Auxiliary Building Model Properties, SSI Analyses, and Structural Integrity Evaluation for the US-APWR Standard Plant

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Revision History

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Abstract

The purpose of this technical report is to present the structural models, soil-structure interaction (SSI) analyses, and structural integrity evaluation of the US-APWR Standard Plant Auxiliary Building (A/B) as referenced by US-APWR Design Control Document (DCD), Chapter 3 (Reference 7.3).

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Appendix No.	Title	Pages
A	ANSYS Post-Processors for Concrete Slabs and Walls	A1-A17

List of Acronyms

The following list defines the acronyms used in this document.

3-D	three dimensional
AC/B	access building
A/B	auxiliary building
CSDRS	certified seismic design response spectra
DCD	Design Control Document
DCR	Demand to Capacity Ratio
EW	east-west
FE	finite element
ISRS	in-structure response spectra
NS	north-south
PS/B	power source building
R/B	reactor building
RSA	response spectrum analysis
SRSS	square root sum of the squares
SSC	system, subsystem and component
SSE	safe shutdown earthquake
SSI	soil-structure interaction
TR	technical report

1.0 INTRODUCTION AND PURPOSE

This report documents the seismic evaluation of the MHI US-APWR Standard Plant Auxiliary Building (A/B) that is classified as a Seismic Category II building.

This report presents the development and validation of the structural models and the results of the seismic response analyses and stress analyses of the A/B. The SSI analyses provide the seismic response of the A/B in terms of maximum seismic displacements relative to the free field motion, absolute accelerations and base force and moment reactions. At a later time, the maximum seismic displacements provided in this report will be combined with non-seismic horizontal displacements that are due to possible differential settlements of the A/B foundation and/or construction tolerances. The combined seismic and non-seismic displacements will be used to demonstrate that the gaps separating the A/B from the adjacent buildings are sufficient to prevent collision between the adjacent structures. In this report, the member stress demands in major representative structural members, that are calculated from the static and response spectrum analyses, are used for overall evaluation of the structural integrity of A/B under load combinations associated with seismic design loads. Future revisions of this report will provide the design of the other A/B structural members as well as detailed evaluation of seismic stability of the building.

The seismic evaluation of the A/B presented in this report is based on two types of seismic response analyses: (1) SASSI soil-structure interaction (SSI) analyses that provide the seismic response for the different generic subgrade conditions described in MHI Technical Report (TR) MUAP 10001 (Reference 7.1) and (2) ANSYS response spectrum analyses (RSA) that provided seismic demands on the A/B structural members.

The SSI analyses of the A/B are performed using two types of models representing the dynamic properties of the A/B structure: (1) dynamic FE models; and (2) a lumped mass stick model. The dynamic FE models of A/B are used for SSI analyses for critical generic site profiles that provide the maximum seismic displacements of the A/B relative to the free field ground motion. The critical generic site conditions, defined as the ones that control the maximum seismic response parameters including accelerations and displacements, are selected based on the results of SSI analyses of a simplified 3-D lumped-mass stick model of the A/B structure resting on the surface of the eight generic site profiles. The certified seismic design response spectra (CSDRS) and the CSDRS compatible time histories that were developed in Section 5.2 of MHI TR MUAP 10001 (Reference 7.1) define the ground motion for the standard design of the A/B.

A detailed FE model of the A/B is used for static and RSA analysis to obtain static and dynamic demands of the major representative structural members of A/B. The ISRS at A/B basemat resulting from lumped-mass stick model SSI analysis is used as the input response spectrum for RSA.

1.1 Description of A/B

As shown on Figure 2.1-1, The A/B is located west of seismic Category I Reactor Building (R/B) complex and north of the seismic Category I West Power Source Building (PS/B). The US-APWR Access Building (AC/B), which is classified as non-seismic, is located west of A/B. The basemats of the R/B and PS/B are established at nominal bottom elevation of (-)36’-3”. Gaps separate the structure of the A/B with the structure of the adjacent buildings.

The A/B is a reinforced concrete building with a basement, one floor level at grade, and two main stories above grade. The plan dimension of A/B is 130'-0" by 236'-0" between exterior dimensions. The A/B reinforced concrete basemat has a nominal thickness of 9'-11" with its base located at 38'-10" below grade (nominal plant elevation (-)36'-3"). The highest roof elevation is 137'-3" above the bottom of the A/B basemat. The A/B reinforced concrete structure consists of shear/bearing walls, columns, roof and floor slabs. Steel girder beams are used to provide additional support to the part of the roof slab and the third floor slab. The reinforced concrete walls and columns carry the vertical and lateral seismic loads from the roof and floor slabs and transfer them to the basemat. The lateral seismic loads are resisted primarily by the reinforced concrete shear walls.

