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June 15, 1984

United States Nuclear Regulatory Commission
Washington, DC 20555

ATTENTION: Mr. George W. Knighton, Chief
Licensing Branch 3
Office of Nuclear Reactor Regulation

SUBJECT: Beaver Valley Power Station - Unit No. 2
Docket No. 50-412
NRC Structural Design Audit

Gentlemen:

Attached are the responses to NRC Structural Design Audit Action Items 4, 7, 8, 9, 10, 12, 19, 20, and 23, which were scheduled to be provided by June 15, 1984, in letter 2NRC-4-018, dated February 27, 1984. These responses along with those provided in letter 2NRC-4-018 and letter 2NRC-4-047, dated April 27, 1984, completes the BVPS-2 written responses to the NRC Structural Design Audit Action Items and to the NRC Structural Engineering Section's review comments on BVPS-2 Standard Review Plan differences.

Please note that in the response to Action Item 7, the Intake Structure has not been addressed. This structure has been previously addressed by Duquesne Light Company and reviewed and approved by the NRC under the BVPS-1 Docket No. 50-334.

If you have any questions on this matter, please contact J. D. O'Neil at (412) 787-5141.

DUQUESNE LIGHT COMPANY

By E. J. Woolever
E. J. Woolever
Vice President

JDO/wjs
Attachment

cc: Mr. G. Walton, NRC Resident Inspector (w/a)
Mr. E. A. Licitra, Project Manager (w/a)

SUBSCRIBED AND SWORN TO BEFORE ME THIS
14th DAY OF June, 1984.
Anita Elaine Reiter
Notary Public

ANITA ELAINE REITER, NOTARY PUBLIC
ROBINSON TOWNSHIP, ALLEGHENY COUNTY
MY COMMISSION EXPIRES OCTOBER 20, 1986

B001
1/1

COMMONWEALTH OF PENNSYLVANIA)
) SS:
COUNTY OF ALLEGHENY)

On this 14th day of June, 1984, before me, a Notary Public in and for said Commonwealth and County, personally appeared E. J. Woolever, who being duly sworn, deposed and said that (1) he is Vice President of Duquesne Light, (2) he is duly authorized to execute and file the foregoing Submittal on behalf of said Company, and (3) the statements set forth in the Submittal are true and correct to the best of his knowledge.

Anita Elaine Reiter
Notary Public

ANITA ELAINE REITER, NOTARY PUBLIC
ROBINSON TOWNSHIP, ALLEGHENY COUNTY
MY COMMISSION EXPIRES OCTOBER 20, 1986

4. For each of the following three structures, assess the impact using three-component seismic input vs using the current two-component combination on the structure design adequacy. In case of significant discrepancies, try to demonstrate that the design margins using as-built material strength and accounting for other conservatisms used in the design were adequate to justify these discrepancies.

Only consider these key floors of the following three buildings:

For the containment - the crane support, apex, reactor support, operating floor, and basement.

For the auxiliary building and the fuel building - the roof, basement, and an operating floor.

If the three-component piping support point spectra are found to be not comparable to those used in the original piping analysis (subject to NRC review and acceptance), develop the floor response spectra accounting for three-component earthquake input for the following piping systems:

A. Primary Loop Cooling System
B. Main Feedwater Line Piping System
C. Component Cooling Water Piping System

These spectra should be used by the piping analysts to demonstrate that the above systems were adequately designed for the three-component earthquake effects. For any deviations from the applicable ASME III criteria, please provide a justification considering the as-built material strength and conservatisms.

Response:

Audit Items 4, 12, and 23 are closely related and are answered in this combined response which addresses two representative structures, the containment and the auxiliary building. In order to address the various aspects of these questions, the sequence outlined below is used:

a. Description of the method of calculating seismic building responses for Category I structures and how they compare with SRP 3.7.2.

b. Description of the procedure used to generate building amplified response spectra (ARS) and how the results would compare to SRP 3.7.2.

c. Description of building design methodology used in the design of these two buildings and how they compare with the guidance for three component seismic input of SRP 3.7.2.

Review of the containment and auxiliary buildings for the impact of three component seismic input concluded that the BVPS-2 structures are adequate as designed and the ARS currently being used on BVPS-2 are acceptable.

a. Description of the Method of Calculating Seismic Building Responses

The containment structure is, for the purpose of seismic analysis, symmetric about its principal axes and can be analyzed using a planar model. This is demonstrated by Table 4.1 which provides the centers of mass and horizontal and vertical centers of rigidity. The containment seismic model is therefore two-dimensional with three degrees of freedom (two translational and one rocking) per mass point. The auxiliary building seismic model was analyzed considering six degrees of freedom per mass point: three translational, two rocking, and one torsional.

Audit Item 12 is related to three components of earthquake response, structural coupling, and the statistical independence of input motions. As demonstrated above, the containment structure is symmetric and therefore experiences no significant coupling between mutually orthogonal axes. The auxiliary building and all other Category I structures account for coupling between mutually orthogonal axes by the use of six degrees of freedom per mass point. Seismic building responses at BVPS-2 were calculated from the SRSS combination of the maximum codirectional response values resulting from each of the three spatial components of earthquake motion calculated independently. This method of combining three components of earthquake motion is in compliance with SRP 3.7.2, part II.6a. Therefore, no need exists for statistical independence of input motion. The calculated building responses (accelerations and displacements) account for three components of earthquake motion and include any coupling effects between mutually orthogonal axes.

b. Description of Procedures Used to Generate ARS

BVPS-2 design response spectra are developed based on the response only in the direction of input motion. The insignificant contribution of cross-coupling is implicit in the two-dimensional model justified for the containment in item a. above. For the auxiliary building, the seismic response in each of the three principal directions resulting from the SRSS combination of the codirectional components is presented in Tables 4.2 to 4.4. The response in the direction of excitation is approximately equal to the SRSS resultant value for each case. The effects of cross-coupling and three-component input motion are therefore insignificant on the structure response. This will also be true of the structure response used in calculating the amplified response spectra. Extended to the generation of ARS, it indicates that three-component ARS, conforming to SRP 3.7.2, part II.6b(1) and those generated for BVPS-2 would be essentially identical.

In conclusion, the BVPS-2 amplified response spectra are adequate for design of piping and equipment. Therefore no further review of such system designs is required.

c. Description of Building Design Methodology

Seismic acceleration responses were used to obtain the earthquake terms of the load equations for the design of the containment and auxiliary building. These load equations and a detailed description of the design approach are given in FSAR Section 3.8.

Containment Structure

The containment is a three-direction earthquake seismic design. Seismic forces in both the external shell and internal structure were developed in compliance with the SRSS provisions of SRP 3.7.2 for three components of earthquake excitation.

Auxiliary Building

The auxiliary building is a shear-wall structure in which shear walls resist the horizontal component of the earthquake in the direction of the shear wall. Earthquake loads from the other horizontal and vertical directions introduce vertical stresses in the shear wall. The design was based on a simultaneous vertical and north-south excitation and then a simultaneous vertical and east-west excitation. This approach is conservative in that only continuous walls parallel to the earthquake direction resisted the shear and overturning forces.

A calculation was made to determine the effect of a three-direction earthquake excitation. It was determined using the SRSS provisions of SRP 3.7.2 that at no location on the base mat interface did a vertical member experience tensile stress. The deadweight compressive stress is reduced but not relieved by the consideration of the three-direction earthquake. Therefore, there will not be a reduction of concrete shear strength, due to tension, from that used in the original design.

It is concluded that the building can meet the provisions of SRP 3.7.2 with respect to three-component seismic excitation.

TABLE 4.1

CONTAINMENT STRUCTURE PROPERTIES

			Cm*(ft)		CR_H**(ft)		CR_V***(ft)	
			X	Z	X	Z	X	Z
Node/Mass	Structure	Elev	G	G	G	G	G	G
1	External Shell	854.22'	0.	0.				
					0.	0.	0.	0.
2	External Shell	813.62'	0.	0.				
					0.	0.	0.	0.
3	External Shell	788.62'	0.	0.				
					0.	0.	0.	0.
4	External Shell	763.62'	0.	0.				
					0.	0.	0.	0.
5	External Shell	738.62'	0.	0.				
					0.	0.	0.	0.
6	External Shell	717.32'	0.	0.				
					0.	0.	0.	0.
7	External Shell	699.72'	0.	0.				
					0.	0.	0.	0.
8.	Mat	680.92'	0.08	-0.07				
					3.35	4.17	2.35	2.34
9	Internals	715.92'	-1.75	-0.78				
					1.17	-4.86	-5.49	-6.49
10	Internals	737.92'	-0.2	-1.2				
					2.25	-0.048	5.5	2.07
11	Internals	767.72'	-0.28	1.8				
					-0.179	-0.493	-0.179	-0.493
12	Internals	792.92'	0.0	0.0				
					0.0	0.0	0.0	0.0
13	Internals	817.92'	3.24	0.0				

NOTES:

*C_m = Center of mass.
**CR_H = Center of stiffness for horizontal forces.
***CR_v = Center of stiffness for vertical forces.

