. Deleted by Revision 0, January 1982.

3. Deleted by Revision 0, January 1982.

4. N. M. Newmark and E. Rosenblueth, Fundamentals of Earthquake Engineering, Section 10.6 and 16.5, Prentice-Hall (1971).

5. K. R. Wichman, et al, "Local Stresses in Spherical and Cylindrical Shells due to External Loadings," Welding Research Council Bulletin WRC-107 (December 1968).

6. P. B. Schanbel, J. Lysmer, and H. B. Seed, "SHAKE: A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites," Earthquake Engineering Research Center, Report No. EERC72-12 (December 1972 as modified for SWEC Computer System in Program ST211 Version 2 Level 0).

7. "NUPIPE Computer Program Verification" Revision 1, Nuclear Services Corporation (August 3, 1976).

8. "Nuclear Power Plant Components," American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, (1971, including all addenda up to Winter, 1972).

9. Deleted by Revision 15, January 1997.

10. "Experimental Elastic Stress Analysis of Cylinder to Cylinder Shell Models and Comparison with Theoretical Predictions," J. M. Corum and W. L. Greenstreet, First International Conference on Structural Mechanics in Reactor Technology, Berlin, Preprints Volume 3, Part G, (1971).

11. J. F. Peterson, "TAC2D - A General Purpose Two-Dimensional Heat Transfer Computer Code," GA-9262, Gulf General Atomic Inc. (September 6, 1969).

12. T. G. Crose, "ASAAS Asymmetric Stress Analysis of Axisymmetric Solids with Orthotropic Temperature-Dependent Material Properties that Can Vary Circumferentially," Air Force Report No. SAMSO-TR-71-297 Aerospace Report No. TR-0172 (S2816-15)-1 (December 29, 1971).

13. Deleted by Revision 15, January 1997.

14. J. G. Grose and R. M. Jones, "SAAS III Finite Element Stress Analysis of Axisymmetric and Place Solids with Different Orthotropic, Temperature-dependent Natural Properties in Tension and Compression," Air Force Report No. SAMSO-TR-71-103, Aerospace Report No. TR0059 (S6816-53)-1, (June 22, 1971).

References for Section B.2 (CONT'D)

15. S. Timoshinko and J. N. Goodier, Theory of Elasticity, McGraw-Hill Book Company, Inc., New York, N. Y., pp 58-60 (1951).

16. A Reanalysis of Safety-Related Piping Systems, Interim Report for Beaver Valley Power Station Unit 1; Submitted to the NRC April 20, 1979.

17. Program Verification on File at Stone & Webster Engineering Corporation, Boston, Mass.

18. Duquesne Light Company to NRC submittal concerning NUREG-0737, Item II.D.1, Pressurizer Safety and Relief Line Piping and Support Evaluation, dated June 24, 1983.

19. NRC Generic Letter 87-02, "Verification of Seismic Adequacy of Mechanical and Electrical Equipment in Operating Reactors, Unresolved Safety Issue (USI) A-46," dated February 19, 1987.

20. USNRC "Supplemental Safety Evaluation Report No. 2 on Seismic Qualification Utility Group's Generic Implementation Procedure, Revision 2, corrected February 14, 1992," dated May 22, 1992.

21. Duquesne Light Company letter to USNRC, "Response to Supplement 1 to Generic Letter 87-02, SQUG Resolution of USI A-46," dated September 22, 1992.

22. Duquesne Light Company letter to USNRC, "Generic Letter 87-02, Summary Report for Resolution of USI A-46," dated January 31, 1996, and Attachment 1, "Beaver Valley Power Station, Unit 1, USI A-46 Seismic Evaluation Report."

23. USNRC letter to Duquesne Light Company, "Safety Evaluation for USI A-46 Program Implementation at Beaver Valley Power Station, Unit No. 1 (BVPS-1)," dated December 9, 1998.

Bibliography for Section B.2.2.5

1. R. H. Johns, T. W. Orange, "Theoretical Elastic Stress Distributions Arising from Discontinuities" and "Edge Loads in Several Shell-Type Structures," National Aeronautics and Space Administration Technical Report R-103 (1961).

2. J. L. Sanders, Jr., "An Improved First Approximation Theory for Thin Shells," National Aeronautics and Space Administration Technical Report R-24.

3. B. Budlansky, P. P. Radkowski, "Numerical Analysis of Unsymmetrical Bending of Shells of Revolution," AIAA Journal 1, 1833 (March 1964).

4. G. Greenbaum, "Comments on Numerical Analysis of Unsymmetrical Bending of Shells of Revolution," AIAA Journal 2, 590 (March 1964).

5. P. E. Grafton and D. R. Strome, "Analysis of Axisymmetric Shells by the Direct Stiffness Method," AIAA Journal 1, No. 10 (1963).

6. J. H. Percy, T. H. H. Pian, S. Klein and D. R. Navaratna, "Application of Matrix Displacement Method of Linear Elastic Analysis of Shells of Revolution," AIAA Paper No. 65-142 (January 1965).

7. R. Anderson, Fundamentals of Vibration, The MacMillan Company, New York, p. 774 (1967).

B.3 WESTINGHOUSE NUCLEAR STEAM SUPPLY SYSTEM

B.3.1 Seismic Category Definitions

Equipment and equipment supports of the Nuclear Steam Supply System are classified into seismic categories equivalent to those contained in Section B.1. This category assignment is considered in the design, material aspects, manufacture and fabrication, and assembly stages. A single system may have components in more than one category.

B.3.2 Equipment List

Components are listed in Table B.3-1 according to the seismic category definitions of Section B.1. The ASME Code is mandatory.

A summary of the seismic requirement for each category is provided in Table B.3-2.

B.3.3 Design Philosophy

In addition to the loads imposed on the system under normal operating conditions, the design of equipment requires that consideration also be given to abnormal loading conditions such as an earthquake. 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, equipment is required to operate within design limits. The design for normal plus DBE and the normal plus DBE plus DBA loading condition is intended to provide a margin in design that ensures capability to shutdown and maintain the nuclear facility in a safe condition. In this case, it is only necessary to ensure that critical equipment does not lose capability to perform its 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 requirements to ensure no loss of function. For example, rotating equipment must not seize and piping and vessels must retain their contents and allow fluid flow.

The seismic design of Seismic Category I mechanical components is covered in the remainder of this Appendix. The seismic evaluation of Seismic Category I instrumentation and electrical equipment is covered in Section 7.2.1.

Seismic Category II equipment is not covered because it is not essential to safe shutdown and isolation of the reactor and its failure would not result in the release of substantial amounts of radioactivity. Non-seismic equipment is not designed for seismic disturbance.

It should be noted that BVPS-1 equipment was designed to the 1965 and 1968 versions of Section III of the ASME Code. A simple approach was sought to evaluate the adequacy of forces or stresses obtained from a conservative elastic analysis for Faulted Condition loadings. The stresses therein obtained frequently exceed yield values for relatively short periods of time. These brief excursions into the plastic range do not affect the integrity of the system. The design "Stress Limits for Various Load Combinations" and the "Loading Conditions and Stress Limits" are presented in Tables B.3-3 and B.3-4.

B.3.4 Seismic System Analysis

B.3.4.1 Analysis of Seismic Category I Mechanical Equipment

The seismic response of Seismic Category I piping and component within Westinghouse scope of responsibility is determined as part of a multi-degree of freedom model which includes the support characteristics. This model is a multi-mass mathematical representation of the system. A sufficient number of masses are included to ensure an accurate determination of the dynamic response. A single mass model is used to determine vertical response loads for the seismic design when justified by the equipment design characteristics and/or the conservatism of the assigned loadings.

Horizontal and vertical seismic umbrella spectra are generally prepared which encompass the floor response spectra at the elevations where the piping system attaches to the building structure. The system is analyzed for the simultaneous occurrence of these horizontal and vertical seismic input motions. The results for the vertical direction are added absolutely to the results of the worse of those for the North-South and East-West directions. The umbrella spectra are compared with the horizontal and vertical floor response spectra developed to assure conservatism of the spectra used in the analysis.

In a coupled system with different structural elements, either the lowest damping value of the system is used for all modes, or equivalent modal damping values are determined according to the energy distribution in each mode. Damping values used are given in Table B.1-3.

The materials employed in systems under Westinghouse scope of supply are standard. The material properties which can effect a variation in modal period are well known, and the known variation in these properties does not account for any measurable or significant shift in period or increase in seismic loads.

Details of the response spectrum analysis are described in Section B.3.5.

B.3.4.2 Analysis of Reactor Vessel Internals

Nonlinear dynamic analysis of the Reactor Equipment System Model (RESM) includes the development of the system finite element model and the synthesized time history accelerations.

The only difference between the LOCA RESM analysis described in Section 14.3.3.3 and the seismic RESM analysis is that, in the LOCA model, the fluid-solid interaction in the downcomer annulus is accounted for in the LOCA hydraulic forces. In the seismic model, the fluid-solid interaction is included by incorporating hydrodynamic masses in the RESM.

The RESM for the nonlinear time-history seismic analysis consists of three concentric structural sub-models connected by nonlinear impact elements and stiffness matrices. The first sub-model represents the reactor vessel shell and its associated components.

The second sub-model represents the reactor core barrel, thermal shield, lower support plate, tie plates, and the secondary support components. This sub-model is physically located inside the first, and is connected to it by a stiffness matrix at the vessel/internals interface. Core barrel to reactor vessel shell impact is represented by nonlinear elements at the core barrel flange, core barrel outlet nozzles, and the lower radial restraints.

The third and innermost sub-model represents the upper support plate assembly consisting of guide tubes, upper support columns, upper and lower core plates, and the fuel. The third sub-model is connected to the first and second by stiffness matrices and nonlinear elements.

As mentioned above, fluid-structure or hydroelastic interaction is included in the reactor pressure vessel model for seismic evaluations. The horizontal hydroelastic interaction is significant in the cylindrical fluid flow region between the core barrel and the reactor vessel annulus. Mass matrices with off-diagonal terms (horizontal degrees of freedom only) attach between nodes on the core barrel, thermal shield, and the reactor vessel. The diagonal terms of the mass matrix are similar to the lumping of water mass to the vessel shell, thermal shield, and core barrel. The off-diagonal terms reflect the fact that all the water mass does not participate when there is no relative motion of the vessel and core barrel. It should be noted that the hydrodynamic mass matrix has no artificial virtual mass effect and is derived in a straightforward, quantitative manner.

The matrices are a function of the properties of two concentric cylinders with the fluid in their cylindrical annulus, the density of the fluid, and the length of the cylinders. Vertical segmentation of the reactor vessel and the core barrel allows inclusion of radii variation along their heights and approximates the effects of beam mode deformation. These mass matrices were inserted between the selected nodes on the core barrel, thermal shield, and the reactor vessel.

The seismic evaluations are performed by including the effects of simultaneous application of time-history accelerations in three orthogonal directions. The ANSYS computer code is used to determine the response of the reactor vessel. In the finite element approach, the structure is divided into a finite number of discreet members or elements. The inertia and stiffness matrices, as well as the force array are first calculated for each element in the local coordinates. Employing appropriate transformations, the element global matrices and arrays are assembled into global structural matrices and arrays, and used for dynamic solution of the system equations.

B.3.5 Seismic Subsystem Analysis

B.3.5.1 Analysis of Seismic Category I Mechanical Equipment

The typical Westinghouse supplied Category I mechanical components are checked for seismic adequacy as follows:

1. If a component falls within one of the many categories which has been previously analyzed using a multi-degree-of-freedom model and shown to be relatively rigid, then the equipment specification for that component is checked to ensure that the specified values are smaller than those used in the previous analysis.

2. If the component cannot be categorized as similar to a previously analyzed component that has been shown to be relatively rigid, then an analysis is performed as described below.

Seismic analysis of typical Westinghouse supplied Seismic Category I mechanical equipment including heat exchangers, pumps, tanks, and valves are analyzed using a multi-degree-of-freedom modal analysis. Appendages, such as motors attached to motor operated valves, are included in the models. The natural frequencies and normal modes are obtained using analytical techniques developed to solve eigenvalue-eigenvector problems. A response spectrum analysis is then performed using horizontal and vertical umbrella spectra that encompass the appropriate floor response spectra developed by Stone & Webster. The simultaneous occurrence of horizontal and vertical motions are included in the analyses. The combined modal seismic response is obtained by adding the individual modal responses by the square root of the sum of the squares method. Combined modal response for closely spaced modal frequencies whose eigenvectors are orthogonal are handled in the above mentioned manner. In the rare event when two significantly closely spaced modal frequencies occur and their eigenvectors are parallel, the combined modal 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.

Hydrodynamic analysis of tanks is performed using the methods described in Chapter 6 of the "U.S. Atomic Energy Commission - TID-7024." Bridge and trolley structures are designed so that restraints prevent derailing due to the DBE. The manipulator crane is designed to prevent disengagement of a fuel assembly from the gripper under the DBE.

The reactor coolant system components and supports, except piping, which is addressed in Section 2 of this Appendix, are designed for the loading combinations and stress limits given in Table B.3-3. The loading conditions are categorized with respect to Normal, Upset, Emergency and Faulted condition. Stress intensity limits for each of the loading conditions is presented in Table B.3-4.

Valves in sample lines are not considered to be part of the reactor coolant system boundary because nozzles connect to the reactor coolant system through a 3/8 inch hole. This hole restricts the flow such that loss through a severance of one of these lines can be made up by normal charging.

B.3.5.2 Analysis of Reactor Vessel Internals

The core internals are dynamically analyzed using the methods described in Section B.3.4.2.

Results of the nonlinear Design Basis Earthquake (SSE) dynamic analysis include the transient displacements and impact loads for various elements of the mathematical model. These displacements, impact loads, and linear component loads (forces and moments) are then used for detailed component evaluations to assess the structural integrity of the reactor vessel, reactor internals, and the fuel. Note that the linear component forces and moments are not the direct output from the modal superposition analysis, but rather are obtained by post-processing the data saved from the nonlinear time-history analysis. From the modal analysis (free vibration analysis), the system eigenvalues (frequencies) and eigenvectors (modal shapes) are stored for later use in the modal superposition analysis. The validity of a complex system structural model is generally verified by comparing the calculated fundamental frequency of the system with the available test data frequency.

The criterion for normal plus OBE loadings is that the stresses are limited to those given by the ASME Nuclear Power Plant Components Code for upset conditions. These limits are intended to assure that the reactor will be able to continue or resume operation. For the normal plus DBE and the normal plus DBE plus Design Basis Accident loading conditions, the criteria core coolant and core shutdown must be assured. This implies that the deformation of the reactor internals must be sufficiently small so that the geometry remains substantially intact. Consequently, the limitations established on the internals are concerned principally with the maximum allowable deflections and/or stability of the parts in addition to a stress criterion to assure integrity of the components. The deflections and stresses caused by the DBE are small in comparison to those caused by the DBA.

B.3.5.3 Analysis of Fuel Assemblies, Control Rods Assemblies, and Control Rod Drives

Fuel assembly component stresses induced by horizontal seismic disturbances are analyzed through the use of computer modeling. The time history floor response, based on a standard seismic time history normalized to Design Basis Earthquake levels is used as the seismic input. The reactor internals and the fuel assemblies are modeled as spring and lumped mass systems. The seismic response of the fuel assemblies is analyzed to determine design adequacy. Detailed discussion of the analyses performed for a typical fuel assembly may be found in WCAP 7950[(2)].

The control rod drive mechanisms (CRDM) are seismically analyzed to confirm that system stresses under seismic conditions do not exceed allowable levels as defined by the ASME Boiler and Pressure Vessel Code, Section III for "Upset" and "Faulted" conditions. Based on these stress criteria, the allowable seismic stresses and resultant bending moments in the structure are determined. The CRDM is mathematically modeled as a system of lumped and distributed masses. The model is analyzed for the applicable seismic loads and bending moments along the length of the CRDM. These values are then compared to the previously calculated allowable seismic bending moments for the equipment to assure adequacy of the design.

B.3.6 Criteria for Seismic Instrumentation Program

Seismic instrumentation is discussed in Section 5.2.8.1.

B.3.7 Seismic Design Control Measures

The following procedure is implemented for Westinghouse supplied Seismic Category I mechanical equipment that fall within one of the many categories which have been analyzed as described in Sections B.3.4 and B.3.5 and has been shown to be relatively rigid with all natural frequencies greater than 30 Hz:

1. Equivalent static acceleration factors for the horizontal and vertical directions are included in the equipment specification. The vendor must certify the adequacy of the equipment to meet the seismic requirement as described in Section B.3.5.

2. The floor response spectra are developed and the cognizant engineer responsible for the particular component checks to ensure that the acceleration values are less than those given in the equipment specification.

Design control generally is discussed in detail in Appendix A.

B.3.8 Code Classes

A tabulation of components and applicable code classes is shown in Table B.3-5 "Equipment Code and Classification List".

B.3.9 Computer Programs used in Dynamic and Static Analysis

The following computer programs have been used in dynamic and static analysis by Westinghouse to determine mechanical loads, stresses, and deformations of Seismic Category I components and equipment.

A description of the basis, capabilities, and extent of application of each program follows. A series of solutions of test problems is included for the WESTDYN program along with comparisons to hand calculations, other computer programs, and/or experimental results. Verification of the remaining programs was provided in the form of a topical report which was submitted in early April 1974.

WESTDYN (or WESDYN-7)

WESTDYN, a Westinghouse adaption of the A. D. Little Company program(3), is a special purpose program for the static and dynamic analysis of redundant piping systems with arbitrary loads and boundary conditions. It computes, at any point in the piping system, the forces, deflections, and stresses that result from the imposed anchor or junction loads, thermal gradients in the system, and gravity loads, in any combination of the three orthogonal axes. The piping system may contain a number of sections, a section being defined as a sequence of straight and/or curved members lying between two network points. A network point is:

1. A junction of two or more pipes

2. An anchor or any point at which motion is prescribed

3. Any arbitrary point.

Any location in the system may sustain prescribed loads or may be subject to elastic constraint in any of its six degrees of freedom. For example, hangers may be arbitrarily spaced along a section and may be of the rigid, flexible, or constant force type.

The response to seismic excitation is analyzed by normal mode, response spectral superposition technique with a lumped mass system. The eigenvalue routines used are the Jacobi rotation and the Givens-Householder schemes(4). The maximum spectral acceleration is applied for each mode at its corresponding frequency from response spectra to obtain the amplitude of the modal coordinate for each mode. A basic assumption is that the maximum modal excitation of each mode occurs simultaneously. The forces, deflections, support reactions, and stresses are calculated for each significant mode. The total response is computed by combining the contributions of the significant modes by several methods, one of which is the square root of the sum of the squares method.

The applicability and validity of the WESTDYN program has been demonstrated by running test problems and comparing the results from this program with the results of hand calculations, other programs, etc. A summary of five test problems are presented in Tables B.3-13, B.3-14, B.3-15, B.3-16 and B.3-17. A complete verification of this program was supplied in a topical report of April, 1974.

FIXFM

FIXFM is a digital computer program which determines the time-history response of a three-dimensional structure excited by arbitrary, time varying forcing functions. The input for FIXFM (obtained from the WESTDYN program) consists of normalized mode shapes, natural frequencies, forcing functions, and an initial deflection vector. The program sets up the modal differential equations of motion. The modal differential equations are solved numerically by a predictor-corrector technique of numerical integration. The modal contributions are then summed at various mass points throughout the structure to obtain the actual time-history response. FIXFM, like WESTDYN, is applied to redundant piping systems.

WESDYN-2

WESDYN-2 is a slightly modified version of the WESTDYN program. The program treats the input of time-history displacement vectors at mass points (from FIXFM) as an imposed deflection condition and proceeds to a usual WESTDYN static solution. In addition to the usual stress solution, the program also calculates axial stress, shear stress, and stress intensity.

STHRUST

The STHRUST code computes hydraulic loads on primary loop components from the blowdown information calculated by the SATAN[5] code, i.e., density, internal energy, and mass flow rate. The entire primary system, including special elements such as the reactor core, pressurizer, and accumulators, is represented by the same two-loop model employed in the SATAN blowdown calculation.

The force nodes are selected along the two-loop geometric model of a reactor plant where the vector forces and their components in a global coordinate system are calculated. Each force node is associated with a control volume which may contain one or two blowdown (SATAN) control volumes depending on the location of the force node in the system. Each force control volume, in turn, has one or two associated apertures (flow areas). STHRUST calculates the time-history of forces at locations where there is a change in either direction or area of flow within the RCL.

The major input information required for the code is:

1. Blowdown hydraulic information which is read directly from the SATAN result tape

2. The orientation of the force node in the system which is input as three projection coefficients along the three coordinate axes of the global coordinate system.

STRUDL

STRUDL, part of the ICES Civil Engineering Computer System[(6)], is a general purpose matrix structural analysis program which can solve for stresses and deflections of structures subjected to static or thermal loads. The basis of the program is the general beam finite element. It is applicable to linear elastic two- and three-dimensional frame or truss structures, e.g., steam generator lower, steam generator upper lateral, and reactor coolant pump lower support structures. STRUDL employs the stiffness formation and is valid only for small displacements. Structure geometry, topology, and element orientation and cross-section properties are described in free format. Member and support joint releases, such as pin and rollers, are specified. Otherwise, six restraint components are assumed at each end of each member and at each support joint.

The STRUDL system performs structural stability and equilibrium checks during the solution process and prints error messages if these conditions are violated. However, the system cannot detect geometry or topology errors. Type, locations, and magnitude of applied loads or displacements are specified for any number of loading conditions. These can be combined as desired during the solution process.

One important feature of STRUDL is that any desired changes, deletions, or additions can be made to the structural model during the solution process. This produces results for a number of structure configurations, each with any number of loading conditions.

The output includes member forces and distortions, joint displacements, support joint reactions, and member stresses.

THESSE

The THESSE computer program was developed by Westinghouse to accomplish RCL equipment support structures analyses and evaluation. Two versions are used:

1. One for normal and upset condition loading using AISC-69 allowable stress equations

2. One for faulted condition loading which LOCA loads are read in time-history form and ultimate stress equations are used.

Westinghouse has expanded the output capabilities of STRUDL to include selective punched card data that is used as input in the THESSE program. The input includes:

1. Six components of forcing acting on the support structure for each of the thermal, weight, pressure, seismic, and LOCA loadings

2. Member geometry and material

3. 6 x 6 member influence coefficient array for each end of each member.

Loads on the structure are combined, transformed to the structure-coordinate system, and multiplied by member influence coefficients. The resulting member forces are then used with member properties in stress and interaction equations to determine the adequacy of each member in the structure. THESSE calculates all member internal forces and moments and determines when the highest stresses occur in each member. These maximum stresses are expressed as a ratio of the maximum stress to the limiting values.

WECAN & WECAN PLUS

WECAN, a one-, two-, and three-dimensional finite element program capable of solving elastic-plastic static structural problems, transient and steady-state thermal problems, and linear and nonlinear dynamic structural problems. Its library of finite elements includes spars, beams, pipes, plane and axisymmetric triangles, three-dimensional solids, plates, plane and axisymmetric shells, three-dimensional shells, friction interface elements, springs, masses, dampers, thermal conductors, hydraulic conductors, convection elements, and radiation elements.

WECAN is capable of predicting mode shapes and natural frequencies, maximum response to harmonic excitation, or complete time-history response to arbitrary forcing functions. The matrix displacement method is applied to each finite element in the idealized structure. A "wave front" direct solution technique is employed to give accurate results in a minimum of computer time. The analysis solution output includes geometry plots, nodal displacements, element stresses, and nodal forces.

ITCHVALVE and FORFUN

The Westinghouse proprietary computer code ITCHVALVE was used to perform the transient hydraulic analysis for the pressurizer safety and relief valve piping system. This program uses the Method of Characteristics approach to generate fluid parameters as a function of time. One-dimensional fluid flow calculations applying both the implicit and emplicit characteristic methods are performed. Using this approach the piping network is input as a series of single pipes. The network is generally joined together at one or more places by two- or three-way junctions. Each of the single pipes has associated with it friction factors, angles of elevation, and flow areas.

The computer program possesses special provisions to allow analysis of valve opening and closing situations.

Fluid acceleration inside the pipe generates reaction forces on all segments of the line that are bounded at either end by an elbow or bend. Reaction forces resulting from fluid pressure and momentum variations are calculated. These forces can be expressed in terms of the fluid properties available from the transient hydraulic analysis performed using program ITCHVALVE.

Unbalanced forces are calculated for each straight segment of pipe from the pressurizer to the relief tank using program FORFUN. The time-histories of these forces are stored on tape to be used for the subsequent structural analysis by Westinghouse using the FIXFM3 and WESDYN2 proprietary computer programs for the pressurizer safety and relief lines.

ITCHVALVE and FORFUN were compared with test data. Piping load data has been generated from the tests conducted by EPRI at the Combustion Engineering Test Facility. Pertinent tests simulating dynamic opening of the safety valves for representative commercial upstream environments were carried out. The resulting downstream piping loadings and responses were measured. Upstream environments for particular valve opening cases of importance, which envelope the commercial scenarios, are:

1. Cold water discharge followed by steam - steam between the pressure source and the loop seal - cold loop seal between the steam and the valve,

2. Hot water discharge followed by steam - steam between the pressure source and the loop seal - hot loop seal between the steam and the valve,

3. Steam discharge - steam between the pressure source and the valve.

Specific thermal hydraulic and structural analyses have been completed for the Combustion Engineering Test Configuration.

The applicability of the ITCHVALVE and FORFUN computer programs for calculating the fluid-induced loads on the piping of the pressurizer safety and relief valves has been demonstrated. For a more detailed description of ITCHVALVE and FORFUN see Reference 7.

ANSYS

ANSYS is a general purpose finite element program with structural and heat transfer capabilities. ANSYS was used for structural and thermal analysis of the replacement steam generators. The code is a commercial software product.

References for Section B.3

1. Deleted by Revision 23.

2. L. T. Gesinski, "Fuel Assembly Safety Analysis for Combined Seismic and Loss-of-Coolant Accident", WCAP-7950, Westinghouse Electric Corporation (July, 1972).

3. Dingwell, I. W. and Bradshaw, R. T., "Static, Thermal, Dynamic Pipe Stress Analysis Operating Manual," Arthur D. Little, Inc.

4. Greenstadt, J., "The Determination of the Characteristic Roots of a Matrix by the Jacobi Method," Chapter 7 of Mathematical Methods for Digital Computers, John Wiley, New York, (1959).

5. Bordelon, F. M., "A Comprehensive Space-Time Dependent Analysis of Loss of Coolant," (SATAN-IV Digital Code), WCAP 7750, Westinghouse Electric Corporation (August 1971).

6. Logcher, R. D., and Flachsbart, B. B., "ICES STRUDL-II, The Structural Design Language Frame Analysis," MIT-ICES-R68-91, Volume 1, Massachusetts Institute of Technology (November 1968).

7. Duquesne Light Company to NRC submittal concerning NUREG-0737, Item II.D.1. Pressurizer Safety and Relief Line Piping and Support Evaluation, dated June 24, 1983.