Figure 2.1-2 shows typical floor plan (basement) of A/B and Figure 2.1-3 presents the typical elevations of the A/B.

2.0 METHODOLOGY FOR DEVELOPMENT OF A/B FE MODELS

2.1 Structural Geometry

The geometric properties of the FE models are based on the Concrete Outline Drawing for Auxiliary Building (Reference 7.8). Openings in walls and slabs are not modeled explicitly and their effect on the stiffness of the A/B structure is considered as described in Section 2.3.2.2. The foundation mat has been modeled as 9'-11" thick, rather than 8'-4" as shown on the drawings, so that the base of the foundation is at the same elevation as the surrounding structures. This thicker foundation mat will be shown on future project documents presenting the complete basic design of the building. Table 2.1-1 presents the main dimensions and weight of the A/B.

Table 2.1-1 A/B Main Dimensions and Properties

Item	Value
Basemat Length in N-S Direction	239'-3"
Basemat Length in E-W Direction	133'-4"
Basemat Thickness	9'-11'
Basement Exterior Wall Thickness	3'-4"/ 4'-2"
Nominal Basemat Bottom Elevation	-36'-3"
Nominal Ground Elevation	2'-7"
Main Roof Slab Top Elevation (not including roof appurtenances)	76'-5"
Total Weight (including equivalent dynamic mass)	226,264 kips
Total Foundation Area	31,900 ft^2
Equivalent Uniform Bearing Pressure of Foundation	7.09 ksf