TABLE 4.2

THREE-COMPONENT EARTHQUAKE AUXILIARY BUILDING ACCELERATION RESPONSE IN THE N/S DIRECTION (ft/sec^2)

Floor Elevation	Response Direction	Contribution From E-W Excitation	Contribution From N-S Excitation	Contribution From Vertical Excitation	SRSS Resultant
710'-6"	N-S	0.36	6.51	0.71	6.56
735'-6"	N-S	0.26	7.83	0.55	7.85
755'-6"	N-S	0.26	9.31	0.47	9.33
773'-6"	N-S	0.32	10.73	0.45	10.74
797'-6"	N-S	1.04	13.60	0.79	13.67

TABLE 4.3

THREE-COMPONENT EARTHQUAKE AUXILIARY BUILDING ACCELERATION RESPONSE IN THE E/W DIRECTION (ft/sec^2)

Floor Elevation	Response Direction	Contribution From E-W Excitation	Contribution From N-S Excitation	Contribution From Vertical Excitation	SRSS Resultant
710'-6"	E-W	6.13	0.35	1.85	6.41
735'-6"	E-W	7.23	0.27	1.50	7.39
755'-6"	E-W	8.83	0.30	1.30	8.93
773'-6"	E-W	10.51	0.36	1.23	10.59
797'-6"	E-W	14.20	1.08	1.61	14.33

TABLE 4.4

THREE-COMPONENT EARTHQUAKE AUXILIARY BUILDING ACCELERATION RESPONSE IN THE VERTICAL DIRECTION (ft/sec^2)

Floor Elevation	Response Direction	Contribution From E-W Excitation	Contribution From N-S Excitation	Contribution From Vertical Excitation	SRSS Resultant
710'-6"	Vertical	1.66	0.62	8.02	8.21
735'-6"	Vertical	1.66	0.75	8.18	8.38
755'-6"	Vertical	1.99	0.68	8.35	8.61
773'-6"	Vertical	1.87	0.87	8.37	8.62
797'-6"*	Vertical	2.48	3.23	8.81	9.71

NOTE:

*Location of degrees of freedom is offset from all lower elevations so rocking/vertical coupling will result.

7. Perform soil-structure interaction analyses for the two key structures (containment and intake structure) to show that the intent of SRP 3.7.2.II.4 is met. Where discrepancies from the SRP are identified, provide a justification by accounting for as-built strength of materials and design conservatisms. Also, compute for the intake structure applicable safety factors against sliding and overturning based on the revised analyses and show conformance to the criteria of SRP Section 3.8.5.

Response:

To demonstrate that the intent of SRP 3.7.2.II.4 is met, an alternate soil-structure model of the containment was developed. The original soil-structure interaction analysis used the finite element method (PLAXLY computer code), in which the soil was modeled as finite elements and the structure as a lumped mass elastic beam (FSAR Section 3.7.2).

The alternate soil-structure interaction analysis uses the same lumped mass elastic beam model to represent the containment structure; the soil is modeled as a half-space using the compliance function method of analysis. The analysis method is based on the three-step solution developed by Kausel and Whitman.

The three-step method consists of the following:

1. Calculation of frequency-dependent soil stiffness (subgrade impedances)
2. Modification of the specified surface motion to account for structure embedment (kinematic interaction)
3. Interaction analysis

These steps are presented on Figure 7.1.

Step 1: Subgrade Impedances

The frequency-dependent stiffness of a footing founded at the surface of a layered medium is computed with the computer program REFUND. The program solves the problem of forced vibration of a rigid plate on a viscoelastic, layered stratum using numerical solutions to the generalized problems of Cerruti and Boussinesq. The effects of unit harmonic horizontal and vertical loads are combined by superposition to produce the total behavior of the plate.

The effects of foundation embedment on the subgrade impedances are included by employing correction factors described by Kausel et al. These correction factors are determined from parametric studies of embedded foundations and are of the form:

$$C_r = \left(1+C_1\frac{R}{H}\right)\left(1+C_2\frac{E}{R}\right)\left(1+C_3\frac{E}{H}\right)$$

in which:

Cr = correction factor
R = foundation radius
E = embedment depth
H = depth to bedrock
C_i = constants, dependent on degree of freedom

Step 2: Kinematic Interaction

In the second step of the analysis shown on Figure 7.1, the purely translational input ground motion specified at the surface of the stratum is transformed into both a translational and rotational motion at the base of the rigid, massless foundation. In a stratum undergoing translational motion only, the boundary conditions at the "excavation" require the foundation to rotate.

Step 3: Interaction Analysis

The third step of the procedure is the analysis of the structural model supported on the frequency-dependent soil spring from Step 1 for the modified seismic input motion from Step 2. The solution is achieved using the computer program FRIDAY. FRIDAY solves the equations of motion in the frequency domain, determining response time histories by convolution of the transfer functions and the Fourier transform of the input excitation.

Tables 7.1, 7.2, and 7.3 provide a summary comparison of the fundamental frequencies, seismic response accelerations, and the total base shears resulting from both analyses. The results of the two analysis methods are in close agreement with the three-step solution consistently giving the more conservative results.

Given that the methodologies of the two solutions are completely different, and that the results are essentially the same, either solution could reasonably be used for design purposes. The resulting design of the structure would be identical for either set of results.

Therefore, the intent of SRP 3.7.2.II.4 is met for BVPS-2.

References:

Kausel, E.; Whitman, R.V.; Morray, J.P.; and Elsabee, F. 1978. "The Spring Method for Embedded Foundations," Nuclear Engineering and Design, Vol. 48, pp 377-392.

TABLE 7.1

COMPARISON OF FUNDAMENTAL FREQUENCIES (Hz)

	PLAXLY	FRIDAY
External Structure	3.5	2.8
Internal Structure	3.5	2.8

TABLE 7.2

COMPARISON OF STRUCTURE RESPONSE - SAFE SHUTDOWN EARTHQUAKE

Elevation (ft)	Horizontal Accelerations (g)	
	PLAXLY Model	FRIDAY Model
854.0	0.163	0.166
813.0	0.126	0.147
788.0	0.118	0.138
763.0	0.109	0.128
738.0	0.101	0.118
717.0	0.098	0.109
699.0	0.098	0.102
681.0	0.098	0.096
818.0	0.199	0.197
793.0	0.171	0.183
767.0	0.140	0.167
738.0	0.126	0.151
716.0	0.116	0.138

TABLE 7.3

COMPARISON OF STATIC STORY FORCES

Elevation (ft)	Horizontal Force (kip) PLAXLY Model	 FRIDAY Model
854.0	1244.	1267.
813.0	811.	947.
788.0	874.	1022.
763.0	807.	948.
738.0	748.	874.
717.0	511.	569.
699.0	511.	532.
681.0	2845.	2787.
818.0	271.	268.
793.0	432.	462.
767.0	1694.	2021.
738.0	1732.	2075.
716.0	1445.	1719.
Total Base Shear	13,925.	15,491.

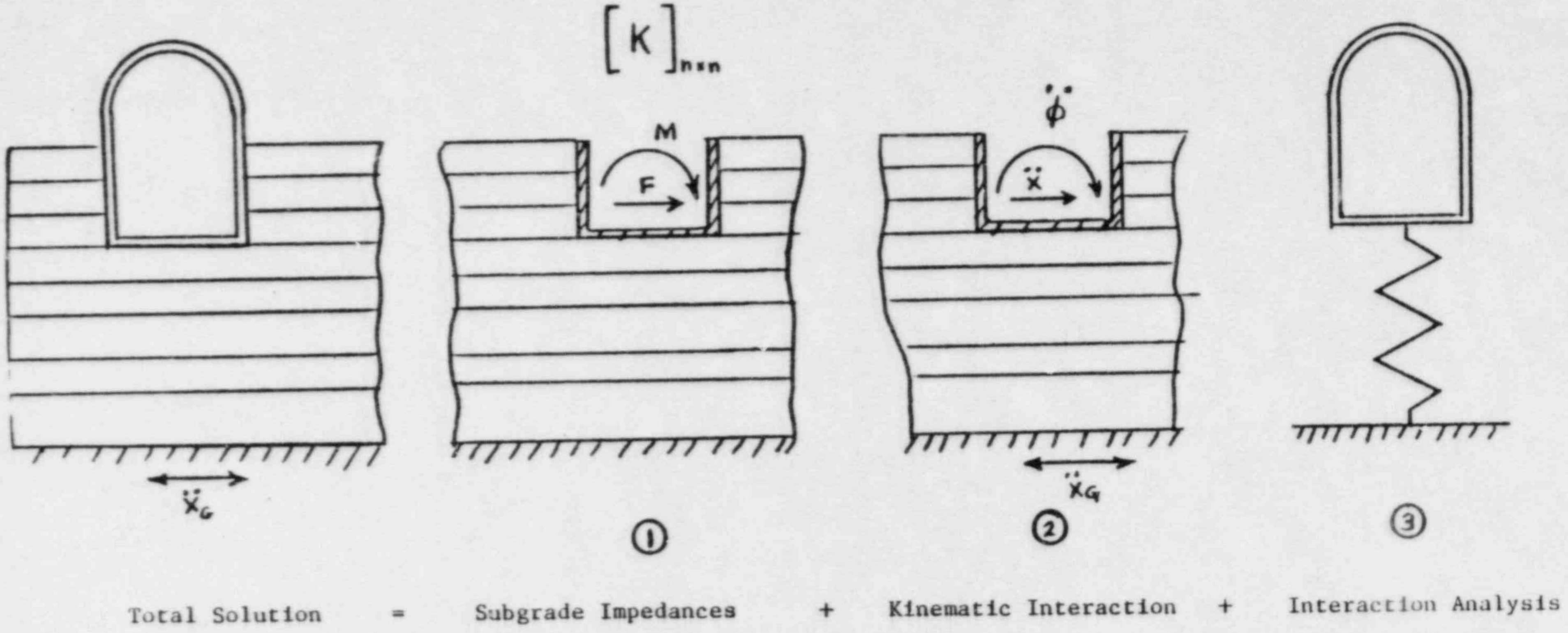


Figure 7.1

Three-Step Soil-Structure
Interaction Solution

Beaver Valley Power Station
Unit 2

8. The applicant did not use the ASME Section III Division 2 code provisions (ACI 359) pertaining to load combinations, design allowables, materials, quality control and special construction techniques for the BVPS-2 design. Instead, the applicant used the applicable provisions contained in the ACI 318-71 code. The applicant is requested to demonstrate that the requirements of the ASME III Division 2 code are met or identify and justify the deviations.

