Enhanced Information for PS/B Design

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Abstract

The purpose of this report is to provide the results of the lumped mass stick model seismic analysis in support of the design of the east and west power source buildings (PS/Bs) as referenced by US-APWR Design Control Document (DCD) (Reference 1), Subsection 3.7.2.8.6.

Stick models representing the building structures for seismic analysis are accepted methodologies in lieu of finite element models (FEMs) provided the models are three-dimensional and take into account torsional and rocking/swaying effects. The seismic response of the PS/B structures is obtained from the time history analysis of lumped mass stick models, with constants from the frequency independent lumped parameters representing the stiffness and damping properties of the soil-structure interaction (SSI). The results from the seismic analyses serve as the basis for the development of equivalent static seismic loads that are applied in conjunction with other design loads on the detailed three-dimensional shell FEM in order to obtain the design stresses in the structural members and components. Refer to DCD Subsection 3.7.2 for additional discussion on the overall analysis process.

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List of Acronyms

A/B	auxiliary building
APWR	Advanced Pressurized Water Reactor
DCD	Design Control Document
DOF	degree of freedom
EW	east-west
FE	finite element
FEM	finite element model
ISRS	in-structure response spectra
MHI	Mitsubishi Heavy Industries, Ltd.
NRC	U. S. Nuclear Regulatory Commission
NS	north-south
PS/B	power source building
R/B	reactor building
SRSS	square root of the sum of squares
SSE	safe-shutdown earthquake
SSI	soil-structure interaction
T/B	turbine building
ZPA	zero period acceleration

1.0 INTRODUCTION

The purpose of this report is to provide the results of the lumped mass stick model analyses in support of the seismic design of the east and west Power Source Buildings (PS/Bs) as referenced by US-APWR Design Control Document (DCD) (Reference 1), Subsection 3.7.2.8.6.

The PS/Bs are statically analyzed using a three-dimensional finite element model (FEM) with the NASTRAN (Reference 2) computer codes as outlined in DCD, Subsection 3.8.4.4. Seismic forces used in the design are obtained from the dynamic analysis of the three-dimensional lumped-mass stick model described within this technical report. The basemat design is described in DCD Subsection 3.8.5.

The plan dimension of each PS/B is nominally 111'-6" x 66'-0" between reference lines of exterior walls. Each PS/B is a reinforced concrete structure consisting of vertical shear/bearing walls and horizontal slabs with one floor level under ground and the main floor level above ground. The walls carry the vertical loads from the structure to the basemat. Lateral loads are transferred to the walls by the roof and floor slabs.

The west PS/B borders the auxiliary building (A/B), reactor building (R/B), and turbine building (T/B). The east PS/B borders the R/B and the T/B. Each PS/B rests on its own basemat. Each PS/B is designed with an expansion joint along its interface with the R/B to assure that no contact will occur between the buildings under a seismic or any other design basis loading. The expansion joint is sized to prevent contact between the structures even if the maximum translational and rotational displacements due to a seismic loading (and other design basis loading) were to occur. The expansion joints size is determined by considering, at all potential interaction locations, the absolute summation of the deflection associated with each super-structure, obtained from the time history analysis results for those structures.

The seismic analysis philosophy of the PS/Bs is stated as follows.

- The east and west PS/Bs are nearly identical structurally, and the west bounding analysis is performed to represent both.

- The safe-shutdown earthquake (SSE) load condition is the same as for the R/B.

- The design of the PS/Bs is based on a static analysis utilizing a three-dimensional FEM, and a seismic dynamic analysis using a three-dimensional lumped mass stick model. The finite element (FE) analysis is discussed within DCD, Subsection 3.8.4.

2.0 SEISMIC SYSTEM ANALYSIS

Stick models representing the building structures for seismic analysis are accepted methodologies in lieu of FEMs provided the models are three-dimensional and take into account torsional and rocking/swaying effects. The seismic response of the PS/B structures is obtained from the time history analysis of lumped mass stick models with constants from the frequency independent lumped parameters representing the stiffness and damping properties of the soil-structure interaction (SSI). The results from the seismic analyses serve as the basis for the development of equivalent static seismic loads that are applied in conjunction with other design loads on the detailed three-dimensional shell FEM in order to obtain the design stresses in the structural members and components. Refer to DCD, Subsection 3.7.2 for additional discussion on the overall analysis process.

2.1 Seismic Analysis Methods

The scope of this technical report is limited to the three-dimensional lumped-mass stick model analyses in support of PS/Bs seismic dynamic design and analysis. Refer to DCD, Subsection 3.8.4.4 for the static analysis of the PS/Bs using three dimensional FE modeling.

Seismic analysis of the two PS/Bs is performed for three orthogonal (two horizontal and one vertical) components earthquake ground motion with consideration of the torsional, rocking, and translational responses of the structures and their foundations (including footings, basemats and buried walls).

Response analysis for both horizontal and vertical components of motion is performed in the time domain using direct integration method. Newmark β method (β=0.25, γ=0.5), which is one of the implicit integration techniques, is adopted. The time step (Δt) is selected small enough such that the use of ½ *Δt* does not change the response by more than 10%. Considering the reciprocal zero period acceleration (ZPA) frequency, *Δt* has been selected as 0.001 sec.

The response of a multi degree of freedom DOF) linear system subjected to seismic excitation is generally represented by the following differential equation of motion:

$$[M]\ddot{\vec{x}} + [C]\dot{\vec{x}} + [K]\vec{x} = -[M]\,\vec{u}_b\,\ddot{u}_g \tag{2.1-1}$$

where

$[M]=$ mass matrix (n×n)

$[C]=$ damping matrix (n×n)

$[K]=$ stiffness matrix (n×n)

$\vec{x}=$ column vector of relative displacements (n×1)

$\dot{\vec{x}}=$ column vector of relative velocities (n×1)

$\ddot{\vec{x}}=$ column vector of relative accelerations (n×1)

$\vec{u}_b=$ influence vector; displacement vector of the structural system when the support undergoes a unit displacement in the direction of the earthquake motion (n×1)

$n =$ number of dynamic DOFs

$\ddot{u}_b =$ ground acceleration

The mass matrix [M] of the lumped mass stick model is diagonal. The size "n" of the matrices in the equation of motion (Equation 3.7.2-1) is equal to the total number of translational and rotational DOF with assigned mass inertia. If the six DOF assigned to the soil lumped SSI parameters are denoted with the suffix "c" and the rest of the DOF representing the response of the superstructure are denoted with suffix "s," the stiffness and damping matrices ([K] and [C]) of the system can be expressed as follows:

$$[K] = \begin{bmatrix} [K_{ss}] & [K_{sc}] \\ [K_{cs}] & [K_{cc}] + [K_c] \end{bmatrix} = \begin{bmatrix} [K_{ss}] & [K_{sc}] \\ [K_{cs}] & [K_{cc}] \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & [K_c] \end{bmatrix}$$

$$[C] = \begin{bmatrix} [C_{ss}] & [C_{sc}] \\ [C_{cs}] & [C_{cc}] + [C_c] \end{bmatrix} = \begin{bmatrix} [C_{ss}] & [C_{sc}] \\ [C_{cs}] & [C_{cc}] \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & [C_c] \end{bmatrix} \tag{2.1-2}$$

where

$$[K_S] = \begin{bmatrix} [K_{ss}] & [K_{sc}] \\ [K_{cs}] & [K_{cc}] \end{bmatrix} \text{ and } [C_S] = \begin{bmatrix} [C_{ss}] & [C_{sc}] \\ [C_{cs}] & [C_{cc}] \end{bmatrix}$$

are the ($n \times n$) matrices representing the structural stiffness and damping; and [K_C] and [C_C] are the (6×6) diagonal matrices assigning the stiffness and damping lumped SSI parameters to the corresponding DOF.

The structural damping matrix [C_S] in global coordinates is derived from the modal damping ratios by following matrix transformation:

$$[C_S]_i = \left[\vec{\phi}^T\right]^{-1} \begin{bmatrix} \ddots & 0 & 0 \\ 0 & 2h_i\omega_i & 0 \\ 0 & 0 & \ddots \end{bmatrix} \left[\vec{\phi}\right]^{-1} \tag{2.1-3}$$

where

h_i = the stiffness weighted modal damping ratio of the i^{th} mode,

ω_i = the natural frequency of vibration (Eigen value) of i^{th} mode (rad/sec),

$\left[\vec{\phi}\right]$ = the mode shape matrix (Eigen vector matrix) normalized with respect to the mass matrix of the combined soil-structure system as follows:

$\left[\vec{\phi}\right]^T \cdot [M] \cdot \left[\vec{\phi}\right] = [I]$ (where [I] is an identity matrix)

The natural frequencies and the normalized mode shape matrix are obtained from the modal analysis of the combined soil-structure system.

The stiffness weighted modal damping ratio h_i of the j^{th} mode is obtained from the following equation:

$$h_j = \frac{\vec{\phi}_j^{\,T}\left[\overline{K}\right]\vec{\phi}_j}{\vec{\phi}_j^{\,T}\left[K\right]\vec{\phi}_j} \tag{2.1-4}$$

where

$\left[K\right]$ = the stiffness matrix of the combined soil-structure system composed as shown in Equation 2.1-2.

$\vec{\phi}_j$ = the j^{th} normalized mode shape vector

$\left[\overline{K}\right] = \sum\left[k_i\right]\cdot\xi_i$ = the modified stiffness matrix constructed from the products of the element stiffness matrices $\left[k_i\right]$ and the applicable damping ratio ξ_i

The stiffness matrix [K_C] and the damping matrix [C_C] representing the dynamic properties of the subgrade are constructed from the lumped SSI parameters. The lumped SSI parameters are calculated from the formulas given in ASCE 4-98, Subsection 3.3.4 (Ref. 3) that are based on closed form solutions for vibrations of rigid basemat resting on elastic-half space. The values of the lumped parameters for damping in horizontal direction are conservatively reduced to 60% of the values calculated from the formulas of ASCE 4-98 (Ref. 3) unless an applicable justification based on site-specific conditions is applied.

2.2 Natural Frequencies and Responses

The total cases of seismic response analyses for the PS/B lumped mass stick model are listed in Table 2.2-1.

A summary of natural frequencies for the PS/Bs is shown in Tables 2.2-2(1) through 2.2-2(4). In these tables, the modal participation factors and modal damping values are listed for each direction of excitation.

2.3 Procedures Used for Analytical Modeling

Models developed for seismic analysis of building structures follow the recommendations given in ASCE Standard 4 (Reference 3), Section 3.1. A detailed PS/B FEM has been developed for the computer program NASTRAN (Reference 2) primarily as a static analysis model for structural design based on loads and load combinations as given in DCD, Section 3.8. The PS/B lumped mass stick model is discussed within this technical report.