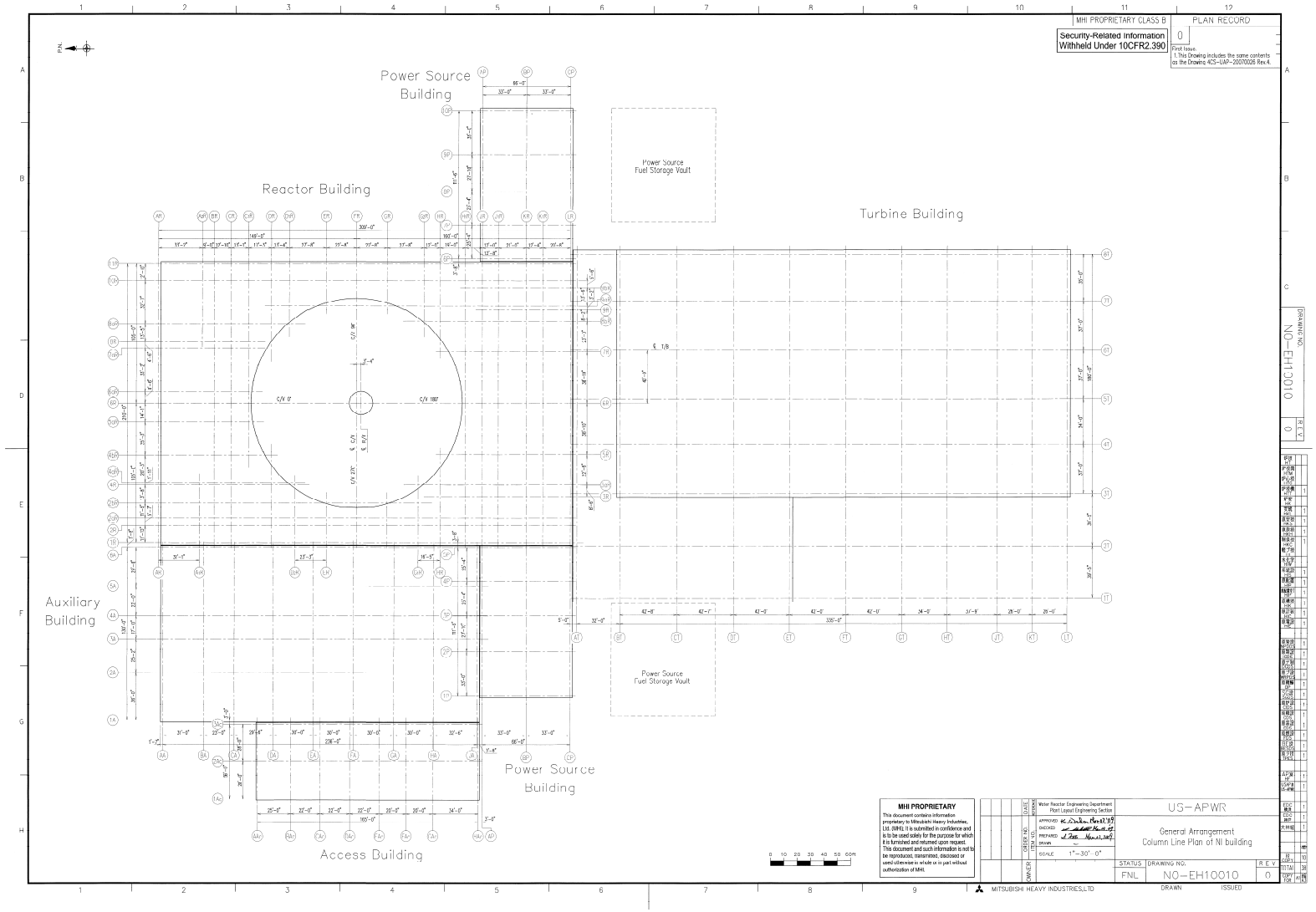


Figure 2.1-1 US-APWR Site Layout

Security-Related Information – Withheld Under 10 CFR 2.390

Figure 2.1-2 Typical Plan (Basement)

Security-Related Information – Withheld Under 10 CFR 2.390

Figure 2.1-3 A/B Typical Elevation

2.2 Material Properties

The A/B is primarily a reinforced concrete building. The analysis considers 4,000 psi concrete with the following properties. The SSE damping ratios are used for the seismic response analyses per DCD Table 3.7.3-1(a) (Reference 7.3).

- Compressive Strength of Concrete, f'_c = 4 ksi
- Young's Modulus, E = 5.19 x 10^5 ksf
- Poisson's Ratio, μ = 0.17
- Critical Damping Ratio = 7 %
- Density = 0.15 kip/ft^3

For the steel girders/beams that support the roof and third floor slab, the following properties are used in the models.

- Young's Modulus, E = 4.176 x 10^6 ksf
- Poisson's Ratio, μ = 0.3
- Critical Damping Ratio = 7 %
- Density = 0.49 kip/ft^3

The critical damping ratio of 7% is for bolted steel structures at SSE stress level per Reg. 1.61 (Reference 7.13)

2.3 Dynamic FE Structural Model

2.3.1 Structural Discretization and Finite Element Types

In FE dynamic model, the A/B is modeled with global Y-axis pointing east, the global X-axis pointing south, and the global Z-Axis pointing up. The origin of the coordinate system is at intersection point of column lines EA and 3A at plant elevation 0'-0".

The model includes shell elements representing the structural walls and slabs, beam elements representing beams and columns, and solid elements representing 9'-11" thick basemat. At top of basemat and the bottom of interior and exterior walls, the shell elements are extended into solid elements that represent basemat. The extended shell elements share same nodes with solid elements but material densities are assigned to be zero. This modeling approach enables transfer of moments from wall to basemat. The interior walls are modeled with shell element's center planes located approximately at the centerline of the actual structure. The exterior walls of the dynamic FE models are set at the exterior faces of the A/B, rather than the centerline of the exterior walls, in order to properly account for the actual size of the basemat in the soil structure interaction. The center planes of the slabs in the model are generally coincident with their actual centerline locations, except that a minor adjustment of the center plane elevation for the second floor slabs are made to simplify the model. The central plane elevation of the second floor slab is set at plant elevation 28'-6". The centerlines of the steel beam elements are considered to be coincident with the central plane of the slabs they support. With the beams and slabs coincident, there is no shear force transfer at the contact surface between the concrete slab and steel beam, therefore the model does not consider the composite action of the concrete slab and the steel beams. Tables 2.3-1 through 2.3-3 provide the location of major structural elements in the model.

The dynamic FE models are developed for use in the SSI analysis of the structure. The models are created in ANSYS and then converted to SASSI format. In order to ensure an appropriate transfer of high frequency seismic waves through the soil-structure interface, two dynamic FE models are developed with maximum element sizes in the horizontal direction of 9 feet and 13 feet. Figures 2.3-1 through 2.3-12 show these dynamic FE models of A/B.

2.3.2 Modeling of Dynamic Stiffness

2.3.2.1 Reduction of Stiffness for Concrete Cracking

The dynamic FE models consider the A/B walls and slabs to be cracked due to out-of-plane bending as described in MHI TR MUAP-10001, Section 4.5.2 (Reference 7.1). The elastic modulus and wall/slab thicknesses of the shell elements are modified so that the out-of-plane flexural stiffness is reduced by 50% while the in-plane shear and axial stiffness remains unchanged. The density of the slab/wall is also adjusted so that the total mass of the slabs and walls do not change.

2.3.2.2 Reduction of Stiffness for Structural Openings

The FE models do not explicitly model wall and slab openings in the shell elements. In order to properly capture the dynamic properties of the slabs/walls with openings, detailed ANSYS models of those slabs/walls with and without openings are analyzed as described in Section 4.3.3 of MHI TR MUAP 10001 (Reference 7.1). The results are compared and the stiffness (elastic modulus) of the FE shell elements are adjusted accordingly.