Response:

A review has been performed to identify the significant differences between the criteria for the BVPS-2 design of the reinforced concrete portion of the external structure of the reactor containment (FSAR Section 3.8.1) and the criteria of ACI 359-80 (ASME Section III, Division 2 with addenda through Winter 1980). The results of this review are summarized in Table 8.1; justifications of differences in design criteria are also given.

Table 8.1

COMPARISON OF BVPS-2 REINFORCED CONCRETE CONTAINMENT STRUCTURE DESIGN CRITERIA WITH ACI 359-80 (ASME III, DIVISION 2, SUBSECTION CC)

<table>
<tr><th>ACI-359 Code Subsection</th><th>Significant Difference and Justification</th></tr>
<tr><td>CC-2223.1</td><td>ACI 359 requires water to be tested, for total solids content, in accordance with APHA 208. BVPS-2 mixing water is tested for total solids in accordance with ASTM D1888. The intent of ACI 359 is met. Later versions of the code invoke ASTM D1888.</td></tr>
<tr><td>CC-2310 & CC-2333</td><td>ACI 359 chemical and physical requirements for Nos. 14 and 18 bars are:
<table>
<tr><td>Carbon</td><td>0.30% maximum</td></tr>
<tr><td>Manganese</td><td>1.50% maximum</td></tr>
<tr><td>Silicon</td><td>0.50% maximum</td></tr>
<tr><td>Phosphorus</td><td>0.05% maximum</td></tr>
<tr><td>Sulfur</td><td>0.05% maximum</td></tr>
<tr><td>Yield strength</td><td>60 ksi minimum</td></tr>
<tr><td>Elongation</td><td>7% minimum in 8-inches</td></tr>
<tr><td>Tensile strength</td><td>90 ksi minimum</td></tr>
</table>
Reinforcing steel in sizes Nos. 14 and 18 is in accordance with ASTM A615 as modified to meet the following chemical and physical requirements:
<table>
<tr><td>Carbon</td><td>0.35% maximum</td></tr>
<tr><td>Manganese</td><td>1.25% maximum</td></tr>
<tr><td>Silicon</td><td>0.15% maximum</td></tr>
<tr><td>Phosphorus</td><td>0.05% maximum</td></tr>
<tr><td>Sulfur</td><td>0.05% maximum</td></tr>
<tr><td>Yield strength</td><td>50 ksi minimum</td></tr>
<tr><td>Elongation</td><td>13% minimum in an 8-inch test sample using a full-section test specimen</td></tr>
<tr><td>Tensile strength</td><td>70 ksi minimum</td></tr>
</table>
The intent of ACI 359 is met.</td></tr>
</table>

Table 8.1 (Cont'd)

ACI-359 Code Subsection	Significant Difference and Justification
CC-3200	Load Criteria - Load Categories, Load Combinations, Load Definitions. See Attachment 8.1. The intent of ACI 359 is met.
CC-3421.6	ACI 359 requires the allowable peripheral shear stress be determined as a function of the membrane stresses. For peripheral shear, the BVPS-2 criteria follow Section 11.10.3 of ACI 318-71 with no reduction in allowable Vc for zones of biaxial tension. This is less conservative than the ACI 359 approach but is reasonable in view of NUREG/CR 2920, "Behavior of Reinforced Concrete Slabs Subjected to Combined Punching Shear and Biaxial Tension," issued September 1982. Also, it has been conservatively assumed that peak punching shear occurs simultaneously with peak biaxial tension. It is expected that these peak values are not coincident.
CC-3431 CC-3432 CC-3511.2	ACI 359 requires straight line theory (the alternate design method of ACI 318-71, Section 8.10, generally known as "working stress design") be used for service load design (CC-3511.2). The allowable stresses for this design method are given in CC-3431 for concrete stresses and in CC-3432 for reinforcing steel stresses and strains. BVPS-2 design for service loads is in accordance with ACI 318-71, Section 10.2 (generally known as "ultimate strength design"), and therefore a direct comparison of allowable stress is not appropriate. The base of the containment wall was reanalyzed using the ACI 359 criteria. Reinforcing steel stresses and strains are in accordance with CC-3432. The intent of ACI 359 is met for reinforcing steel stresses and strains. The maximum concrete stress allowed by CC-3431 is 0.60 f'c. Analysis indicates that the corresponding BVPS-2 concrete stress is 0.79 f'c. Justification of the BVPS-2 design is based upon the actual concrete compressive strengths which are approximately 4000 psi, as compared to a design compressive strength of 3000 psi. Calculated compressive stress at the base of the containment wall does not exceed 2400 psi for the test service load. Therefore, the intent of ACI 359 is met for concrete stresses.
CC-4122.1	ACI 359 requires that each concrete placement be identified on as-built sketches. BVPS-2 requires the completion of concrete pour release cards and the testing of constituents and concrete. The pour release cards serve as records of the extent of the pour. The concrete testing, in accordance with specified testing frequency, provides a record of the quality of concrete placed. BVPS-2 therefore complies with the intent of ACI 359-80 for concrete quality traceability.

Table 8.1 (Cont'd)

ACI-359 Code Subsection	Significant Difference and Justification
CC-4323.2	ACI 359 allows bar Nos. 3 through 5 to be cold bent once; bar Nos. 6 and larger shall be preheated. BVPS-2 permits No. 3 to No. 8 bars to be cold-bent once then straightened, or straightened once to remove an inadvertent bend as long as the temperature of the bar at the area in question exceeds 60°F and the maximum bend angle is 105°. Preheat is required for subsequent straightening or bending and for all bending of bars No. 9 and larger. BVPS-2 requirements are more restrictive than ACI 318-71. BVPS-2 therefore complies with the intent of ACI 359-80.
CC-5332	ACI 359 specifies radiographic examination of welded joints of reinforcing bars. BVPS-2 performs full-size tensile testing of arc-welded joints. Production splices or sister splices, made under similar position and accessibility conditions, are selected at random for testing. Every splice tested must equal or exceed 125 percent of the bar-specified minimum yield strength. The average tensile strength of each group of 15 consecutive splices must equal or exceed the bar minimum tensile strength.
CC-6232	ACI 359 specifies radial displacements of the cylinder be taken at a minimum of five elevations between the base slab and springline; vertical displacement to be taken at the dome apex and two intermediate points between the apex and the springline. BVPS-2 measures radial displacements at three elevations between the base slab and the springline of the cylinder. These measurements are made at six equally-spaced meridians. Vertical displacement is measured at the springline at six meridians spaced around the containment and at the apex of the dome. BVPS-2 complies with Regulatory Guide 1.18.

ATTACHMENT 8.1

COMPARISON OF LOAD COMBINATIONS
BVPS-2 DESIGN CRITERIA VS ACI 359-80

Service Condition	ACI 359	BVPS-2 Structural Design Criteria	Justification
Test	$1.0D+1.0L+1.0P_t+1.0T_t$	$1.0D^*+1.0P_t+1.0T_t$	
Construction	$1.0D+1.0L+1.0T_o+1.0W$	---	Absence of these combinations in design criteria has no impact since containment is designed for and governed by severe loads.
Normal	$1.0D+1.0L+1.0R_o+1.0P_v$	---	
Severe Environmental	$1.0D+1.0L+1.0T_o+1.0\ OBE+1.0R_o+1.0P_v$		
Factored Loads			
Severe Environmental	$1.0D+1.3L+1.0T_o+1.5\ OBE+1.0R_o+1.0P_v$**	---	**ACI 359 does not require these load combinations to be checked since they are also specified under Service Loads.
	$1.0D+1.3L+1.0T_o+1.5W+1.0R_o+1.0P_v$**	---	
Extreme Environmental	$1.0D+1.0L+1.0T_o+1.0W_t+1.0R_o+1.0P_v$	$1.0D^*+1.0T_o+1.0W_t$	Pipe reactions, Ro, have negligible effect on the overall structure. Ro is analyzed for its local effects on the reinforced concrete section. Pv is not considered because it is slightly subatmospheric and would tend to reduce the stresses due to the pressure drop during a tornado.

Service Condition	ACI 359	BVPS-2 Structural Design Criteria	Justification
Extreme Environmental	$1.0D+1.0L+1.0T_o+1.0SSE+1.0R_o+1.0P_v$	---	Does not govern. Effect is less than abnormal/extreme environmental.
Abnormal	$1.0D+1.0L+1.5P_a+1.0T_a+1.0R_a$	$1.0D^*+1.5P_a+1.0T_a$	Ra has negligible effect on overall structure. Local effects are analyzed.
	$1.0D+1.0L+1.0P_a+1.0T_a+1.25R_a$	---	Does not govern.
Abnormal/ Severe Environmental	$1.0D+1.0L+1.25P_a+1.0T_a+1.25\ OBE+1.0R_a$	$1.0D^*+1.25P_a+1.0T_a+1.25\ OBE$	Ra has negligible effect on overall structure. Local effects are analyzed.
Abnormal/ Severe Environmental	$1.0D+1.0L+1.25P_a+1.0T_a+1.25W+1.0R_a$	---	Effects of 1.25 W are negligible in comparison to 1.25 OBE or 1.0 SSE.
Abnormal/ Severe Environmental	$1.0D+1.0L+1.0T_o+1.0\ OBE$ or $1.0W+1.0H_a$	---	Negligible internal flooding. Equation does not apply.
Abnormal/ Extreme Environmental	$1.0D+1.0L+1.0P_a+1.0T_a+1.0SSE+1.0R_a$	$1.0D^*+1.0P_a+1.0T_a+1.0SSE$	Ra has negligible effect on overall structure. Local effects are analyzed.

NOTE: Since ACI 318-71 equations are not applicable to containment design, comparison is made between BVPS-2 criteria and ACI 359-80.