TABLES FOR APPENDIX B

Table B.1-1

STRUCTURES AND SYSTEMS REQUIRING
DESIGN FOR SEISMIC LOADING

The following Seismic Category I structures and components are designed to resist the seismic loading described in Appendix B:

STRUCTURES

Containment Structure

- Reinforced Concrete Substructure
- Reinforced Concrete Superstructure
- Reinforced Concrete Interior Shields and Walls
- Steel Plate Liner
- Piping, Duct, and Electrical Penetrations and Shield Wall
- Personnel Access Hatch
- Equipment Access Hatch

Cable Vault and Cable Tunnel

Pipe Tunnel to Containment from Auxiliary Building

Main Steam Valve Area

Pump Room below Main Steam Valve Area

Safeguards Areas

Safeguards and Main Steam Valve Area Ventilation Rooms

Primary Auxiliary Building

- Reinforced Concrete Substructure
- Steel Superstructure

Fuel Building

- Reinforced Concrete Substructure
- Steel Superstructure
- Spent Fuel Storage Racks
- Fuel Handling Trolley Support Structure

Duct Lines and Manholes to Intake Structure and Diesel Generator Building

Table B.1-1 (CONT'D)

STRUCTURES AND SYSTEMS REQUIRING
DESIGN FOR SEISMIC LOADING

Portions of Service Building

Main Control Room
Emergency Switchgear and Relay Room
Battery Rooms
Cable Tray Area in Service Building
Cable Tunnel
Air Conditioning Equipment Room for Control Room
Diesel Generator Building
Primary Grade Water Pump Room (adjacent to diesel enclosure)
River Water Pumps and Engine-Driven Fire Pump Intake Structure
Waste Gas Storage Area
Coolant Recovery Tank Structure
Demineralized Water Storage Tank Enclosure and Mat
Refueling Water Tank Mat
Caustic Tank Mat (note: Caustic Tank retired in place)
Quench Spray Chemical Addition Building

<u>SYSTEMS AND COMPONENTS</u>

Containment Isolation Valves - Containment Isolation Valves and Associated Piping

Reactor Coolant System

Steam Generators
Steam Generator Supports
Reactor Coolant Pumps
Reactor Coolant Pump Supports
Reactor Coolant Pump Oil Collection System
Pressurizer and Pressurizer Heaters
Pressurizer Support
Top Segment of Pressurizer Thermal Insulation
Pressurizer Safety Valves Inlet Piping Insulated Enclosures
Reactor Vessel
Reactor Core Support Structure
Reactor Control Rod Guide Structure
Fuel Assemblies
Control Rod and Drive Shaft Assemblies
Incore Instrumentation Thimbles
Reactor Vessel Supports and Neutron Shield Tank
Control Rod Drive Mechanisms
Reactor Coolant Piping, Valves, and Supports
Reactor Coolant Bypass Piping, Valves, and Supports
Pressurizer Surge Line
Pressurizer Spray Lines, Valves, and Supports
Pressurizer Safety and Relief Valves Piping

Table B.1-1 (CONT'D)

STRUCTURES AND SYSTEMS REQUIRING
DESIGN FOR SEISMIC LOADING

Safety Injection System

Accumulators and Supports
Boron Injection Tank
Low Head Safety Injection Pumps and Piping
All Other Piping, Valves, and Supports

Containment Depressurization System

Quench Spray Subsystems
Refueling Water Storage Tank
Quench Spray Pumps
Chemical Addition Tank (retired in place)
Quench Spray Chemical Injection Pumps (retired in place)
All Piping, Valves, and Supports Associated with and Connecting above Components (portions retired in place)

Recirculation Spray Subsystems
Recirculation Spray Pumps and Piping
Recirculation Spray Heat Exchangers
Reactor Containment Sump and Screens
All Other Piping, Valves, and Supports

Containment Vacuum and Leakage Monitoring System

Open Pressure Taps up to and Including Capped Tubing Outside Containment

Chemical and Volume Control System

Boric Acid Tanks
Boric Acid Transfer Pumps
Boric Acid Blender
Charging/Safety Injection Pumps
Regenerative Heat Exchanger
Nonregenerative Heat Exchanger
Reactor Coolant Filter
Volume Control Tank
Seal Water Heat Exchanger
Seal Water Filter
Seal Water Injection Filters
Excess Letdown Heat Exchanger
Piping, Valves, and Supports Associated with above Components

Residual Heat Removal System

Residual Heat Removal Pumps

Table B.1-1 (CONT'D)

STRUCTURES AND SYSTEMS REQUIRING
DESIGN FOR SEISMIC LOADING

Residual Heat Exchangers
All Piping, Valves, and Supports

Component Cooling System

Primary Plant Component Cooling Water Heat Exchangers
Primary Plant Component Cooling Water Pumps
Component Cooling Surge Tank
Piping, Valves, and Supports Associated with above Components and Following:

Lines to and from Residual Heat Exchangers and Residual Heat Removal Pump Seal Coolers
Lines to and from Fuel Pool Heat Exchangers
8 In., 18 In., and 24 In. Headers and in Lines to and from Components not Listed above up to and including Second Automatic Isolation Valve

Fuel Pool Cooling System

Fuel Pool Pumps
Fuel Pool Heat Exchangers
Piping, Valves, and Supports Associated with above components

River Water System

River Water Pumps
All River Water Piping, Valves, and Supports to Seismic Category I Components

Sample System

Primary Coolant and Blowdown Sample Lines to and including Containment Isolation Valve Outside Containment

Fire Protection System

Engine Drive Fire Pump and Line with Associated Valves and Supports to River Water System

Fuel Handling System

Manipulator Crane in Containment
Movable Platform with Hoist in Fuel Building
Fuel Handling Trolley in Fuel Building
Fuel Transfer Tube with Blind Flange
Reactor Cavity Seal (installed position)
Refueling Cavity Cofferdam in Containment

Table B.1-1 (CONT'D)

STRUCTURES AND SYSTEMS REQUIRING
DESIGN FOR SEISMIC LOADING

Auxiliary Steam and Air Removal System

Containment Isolation Valves and Piping in between

Vent and Drain System

Containment Isolation Valves and Piping in between

Ventilation and Air Conditioning

Supplementary Leak Collection and Release System
Containment Purge System Isolation Valves and
Duct Work Between Valves
River Water Pump Area Ventilation System
Diesel Generator Building Ventilation System
Air Conditioning System for Control Room Area
Ventilation Vent Stack

Main Steam System

Steam Piping from Main Steam Lines to Turbine Driven
Steam-Generator Auxiliary Feedpump
Main Steam Piping from Steam Generators to and
including Main Steam Nonreturn Valve, including
Trip Valves

Feedwater System

Primary Plant Demineralized Water Storage Tank
Steam Generator Auxiliary Feedpumps
Following Piping, Valves and Supports:
From Primary Plant Demineralized Water Storage Tank
to Steam Generator Auxiliary Feedpumps
From Steam Generator Auxiliary Feedpumps
to Steam Generator Feed Lines
Steam Generator Feed Lines Inside Containment to and
including First Containment Isolation Valve Outside
Containment

Steam Generator Blowdown System

Steam Generator Blowdown Piping, Valves, and Supports
Inside Containment to and including Containment
Isolation Valves Outside Containment and Piping/Components
Up to the First Pipe Support in the Cable Vault (El. 722'6")

Table B.1-1 (CONT'D)

STRUCTURES AND SYSTEMS REQUIRING
DESIGN FOR SEISMIC LOADING

Gaseous Waste Disposal System

Charcoal Delay Beds
Decay Tanks
Compressors
Surge Tank
Waste Gas Piping, Valves, and Supports from the Charcoal Delay Beds inlet and bypass valve up to and including Isolation Valve Downstream of Decay Tanks

Process Radiation Monitoring System

Recirculation Spray Heat Exchanger River Water Monitors
Fuel Building Ventilation Exhaust Monitors
Containment Purge Exhaust Monitors

Area Radiation Monitoring System

Main Control Room Monitor
Main Control Room Radiation Monitoring System Cabinets

Instrumentation and Control

All Instrumentation and Control Required During a Design Accident or Controlled Shutdown
Reactor Protection
Safety Injection
Containment Isolation Phases A and B
Feedwater Isolation
Steam Line Isolation
Steam Generator Water Level Control System

Electrical System

Emergency Diesel Generators
Station Service Batteries and Chargers for Seismic Category I Components
Vital Bus and Vital Bus Inverters
480 V Emergency Unit Substation for Seismic Category I Components
4160 V Emergency Station Service Switchgear for Seismic Category I Components
Control Panel Boards for Seismic Category I Components
D-C Switchboards and Distribution Panel for Seismic Category I Components
Emergency Motor Control Centers

Table B.1-1 (CONT'D)

STRUCTURES AND SYSTEMS REQUIRING
DESIGN FOR SEISMIC LOADING

Motors for Seismic Category I Components
Emergency Shutdown Panel
Main Control Board
Heat Tracing of Seismic Category I Piping and Tanks
All Cable to Components, Instruments, and Controls Required During a Design Accident or Controlled Shutdown

Emergency Diesels

Fuel Oil Day Tanks
Fuel Oil Transfer Pumps
Underground Fuel Oil Storage Tanks
Emergency Diesel Generator Cooling System
Fuel Oil Piping, Valves, and Supports to Emergency Diesel Generators, except Fill Lines for Underground Fuel Oil Storage Tanks

Hydrogen Analyzers

Hydrogen Analyzers (0-10%) including Tubing, Valves and Supports inside the Cable Vault Areas

Miscellaneous

Reactor Containment Crane (not operating)
Fuel Building Crane (not operating)
Reactor Cavity Seal Storage Rack (vertical & horizontal positions)
Reactor Containment Jib Cranes (not operating) - CR-42 and 44
Reactor Containment Auxiliary Crane (not operating)

(See also, Table B.3-1 for NSSS Fluid Systems/Components)

Table B.1-2

DISTRIBUTION OF DAMPING VALUES (PERCENT OF CRITICAL)

Mode	Contribution from Flexural Motion		Contribution from Rigid Body Motion in Subgrade		Summation of Modal Damping
	Containment Structure	Internal Structure	Translation	Rocking	
1	0.11	0.0089	6.69	3.62	10.4
2	---	---	34.7	2.1	36.8
3	1.32	0.62	0.017	0.58	2.5
4	0.57	1.36	1.10	0.73	3.8

Table B.1-3

DAMPING FACTORS

	Stress Level		Type and Condition of Structure of Component	Percentage of Critical Damping
1.	Low stress, well below proportional limit. Stresses below 0.25 yield point	a.	Steel, reinforced concrete; no cracking and no slipping at joints	0.5 to 1.0
2.	Working stress limited to 0.5 yield point.	a.	Welded steel, well reinforced concrete (with only slight cracking)	2.0
		b.	Reinforced concrete (with considerable cracking)	2.0
		c.	Bolted steel	5.0
3.	At or just below yield point	a.	Welded steel	5.0
		b.	Reinforced concrete	5.0
		c.	Bolted steel	7.0
4.	Vital piping systems			0.5 OBE * 1.0 DBE

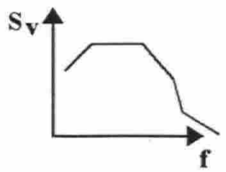
Total systems damping for structures including damping from motion in subgrade is assigned to be 5.0 percent for the Operational Basis Earthquake and 7.0 percent for the Design Basis Earthquake.

* Refer to Section B.2.1.12 regarding the use of alternate damping values in ASME Code Case N-411.

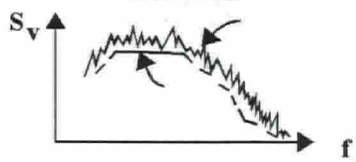
Table B.1-4

COMPARISON OF SHEAR AND OVERTURNING MOMENT
IN EXTERNAL STRUCTURE OF THE REACTOR CONTAINMENT OBE

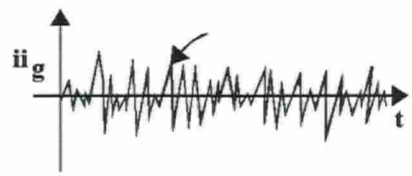
I — **INPUT A**



II — **INPUT B**



III — **INPUT C**



HEIGHT ABOVE MAT	I: SHEAR IN KIPS SRSS	I: OVER-TURNING MOMENT K. FT. SRSS	II: SHEAR IN KIPS SRSS	II: SHEAR IN KIPS SRSS + ABS÷2	II: OVERTURNING MOMENT K. FT. SRSS	II: OVERTURNING MOMENT K. FT. SRSS + ABS÷2	III: SHEAR IN KIPS	III: OVERTURN MOMENT K. FT.
172.50	1100	0	1546	1962	0	0	1915	0
127.10	1560	0	2527	3144	70389	89330	3021	87000
106.75	2560	81800	3265	3989	121813	153310	3785	147976
86.40	3320	149300	3884	4693	188256	234486	4306	225001
66.05	3980	230300	4438	5380	267295	329988	4588	312628
45.70	4530	322300	4984	6073	357608	439471	4680	405994
25.35	5090	425800	5574	6799	459032	563056	4623	500393
top of mat	5680	541300	6240	7600	572463	701416	4623	591302

A: BVPS 1 job response spectrum for 5 percent damping

B: Unsmoothed response spectrum envelopes the design response spectrum A.

C: Artificial time-history whose response spectrum for 5 percent damping is denoted by B.

Table B.2-4

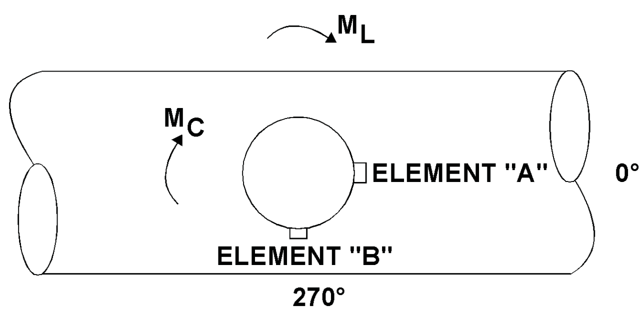
COMPARISON OF PITRUST WITH FRANKLIN
INSTITUTE PROGRAM CYLNOZ AND HAND CALCULATION

Source of Stress	Franklin Institute Corrected Values	Output from PITRUST	Hand Calculation
Circumferential			
p(Normal)	395.	399.	399.99
p(Bending)	1875.	1883.	1887.3
Mc(Normal)	35.85	35.85	36.06
Mc(Bending)	364.7	366.6	354.3
ML(Normal)	79.05	79.66	79.54
ML(Bending)	90.52	80.57	79.42
Axial			
p(Normal)	813.	812.	814.8
p(Bending)	812.3	827.	810.6
Mc(Normal)	91.79	105.	95.45
Mc(Bending)	158.8	160.	158.8
ML(Normal)	37.06	37.0	37.12
ML(Bending)	117.9	105.	103.85
Shear Stress by Mτ	6.63	6.63	6.63
Shear Stress by Vc	106.1	106.1	106.1
Shear Stress by VL	106.1	106.1	106.1

Table B.2-5

COMPARISON OF PITRUST WITH REFERENCE 1 RESULTS

Location & Cause	PITRUST Results	Exp. Results (Ref. 1)
Element "A"		
Longt. Moment		
Circumf. Stress	20438.9 psi	20000 psi (Fig. 16,
Axial Stress	26292.6 psi	25000 psi Ref. 1)
Element "B"		
Circumf. Moment		
Circumf. Stress	22016.2 psi	24000 psi (Fig. 15,
Axial Stress	13105.8 psi	13000 psi Ref. 1)



Reference:

1. J. M. Corum and N. L. Greenstreet "Experimental Elastic Stress Analysis of Cylinder to Cylinder Shell Models and Comparison with Theoretical Predictions", International Conference on Structural Mechanics in Reactor Technology, Berlin, Preprints Vol. 3, Part G (1971).

Table B.2-6

COMPARISON OF PILUG COMPUTER PROGRAM OUTPUT
WITH HAND CALCULATIONS

Test Problem: Run Pipe 0.D.=17 in.; Run Pipe Thickness=0.812 in.
Axial Length of LUG-12 in.;
Width of LUG along Circumf=3 in.
Loads: P-3399 lb; Vc=-1788 lb; Vl=2478 lb;
Mc=81834 in-lb; Ml=103320 in-lb
Mt=76284 in-lb

Stress in Circumferential Direction (all units are in psi):

Fig.	B	Stress From Hand Calculation	PILUG Computer Output	Remarks
3C	.5485	387	330	Membrane Stress due to P
IC	.326	2165	2160	Bending Stress due to P
3A	.294	671	629	Membrane Stress due to Mc
IA	.388	18976	19904	Bending Stress due to Mc
3B	.467	3014	2961	Membrane Stress due to M_L
IB	.416	6143	5969	Bending Stress due to M_L

Stress in Axial Direction:

Fig.	B	Stress From Hand Calculation	PILUG Computer Output	Remarks
4C	.4447	683	690	Membrane Stress due to P
2C	.4632	773	792	Bending Stress due to P
4A	.294	1897	1864	Membrane Stress due to Mc
2A	.550	6357	5942	Bending Stress due to Mc

Table B.2-6 Cont.

COMPARISON OF PILUG COMPUTER PROGRAM OUTPUT
WITH HAND CALCULATIONS

Fig.	B	Stress From Hand Calcul.	Computer Output	Remarks
4B	.467	2365.	2328	Membrane Stress due to M_L
2B	.582	4989.7	4842	Bending Stress due to M_L

Shear Stress:

		1304.8	1304.8	Shear Stress due to $M\tau$
		-366.99	-366.99	Shear Stress due to Vc
		127.15	127.15	Shear Stress due to V_L

Table B.2-7

SUMMARY OF COMPARISON OF SAVAL COMPUTER OUTPUT WITH HAND CALCULATION AS-DESIGNED CONDITION

Variable	Hand Calculation	SAVAL
Valve & Nozzle Weight (lb)	714.09	714.09
Run Pipe Stiffness (in-lb/Rad.)	37,950,000	38,083,056
Nozzle Stiffness (in-lb/Rad.)	1,120,000,000	1,120,619,008
Equivalent Stiffness (in-lb/Rad.)	36,700,000	36,831,376
Nat. Rotational Frequency (cps)	22.0	22.19
Time Ratio	1.11	1.11
Dynamic Load Factor	1.22	1.22
Circumferential Moment x D.L.F. (in-lb)	314,760	314,760
Net Vertical Force (lb)	14,423	14,436
Nozzle Stress (psi)	6,600	6,597 *
PITRUST Stress Intensity (psi)	62,782	62,789 *
Stress Intensification Factor	5.6	5.608
Equation (9) Stress (psi)	36,651.9	36,681 *

*Allowable Stress=1.2 Sh=1.2 (15,490) = 18,588 psi

Table B.2-8

SUMMARY OF COMPARISON OF SAVAL COMPUTER
OUTPUT WITH HAND CALCULATION
REINFORCED CONDITION (1 1/4" PAD)

Variable	Hand Calculation	SAVAL
Valve & Nozzle Weight (lb)	714.09	714.09
Run Pipe Stiffness (in-lb/Rad.)	181,500,000	181,490,256
Nozzle Stiffness (in-lb/Rad.)	1,120,000,000	1,120,619,008
Equivalent Stiffness (in-lb/Rad.)	156,200,000	156,193,808
Natural Rotational Frequency (cps)	45	45.7
Time Ratio	2.27	2.29
Dynamic Load Factor	1.13	1.13
Circumferential Moment x D.L.F. (in-lb)	291,540	291,540
Net Vertical Force (in-lb)	14,436	14,436
Nozzle Stress (psi)	6,144	6,144
PITRUST Stress Intensity (psi)	17,046	17,046
Stress Intensification Factor	2.59	2.59
Equation (9) Stress (psi)	16,186	16,200

Table B.2-10

PEAK BROADENING - SAMPLE CALCULATION

An example of the method of data calculation described in Section B.2.2.1 is given below.

a. Number of modes within peak = 5, B = 1.0 percent, Wn = 10 Hz if broadening is ±20 percent (Wn), mode spread = 10 percent

Wn, Hz	TR
8.	2.775
9.	5.241
10.	50.010
11.	4.737
12.	2.270

$$\text{Ratio } \frac{\text{TR SRSS}}{\text{TR PEAK}} = K = \frac{50.634}{50.010} = 1.012$$

b. Number of modes = 9, B = 1.0 percent, Wn = Hz

if peak broadening is ±20 percent (Wn), mode spread = 5 percent

Wn, Hz	TR
8.	2.775
8.5	3.597
9.	5.241
9.5	10.069
10.	50.010
10.5	9.560
11.	4.737
11.5	3.094
12.	2.270

$$\text{Ratio } \frac{\text{TR SRSS}}{\text{TR PEAK}} = K = \frac{52.717}{50.010} = 1.054$$

Table B.2-11

1G FLAT RESPONSE
DYNAMIC FACTOR STUDY

		Maximum Dynamic Moment		Maximum Static Moment					
Model Beam	Fundamental Frequency	Sum	Moment, In-Lb	Load Type	Moment, In-Lb	Location	Ks/c	Ks/u	Ka/u
Cantilever	1	*SRSS	620,000	Concentrated	700,000	Fixed end	.89	.89	.99
		Absolute	694,900	Uniform	700,000				
Simple-Simple	1	SRSS	179,000	Concentrated	348,000	Midspan	.51	1.03	1.07
		Absolute	186,000	Uniform	174,000				
Fixed-Fixed	1	SRSS	103,000	Concentrated	174,000	Fixed end	.59	.89	.97
		Absolute	112,000	Uniform	116,000				
SF - No overhang	1	SRSS	152,000	Concentrated	261,000	Fixed end	.58	.87	.97
		Absolute	169,000	Uniform	174,000				
SF - 16% overhang	1.34	SRSS	83,200	Concentrated	162,000	Fixed end	.51	.75	1.03
		Absolute	114,000	Uniform	111,000				
SF - 33% overhang	1.04	SRSS	57,000	Concentrated	77,400	Fixed end	.74	.74	1.15
		Absolute	890,000	Uniform	77,200				
SF - 50% overhang	.62	SRSS	152,000	Concentrated	174,000	Simple support	.87	.87	1.01
		Absolute	176,000	Uniform	174,000				

*Square root of the sum of the squares

Table B.2-12

MODAL DENSITY, N*
DYNAMIC FACTOR STUDY

Mode No.	Cantilever Freq.,Hz	Fixed Fixed Freq., Hz	Simple Fixed Freq., Hz	Simple Simple Freq., Hz	Simple Fixed 33% Overhang Freq.
1	1.0	1.0	1.0	1.0	1.0
2	5.8	2.7	3.2	3.8	2.9
3	15.3	4.9	6.3	8.2	6.5
4	28.0	7.5	10.2	13.6	8.4
5	43.2	10.2	14.0	19.5	13.3
6	59.6	-	-	-	-

* Modal density is 1 based on a ±10% criterion. Resultant modes are spaced such that any adjacent mode does not fall within ±10% of the object mode.

Table B.2-13

AMPLIFIED RESPONSE
DYNAMIC FACTOR STUDY

Model Beam	First Mode	Dynamic Load High	Dynamic Load Low	Maximum Dynamic Moment: Summation Technique	Maximum Dynamic Moment: Moment, In-Lb	Maximum Dynamic Moment: Location	Maximum Static Moment *Uniform Load, In-Lb	Ks/u	Ka/u
	g_o	g_{max}	g_c						
SF - 33% overhang	f_o	Δf	f_c						
Model 6a	.10	2.87	.33	SRSS	20,000	Fixed end	222,000	.09	.13
	.70	3-4	20	Absolute	30,000	Fixed end			
Model 6B	.10	2.87	.33	SRSS	148,000	Fixed end	222,000	.67	.71
	1.0	3-4	20	Absolute	157,000	Fixed end			
Model 6C	2.87	2.87	.33	SRSS	102,000	Simple	222,000	.45	.53
	3.3	3-4	20	Absolute	118,000	Simple			
Model 6D	.40	2.87	.33	SRSS	22,000	Fixed end	31,000	.71	1.03
	10	3-4	20	Absolute	32,000	Fixed end			
Model 6E	.33	2.87	.33	SRSS	20,000	Fixed end	25,700	.78	1.05
	20	3-4	20	Absolute	27,000	Fixed end			
Model 6F	.30	2.87	.33	SRSS	18,000	Fixed end	23,400	.77	1.07
	33	3-4	20	Absolute	25,000	Fixed end			

*g_{max} (peak acceleration) if f_o (fundamental frequency) $< f_p$ (peak frequency); g = acceleration at f_o if $f_o > f_p$

Table B.2-15

TAC2D - SAMPLE PROBLEM

PROBLEM DESCRIPTION

The problem is to determine the transient temperature distribution in a right circular cylinder which is initially at temperature T_1. At time t = 0, the temperature at the surface is instantaneously changed to T_2 and maintained at that value. Mathematically the problem is defined by the following equations:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial t}\right)+\frac{\partial^2 T}{\partial z^2}=\frac{1}{K}\frac{\partial T}{\partial t};0\leq r\leq R \quad (1)$$

$$T(r,z,0) = T_1 \quad (2)$$

$$T(R,z,t) = T_2 \quad (3)$$

$$T(r,\pm\frac{L}{2},t) = T_2 \quad (4)$$

where:
t = time

r = radius

z = axial coordinate

R = outside radius of the cylinder

L = length of the cylinder and the diffusivity

and

$$K=\frac{k}{\rho c} \quad (5)$$

where:
K = thermal diffusivity

k = thermal conductivity

p = density

c = specific heat capacity.

Table B.2-15 (CONT'D)

TAC2D - SAMPLE PROBLEM

For the specific problem analyzed, the following numerical values were used:

R = 12.0 in.	ρc = 40.0 Btu/ft^3-F
L = 48.0 in.	T_1 = 0.0 F
K = 20.0 Btu/hr-ft-F	T_2 = 1000.0 F

ANALYTICAL SOLUTION

It may be shown(1) that the solution is

$$\frac{T-T_1}{T_2-T_1}=1-f(z,t)\ g(r,t) \tag{6}$$

$$f(z,t)=\frac{4}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{(2n-1)}\cos\ (2n-1)\frac{\pi z}{L}e^{-k\frac{(2n-1)\pi}{L}^{2}t} \tag{7}$$

$$g\ (r,t)=2\sum_{n=1}^{\infty}\frac{J_{o}\frac{r}{R}\gamma_m}{\gamma_m J_1(\gamma_m)}e^{-k\gamma_m^2 t} \tag{8}$$

where the Υ_m are the roots of

$$J_0\ (\gamma_m) = 0 \tag{9}$$

The roots γ_m of Equation 9 and the functions J_1 (γ_m) have been tabulated(2) and need not be computed.

From the definition of the problem there is symmetry about the geometry center of the cylinder and the origin of the coordinate system taken at that point, as is reflected in the boundary conditions, Equations (3) and (4).

Table B.2-15 (CONT'D)

TAC2D - SAMPLE PROBLEM

NUMERICAL SOLUTION WITH TAC2D

A cross section of the problem model for TAC2D is shown in Figure B.2-8. The model extends only to the axial midplane of the cylinder where an adiabatic boundary may be specified by virtue of the symmetry condition described above. The solid material is represented by one material block. The boundary conditions on the four external boundaries are described by Coolants 1 through 4 (specifically, Coolant Blocks 1 through 4). The material and coolant thermal parameters, as specified by the input functions, are given in tabular form. All coolants have the standard specific heat of 1.0 Btu/lb-F. Coolants 1 and 2, which represent the adiabatic external boundaries, have the standard heat transfer coefficient of 10^{-6} Btu/hr-ft^{2}-F and the standard flow rate of 10^{6} lb/hr.

INPUT THERMAL PARAMETER FUNCTIONS FOR TAC2D SAMPLE PROBLEM

1.	Material Thermal Parameters:	SPECI (X) = 40.0
		RCONI (X) = 20.0
		ACONI (X) = 20.0
2.	Coolant Thermal Parameters:	H3A (X) = 1.0E+08
		FL03A (X) = 1.0E+08
		TIN3A (X) = 1460.0
		H4A (X) = 1.0E+08
		FL04A (X) = 1.0E+08
		TIN4A (X) = 1460.0

References:

1. H. S. Carslaw and J. C. Jaeger, Conduction of Heat in Solids, Oxford at the Clarendon Press, p. 227. (1959)

2. E. Jahnke and F. Ende, "Tables of Functions," Dover Publications, Fourth Edition, (1945)

Table B.2-16

ASAAS SAMPLE PROBLEM

PROBLEM DESCRIPTION

An infinitely long, solid, circular cylinder is subjected to cosθ and cos 2θ pressure distributions. A closed-form solution of this problem may be obtained by the A.E.H. Love Methodology[1].