The basic dimensions of the PS/Bs are presented in the general arrangement drawings in DCD, Section 1.2. The PS/B model considers all six DOFs (three rotational and three translational) and incorporate mass and stiffness eccentricities to assure that torsional and rocking/swaying effects, and any cross-directional coupling, are captured. Torsional and rocking/swaying effects are also captured at the basemat/subgrade interface through the use of lumped SSI parameters for all six DOF. The frequency independent lumped parameter formulation and methodology for calculation of lumped stiffness and damping coefficients is addressed in detail in the SSI analysis discussion in DCD, Subsection 3.7.2.4.

2.3.1 3D Lumped Mass Stick Model

The eccentricities between the centroid (the neutral axis for axial and bending deformation), the center of rigidity (the neutral axis for shear and torsional deformation), and the center of mass of structures are considered in the seismic lumped-mass stick model. The stick model representing the PS/Bs is three-dimensional and takes into account torsional and rocking/swaying effects even when eccentricities are small. The eccentricity between the center of mass and center of building rigidity is accounted for directly in the model for non-symmetric structures. For accidental torsion see Section 2.10 below.

The dynamic analysis of any complex system requires the discretization of its mass and elastic properties. This is to be accomplished by concentrating the mass of the system at distinct characteristic points or nodes, and interconnecting them by a network of elastic springs representing the stiffness properties of the systems. The stiffness properties are to be computed either by manual calculations for simple systems or by FE methods for more complex systems.

Nodes are to be located at mass concentrations and at additional points within the system. They are to be selected in such a way as to provide an adequate representation of the mass distribution and high-stress concentration points of the system.

At each node, the DOF corresponding to translations along three orthogonal axes, and rotations about these axes are assigned. The number of DOFs should be reduced by the number of constraints, where applicable.

The size of the model is reviewed such that a sufficient number of masses or DOFs are used to compute the response of the system. A model is considered adequate provided that additional DOFs do not result in more than a 10% increase in response, or the number of DOFs equals or exceeds twice the number of modes with frequencies less than 33 hertz.

To model the interaction of the basemat and the PS/Bs with the underlying subgrade, frequency-independent lumped parameters are established vertically at the bottom of the basemat, and horizontally at the center of basemat with the subgrade boundary. The lumped parameter coefficients representing the stiffness and the damping properties of the SSI, are developed in accordance with Tables 2.3-1 and 2.3-2.

Analyses are performed as discussed in DCD, Section 3.8 based on applicable design loads and load combinations on the detailed three-dimensional FEM that is developed for computation of internal forces and stresses in the structural members and components of PS/Bs.

The detailed FE mathematical models that are initially prepared for static design analysis as outlined in DCD, Subsection 3.8.4.4 are used to verify that the lumped mass stick models realistically represent the dynamic properties of the PS/Bs.

2.3.2 Summary of Structural Modeling

The primary structural components of the PS/Bs are represented by a lumped mass stick model. The basemat is modeled at three node elevations: upper, [middle] mass, and lower basemat levels. Refer to Subsection 2.3.5 for modeling of shear walls.

The node centroid is defined as the center of rigidity in the vertical direction. Because the center of shear rigidity is not generally the same as the centroid (the center of vertical rigidity), the lumped-mass stick model has two stick elements for each node elevation. One element is for the vertical direction with axial area located at the centroid, and the other element is for the horizontal directions with all other remaining sectional properties (i.e., excluding axial area) located at the center of shear rigidity. Both stick elements are rigidly connected to the common centers of mass at each node level.

The lumped mass stick model of the PS/B as shown in Figure 2.3-1 is used to obtain the seismic response.

Figure 2.3-2 provides the elevation views of the PS/B lumped mass stick model in the north-south (NS) and east-west (EW) planes.

Table 2.3-3 lists the lumped masses modeled for the PS/B based on node elevation.

2.3.3 Material Properties

The values of the modulus of elasticity and Poisson's ratio for concrete and steel are given below for materials at or near ambient temperatures.

(a) Concrete

The properties of concrete, E_c, and ν_c (concrete weighing between 90 and 155 lb/cu ft), is:

$E_c(psi) = w_c^{1.5} 33\sqrt{f_c'}$ and

$$G \text{ (ksi)} = E_c / 2(1 + \nu_c) \qquad (2.3\text{-}1)$$

where

$f_c' =$ specified 28-day compressive strength of concrete (psi)

$w_c =$ unit weight of concrete (psi)

$\nu_c = 0.17$ (Poisson's ratio for concrete)

(b) Steel

The properties of ferritic structural steel and non-prestressed reinforcement, E_s, and ν_s are:

$E_s(psi) = 29{,}000{,}000\,psi$ and $\nu_s = 0.3$

Material constants including the damping value used for the reinforced concrete PS/Bs are given in Table 2.3-4.

2.3.4 Mass Points and Associated Weights (*W*)

The mass points are established at the major horizontal slab levels (roof, 1st floor level, and 3 mass points in the basemat) represented by nodes in the lumped mass stick model. The mass properties of a stick model consist of the total weight *W*, the weight moment of inertia (J_{xx}, J_{yy}, J_{zz}), and the center of mass. They are evaluated using manual calculations as described below.

The inertial properties of each mass point include all tributary mass expected to be present at the time of the earthquake. In addition to the building structure mass, mass equivalent to a floor load of 50 pounds per square foot is considered to represent miscellaneous dead weights such as minor equipment, piping, and raceways. Also, mass equivalent to 25% of the floor design live load and 75% of the roof design snow load is included at the applicable mass point. The mass of major equipment is distributed over a representative floor area or included as concentrated lumped masses at the equipment locations.

Figure 2.3-3 shows how the tributary weight and the inertia moment of lumped masses are computed. Mass moment of inertia is considered at all of the mass points for all three rotational DOFs, and evaluated assuming that the weight of the volume tributary to that elevation is distributed equally at the mass point floor level.

For floor systems rigid in plane, the total number of DOFs are reduced but out-of-plane flexibility of the floor system is included when vertical amplification of motion is significant.

2.3.5 Shear Stiffness

The effect of in-plane shear deformation is included in the model. The effective shear area is computed from the sum of the component shear areas of the individual walls parallel to the direction of the applied force for use in the simple lumped mass stick model.

The stiffness of the stick model is evaluated as shown in Figure 2.3-4 using a manual calculation under the following assumptions:

- Walls continuously built up from the basemat, whose thickness is more than 20 in., are treated as seismic walls.
- The openings whose area is more than 2,880 in.^{2} (80 in. x 36 in.) are considered in evaluating the stiffness of walls.

Where a shear wall has no flange [perpendicular] elements at its ends, the shear area is equal to the total web area divided by 1.2 in accordance with ASCE-4 (Reference 3), Subsection C3.1.8.3. When flanges are present, the shear area is equal to the total web area. Where applicable, the effective flange width of each perpendicular wall is calculated using the following reduction due to shear lag effects:

$$W_e = \frac{H}{3} \le \frac{W}{2} \tag{2.3-2}$$

where

$W_e =$ effective flange width on each side of the wall,

$H =$ total height of the wall,

$W =$ actual width of the flange on each side of the wall.

2.3.5.1 Effective Shear Area

Shear walls parallel to direction of earthquake motion are considered to evaluate the effective shear areas in each of the two horizontal axes. From the requirement that the shear deformation δ_S of the wall with openings be equal to the shear deformation δ'_S of a wall without openings with height equal the story height (*H*), the effective cross section area of the wall (A_e) is obtained from the following equation and as depicted in Figure 2.3-5.

$$\delta_S = \sum_{i=1}^{n} \frac{Q\kappa_i h_i}{GA_i} \quad \delta_S^{'} = \frac{QH}{GA_e}$$

because $\delta_S = \delta_S^{'}$,

$$A_e = \frac{H}{\sum_{i=1}^{n} \frac{\kappa_i h_i}{A_i}} \tag{2.3-3}$$

2.3.5.2 Geometrical Moment of Inertia

Geometrical moment of inertia of shear walls is calculated around the horizontal axis that goes through the centroid. The effective flange width of each perpendicular wall may be calculated using the following reduction due to shear lag effects

$$W_e = \frac{H}{3} \le \frac{W}{2} \tag{2.3-4}$$

where

$W_e =$ effective flange width on each side of the wall.

$H =$ total height of the wall

$W =$ actual width of the flange on each side of the wall

Equivalent moments of inertia (I_e) are calculated for the walls with openings using the equal bending rotation methodology as shown in Figure 2.3-6. The bending rotation θ of the wall with openings loaded with the unit bending moment M is calculated where I_i and h_i are the moment of inertia and height of wall segment as shown in Figure 2.3-3. The bending rotation θ' of equivalent wall without openings with height equal the story height (*H*) and cross section with equivalent moment of inertia I_e is determined as follows:

$$\theta = \int_0^{h_1} \frac{M}{EI_1} dh + \cdots + \int_{h_1+\cdots+h_{n-1}}^{h_1+\cdots+h_{n-1}+h_n} \frac{M}{EI_n} dh$$

$$\theta' = \int_0^{H} \frac{M}{EI_e} dh = \frac{MH}{EI_e}$$

$$because\ \theta = \theta' \qquad (2.3\text{-}5)$$

$$I_e = \frac{H}{\sum_{i=1}^{n} \frac{h_i}{I_i}}$$

2.3.6 Torsional Stiffness

The stiffness elements are located at the center of rigidity when a single lumped mass stick model is used for two horizontal earthquake components. The appropriate torsional stiffness value is applied when the center of mass is not coincident with the center of rigidity. The torsional rigidity, K_p, is computed as follows:

$$K_p = \sum_{i=1}^{N} \left(K_{yi} \overline{X}_i^2 + K_{xi} \overline{Y}_i^2 \right) - X_{cr}^2 \sum_{i=1}^{N} K_{yi} - Y_{cr}^2 \sum_{i=1}^{N} K_{xi} \qquad (2.3\text{-}6)$$

where

$\overline{X}_i, \overline{Y}_i =$ coordinates of the i^{th} wall or column elements

$K_{xi}, K_{yi} =$ stiffness of the i^{th} wall or column, including bending and shear effects, assuming rigid connection to the floor, in x and y directions, respectively

$X_{cr}, Y_{cr} =$ coordinates of the center of rigidity

$$X_{cr} = \frac{\sum_{i=1}^{N} \left(\overline{X}_i K_{yi} \right)}{\sum_{i=1}^{N} \left(K_{yi} \right)}, \quad Y_{cr} = \frac{\sum_{i=1}^{N} \left(\overline{Y}_i K_{yi} \right)}{\sum_{i=1}^{N} \left(K_{xi} \right)} \qquad (2.3\text{-}7)$$

The torsional constant (I_{zz}) of seismic walls is calculated around the vertical axis that goes through the center of shear rigidity.