*Dead load includes the effects of earth and hydrostatic forces and ice and snow loads when their effect increases resultant stresses. Additional live loads (L) are negligible and thus are ignored.

9. Perform an ultimate capacity analysis for the containment.

Response:

The BVPS-2 reinforced concrete reactor containment structure is a right circular cylinder with a hemispherical dome. The cylinder contains an equipment hatch, a personnel hatch, and numerous penetrations for piping and electrical leads. The cylinder has an inside diameter of 126.0 ft and a wall thickness of 4.5 ft; the dome is 2.5 ft thick. The cylinder is supported on a 10.0 ft thick circular foundation mat (FSAR Section 3.8.1).

Concrete design was based on a minimum compressive strength, at 28 days, of 3000 psi.

The concrete in the cylinder and dome is reinforced with continuous 2.25 in. diameter (No. 18S) steel reinforcing bars arrayed in the hoop and meridional directions. Supplemental reinforcing steel was installed around penetrations to account for stress concentrations. Heavy reinforcement was provided at the junction of the cylinder wall and the foundation mat to control flexure and shear at this discontinuity. The cylinder also contains tangential/diagonal reinforcement designed to resist earthquake forces. The foundation mat is reinforced with 2.25 in. diameter (No. 18S) reinforcing bars in radial and circumferential arrays at the top and in a rectilinear pattern at the bottom. Reinforcement is ASTM A615 with a minimum yield strength of 50,000 psi.

Reinforcing steel was proportioned using the ultimate strength design method with combinations of various factored loads (FSAR Section 3.8.1). These loads include the pressure (45.0 psig) and temperature (280°F) effects of the postulated LOCA, earthquake force, internal and external missiles, tornado wind, and pipe rupture loads. The largest single demand for strength in the pressure boundary comes from the LOCA pressure, which has a 1.5 load factor.

The containment is fully lined throughout with 0.375 in. thick steel plate on the cylinder, 0.5 in. steel plate on the dome and 0.25 in. steel plate covering the foundation mat. All liner welds are leaktight and covered with steel test channels. The liner steel is SA537, Grade B, with a minimum yield strength of 60,000 psi.

The BVPS-2 containment design did not take credit for the load-carrying capacity of the liner; all the load was assumed to be taken by the reinforced concrete.

The as-built material strengths for the containment structure are:

a. concrete: minimum f'c = 3500 psi at 28 days
mean f'c = 4460 psi at 28 days

b. reinforcing bars:

No. 18S minimum fy = 52,000 psi
mean fy = 56,500 psi
No. 14 minimum fy = 52,900 psi
mean fy = 57,900 psi

c. liner plate minimum fy = 61,300 psi
mean fy = 79,000 psi

The ultimate pressure capacity of the concrete containment is calculated to be 124 psi, based on general yielding of the hoop bars in the membrane zone of the wall at locations away from structural discontinuities based on minimum yield strengths.

The following areas were checked to verify that they can develop an ultimate capacity equal to or greater than that of the membrane zone:

1. foundation mat
2. wall/mat junction
3. areas local to major penetrations through the wall
4. dome/wall junction
5. dome (membrane zone)

The 124-psi ultimate pressure capacity corresponds to 2.8 times the original design pressure of the containment.

10. Identify the differences between ASME III Division 2 and specific criteria used in design of BVPS-2 liner and justify any deviations therefrom.

Response:

A review of the ASME III Division 2 code was performed. A summary of the significant differences between the 1980 edition of ASME III Division 2 criteria and that used in the design of the BVPS-2 liner (the 1971 edition through and including the 1972 Winter addenda of ASME III Division 1 which was used as a guide), along with justifications, are presented in Table 10.1.

Table 10.1

	ASME III Division 2, 1980 Edition Criteria	BVPS-2 Criteria	Justification
CC-1000 Introduction	CC-1120 The rules of Division I shall apply as required in this subsection for parts and appurtenances not backed by concrete for load carrying purposes. Those parts or appurtenances stamped in accordance with Division 2 shall meet the requirements of subsection NCA, CC-.000, CC-6000, CC-7000, and CC-8000 in lieu of the corresponding requirements of Division 1. Those parts or appurtenances stamped in accordance with Division 1 shall meet all the requirements of Division 1 and NCA-2134(e).	BVPS-2 components not backed by concrete followed the rules of ASME III Division 1. Those portions backed by concrete used ASME III Division I as a guide in the selection of materials, fabrication (including welding), nondestructive examination, design and inspection of the steel liner and mat embedments.	The BVPS-2 components backed by concrete are shown by the following comparisons to meet the intent of Division 2 for a leaktight membrane.
CC-2000 Materials	CC-2523.2 Impact test specimens for Charpy V-notch tests shall be oriented in accordance with the requirements given for tensile test specimens in SA-370.	BVPS-2 impact test specimens for Charpy V-notch used the rules of NE-2220 for orientation and location.	BVPS-2 followed the rules of Division 1 which assures that the materials have adequate impact properties.
	CC-2528 Calibration of temperature instruments and Charpy V-notch impact test machines, used in impact testing, shall be performed at the following frequency:	BVPS-2 used the criteria of NE-2610. That is: Materials manufacturers shall document and maintain Quality Assurance Programs (See NA-4000). As a minimum, the programs shall provide for the following, as applicable:	BVPS-2 uses ASME III Quality Assurance programs and industry practices for the performance of tests.
	a. Temperature instruments used to control test temperature of specimens shall be calibrated and the results recorded to meet the requirements of NCA-4134.12 and NCA-4134.17 at least once in each three month interval.	a. Calibration and periodic check for accuracy of all mechanical testing and nondestructive examination.	

Table 10.1 (Cont'd)

ASME III Division 2, 1980 Edition Criteria	BVPS-2 Criteria	Justification
b. Charpy V-notch impact test machines shall be calibrated and the results recorded to meet the requirements of NCA-4134.12 and NCA-4134.17. The calibrations shall be performed at least once in each 12 month interval using methods outlined in ASTM E 23 and employing standard specimens obtained from the U. S. Army Materials Research Center.	Each program shall be subject to review by the manufacturer of components, parts, and appurtenances in accordance with NA-4000. BVPS-2 uses the criteria of NE-2350 for the performance of Charpy V-notch tests.	
CC-2531 Liner material shall be examined and repaired in accordance with the material specification and as otherwise required by this Article.	BVPS-2 followed the criteria of NE-2510 where identified defects in material were repaired using an approved method based on the extent of repairs (see NE-4621.1). Defective material that could not be satisfactorily repaired was rejected.	BVPS-2 methods of detection and repairs meets the intent of Division 2 by returning the material to the original requirements or replacing with nondefective material.
CC-2532 Ferritic steel products which are used in the quenched and tempered condition shall be examined by the methods specified in this Article for each product form after the quenching and tempering phase of the heat treatment.	BVPS-2 followed the criteria of the applicable Section II material specifications for each product form.	BVPS-2 material examinations of quenched and tempered steel meet the intent of Division 2 by providing assurance that the material meets nuclear industry standard practices.
CC-2534.2 Acceptance examinations shall be performed at the time of manufacturing.	BVPS-2 followed the criteria of the applicable Section II material specification for each product form at the time of manufacturing.	BVPS-2 material examinations meet the intent of Division 2 by providing assurance that the material is acceptable at the time of manufacturing.

Table 10.1 (Cont'd)

	ASME III Division 2, 1980 Edition Criteria	BVPS-2 Criteria	Justification
	CC-2613 Chemical Analysis Test (Due to length the text of CC-2613 is not given).	BVPS-2 followed the criteria of NE-2432, ASME IX and the requirements of SFA-5.4 and SFA-5.5 of ASME II Part C.	BVPS-2 followed rules which provided assurance that the welding materials complied with nuclear industry standards, thus meeting the intent of Division 2.
CC-3000 Design	CC-3131 Service load Category, CC-3132 Factored load Category, and CC-3133 Serviceability, CC-3220 to and including CC-3230.	The loads and load combinations used in the design of BVPS-2 are shown in Attachment 10.1.	The BVPS-2 use of similar load combinations as Division 2 and the allowables of NE-3000 results in a design meeting the intent of Division 2.
	CC-3720 The calculated strains and stresses for the liner shall not exceed the values given in Table CC-3720-1. The load combinations shown in Table CC-3230-1 are applicable to the liner except that load factors for all load cases may be taken equal to 1.0. The load combinations are given in Attachment 10.1. The strain allowables are given in Attachment 10.2.	The stress allowables used in the design of BVPS-2 are shown in Attachment 10.2.	
	CC-3730 (b) The allowable force and displacement capacities of liner anchors are given in Table CC-3730-1. These values are listed in Attachment 10.3.	BVPS-2 used the tension and shear allowable design loads shown in Attachment 10.3. The BVPS-2 anchors of the general liner are designed for the load combinations shown in Attachment 10.1. Where anchors have mechanical loads, the mechanical loads are added to the load combinations in Attachment 10.1. For displacement limited loads, the BVPS-2 allowable design loads are well below the Division 2 allowables. For mechanical loads, the	BVPS-2 anchor studs have an adequate margin based on worst case design loads and ultimate displacements.