The pertinent parameters of the cylinder are:

Dimension and Properties	Loading and Boundary Conditions
$r_o = a$	$\sigma_r = p_o (\cos\theta + \cos 2\theta)$
$\ell = a$	$\sigma_{r\theta} = p_o \sin\theta$
$E = 10 \times 10^6$ psi	$u_z = o$
$\nu = 0.25$	$u_r \big\|_{r=o} = 0$
$a = 1$ inch	$p_o = 10000$ psi

The following solution can be verified by consulting Reference 1.

$$\sigma_r = p_o (r \cos\theta + \cos 2\theta) \quad (1)$$

$$\sigma_\theta = p_o\left[3r\cos\theta + \frac{2r^2 - a^2}{a^2}\cos 2\theta\right] \quad (2)$$

$$\sigma_{r\theta} = P_o\left[r \sin\theta + \frac{r^2 - a^2}{r^2}\sin 2\theta\right] \quad (3)$$

$$u_r = p_o\left[\frac{(1-4\nu)(1+\nu)r^2}{2Ea}\cos\theta + \frac{1+\nu}{E}\left(r - \frac{2\nu r^3}{3a^2}\right)\cos 2\theta\right] \quad (4)$$

$$u_\theta = P_o\left\{\frac{(5-4\nu)(1+\nu)r^2}{2Ea}\sin\theta + \frac{1+\nu}{E}\left[\left(1 - \frac{2\nu}{3}\right)\frac{r^3}{a^2} - r\right]\sin 2\theta\right\} \quad (5)$$

References:

1. A. E. H. Love, A Treatise on the Mathematical Theory of Elasticity, Dover Publications, New York, N.Y., (1944)

Table B.2-17

VESSEL PENETRATION ANALYSIS - SAMPLE PROBLEM

PROBLEM DESCRIPTION

A thin-walled cylindrical vessel is subjected to applied loads from a rigid cylindrical attachment. A solution of this problem may be obtained by the use of Reference 1.

The pertinent parameters of the problem are:

Dimensions	Loading
T = .375 in	P = 1,000 lb
r = 8.0 in	Mc = 1,000 in-lb
Rm = 19.1875 in	M_L = 1,000 in-lb
	M_T = 1,000 in-lb
	V_c = 1,000 in-lb
	V_L = 1,000 in-lb

Reference:

1. K. R. Wichman, A. G. Hopper, J. L. Mershon, "Local Stresses in Spherical and Cylindrical Shell Due to External Loadings," Welding Research Council Bulletin 107 (December 1968)

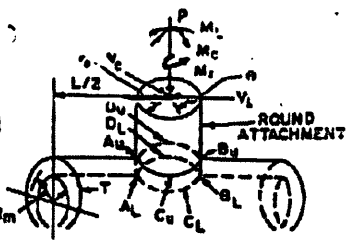
Table B.2-18

SUMMARY OF MANUAL CALCULATIONS

Computation Sheet for Local Stresses in Cylindrical Shells

1. Applied Loads*
   - Radial load, P 1000 lb.
   - Circ. Moment, M_c 1000 in. lb.
   - Long. Moment, M_L 1000 in. lb.
   - Torsion Moment, M_T 1000 in. lb.
   - Shear Load, V_c 1000 lb.
   - Shear Load, V_L 1000 lb.
2. Geometry
   - Vessel thickness, T = .375 in.
   - Attachment radius, r_o = 8.0 in.
   - Vessel radius, R_m = [illegible] in.
3. Geometric Parameters
   - $\gamma = \frac{R_m}{T}$ = 51.167
   - $\beta = (0.875)\frac{r_o}{R_m}$ = .3648
   - Stress Concentration due to:
     - a) membrane load, K_n = 1.0
     - b) bending load, K_b = 1.0

*NOTE: Enter all force values in accordance with sign convention



CYLINDRICAL SHELL

From Fig.	Read curves for	Compute absolute values of stress and enter result	A_U	A_L	B_U	B_L	C_U	C_L	D_U	D_L
3C	$\frac{N\phi}{P/R_m}$ = 1.78	$K_n\left(\frac{N\phi}{P/R_m}\right)\cdot\frac{P}{R_mT}$ = 247	-247	-247	-247	-247	-247	-247	-247	-247
1C	$\frac{M\phi}{P}$ = .023	$K_b\left(\frac{M\phi}{P}\right)\cdot\frac{6P}{T^2}$ = 981	-981	+981	-981	+981	-981	+981	-981	+981
3A	$\frac{N\phi}{M_c/R_m^2\beta}$ = 1.41	$K_n\left(\frac{N\phi}{M_c/R_m^2\beta}\right)\cdot\frac{M_c}{R_m^2\beta T}$ = 28					-28	-28	+28	+28
1A	$\frac{M\phi}{M_c/R_m\beta}$ = .057	$K_b\left(\frac{M\phi}{M_c/R_m\beta}\right)\cdot\frac{6M_c}{R_m\beta T^2}$ = 360					-360	+360	+360	-360
3B	$\frac{N\phi}{M_L/R_m^2\beta}$ = 2.63	$K_n\left(\frac{N\phi}{M_L/R_m^2\beta}\right)\cdot\frac{M_L}{R_m^2\beta T}$ = 52	-52	-52	+52	+52				
1B or 1B-1	$\frac{M\phi}{M_L/R_m\beta}$ = .0067	$K_b\left(\frac{M\phi}{M_L/R_m\beta}\right)\cdot\frac{6M_L}{R_m\beta T^2}$ = 41	-41	+41	+41	-41				
Add algebraically for summation of ϕ stresses, σ_ϕ =			-1321	+723	-1135	+745	-1616	+1066	-840	+902
4C	$\frac{N_x}{P/R_m}$ = 4.4	$K_n\left(\frac{N_x}{P/R_m}\right)\cdot\frac{P}{R_mT}$ = 612	-612	-612	-612	-612	-612	-612	-612	-612
2C	$\frac{M_x}{P}$ = .0088	$K_b\left(\frac{M_x}{P}\right)\cdot\frac{6P}{T^2}$ = 375	-375	+375	-375	+375	-375	+375	-375	+375
4A	$\frac{N_x}{M_c/R_m^2\beta}$ = 5.0	$K_n\left(\frac{N_x}{M_c/R_m^2\beta}\right)\cdot\frac{M_c}{R_m^2\beta T}$ = 99					-99	-99	+99	+99
2A	$\frac{M_x}{M_c/R_m\beta}$ = .0235	$K_b\left(\frac{M_x}{M_c/R_m\beta}\right)\cdot\frac{6M_c}{R_m\beta T^2}$ = 143					-143	+143	+143	-143
4B	$\frac{N_x}{M_L/R_m^2\beta}$ = 1.52	$K_n\left(\frac{N_x}{M_L/R_m^2\beta}\right)\cdot\frac{M_L}{R_m^2\beta T}$ = 30	-30	-30	+30	+30				
2B or 2B-1	$\frac{M_x}{M_L/R_m\beta}$ = .81	$K_b\left(\frac{M_x}{M_L/R_m\beta}\right)\cdot\frac{6M_L}{R_m\beta T^2}$ = 61	-61	+61	+61	-61				
Add algebraically for summation of x stresses, σ_x =			-1078	-206	-896	-268	-1229	-193	-795	-281
Shear stress due to Torsion, M_T		$\tau_{\phi x} = \tau_{x\phi} = \frac{M_T}{2\pi r_o^2 T}$ = 7	+7	+7	+7	+7	+7	+7	+7	+7
Shear stress due to load, V_c		$\tau_{x\phi} = \frac{V_c}{\pi r_o T}$ = 106	+106	+106	-106	-106				
Shear stress due to load, V_L		$\tau_{x\phi} = \frac{V_L}{\pi r_o T}$ = 106					-106	-106	+106	+106
Add algebraically for summation of shear stresses, τ =			+113	+113	-99	-99	-99	-99	+113	+113

Table B.2-19

SUMMARY OF COMPUTER CALCULATIONS

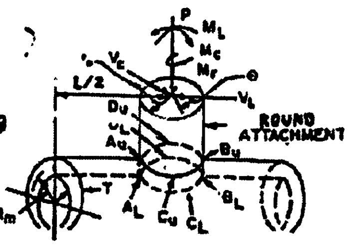
Computation Sheet for Local Stresses in Cylindrical Shells

1. Applied Loads*
   - Radial load, P 1000 lb.
   - Circ. Moment, Mc 1000 in. lb.
   - Long. Moments, ML 1000
   - Torsion Moment, MT 1000 in. lb.
   - Shear Load, Vc 1000 lb.
   - Shear Load, VL 1000 lb.
2. Geometry
   - Vessel thickness, T .375 in.
   - Attachment radius, r_o 8.0 in.
   - Vessel radius, Rm [illegible] in.

3. Geometric Parameters
   - $\gamma = \frac{R_m}{T}$ 51.167
   - $\beta = (0.875)\frac{r_o}{R_m}$ .3698

Stress Concentration due to:
a) membrane load, Kn 1.0
b) bending load, Kb 1.0

*NOTE: Enter all force values in accordance with sign convention



CYLINDRICAL SHELL

From Fig.	Read curves for	Compute absolute values of stress and enter result	Au	AL	Bu	BL	Cu	CL	Du	DL
			STRESSES – If load is opposite that shown, reverse signs shown							
3C	$\frac{N\phi}{P/R_m}$ = 1.77	$K_n\left(\frac{N\phi}{P/R_m}\right)\cdot\frac{P}{R_mT}$ = 246	-246	-246	-246	-246	-246	-246	-246	-246
1C	$\frac{M\phi}{P}$ .022	$K_b\left(\frac{M\phi}{P}\right)\cdot\frac{6P}{T^2}$ = 937	-937	+937	-937	+937	-937	+937	-937	+937
3A	$\frac{N\phi}{M_c/R_m^2\beta}$ 1.41	$K_n\left(\frac{N\phi}{M_c/R_m^2\beta}\right)\cdot\frac{M_c}{R_m^2\beta T}$ = 28					-28	-28	+28	+28
1A	$\frac{M\phi}{M_c/R_m\beta}$ .059	$K_b\left(\frac{M\phi}{M_c/R_m\beta}\right)\cdot\frac{6M_c}{R_m\beta T^2}$ = 357					-357	+357	+357	-357
3B	$\frac{N\phi}{M_L/R_m^2\beta}$ 2.62	$K_n\left(\frac{N\phi}{M_L/R_m^2\beta}\right)\cdot\frac{M_L}{R_m^2\beta T}$ = 52	-52	-52	+52	+52				
1B or 1B-1	$\frac{M\phi}{M_L/R_m\beta}$ .0066	$K_b\left(\frac{M\phi}{M_L/R_m\beta}\right)\cdot\frac{6M_L}{R_m\beta T^2}$ = 40	-40	+40	+40	-40				
Add algebraically for summation of ϕ stresses, σ_ϕ =			-1275	+679	-1091	+703	-1568	+1020	-798	+362
4C	$\frac{N_x}{P/R_m}$ 4.4	$K_n\left(\frac{N_x}{P/R_m}\right)\cdot\frac{P}{R_mT}$ = 614	-614	-614	-614	-614	-614	-614	-614	-614
2C	$\frac{M_x}{P}$ .0087	$K_b\left(\frac{M_x}{P}\right)\cdot\frac{6P}{T^2}$ = 373	-373	+373	-373	+373	-373	+373	-373	+373
4A	$\frac{N_x}{M_c/R_m^2\beta}$ 5.0	$K_n\left(\frac{N_x}{M_c/R_m^2\beta}\right)\cdot\frac{M_c}{R_m^2\beta T}$ = 99					-99	-99	+99	+99
2A	$\frac{M_x}{M_c/R_m\beta}$ [illegible]	$K_b\left(\frac{M_x}{M_c/R_m\beta}\right)\cdot\frac{6M_c}{R_m\beta T^2}$ = 142					-142	+142	+142	-142
4B	$\frac{N_x}{M_L/R_m^2\beta}$ 1.53	$K_n\left(\frac{N_x}{M_L/R_m^2\beta}\right)\cdot\frac{M_L}{R_m^2\beta T}$ = 30	-30	-30	+30	+30				
2B or 2B-1	$\frac{M_x}{M_L/R_m\beta}$ .01	$K_b\left(\frac{M_x}{M_L/R_m\beta}\right)\cdot\frac{6M_L}{R_m\beta T^2}$ = 62	-62	+62	+62	-69				
Add algebraically for summation of x stresses, σ_x =			-1079	-209	-895	-280	-1228	-198	-796	-284
Shear stress due to Torsion, MT		$\tau_{\phi x} = \tau_{x\phi} = \frac{M_T}{2\pi r_o^2 T}$ 7	+7	+7	+7	+7	+7	+7	+7	+7
Shear stress due to load, Vc		$\tau_{x\phi} = \frac{V_c}{\pi r_o T}$ 106	+106	+106	-106	-106				
Shear stress due to load, VL		$\tau_{x\phi} = \frac{V_L}{\pi r_o T}$ 106					-106	-106	+106	+106
Add Algebraically for summation of shear stresses, τ =			+113	+113	-99	-99	-99	-99	+113	+113

Table B.2-20

SHELL 1 - SAMPLE PROBLEM

PROBLEM DESCRIPTION

A long thin-walled circular cylinder is subjected to a constant internal pressure distribution. A solution of this problem may be obtained by the use of Reference (1).

The pertinent parameters of the cylinder are:

Dimension and Properties	Loading and Boundary Conditions
R = 25 in	$Fr_{Z=0} = M_{Z=0} = \delta z_{Z=0} = 0$
1 = 20 in	
t = 0.5 in	$Fr_{z=1} = M_{z=1} = Fz_{z=1} = 0$
$E = 28 \times 10^6$ psi	
v = 0.3	$P_i = 75$ psi

The following solution can be verified by consulting Reference 1.

$$\delta_R = \frac{pR^2}{Et} \quad (1)$$

$$\sigma_\theta = \frac{pR}{t} \quad (2)$$

PROBLEM RESULTS

Variable	Exact	Shell 1
δ_R	3.348×10^{-3} in	3.342×10^{-3} in
σ_θ	3,750 psi	3,750 psi

Reference:

1. R. J. Ruark, Formulas for Stress and Strain, McGraw-Hill Book Company, Fourth Ed., New York, N.Y., (1965)

Table B.2-21

STRESS ANALYSIS OF SHELLS OF REVOLUTION
SAMPLE PROBLEM

PROBLEM DESCRIPTION

Dimensions and Properties	Loading and Boundary Conditions
R = 25 in	$F_{R\,z=0} = M_{z=0} = \delta z_{z=0} = 0$
1 = 20 in	
t = 0.5 in	$F_{R\,z=1} = M_{z=1} = Fz_{z=1} = 0$
$E = 28 \times 10^6$ psi	
$\upsilon = 0.3$	$P_{OUT} = 75$ psi

The following solution can be verified by consulting Reference 1.

$$\delta_R = \frac{pR^2}{E_t} \quad (1)$$

$$\sigma_\theta = \frac{pR}{t} \quad (2)$$

PROBLEM RESULTS

Variable	Exact	Stress Analysis of Shells of Rev.
δ_R	3.348×10^{-3} in	3.361×10^{-3} in
σ_θ	3,750 psi	3,764 psi

Reference:

1. R. J. Roark, Formulas for Stress and Strain, McGraw-Hill Book Company, Fourth Ed., New York, N.Y., (1965)

Table B.2-22

EXACT AND COMPUTER STRESSES FOR HOLLOW CYLINDER OF FIGURE B.2-13

PROBLEM DESCRIPTION

The pertinent parameters of the cylinder are:

σ_i	= 5000 psi	r_i	= 1 in.
σ_o	= 10,000 psi	r_o	= 2 in.
E	= 30 x 10^6 psi	υ	= 0.3

PROBLEM RESULTS

Stress at Element Center (psi)

Element	σ_r EXACT	σ_r SAAS	σ_θ EXACT	σ_θ SAAS
1	-7400	-7329	-15,933	-16,032
2	-9490	-9473	-13,844	-13,840

Table B.2-23

ST-167 - SAMPLE PROBLEM

The equations of motion to be solved are:

$$\begin{bmatrix} 2m & -\frac{1}{2}ml & \frac{1}{2}ml \\ -\frac{1}{2}ml & \frac{1}{3}ml^2 & 0 \\ \frac{1}{2}ml & 0 & \frac{1}{3}ml^2 \end{bmatrix} \begin{Bmatrix} \ddot{\chi} \\ \ddot{\phi} \\ \ddot{\ell} \end{Bmatrix} + \begin{bmatrix} 6k & -2kl & 2kl \\ -2kl & -2kl^2 & 0 \\ 2kl & 0 & 2kl^2 \end{bmatrix} \begin{Bmatrix} \chi \\ \phi \\ \ell \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \\ 0 \end{Bmatrix}$$

Results of hand calculations of this problem are as follows:

1. The three eigenvalues, W^2, are: 2.535898 $\frac{K}{m}$

   6.0 $\frac{K}{m}$

   9.464102 $\frac{K}{m}$

2. The three eigenvectors are:

$$\begin{bmatrix} -1.577350 & 0 & -0.422650 \\ -1 & 1 & -1 \\ 1 & 1 & 1 \end{bmatrix}$$

For comparison, the results of computer program ST-167 solution are as follows:

1. The three eigenvalues are: 2.536577 $\frac{K}{m}$

   6.006006 $\frac{K}{m}$

   9.499567 $\frac{K}{m}$

2. The comparable eigenvectors are:

$$\begin{bmatrix} -1.578928 & 0 & -0.423072 \\ -1 & 1 & -1 \\ 1 & 1 & 1 \end{bmatrix}$$

Table B.2-24

LOAD COMBINATIONS AND ACCEPTANCE CRITERIA FOR PRESSURIZER SAFETY AND RELIEF VALVE PIPING AND SUPPORTS - UPSTREAM OF VALVES

Combination	Plant/System Operating Conditions	Load Combination	Piping Allowable Stress Intensity
I	Normal	N	1.0 S_h
2	Upset	N + OBE + SOT_U	1.2 S_h
3	Emergency	N + SOT_E	1.8 S_h
4	Faulted	N + MS/FWPB or DBPB + SSE + SOT_F	2.4 S_h
5	Faulted	N + LOCA + SSE + SOT_F	2.4 S_h

NOTES:

(1) See Table B.2-26 for SOT definitions and other load abbreviations.

(2) The bounding number of valves (and discharge sequence if setpoints are significantly different) for the applicable system operating transient defined in Table B.2-26 should be used.

(3) Verification of functional capability is not required, but allowable loads and accelerations for the safety-relief valves must be met.

(4) Use SRSS for combining dynamic load responses.

(5) Combinations to be made with components of applicable moments.

Table B.2-25

LOAD COMBINATIONS AND ACCEPTANCE CRITERIA
FOR PRESSURIZER AND RELIEF VALVE PIPING
AND SUPPORTS - SEISMICALLY DESIGNED DOWNSTREAM PORTION

Combination	Plant/System Operating Conditions	Load Combination	Piping Allowable Stress Intensity
1	Normal	N	1.0 S_h
2	Upset	N + SOT_U	1.2 S_h
3	Upset	N + OBE + SOT_U	1.8 S_h
4	Emergency	N + SOT_E	1.8 S_h
5	Faulted	N + MS/FWPB or DBPB + SSE + SOT_F	2.4 S_h
6	Faulted	N + LOCA + SSE + SOT_F	2.4 S_h

NOTES:

(1) This table is applicable to the seismically designed portion of downstream non-Category I piping (and supports) necessary to isolate the Category I portion from the non-seismically designed piping response, and to assure acceptable valve loading on the discharge nozzle.

(2) See Table B.2-26 for SOT definitions and other load abbreviations.

(3) The bounding number of valves (and discharge sequence if setpoints are significantly different) for the applicable system operating transient defined in Table B.2-26 should be used.

(4) Verification of functional capability is not required, but allowable loads and accelerations for the safety-relief valves must be met.

(5) Use SRSS for combining dynamic load responses.

(6) Combinations to be made with components of applicable moments.

Table B.2-26

DEFINITIONS OF LOAD ABBREVIATIONS

N	=	Sustained loads during normal plant operation
SOT	=	System operating transient
SOT_U	=	Relief valve discharge transient
SOT_E	=	Safety valve discharge transient(1)
SOT_F	=	Maximum of $SOT_{U\ and\ SOTE}$; or transition flow
OBE	=	Operating basis earthquake
SSE	=	Safe shutdown earthquake
MS/FWPB	=	Main steam or feedwater pipe break
DBPB	=	Design basis pipe break
LOCA	=	Loss-of-coolant accident
S_h	=	Basic material allowable stress at maximum (hot) temperature

---

(1) Although certain nuclear steam supply systems design transients (for example, loss of load) which are classified as upset conditions may actuate the safety valves, the extremely low number of actual safety valve actuations in operating pressurizer water reactors justifies the emergency condition from the ASME design philosophy and a stress analysis viewpoint. However, if actuation of safety valves would occur, a limitation must be placed to shut down the plant for examination of system integrity.

Table B.2-27

LOAD COMBINATIONS AND ALLOWABLES FOR
QA CATEGORY I PIPING 2" DIAMETER AND SMALLER

Load combinations and allowable stress limits for small bore piping are shown in the following table. Either equation set (A) or (B) must be met in its entirety.

		Load Combination	Allowable
(A)			
	1)	P + D	S_H
	2)	P + D + SRSS{E, H}	1.2 S_H
	3a)	T + R + A	S_A
	3b)	P + D + T + R + A	$S_A + S_H$
	4)	P + D + SRSS{E', H}	1.8 S_H
(B)			
	1)	P + D	S_H
	2)	P + D + SRSS{(E + A), H}	1.2 S_H
	3a)	T + R	S_A
	3b)	P + D + T + R	$S_A + S_H$
	4)	P + D + SRSS{E', H}	1.8 S_H

Notes:

1. For definitions of terms, see Table B.2-31.
2. Equation 3a or 3b may be utilized.
3. For piping attached to containment penetrations, see Table B.2-28.
4. For piping that is supported from the containment wall, the effects of R' shall be considered.

Table B.2-28

LOAD COMBINATIONS AND ALLOWABLES FOR QA CATEGORY I PIPING 2" DIAMETER AND SMALLER ATTACHED TO CONTAINMENT PENETRATIONS (CONTAINMENT PRESSURE BOUNDARY)

Load combinations and allowable stress limits for small bore piping attached to containment penetrations (containment pressure boundary) are shown in the following table. Either equation set (A) or (B) must be met in its entirety.

		Load Combination	**Allowable**
(A)			
	1)	P + D	S_H
	2)	P + D + SRSS{E, H}	1.2 S_H
	3a)	T + R' + A	S_A
	3b)	P + D + T + R' + A	$S_A + S_H$
	4)	P + D + SRSS{(E' + A'), H}	1.8 S_H
(B)			
	1)	P + D	S_H
	2)	P + D + SRSS{(E + A), H}	1.2 S_H
	3a)	T + R'	S_A
	3b)	P + D + T + R'	$S_A + S_H$
	4)	P + D + SRSS{(E' + A'), H}	1.8 S_H

Notes:

1. For definitions of terms, see Table B.2-31.
2. Equation 3a or 3b may be utilized.

Table B.2-29

LOAD COMBINATIONS AND ALLOWABLES FOR QA CATEGORY I SMALL BORE PIPING SUPPORTS (2" PIPE DIAMETER AND LESS)

Load combinations and allowable stress limits for small bore pipe supports are shown in the following table.

	Load Combination	Allowable Normal Stress	Allowable Shear Stress
1)	D + T + R	0.6 S_Y	0.4 S_Y
2)	D + T + R + SRSS{(E + A) + H}	0.8 S_Y	0.52 S_Y
3)	D + T + R + SRSS(E' + H)	0.8 S_Y	0.52 S_Y

Notes:

1. For definitions of terms, see Table B.2-31.
2. Member allowable normal and shear stress are shown in the above table. For load combinations which include seismic loading, allowable normal and shear stresses have been increased by 33% as shown in the table. However, the AISC code check for compression and buckling remains unchanged.
3. For supports on active components, see Table B.2-30.

Table B.2-30

LOAD COMBINATIONS AND ALLOWABLES FOR QA CATEGORY I SMALL BORE PIPING (2" DIAMETER AND LESS) EQUIPMENT NOZZLES AND ACTIVE COMPONENT SUPPORTS

Load combinations and allowable stress limits for equipment nozzles and supports on active components of small bore piping are shown in the following table.

	Load Combinations	**Allowables**
1)	D + T + R	
2)	D + T + R + SRSS{(E + A) + H}	See Notes Below
3)	D + T + R + SRSS{(E' + A') + H}	

Notes:

1. For definitions of terms, see Table B.2-31.
2. For equipment nozzles the loads are limited to vendor approved allowables or are accepted by comparison with the loading used in the equipment qualification or by alternate analysis.
3. For active component supports the allowables are the same as for pipe supports, see Table B.2-29. The active component qualification includes the effect of the above loadings.
4. In Equation 2, replace R with R' for equipment or active components on piping that either penetrate the containment or is attached to the containment.

Table B.2-31

DEFINITION OF TERMS

The following table provides the definitions of the terms for Tables B.2-27, B.2-28, B.2-29 and B.2-30.

D	-	Sustained mechanical loads, including deadweight of piping, components, contents, and insulation.
P	-	Longitudinal pressure stress.
T	-	Loads due to Thermal Expansion of the system in response to the system fluid operating temperature.
R	-	Loads induced in the piping due to the thermal growth of equipment and/or structures to which the piping is connected.
R'	-	Loads induced in the piping due to the growth of the Reactor Containment Building as a result of BVPS-1 plant faulted conditions.
E	-	Loads due to OBE Seismic Inertia.
E'	-	Loads due to DBE Seismic Inertia.
A	-	Loads induced in the piping due to OBE Anchor Movements including Orbital Motion (1/2 range of moments to be used).
A'	-	Loads induced in the piping due to DBE Anchor Movements including Orbital Motion (1/2 range of moments to be used).
H	-	Loads induced in the piping due to fluid transient loads.
S_H	-	Allowable material stress at maximum operating temperature.
S_C	-	Allowable material stress at room temperature (70°F).
S_A	-	Allowable material stress range for expansion stress = $f(1.25S_C + 0.25S_H)$.
f	-	Stress range reduction factor due to cyclic conditions (= 1 for 7000 cycles and less).
S_Y	-	Yield Strength of material.

