5.4 ACS SASSI FE Model of the PS/B

5.4.1 Description of the PS/B ACS SASSI Model

The ACS SASSI dynamic FE model used in the SSI analyses of the PS/B is a 3-D FE model of the West PS/B initially developed using ANSYS before being translated into SASSI format. The model includes shell elements representing the walls and slabs, beam elements representing beams and columns, and solid elements representing the basemat; with a mesh varying in size from 6’ to 8’.

Stress levels under critical seismic load conditions are computed for all shear walls in the model. Shear walls with stress levels, including in-plane and out-of-plane stresses, below the cracking stress capacity of concrete, are modeled with their gross section properties and are adjusted for openings if applicable. The material (elastic modulus) and geometric (thickness) properties of slabs and shear walls with in-plane shear stresses less than the concrete shear capacity but with out-of-plane bending stresses greater than the concrete modulus of rupture are modified to reflect the out-of-plane cracked concrete properties, with unchanged in-plane stiffness and mass. The cracked concrete properties represent one-half of the out-of-plane flexural stiffness.

The ACS SASSI Dynamic FE model at several elevations is shown in Figures 5.4.1-1 through 5.4.1-6.

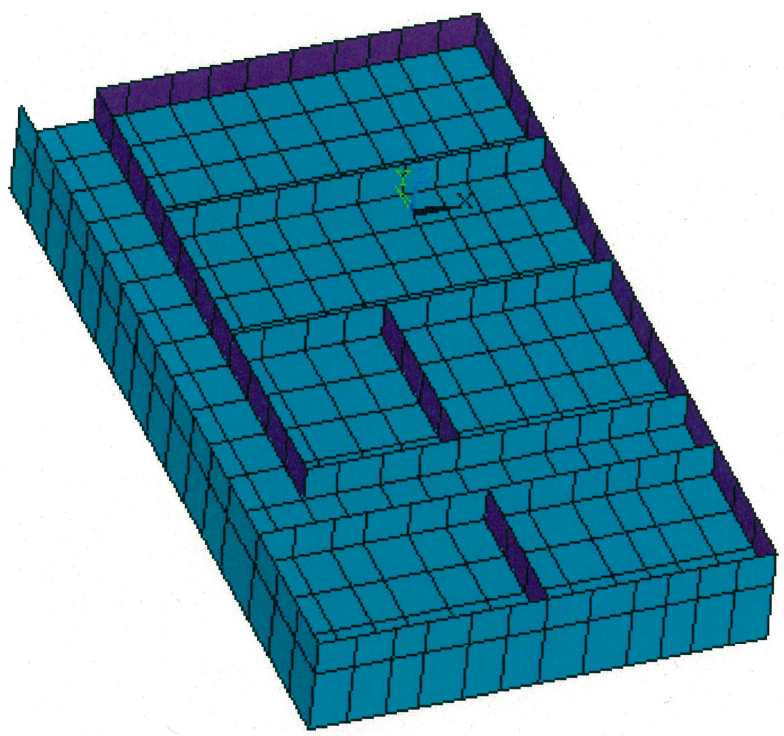

Figure 5.4.1-1 ACS SASSI Dynamic Model Basemat (Elev. -26’-4”)

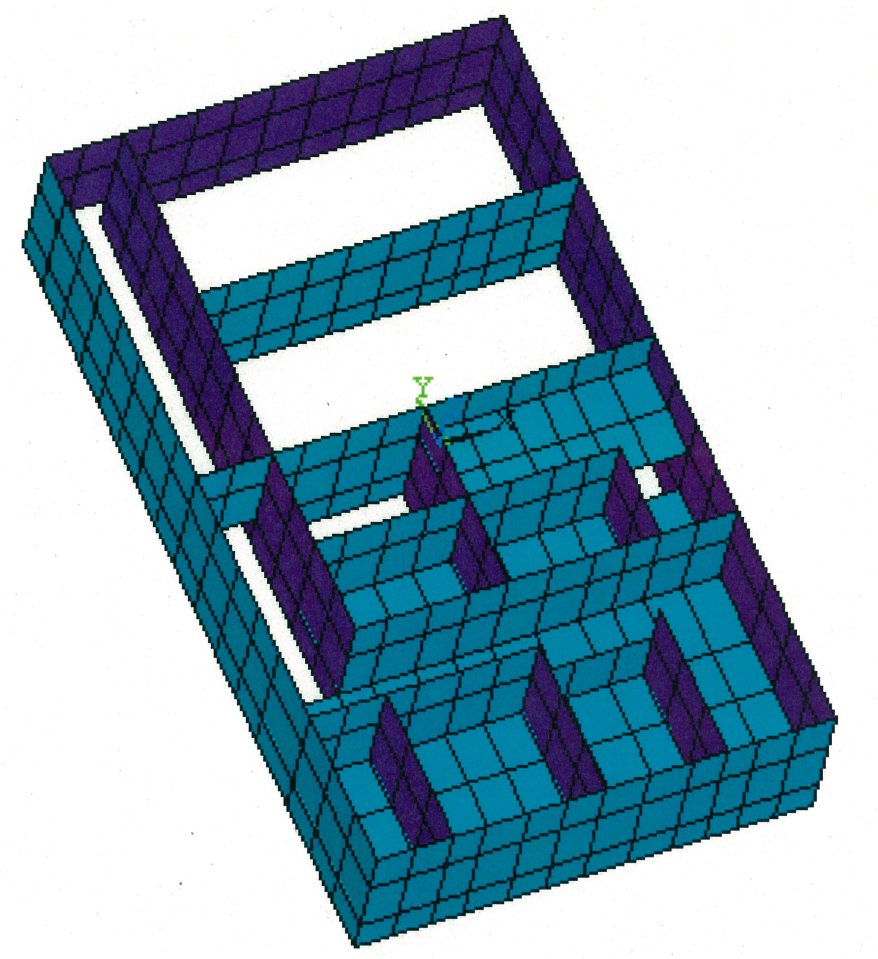

Figure 5.4.1-2 ACS SASSI Dynamic Model Intermediate Floor (Elev. -14'-2" & -4'-10")

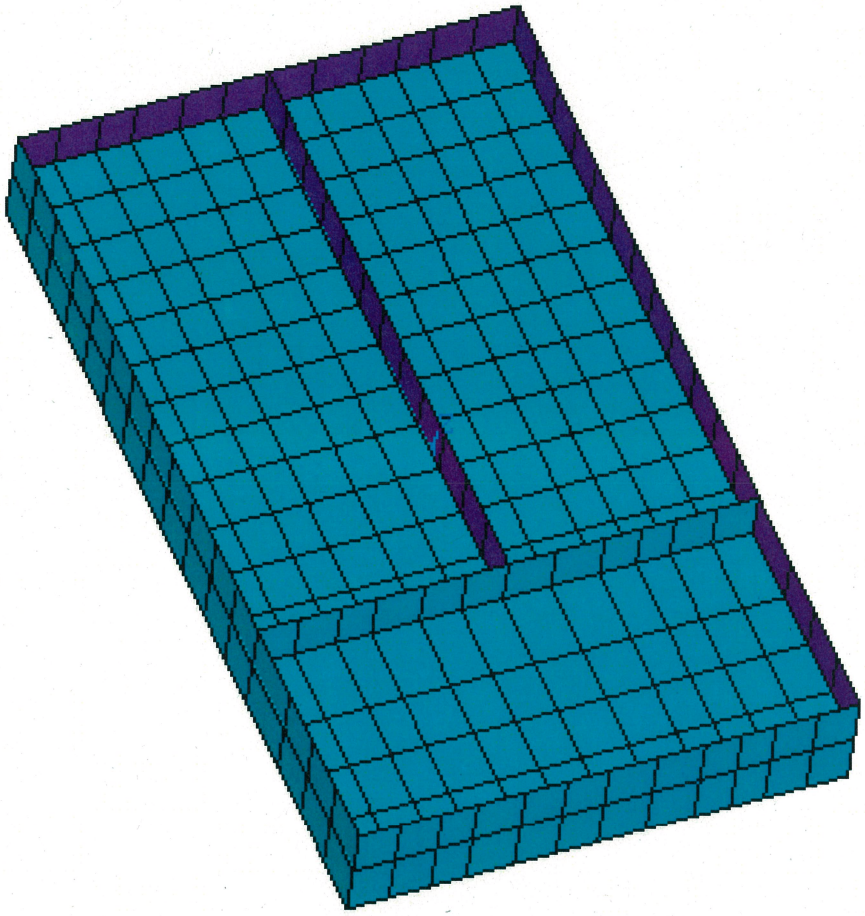

Figure 5.4.1-3 ACS SASSI Dynamic Model First Floor (Elev. 3'-7")

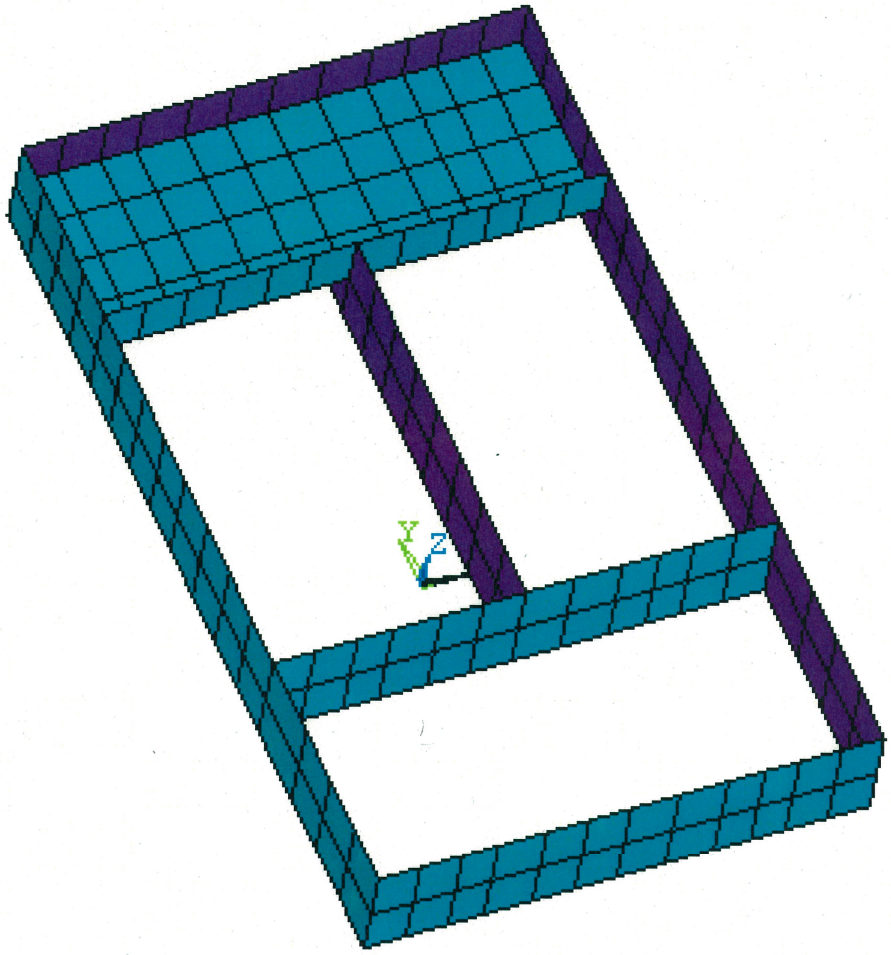

Figure 5.4.1-4 ACS SASSI Dynamic Model Intermediate Floor (Elev. 24'-2")