Table 10.1 (Cont'd)

	ASME III Division 2, 1980 Edition Criteria	BVPS-2 Criteria	Justification
		BVPS-2 allowable design loads are greater than the Division 2 allowables. As shown on Figures 10.1 and 10.2 there is adequate margin between the BVPS-2 allowable design loads and the ultimate failure capacity of the anchor. The BVPS-2 values result in a factor of safety of 3 for tension and 10 for shear when comparing the displacement at the allowable design load to the anchor's ultimate displacement (based on the Nelson Stud).	
	CC-3750(a) The design allowables for brackets, attachments, and the liner in the vicinity shall be the same as those given in AISC, Manual of Steel Construction, Part 5, Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings, for resisting mechanical loads in the construction, test, and normal categories. For all other categories the allowables may be increased by a factor of 1.5, except for impulse loads and impact effects.	BVPS-2 liner, inserts, and overlay plates in the vicinity of brackets and attachments used the guidelines of ASME III, Division 1, NE-3000 and the load combinations given in Attachment 10.1, plus the mechanical loads.	BVPS-2 use of NE-3000 methods for analysis are comparable to Division 2.
CC-4000 Fabrication and Construction	CC-4522.1.1 At the specified increments of elevation, the difference between the maximum diameter and the minimum diameter shall not exceed 1/2 of 1 percent.	BVPS-2 used the criteria of Division 1 which has a tolerance of 1 percent.	The BVPS-2 liner meets the intent of Division 2 by using nuclear industry standard practices for pressure vessel construction.

Table 10.1 (Cont'd)

	ASME III Division 2, 1980 Edition Criteria	BVPS-2 Criteria	Justification
	The overall containment plumbness of the liner cylinder between the springline (start of dome) and the bottom shall be 1 in 200 based on the total height of the cylinder.	BVPS-2 requires a plumbness of 1 in 480.	BVPS-2 is more stringent than Division 2
CC-5000 Construction and Examination	CC-5111 Nondestructive examinations shall be in accordance with the procedures of ASME V.	BVPS-2 used Appendix X of Division 1 for Class MC components and ASME V for all other items of the containment liner.	BVPS-2 examination procedures are equivalent to, thus meeting, the intent of Division 2
	CC-5122.1 Qualification Procedure (Test not listed due to length.) Division 2 adds exception to SNT-TC-1A.	BVPS-2 required personnel to be qualified to SNT-TC-1A, in accordance with the requirements of Division 1, NE-5521.	BVPS-2 followed the practices in effect at the time of examinations; these practices meet the intent of Division 2 to provide a procedure qualified to nuclear industry standard practices.
	CC-5536.2 Leak testing of leak-chase systems shall be performed in accordance with T-1030 of Section V except that the test pressure shall be at least 115 percent of design pressure.	BVPS-2 followed the rules of Section V, with a test pressure of design pressure to 111 percent of design pressure, and Regulatory Guide 1.19 for leak testing.	BVPS-2 meets the intent of of Division 2 to assure the leak tightness of the leak chase system.
CC-6000 Structural Integrity Test of Containment Structures	CC-6000 Stipulates the requirements for the initial acceptance testing of concrete containment structures.	BVPS-2 criteria meet the requirements of NRC Regulatory Guide 1.18.	BVPS-2 meets the intent of Division 2 to assure the structural adequacy of the concrete containment structure.
CC-7000 Overpressure Protection	CC-7000 makes the rules of NE-7000 applicable.	BVPS-2 follows the rules of NE-7000.	BVPS-2 meet the requirements of Division 2.

Attachment 10.1

Load Combinations Comparison

Division 2 (Table CC-3230-1)

Category	Load Combination
Service	
Test	$D + P_t + T_t$*
Construction	$D + W$**
Normal	$D + T_o + P_v$***
Severe Environmental	$D + T_o + E_o + P_v$
	$D + T_o + P_v$
Factored	
Extreme Environmental	$D + T_o + E_{ss} + P_v$
	$D + T_o + P_v$
Abnormal	$D + P_a + T_a$
Abnormal/Severe Environmental	$D + P_a + T_a + E_o$ $D + P_a + T_a$ $D + T_o + E_o + E_{ss}$ $D + T_o$
Abnormal/Extreme Environmental	$D + P_a + T_a + E_{ss}$

BVPS-2 (FSAR Table 3.8-9)

Category	Load Combination
Test	$D + P_t$
Normal (Cyclic)	$D + P_o + T_o + 1/2$ SSE 100 cycles of P_o 400 cycles of T_o 100 cycles of 1/2 SSE
Severe Operational	$D + P_{min} + 1/2$ SSE $D + P_{min} + T_{min} + 1/2$ SSE
Emergency	$D + P_d + T_d +$ SSE

NOTES:

*Test temperature is approximately ambient.

**Construction loads were not considered as a loading combination for BVPS-2. The BVPS-2 liner was supported to resist distortion or collapse during construction by wind bracing which was designed per industry standard API-650.

***The pressure P_v is equal to P_{min}.

For definition of terms, see FSAR Section 3.8.1.

The liner, excluding areas of penetrations, airlocks, equipment hatch, insert plates, and overlay plates, does not encounter the following loads which are given in the load combinations of Division 2 and excluded from the load combination comparison.

L - Live Load	The liner outside the areas excluded above has no induced live loads.
F - Prestress	The BVPS-2 containment is not a prestress design.
R_o - Pipe Reactions	The pipe reaction loads are resisted by the containment liner penetrations, including reinforcement plate, which would result in insignificant loads being imposed on the liner which falls under Division 2 rules.
W - Wind (Applicable for construction only)	The containment liner is not credited for structural strength in the design of the reinforced concrete structure which is the structural element for the wind loads. Since the wind load is not a governing load it is not considered in the liner analysis.
W_t - Tornado	Same as for W, also the wind pressure and differential pressure loads are less than the maximum internal design pressure. The containment liner is protected from tornado generated missles by the reinforced concrete structure which is the structural element for the tornado loads. Since the tornado wind load is not a governing load it is not considered in the liner analysis.
H_a - Internal Flooding	The pressure due to internal flooding is less than the maximum internal design pressure.
R_r - Local Effects	The BVPS-2 containment liner has no postulated loads generated by a ruptured high energy pipe break, jet impingement, or impact of a ruptured high energy pipe.

Attachment 10.2

Stress Strain Allowable Comparison

Division 2 (Table CC-3720-1)

Load Category	Membrane	Combined Membrane and Bending
Service	$\varepsilon_{st} = \varepsilon_{sc} = 0.002$ in/in	$\varepsilon_{st} = \varepsilon_{sc} = 0.004$ in/in
Factored	$\varepsilon_{sc} = 0.005$ in/in	$\varepsilon_{sc} = 0.014$ in/in
	$\varepsilon_{st} = 0.003$ in/in	$\varepsilon_{st} = 0.010$ in/in

BVPS-2 (FSAR Table 3.8-9)

Load Category	Allowable Stress psi	Allowable Strain* (in/in)
Emergency	$P_m+P_b+Q<3Sm$	0.0024
Test	$P_m <0.9Sy$	0.0019
	$P_m+P_b<1.35Sy$	0.0029
Severe Operational	$P_m<Sm$	0.0008
	$P_m+P_b<1.5Sm$	0.0012
	$P_m+P_b+Q<3Sm$	0.0024
Normal (Cyclic)	Use method of NB-3222.4(d) or (e)	

NOTE:

*The strains shown were calculated for comparison purposes. They are for SA-537 Grade B liner material using a modulus of elasticity of 27.9 x 10^6 psi.

$$\text{Strain} = \frac{\text{Allowable Stress}}{\text{Modulus of Elasticity}}$$

fst = allowable liner plate tensile stress (psi)
fsc = allowable liner plate compressive stress (psi)
ε_{st} = allowable liner plate tensile strain (in./in.)
ε_{sc} = allowable liner plate compressive strain (in./in.)

Pm = General primary membrane stress intensity (psi)
Pl = Local membrane stress intensity (psi)
Pb = Primary bending stress intensity (psi)
Q = Secondary membrane plus bending stress intensity (psi)
Sm = Allowable stress intensity (psi)
Sy = Liner plate yield stress (psi)

Attachment 10.3

Liner Anchor Allowable Comparison

Division 2 (Table CC-3730-1)			BVPS-2 Criteria	
Category	Mechanical Force Loads	Displacement Limited Loads	Category	Allowable Load
Test, Normal, Severe Environmental, Extreme Environmental	$F_a = 0.67 F_y$ $F_a = 0.33 F_u$ Lesser of	$\delta_a = 0.25 \delta_u$	Tension Shear	$0.9F_u$ $0.85F_u$
Abnormal, Abnormal/Severe Environmental, Abnormal/Extreme Environmental	$F_a = 0.9 F_y$ $F_a = 0.5 F_u$	$\delta_a = 0.50 \delta_u$		

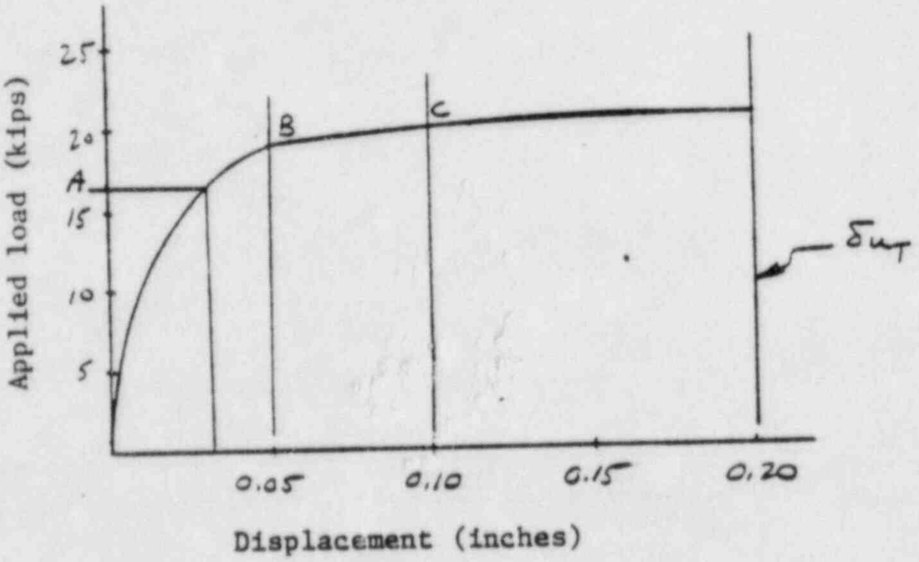
F_a = allowable liner anchor force capacity (lb).