Table B.3-1

NSSS FLUID SYSTEMS COMPONENT SEISMIC CATEGORY LIST

COMPONENT REACTOR COOLANT SYSTEM	SEISMIC CATEGORY
Reactor Vessel	I
Full Length CRDM Housing	I
Reactor Coolant Pump Assembly	I
Reactor Coolant Pump Casing	I
Reactor Coolant Pump Internals	I
Reactor Coolant Pump Motor	I
Steam Generator	I
RC Stop Valves	I
Pressurizer	I
Reactor Coolant Piping, Fittings and Fabrication	I
Surge Pipe, Fittings and Fabrication	I
Pressurizer Sprayline	I
Loop Bypass Line	I
RC Narrow Range Temperature Detectors Thermowells	I
RC Wide Range Temperature Detectors Thermowells	I
Safety Valves	I
Relief Valves	I
Valves to RC System Boundary	I
Piping to RC System Boundary	I

Table B.3-1 (CONT'D)

NSSS FLUID SYSTEMS COMPONENT SEISMIC CATEGORY LIST

COMPONENT	
CHEMICAL AND VOLUME CONTROL SYSTEM	
Regenerative HX	I
Letdown HX	I
Mixed Bed Demineralizer	II
Cation Bed Demineralizer	II
Reactor Coolant Filter	I
Volume Control Tank	I
Charging Pumps	I
Seal Water Injection Filter	I
Letdown Orifices	I
Excess Letdown HX	I
Seal Water HX	I
Boric Acid Tanks	I
Boric Acid Filter	I
Boric Acid Transfer Pump	I
Boric Acid Blender	I
Boric Acid Batching Tank	II
RESIDUAL HEAT REMOVAL LOOP	
Residual Heat Removal Pump	I
Residual Heat Exchanger	I
Residual Heat Removal Piping	I
Residual Heat Removal Valves	I
SAFETY INJECTION SYSTEM	
Accumulators	I
High Head SIS Pumps	I
Low Head SIS Pump	I
Boron Injection Tank	I

Table B.3-2

SUMMARY OF SEISMIC REQUIREMENTS

ANALYSIS	LIMITS	TYPE OF ANALYSIS
DBE + NORMAL + DBA	NLSF, Permanent Deformation Permitted (Faulted Condition)	Dynamic + Blowdown
DBE + NORMAL	NLSF, Permanent Deformation Permitted (Faulted Condition)	Dynamic
OBE + NORMAL	Applicable Code Stresses (Upset Condition)	Dynamic

DBE — The "Design Basis Earthquake" is that earthquake giving rise to the maximum vibratory ground acceleration at a site which can be reasonably predicted from geologic and seismic evidence.

OBE — The "Operating Basis Earthquake" is that earthquake which is of sufficient probability of occurrence to require its resulting ground accelerations at the site to be considered for operational loadings.

NORMAL — Those normal operation occurrences which are expected frequency and regularly in the course of power operation, refueling, maintenance, or maneuvering of the plant.

DBA — The "Design Basis Accident" is the double ended rupture of the largest pipe in the reactor coolant system.

NLSF — No loss of safety function. Permanent deformation permitted to the extent there is no loss of safety function.

DYNAMIC — A response spectrum analysis or other dynamic analysis or test.

BLOWDOWN — Loads caused by the DBA which are to be combined with the seismic loads for safety equipment.

Table B.3-3

STRESS LIMITS FOR VARIOUS LOAD COMBINATIONS

	LOAD COMBINATION	STRESS LIMIT (NOTE 1)
1.	Normal (deadweight, thermal and pressure)	Normal Conditions
2.	Normal and Operational Basis Earthquake	Upset Condition
3.	Normal and Design Basis Earthquake	Faulted Condition
4.	Normal and Pipe Rupture	Faulted Condition
5.	Normal, Design Basis Earthquake, and Pipe Rupture	Faulted Condition

Note 1: Definition of Terms from Summer 1968 Addenda to the ASME Boiler and Pressure Vessel Code, Section III.

The Operating Condition categories are defined as follows:

1. Normal Condition - Any condition in the course of system startup, operation in the design power range and system shutdown, in the absence of Upset, Emergency or Faulted Conditions.

2. Upset Condition - Any deviations from Normal Conditions anticipated to occur often enough that design should include a capability to withstand the conditions without operational impairment. The Upset Condition includes those transients caused by a fault in a system component requiring its isolation from the system, transients due to a loss of load or power and any system upset not resulting in a forced outage. The estimated duration of an Upset Condition shall be included in the Design Specifications. The Upset Conditions include the effect of the specified earthquake for which the system must remain operational or must regain its operational status.

3. Emergency Condition - Any deviations from normal conditions which require shutdown for correction of the conditions or repair of damage in the system. The conditions have a low probability of occurrence but are included to provide assurance that no gross loss of structural integrity will result as a concomitant effect of any damage developed in the system. The total number of postulated occurrences for such events shall not exceed twenty-five (25).

Table B.3-3 (CONT'D)

STRESS LIMITS FOR VARIOUS LOAD COMBINATIONS

4. Faulted Condition - Those combinations of conditions associated with extremely low probability postulated events whose consequences are such that the integrity and operability of the nuclear energy system may be impaired to the extent where considerations of public health and safety are involved. Such considerations require compliance with safety criteria as may be specified by jurisdictional authorities. Among the Faulted Conditions may be a specified earthquake for which safe shutdown is required.

Table B.3-4

LOADING CONDITIONS AND STRESS LIMITS

A. PRESSURE VESSELS

where:

P_m	=	primary general membrane stress intensity
PL	=	primary local membrane stress intensity
PB	=	primary bending stress intensity
Q	=	secondary stress intensity
S_m	=	stress intensity from ASME B&PV Code, Section III, Nuclear Vessels
Sy	=	minimum specified material yield (ASME B&PV Code, Section III, Table N-421 or equivalent)

STRESS LIMIT		LOAD COMBINATION
1. Normal Condition	(a)	Pm ≤ Sm
	(b)	Pm (or PL) + PB ≤1.5*Sm
	(c)	Pm (or PL) + PB ± Q ≤3.0*Sm
2. Upset Condition	(a)	Pm ≤ Sm
	(b)	Pm (or PL) + PB ≤1.5*Sm
	(c)	Pm (or PL) + PB + Q ≤3.0*Sm
3. Emergency Condition	(a)	Pm ≤1.2*Sm or Sy } whichever is larger
	(b)	Pm (or PL) + PB ≤ 1.5*(1.2*Sm) or 1.5*Sy] } whichever is larger
4. Faulted Condition		Design Limit Curves as discussed in the text and as shown in Figure B.3-3 and Figure B.3-4 (4)

Table B.3-4

LOADING CONDITIONS AND STRESS LIMITS

B. EQUIPMENT SUPPORTS

	STRESS LIMIT	LOAD COMBINATION
1.	Normal Condition	Working Stresses or Applicable Factored Load Design Values
2.	Upset Condition	Working Stresses or Applicable Factored Load Design Values
3.	Emergency Condition	Within Yield After Load Redistribution
4.	Faulted Condition	Permanent Deflection of Supports Limited to Maintain Supported Equipment Within Design Limit Curves as discussed in the text and attached

NOTES

Note 1: The limits on local membrane stress intensity (PL ≤1.5*Sm) and primary membrane plus primary bending stress intensity (Pm (or PL) + PB ≤1.5*Sm) need not be satisfied at a specific location if it can be shown by means of limit analysis or by tests that the specified loadings do not exceed 2/3 of the lower bound collapse load as per paragraph N-417.6(b) of the ASME B&PV Code, Section III, Nuclear Vessels.

Note 2: In lieu of satisfying the specific requirements for the local membrane (PL ≤1.5*S) or the primary plus secondary stress intensity (PL + PB + Q≤3*Sm) at a specific location, the structural action may be calculated on a plastic basis and the design will be considered to be acceptable if shakedown occurs, as opposed to continuing deformation, and if the deformations which occur prior to shakedown do not exceed specified limits, as per paragraph N-417.69a) (2) of the ASME B&PV Code, Section III, Nuclear Vessels.

Note 3: The limits on local membrane stress intensity (PL≤1.5*Sm) and primary membrane plus primary bending stress intensity (PM (or PL) + PB≤1.5*Sm) need not be satisfied at a specific location if it can be shown by means of limit analysis or by tests that the specified loadings do not exceed 120 percent of 2/3 of the lower bound collapse load as per paragraph N-417.10(c) of the ASME B&PV Code, Section III, Nuclear Vessels.

Note 4: As an alternate to the design limit curves which represent a pseudo plastic instability analysis, a plastic instability analysis may be performed in some specific cases considering the actual strain-hardening characteristics of the material, but with yield strength adjusted to correspond to the tabulated value at the appropriate temperature in Table N-424 or N-425, as per paragraph N-417.11(c) of the ASME B&PV Code, Section III, Nuclear Vessels. These specific cases will be justified on an individual basis.

Table B.3-5

EQUIPMENT CODE AND CLASSIFICATION LIST

Component	Code	Code Class	Addenda	Case
Reactor Coolant System				
Replacement Reactor Vessel Closure Head	ASME III, 89	1	None	2142-1 2143-1 N-525 N-474-1
Reactor Vessel	ASME III, 68	A	Thru W 68	1332-3 1335-2 1336
Full Length CRDM Housing	ASME III, 68	A	Thru W 69	NA
Steam Generator (tube side)	ASME III, 89	1	NA	N-20-3 N-71-16 N-411-1 N-474-2
(shell side)	ASME III, 89	2	NA	NA
Reactor Coolant Stop Valves	ASME III, 68	A (Body & Bonnet)	Thru W 68	NA
Pressurizer	ASME III, 65	A	Thru W 66	1401
Reactor Coolant Piping, Fittings, and Fabrication**	ANSI B31.1, 67	NA	NA	NA
Surge Pipe, Fittings, and Fabrication	ANSI B31.1, 67	NA	NA	NA
Loop Bypass Line	ANSI B31.3, 67	NA	NA	NA
Reactor Coolant Narrow Range Temperature Detector Thermowells	ASME III	1	NA	NA
Reactor Coolant Wide Range Temperature Detector Thermowells	ANSI B31.1, 67	NA	NA	NA

TABLE B.3-5 (CONT'D)

EQUIPMENT CODE AND CLASSIFICATION LIST

Component	Code	Code Class	Addenda	Case
Reactor Coolant System (Cont'd)				
Safety Valves	ASME III	NA	Thru S 68	NA
Relief Valves	ASA 16.5	NA	NA	NA
Valves to Reactor Coolant System Boundary	ASA 16.5, MSS-SP 66A	NA	NA	NA
Pressurizer Relief Tank	ASME VIII	NA	Thru S 68	NA
CRDM Head Adapter Plugs	ASME III, 89	NA	NA	NA
Reactor Coolant Pump Standpipe Orifice	No Code	NA	NA	NA
Reactor Coolant Pump Standpipe	ASME VIII	NA	NA	NA
Reactor Coolant Pump				
Casing	ASME III, 68	A	NA	1355
Main Flange	ASME III, 68	A	NA	NA
Thermal Barrier	ASME III, 68	A	NA	NA
No. 1 Seal Housing	ASME III, 68	A	NA	NA
No. 2 Seal Housing	ASME III, 68	A	NA	NA
Pressure Retaining Bolting	ASME III, 68	A	NA	NA
Remaining Parts	ASME III, 68	A	NA	NA
Reactor Coolant Pump Motor	NEMA MG1, 67	NA	NA	NA
Shaft Coupling	NEMA MG, 67	NA	NA	NA
Armature	NEMA MG1, 67	NA	NA	NA
Flywheel	ASTM A-533, Grade B Class 1 + E Spec Provisions	NA	NA	NA
Motor Bolting	NEMA MG1	NA	NA	NA
Upper Oil Cooler	TEMA***	C	NA	NA
Lower Oil Cooler	TEMA***	C	NA	NA

TABLE B.3-5 (CONT'D)

EQUIPMENT CODE AND CLASSIFICATION LIST

Component	Code	Code Class	Addenda	Case
Chemical and Volume Control System				
Regenerative Heat Exchanger	ASME III	C	NA	NA
Nonregenerative Heat Exchanger	ASME III	C Tube Side	NA	NA
	ASME VIII	C Shell Side	NA	NA
Mixed Bed Demineralizers	ASME III	C	NA	NA
Reactor Coolant Filter	ASME III	C	NA	NA
Volume Control Tank	ASME III	C	NA	NA
Seal Water Heater Exchanger	ASME III	C Tube Side	NA	NA
	ASME VIII	C Shell Side	NA	NA
Excess Letdown Heat Exchanger	ASME III	C Tube Side	NA	NA
	ASME VIII	C Shell Side	NA	NA
Chemical Mixing Tank	ASME VIII	(Not Stamped)	NA	NA
Cation Bed Demineralizer	ASME III	C	NA	NA
Boric Acid Tanks	ASME VIII	(Not Stamped)	NA	NA
Batching Tank	ASME VIII	(Not Stamped)	NA	NA
Seal Water Injection Filters	ASME III	C	NA	NA
Boric Acid Filter	ASME III	C	NA	NA
Seal Water Filter	ASME III	C	NA	NA
Resin Fill Tank	ASME VIII	(Not Stamped)	NA	NA
Valves	USAS B31.1**		NA	NA
	ANSI B16.5		NA	NA

TABLE B.3-5 (CONT'D)

EQUIPMENT CODE AND CLASSIFICATION LIST

Component	Code	Code Class	Addenda	Case
Emergency Core Cooling System				
Accumulators	ASME III	C	NA	NA
Boron Injection Tank	ASME III	C	NA	NA
Valves	ASA B16.5 or		NA	NA
	MSS-SP-66	NA	NA	NA
Residual Heat Removal System				
Residual Heat Exchangers - Tube Side	ASME III	C	NA	NA
Shell Side	ASME VIII	NA	NA	NA
Residual Heat Removal Valves	ANSI B31.1	NA	NA	NA
	ASME III, 68	NA	NA	NA
	ASA B16.5	NA	NA	NA
Residual Heat Removal Pumps	No Code	NA	NA	NA

** Under USAS B31.1 - 1967, there is no Class as such.
*** TEMA - Tubular Exchangers Manufacturer's Association

NA - Not Applicable

Table B.3-13

WESTDYN TEST PROBLEM NUMBER 1
A.D. Little Hand Calc./WESTDYN Comparison

Object: Determine the ability of WESTDYN to calculate the deflections of a cantilever with a concentrated load and moment at the free end. See if transfer matrices develop any round off error when this same cantilever is divided into five sections with ten members each.

Result: Deflections and moments along the cantilever from WESTDYN were compared to those found in a hand calculation by I. W. Dingwell (A. D. Little Company). The comparisons indicate that WESTDYN computations are accurate, and that no round off error is incurred through the 50 transfers from member to member.

Deflections (in Inches)	Point	A.D. Little Hand Calc.	WESTDYN Case A	WESTDYN Case B
D_y	10	-.103	-.103	-.103
	20	-.303	-.301	-.301
	30	-.534	-.531	-.531
	40	-.733	-.729	-.729
	50	-.836	-.832	-.832
Moments (Inch-Kips)				
M_z	0	25,000.0	25,000.4	24,000.4
	25	0.0	0.0	-.80
	50	25,000.0	25,000.0	25,000.0

Case A = Cantilever split into 5 sections - 1 or 2 members per section

Case B = Cantilever split into 5 sections - 10 members per section

Table B.3-14

WESTDYN TEST PROBLEM NUMBER 2
AISC/WESTDYN COMPARISON

Object: To determine if WESTDYN correctly calculates piping loads and support reactions for a straight pipe under distributed (deadweight) loading.

Result: The forces and moments obtained from WESTDYN were compared to the answers given on Page 2-133, example 37 of the AISC Manual of Steel Constuction.

	Fy		Mz	
Position	AISC	West	AISC	West
1 BEG	38.00	37.95	0.	0.
2 END	60.30	62.05	-14,460.	-14,462.
2 BEG	62.00	60.26	14,460.	14,462.
3 END	39.70	39.74	-2,148.	-2,145.
3 BEG	-4.00	-4.02	2,148.	2,145.
4 END	4.00	4.02	-6,960.	-6,963.
4 BEG	55.80	55.80	6,960.	6,963.
5 END	-44.20	-44.20	0.	-3.
6 END	-3.30	-3.30	11,724.	11,655.
7 END	0.00	0.00	11,700.	11,720.
8 END	44.20	44.20	0.	0.

Table B.3-15

WESTDYN TEST PROBLEM NUMBER 3

Object: Determine the ability of WESTDYN to find thermal and deadweight loads and movements.

PARAMETERS:

1) Joint Coordinates - The coordinate system origin is located at the intersection of the tangents through node points 4 and 5.

Node Point	X (in.)	Y (in.)	Z (in.)
1	-108.3	-145.2	0.0
2	-108.3	-36.3	0.0
3	-72.0	0.0	0.0
4	-36.3	0.0	0.0
5	0.0	0.0	35.3
6	0.0	0.0	77.3

2) Physical Properties:

Diameter	= 7.288 in.
Thickness	= 0.241 in.
Bend Radius	= 36.3 in.
Unit Weight	= 2.581 lb/in.
ΔT	= 850 F
μ	= 0.300
E	= 24 x 10^6 psi
α	= 7.1565 x 10^{-6} in./in. F

TABLE B.3-15 (CONT'D)

WESTDYN TEST PROBLEM NUMBER 3
KELLOGG/MEC-21/WESTDYN THERMAL LOAD COMPARISON:

Forces (Kips And Inch-Kips)	Node Point 1			Node Point 6		
	Kellogg	MEC-21	WESTDYN	Kellogg	MEC-21	WESTDYN
F_x	-1.75	-1.74	-1.72	1.75	1.74	1.72
F_y	-1.71	-1.69	-1.68	1.71	1.69	1.68
F_z	-0.64	-0.64	-0.63	0.64	0.64	0.63
M_x	-56.04	-55.66	-55.24	95.04	93.90	93.59
M_y	14.40	14.50	14.20	-80.52	-80.01	-79.02
M_z	133.08	132.57	130.60	-63.36	-63.08	-62.52

MEC-21/WESTDYN THERMAL LOAD DEFLECTION COMPARISON:

Deflections (In Inches And Radians)	Node Point 1		Node Point 2		Node Point 3	
	MEC-21	WESTDYN	MEC-21	WESTDYN	MEC-21	WESTDYN
Dx	0.000	0.000	-0.517	-0.515	-0.322	-0.319
Dy	0.000	0.000	0.661	0.661	0.777	0.777
Dz	0.000	0.000	-0.242	-0.243	-0.407	-0.408
Rx	0.0000	0.000	-0.0029	-0.0028	0.0005	0.0005
Ry	0.0000	0.000	0.0026	0.0025	0.0025	0.0025
Rz	0.0000	0.000	-0.0052	-0.0050	-0.0074	-0.0073
	Node Point 4		Node Point 5		Node Point 6	
Dx	-0.106	-0.102	0.059	0.062	0.000	0.000
Dy	0.483	0.484	0.075	0.077	0.000	0.000
Dz	-0.483	-0.483	-0.249	-0.249	0.000	0.000
Rx	0.0027	0.0026	0.0031	0.0030	0.0000	0.000
Ry	0.0016	0.0016	-0.0023	-0.0022	0.0000	0.000
Rz	-0.0087	-0.0085	-0.0042	-0.0042	0.0000	0.000

TABLE B.3-15 (CONT'D)

MEC-21/WESTDYN DEADWEIGHT LOAD COMPARISON:

	Node Point					
MEC-21	1	2	3	4	5	6
F_x kips	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036
F_y	-0.511	-0.230	-0.083	0.009	0.156	0.262
F_z	0.002	0.002	0.002	0.002	0.002	0.002
M_x inch-kips	0.797	-1.045	-1.128	-1.128	2.609	11.191
M_y	-0.476	-0.476	-0.393	-0.311	1.092	2.583
M_z	1.420	-2.540	1.090	2.404	0.127	0.127
D_x inches	0.000	0.001	0.007	0.007	0.002	0.000
D_y	0.000	0.000	-0.010	-0.019	-0.008	0.000
D_z	0.000	-0.007	-0.009	-0.005	-0.000	0.000
R_x radians	0.0000	-0.0001	-0.0003	-0.0003	-0.0003	0.0000
R_y	0.0000	-0.0001	-0.0001	-0.0001	-0.0001	0.0000
R_z	0.0000	-0.0001	-0.0003	-0.0002	-0.0000	0.0000
B31.1 Stress (psi)	186.	347.	191.	327.	353.	1,262.
WESTDYN						
F_x kips	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
F_y	-0.51	-0.28	-0.08	0.01	0.16	0.26
F_z	0.00	0.00	0.00	0.00	0.00	0.00
M_x inch-kips	-0.80	-1.04	-1.12	-1.12	2.58	11.15
M_y	-0.47	-0.47	-0.39	-0.31	1.09	2.58
M_z	1.40	-2.56	1.08	2.41	0.16	0.16
D_x inches	0.000	0.001	0.007	0.007	0.002	0.0000
D_y	0.000	0.000	0.010	0.020	0.009	0.0000

TABLE B.3-15 (CONT'D)

MEC-21/WESTDYN DEADWEIGHT LOAD COMPARISON:

WESTDYN	Node Point					
(CONT'D)	1	2	3	4	5	6
D_z	0.000	0.007	0.009	0.005	0.000	0.000
R_x radians	0.0000	0.0001	0.0003	0.0003	0.0003	0.0000
R_y	0.0000	0.0001	0.0001	0.0001	0.0001	0.0000
R_z	0.0000	0.0001	0.0003	0.0002	0.0000	0.0000

Results: A multi-plane pipe bend problem proposed by W. Hovgaard was used and compared with an M.W. Kellogg hand calculation and the MEC-21 computer code. This example problem was first proposed by W. Hovgaard to illustrate an algebraic method of calculating the stress in multi-plane pipe bends[1]. It has since been used as a benchmark in the piping industry.

In the first, a comparison of forces is made from two sources; the MEC-21/7094 piping flexibility analysis program[2], and the M.W. Kellogg general analytical method[3]. In the latter, the MEC-21 displacements and stresses are given.

Comparison shows a variation in forces, moments, deflections, and rotations of less than 5 percent from Kellogg and MEC-21 for both thermal and deadweight analyses.

References:

1. W. Hovgaard, "Stress in Three-dimensional Pipe Bends," Trans. ASME, Volume 57, paper FSP-57-12, pp. 401-416, (1935).

2. J. H. Grifin, "MEC-21/7094," LA-2229, Engineering and Equipment TID-4500 (31st Edition).

3. Design of Piping Systems, M. W. Kellogg Company, 2nd Edition, John Wiley & Sons, New York (1956).

Table B.3-16

WESTDYN TEST PROBLEM NUMBER 4

Object: Determine the ability of WESTDYN to calculate fre- quencies and influence coefficients.

FREQUENCIES IN ORDER:

Neubert Calc.	Neubert Meas.	WESTDYN
109.0	110	112.03
115.9	117	116.61
135.0	134	138.16
212.5	214	216.37
352.4	357	404.29
394.6	382	423.09
422.2	416	451.92
532.1	553	549.05
655.8	-	735.71
684.9	697	761.02
760.7	-	852.46
821.1	821	892.55
849.3	852	895.71
873.2	885	914.27
903.5	898	937.52
928.2	927	959.39
935.6	-	965.96
939.0	-	973.31

Table B.3-16 (CONT'D)

NEUBERT/WESTDYN COMPARISON OF INFLUENCE COEFFICIENTS:

Neubert Influence Coefficients x 10^5 in/lb

	Calculated	Measured		Calculated	Measured
1 x	0.820	0.822	1 z	0.133	0.115
2 x	0.835	0.810	2 z	0.925	0.89
3 x	0.310	0.330	2 z	0.914	0.947
4 x	0.311	0.295	4 z	0.134	0.124
5 x	0.740	0.740	5 z	0.305	0.260
6 x	1.304		6 z	0.305	
7 x	1.861		7 z	0.305	0.280
8 x	1.874	1.83	8 z	0.810	
9 x	1.891		9 z	1.486	
10 x	1.906	1.88	10 z	1.994	2.08
11 x	1.327		11 z	1.981	
12 x	0.740	0.655	12 z	1.967	2.05
13 x	0.740		13 z	1.466	
14 x	0.740		14 z	0.802	

WESTDYN Influence Coefficients x 10^5 in/lb

1 x	0.814	1 z	0.138
2 x	0.834	2 z	0.950
3 x	0.317	3 z	0.937
4 x	0.308	4 z	0.134
5 x	0.712	5 z	0.305
6 x	1.232	6 z	0.305
7 x	1.753	7 z	0.305

Table B.3-16 (CONT'D)

WESTDYN Influence Coefficients x 10^5 in/lb (Cont'd)

	Calculated	Measured		Calculated	Measured
8 x	1.768		8 z	0.792	
9 x	1.784		9 z	1.496	
10 x	1.798		10 z	1.984	
11 x	1.255		11 z	1.969	
12 x	0.712		12 z	1.955	
13 x	0.712		13 z	14.76	
14 x	0.712		14 z	0.734	

Results: The Neubert problem, a well documented three- dimensional frame problem, was used. Frequencies from WESTDYN were compared to those obtained by Neubert. Frequencies less than 200 cps varied by less than 2 percent. This variation increased as frequencies became larger, with variations up to 15 percent. It should be noted that at these higher frequencies, the frequencies which are closest do not necessarily represent the same mode.

In comparing influence coefficients, forces in the x and z directions were applied at Node Point 10. Variation from Neubert's results was less than 5 percent in all cases and usually much less.

Reference:

1. E. Neubert, "Dynamic Behavior of a Foundation-like Structure, Mechanical Impedance Method", ASME (1958).

Table B.3-17

WESTDYN TEST PROBLEM NUMBER 5

Object: Determine the ability of WESTDYN to calculate individual and cumulative modal response to shock spectra input. Combination by both absolute sum, and square root of the sum of the squares, is calculated for transverse displacements and bending moments in a lumped mass cantilever. Comparison is then made between WESTDYN, and hand calculations based on "Response of Structural Systems to Ground Shock", by D. Young, Yale University.

Results: The response given by WESTDYN agrees very well with that found by the hand calculations. The maximum deviations from Young are 0.4 percent for displacements, 1.5 percent for bending moments, for the absolute sums.

	Freq	Point 1	Point 2	Point 3	Point 4	Point 5
Hand Calc.	3.0	4.230	2.767	1.421	0.406	0.000
	17.6	-0.417	0.114	0.346	0.190	0.000
	46.7	0.065	-0.071	0.020	0.077	0.000
	81.5	-0.009	0.016	-0.025	0.025	0.000
WESTDYN	3.0	4.229	2.768	1.423	0.407	0.000
	17.49	-0.417	0.113	0.346	0.192	0.000
	45.75	0.065	-0.070	0.019	0.078	0.000
	78.27	-0.009	0.016	-0.024	0.024	0.000

Total System Response

		Point 1	Point 2	Point 3	Point 4	Point 5
Hand Calc.	ABS SUM ΔX	4.721	2.967	1.811	0.698	0.000
	ABS SUM MZ	0	1169.	1363.	1468.	2586.
	RMS ΔX	4.252	2.770	1.463	0.456	0.000
	RMS MZ	0	647.	776.	877.	1463.
WESTDYN	ABS SUM ΔX	4.720	2.967	1.812	0.701	0.000
	ABS SUM MZ	0	1163.	1361.	1474.	2595.
	RMS ΔX	4.250	2.771	1.465	0.457	0.000
	RMS MZ	0	643.	782.	890.	1484.