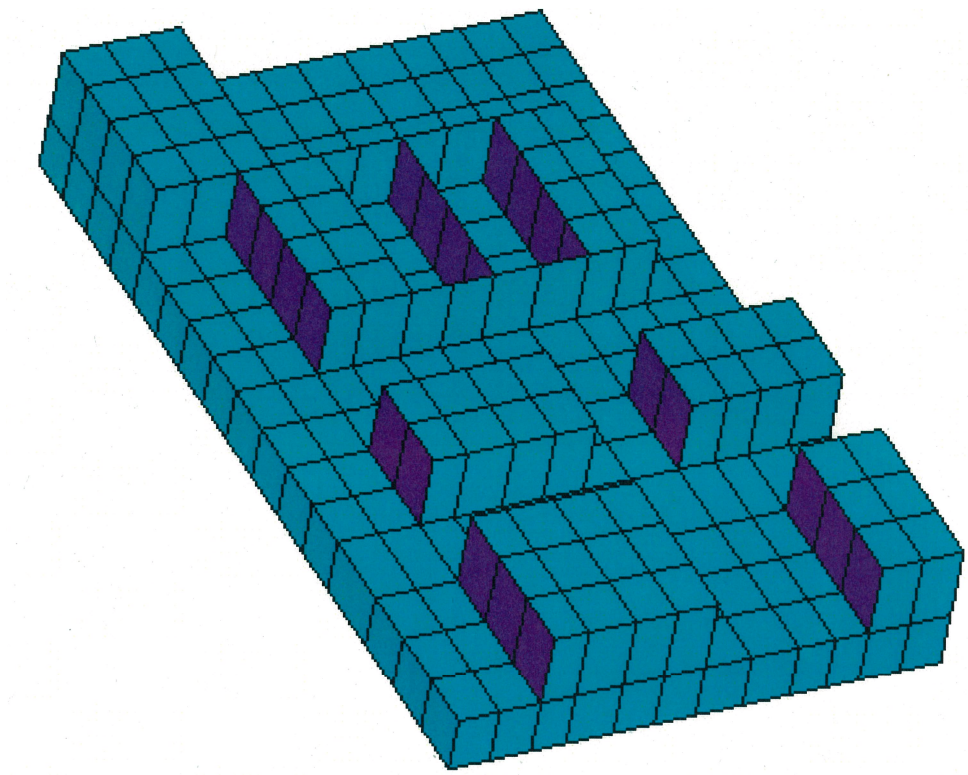

Figure 5.4.1-5 ACS SASSI Dynamic Model Roof (Elev. 39''-6")

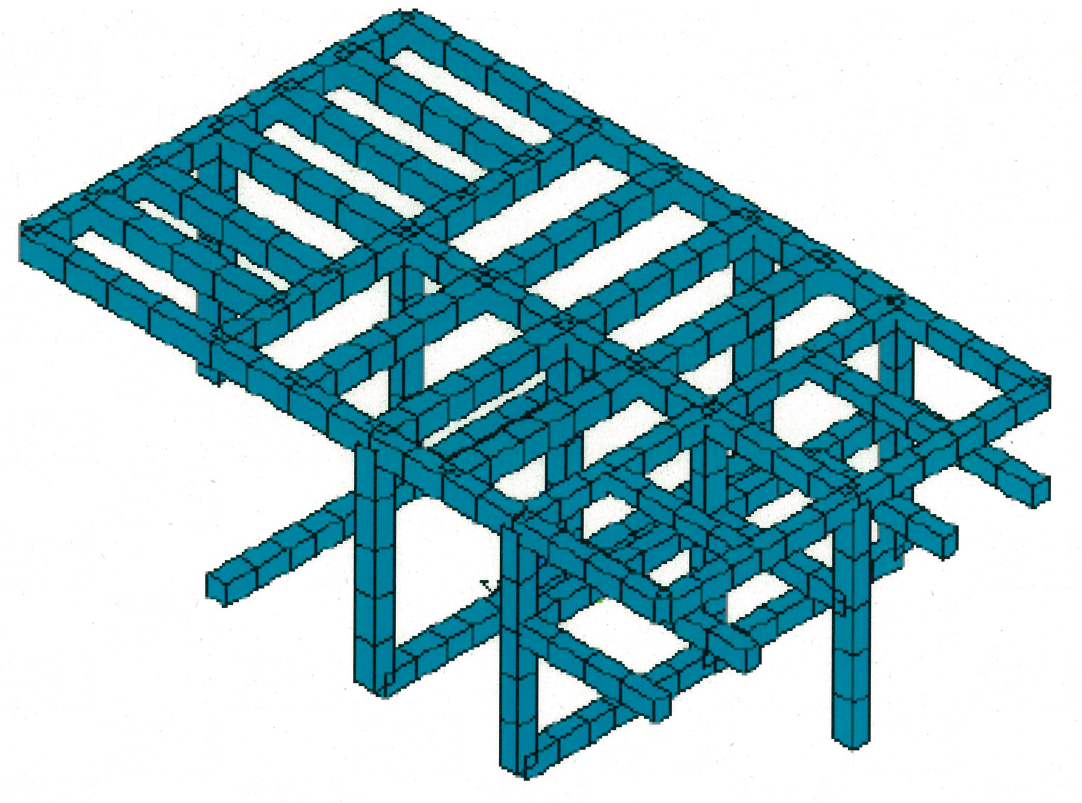

Figure 5.4.1-6 ACS SASSI Dynamic Model Beams & Columns

5.4.2 Validation of the PS/B ACS SASSI Model

The validation of the PS/B dynamic FE model utilizes uncracked concrete material properties. See Section 5.5 for discussion of the effects of concrete cracking.

The 1g static ANSYS analyses are performed on the detailed ANSYS dynamic FE models of the PS/B producing several results that are compared validate the ACS SASSI dynamic model. The models include structural weight of the model, the mass properties, and the stiffness of the structure. Table 5.4.2-1 compares the structural weight of the dynamic FE model to that of the detailed static model. The structural weights of both models are found to be comparable.

Table 5.4.2-2 compares the mass properties of the dynamic FE model to those of the detailed static model. They include the center of mass and mass inertia of the models and are also found to be comparable.

Table 5.4.2-1 Structural Weight of PS/B Dynamic FE Model

Location	Weight (kips)		(1)/(2) ratio
	(1)	(2)	
	ANSYS Model	Detailed Static Model	
Roof level	7521[(a)]	7273[(a)]	103%
Ground Floor Level	11741	11576	101%
Base Mat Level	16078[(b)]	15461[(b)]	104%
Total	35340	34310	103%

Notes

(a) The Dynamic FE model includes an addition 275 kip load (= 75% of 50 psf snow load) not included in the detailed static model.

(b) In the detailed static model, the basemat weight is based on centerline-to-centerline external wall distances and not on the actual foundation dimensions which explains the weight difference between the two models.

Table 5.4.2-2 Mass Properties of PS/B Dynamic FE Model

Model	Mass Center Coordinates[(a)] (ft)			Mass Inertia about Center of Mass (kip-ft^2)		
	Xc	Yc	Zc	IXX	IYY	IZZ
(1) ANSYS Model	0.22	-1.42	-5.06	6.63E+07	4.02E+07	5.74E+07
(2) Detailed Static Model	0.37	-1.63	-4.80	6.45E+07	3.88E+07	5.65E+07
Ratio (1)/(2)				103%	104%	102%

Note

(a) (a) Located at center of building footprint and elevation 0’-0”.

The stiffness of the PS/B structure is compared in all three directions (X, Y, and Z) using the displacement of the northwest corner of the building. The displacement distributions for all three directions, respectively, are shown in Figures 5.4.2-1 through 5.4.2-3.

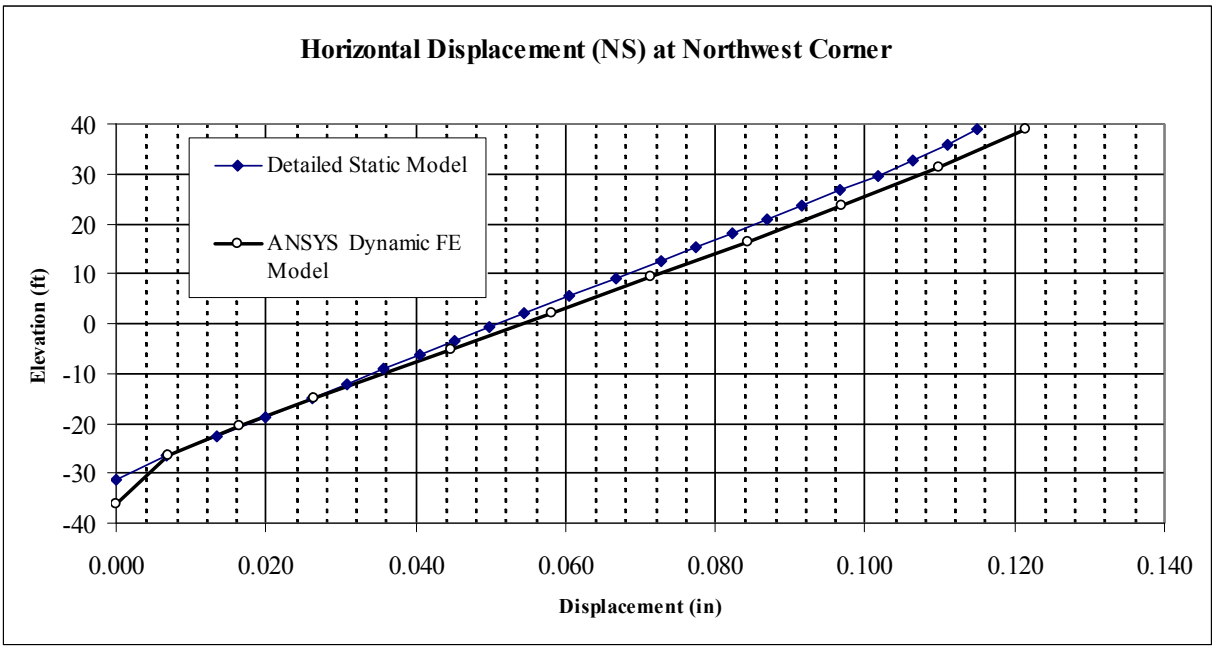

Figure 5.4.2-1 Horizontal Displacement Results Under 1g Load in NS Direction (X)

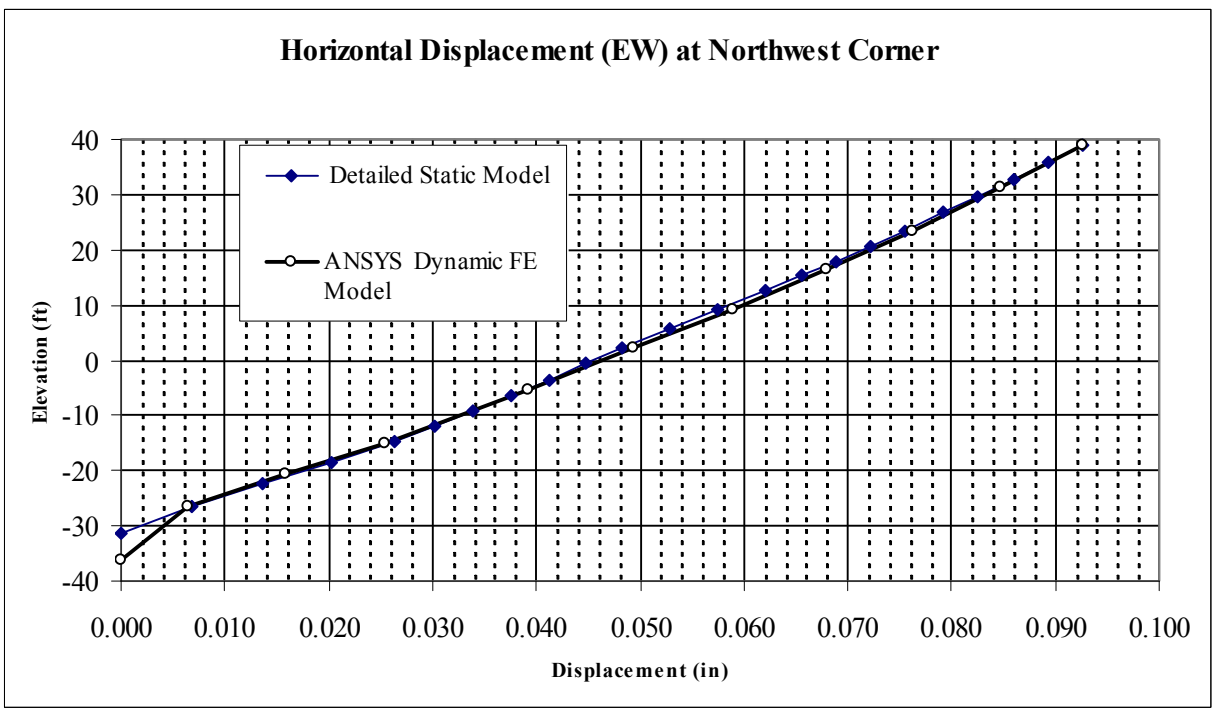

Figure 5.4.2-2 Horizontal Displacement Results Under 1g Load in EW Direction (Y)