These effects are combined with the cracking effects. The resulting adjusted properties are shown in Table 2.3-4.

2.3.3 Equivalent Dynamic Mass

In addition to building structural dead weight, the inertial properties of the model include equivalent seismic mass. The equivalent mass consists of permanent equipment self-weight, 25% live load and piping load (or 75% snow load for roof, whichever is greater). The loads including equipment self-weight, piping load and live load for the A/B are obtained from "**Load Distribution Auxiliary Building" and** “Component Weight List Auxiliary Building” (References 7.5, 7.6 respectively). The concrete density is adjusted to consider the additional equivalent seismic mass. The total weight of A/B model calculated from 13 ft mesh dynamic model is shown on Table 2.1-1.

2.3.4 Modeling of Equipment

The heaviest equipment weight (mass) is less than 1% of the total building weight (mass), therefore the dynamic model does not simulate the stiffness of such equipment and the equipment mass is lumped to the structural members as described in Section 2.3.3. This is in accordance with the procedure specified in SRP 3.7.2-8 Section 3 (Reference.7.10),

Table 2.3-1 Z-coordinates of Slabs in A/B Model (Bottom to Top)

Z (ft)	Elevation (in)	Description
-36’-3”	-435	Bottom of Basemat (Bottom)
-26’-4”	-316	Top of Basemat (B1F)
-14’-4”	-172	Basement Intermediate Floor (B2MF)
-8’-7”	-103	Basement Intermediate Floor (B1MF)
3’-7”	43	First Floor (Gslab)
15’-9”	189	First Floor Intermediate Floor (F1MF)
28’-6”	342	Second Floor (F2F)
50’-2”	602	Third Floor (F3F)
61’-6”	738	Third Floor Intermediate Floor (F3MF)
76’-5”	917	Fourth Floor (F4F)
89’-7”	1075	Roof 1
96’-0”	1152	Roof2
101’-0”	1212	Roof3

Table 2.3-2 X-coordinates of Walls/Columns in A/B Model (North to South)

X (ft)	Column Line	Description
-115.083	AA*	North Exterior Wall
-104.750	AA1**	
-91.791	AA2**	
-82.500	BA	North Interior Wall
-70.916	BA1**	
-59.500	CA	North Interior Wall
-49.666	CA1**	
-44.750	CA2**	
-39.833	CA3**	
-30.000	DA	North Interior Wall
-18.166	DA1**	
-15.000	DA2**	
-9.833	DA3**	
0.000	EA	Center of the Building
9.333	EA1**	
15.000	EA2**	
20.500	EA3**	
30.000	FA	South Interior Wall
37.417	FA1**	
45.000	FA2**	
50.083	FA3**	
60.000	GA	South Interior Wall
69.917	GA1**	
75.000	GA2**	
82.583	GA3**	
90.000	HA	South Interior Wall
100.833	HA1**	
111.667	HA2**	
124.167	JA*	South Exterior Wall

* Most Outside of the Exterior Wall
**For convenience of modeling only, not shown on drawings

Table 2.3-3 Y-coordinates of Walls/Columns in A/B Model (West to East)

Y (ft)	Column Line	Description
-62.833	1A*	West Exterior Wall
-52.167	1A1**	
-44.458	1A2**	
-33.000	1A3**	
-25.167	2A	West Interior Wall
-13.167	2A1**	
0.000	3A	Center of the Building
8.5	3A1**	
17.000	4A	East Interior Wall
28.917	4A1**	
39.000	5A	East Interior Wall
47.667	5A1**	
52.583	5A2**	
60.333	5A3**	
69.667	6A*	East Exterior Wall

* Most Outside of the Exterior Wall
**For convenience of modeling only, not shown on drawings

Table 2.3-4 Stiffness Reduction for Walls with Opening(s)