F_y = liner anchor yield force capacity (lb).

F_u = liner anchor ultimate force capacity (lb).

δ_a = allowable displacement for liner anchors (in).

δ_u = ultimate displacement capacity for liner anchors (in).



A = Tension allowable for BVPS-2
B,C = Division 2 allowables for displacement limited loads
δ_{u_T} = Ultimate displacement based on TRW Nelson, Figure 1

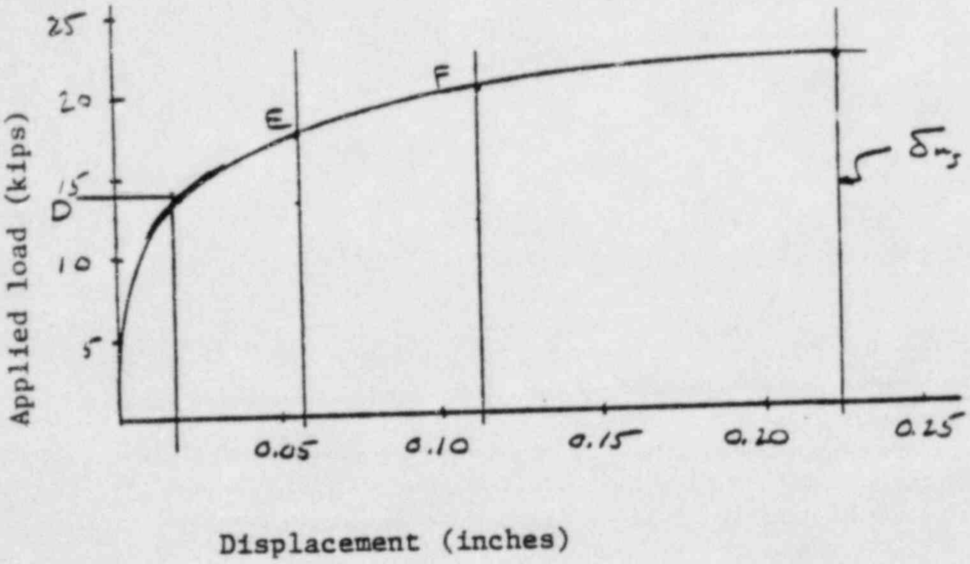
Note:

From "Embedment Properties of Headed Studs," Figure 1, TRW Nelson.

Figure 10.1

Tension vs. Displacement for 5/8-inch Diameter Stud

Beaver Valley Power Station
Unit 2



D = Shear allowable for BVPS-2
E,F = Division 2 allowables for displacement limited loads
δ_{u_s} = Ultimate displacement based on TRW Nelson, Figure 16

Note:

From "Embedment Properties of Headed Studs," Figure 16, TRW Nelson.

Figure 10.2

Shear vs. Displacement
for 5/8-inch Diameter Stud

Beaver Valley Power Station
Unit 2

12. BVPS-2 design response spectra are developed based on the response only in the direction of input motion. Coupling between orthogonal directions of response is not considered. Also, BVPS-2 uses a two-directional input-motion criterion without consideration of the statistical independency among different input time histories.

    The applicant should provide support documents to demonstrate that the Category I structures are reasonably symmetric as was claimed in Amendment 1, therefore, coupling in structural response between mutually orthogonal axes of structures is indeed insignificant. Moreover, the statistical independency of the input motions used in the analysis should be considered in order to comply with the current SRP Section 3.7.2 provisions.

    Response:

    Refer to the response to Item 4.

19. With respect to Category I duct banks, describe the design criteria and analysis procedures used to demonstrate the adequacy, and also indicate if the applicable criteria of SRP Section 3.8.4 were met. For any deviations from the criteria identified, please provide a justification considering the as-built material strengths and conservatisms, as appropriate.

Response:

The design criteria and analysis procedures used to demonstrate the adequacy of the buried seismic Category I conduit duct bank systems at BVPS-2 are in accordance with the Standard Review Plan (SRP) Section 3.8.4 criteria. The analysis considers the following conditions:

(1) Soil pressure
(2) Seismic wave effect on conduits at free field
(3) Seismic wave effect on conduits at bends and tees
(4) Differential movements between structures and adjacent soil due to settlement and seismic motion.

Condition (1) was assessed using well-known methodology such as that of Terzaghi (1955). The effect of the soil pressure on the structural integrity of the buried conduits at BVPS-2 is insignificant due to their cross-section configuration. A typical cross-section of a buried conduit duct bank is shown on Figure 19.1. The effect of conditions (2), (3), and (4) were established with an equivalent static analysis which considers the conduit duct bank as a beam element supported on an elastic foundation.

The basic assumptions inherent in the analysis of buried conduit duct banks are:

(1) Conduits satisfy elementary theory of beams

(2) Soil behaves as a linear elastic, homogeneous, and isotropic material

(3) The portion of the conduit duct bank away from discontinuities such as free ends, bends, and tees will move with the surrounding soil in the presence of a seismic wave.

Effect of Seismic Waves in the Free Field

The buried conduit duct banks in the free field (away from discontinuities) were analyzed following the recommendations of the ASCE Nuclear Structures and Materials Seismic Analysis Committee (1983).

They recommend that the analysis of buried conduit duct banks be based on the effects of only one type of seismic wave, which produces the following:

Axial Strain: $$\varepsilon_a = \pm \frac{V_m}{c}$$

Curvature: $$\Psi = \pm \frac{A_m}{c}$$

Where:

ε_a = maximum axial strain

Ψ = maximum curvature

V_m = maximum soil particle velocity

A_m = maximum soil particle acceleration

c = wave propagation velocity

The axial and bending stresses on the buried conduit duct banks are added algebraically. The conduit duct banks are designed so that the combined stresses and strains remain within the allowable values of the SRP Section 3.8.4 acceptance design criteria.

Seismic Wave Effect on Conduits at Bends and Tees

The effect of the seismic wave on the bends and tees of the buried conduit duct banks is assessed by considering the conduit duct bank as a beam element supported on an elastic foundation. The analysis is based on the method proposed by Shah and Chu (1974). The shear, axial, and bending forces induced at the bends and tees by the relative seismic displacement between the conduit duct bank and the surrounding soil are computed based on compatibility of displacements. The analysis considers the frictional resistance and maximum slippage length at the conduit duct bank-soil interface and the overall stiffness of the bend or tee when establishing the governing compatibility and equilibrium equations. The conduit bends and tees were designed in compliance with the acceptance design criteria of SRP Section 3.8.4.

Differential Movements Between Structures and Adjacent Soil Due to Settlement and Seismic Motion

The effect on the buried conduit duct bank produced by differential movements between the structures to which they are attached and the adjacent soil is assessed by considering the conduit as a beam element supported on an elastic foundation. The analysis is based on compatibility of displacements at the point of attachment. The analytical model considers the beam on elastic foundation and the material in the shake space as two different spring elements acting in series. A typical junction detail and the analytical model are shown on Figures 19.2 and 19.3. The forces on each of the springs is obtained using the maximum relative displacement corresponding to settlement or seismic motion of the structure. The shear and bending forces along the buried conduit are then computed treating the conduit as a beam on elastic foundation with a concentrated load acting at the point of attachment.

References:

Shah, H. H. and Chu S. L. 1974. "Seismic Analysis of Underground Structural Elements," ASCE, Journal of the Power Division, July 1974, p. 53-62.

Terzaghi, K. 1955. "Evaluation of Coefficients of Subgrade Reaction," Geotechnique, p. 297-325.

Working Group for Seismic Response of Buried Pipes and Structural Components 1983. "Seismic Response of Buried Pipes and Structural Components," report by the Seismic Analysis Committee of the ASCE Nuclear Structures and Materials Committee, 1983.