2.3.7 Axial Stiffness

Vertical axial area of each element of the lumped mass stick model is equal to the summation of effective shear areas in the two horizontal directions. However, the overlapping area such as the corner area of box walls is subtracted from the summation. No free-standing columns exist in the PS/Bs.

The mass and element properties of the PS/B model elements are summarized in Tables 2.3-5 and 2.3-6, respectively.

2.4 Soil-Structure Interaction (SSI)

Generic soil profiles have been established to bound a range of potential soil conditions at typical sites. These soil profiles are used to define the seismic responses of the PS/Bs.

As described in DCD, Subsection 3.7.2.4, the site-independent SSI analyses of US-APWR standard plant are performed by assuming absolutely rigid basemat that rests on uniform linear-elastic half-space. A viscous damping represents the dissipation of energy in the elastic-half space that is due to radial damping in the subgrade media. This assumption allows the use of simple closed solutions in terms of frequency-independent lumped parameters that describe the stiffness and the dissipation of energy in the SSI system in the six DOFs. Three DOFs represent the translations of the basemat in two orthogonal horizontal directions and in the vertical direction. Two DOFs represent the rocking of the basemat about two horizontal axes, and one rotational DOF describes the torsional vibrations of the basemat. The lumped parameters representing the stiffness and damping properties of the SSI are calculated from the formulas presented in Table 2.3-2. The values of the lumped SSI parameters for damping in two horizontal translational DOF are conservatively set at 60% of the theoretical dashpot values obtained from formulas in Table 2.3-2.

For the half-space modeling of the soil media, the lumped parameter (soil spring) method is used. When the soil below the basemat is relatively uniform to a depth equal to a rectangular foundation dimension, frequency-independent soil spring and dashpot constants as shown in Table 2.3-2 are considered for the basemats of the PS/Bs.

To account for the SSI effects, the soil springs and dashpots are attached at the base bottom of the PS/B stick model. The soil spring constants and damping coefficients are evaluated by the procedure for a rectangular base, which is described in Table 2.3-2. The horizontal damping coefficients are reduced to 60% of the evaluated values conservatively. The calculated soil spring constants and damping coefficients are shown in Table 2.4-1.

For impedance function calculations, the PS/Bs foundations are approximated by equivalent rectangular shapes. The equivalent rectangular dimensions are computed by equating basemat soil contact area for translational modes of excitation and by equating contact area moment of inertia with respect to the reference axis of rotation for rotational modes of excitation.

A fixed base analysis considers the hard rock site listed in Table 2.4-2. The values used for the soil shear wave velocities are considered to be compatible to the strain level corresponding to the site-independent SSE. Table 2.4-3 summarizes the US-APWR standard plant seismic SSI analysis cases, with respect to the input time histories applied to the stick models resting on the uniform elastic half-space having the different subgrade conditions listed above.

For structures founded on materials having a shear wave velocity of 8,000 feet per second or higher under the entire surface of the foundation, a fixed base assumption is adopted.

To evaluate design envelopes of seismic responses of the PS/B with respect to the input time histories applied to the stick models resting on the uniform elastic half-space, four cases of

SSI analyses are performed as shown in Table 2.4-3. The enveloping results are obtained from the responses of all SSI cases to cover a wide range of site conditions.

2.4.1 Site-Specific SSI Analysis

The results of the site-independent SSI analysis and assumptions contained in the US-APWR standard plant design are validated through a site-specific SSI analysis to take into account site-specific conditions such as soil layering, location of water table and embedment of the basemat.

Refer to DCD, Subsection 3.7.2.4.1 for requirements of site-specific SSI analyses to validate the site-independent SSI analyses.

2.5 Development of Floor Response Spectra

Refer to DCD Subsection 3.7.2.5 for the methodology of developing the in-structure response spectra (ISRS) from the results of the site-independent seismic analysis. Seismic response spectra for the three components of earthquake motion are computed for the PS/Bs model nodal points where response spectra are needed, using the results obtained from design soil profile cases defined by the different soil conditions summarized in Table 2.4-2. The floor response spectra for the PS/Bs design are generated by enveloping the nodal response spectra of the design soil profiles.

To account for variations in the structural frequencies due to the uncertainties in parameters, such as material and mass properties of the structures, damping values, soil properties, SSI analysis techniques, and the seismic modeling methods, the computed floor response spectra are smoothed and peaks associated with the structural frequencies broadened by ±15%.

The response spectra are generated in accordance with Regulatory Guide 1.122 (Reference 4). Floor response spectra are developed for damping values equal to 0.5%, 2%, 3%, 4%, 5%, 7%, 10%, and 20% of critical damping. The envelopes of the floor response spectra for the design soil profiles are developed as follows:

- The spectral acceleration is calculated at the same frequencies for each of the design soil profiles
- The maximum spectral acceleration at each frequency from any of the design soil profiles is then selected for the envelope
- The enveloped floor response spectra are then broadened by ±15%.

The broadened floor response spectra for SSE with 5% damping at PS/B floor slab elevation 3'-7" and roof slab elevation 39'-6" are provided in Figures 2.5-1, 2.5-2, and 2.5-3.

2.6 Three Components of Earthquake Motion

As described in DCD, Subsection 3.7.2.6, seismic system analyses are performed considering the simultaneous occurrences of the two orthogonal horizontal and the vertical components of an earthquake. The acceleration time histories of the horizontal H1 and H2 components of the earthquake are applied in NS and EW directions respectively. The acceleration time history V is applied in the vertical direction.

In the response analyses, the three components of earthquake are applied on the lumped mass stick model either simultaneously or separately. In the analyses with the three earthquake components applied simultaneously, the effect of the three components of earthquake motion is included within the analytical procedure so that further combination is not necessary.

In analyses with the earthquake components applied separately and in the response spectrum and equivalent static analyses, the effect of the three components of earthquake motion are combined using one of the following methods:

(i) The time-history responses from the three earthquake components are combined algebraically at each time step to obtain the combined response time-history.

(ii) The peak responses due to the three earthquake components from the response spectrum and equivalent static analyses are combined using the square root of the sum of squares (SRSS) method.

(iii) The peak responses due to the three earthquake components are combined directly, using the assumption that when the peak response from one component occurs, the responses from the other two components are 40% of the peak (100%-40%-40% method). Combinations of seismic responses from the three earthquake components, together with variations in sign (plus or minus), are considered.

2.7 Combination of Modal Responses

Refer to DCD, Subsection 3.7.2.7 for the methodology of combining modal responses.

2.8 Effects of Parameter Variations on Floor Response Spectra

As described in DCD, Subsection 3.7.2.5, the computed ISRS are smoothed by filling in valleys between peaks to account for variations in the structural frequencies due to the uncertainties in parameters, such as material and mass properties of the structures, damping values, soil properties, SSI analysis techniques, and the seismic modeling methods. The peaks associated with the structural frequencies are broadened by ±15%. Refer to DCD, Subsection 3.7.2.9 for further discussion.

2.9 Use of Constant Vertical Static Factors

The US-APWR standard plant design does not utilize constant vertical static factors in the seismic design. The vertical component of the seismic motion is obtained using one of the analysis methods described in DCD, Subsection 3.7.2.1. The vertical component is combined with the horizontal components of the seismic motion as described in DCD, Subsection 3.7.2.6.

2.10 Method Used to Account for Torsional Effects

The torsional effect is included in the design of PS/Bs by use of the following process:

- Computation of the horizontal mass properties on each floor elevation of the building lumped mass stick models, and the corresponding nodal accelerations.
- Computation of the eccentricity by determining the distance between the center of mass at each floor with respect to its center of rigidity, computed separately for each floor level, as required by ASCE 4 (Ref. 3) Subsection 3.1.1(d).

For member design only, an additional building torsion (accidental torsion) is considered per Subsection 3.3.1.2(a) of ASCE 4 (Ref. 3). This accounts for the effects of non-vertically incident or incoherent waves, taking an eccentricity of 5% of the plan dimension for each floor perpendicular to the direction of the applied motion.

2.11 Comparison of Responses

As identified in DCD, Subsection 3.7.2.12, the response spectra obtained from artificial ground motion time histories are compared with the target response spectra to assure that the spectra derived from the time histories match/envelope the certified seismic design response spectra with an approximate mean based fit.

2.12 Determination of Dynamic Stability of PS/Bs

Dynamic methods and procedures used to determined dynamic stability of the PS/Bs are outlined in DCD, Subsection 3.8.5.5. Consideration of structure-to-structure interaction is discussed in DCD, Subsection 3.7.2.8.

2.13 Analysis Procedure for Damping

The procedure used to account for damping in various elements of the PS/Bs soil-structure system model are discussed in Section 2.4 above. The calculated soil spring constants and damping coefficients are shown in Table 2.4-1.

Table 2.2-1 Total Seismic Response Analyses Cases

Case No.	Soil	Direction of Excitation (Input Motion)		
		NS	EW	UD
1	Soft	○		
2			○	
3				○
4	Medium 1	○		
5			○	
6				○
7	Medium 2	○		
8			○	
9				○
10	Hard Rock (Base-Fixed)	○		
11			○	
12				○

Table 2.2-2(1) Summary of Natural Frequencies for PS/B (Soft Soil)

Mode	Freqency (Hz)	Period (sec)	Modal Participation Facter			Effective Mass			Modal Damping	Remarks
			NS(X)	EW(Y)	UD(Z)	NS(X)	EW(Y)	UD(Z)		
1	3.03	0.330	8.1	0.0	0.0	65.82	0.00	0.00	0.007	NS direction
2	3.49	0.286	0.0	8.6	-0.2	0.00	74.44	0.06	0.006	EW direction
3	5.09	0.197	0.0	0.3	9.4	0.00	0.12	88.61	0.002	UD direction
4	6.23	0.161	0.5	0.0	0.0	0.24	0.00	0.00	0.005	
5	7.07	0.141	0.0	3.8	-0.3	0.00	14.19	0.11	0.004	EW direction
6	7.15	0.140	4.8	0.0	0.0	22.70	0.00	0.00	0.005	NS direction
7	20.90	0.048	0.0	-0.1	0.0	0.00	0.02	0.00	0.065	
8	22.28	0.045	-0.2	0.0	0.0	0.03	0.00	0.00	0.064	
9	24.91	0.040	0.0	0.0	0.0	0.00	0.00	0.00	0.066	
10	27.04	0.037	0.0	-0.2	0.0	0.00	0.04	0.00	0.069	
11	28.78	0.035	0.1	0.0	0.0	0.02	0.00	0.00	0.068	
12	34.75	0.029	0.0	0.0	-0.2	0.00	0.00	0.03	0.069	
13	38.41	0.026	0.0	0.0	0.0	0.00	0.00	0.00	0.067	
14	39.12	0.026	0.0	0.0	0.0	0.00	0.00	0.00	0.067	
15	41.41	0.024	0.0	0.0	0.0	0.00	0.00	0.00	0.069	
16	56.56	0.018	0.0	0.0	0.0	0.00	0.00	0.00	0.069	
17	59.61	0.017	0.0	0.0	0.0	0.00	0.00	0.00	0.070	
18	60.92	0.016	0.0	0.0	0.0	0.00	0.00	0.00	0.070	