Wall Name	Wall Height (ft)	Wall Length (ft)	Wall Thick (ft)	Dimensions of Opening /door One (ft)			Dimensions of Opening /door Two (ft)			Stiffness Ratios		Cracked Section		
				Distance to Column Start	Width	Height	Distance to Column Start	Width	Height	Outplane	Inplane	Ec (ksf)	γ_c (k-sec^2/ft^4)	t_c (ft)
Basemat (el.-26'-4")_NS														
NS_1A_B1FB1FM_DA_EA	16.58	30.00	3.33	4.00	6.67	8.50				0.78	0.72	505154	0.0056	2.46
NS_1A1_B1FB1FM_BA1_CA1	16.58	21.25	1.00	7.42	3.00	16.58	13.09	3.00	16.58	0.72	0.72	526858	0.0047	0.71
NS_2A1_B1FB1FM_BA1_DA	16.58	40.92	2.17	1.08	3.00	6.67				0.93	0.92	667208	0.0063	1.55
NS_2A1_B1FB1FM_EA3_HA	16.58	69.50	2.17	9.25	3.00	16.58	10.92	3.00	16.58	0.56	0.47	314462	0.0055	1.68
NS_3A_B1FB1FM_CA_DA	16.58	29.50	1.67	25.17	4.33	16.58				1.00	1.00	734132	0.0056	1.18
NS_3A_B1FB1FM_HA_JA	16.58	32.50	3.33	1.67	6.33	8.33				0.82	0.77	549892	0.0058	2.43
NS_4A1_B1FB1FM_CA_DA	16.58	29.50	1.00	1.67	3.33	6.67				0.90	0.87	623673	0.0062	0.72
NS_4A1_B1FB1FM_DA3_FA	16.58	39.83	3.50	1.75	3.33	16.58				0.91	0.82	567553	0.0057	2.62
NS_5A_B1FB1FM_DA3_FA	16.58	39.83	2.17	12.34	3.33	6.67	35.16	3.00	6.67	0.92	0.90	656052	0.0061	1.55
NS_5A2_B1FB1FM_DA_EA	16.58	30.00	2.33	1.67	3.00	16.58				0.90	0.75	502553	0.0054	1.81
NS_6A_B1FB1FM_EA_FA	16.58	30.00	3.33	1.50	6.67	8.50				0.78	0.72	501908	0.0056	2.47
NS_1A1_B1FMF1F_BA_BA1	16.58	11.58	1.75	7.16	3.00	6.67				0.77	0.72	514314	0.0057	1.28
NS_1A1_B1FMF1F_BA1_CA1	16.58	21.25	1.75	7.42	3.00	6.67	18.42	3.00	6.67	0.87	0.86	627730	0.0058	1.24
NS_4A_B1FMF1F_DA3_FA	12.00	39.83	3.17	16.66	2.50	6.00	22.33	2.50	6.00	0.94	0.90	642024	0.0060	2.29
NS_4A1_B1FMF1F_AA2_BA	12.00	9.29	2.25	1.13	3.00	6.67				0.68	0.59	400646	0.0050	1.71
NS_4A1_B1FMF1F_DA3_FA	12.00	39.83	3.50	1.75	3.33	12.00				0.91	0.84	588054	0.0058	2.59
NS_4A1_B1FMF1F_FA_HA	12.00	60.00	2.00	1.67	3.00	6.67	31.00	3.00	6.67	0.90	0.85	611047	0.0061	1.45
NS_5A_B1FMF1F_AA_CA	12.00	54.00	2.33	1.75	3.00	12.00				0.95	0.90	643811	0.0061	1.69
NS_5A_B1FMF1F_FA_HA	12.00	60.00	2.00	1.67	3.00	6.67	31.00	3.00	6.67	0.90	0.85	611047	0.0061	1.45
NS_5A2_B1FMF1F_DA1_EA	12.00	18.17	2.33	15.00	3.00	6.67				0.84	0.74	505438	0.0056	1.76
GSLAB (el.3'-7")_NS														
NS_1A_F1FF2F_AA_EA	26.25	113.50	3.33	32.67	19.67	14.00	87.50	6.67	8.50	0.83	0.76	535415	0.0056	2.46
NS_2A_F1FF1MF_DA3_EA3	12.17	30.33	2.50	1.25	3.00	6.67				0.90	0.88	635161	0.0061	1.79
NS_2A_F1FF1MF_HA_JA	12.17	32.50	4.00	27.92	3.00	6.67				0.91	0.89	640454	0.0062	2.87
NS_4A1_F1FF1MF_GA2_JA	12.17	47.50	2.67	42.83	3.00	6.67				0.94	0.93	674821	0.0063	1.90
NS_5A_F1FF1MF_DA3_FA	12.17	39.83	2.50	1.21	3.00	6.67				0.93	0.91	666703	0.0063	1.78
NS_5A_F1FF1MF_FA_HA	12.17	60.00	3.08	65.33	3.00	6.67				1.00	1.00	734146	0.0064	2.18
NS_5A3_F1FF1MF_DA3_EA	12.17	9.83	1.50	7.83	2.00	12.17				1.00	1.00	734161	0.0053	1.06
NS_5A3_F1FF1MF_EA_EA2	12.17	15.00	2.17	6.33	2.50	12.17				0.83	0.83	611788	0.0055	1.53
NS_5A3_F1FF1MF_EA2_FA2	12.17	30.00	2.67	5.96	2.50	12.17	19.92	2.50	12.17	0.77	0.45	251834	0.0042	2.47
NS_5A3_F1FF1MF_FA2_GA2	12.17	30.00	2.67	6.25	2.50	12.17	20.58	2.50	12.17	0.81	0.48	275224	0.0043	2.43
NS_5A3_F1FF1MF_GA2_HA	12.17	15.00	2.67	6.30	2.50	12.17				0.83	0.83	611788	0.0055	1.89