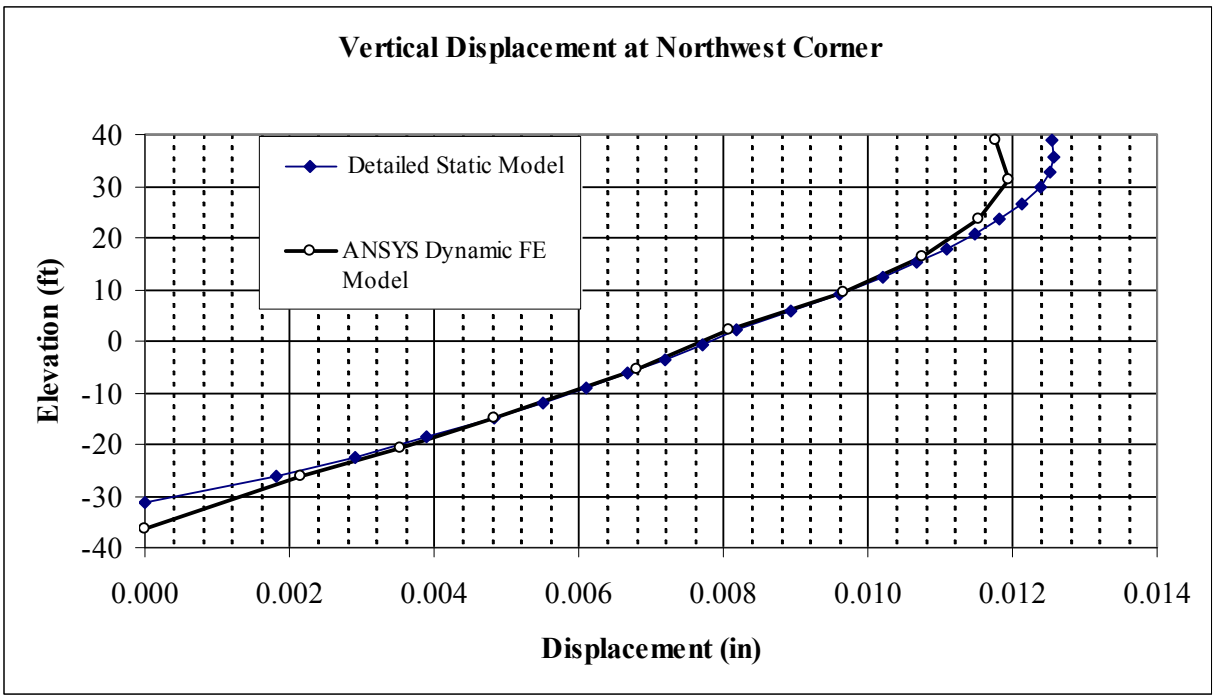

Figure 5.4.2-3 Vertical Displacement Results Under 1g Load in Vertical Direction (Z)

Several modal analyses were performed on the Dynamic FE model with varying mesh sizes. Results were then compared to verify the adequacy of the chosen mesh size (6' to 8') to capture the dynamic properties of the structure. The results of modal analyses for three different mesh sizes (3' to 5', 5' to 8' and 8' to 10') in all three directions are shown in Figures 5.4.2-4 through 5.4.2-6.

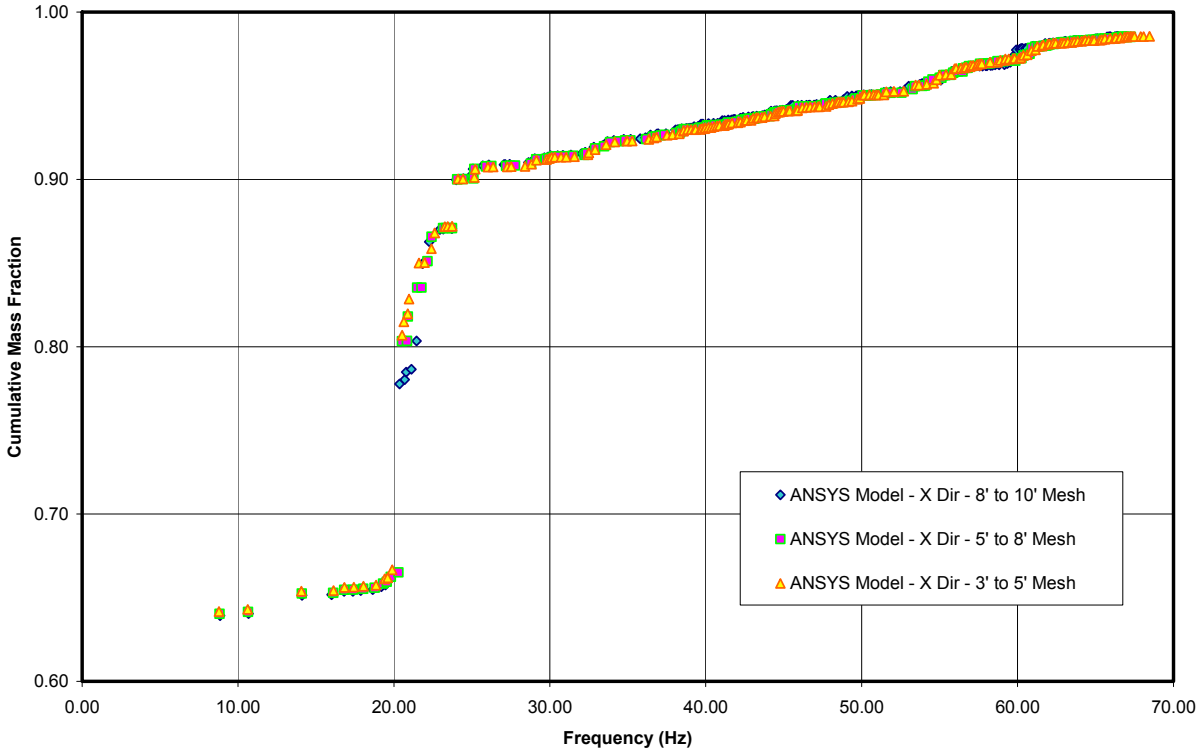

Figure 5.4.2-4 Verification of Mesh Size in X-Direction

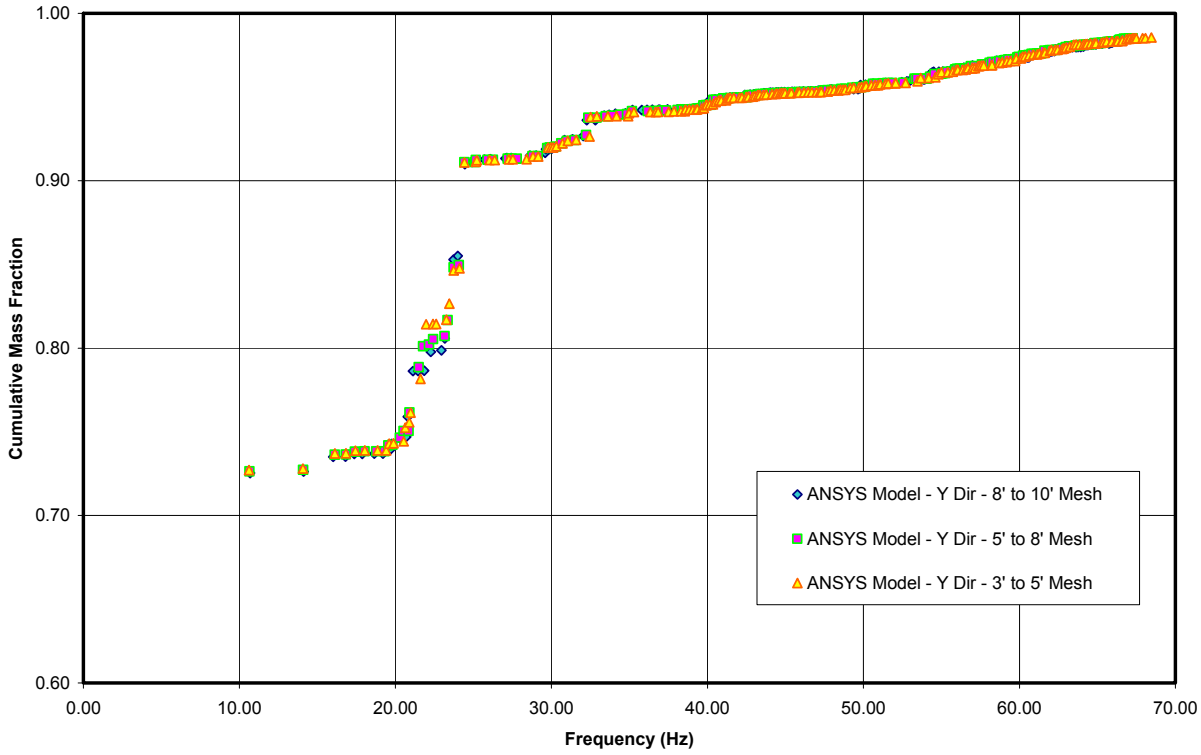

Figure 5.4.2-5 Verification of Mesh Size in Y-Direction

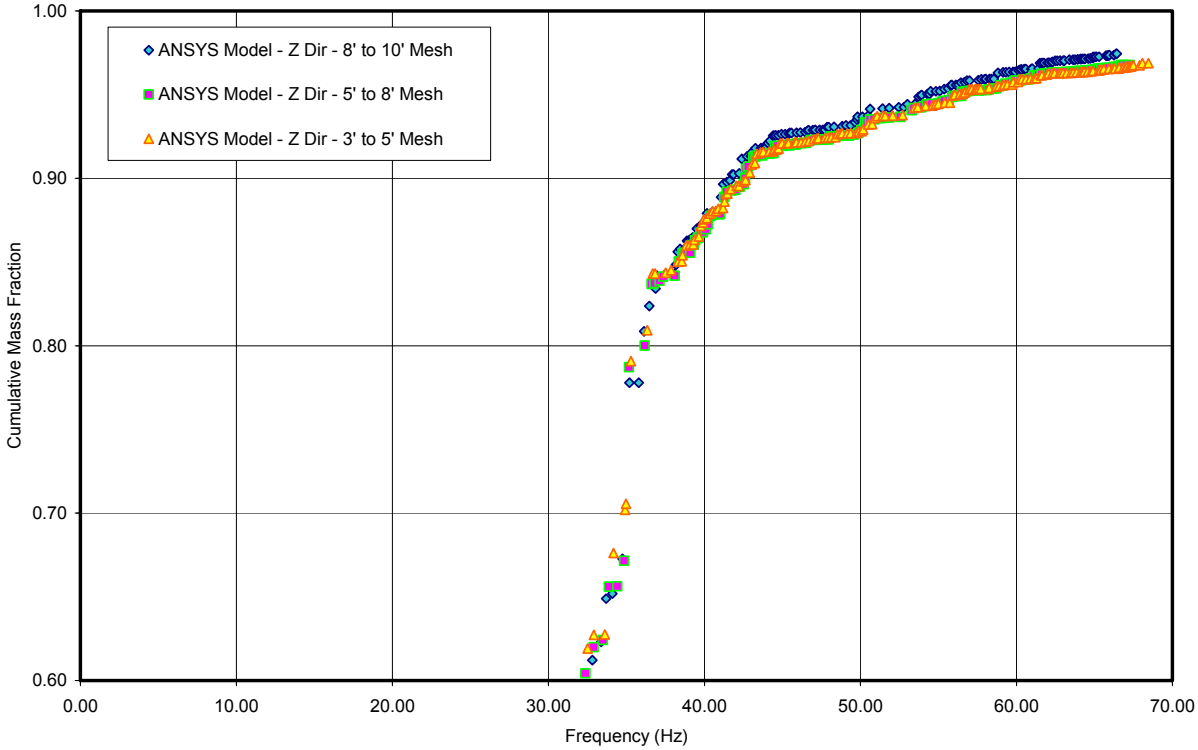

Figure 5.4.2-6 Verification of Mesh Size in Z-Direction

A Modal analysis is then performed on the ANSYS dynamic model with the selected mesh size of 6' to 8' and with fixed base condition and uncracked concrete section properties. The resulting first 3 dominant modal properties for X, Y and Z direction vibrations are shown in Tables 5.4.2-3 thru 5.4.2-5, respectively. The ANSYS dynamic FE model is translated into SASSI format using the built in converter in ACS SASSI. Validation SSI analyses are performed with the PS/B dynamic model resting on the surface of a half-space with hard-rock properties. This is to simulate the response of the structure under a fixed base condition. The ANSYS dominant modal frequencies described above are used in these SSI analyses as calculation frequency steps (points). TFs and ARS obtained from these SSI validation analyses at selected nodes are presented below.