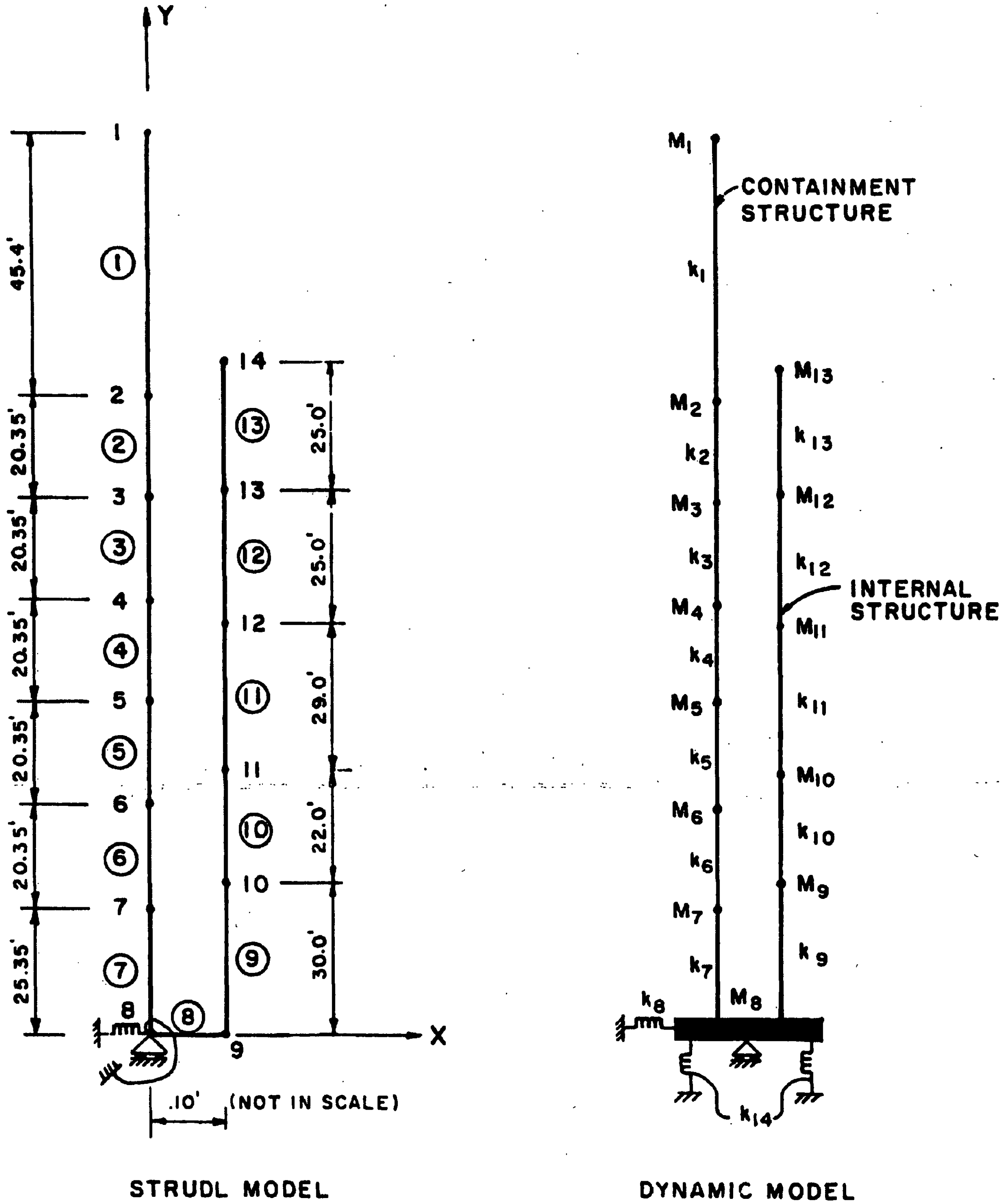
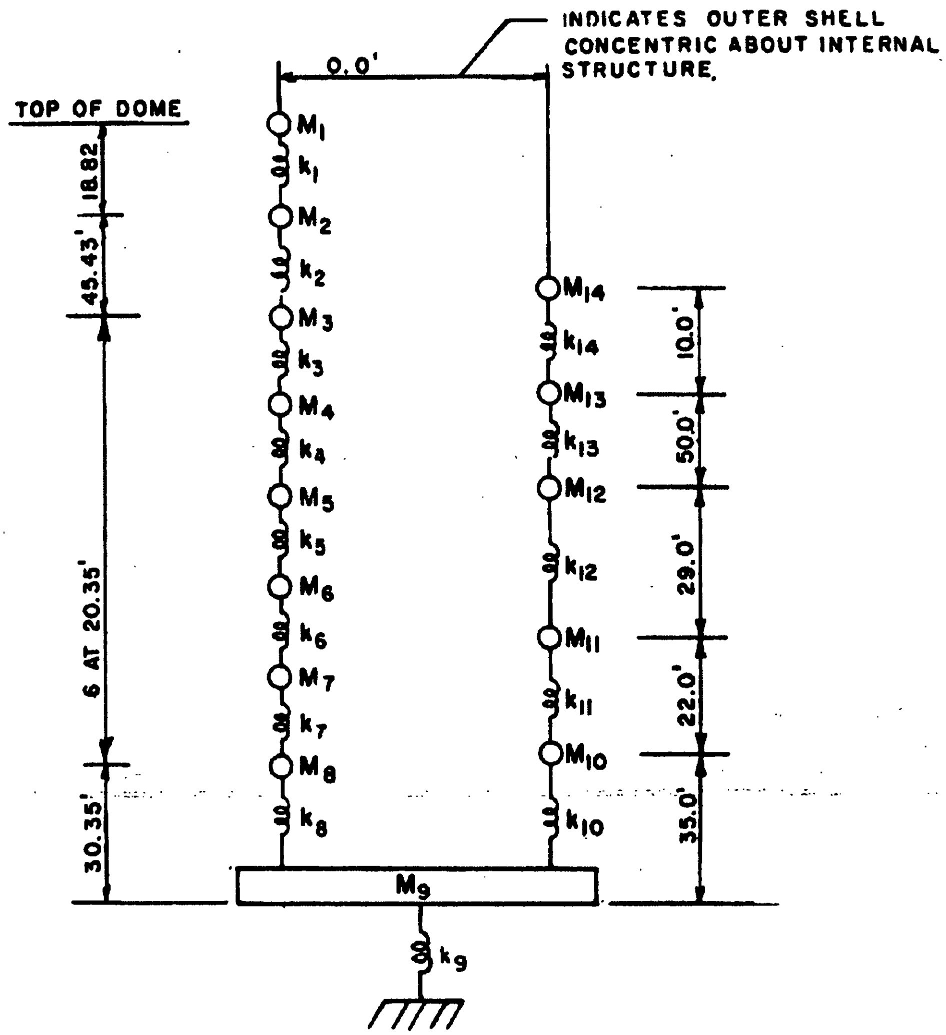


FIGURE B-1-1
SEISMIC ANALYSIS
CONTAINMENT STRUCTURE
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

REV. 0 (1/82)



LUMPED MASS MODEL

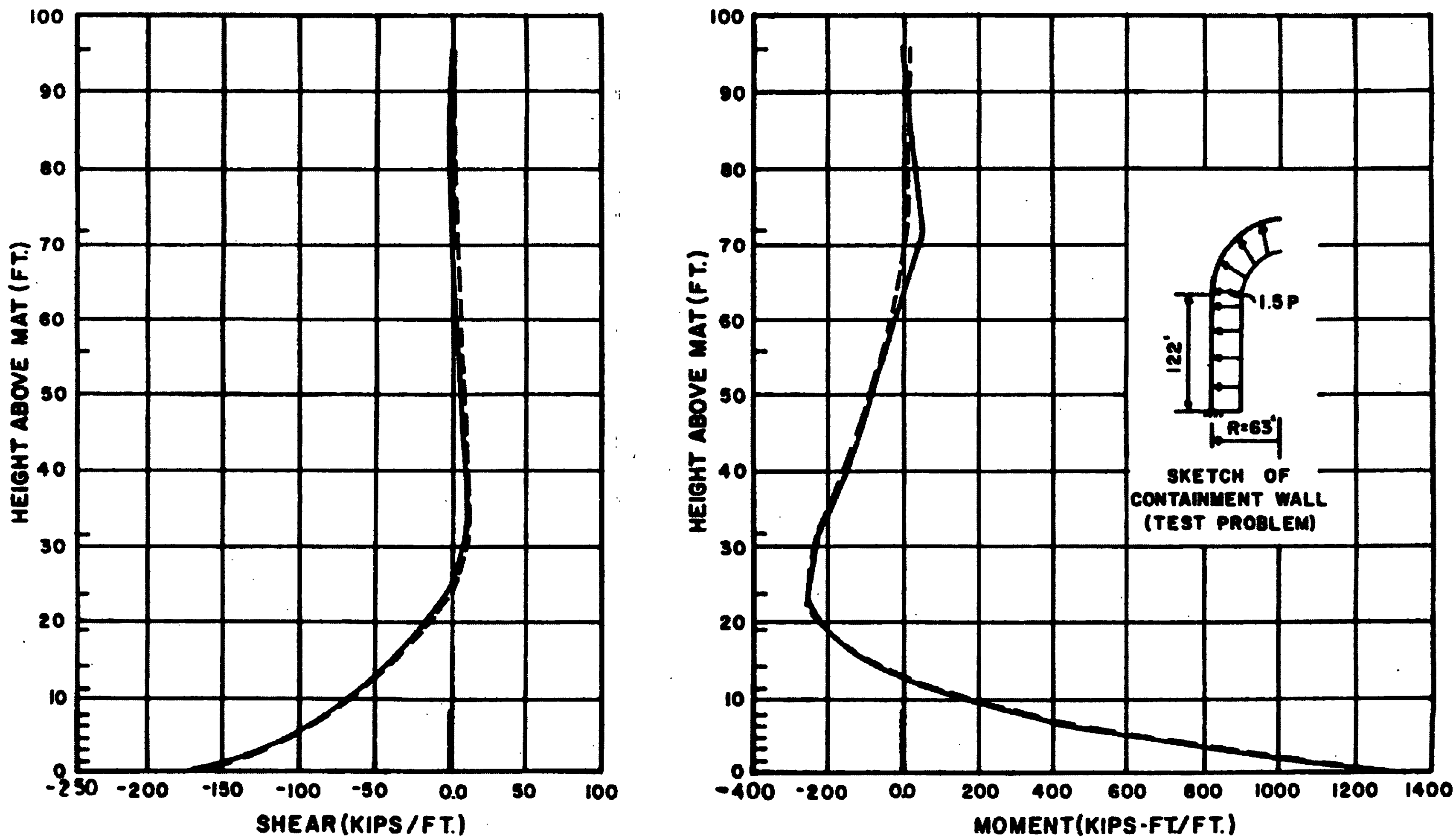
M_1, M_2 ....M_{14} = REAL LUMPED MASSES

k_1, k_2..... k_8, k_{10}....k_{14} = VERTICAL STRUCTURAL SPRINGS

k_9 = VERTICAL SOIL SPRING

FIGURE B.1-2
VERTICAL DYNAMIC MODEL FOR SEISMIC ANALYSIS OF CONTAINMENT STRUCTURE
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

REV. 0 (1/82)



NOTE:

—— HAND CALCULATIONS BASED ON "THEORY OF PLATES & SHELLS"

- - - SHELL I

FIGURE B.1-3
COMPARISON OF SHELL 1 VS. HAND CALCULATIONS - SH 1
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

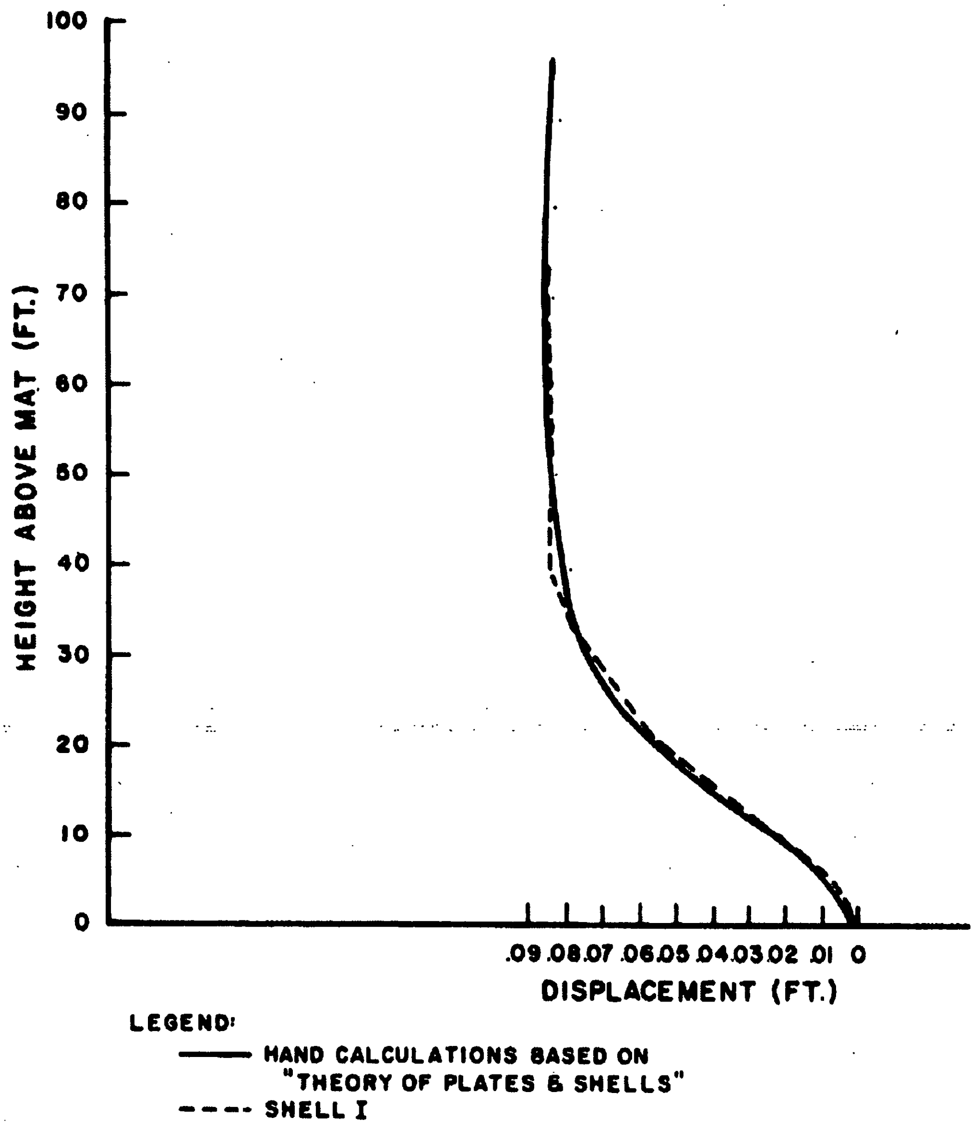


FIGURE B.1-4
COMPARISON OF SHELL 1 VS.
HAND CALCULATIONS - SH 2

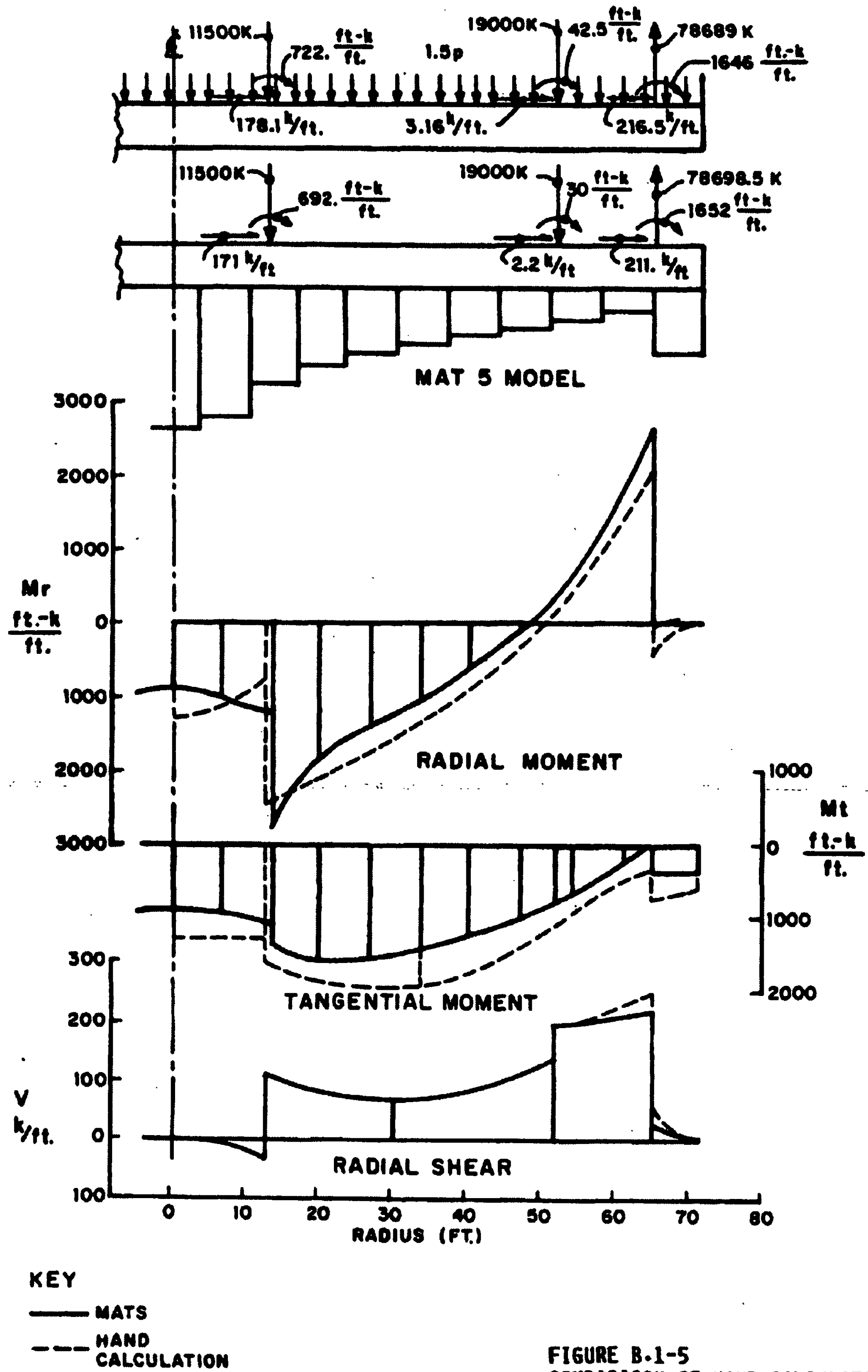


FIGURE B.1-5
COMPARISON OF HAND CALCULATIONS
TO MAT 5 PROGRAM

BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

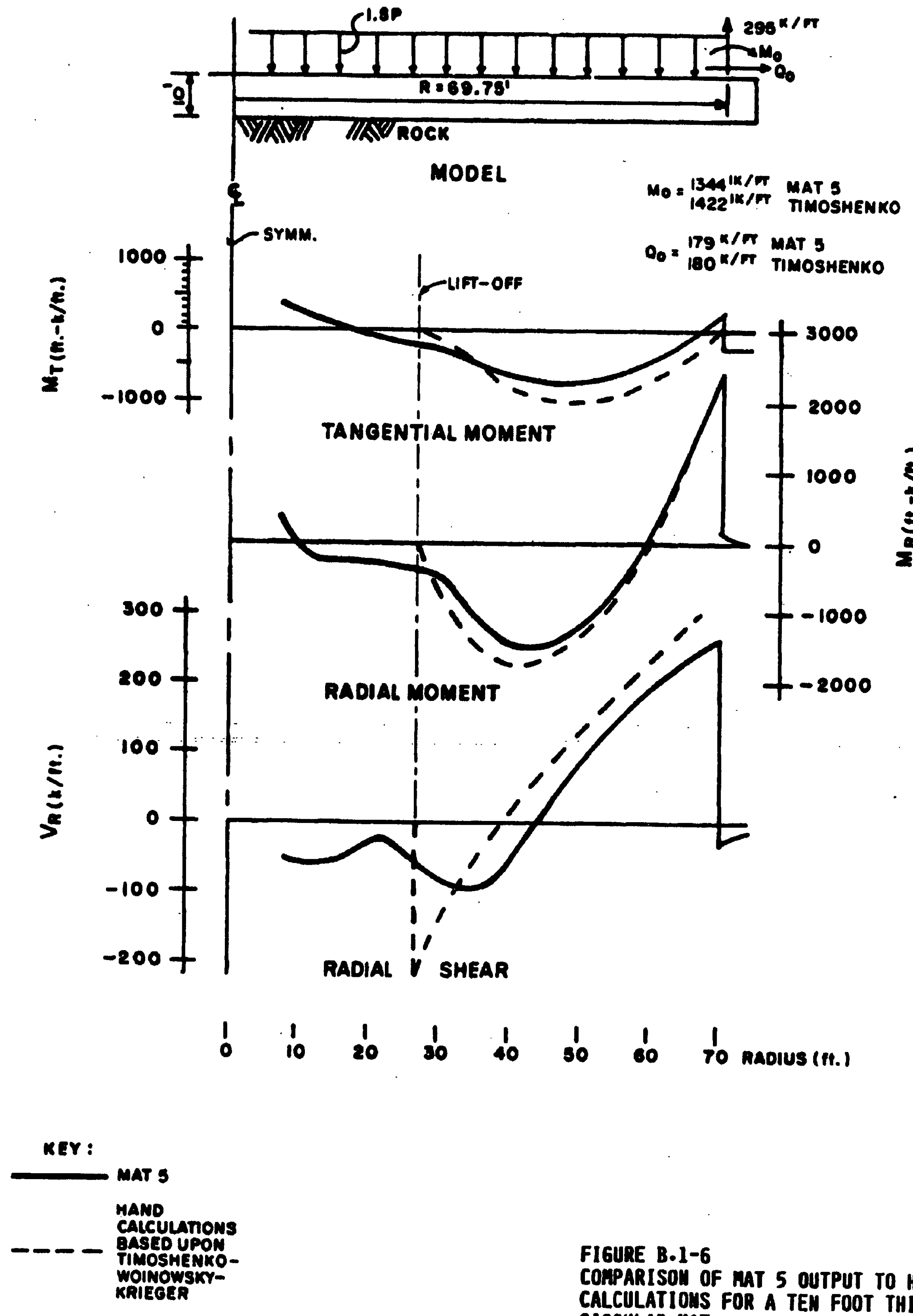


FIGURE B.1-6
COMPARISON OF MAT 5 OUTPUT TO HAND CALCULATIONS FOR A TEN FOOT THICK CIRCULAR MAT

BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

REV. 0 (1/82)

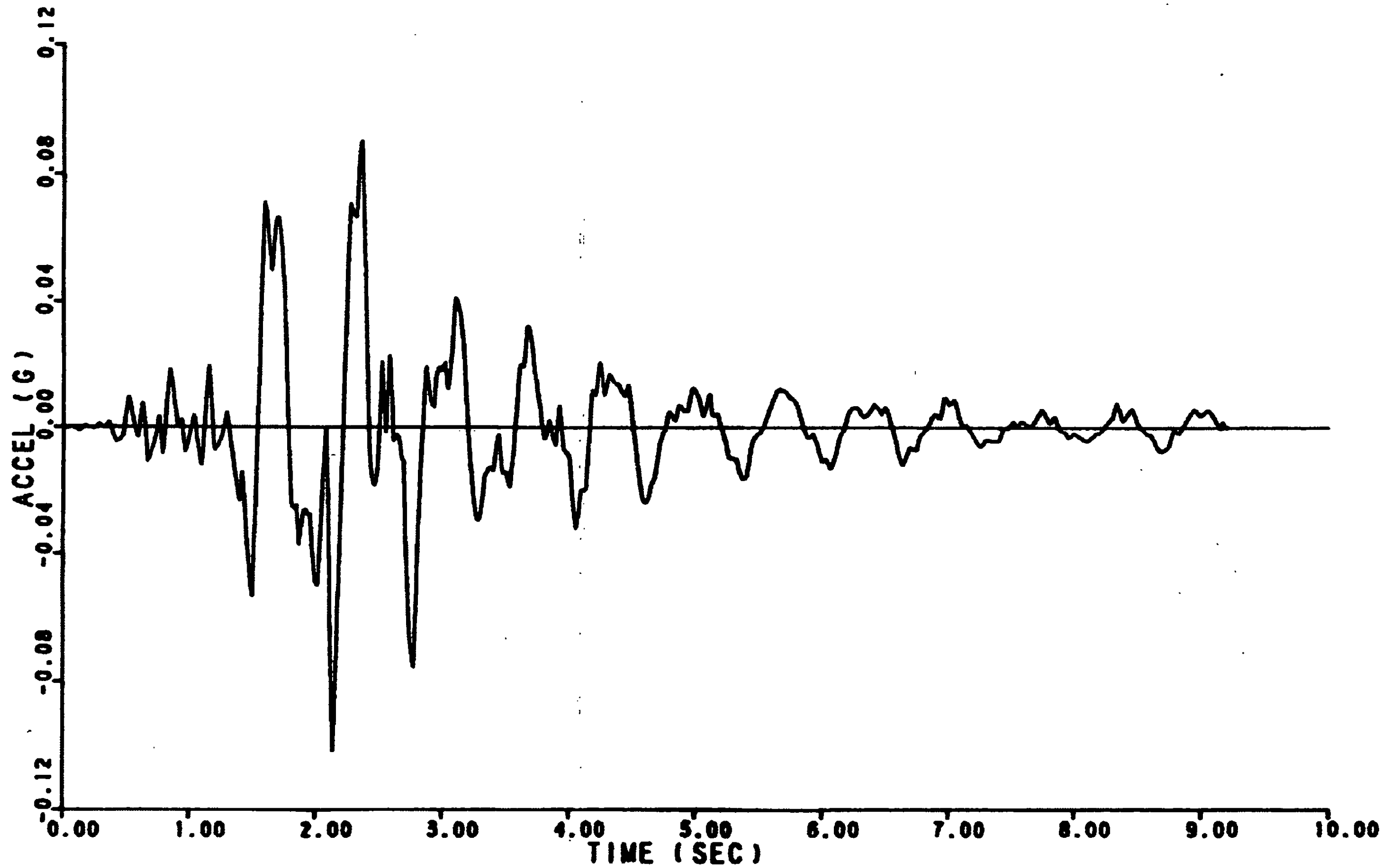


FIGURE B.1-7
RESULTS OF TIME HISTORY PROGRAM
CONTAINMENT STRUCTURE-OPERATING
FLOOR LEVEL TIME HISTORY OF
STRUCTURE RESPONSE
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

REV. 0 (1/82)