Table 2.3-4 Stiffness Reduction for Walls with Opening(s) (continued)

Wall Name	Wall Height (ft)	Wall Length (ft)	Wall Thick (ft)	Dimensions of Opening /door One (ft)			Dimensions of Opening /door Two (ft)			Stiffness Ratios		Cracked Section		
				Distance to Column Start	Width	Height	Distance to Column Start	Width	Height	Outplane	Inplane	Ec (ksf)	γ_c (k-sec^2/ft^4)	t_c (ft)
GSLAB (el.3'-7")_NS														
NS_5A3_F1FF1MF_HA_HA2	12.17	21.67	1.67	5.33	2.50	12.17	12.67	2.50	12.17	0.77	0.77	564728	0.0051	1.18
NS_6A_F1FF1MF_CA_JA	12.17	182.00	3.33	6.67	8.33	8.50	173.33	6.67	8.50	0.95	0.94	684242	0.0062	2.38
NS_4A_F1MFF2F_DA3_EA3	14.08	30.33	2.00	1.33	3.00	6.00	19.16	3.00	6.00	0.82	0.77	552152	0.0059	1.45
NS_4A_F1MFF2F_EA3_FA1	14.08	16.92	3.33	13.92	3.00	6.00				1.00	1.00	734047	0.0061	2.36
NS_4A_F1MFF2F_FA1_FA3	14.08	12.67	2.83	1.17	3.00	6.00				0.78	0.71	498223	0.0057	2.10
NS_4A_F1MFF2F_GA1_HA2	14.08	41.75	2.42	17.08	3.00	6.00	22.58	3.00	6.00	0.93	0.90	653876	0.0061	1.74
NS_4A_F1MFF2F_HA2_JA	14.08	10.83	2.00	1.21	3.00	6.00				0.78	0.71	497870	0.0056	1.48
Second Floor (25'-3")_NS														
NS_1A_F2FF3F_HA_JA	20.83	32.50	2.67	4.83	8.00	8.50				0.78	0.76	548383	0.0058	1.91
NS_1A2_F2FF3F_HA_JA	20.83	32.50	1.67	3.00	8.67	20.83				0.76	0.72	513173	0.0047	1.21
NS_2A1_F2FF3F_DA_EA	20.83	30.00	1.00	2.00	6.67	8.50				0.79	0.79	573903	0.0060	0.71
NS_2A1_F2FF3F_EA_HA	20.83	90.00	1.00	43.16	6.67	8.50	80.83	6.67	8.50	0.93	0.91	659985	0.0061	0.72
NS_3A_F2FF3F_DA_FA	20.83	60.00	2.67	9.33	6.67	8.50	41.83	6.67	8.50	0.79	0.78	565440	0.0059	1.90
NS_3A_F2FF3F_FA_HA1	20.83	70.83	2.67	13.17	6.67	8.50				0.91	0.90	660113	0.0063	1.90
NS_5A3_F2FF3F_EA_GA	20.83	60.00	1.00	11.83	6.67	8.50	41.83	6.67	8.50	0.90	0.88	645139	0.0060	0.71
NS_5A3_F2FF3F_GA_HA1	20.83	40.83	1.00	11.17	6.67	8.50				1.00	1.00	734146	0.0062	0.71
NS_6A_F2FF3F_CA_DA	20.83	29.50	2.67	6.67	6.67	8.50				0.79	0.78	570534	0.0060	1.89
NS_6A_F2FF3F_HA_JA	20.83	32.50	2.67	22.08	8.00	8.50				0.78	0.75	542541	0.0058	1.92
Third Floor (50'-2")_NS														
NS_3A_F3FF3MF_CA_DA	12.17	29.50	1.00	9.83	3.00	12.17	14.75	3.00	12.17	0.80	0.80	584828	0.0053	0.71
NS_1A2_F3FF4F_DA3_FA	26.58	39.83	1.33	33.50	5.00	6.67				0.91	0.86	609808	0.0062	0.97
NS_6A_F3FF4F_CA_DA	26.58	29.50	2.67	6.67	6.67	8.50				0.81	0.84	630194	0.0062	1.85
NS_6A_F3FF4F_HA_JA	26.58	32.50	2.67	21.00	9.33	9.00				0.76	0.74	538959	0.0059	1.90
Fourth Floor and Beyond (76'-5"_101'-0")_NS														
NS_5A_F4FRoof1_HA_JA	13.67	32.50	1.75	27.17	3.33	6.83				0.91	0.88	634064	0.0062	1.26
NS_6A_F4FRoof1_HA_JA	13.67	32.50	0.83	24.50	6.00	9.00				0.82	0.73	501666	0.0054	0.63
NS_6A_F4FRoof3_CA_DA	25.08	29.50	0.83	6.67	6.67	9.00				0.80	0.81	602361	0.0061	0.58
Basemat (el.-26'-4")_EW														
EW_BA_B1FB1FM_1A_4A	16.58	79.00	2.67	1.67	3.00	6.67	73.00	3.00	6.67	0.93	0.93	683523	0.0064	1.89
EW_BA_B1FB1Fm_4A_5A	16.58	22.00	2.67	17.33	3.00	6.67				0.88	0.83	594290	0.0061	1.94
EW_BA1_B1FB1FM_2A1_4A	16.58	31.00	3.50	1.08	3.33	16.58				0.89	0.76	520979	0.0055	2.67
EW_CA_B1FB1FM_1A3_2A1	16.58	19.83	2.67	1.25	6.58	16.58				0.67	0.67	490471	0.0044	1.89