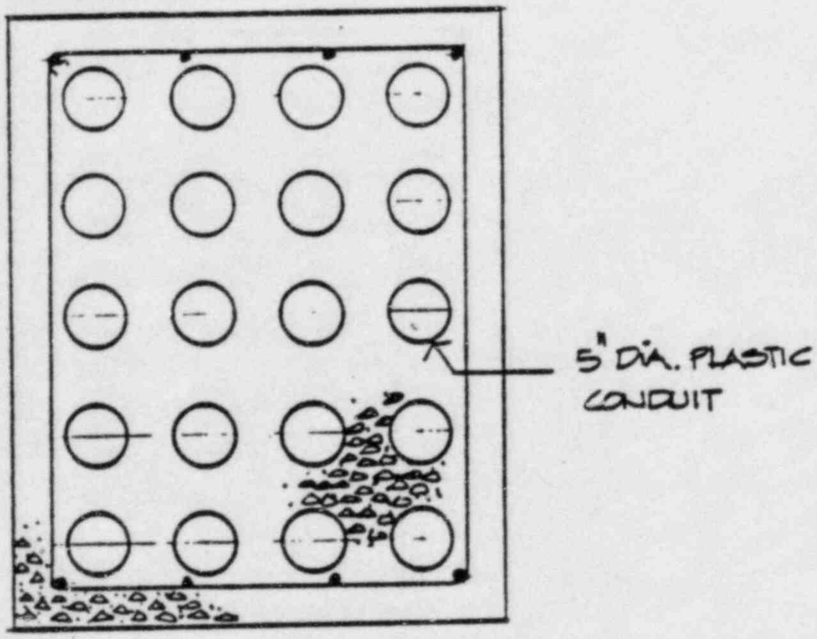


Figure 19.1

Typical Cross-Section of Buried Conduit Duct Bank

Beaver Valley Power Station
Unit 2

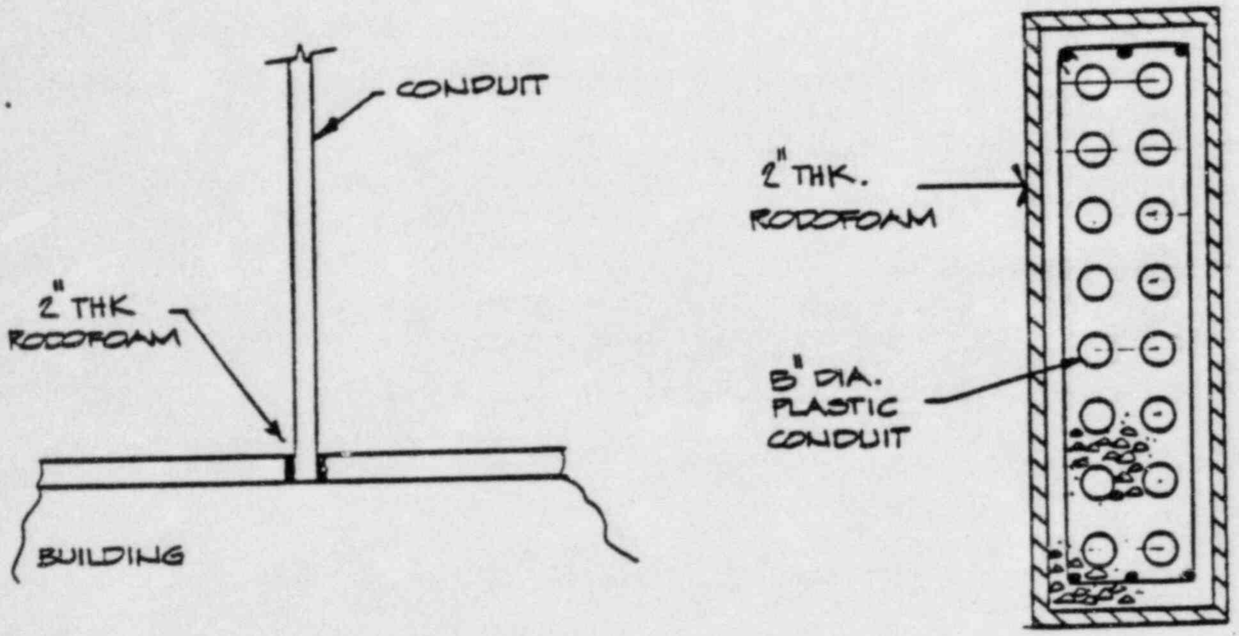
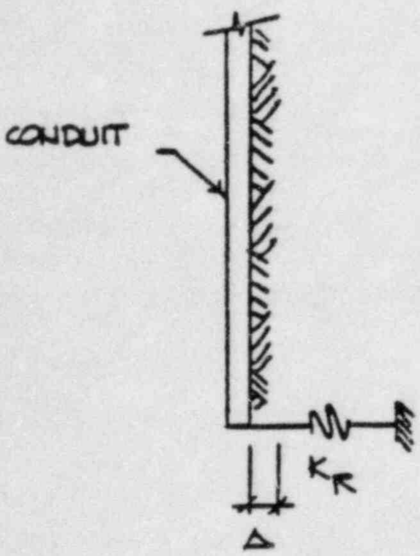


Figure 19.2

Typical Detail for Attachment of Buried Conduit to Structure

Beaver Valley Power Station
Unit 2



WHERE:

Δ = DIFFERENTIAL MOVEMENT BETWEEN STRUCTURE AND ADJACENT SOIL DUE TO SETTLEMENT OR SEISMIC MOTION

K_R = STIFFNESS PROVIDED BY RODOFOAM

Figure 19.3

Analytical Model for Attachment of Buried Conduit to Structure

Beaver Valley Power Station
Unit 2

20. Describe the key types of cable tray (and conduit) configurations used at BVPS-2. For each of the configurations identified, evaluate if the criteria provided in SRP Section 3.8.4 were fully met in the design and analysis of the trays (and conduit). For any deviations from the criteria identified, please provide a justification considering the as-built material strength and conservatisms, as appropriate. The selection of key types of cable trays should consider the various layers of decking as well as the variability in supports and anchoring effects.

Response:

20.1 Support Configurations

20.1.1 Cable Tray Supports

The cable tray supports at BVPS-2 are of three basic types: trapeze, propped cantilever, and cantilever. An illustration of each type of support is shown on Figure 20.1. The standard vertical spacing between cable trays is 1'-4".

A standard arrangement of trapeze supports in a straight run is shown on Figure 20.2. Bracing in the longitudinal direction is generally provided at 40'-0" intervals. On standard straight runs consisting of propped cantilever and cantilever type supports, bracing in the longitudinal direction is generally provided at 32'-0" intervals.

20.1.2 Conduit Supports

The conduit supports at BVPS-2 are of three basic types: braced cantilever, direct attachment, and cantilever. Standard conduit supports of each type are shown on Figure 20.3.

Figure 20.4 shows a standard arrangement of conduit supports. When the number of spans in a straight run exceeds 6, an anchor support (as shown on Figure 20.4) is provided so that the resultant straight runs at either side of the anchor are less than or equal to 32'-0".

20.1.3 Member Size

The standard cable tray and conduit supports are composed of bolted cold-formed Unistrut P1001 and P1004A structural members. The cable tray ladders are of the T.J. Cope 4247 series with standard manufactured length of 12'-0" and rung spacing of 6 in.

20.1.4 Span Length of Tray and Conduit Supports

The maximum span length of standard tray and conduit supports is 8'-0".

20.1.5 Cable Tray and Conduit Weight

The standard cable tray supports were designed based on a uniformly distributed total load per cable tray (cable, tray, and cover) acting on a tributary span of 8'-0".

The standard conduit supports were designed based on a uniformly distributed load which accounted for the weight of the conduit plus the weight of cables.

20.1.6 Standard Cases

Standard cable tray and conduit support systems at BVPS-2 were defined and designed based on technical guidelines which meet the design criteria defined in Section 20.2.

20.1.7 Special Cases

Support systems requiring deviation from the standard support configuration were termed special case systems. These systems were analyzed and designed using the analysis methods and acceptance criteria described in Section 20.2.

The following conditions constitute special case systems:

(1) Cable tray and conduit systems for which the total raceway weight exceeds the design basis of the standard.

(2) Systems with support spacings exceeding those of the standard.

(3) Systems with supports having geometrical configurations different from those described in the standards.

20.2 Design Procedure

The BVPS-2 criteria for the analysis and design of cable tray supports, cable tray ladders, conduit supports, conduits, and the hardware required for their installation is in accordance with the Standard Review Plan (SRP) Section 3.8.4. Considered in the design procedure are parameters such as number of cable tray levels, member sizes, and anchoring conditions.

Two different methods of analysis were used to verify the adequacy of the support systems:

(1) Equivalent static analysis

(2) Dynamic analysis using response spectrum modal analysis

NRC STRUCTURAL AUDIT ACTION ITEMS

20.2.1 Methods of Analysis

Equivalent Static Analysis

To determine the value of the seismic acceleration to be used in the analysis, the relevant response spectra curves are reviewed to determine the "cutoff frequency" (frequency which separates the rigid range from the resonance range of the response spectra curves). Components having fundamental natural frequencies above the cutoff frequency were analyzed using the rigid range response accelerations. Components having fundamental natural frequencies below the cutoff frequency were analyzed using the peak response acceleration from the resonant range, increased by 50 percent to account for all significant dynamic modes under a resonant situation.

Dynamic Analysis using Response Spectrum Modal Analysis

A dynamic analysis was performed when support system complexity precluded equivalent static analysis, or when equivalent static analysis was overly conservative.

A "lumped mass" approach was employed in the dynamic analysis. The support system was idealized as a series of discrete masses interconnected by linear elastic springs.

The actual peak spread amplified response spectrum was used as the seismic design excitation.

20.2.2 Damping

The following percentages of critical damping are being used in the analysis and design of cable trays, cable tray supports, conduits, and conduit supports:

4 percent damping for 1/2 SSE

8 percent damping for SSE

20.2.3 Load Combination

The load combinations of the BVPS-2 design criteria are:

(1) D+E
(2) D+E'

Where:

D = dead loads
E = 1/2 SSE loads
E'= SSE loads

All seismic Category I conduit and cable tray systems at BVPS-2 are located inside buildings; therefore, normal wind (W) and tornado wind (Wt) loads are not considered in their design. The nature and flexibility of these systems make the effect of thermal loads (To and Ta) insignificant. Pressure load (Pa), pipe reaction loads (Ro and Ra), and pipe rupture loads (Yr, Yj, and Ym) are not applicable and thus were not considered.

When these nonapplicable loading terms are eliminated from the load combinations of SRP 3.8.4, the resulting combinations are identical to those of BVPS-2.

The cable and conduit support systems were analyzed for seismic loads in each individual direction (axial, transverse, and vertical). The loads produced by each horizontal direction earthquake were added by the absolute sum to those produced by the vertical direction earthquake (axial + vertical and transverse + vertical). Each component of the support systems was designed to withstand the effect of both seismic load combinations.

20.2.4 Acceptance Criteria

The cable tray and conduit support systems design acceptance criteria are in compliance with the AISC "Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings," the AISI "Cold-formed Steel Design Manual," and/or the following requirements:

One-Half Safe Shutdown Earthquake (1/2 SSE)

The combined stresses on standard cases due to 1/2 SSE seismic loads, plus dead load, are not to exceed 75 percent of the minimum yield strength of the material.

In addition, the special case designs were limited to the required section strength (S), based on the elastic design methods and the allowables defined in Part I of the AISC "Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings," or in the AISI "Cold-formed Steel Design Manual" as applicable.