Figures 5.4.2-7 thru 5.4.2-9 present some of the transfer functions at selected representative nodes obtained from such SSI analyses. These figures indicate amplification spikes at or close to the ANSYS dominant frequency points and therefore validate the model translation.

Table 5.4.2-3 Modal Properties of First 3 Modes, X-Direction (N-S)

MODE	FREQUENCY (HZ)	PERIOD (sec)	PARTIC.FACTOR	EFFECTIVE MASS (Kips*sec^2/ft)
1	8.84	0.1130	21.02	441.86
13	20.36	0.0491	8.96	80.43
18	21.84	0.0458	-5.65	31.93

Table 5.4.2-4 Modal Properties of First 3 Modes, Y-Direction (E-W)

MODE	FREQUENCY (HZ)	PERIOD (sec)	PARTIC.FACTOR	EFFECTIVE MASS (Kips*sec^2/ft)
2	10.68	0.0936	22.33	498.66
24	24.45	0.0409	-6.14	37.74
22	23.72	0.0422	-5.69	32.45

Table 5.4.2-5 Modal Properties of First 3 Modes, Z-Direction (Vertical)

MODE	FREQUENCY (HZ)	PERIOD (sec)	PARTIC.FACTOR	EFFECTIVE MASS (Kips*sec^2/ft)
10	19.46	0.0514	8.2072	67.36
6	17.37	0.0576	7.5271	56.66
14	20.69	0.0483	-6.8528	46.96

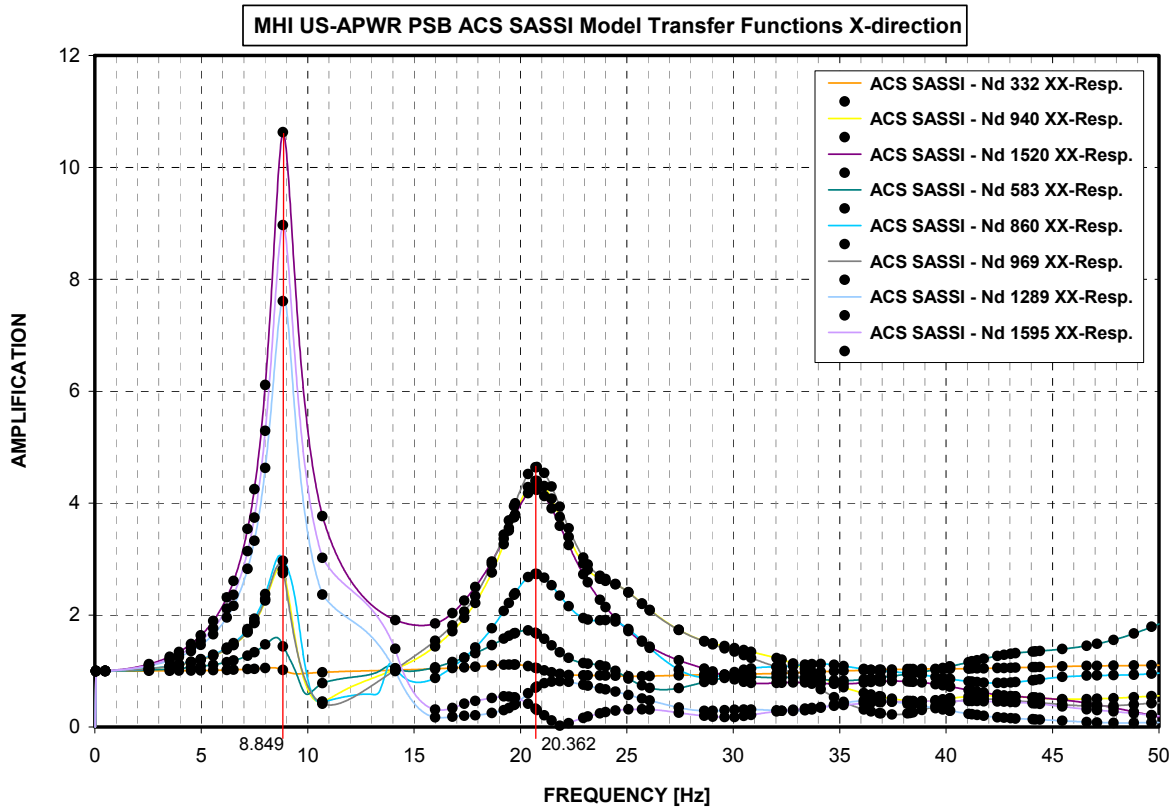

Figure 5.4.2-7 ACS SASSI Dynamic Model Transfer Functions, X-Direction

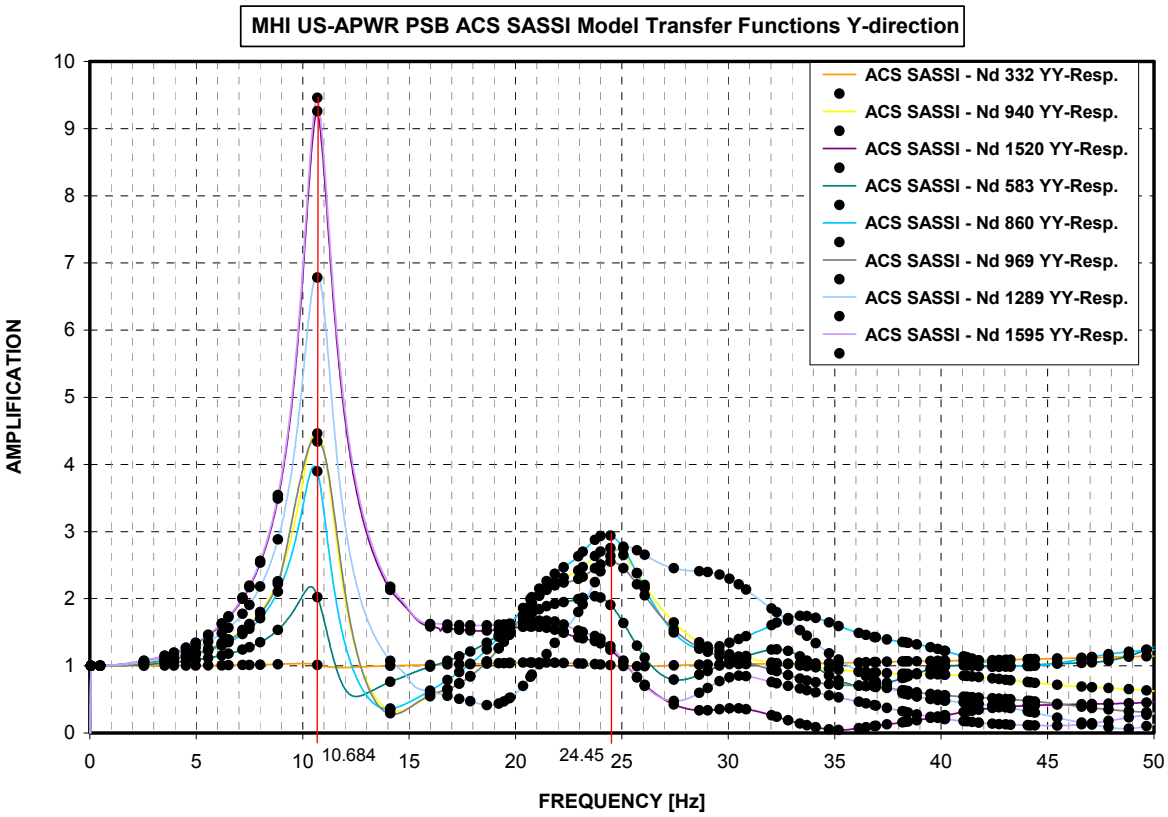

Figure 5.4.2-8 ACS SASSI Dynamic Model Transfer Functions, Y-Direction

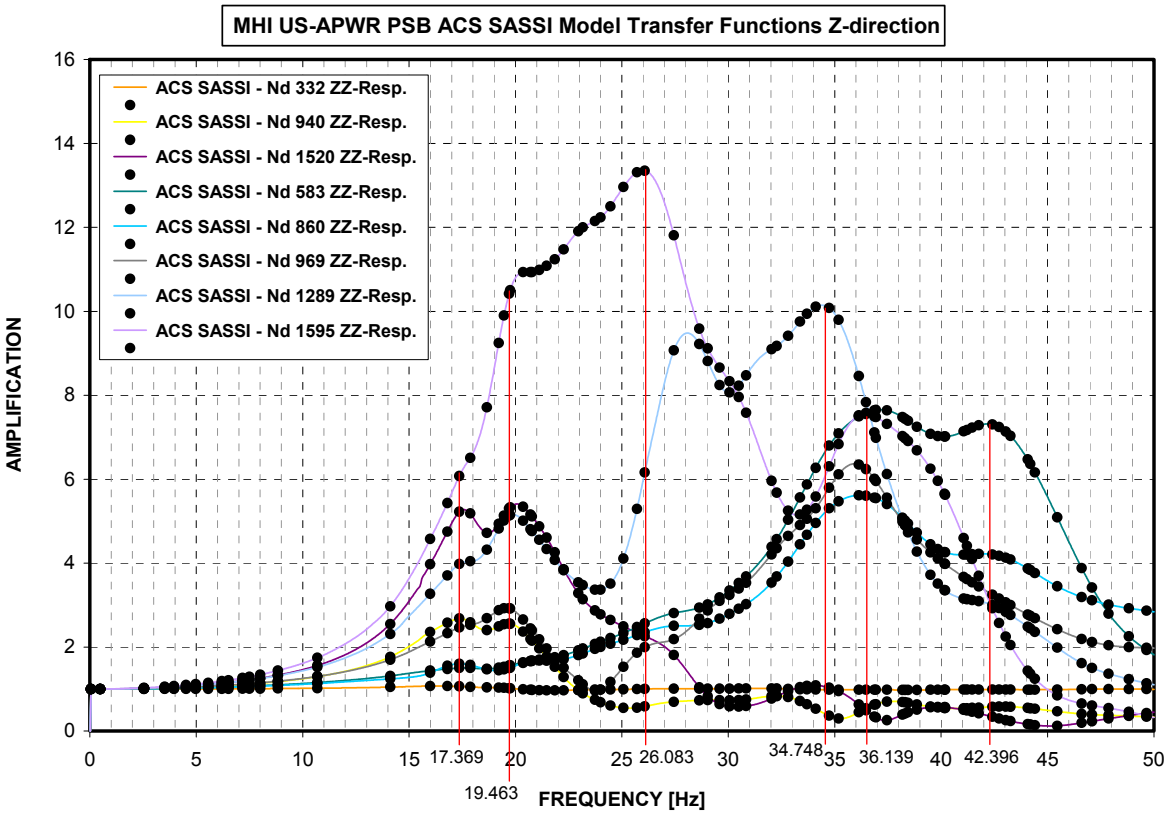

Figure 5.4.2-9 ACS SASSI Dynamic Model Transfer Functions, Z-Direction

The comparison of the ARSs at selected representative nodes both from modal-superposition transient dynamic analysis on the detailed static model and SSI analysis on translated ANSYS model are shown in Figures 5.4.2-10 thru 5.4.2-18. In both analyses, a constant mode/material damping ratio of 0.07 is applied.