Table 2.3-4 Stiffness Reduction for Walls with Opening(s) (continued)

Wall Name	Wall Height (ft)	Wall Length (ft)	Wall Thick (ft)	Opening /door One Dimensions (ft)			Opening /door Two Dimensions (ft)			Stiffness Ratios		Cracked Section		
				Distance to Column Start	Width	Height	Distance to Column Start	Width	Height	Outplane	Inplane	Ec (ksf)	γ_c (k-sec^2/ft^4)	t_c (ft)
Basemat (el.-26'-4")_EW														
EW_CA_B1FB1FM_2A1_4A1	16.58	42.92	2.67	1.08	3.33	16.58				0.92	0.85	603022	0.0059	1.96
EW_CA2_B1FB1FM_5A1_6A	16.58	20.33	1.00	0.50	3.33	6.67				0.87	0.77	537807	0.0058	0.75
EW_DA3_B1FB1FM_1A_1A2	16.58	16.71	1.08	1.67	3.00	6.67				0.85	0.80	566783	0.0059	0.79
EW_DA2_B1FB1FM_5A2_6A	16.58	15.42	1.08	1.67	3.00	6.67				0.85	0.80	566783	0.0059	0.79
EW_EA_B1FB1Fm_1A_1A2	16.58	16.71	1.00	1.67	3.00	6.67				0.86	0.80	566212	0.0059	0.73
EW_HA_B1FB1FM_4A1_5A	16.58	10.08	2.50	1.25	3.00	6.67				0.73	0.69	496622	0.0057	1.81
EW_AA2_B1FMF1F_1A_4A	12.00	79.00	2.58	1.67	3.00	6.67	76.00	3.00	6.67	0.96	0.96	705307	0.0063	1.83
EW_BA_B1FMF1F_4A_5A	12.00	22.00	2.67	1.67	2.00	6.67	18.67	3.33	12.00	0.91	0.87	622715	0.0051	1.93
EW_BA1_B1FMF1F_2A1_4A	12.00	31.00	3.50	1.08	3.33	12.00				0.89	0.79	551876	0.0056	2.62
EW_FA_B1FMF1F_2A_2A1	12.00	12.00	3.33	1.67	3.00	6.67				0.76	0.67	461160	0.0053	2.51
EW_HA_B1FMF1F_4A1_5A	12.00	10.08	2.50	1.25	3.00	6.67				0.71	0.61	419768	0.0051	1.90
EW_CA3_B1FF1F_1A1_2A1	28.58	39.00	2.50	16.17	3.00	28.58	36.00	3.00	28.58	0.85	0.85	621200	0.0056	1.77
GSLAB (el.3'-7")_EW														
EW_CA_F1FF1MF_1A_4A	12.17	79.00	2.67	35.17	10.00	12.00	67.33	10.00	8.33	0.87	0.73	494519	0.0048	2.06
EW_CA_F1FF1MF_4A_5A	12.17	22.00	2.67	19.00	3.00	6.83				1.00	1.00	733986	0.0061	1.89
EW_CA2_F1FF1MF_5A2_6A	12.17	15.42	1.00	1.00	3.33	16.25				1.00	1.00	734275	0.0047	0.71
EW_DA3_F1FF1MF_5A_5A1	12.17	8.67	2.42	4.83	3.00	12.17				0.65	0.65	480018	0.0043	1.71
EW_DA3_F1FF1MF_5A1_6A	12.17	20.33	1.50	18.17	3.00	12.17				0.86	0.72	482873	0.0051	1.16
EW_GA_F1FF1MF_1A_2A	12.17	36.00	2.00	30.33	3.33	6.67				0.91	0.88	637579	0.0062	1.44
EW_GA1_F1FF1MF_4A_4A1	12.17	11.92	4.17	1.75	3.00	12.17				0.75	0.75	549326	0.0049	2.95
EW_HA_F1FF1MF_1A_2A	12.17	36.00	2.00	30.33	3.33	6.67				0.91	0.88	637579	0.0062	1.44
EW_FA_F1MFF2F_2A_2A1	14.08	12.00	3.33	9.17	2.00	14.08				0.83	0.52	300558	0.0043	2.98
EW_HA_F1MFF2F_2A_2A1	14.08	12.00	3.33	1.67	3.33	6.67				0.74	0.69	485053	0.0055	2.44
Second Floor (25'-3")_EW														
EW_CA_F2FF3F_5A_6A	20.83	30.67	2.50	10.33	3.00	6.67				0.92	0.92	679639	0.0064	1.76
EW_CA2_F2FF3F_5A2_6A	20.83	17.08	1.00	1.00	3.33	6.83				0.80	0.63	412942	0.0055	0.80
EW_DA_F2FF3F_1A_3A	20.83	62.83	2.67	52.17	6.67	8.50				0.90	0.90	656915	0.0063	1.89
EW_EA_F2FF3F_3A_6A	20.83	69.67	1.00	59.66	6.67	8.50				0.91	0.90	653417	0.0063	0.71
EW_JA_F2FF3F_4A_6A	20.83	52.67	3.33	27.33	3.00	7.17				0.95	0.94	684881	0.0064	2.37
Third Floor (50'-2")_EW														
EW_CA2_F3FF4F_5A2_6A	26.58	22.00	1.00	1.00	3.33	6.83				0.89	0.77	525765	0.0059	0.76
EW_HA2_F3FF4F_4A_5A	26.58	22.00	1.00	1.00	3.33	6.83				0.89	0.77	525765	0.0059	0.76
Fourth Floor and Beyond (76'-5"_101'-0")_EW														
EW_BA_F4FRoof3_5A_6A	25.08	30.67	1.75	20.67	5.00	6.67				0.87	0.88	651619	0.0063	1.23
EW_DA_F4FRoof3_5A_6A	25.08	30.67	1.75	3.33	13.58	20.08				0.63	0.35	188832	0.0032	1.67