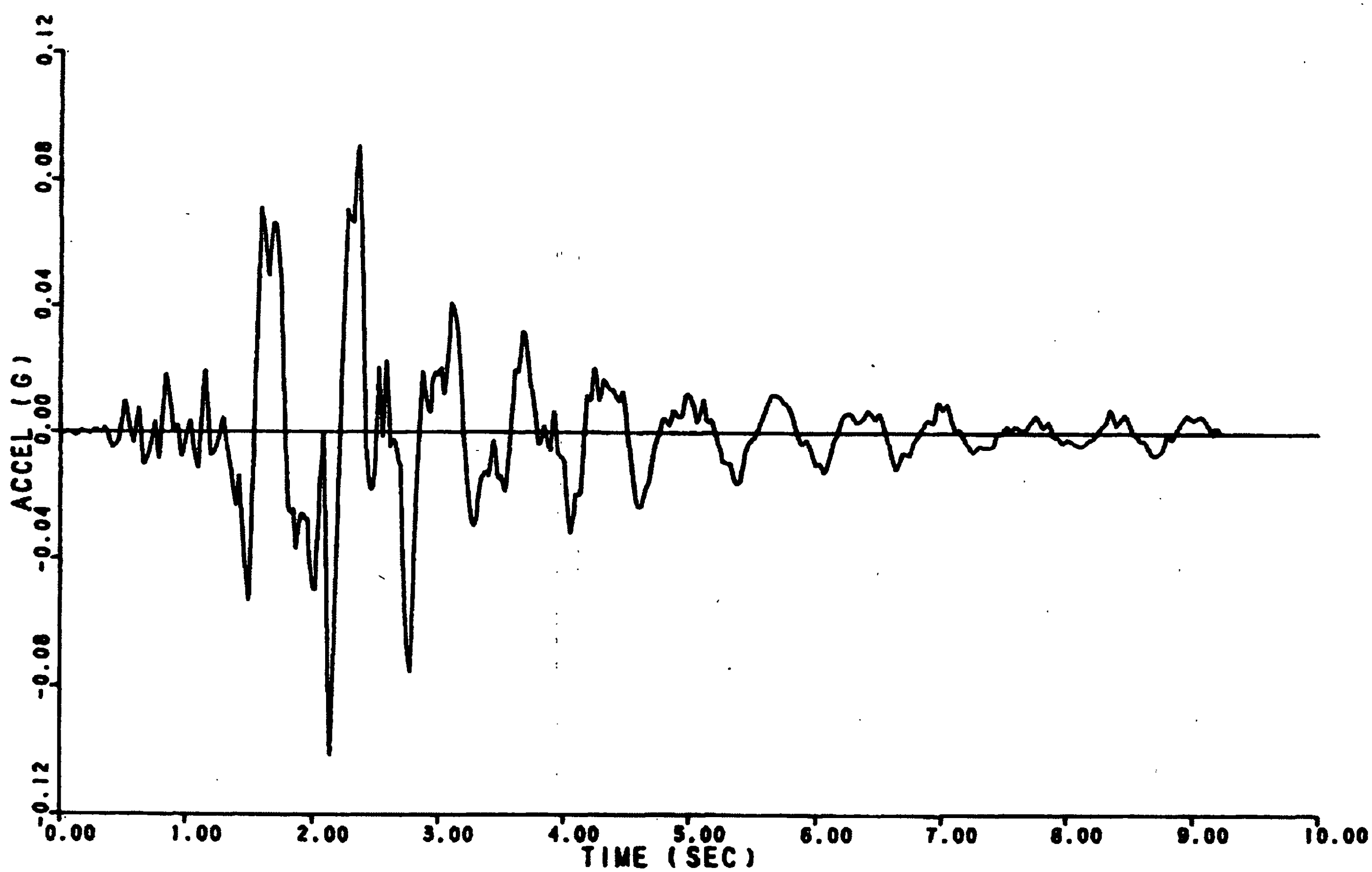
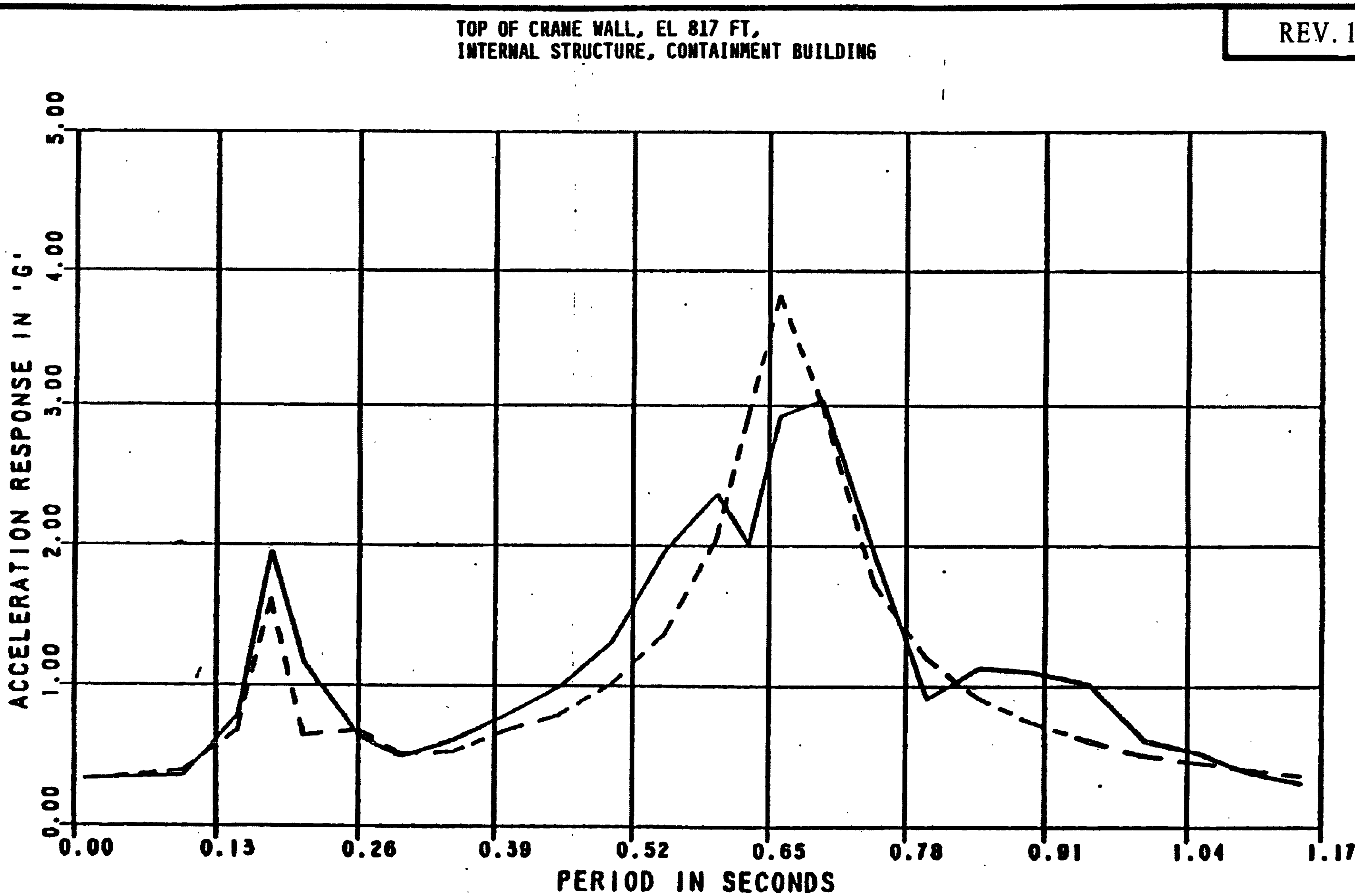


FIGURE B.1-8
RESULTS OF STRUDL II ANALYSIS
CONTAINMENT STRUCTURE-OPERATING
FLOOR LEVEL TIME HISTORY OF
STRUCTURE RESPONSE
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

REV. 19



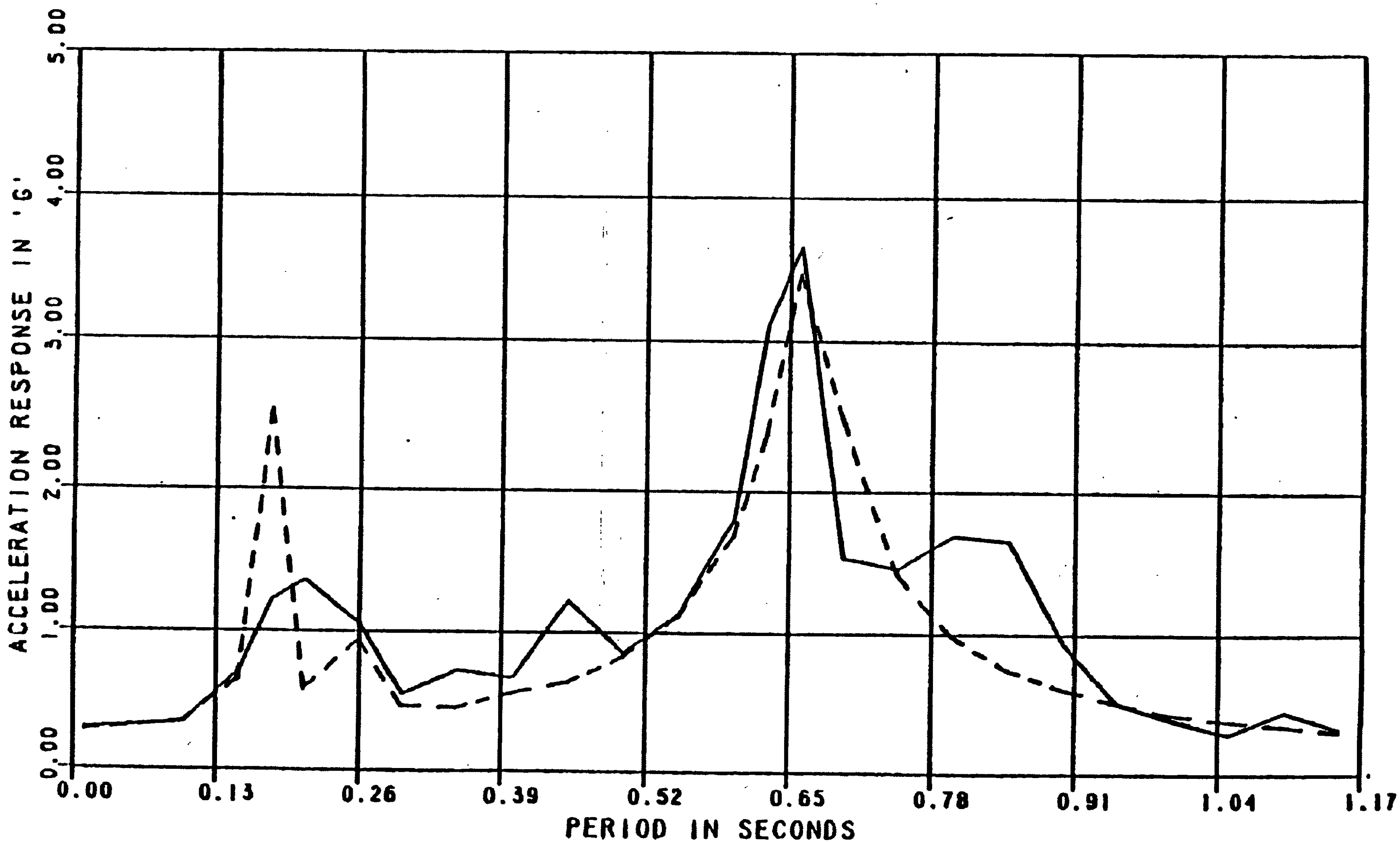
- - - FREQUENCY RESPONSE METHOD, EL CENTRO, R-.3, DBE NORMALIZED TO .125G

——— TIME HISTORY METHOD, EL CENTRO NORMALIZED TO .125G

.005 = EQUIPMENT DAMPING

.07 = STRUCTURAL DAMPING

FIGURE B.1A-1A
TIME HISTORY - FREQUENCY RESPONSE METHODS COMPARISON
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT



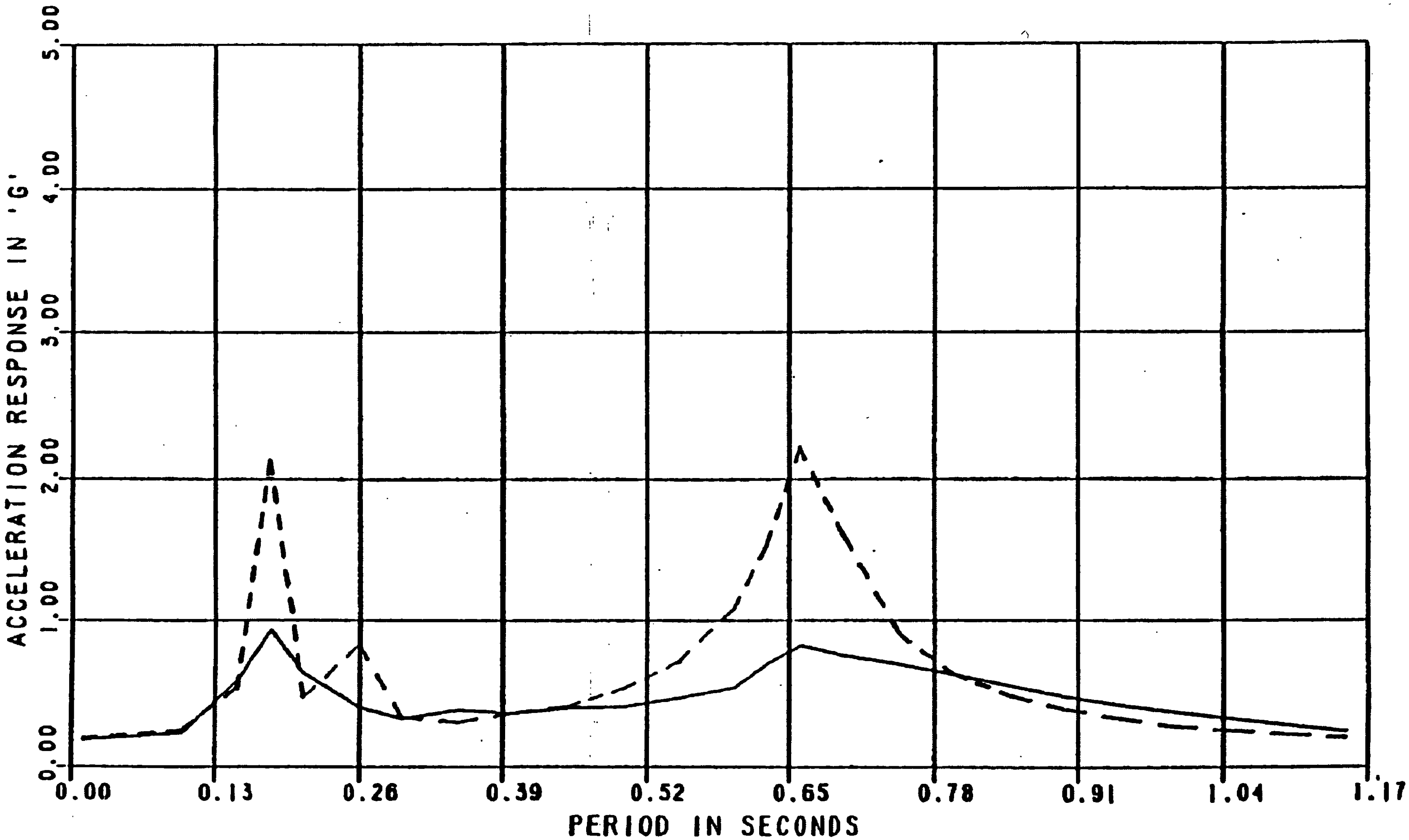
REV. 19

- - - FREQUENCY RESPONSE METHOD, TAFT, R-.3,
DBE NORMALIZED TO .1256
——— TIME HISTORY METHOD FOR TAFT
NORMALIZED TO .1256
.005 = EQUIPMENT DAMPING
.07 = STRUCTURAL DAMPING

FIGURE B.1A-1B
TIME HISTORY - FREQUENCY
RESPONSE METHODS COMPARISON
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

REV. 19

TOP OF CRANE WALL, EL 817 FT,
INTERNAL STRUCTURE, CONTAINMENT BUILDING



- - - FREQUENCY RESPONSE METHOD, HELENA EW, R-.3
DBE NORMALIZED TO .1256

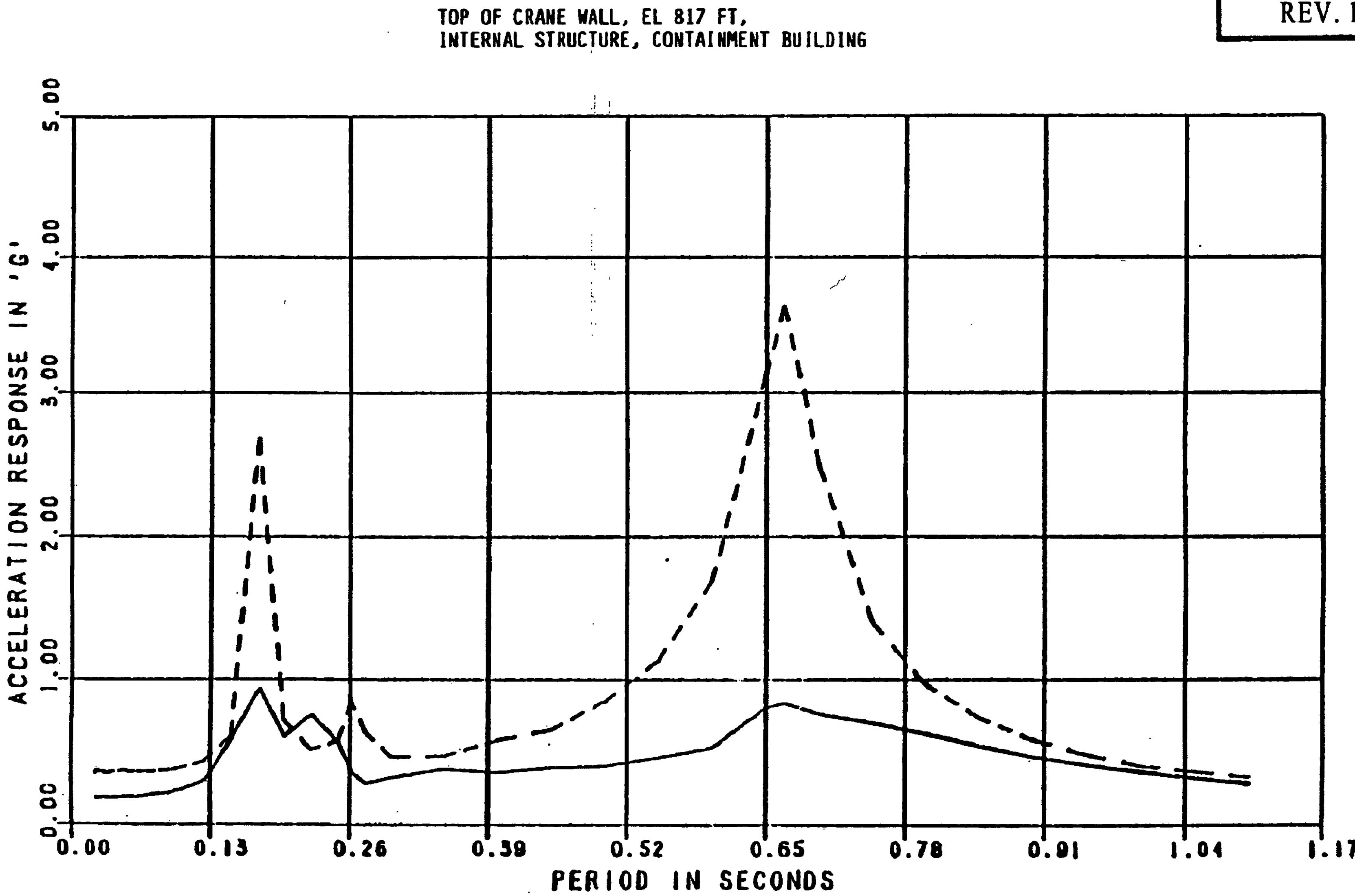
——— TIME HISTORY METHOD FOR HELENA EW
NORMALIZED TO .1256

.005 = EQUIPMENT DAMPING

.07 = STRUCTURAL DAMPING

FIGURE B.1A-1C
TIME HISTORY - FREQUENCY
RESPONSE METHODS COMPARISON
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

REV. 19



- - - FREQUENCY RESPONSE METHOD, R-.3, DBE NORMALIZED TO .125G

—— TIME HISTORY METHOD FOR HELENA EW NORMALIZED TO .125G

.005 = EQUIPMENT DAMPING

.07 = STRUCTURAL DAMPING

FIGURE B.1A-2A
TIME HISTORY - FREQUENCY
RESPONSE METHODS COMPARISON
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

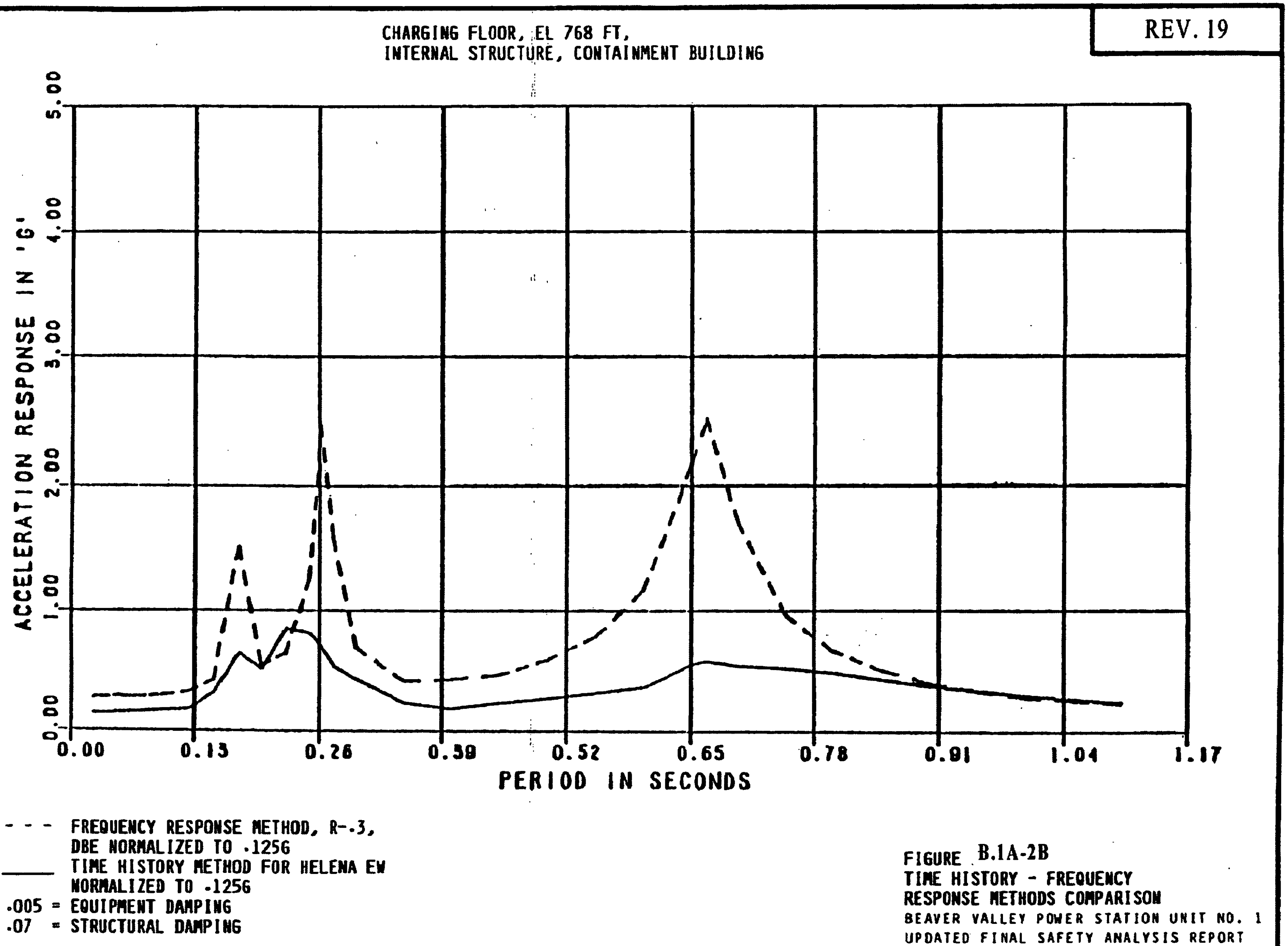
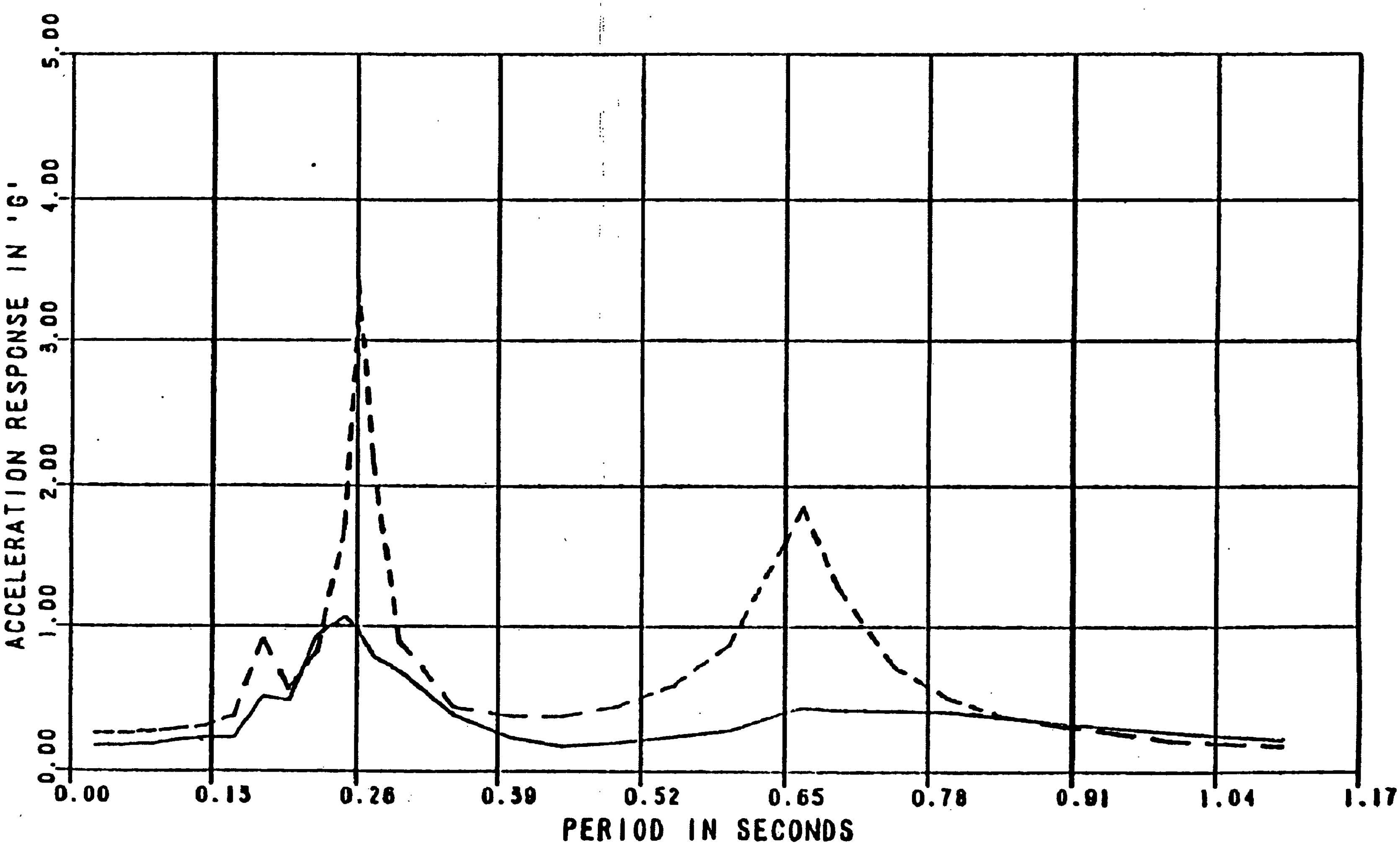


FIGURE B.1A-2B
TIME HISTORY - FREQUENCY
RESPONSE METHODS COMPARISON
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