Table 2.2-2(2) Summary of Natural Frequencies for PS/B (Medium 1)

Mode	Freqency (Hz)	Period (sec)	Modal Participation Facter			Effective Mass			Modal Damping	Remarks
			NS(X)	EW(Y)	UD(Z)	NS(X)	EW(Y)	UD(Z)		
1	7.25	0.138	7.0	0.0	0.0	48.50	0.00	0.00	0.045	NS direction
2	8.62	0.116	0.0	7.4	-0.2	0.00	55.10	0.03	0.045	EW direction
3	15.13	0.066	0.4	0.0	0.0	0.16	0.00	0.00	0.051	
4	16.14	0.062	-0.1	0.4	9.1	0.01	0.19	82.75	0.022	UD direction
5	18.70	0.053	5.2	0.0	0.1	27.11	0.00	0.02	0.044	NS direction
6	19.50	0.051	0.0	4.9	-0.6	0.00	23.74	0.39	0.039	EW direction
7	26.48	0.038	0.0	-0.3	-0.4	0.00	0.07	0.19	0.056	
8	30.36	0.033	2.2	0.0	0.0	4.68	0.00	0.00	0.050	
9	31.93	0.031	0.0	3.1	0.0	0.00	9.70	0.00	0.040	
10	32.23	0.031	2.9	0.0	-0.1	8.29	0.00	0.01	0.046	
11	33.74	0.030	0.1	0.0	0.0	0.01	0.00	0.00	0.049	
12	38.87	0.026	-0.1	0.0	-2.2	0.00	0.00	4.81	0.054	
13	47.85	0.021	0.0	0.0	0.0	0.00	0.00	0.00	0.040	
14	47.95	0.021	0.0	0.0	-0.1	0.00	0.00	0.01	0.046	
15	48.96	0.020	0.1	0.0	-0.1	0.01	0.00	0.01	0.054	
16	61.58	0.016	0.0	0.0	-0.8	0.00	0.00	0.59	0.065	
17	64.66	0.015	0.2	0.0	0.0	0.03	0.00	0.00	0.041	
18	65.29	0.015	0.0	-0.1	-0.1	0.00	0.01	0.00	0.054	

Table 2.2-2(3) Summary of Natural Frequencies for PS/B (Medium 2)

Mode	Freqency (Hz)	Period	Modal Participation Facter			Effective Mass			Modal Damping	Remarks
		(sec)	NS(X)	EW(Y)	UD(Z)	NS(X)	EW(Y)	UD(Z)		
1	8.36	0.120	6.4	0.0	0.0	40.87	0.00	0.00	0.062	NS direction
2	9.95	0.101	0.0	6.7	-0.1	0.00	45.15	0.01	0.062	EW direction
3	16.72	0.060	0.3	0.0	0.0	0.10	0.00	0.00	0.065	
4	21.34	0.047	4.1	-0.1	-1.1	16.67	0.02	1.10	0.064	NS direction
5	21.91	0.046	0.6	1.5	7.2	0.32	2.39	51.99	0.054	UD direction
6	22.74	0.044	-0.1	3.4	-3.1	0.01	11.64	9.78	0.062	EW,UD direction
7	28.81	0.035	0.0	-0.3	-0.8	0.00	0.09	0.65	0.065	
8	31.98	0.031	0.2	0.0	0.2	0.03	0.00	0.03	0.068	
9	37.15	0.027	0.0	0.0	0.0	0.00	0.00	0.00	0.066	
10	47.63	0.021	0.5	0.3	-3.8	0.21	0.10	14.40	0.050	UD direction
11	49.98	0.020	-0.6	5.3	0.2	0.33	28.29	0.04	0.012	EW direction
12	50.23	0.020	4.3	0.7	0.5	18.77	0.50	0.28	0.033	NS direction
13	53.76	0.019	3.4	-0.1	-0.2	11.37	0.00	0.03	0.043	NS direction
14	55.08	0.018	0.1	0.8	-0.4	0.01	0.58	0.16	0.063	
15	70.65	0.014	0.0	0.0	3.2	0.00	0.00	10.35	0.039	UD direction
16	75.72	0.013	0.0	0.0	0.0	0.00	0.00	0.00	0.009	
17	93.11	0.011	0.0	0.2	0.0	0.00	0.05	0.00	0.014	
18	101.29	0.010	0.3	0.0	0.0	0.12	0.00	0.00	0.010	

Table 2.2-2(4) Summary of Natural Frequencies for PS/B (Hard Rock)

Mode	Freqency (Hz)	Period	Modal Participation Facter			Effective Mass			Modal Damping	Remarks
		(sec)	NS(X)	EW(Y)	UD(Z)	NS(X)	EW(Y)	UD(Z)		
1	8.88	0.113	6.1	0.0	0.0	36.91	0.00	0.00	0.070	NS Direction
2	10.54	0.095	0.0	6.3	-0.1	0.00	40.09	0.01	0.070	EW direction
3	17.31	0.058	0.3	0.0	0.0	0.08	0.00	0.00	0.070	
4	22.23	0.045	3.6	0.0	-0.3	12.72	0.00	0.08	0.070	NS direction
5	23.41	0.043	0.1	3.1	1.4	0.01	9.36	1.89	0.070	EW direction
6	25.06	0.040	0.1	-0.6	6.4	0.02	0.36	40.54	0.070	UD direction
7	29.80	0.034	0.0	-0.3	-1.0	0.00	0.09	0.97	0.070	
8	32.38	0.031	0.0	0.0	0.2	0.00	0.00	0.04	0.070	
9	37.98	0.026	0.0	0.0	0.0	0.00	0.00	0.00	0.070	
10	52.81	0.019	-0.5	0.0	0.9	0.20	0.00	0.80	0.070	
11	54.06	0.018	0.1	-0.1	2.3	0.02	0.01	5.21	0.070	
12	56.75	0.018	0.0	0.2	0.7	0.00	0.05	0.44	0.070	

Table 2.3-1 Lumped Representation of Structure-Foundation Interaction at Surface for Circular Base

Motion	Equivalent Spring Constant	Equivalent Damping Coefficient
Horizontal	$k_x = \dfrac{32(1-\nu)GR}{7-8\nu}$	$c_x = 0.576 k_x R\sqrt{\dfrac{\rho}{G}}$
Rocking	$k_\psi = \dfrac{8GR^3}{3(1-\nu)}$	$c_\psi = \dfrac{0.30}{1+B_\psi} k_\psi R\sqrt{\dfrac{\rho}{G}}$
Vertical	$k_z = \dfrac{4GR}{1-\nu}$	$c_z = 0.85 k_z R\sqrt{\dfrac{\rho}{G}}$
Torsional	$k_t = \dfrac{16GR^3}{3}$	$c_t = \dfrac{\sqrt{K_t I_t}}{1+2I_t/\rho R^5}$

Definition of Terms:

$\nu =$ Poisson's ratio of foundation medium

$G =$ shear modulus of foundation medium

$R =$ radius of circular basemat

$\rho =$ mass density of foundation medium

$$B_\psi = \frac{3(1-\nu)I_0}{8\rho R^5}$$

$I_0 =$ total mass moment of inertia of structure and basemat about rocking axis at the base

$I_t =$ polar mass moment of inertia of structure and basemat

Table 2.3-2 Lumped Representation of Structure-Foundation Interaction at Surface for Rectangular Base

Motion	Equivalent Spring Constant	Equivalent Damping Coefficient
Horizontal	$k_x = 2(1+\nu)G\beta_x\sqrt{BL}$	Use the results for circular base with the following equivalent radius R:
Rocking	$k_\psi = \dfrac{G}{1-\nu}\beta_\psi BL^2$	
Vertical	$k_z = \dfrac{G}{1-\nu}\beta_z\sqrt{BL}$	(1) $R = \sqrt{BL/\pi}$ for translation
Torsional	Use Table 5-1 with $R = \sqrt[4]{BL\left(B^2+L^2\right)/6\pi}$	(2) $R = \sqrt[4]{BL^3/3\pi}$ for rocking

Definition of Terms:

ν and G are as defined previously

$B =$ width of the basemat perpendicular to the direction of horizontal excitation

$L =$ width of the basemat perpendicular to the direction of horizontal excitation

$\beta_x, \beta_\psi, \beta_z =$ constants that are functions of the dimensional ratio, L/B

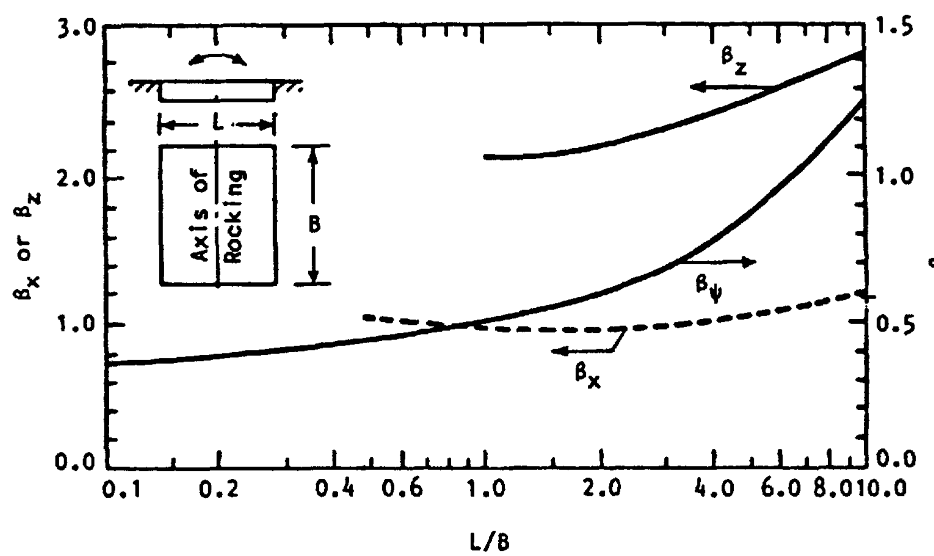


FIGURE 3.3-3. Constants β_x, β_ψ and β_z for Rectangular Bases (Richart, F. E., et al., *Vibrations of Soils and Foundations*, Copyright 1970. Reprinted by permission of Prentice-Hall, Inc., Upper Saddle River, NJ)