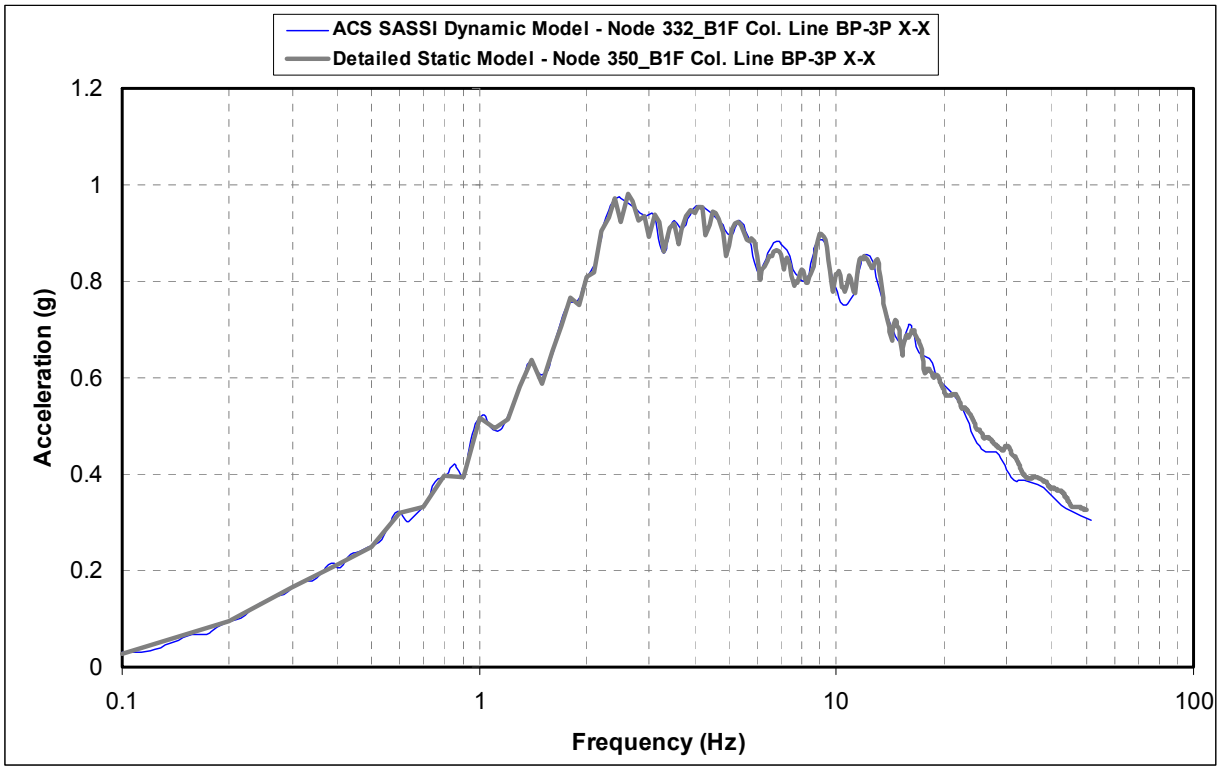

Figure 5.4.2-10 ARS Comparison , Basemat X-Direction

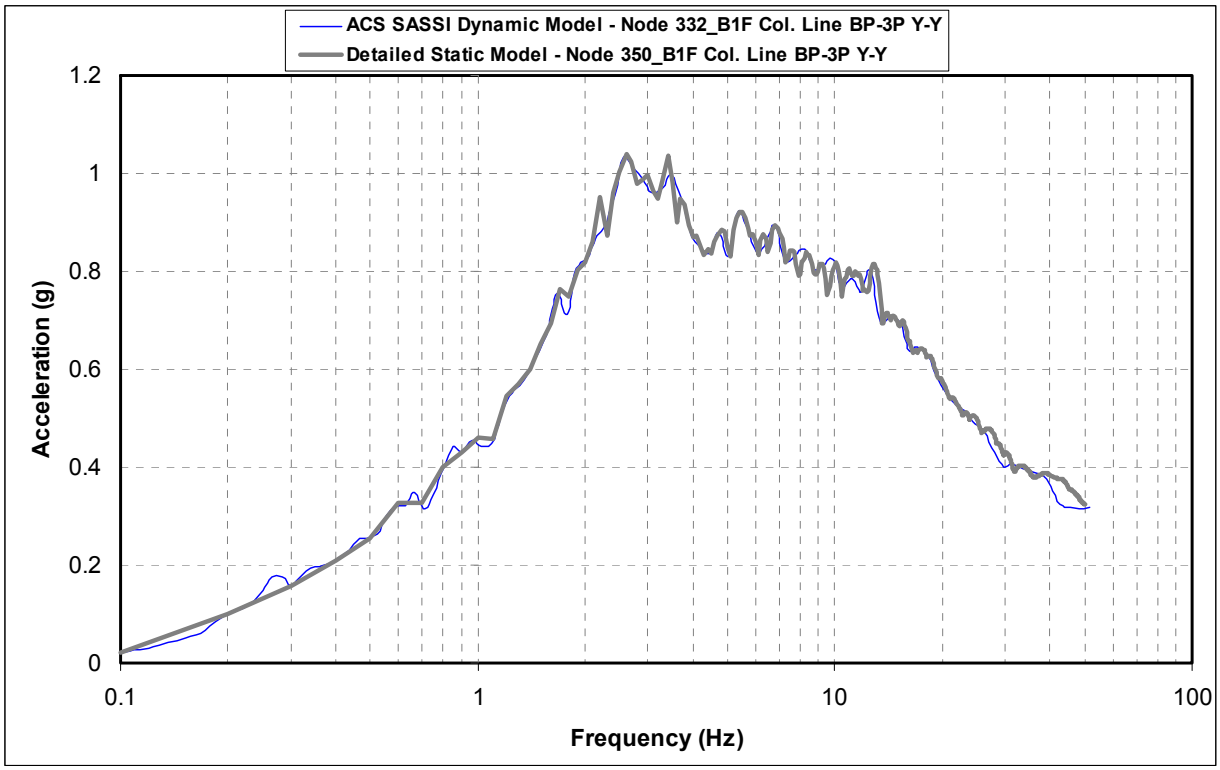

Figure 5.4.2-11 ARS Comparison, Basemat Y-Direction

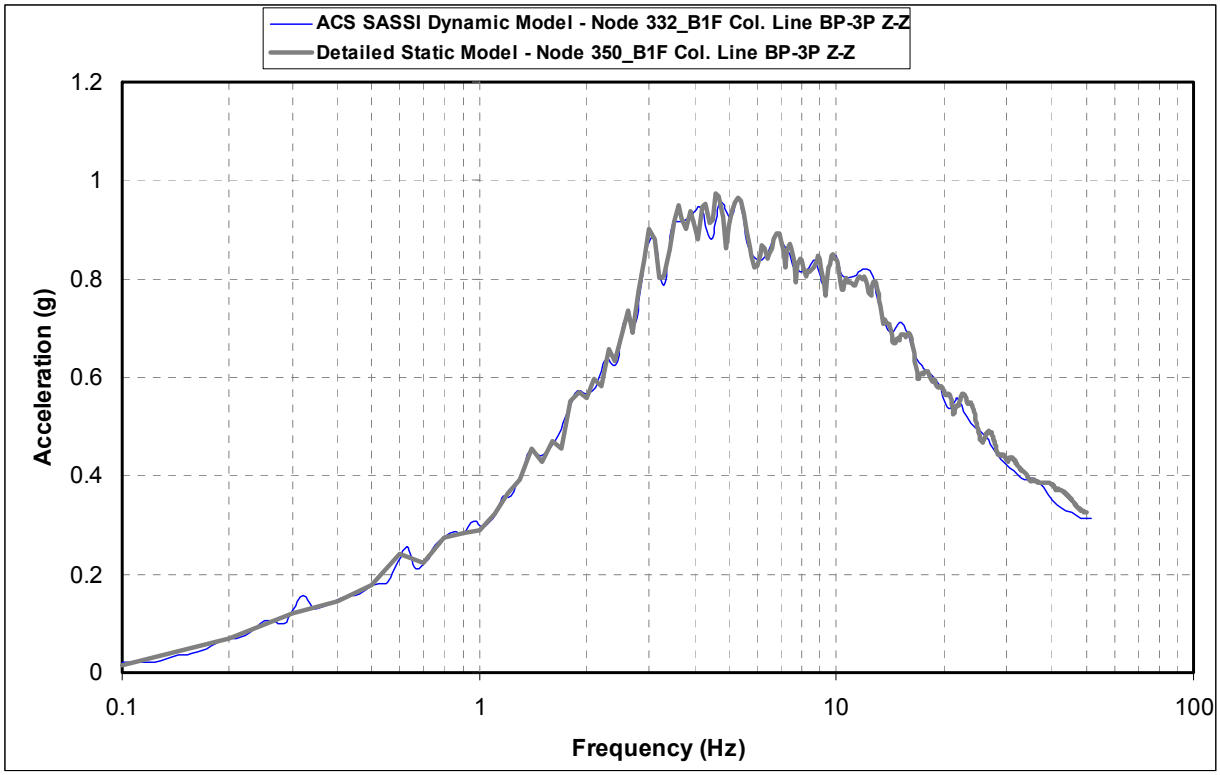

Figure 5.4.2-12 ARS Comparison, Basemat Z-Direction

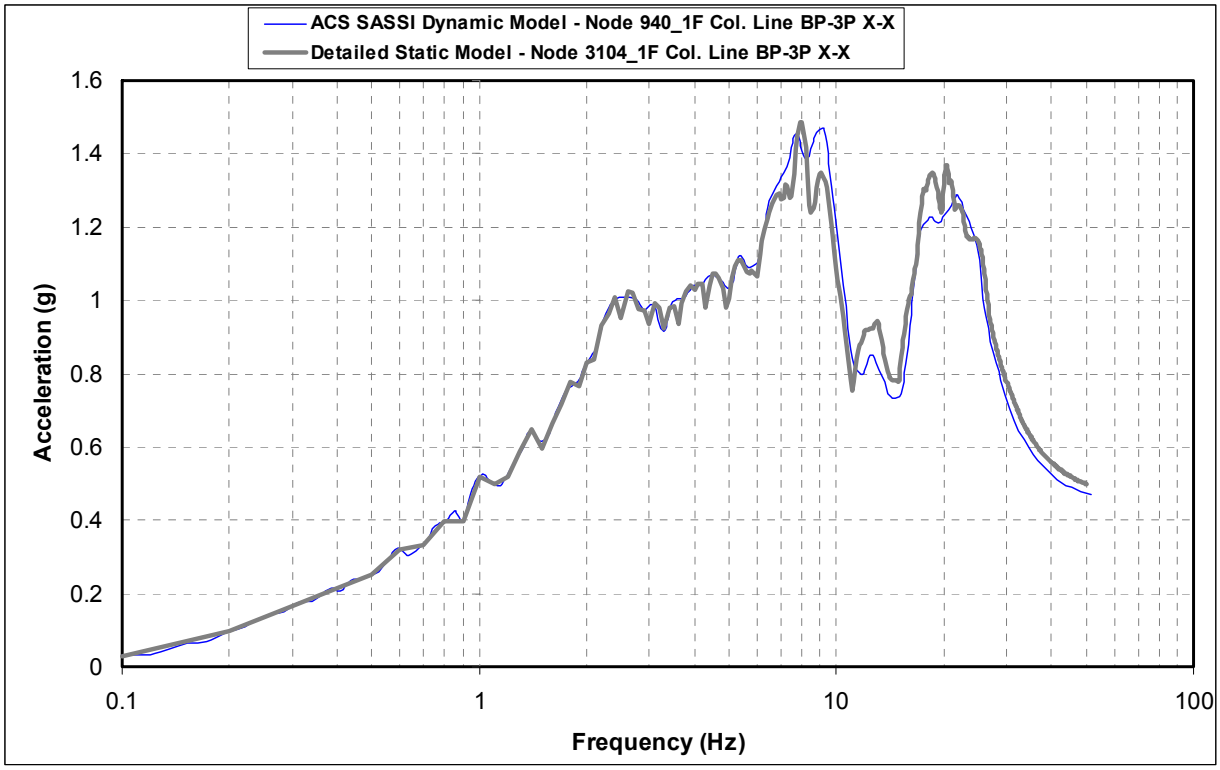

Figure 5.4.2-13 ARS Comparison, Ground Floor X-Direction

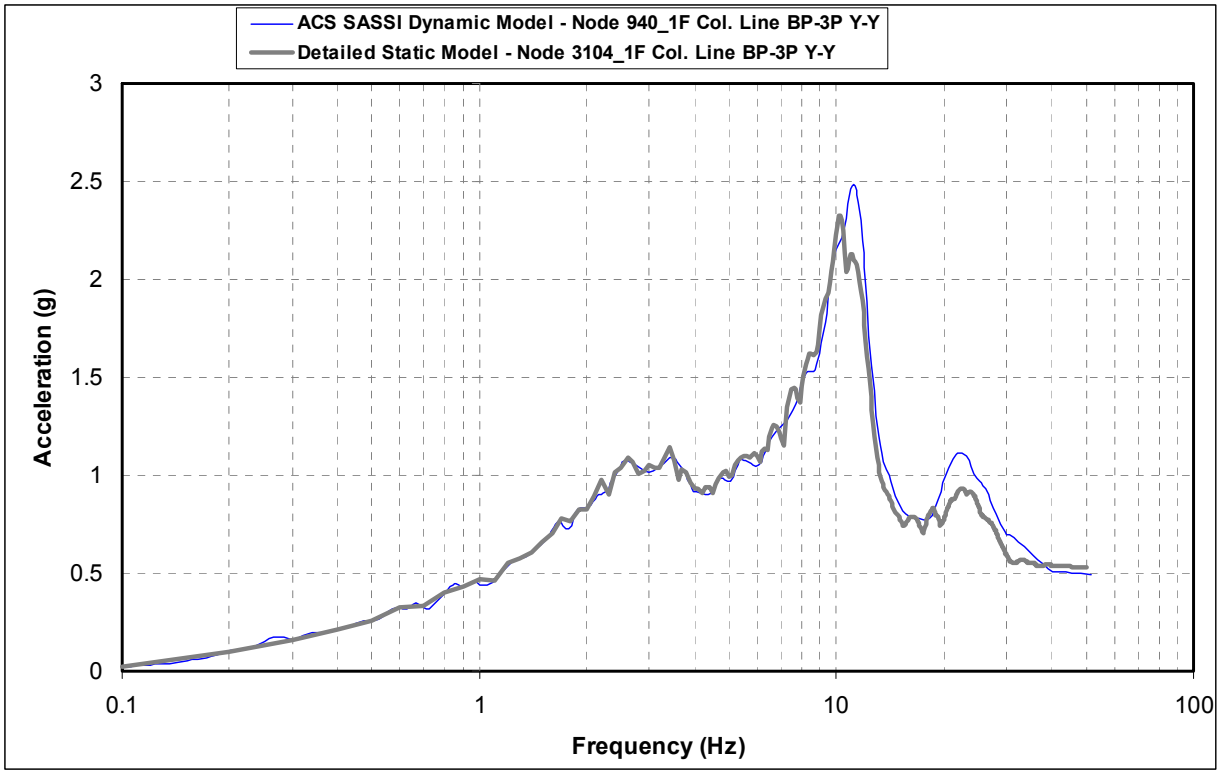

Figure 5.4.2-14 ARS Comparison, Ground Floor Y-Direction

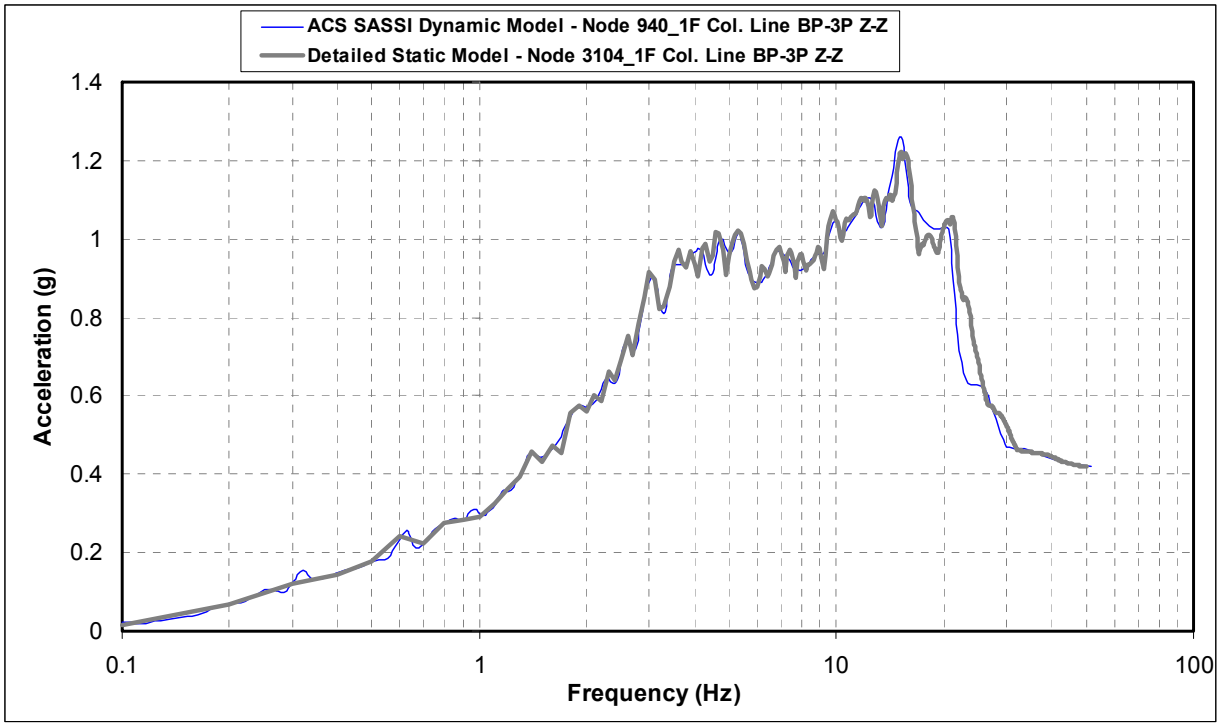

Figure 5.4.2-15 ARS Comparison, Ground Floor Z-Direction

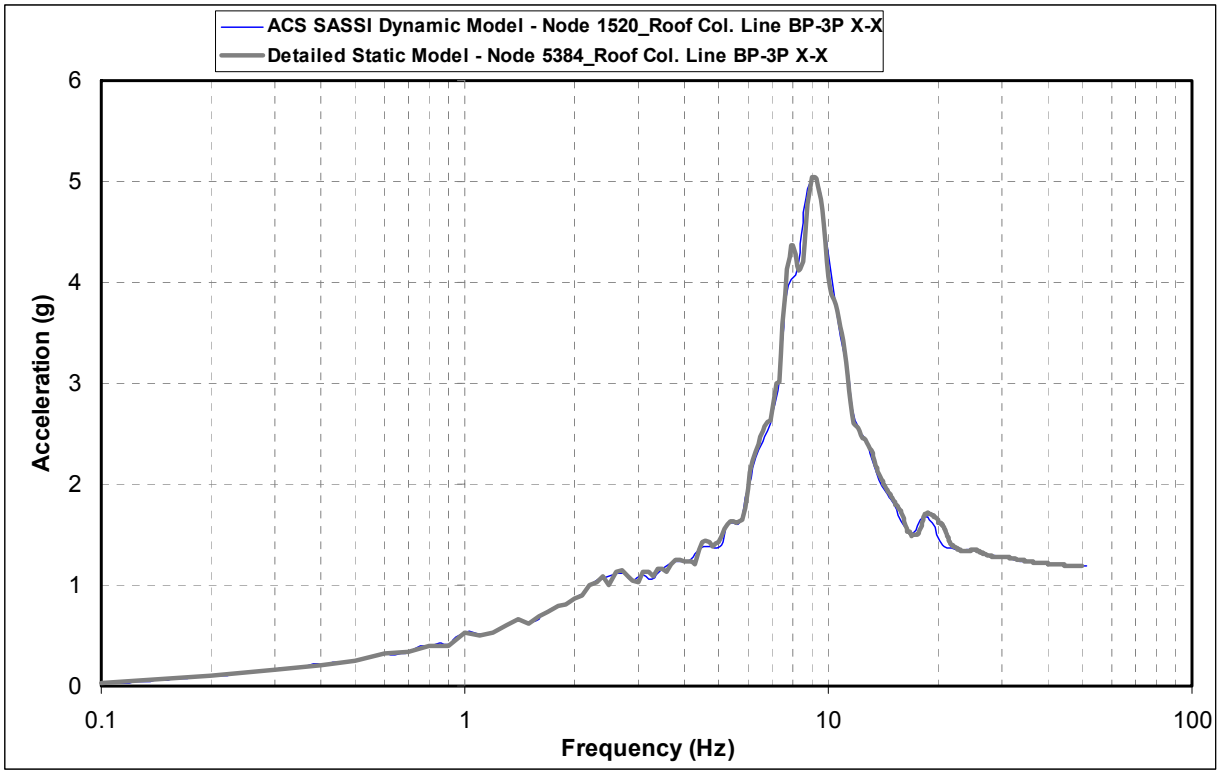

Figure 5.4.2-16 ARS Comparison, Roof X-Direction

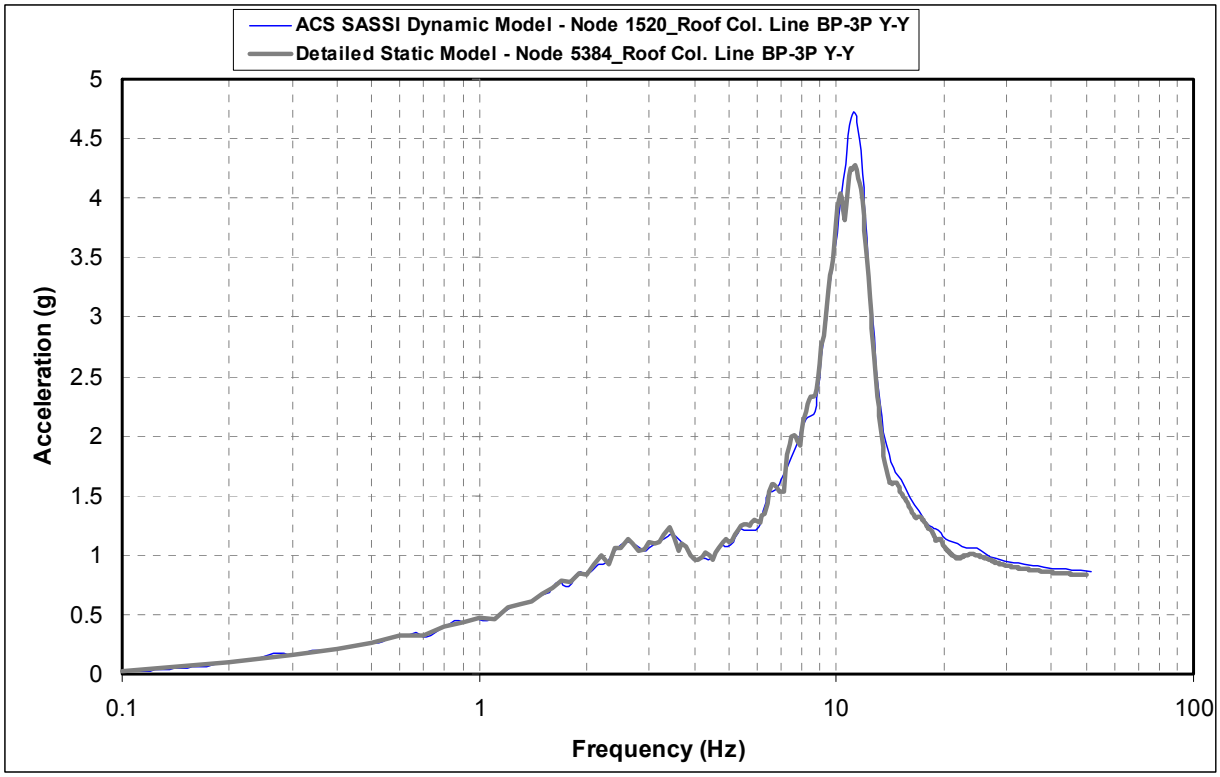

Figure 5.4.2-17 ARS Comparison, Roof Y-Direction

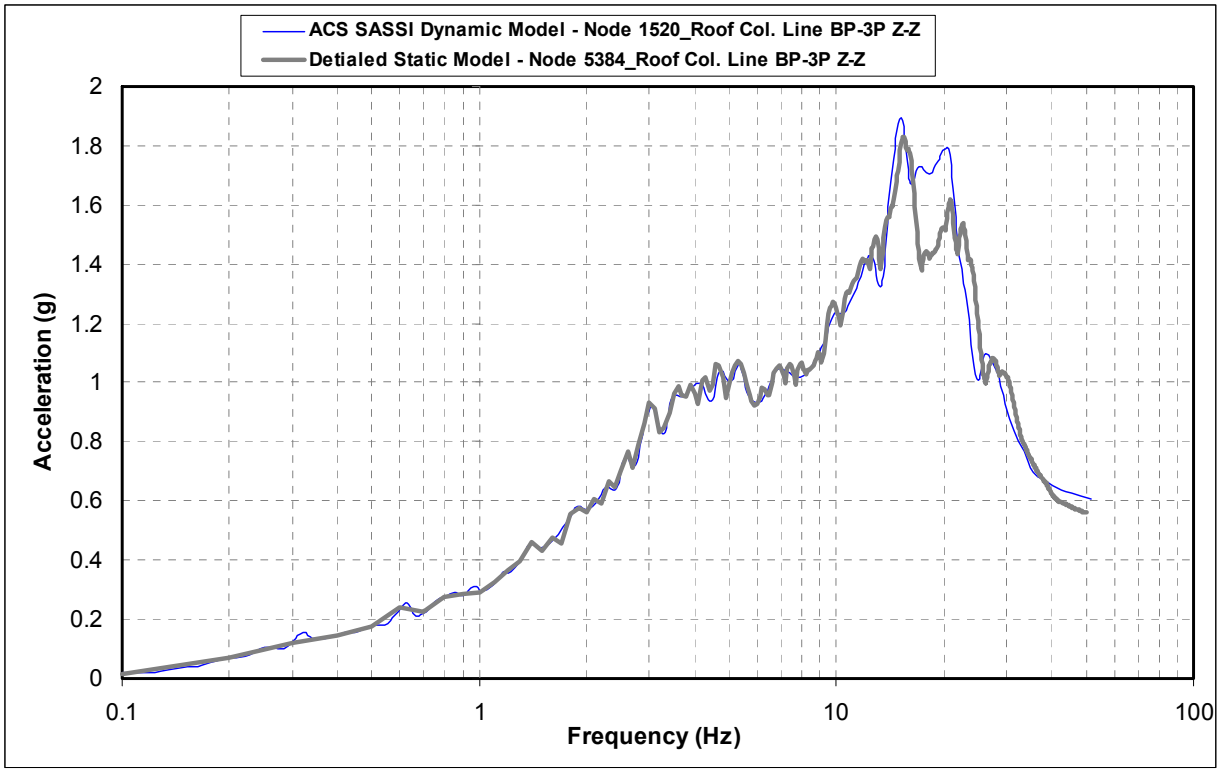

Figure 5.4.2-18 ARS Comparison, Roof Z-Direction

5.5 Consideration of Concrete Cracking in Dynamic Analyses

5.5.1 Concrete Cracking of PS/B

Following the procedure/methodology described in Section 4.5, evaluation of the concrete member stress level and stiffness is performed for concrete structural members/shear walls of the PS/B. The calculated stresses along with the concrete capacity of members are tabulated in Tables 5.5.1-1 through 5.5.1-3.

Table 5.5.1-1 shows that stresses in PS/B shear walls due to in-plane shear are less than the shear capacity. This is why shear walls in the PS/B Dynamic FE model are assigned the elastic in-plane stiffness of the concrete gross section, i.e. no cracking properties of the concrete is considered for shear wall in-plane stiffness.

Table 5.5.1-2 shows that out-of-plane bending moments of the exterior walls (walls with a thickness of 32 in and 21 in) are greater than the concrete cracking moments. The out-of-plane stiffnesses of these walls are adjusted for concrete cracking based on Table 3-1 of ASCE 43-05. The detailed calculation of the effective stiffness of these walls indicates that the effective stiffness of Table 3-1 of ASCE 43-05 is sufficiently accurate and adequate to represent the behavior of these walls under seismic loads combined with other applicable loads.. Table 5.5.1-2 also indicates that cracked concrete properties need not be considered for interior walls (walls with a thickness of 20 inches and 12 inches). This is why elastic gross section properties are assigned to interior walls in the PS/B Dynamic FE model.

Flexural stiffness of floor/roof slabs and beams in the PS/B FE Dynamic model are adjusted for cracked concrete properties based on Table 3-1 of ASCE 43-05. The shear and axial stiffness of these slabs and beams are kept unchanged. Based on the results shown in Table 5.5.1-3, the out-of-plane moment of the floor slab at elevation 3'-7" is smaller than the concrete cracking moment. Despite these results, the floor slab at elevation 3'-7" is assigned a cracked flexural stiffness as a conservative measure. After all, a more flexible slab will result in a greater amplification of vertical seismic accelerations.