REV. 19

STEAM GENERATOR SUPPORT, EL 738.5 FT,
INTERNAL STRUCTURE, CONTAINMENT BUILDING



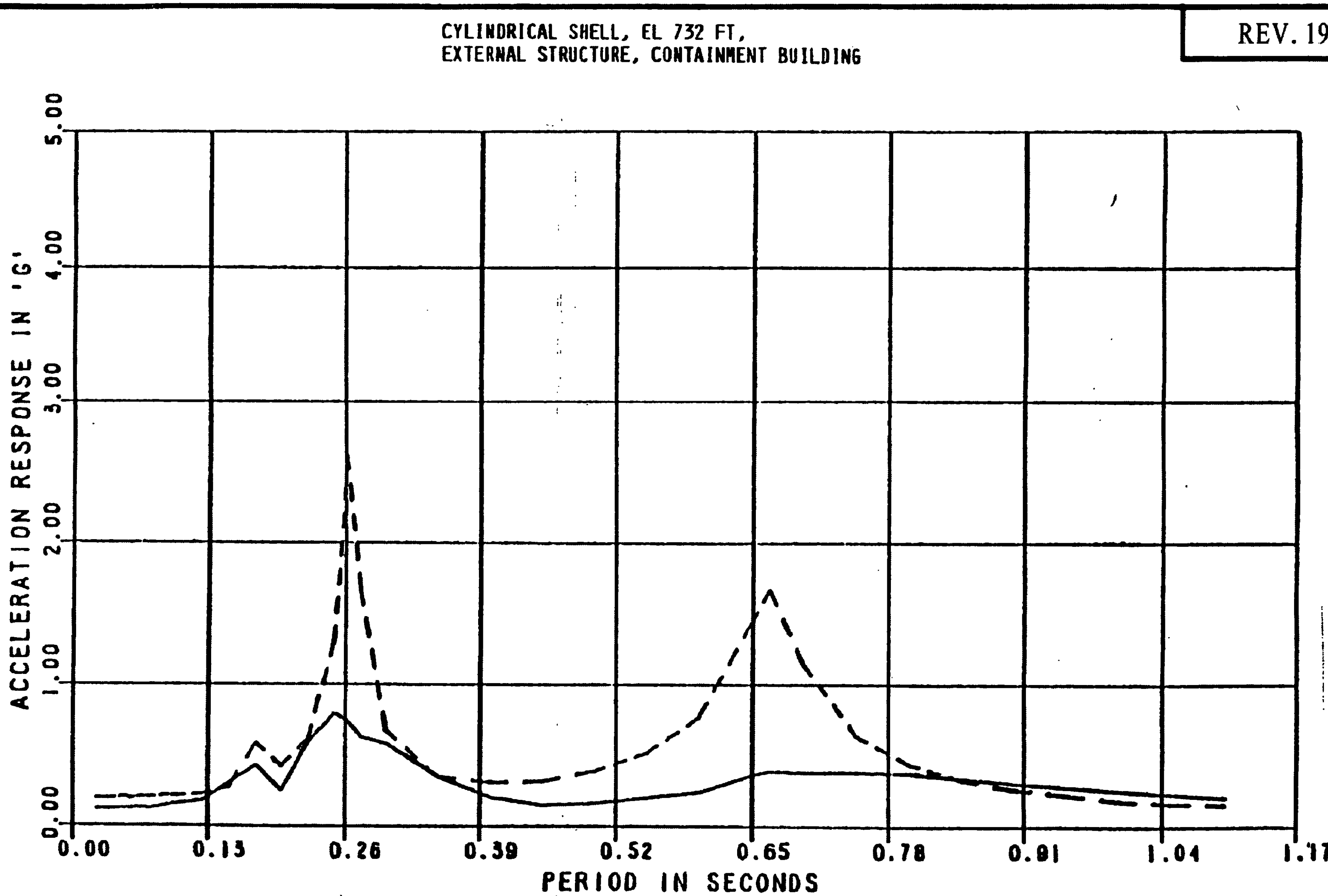
- - - FREQUENCY RESPONSE METHOD, R-.3,
DBE NORMALIZED TO .125G

_____ TIME HISTORY METHOD FOR HELENA EW
NORMALIZED TO .125G

.005 = EQUIPMENT DAMPING
.07 = STRUCTURAL DAMPING

FIGURE B.1A-2C
TIME HISTORY - FREQUENCY
RESPONSE METHODS COMPARISON
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

REV. 19



- - - FREQUENCY RESPONSE METHOD, R-.3, DBE NORMALIZED TO .1256

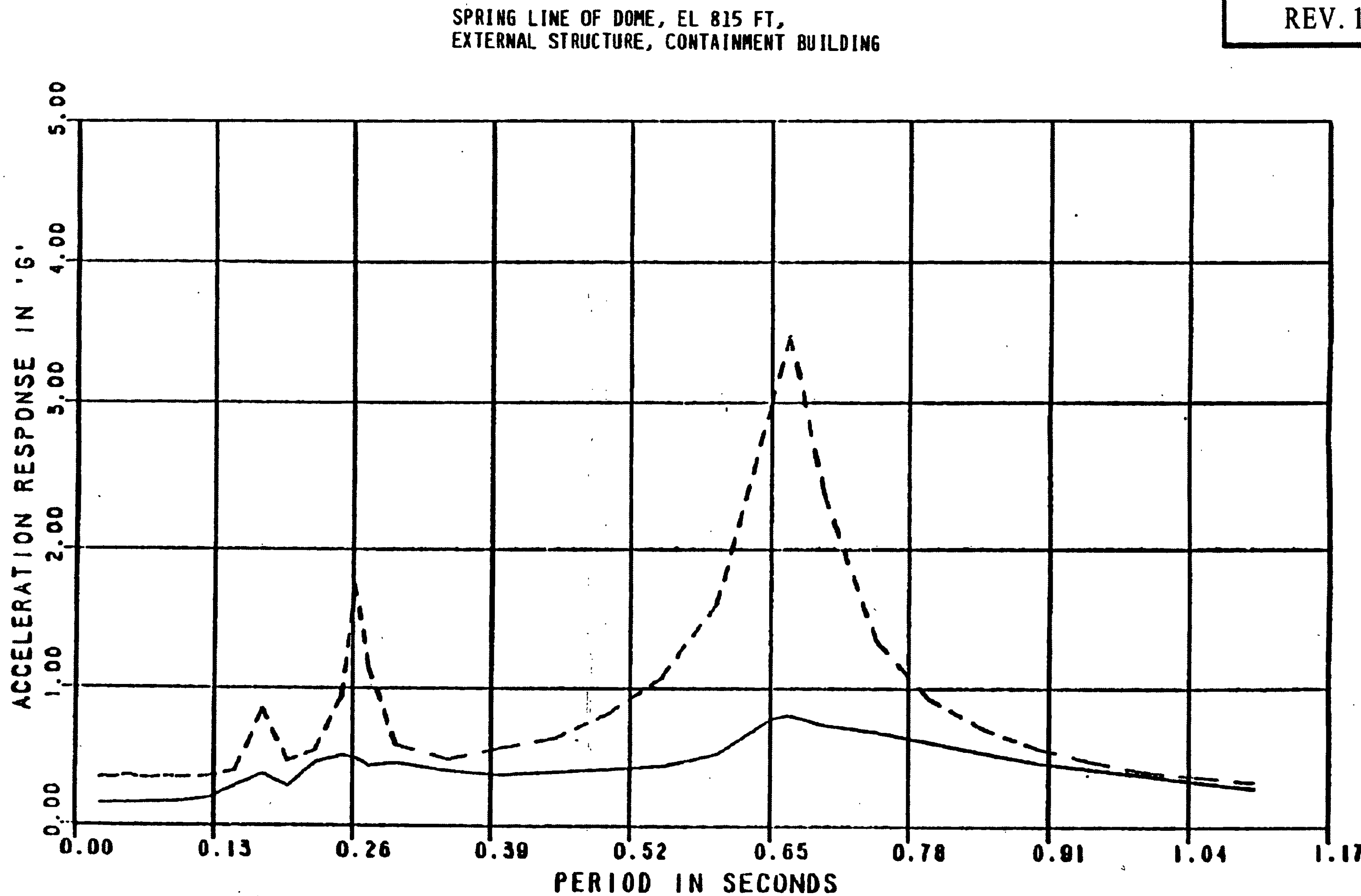
——— TIME HISTORY METHOD FOR HELENA EW NORMALIZED TO .1256

.005 = EQUIPMENT DAMPING

.07 = STRUCTURAL DAMPING

FIGURE B.1A-2D
TIME HISTORY - FREQUENCY RESPONSE METHODS COMPARISON
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

REV. 19



- - - FREQUENCY RESPONSE METHOD, R-.3, DBE NORMALIZED TO .125G

——— TIME HISTORY METHOD FOR HELENA EW NORMALIZED TO .125G

.005 = EQUIPMENT DAMPING

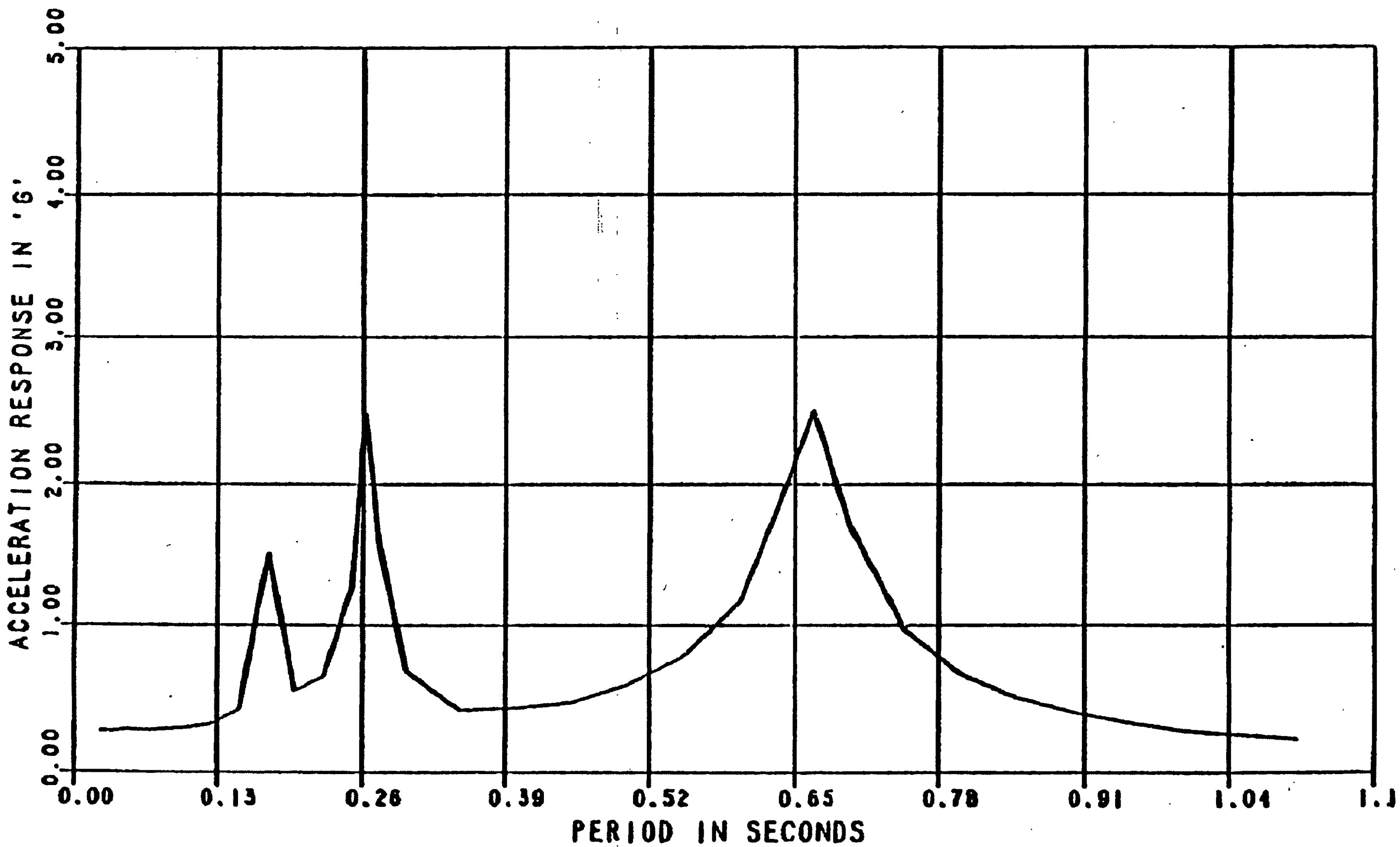
.07 = STRUCTURAL DAMPING

FIGURE B.1A-2E
TIME HISTORY - FREQUENCY
RESPONSE METHODS COMPARISON

BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

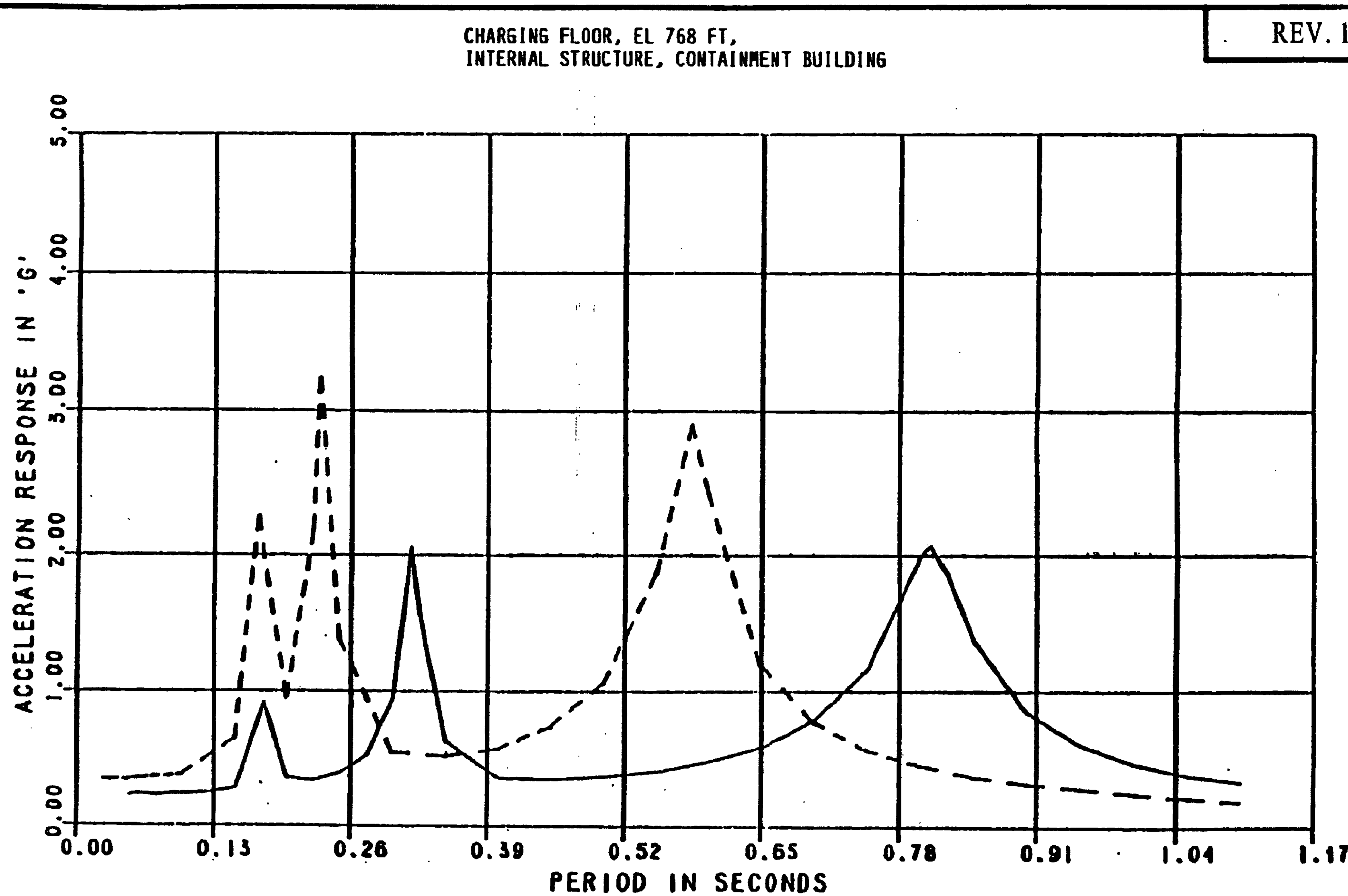
REV. 19

CHARGING FLOOR, EL 768 FT,
INTERNAL STRUCTURE, CONTAINMENT BUILDING



FREQUENCY RESPONSE METHOD, G-18000 PSI,
R-.3, DBE NORMALIZED TO .125G
.005 = EQUIPMENT DAMPING
.07 = STRUCTURAL DAMPING

FIGURE B.1A-3A
AMPLIFIED RESPONSE SPECTRA
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT



- - - FREQUENCY RESPONSE METHOD, G-24000 PSI, R-.3, DBE NORMALIZED TO .125G

——— FREQUENCY RESPONSE METHOD, G-12000 PSI, R-.3, DBE NORMALIZED TO .125G

.005 = EQUIPMENT DAMPING
.07 = STRUCTURAL DAMPING

FIGURE B.1A-3B
COMPARISON OF SOIL SHEAR MODULUS AT CHARGING FLOOR
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

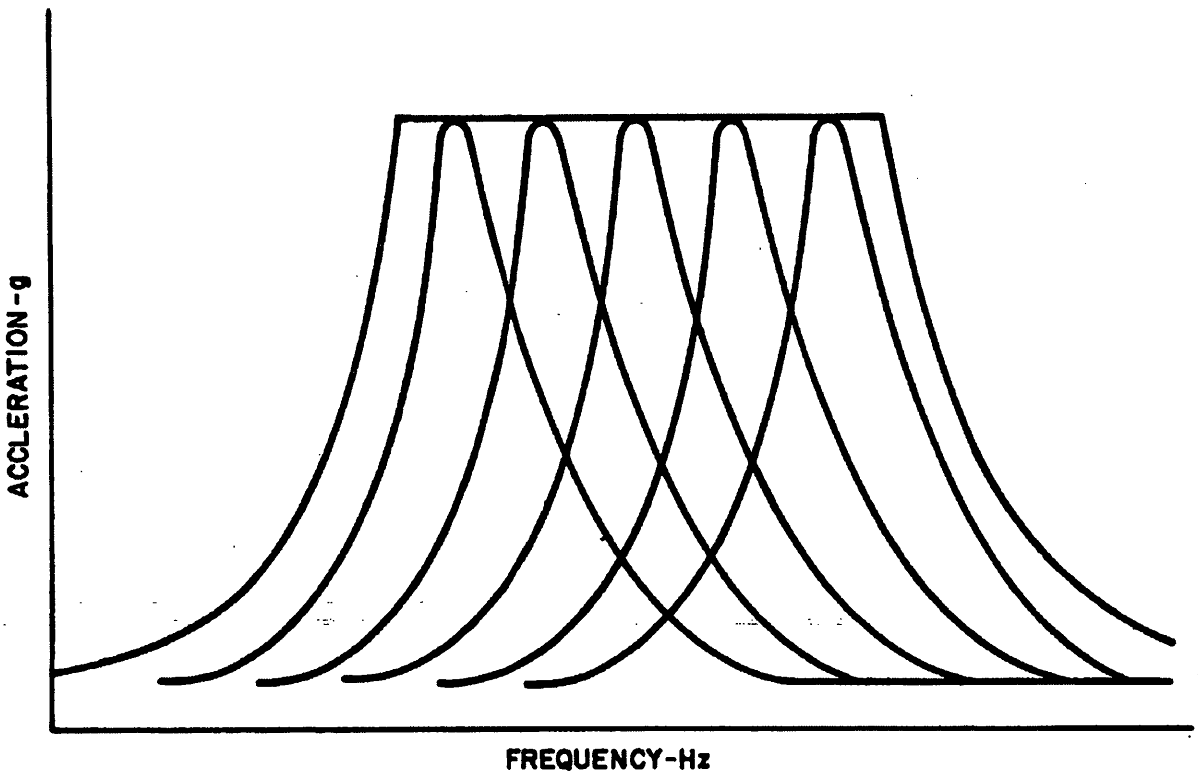


FIGURE B.2-1
REPRESENTATION OF FAMILY OF PEAK RESPONSE CURVES WITHIN BROADENED RESONANT PEAK

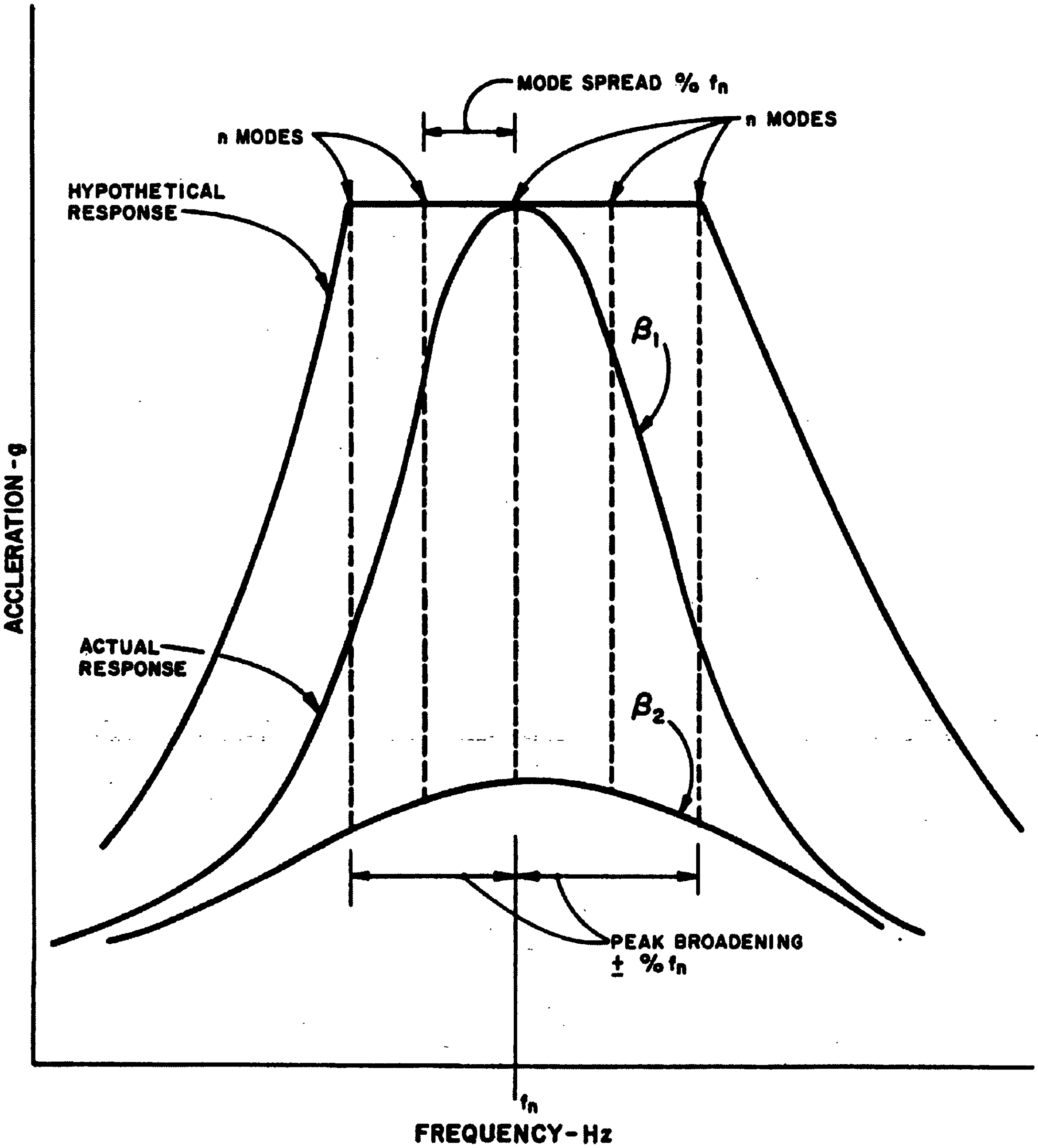


FIGURE B-2-2
HYPOTHETICAL VS ACTUAL RESPONSE OF MULTIPLE MODES WITHIN BROADENED RESPONSE PEAK

REV. 0 (1/82)

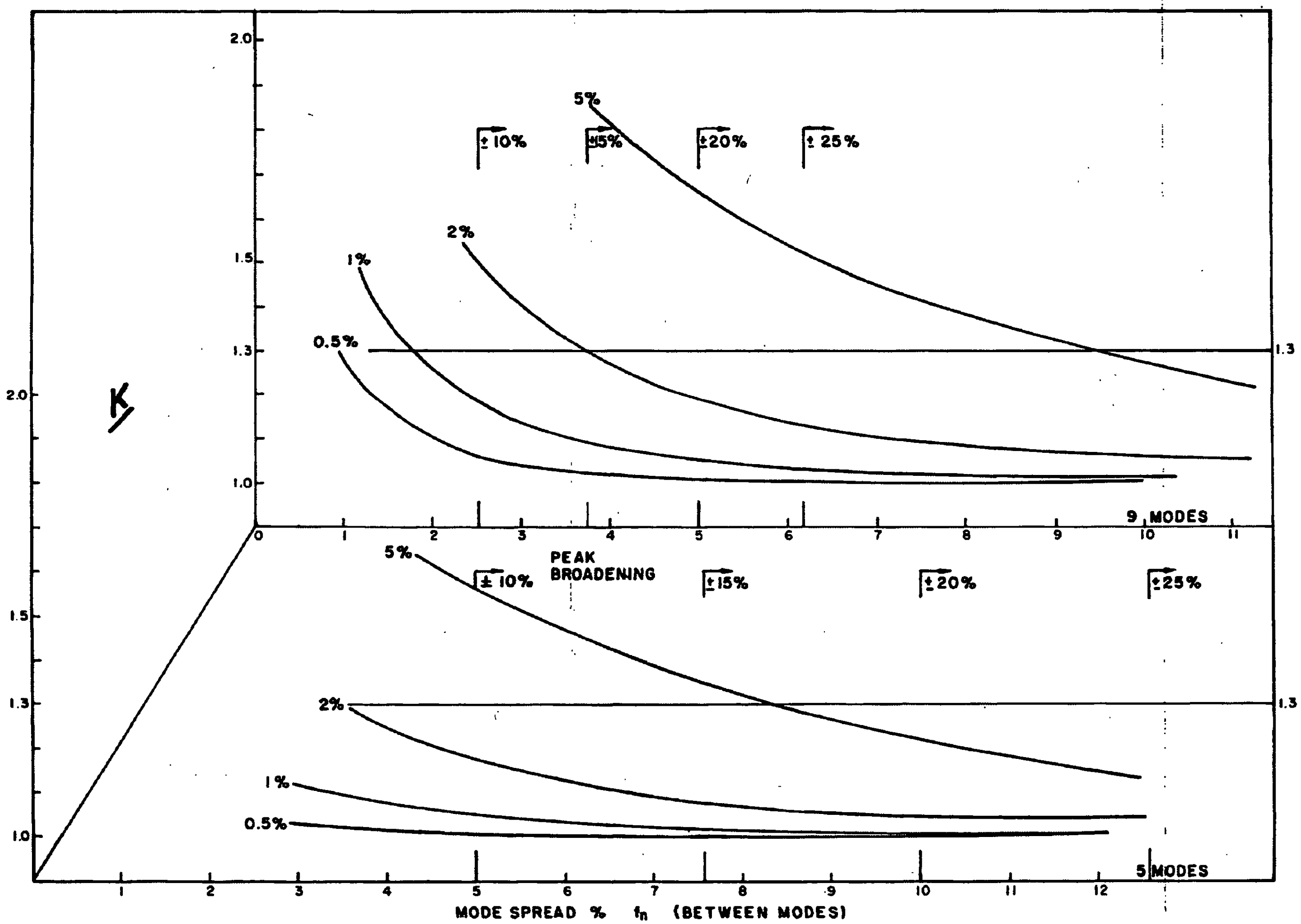


FIGURE B-2-3
JUSTIFICATION OF STATIC LOAD FACTOR
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

REV. 0 (1/82)