Source: ASCE 4-98, Table 3.3-3 and Figure 3.3-3 (Reference 3)

Table 2.3-3 List of Masses of Stick Model for PS/B

Building	Mass (J_{int})	Elevation	Description
PS/B	PSB2	EL 39'- 6”	The roof level of PS/B
	PSB1	EL 3'- 7”	1st floor level
	BSTP	EL -26'- 4”	The upper level of basemat
	BASE	EL -30'- 6”	The [middle] mass level of basemat
	BSBM	EL -34'- 8”	The lower level of basemat

Table 2.3-4 Material Constants and Damping Value

Building	Young’s Modulus E (ksi)	Shear Modulus G (ksi)	Poisson’s Ratio ν	Damping Value h (%)	Remark
PS/B	3,605	1,540	0.17	7.0	F'_c=4,000psi

Table 2.3-5 Mass Properties of Stick Model for PS/B

Mass Name	Elevation (in)	Weight W ($\times 10^6$lb)	Weight Moment of Inertia ($\times 10^{12}$lb·in^2)			Mass Center (in)	
			J_{yy} NS	J_{xx} EW	J_{zz} Torsional	X_g NS	Y_g EW
PSB2	474.0	7.89	0.458	1.25	1.70	393.9	707.9
PSB1	43.0	11.4	0.668	1.82	2.46	396.9	656.6
BSTP*	-316.0	—	—	—	—	398.5	645.0
BASE	-366.0	15.0	0.894	2.41	3.25	398.5	645.0
BSBM*	-416.0	—	—	—	—	398.5	645.0

Total : 34.29×10^6 (lb)

* = BSTP and BSBM are subordinate points of BASE.

Table 2.3-6 Element Properties of Stick Model for PS/B

Element Name	Torsional Const. I_{zz} ($\times 10^{11}$in^4)	Shear Area ($\times 10^5$in^2)		Moment of Inertia ($\times 10^{11}$in^4)		Shear Center (in)		Axial Area A_a ($\times 10^5$in^2)	Centroid (in)	
		A_x NS	A_y EW	I_{yy} NS	I_{xx} EW	X_s NS	Y_s EW		X_c NS	Y_c EW
PSB2	0.298	0.559	0.577	0.0622	0.207	397.0	691.1	1.14	404.0	705.0
PSB1	0.414	0.952	0.942	0.0898	0.274	396.0	659.3	1.82	394.0	648.0

Table 2.4-1 Soil Spring Constants and Damping Coefficients for PS/B

(Horizontal)

Direction		Horizontal		Rotational	
		Spring Constant ($\times 10^8$lb/in)	Damping Coefficient ($\times 10^7$lb-s/in)	Spring Constant ($\times 10^{14}$lb-in/rad)	Damping Coefficient ($\times 10^{13}$lb-in-s/rad)
NS K_x :Horizontal K_{yy}: Rotational	Soft	0.712	0.120	0.162	0.0201
	Medium 1	9.94	0.480	2.17	0.0773
	Medium 2	36.9	0.960	8.06	0.155
	Hard Rock	Fixed Base Assumption *			
EW K_y : Horizontal K_{xx}: Rotational	Soft	0.655	0.108	0.356	0.0499
	Medium 1	9.14	0.450	4.76	0.194
	Medium 2	34.0	0.900	17.7	0.392
	Hard Rock	Fixed Base Assumption *			

(Vertical)

Direction		Spring Constant ($\times 10^8$lb/in)	Damping Coefficient ($\times 10^7$lb-s/in)
UD K_z	Soft	0.928	0.397
	Medium 1	12.4	1.52
	Medium 2	46.1	3.03
	Hard Rock	Fixed Base Assumption *	

(Torsional)

Direction		Spring Constant ($\times 10^{14}$lb-in/rad)	Damping Coefficient ($\times 10^{13}$lb-in-s/rad)
Torsional K_{zz}	Soft	0.317	0.0233
	Medium 1	4.59	0.0994
	Medium 2	17.0	0.201
	Hard Rock	Fixed Base Assumption *	

* The point located at the upper level of the basemat (BSTP) is considered as the fixed end point when a fixed base assumption is adopted.

Table 2.4-2 Soil Conditions

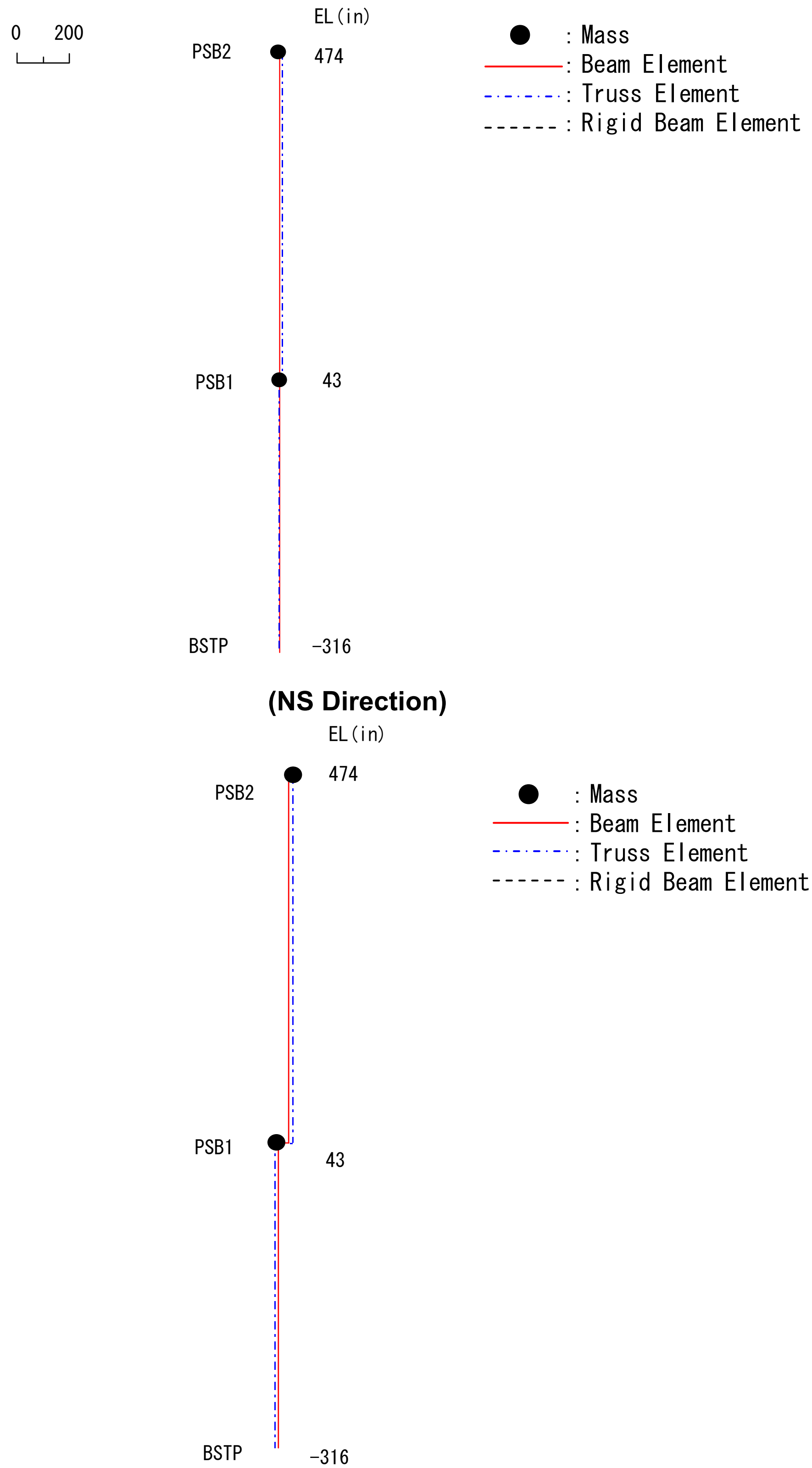
	Soft Soil	Stiff Soil Medium 1	Soft Rock Medium 2	Fixed (Hard Rock)
V_s (fps)	1,000	3,500	6,500	(8,000)
V_s (m/s)	305	1,070	1,980	(2,500)
Density (pcf)	110	130	140	(160)
Poisson's Ratio	0.40	0.35	0.35	(0.30)

Table 2.4-3 Seismic SSI Analysis Cases

Case No.	Soil Properties				Input Waves (SSE)		
	Soft	Medium 1	Medium 2	Fixed Base	Ha	Hb	V
1	√				√	√	√
2		√			√	√	√
3			√		√	√	√
4				√	√	√	√

Security-Related Information – Withhold Under 10 CFR 2.390

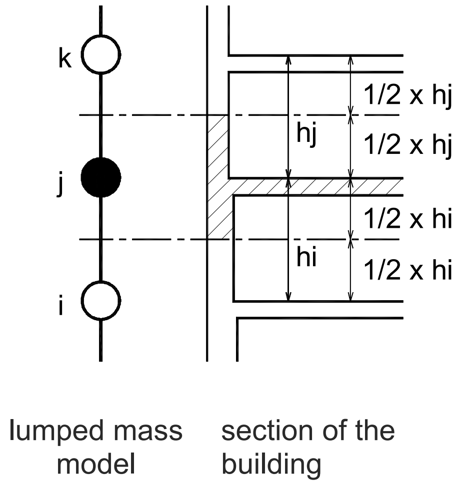
Figure 2.3-1 Stick Model for PS/B including Basemat

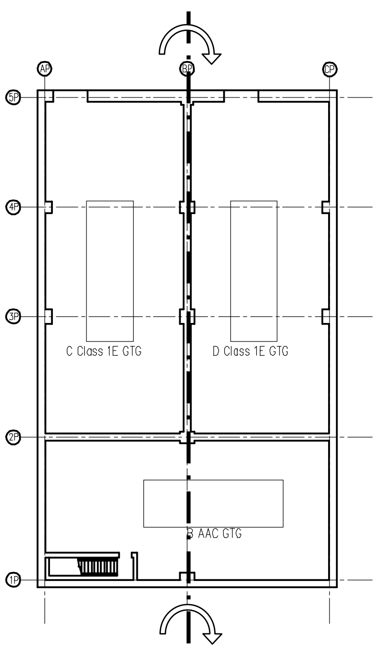


(NS Direction)