Table 4-10 of Technical Report MUAP 10006 presents updated seismic loads for design of PS/B that are based on the results of the updated set of site-independent SASSI analyses on PS/B dynamic FE model. The magnitudes of these loads are similar to those used for standard design of the PS/B as documented in DCD Rev. 2 and in Table 5.5.1-1 below to evaluate the level of in-plane cracking in PS/B shear walls. Based on these observations, it can be concluded that the levels of shear stress in the shear walls of PS/B that are mainly due to horizontal seismic loads will be similar to those obtained from the previous set of analyses, and that the conclusion that the concrete cracking does not affect the in-plane shear stiffness will remain valid.

Table 4-11 of MUAP-10006 presents the updated local out-of-plane seismic design loads on PS/B slabs and walls that consider the amplification of the response due to the out-of-plane flexibility. The DCD Rev. 2 design did not consider the amplification of the response due to the out-of-plane flexibility of the slabs and walls that will result in higher flexure stresses in these reinforced concrete members than those presented below in Tables 5.5.1-2 and 5.5.1-3. This confirms the adequacy of the modeling approach to reduce the out-of-plane stiffness of these elements in order to consider effects of concrete cracking.

A revised set of static analyses of detailed FE model of PS/B will provide detailed information about the stress levels generated by the updated seismic loads in Tables 4-10 and 4-11 of MUAP-10006. The demands calculated from these analyses will be used to estimate the

possibility of concrete cracking of different structural members following the methodology specified in Section 4.5.

Table 5.5.1-1 PS/B Shear Wall In-Plane Shear Stress/Stiffness Evaluation

Location	Elevation	NS Shear Area Ax ($x10^5$ in^2)	NS Shear Vx (kip)	NS Shear Stress (psi)	Shear hw /lw	capacity capacity Vc (psi)	EW Shear Area Ay ($x10^5$ in^2)	EW Shear Vy (kip)	EW Shear Stress (psi)
PSB2	39'-6"	0.555x0.8	7,170	162	1.42	196	0.577x0.8	7,450	161
PSB1	3'-7"	0.962x0.8	12,500	162	1.18	227	0.936x0.8	13,100	175
BSTP	26'-4"	0.946x0.8	13,359	176	1.18	227	0.934x0.8	13,959	187
		Ax = 0.8 Ag					Ay =0.8Ag		

Table 5.5.1-2 Stiffness Evaluation due to Out-of-Plane Bending

Wall thickness (in)	Moment Ma (k-ft)	Mcr (k-ft)	Ie (in^4)	0.5 Ig (in^4)	0.5Ig / Ie	Comments
32	8.93	6.75	1575	1365	0.87	crack
21	4.91	2.91	359	386	1.07	crack
20	1.48	2.64				No crack (Ie = Ig)
12	0.3	0.95				No crack (Ie = Ig)
Ie = Effective moment of inertia, Ig = Gross mement of inertia						
Ma: Moment in Service State, Mcr: Cracking Moment						

Table 5.5.1-3 Stiffness Evaluation for Beam, Roof, and Floor Slabs

R.Concrete Member	Element No.	Elevatior	Thickness (in)	Moment Ma (k-ft)	Mcr (k-ft)	Ie (in^4)	0.5 Ig (in^4)	Comments
Roof Slab	17179	39'-6"	15	1.64	1.48	227	141	crack
Floor Slab	10302	3'-7"	32	5.52	6.75			No crack
Floor Slab	10434	3'-7"	32	4.46	6.75			No crack (Ie = Ig)
Beam	RG5	3'-7"	40	763.85	607.16	252350	184320	crack

5.5.2 Concrete Cracking of R/B Complex

