EXHIBIT V - SEISMIC ANALYSIS OF REACTOR VESSEL

V.1 ABSTRACT AND RESULTS

The maximum seismic shears and moments in the Peach Bottom reactor pressure vessel and vessel internals due to the maximum credible earthquake (MCE) have been determined. The maximum credible earthquake response spectra used in this analysis is shown in Figure C.3.2. The results for those components that develop significant seismic loads are given in the following table:

SIGNIFICANT SEISMIC SHEARS AND MOMENTS

	MCE
RPV Support Skirt Moment	6,320 kip-ft
RPV Support Skirt Shear	205 kips
Fuel Assy. Moment	0.89 kip-ft/assy
CRD Housing Moment	2.97 kip-ft each
Total Fuel Shear on Top Guide	133 kips
Shroud Support Moment	6,219 kip-ft
Shroud Support Shear	287 kips
RPV Stabilizer Force	267 kips

V.2 ANALYSIS

V.2.1 Mathematical Model

The Peach Bottom system was modeled with 40 discrete lumped masses connected by massless springs. Relatively lightweight components such as the jet pumps, steam dryer, in-core housing, in-core guide tube, and spargers were not modeled separately; only their mass effects being accounted for. This simplification is made to limit the complexity of the analysis and is valid since the dynamic effects of these components on the rest of the system is slight. Should the seismic response of these components be of interest, the response of the reactor vessel at their points of attachment to the vessel would then be used as input forcing functions. Because of the solidity of the site foundation, the reactor building was modeled as fixed at its base.

V.2.2 Mass and Elastic Properties

To develop equivalent lumped masses, the system components are visualized as consisting of vertical segments. The lumped mass, located in general at the center of mass of each segment, represents the sum of: (1) the segment mass, (2) components in the segment not modeled separately (such as the dryer mass being lumped into a vessel mass), (3) the enclosed water mass effects discussed in detail in paragraph V.2.3.

The system flexibility matrix is determined by using the elastic properties of cross-sectional moment of inertia, shear area, length, Young's Modulus, and Poisson's ratio for each component segment between lumped masses to derive individual segment matrices which are then combined as discussed in paragraph V.2.6. Shearing deformations are accounted for in the derivation of the segment flexibility coefficients.

V.2.3 Hydrodynamic Mass

In order to account for the effects of the core cooling water on the dynamic characteristics of the system, hydrodynamic mass (or apparent mass) terms have been included in the system mass matrix. The hydrodynamic mass manifests itself as a dynamic coupling between the real masses and therefore appears in the mass matrix at diagonal as well as off-diagonal locations. These hydrodynamic masses are added algebraically to the lumped metal masses to form the total mass matrix.

V.2.4 Natural Frequencies and Mode Shapes

The overall system flexibility matrix is derived by using the matrix force method which is described in detail in reference 1. Given the flexibility matrix, f, the stiffness matrix, K, of the system can be found by inversion. From the mass matrix, (non-diagonal in this case), and the stiffness matrix, the undamped natural frequencies and normalized mode shapes are computed.

V.2.5 Equivalent Modal Damping

Damping coefficients for individual component elements are given as follows:

Component	MCE Coefficient (% Critical Damping)
Reactor Vessel	2.0
Vessel Support Skirt	2.0
Shroud	2.0
Shroud Head and Separators	2.0
Fuel	7.0
Control Rod Guide Tubes	2.0
CRD Housings	3.5
Shield and Pedestal	5.0
Reactor Building	5.0

Modal damping values are then computed for each mode on the basis of modal-displacement and mass.

V.2.6 Earthquake Response

The equation of motion of the system in matrix form is as follows:

$$M\left(\ddot{X} + \ddot{Y}\right) + C\,\dot{X} + K\,X = O \tag{V.1}$$

where:

- M = mass matrix, n x n (this includes the hydrodynamic mass)
- X = column vector of displacement relative to ground (n x 1)
- C = damping matrix (n x n)
- K = stiffness matrix (n x n)
- $\ddot{Y}$ = column vector of ground accelerations (n x 1)
- $(\ddot{\ })$ = second derivative with respect to time
- $(\dot{\ })$ = first derivative with respect to time