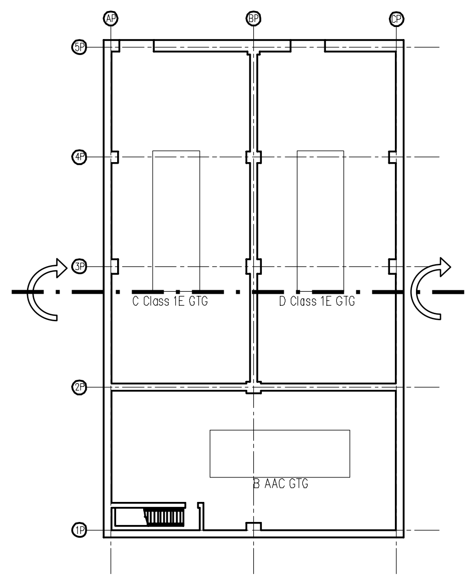
(EW Direction)

Figure 2.3-2 Stick Model (PS/B)





(NS direction)



(EW direction)

Figure 2.3-3 Weight and Inertia Moment of Lumped Masses

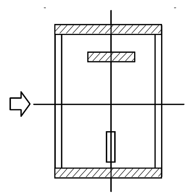
configuration (building)	section area	geometrical moment of inertia	axial real
	area of the shear walls effective to the seismic force (shown in the figure)	estimated for the shear walls effective to the seismic force (shown in the figure)	total axial area of the shear walls and columns effective to the seismic force

Figure 2.3-4 Method to Compute Section Area, Geometrical Moment of Inertia and Axial Area by Manual Calculation

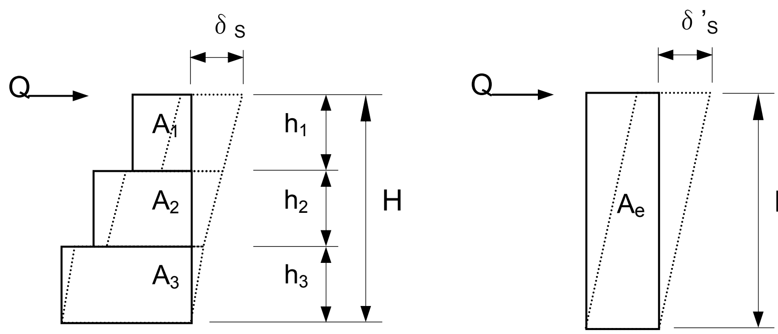


Figure 2.3-5 Method to Calculate Equivalent Shear Area

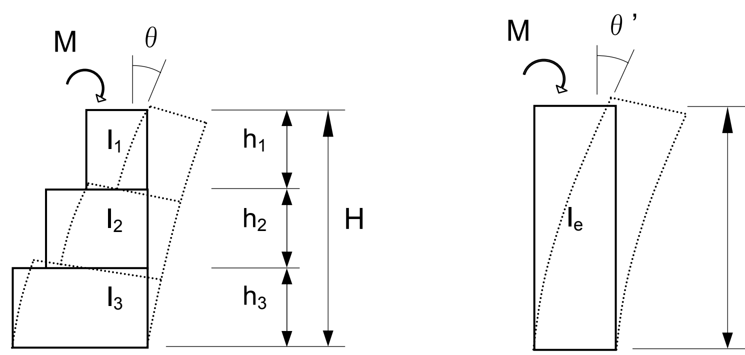


Figure 2.3-6 Method to Calculate Equivalent Moment of Inertia

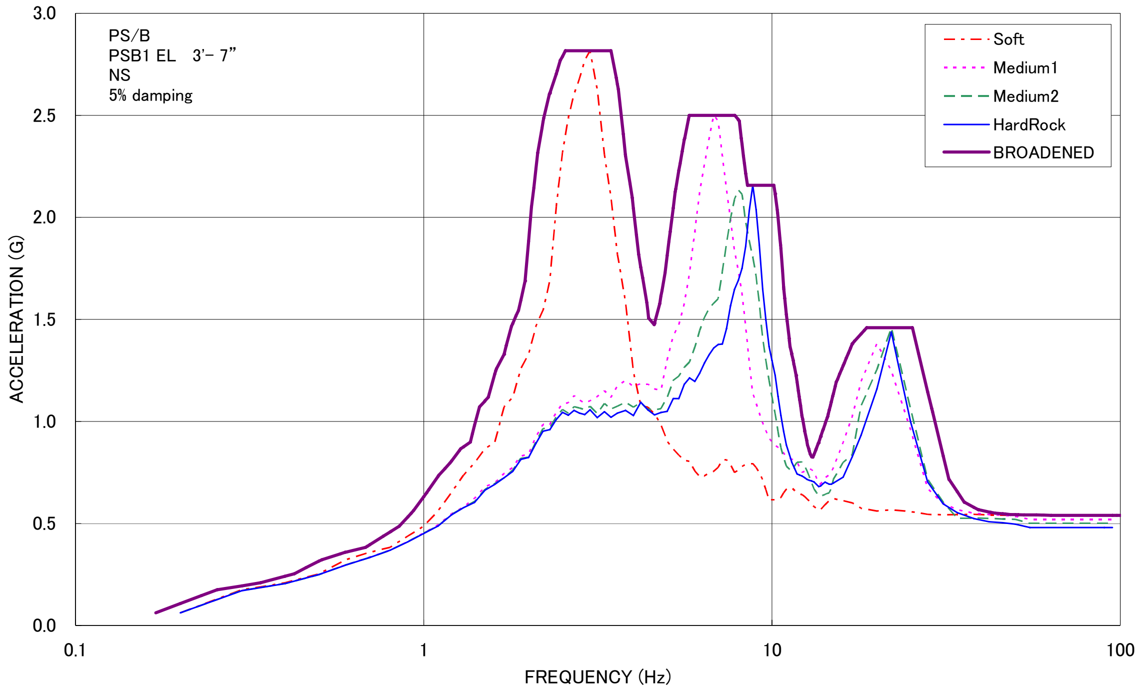


Figure 2.5-1 ISRS of PS/B (NS Direction)
(Sheet 1 of 2)

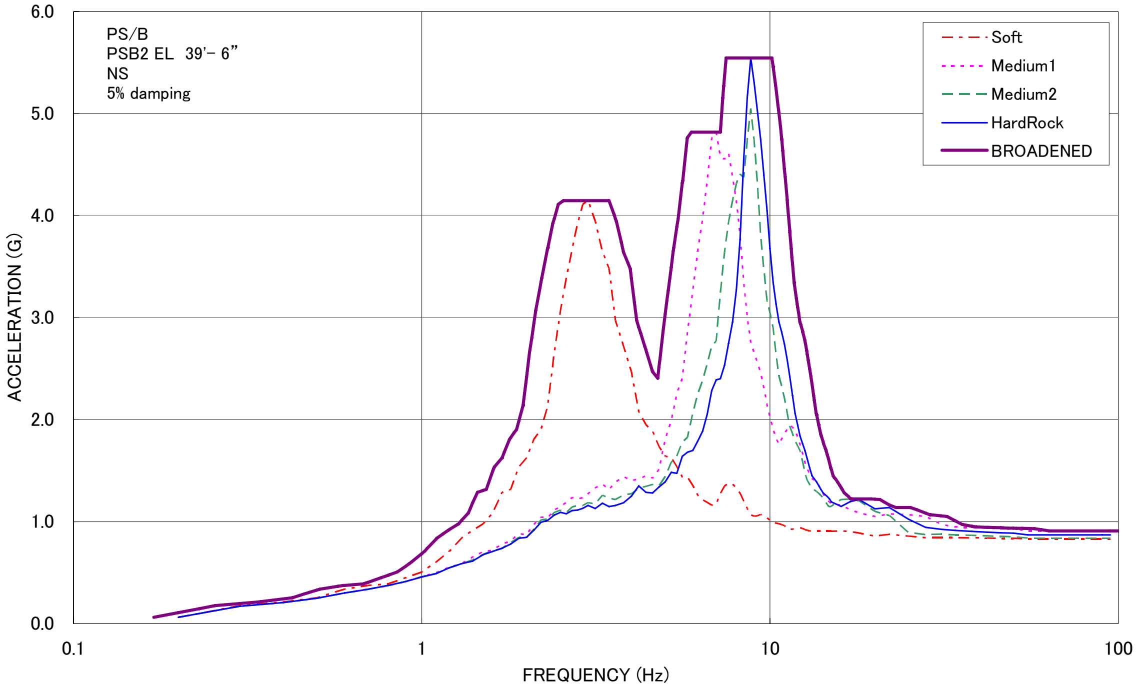


Figure 2.5-1 ISRS of PS/B (NS Direction)
(Sheet 2 of 2)

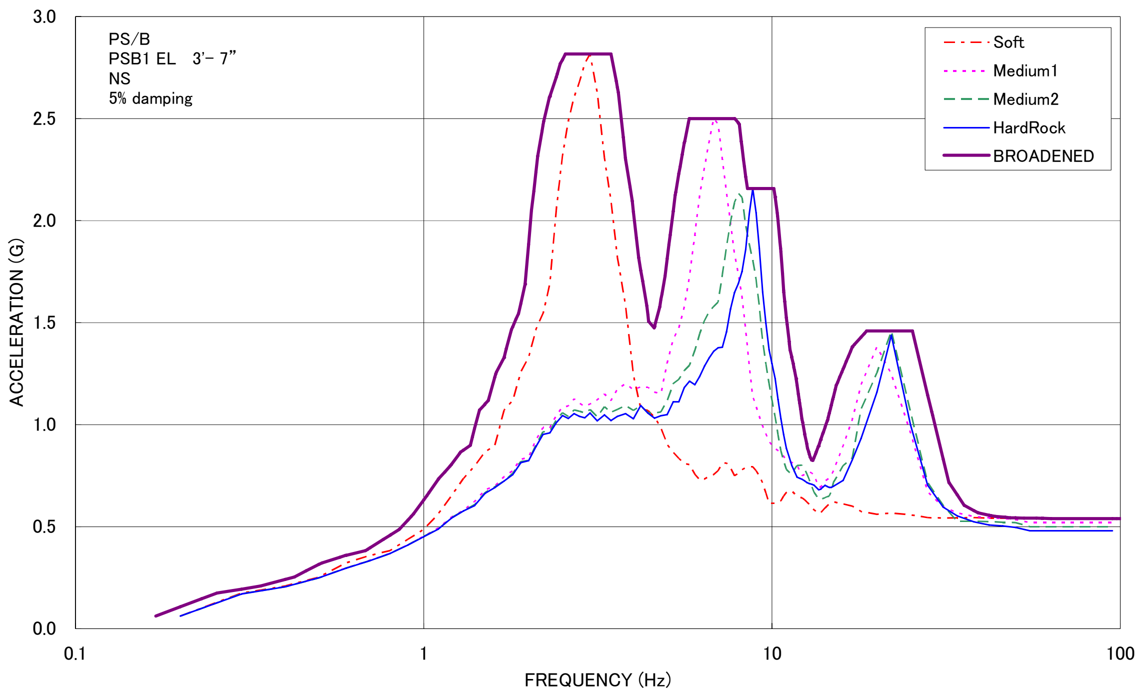


Figure 2.5-2 ISRS of PS/B (EW Direction)
(Sheet 1 of 2)