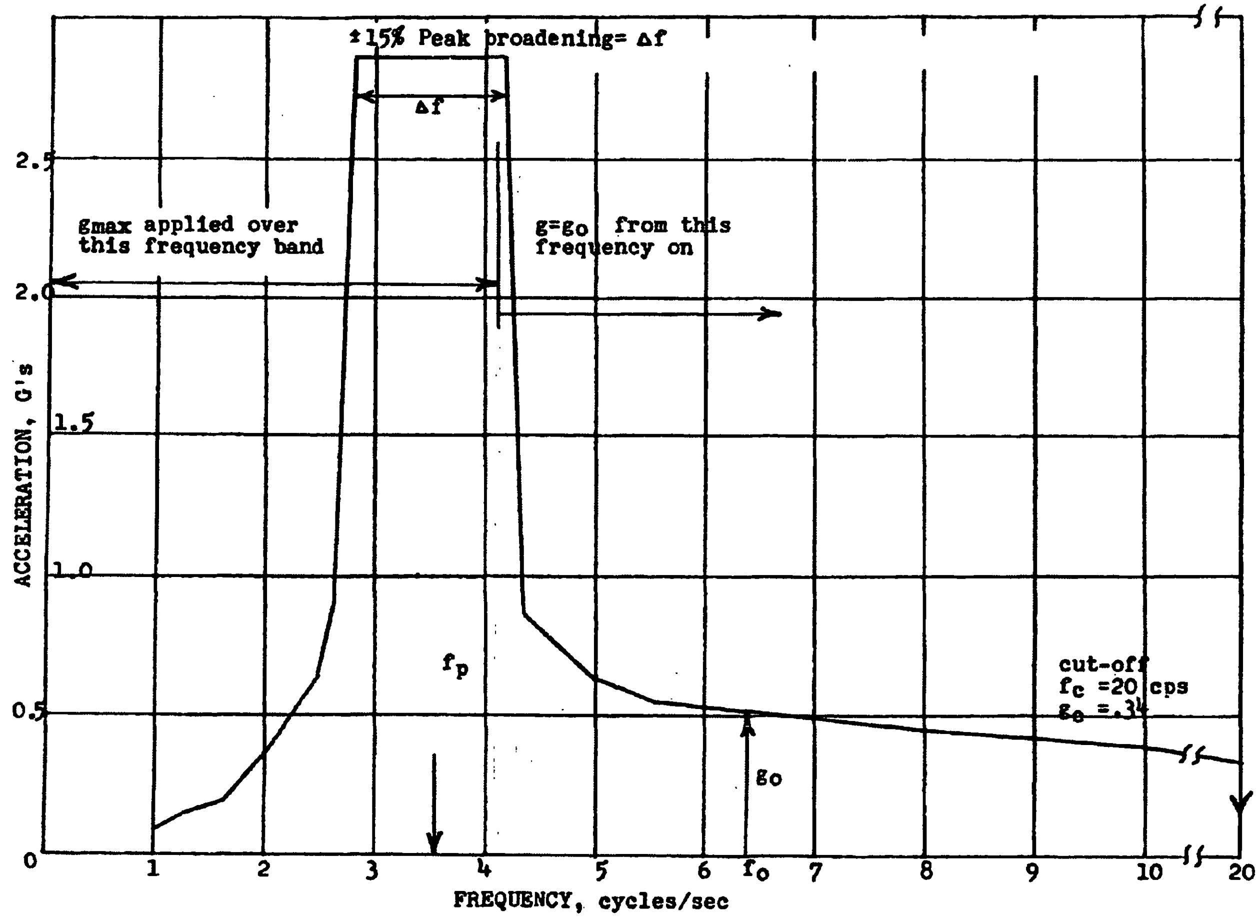


FIGURE B.2-4
AMPLIFIED RESPONSE SPECTRA
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

REV. 0 (1/82)

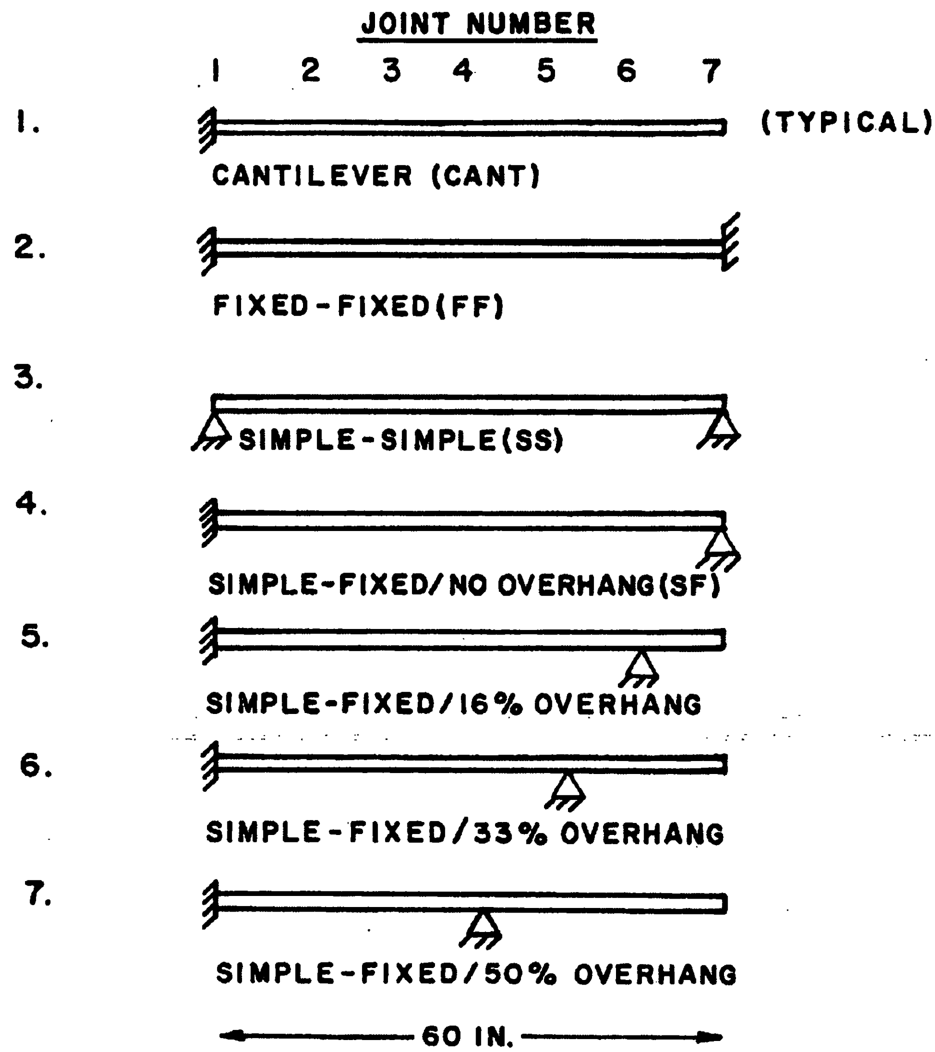
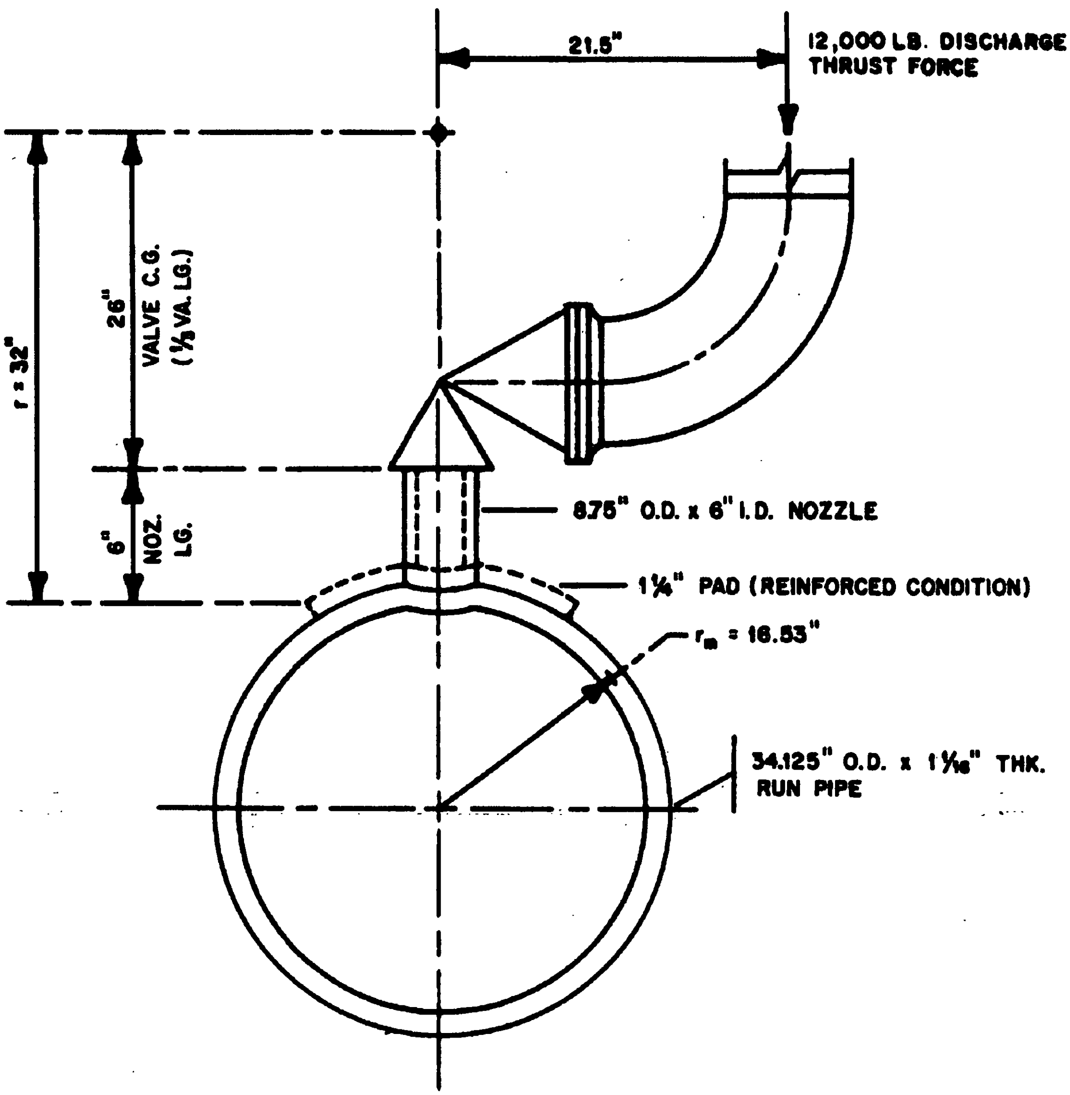


FIGURE B.2-5
MODEL BEAMS
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT



VALVE WT. = 660 LBS.

VALVE LENGTH = 78", CG = 1/3 x 78 = 26"

VALVE OPENING TIME = .05 SEC. (ASSUME)

NOZZLE LENGTH = 6"

NOZZLE O.D. = 8.75" I.D. = 6.0"

VALVE SET PRESSURE = 850psi

FIGURE B.2-7
TEST PROBLEM - "SAVAL"

REV. 0 (1/82)

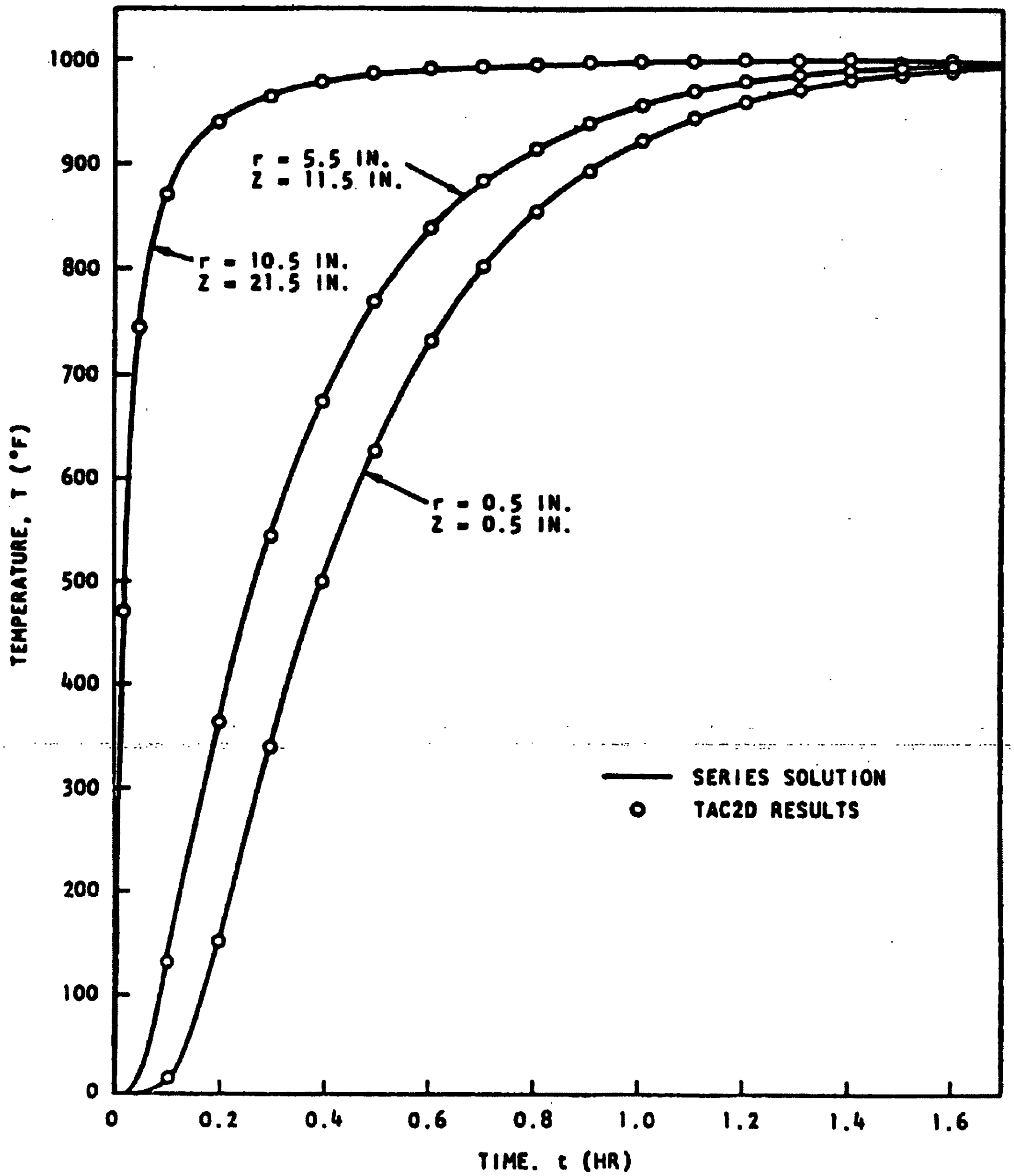


FIGURE B-2-9
TRANSIENT TEMPERATURES IN A RIGHT CIRCULAR CYLINDER - COMPARISON OF TAC2D RESULTS WITH SERIES SOLUTION

BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

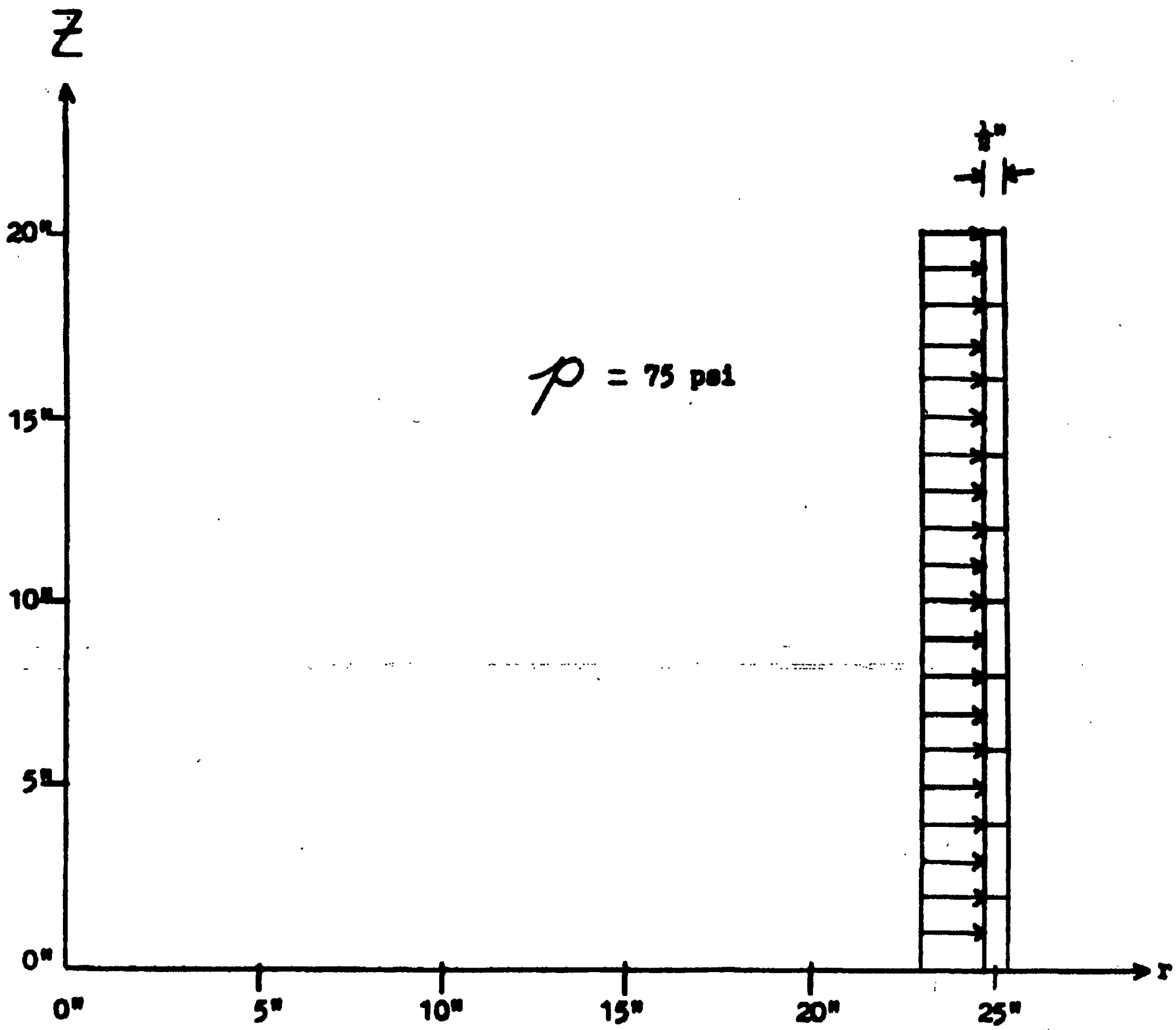


FIGURE B.2-12
TEN ELEMENT IDEALIZATION OF
THIN-WALL CYLINDER

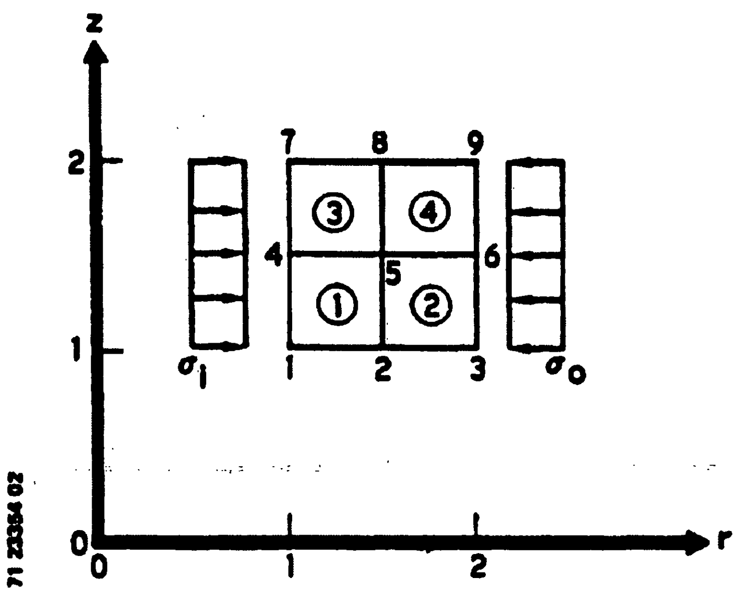


FIGURE B.2-13
FOUR-ELEMENT IDEALIZATION OF
HOLLOW CYLINDER
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT

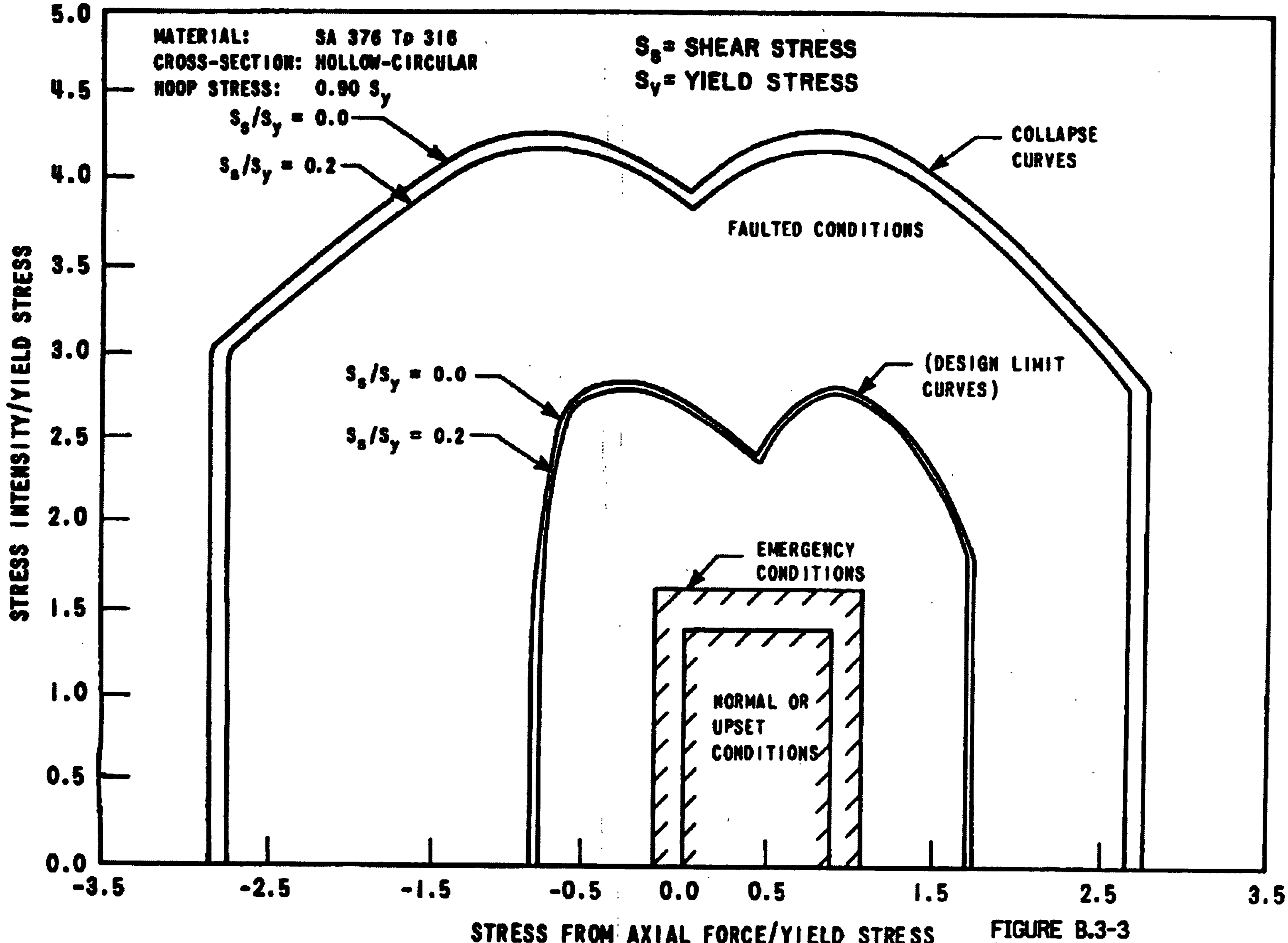


FIGURE B.3-3
COMPARISON BETWEEN DESIGN & COLLAPSE CONDITIONS FOR S_Y HOOP STRESS OF 0.9

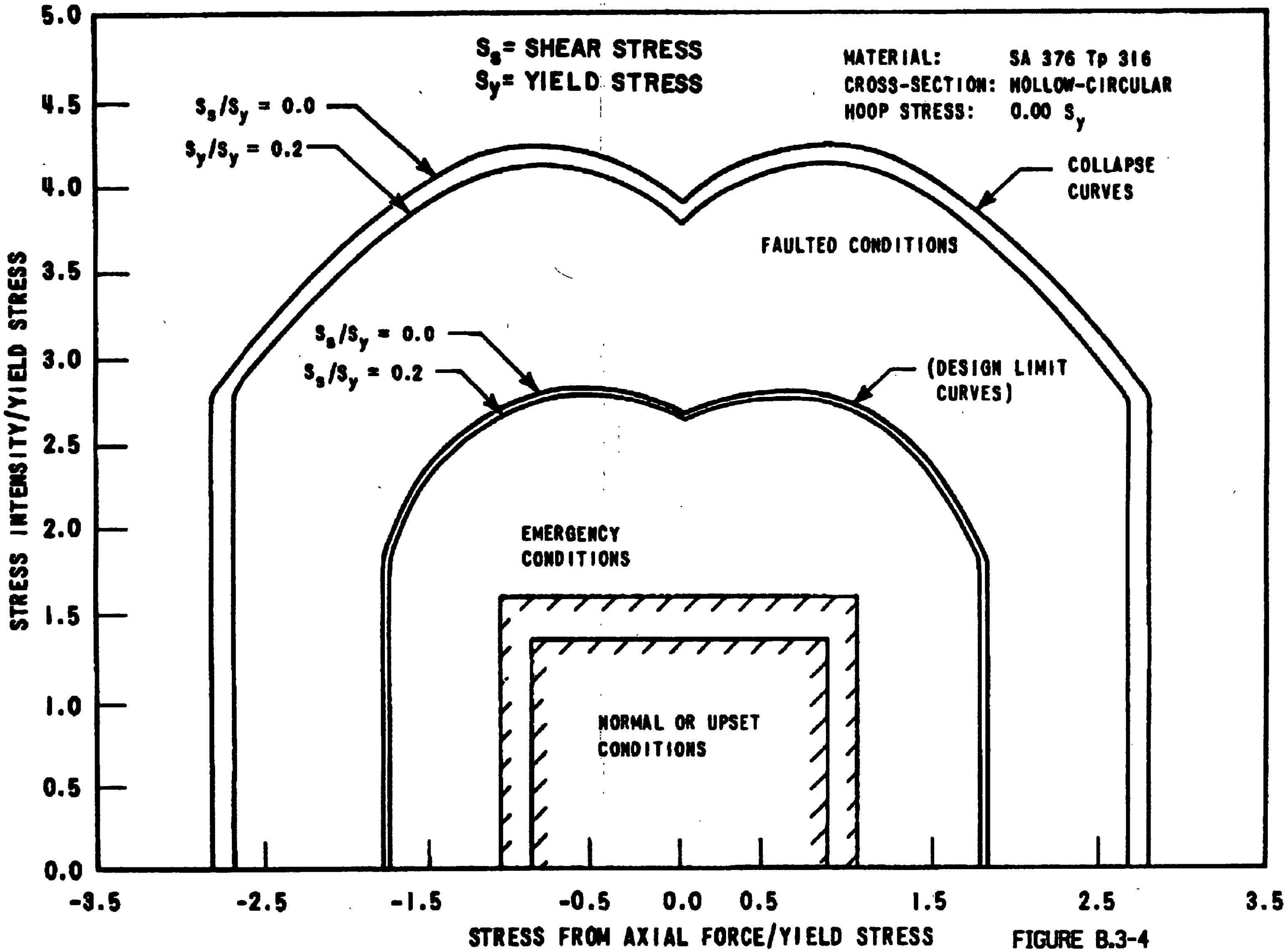


FIGURE B.3-4
COMPARISON BETWEEN DESIGN AND COLLAPSE CONDITIONS FOR S_Y HOOP STRESS OF 0.0
BEAVER VALLEY POWER STATION UNIT NO. 1
UPDATED FINAL SAFETY ANALYSIS REPORT