Upon removing the ground acceleration vector to the right side of Equation (V.1), the equation reduces to the classical form:

$$M\,\ddot{X} + C\,\dot{X} + K\,X = -\,M\,\ddot{Y} \tag{V.2}$$

To uncouple equation (V.2) set

$$X = \phi q,\ \phi = \text{modal matrix} \tag{V.3}$$

Equation (V.2) then becomes

$$M\phi\,\ddot{q} + C\phi\,\dot{q} + K\phi\,q = -\,M\,\ddot{Y} \tag{V.4}$$

Pre-multiplying by the transpose of ϕ and using the orthogonality conditions:

$$\phi^{T} M\phi\,\ddot{q} + \phi^{T} C\,\phi\,\dot{q} + \phi^{T} K\,\phi\,q = -\,\phi^{T}\,M\,\ddot{Y} \tag{V.5}$$

$$\ddot{q} + \phi^{T}\,C\phi\,\dot{q} + \phi^{T}\,K\phi q = -\,\phi^{T}\,M\,\ddot{Y} \tag{V.6}$$

This procedure for uncoupling the equation of motion by using the modal matrix of the undamped system requires that damping in the system be small. It is further assumed that the damping matrix C is such that $\phi^{T}C\phi$ is a diagonal matrix. The elements of this diagonal matrix are the modal damping values. With these assumptions, Equation (V.6) may be written as:

$$\ddot{q}_i + 2\beta_i\omega_i\dot{q}_i + \omega_i^{\,2}q_i = -S\ddot{U}g\,(+) \qquad (V.7)$$

$$i = 1, 2, \text{-----}N$$

where:

$ß_i$ = damping ratio for the i^{th} mode expressed as percent of critical damping

ω_i = i^{th} natural angular frequencies of the system

S_i = modal participation factor for the i^{th} mode = $\phi_i^T M I_u$

U_g = earthquake ground acceleration time history

ϕ_i^T = transpose of the i^{th} mode shape

I_u = (n x 1) column vector whose elements are all unity

The system of one degree of freedom equation represented by Equation (V.7) subjected to the initial conditions

$$q_i\,(0) = 0$$
$$\dot{q}_i\,(0) = 0$$

determines the modal response q_i (+). Using Equation (V.7), the maximum seismic modal response (displacement, acceleration, or load response) can be determined for each natural frequency of interest from the response spectrum curve. Response spectrum curves are essentially plots of the maximum responses of single-degrees-of-freedom systems described by Equation (V.7) with S_i = 1.0 against various natural periods or frequencies. Having found the maximum modal responses, $\bar{q}_i$, i = l, ...m, the maximum physical displacement for the i^{th} mode is given by:

$$\bar{X}_i = S_i\,\bar{q}_i\,\phi_i \qquad (V.8)$$

where:

$$\bar{X}_i = \begin{bmatrix} \bar{X}_{1i} \\ \bar{X}_{2i} \\ \ddots \\ \bar{X}_{ni} \end{bmatrix} \qquad \phi_i = \begin{bmatrix} \phi_{1i} \\ \phi_{2i} \\ \ddots \\ \phi_{Ni} \end{bmatrix}$$

As shown in reference 2, the maximum physical response for each mass can be taken to be the square root of the sums of the squares of each of the maximum responses for each mode; i.e.,

$$(x_i) \max \left[\sum_{j=1}^{m} \bar{X}_{ij}{}^2 \right]^{1/2}$$

$$i = 1, \ldots, N$$

Similarly, the maximum load response for the i^{th} mode if found from:

$$\bar{L}_i = S \bar{X}_i$$

where:

$$\bar{L}_i = \begin{bmatrix} \bar{L}_{1i} \\ \bar{L}_{2i} \\ \ddots \\ \bar{L}_{ni} \end{bmatrix}$$

Where n is the number of rows in the S matrix

S = Stress or load matrix

The maximum load response is again taken to be the square root of the sums of the squares of each of the maximum responses for each mode; i.e.,

$$\left(L_i\right) \max = \left[\sum_{j=1}^{m} \bar{L}_{ij}^{2}\right]^{1/2}$$

$$i = 1, \ldots n$$

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REFERENCES

1. Leckie, F. A. and Pestel, E. C., Matrix Methods in Elasto-Mechanics, McGraw-Hill, 1963.

2. Clough, R. W. "Earthquake Analysis by Response Spectrum Superposition," Bull, Seismological Society of America, Vol 52, No. 3, July, 1962.