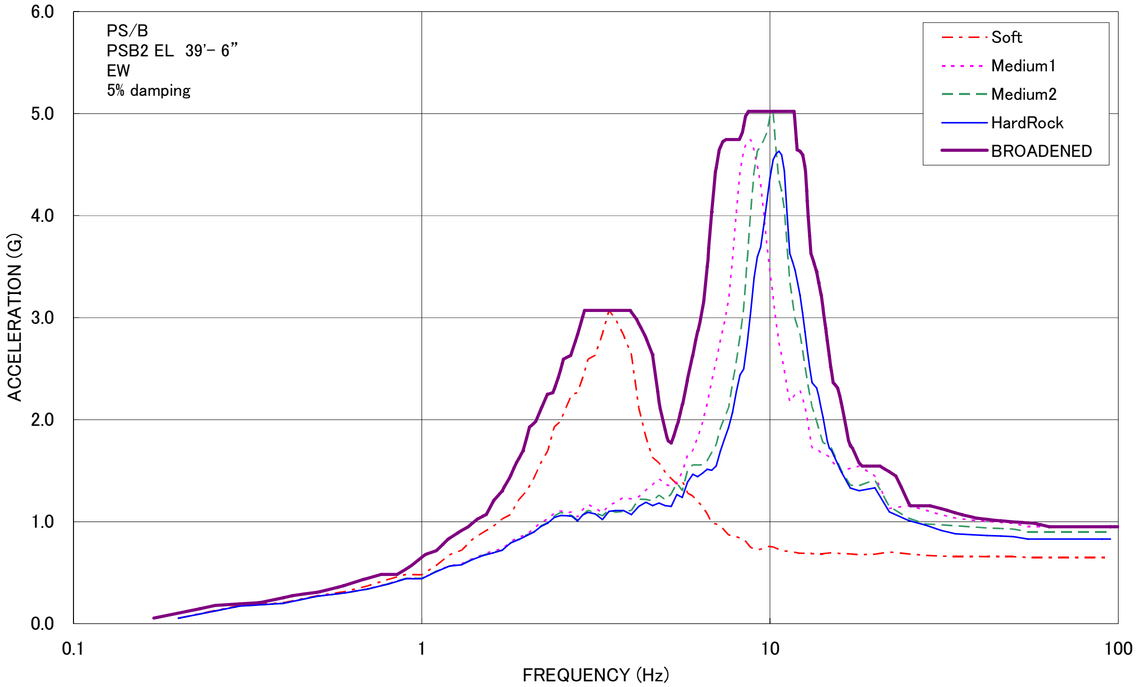


Figure 2.5-2 ISRS of PS/B (EW Direction)
(Sheet 2 of 2)

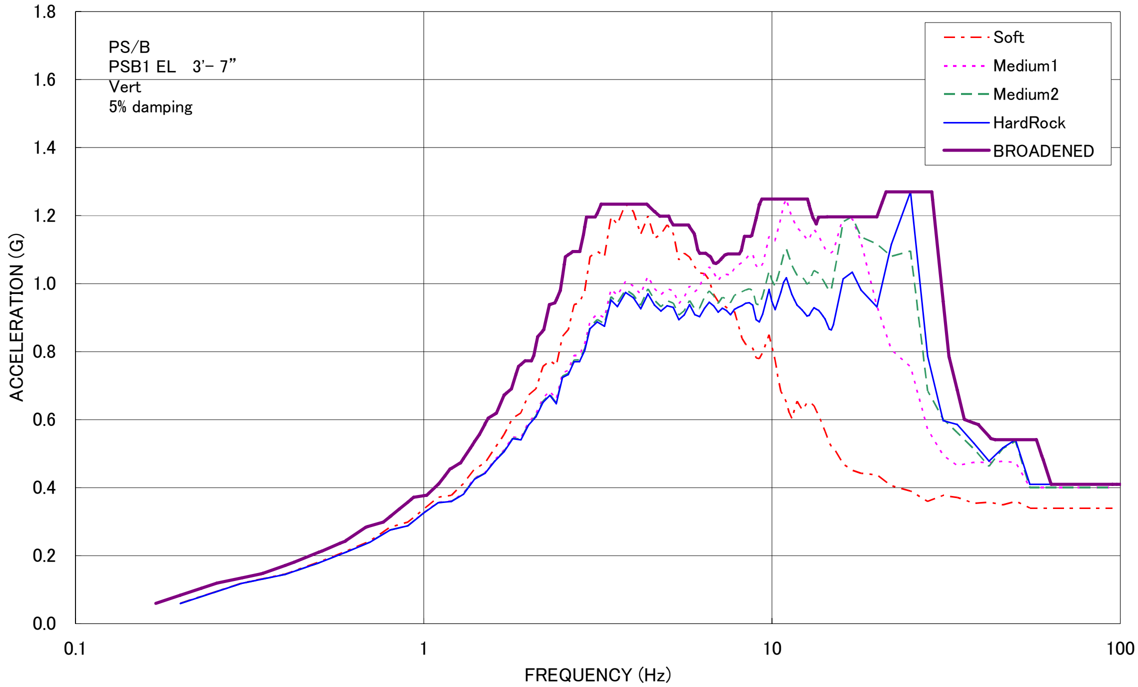


Figure 2.5-3 ISRS of PS/B (Vertical Direction)
(Sheet 1 of 2)

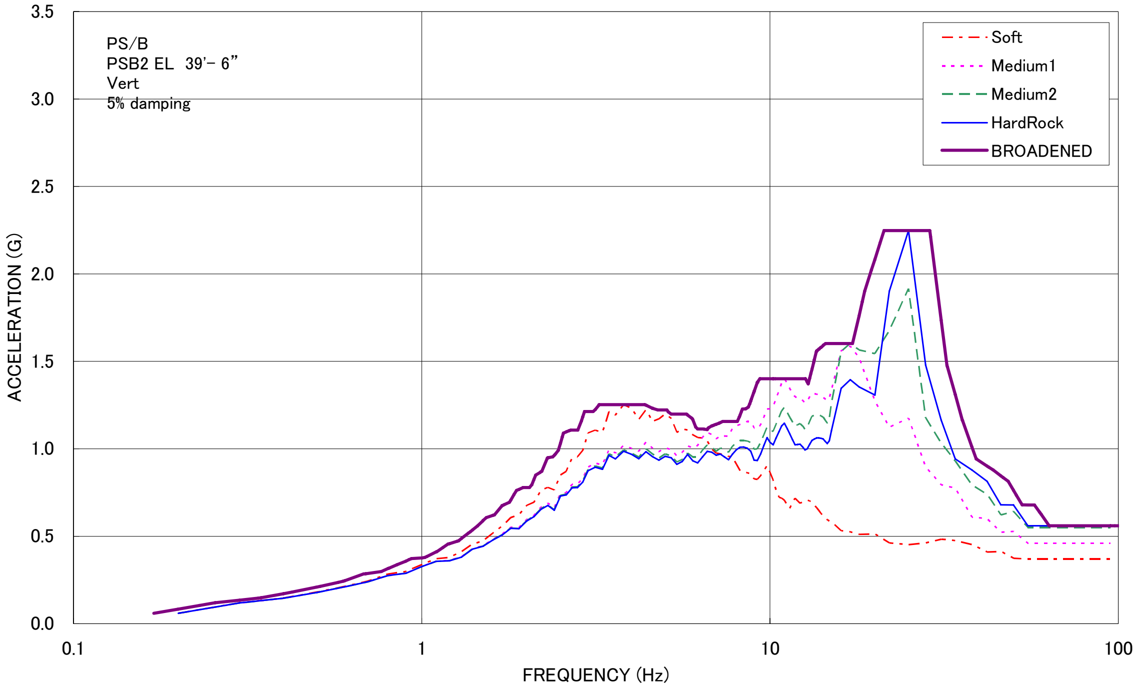


**Figure 2.5-3 ISRS of PS/B (Vertical Direction)
(Sheet 2 of 2)**

3.0 SEISMIC DESIGN VALUES

Refer to DCD, Subsection 3.8.4 for the design of the east and west PS/Bs as reinforced concrete structures consisting of vertical shear/bearing walls and horizontal slabs. Seismic forces obtained from the dynamic analysis described within this technical report are applied in load combinations given in DCD, Subsection 3.8.4.3.

The maximum responses for acceleration, displacement, shear force, bending moment and axial force are shown in Tables 3.0-1 to 3.0-7. Design values for shear force, bending moment and axial force are shown in Table 3.0-8.