The same procedure/methodology described in Section 5.5.1 is used for the R/B complex.

From Table 5.5.2-1, it can be concluded that except for the walls at location FH08, FH07 and FH06, the required shear stress of remaining walls are less than or equal to the shear capacity of concrete. However, it should be noted that in the calculation of shear capacity of concrete, the axial compressive force and steel reinforcement have not been considered. In addition, the thickness of walls at FH08, FH07, and HF06 elevations is increased from 2 feet to 3 feet in NS direction and from 1'-9" to 2 feet in EW direction.

Table 5.5.2-2 shows that out-of-plane bending moments of selected elements at various elevations. Except for in the FH/A, the out-of-plane bending moment in the shear walls is less than the cracking moment capacity of the concrete.

Based on the results shown in Table 5.5.2-3, flexural stiffness of the floor and roof slabs in various areas of the R/B FE dynamic model are adjusted for cracked concrete properties based on Table 3-1 of ASCE 43-05. The shear and axial stiffness of the slabs and beams are kept unchanged.

Table 5.5.2-4 compares the nominal concrete shear stress capacity with the shear stress levels in the shear walls of the R/B equivalent to the response obtained from the updated set of site-independent soil-structure interaction (SSI) analyses documented in Table 4-7 of technical report MUAP-10006. The comparison shows that the difference in the estimated shear stress levels between the two sets of analyses is less than 25%. The shear stress levels obtained from the SASSI analyses remain below the nominal concrete shear stress capacities of the shear walls for all walls but the NS shear walls of the fuel handling area (FHA), which in the lumped mass stick model are the only ones considered having reduced shear stiffness due to concrete cracking.

Tables 4-8 and 4-9 of MUAP-10006 present the updated local out-of-plane seismic design loads on R/B slabs and walls that consider the amplification of the response due to the out-of-plane flexibility of the slabs and walls. The DCD Rev. 2 design did not consider the amplification of the response due to the out-of-plane flexibility of the slabs and walls so the consideration of out-of-plane response of flexible slab and walls will result in higher flexure stresses in these reinforced concrete members than those presented in Tables 5.5.2-2 and 5.5.2-3. This further confirms that the reduction of the out-of-plane stiffness of these elements in order to consider effects of concrete cracking is adequate.

A revised set of static analyses of detailed FE models of R/B complex structures will provide detailed information about the stress levels generated by the updated seismic loads documented in Tables 4-5 through 4-9 of Technical Report MUAP-10006. The demands calculated from these analyses will be used to estimate the possibility of concrete cracking of different structural members following the methodology specified in Section 4.5.