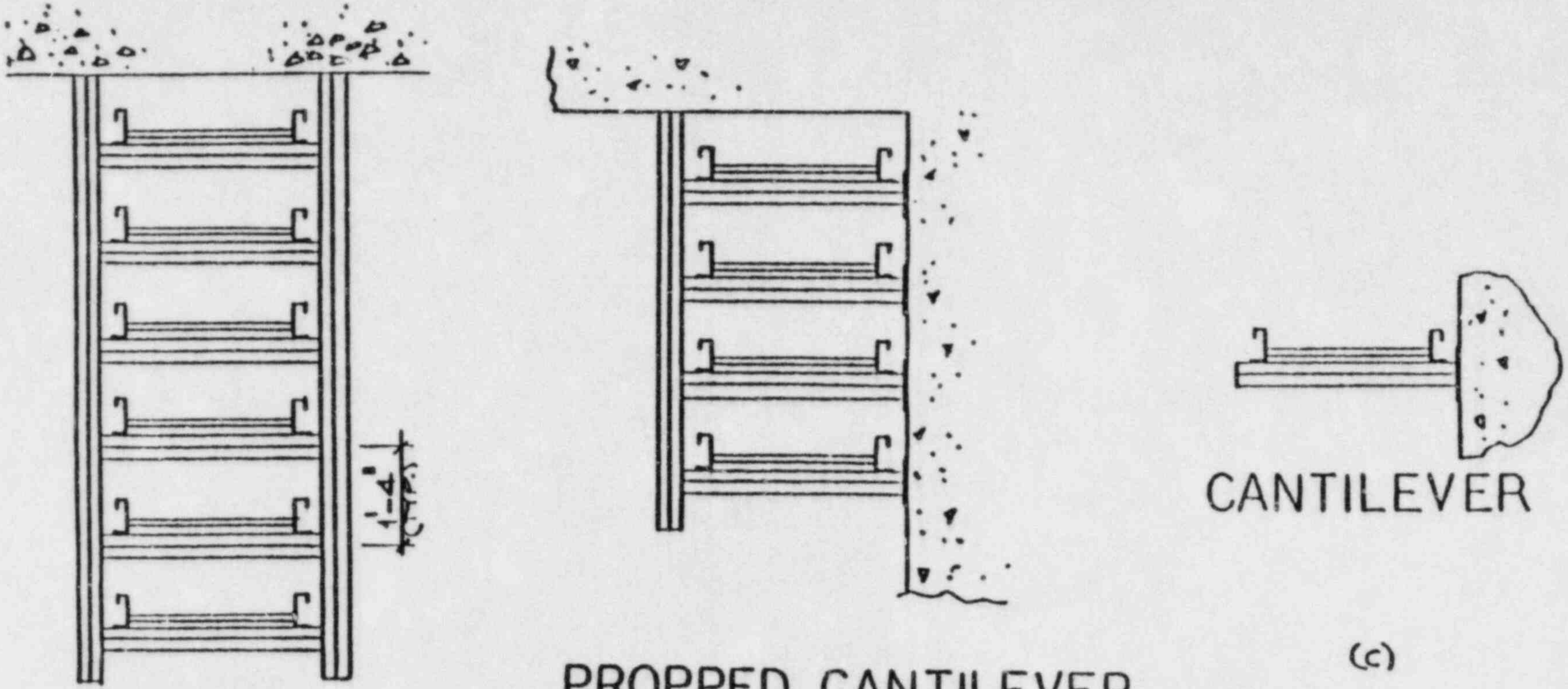
The 1/3 increase in stresses allowed by the AISC and AISI manuals was not permitted.

Safe Shutdown Earthquake (SSE)

The combined stresses on standard cases due to SSE seismic loads, plus dead load, are not to exceed 100 percent of the minimum yield strength of the material.

In addition, the special case designs were limited to 1.6 times the required section strength (S), based on the elastic design methods and allowables defined in Part I, "Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings," or in the AISI "Cold-Formed Steel Design Manual" as applicable.

The 1/3 increase in stresses allowed by the AISC and AISI manuals was not permitted.



TRAPEZE
(a)

PROPPED CANTILEVER
(b)

CANTILEVER
(c)

Figure 20.1

Standard Cable Tray Support Types

Beaver Valley Power Station -
Unit 2

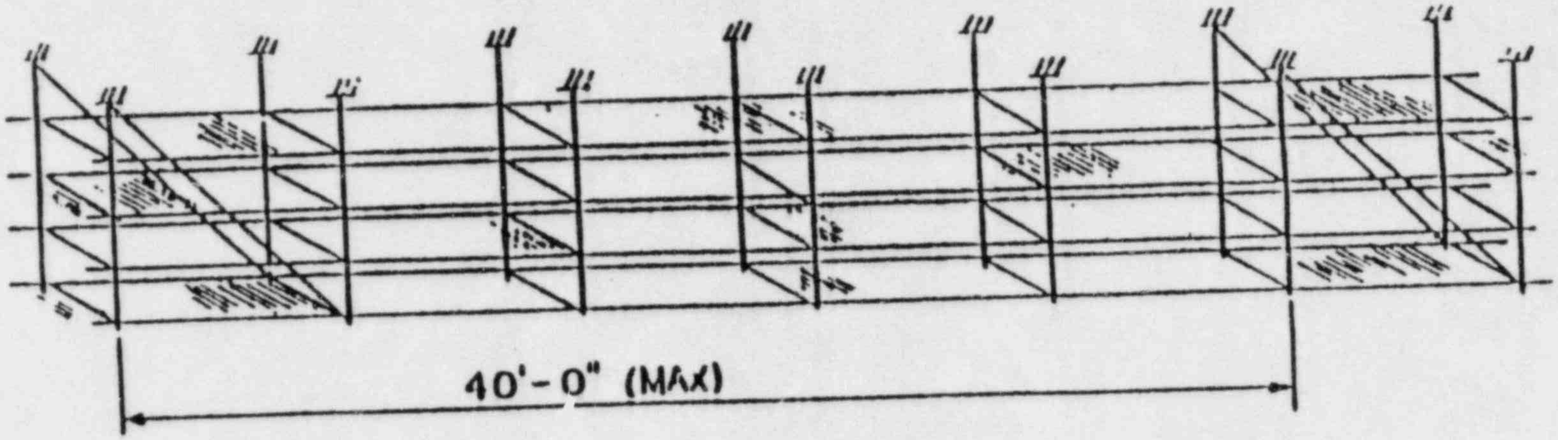
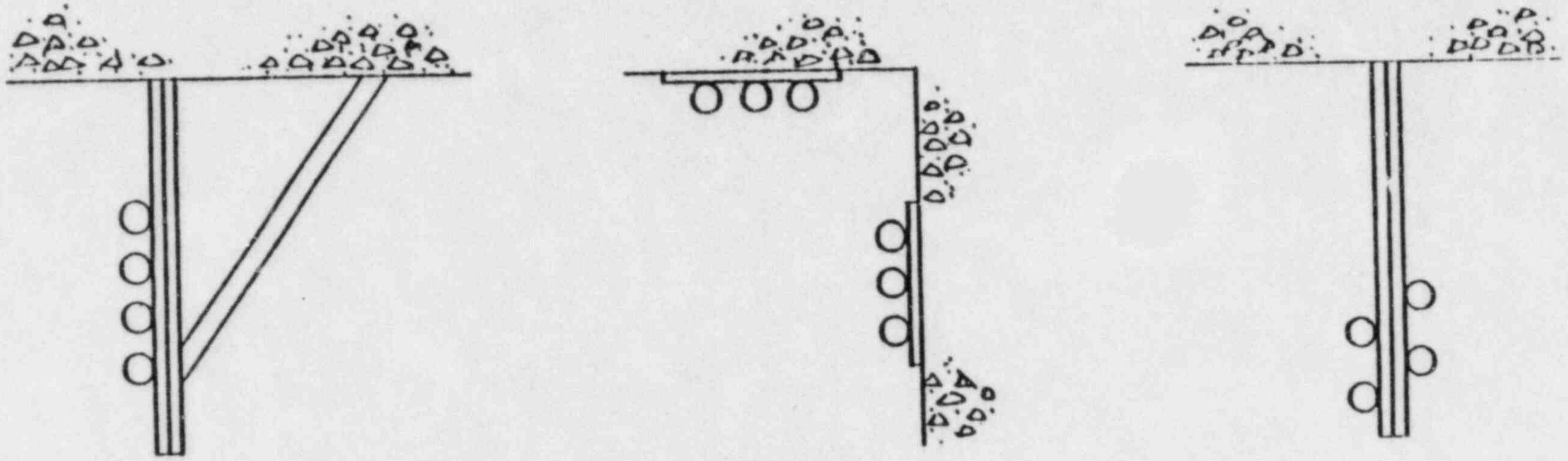


Figure 20.2

Typical Standard Arrangement of Trapeze Supports in a Straight Run

Beaver Valley Power Station
Unit 2



BRACED CANTILEVER
(a)

DIRECT ATTACHMENT
(b)

CANTILEVER
(c)

Figure 20.3

Standard Conduit Support Types

Beaver Valley Power Station
Unit 2

Figure 20.4

Typical Standard Arrangement
of Conduit Supports

Beaver Valley Power Station
Unit 2

23. If the three-component piping support point spectra are found to be not comparable to those used in the original piping analysis (subject to NRC review and acceptance), demonstrate that the key safety-related systems, equipment, and piping have met the three-component earthquake consideration criterion given in SRP Section 3.7.3. The evaluation should include the following key items within various Category I structures:

    1. Containment - reactor vessel support, one steam generator, pressurizer, one hot-leg piping system, and primary coolant pump
    2. Auxiliary building - component cooling water pump, boric acid transfer pump
    3. Control building - main control board
    4. Fuel building - fuel pool cooling pump
    5. Intake structure - service water pump

    For any identified deviations from the above SRP Section 3.7.3 criterion, use as-built material strength and design conservatisms to justify the deviations.

    Response:

    Refer to the response to Item 4.