Table 3.0-1(1) PS/B Lumped Mass Stick Model, Maximum Accelerations Soil Subgrade (V_s = 1,000 ft/s)

Model	Mass Node	Max. NS Acc. (g)				Max. EW Acc. (g)				Max. Vert. Acc. (g)			
		Earthquake				Earthquake				Earthquake			
		H1	H2	V	3-C*	H1	H2	V	3-C*	H1	H2	V	3-C*
PS/B	PSB2	0.83	0.00	0.00	0.83	0.00	0.65	0.02	0.65	0.00	0.02	0.37	0.37
	PSB1	0.54	0.00	0.00	0.54	0.00	0.52	0.01	0.52	0.00	0.01	0.34	0.34

* = combined by SRSS method

Table 3.0-1(2) PS/B Lumped Mass Stick Model, Maximum Accelerations Rock Subgrade (V_s = 3,500 ft/s)

Model	Mass Node	Max. NS Acc. (g)				Max. EW Acc. (g)				Max. Vert. Acc. (g)			
		Earthquake				Earthquake				Earthquake			
		H1	H2	V	3-C*	H1	H2	V	3-C*	H1	H2	V	3-C*
PS/B	PSB2	0.91	0.00	0.00	0.91	0.00	0.95	0.03	0.95	0.01	0.03	0.46	0.46
	PSB1	0.52	0.00	0.00	0.52	0.00	0.48	0.02	0.48	0.00	0.01	0.40	0.40

* = combined by SRSS method

Table 3.0-1(3) PS/B Lumped Mass Stick Model, Maximum Accelerations Rock Subgrade (V_s = 6,500 ft/s)

Model	Mass Node	Max. NS Acc. (g)				Max. EW Acc. (g)				Max. Vert. Acc. (g)			
		Earthquake				Earthquake				Earthquake			
		H1	H2	V	3-C*	H1	H2	V	3-C*	H1	H2	V	3-C*
PS/B	PSB2	0.84	0.00	0.01	0.84	0.00	0.90	0.03	0.90	0.01	0.03	0.55	0.55
	PSB1	0.50	0.00	0.01	0.50	0.00	0.55	0.04	0.55	0.00	0.01	0.40	0.40

* = combined by SRSS method

Table 3.0-1(4) PS/B Lumped Mass Stick Model, Maximum Accelerations Hard Rock Subgrade (V_s = 8,000 ft/s)

Model	Mass Node	Max. NS Acc. (g)				Max. EW Acc. (g)				Max. Vert. Acc. (g)			
		Earthquake				Earthquake				Earthquake			
		H1	H2	V	3-C*	H1	H2	V	3-C*	H1	H2	V	3-C*
PS/B	PSB2	0.87	0.00	0.01	0.87	0.00	0.83	0.03	0.83	0.01	0.03	0.56	0.56
	PSB1	0.48	0.00	0.01	0.48	0.00	0.50	0.04	0.50	0.00	0.01	0.41	0.41

* = combined by SRSS method

Table 3.0-2(1) PS/B Lumped Mass Stick Model, Maximum Acceleration (NS)

Building	Element	NS Maximum Acceleration（g）			
		Separate Directional Input			
		Soft	Medium 1	Medium 2	Hard Rock
PS/B	PSB2	0.834	0.914	0.839	0.868
	PSB1	0.539	0.515	0.495	0.477
BASE	BSTP	0.396	0.337	0.316	-

Table 3.0-2(2) PS/B Lumped Mass Stick Model, Maximum Acceleration (EW)

Building	Element	EW Maximum Acceleration（g）			
		Separate Directional Input			
		Soft	Medium 1	Medium 2	Hard Rock
PS/B	PSB2	0.653	0.948	0.896	0.829
	PSB1	0.521	0.477	0.552	0.500
BASE	BSTP	0.435	0.355	0.324	-

Table 3.0-2(3) PS/B Lumped Mass Stick Model, Maximum Acceleration (UD)

Building	Element	UD Maximum Acceleration （g）			
		Separate Directional Input			
		Soft	Medium 1	Medium 2	Hard Rock
PS/B	PSB2	0.368	0.461	0.547	0.565
	PSB1	0.342	0.404	0.404	0.409
BASE	BSTP	0.342	0.344	0.319	-

Table 3.0-3(1) PS/B Lumped Mass Stick Model, Maximum Displacements Soil Subgrade (V_s = 1,000 ft/s)

Model	Mass Node	Max. NS Disp. (in)				Max. EW Disp. (in)				Max. Vert. Disp. (in)			
		Earthquake				Earthquake				Earthquake			
		H1	H2	V	3-C*	H1	H2	V	3-C*	H1	H2	V	3-C*
PS/B	PSB2	0.86	0.00	0.00	0.86	0.00	0.53	0.01	0.53	0.00	0.02	0.10	0.10
	PSB1	0.54	0.00	0.00	0.54	0.00	0.40	0.01	0.40	0.00	0.00	0.10	0.10

* = combined by SRSS method

Table 3.0-3(2) PS/B Lumped Mass Stick Model, Maximum Displacements – Rock Subgrade (V_s = 3,500 ft/s)

Model	Mass Node	Max. NS Disp. (in)				Max. EW Disp. (in)				Max. Vert. Disp. (in)			
		Earthquake				Earthquake				Earthquake			
		H1	H2	V	3-C*	H1	H2	V	3-C*	H1	H2	V	3-C*
PS/B	PSB2	0.17	0.00	0.00	0.17	0.00	0.12	0.00	0.12	0.00	0.00	0.02	0.02
	PSB1	0.08	0.00	0.00	0.08	0.00	0.06	0.00	0.06	0.00	0.00	0.01	0.01

* = combined by SRSS method

Table 3.0-3(3) PS/B Lumped Mass Stick Model, Maximum Displacements Rock Subgrade (V_s = 6,500 ft/s)

Model	Mass Node	Max. NS Disp. (in)				Max. EW Disp. (in)				Max. Vert. Disp. (in)			
		Earthquake				Earthquake				Earthquake			
		H1	H2	V	3-C*	H1	H2	V	3-C*	H1	H2	V	3-C*
PS/B	PSB2	0.12	0.00	0.00	0.12	0.00	0.09	0.00	0.09	0.00	0.00	0.01	0.01
	PSB1	0.05	0.00	0.00	0.05	0.00	0.04	0.00	0.04	0.00	0.00	0.01	0.01

* = combined by SRSS method

Table 3.0-3(4) PS/B Lumped Mass Stick Model, Maximum Displacements Hard Rock Subgrade (V_s = 8,000 ft/s)

Model	Mass Node	Max. NS Disp. (in)				Max. EW Disp. (in)				Max. Vert. Disp. (in)			
		Earthquake				Earthquake				Earthquake			
		H1	H2	V	3-C*	H1	H2	V	3-C*	H1	H2	V	3-C*
PS/B	PSB2	0.11	0.00	0.00	0.11	0.00	0.08	0.00	0.08	0.00	0.00	0.01	0.01
	PSB1	0.04	0.00	0.00	0.04	0.00	0.03	0.00	0.03	0.00	0.00	0.00	0.00

* = combined by SRSS method

Note: Displacements shown in the above table include the subgrade displacements.

Table 3.0-4(1) PS/B Lumped Mass Stick Model, Maximum Displacement (NS)

Building	Element	NS Maximum Displacement（in）			
		Separate Directional Input			
		Soft	Medium 1	Medium 2	Hard Rock
PS/B	PSB2	0.862	0.173	0.124	0.111
	PSB1	0.540	0.079	0.051	0.042
BASE	BSTP	0.287	0.020	0.005	-

Table 3.0-4(2) PS/B Lumped Mass Stick Model, Maximum Displacement (EW)

Building	Element	EW Maximum Displacement（in）			
		Separate Directional Input			
		Soft	Medium 1	Medium 2	Hard Rock
PS/B	PSB2	0.532	0.118	0.093	0.077
	PSB1	0.396	0.058	0.044	0.034
BASE	BSTP	0.281	0.018	0.005	-

Table 3.0-4(3) PS/B Lumped Mass Stick Model, Maximum Displacement (UD)

Building	Element	UD Maximum Displacement（in）			
		Separate Directional Input			
		Soft	Medium 1	Medium 2	Hard Rock
PS/B	PSB2	0.101	0.016	0.011	0.010
	PSB1	0.098	0.012	0.007	0.005
BASE	BSTP	0.095	0.009	0.003	-

Table 3.0-5(1) PS/B Lumped Mass Stick Model, Maximum Shearing Force (NS)

Building	Element	NS Shearing Force（kips）						
		Separate Directional Input				Maximum Value	Margin	Margined Load
		Soft	Medium 1	Mediu m 2	Hard Rock			
PS/B	PSB2	6,600	7,170	6,570	6,770	7,170	1.00	7,170
	PSB1	12,480	12,420	12,190	11,970	12,480	1.00	12,500
Soil		16,410	15,500	15,270	-	16,410	1.00	16,500

Table 3.0-5(2) PS/B Lumped Mass Stick Model, Maximum Shearing Force (EW)

Building	Element	EW Shearing Force（kips）						
		Separate Directional Input				Maximum Value	Margin	Margined Load
		Soft	Medium 1	Medium 2	Hard Rock			
PS/B	PSB2	5,170	7,450	7,060	6,500	7,450	1.00	7,450
	PSB1	11,060	11,910	13,010	12,130	13,010	1.00	13,100
Soil		16,840	14,360	16,310	-	16,840	1.00	16,900

Table 3.0-6(1) PS/B Lumped Mass Stick Model, Maximum Bending Moment (NS)

Building	Element	NS Bending Moment (×10^{3}kips*in)						
		Separate Directional Input				Maximum Value	Margin	Margined Load
		Soft	Medium 1	Medium 2	Hard Rock			
PS/B	PSB2	362	372	404	372	404	1.00	404
		3,200	3,420	3,040	3,180	3,420	1.00	3,420
	PSB1	3,670	3,770	3,290	3,420	3,770	1.00	3,770
		7,970	8,220	7,670	7,670	8,220	1.00	8,220
Soil		9,560	9,660	9,050	-	9,660	1.00	9,660

Table 3.0-6(2) PS/B Lumped Mass Stick Model, Maximum Bending Moment (EW)

Building	Element	EW Bending Moment (×10^{3}kips*in)						
		Separate Directional Input				Maximum Value	Margin	Margined Load
		Soft	Medium 1	Medium 2	Hard Rock			
PS/B	PSB2	450	698	587	472	698	1.00	698
		2,540	3,910	3,410	3,100	3,910	1.00	3,910
	PSB1	2,980	4,670	3,790	3,530	4,670	1.00	4,670
		6,940	8,930	8,430	7,720	8,930	1.00	8,930
Soil		8,550	10,300	9,910	-	10,300	1.00	10,300

Table 3.0-7 PS/B Lumped Mass Stick Model, Maximum Axial Force (UD)

Building	Element	UD Axial Force (kips)						
		Separate Directional Input				Maximum Value	Margin	Margined Load
		Soft	Medium 1	Medium 2	Hard Rock			
PS/B	PSB2	2,930	3,650	4,310	4,460	4,460	1.00	4,460
	PSB1	6,850	8,150	8,510	8,960	8,960	1.00	8,960
Soil		8,810	10,670	11,920	-	11,920	1.00	12,000

Table 3.0-8(1) Lumped Mass Stick Model Design
Shear Forces and Moments

Model	Mass Node	Elevation (in)	NS Direction		EW Direction	
			Shear Force (kip)	Moment (kip-ft)	Shear Force (kip)	Moment (kip-ft)
PS/B	PSB2	474	7,170	285,000	7,450	326,000
	PSB1	43	12,500	685,000	13,100	744,000

Table 3.0-8(2) Lumped Mass Stick Model Design
Axial Forces

Model	Mass Node	Elevation (in)	UD Direction
			Axial Force (kip)
PS/B	PSB2	474	4,460
	PSB1	43	8,960

Notes:
1) The forces and moments shown above envelope all four generic subgrade conditions and are applied to the FEMs for structural design as described in Section 3.8.

2) The forces and moments are obtained by combination of the three orthogonal directions used in the model by SRSS or the Newmark 100%-40%-40% method.

4.0 REFERENCES

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