Table 5.5.2-1 R/B Shear Wall In-Plane Shear Stress/Stiffness Evaluation

Location	Elevation (ft)	NS Shear Area Ax ($10^5 in^2$)	NS Shear Vx kip	NS Shear Stress (psi)	hw/lw	Nominal Vc (psi)	EW Shear Area Ax ($10^5 in^2$)	EW Shear Vx kip	EW Shear Stress (psi)	hw/lw	Nominal Vc (psi)
FH08	154.5	0.543	16,000	368	1.23	276	0.922	8,500	115		
FH07	125.67	0.786	22,500	358	1.23	276	0.922	13,600	184	0.43	404
FH06	101	0.794	25,500	401	1.23	276	0.875	17,300	247	0.43	404
RE41	101	1.19	15,400	162	0.15	450	0.479	9,200	240	0.37	415
RE42	101	0.816	7,800	119			0.533	4,400	103		
RE05	115.5	2.04	17,600	108			1.6	18,600	145	0.07	463
RE04	101	2.13	30,800	181	0.08	462	2.17	40,200	232	0.12	455
RE03	76.417	7.02	95,800	171	0.08	461	7.39	108,100	183	0.13	454
RE02	50.167	7.95	137,600	216	0.08	461	7.79	152,100	244	0.12	455
RE01	25.25	8.09	168,200	260	0.07	463	8.29	184,400	278	0.10	458

Table 5.5.2-2 Stiffness Evaluation due to Out-of-Plane Bending (Sheet 1 of 2)

Element No.	Elevation (ft)	Coordination	Thickness (in)	Mcr (kip-ft/in)	Ma (kip-ft/in)	Mcr / Ma	0.5Ig (in^4)	Ie (in^4)	Comment
RE00									
140335	3.58	CL-J, L, C,	44	12.75	3.44	3.71			uncrack
	3.58	cl-a	40	10.5409	1.14951	9.17			uncrack
	3.58	cl-1, 11	40	10.5409	1.17397	8.98			uncrack
140117	3.58	CL-2, C to J	42	11.62	3.74	3.11			uncrack
	3.58	CL-2,10, E to G	30	5.92927	0.88048	6.73			uncrack
RE01									
161753	25.25	CL-2, C to H1	46	13.94	10.29	1.35			uncrack
	25.25	CL-2, E to G	32	6.74619	1.29345	5.22			uncrack
160237	25.25	CL-1,7,6,5,11	40	10.54	8.28	1.27			uncrack
	25.25	CL-A, J,L,	40	10.5409	1.87551	5.62			uncrack
	25.25	CL-H1	32	6.74619	1.5004	4.50			uncrack
	25.25	CL-C	24	3.79473	1.1253	3.37			uncrack
162222	25.25	CL-A, 4b to 5a	93	56.98	121.35	0.47	33515	15419	crack
RE02									
180256	50.17	CL-1, 2, 10, 11	32	6.75	9.55	0.71	1365	1251	crack
	50.17	CL-5,6,7	40	10.5409	2.00977	5.24			uncrack
182484	50.17	CL-A, 4a to 4b	152	152.2	43.39	3.51			uncrack
	50.17	CL-A, J,k, L	40	10.5409	2.33276	4.52			uncrack
	50.17	CL-C,H2	24	3.79473	1.39966	2.71			uncrack
RE03									
183134	76.42	CL-6a, A to A1	85	47.6	1.05	45.3			uncrack
220363	76.42	CL-2, D2 to E	52	17.81	9.15	1.95			uncrack
220016	76.42	CL-1, D2 to E	28	5.17	7.73	0.67	915	704.2	crack
	76.42	CL-1, 11	28	5.16505	1.63002	3.17			uncrack
	76.42	CL-2, 10	32	6.74619	1.86288	3.62			uncrack
	76.42	CL-2a,5,6,7,9b	40	10.5409	2.3286	4.53			uncrack
	76.42	CL-J,K,L	40	10.5409	2.76914	3.81			uncrack
	76.42	CL-A	24	3.79473	1.66149	2.28			uncrack
RE04, RE41, RE42									
240699	101	CL-11	40	10.54	7.15	1.47			uncrack
		CL-1,2a,5,6,7,9b	40	10.5409	1.00745	10.46			uncrack
		CL-H	21	2.90534	0.56915	5.10			uncrack
		CL-K	40	10.5409	1.0841	9.72			uncrack
240522	101	CL-A,C,	24	3.79	2.15	1.76			uncrack
RE05									
	115.5	CL-5,7	20	2.63523	0.61333	4.30			uncrack
	115.5	CL-6	40	10.5409	1.22667	8.59			uncrack
	115.5	CL-L	21	2.90534	0.693	4.19			uncrack
	116.5	CL-K	40	10.5409	1.32	7.99			uncrack

Table 5.5.2-2 – Stiffness Evaluation due to Out-of-Plane Bending (Sheet 2 of 2)

FH06, FH07,FH08									
	101	CL-2b, 11,A to C	36	8.53815	33.1126	0.26			crack
	101	CL-A,C,	24	3.79473	24.0049	0.16			crack
200110	125.67	CL-11,A to A2	36	8.54	6.08	1.40			uncrack
200045	125.67	CL-1, 5a to 6	24	3.79	3.4	1.11			uncrack
200051	125.67	CL-A, 6 to 6a	24	3.79	5.74	0.66	576	397.9	crack
240944	125.67	CL-C,6 to 6a	24	3.79	4.78	0.79	576	737.9	crack
200390	154.5	CL-C,5a to 6	24	3.79	2.33	1.63			uncrack

Table 5.5.2-3 Stiffness Evaluation for Slabs

Element No.	Elevation (ft)	Coordination	Thickness (in)	Mcr (kip-ft)	Ma (kip-ft)	Mcr / Ma	0.5Ig (in^4)	Ie (in^4)	Comment
200599	154.5	CL-B to C, 5a to 4b	15	17.76	17.04	1.042			uncrack
231572	115.5	CL-J to K, 7 to 6	40	126.492	213.348	0.593	2667	1569	crack
210318	101	CL-E to F, 11 to 10	15	17.76	29.52	0.602	140.63	137.27	crack
	101	CL-D to D2, 2 to 4b	44	153.054	38.593	4.0			uncrack
	101	CL-C to D, 2b to 4b	36	102.458	53.739	1.9			uncrack
183716	76.42	CL-B to C, 6a to 7a	28	61.98	22.056	2.810			uncrack
	76.42	CL-K to L, 7 to 9b	52	213.77	291.828	0.7			crack
	76.42	CL-H to J, 6 to 7	32	80.954	9.255	8.7			uncrack
	76.42	CL-C to D, 2 to 4	30	71.151	38.1743	1.9			uncrack
181639	65	CL-K to L, 7 to 6	40	124.8	102.48	1.22			uncrack
163433	50.17	CL-J to K, 7 to 6	40	126.48	93	1.36			uncrack
	50.17	CL-G to G2, 9a to 10	46	167.284	15.939	10.5			uncrack
	50.17	CL-H to H1, 2 to 3	24	45.537	26.912	1.7			uncrack
142831	25.25	CL-J to K, 7 to 6	40	126.48	173.76	0.7	2666.67	2847.53	crack

Table 5.5.2-4 R/B Walls Shear Stress Levels Based on Updated SSI analyses

Location	Elev. (ft)	Shear Stress Levels (psi)				Nominal Concrete Shear Stress Capacity (psi)	
		DCD Rev. 2		MUAP-10001, Rev. 0		NS	EW
		NS	EW	NS	EW		
FH08	154.5	368	115	373	139	276	
FH07	125.67	358	184	406	225	276	404
FH06	101	401	247	464	304	276	404
RE41	101	162	240	159	271	450	415
RE42	101	119	103	151	134		
RE05	115.5	108	145	98	145		463
RE04	101	181	232	152	203	462	455
RE03	76.42	171	183	234	209	461	454
RE02	50.167	216	244	269	268	461	455
RE01	25.25	260	278	322	308	463	458

6.0 REFERENCES

1. Seismic Design Parameters, NUREG-0800 Section 3.7.1, Revision 3, U.S. Nuclear Regulatory Commission, Washington, DC, March 2007.

2. ACS SASSI: Version 2.3.0, Ghiocel Predictive Technologies, Inc., June 15, 2009.

3. Deleted.

4. Seismic System Analysis, NUREG-0800 Section 3.7.2, Revision 3, U.S. Nuclear Regulatory Commission, Washington, DC, March 2007.

5. Non-Stationary Spectral Matching, Seismological Research Letters #63, Page 30, Abrahamson, N. A., 1992.

6. Generation of Synthetic Time Histories Compatible with Multi-Damping Design Response Spectra, 9th SMiRT, pages 105-110, Lilhan, K, and W.S. Tseng, 1987.

7. Surface Geology Based Strong Motion Amplification Factors for the San Francisco Bay and Los Angeles Areas, A PEARL report to PG&E/CEC/Caltrans, Award No. SA2120-59652. Silva, W. J.S. Li, B. Darragh, and N. Gregor, 1999.

8. Guidelines for Determining Design Basis Ground Motions, Volumes 1-5, TR-102293, Electric Power Research Institute, Palo Alto, CA, 1993.

   Vol.1: Methodology and Guidelines for Estimating Earthquake Ground Motion in Eastern North America

   Vol. 2: Appendices for Ground Motion Estimation

   Vol. 3: Appendices for Field Investigations

   Vol. 4: Appendices for Laboratory Investigations

   Vol. 5: Quantification of Seismic Source Effects

9. CEUS Ground Motion Project, Final Report, Technical Report TR-1009684, Electric Power Research Institute, Palo Alto, CA, 2004.

10. Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-Consistent Ground Motions Spectra Guidelines, NUREG/CR-6728, Prepared for Division of Engineering Technology, Washington, DC., 2001.

11. Characteristics of Vertical Strong Ground Motions for Applications to Engineering Design, NCEER-97-0010, Proceedings of the FHWA/NCEER Workshop on the National Representation of Seismic Ground Motion for New and Existing Highway Facilities, I.M. Friedland, M.S Power and R. L. Mayes eds., Silva, W.J., 1997.

12. ANSYS, Advanced Analysis Techniques Guide, Release 11.0, ANSYS, Inc., 2007.

13. Seismic Analysis of Safety-Related Nuclear Structures and Commentary, ASCE 4-98, American Society of Civil Engineers, 1998.

14. Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities, ASCE/SEI 43-05, American Society of Civil Engineers, 2005.

15. Code Requirements for Nuclear Safety Related Concrete Structures, ACI 349-01, American Concrete Institute, 2001.

16. Design Response Spectra for Seismic Design of Nuclear Power Plants, RG 1.60, Revision 1, U. S. Nuclear Regulatory Commission, December 1973.

17. Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Development of Hazard- and Risk-Consistent Seismic Spectra for Two Sites, NUREG/CR-6769, U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington, DC 20555-0001, 2002.

18. Empirical Response Spectral Attenuation Relations for Shallow Crustal Earthquakes, Seismological Research Letter, 68(1), pages 94-127, Abrahamson, N.A. and Silva, W.J., 1997.

19. Properties of vertical ground motions, Bulletin of the Seismological Society of America, 92(2), pages 3152-3164, Beresnev, I.A, Nightengale, A.M. Silva, W.J., 2002.

20. Updated Near-Source Ground-Motion (Attenuation) Relations for the Horizontal and Vertical Components of Peak Ground Acceleration and Acceleration Response Spectra, Bulletin of the Seismic Society of America, 93(1), pages 314-331, Campbell, K. W. and Y. Bozorgnia, 2003.

21. SPECTRA 2650, User's Manual, URS Washington Division, Version 3.0.

22. PEER NGA Strong Motion Database, Pacific Earthquake Engineering Research Center, http://peer.berkeley.edu/nga/, University of California, Berkeley, CA, 2006.

23. Earthquake Engineering Criteria for Nuclear Power Plants, Energy. Title 10, Code of Federal Regulations, Part 50, Appendix S, U.S. Nuclear Regulatory Commission, Washington, DC.

24. Soil-Structure Interaction Analyses and Results for the US-APWR Standard Plant, MUAP-10006, Revision 1, Mitsubishi Heavy Industries, Ltd., January 2011.

25. Assessment of Seismic Hazard at 34 U.S. Nuclear Plant Sites, TR-1016736, Electric Power Research Institute, Palo Alto, CA, 2008.