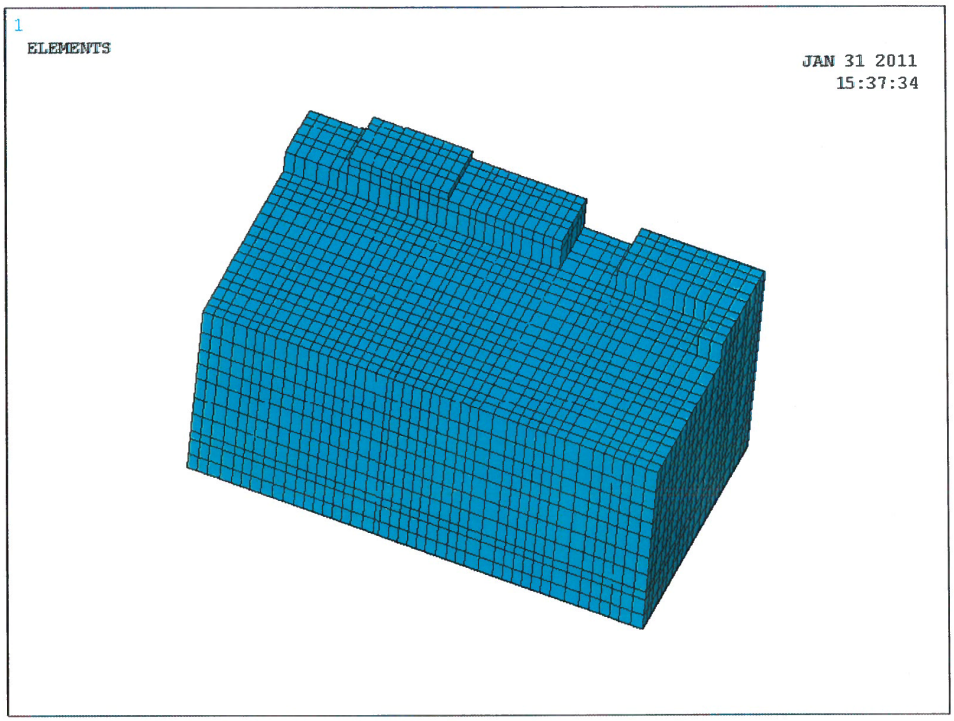


Figure 2.3-1 9-ft Mesh Dynamic FE Model

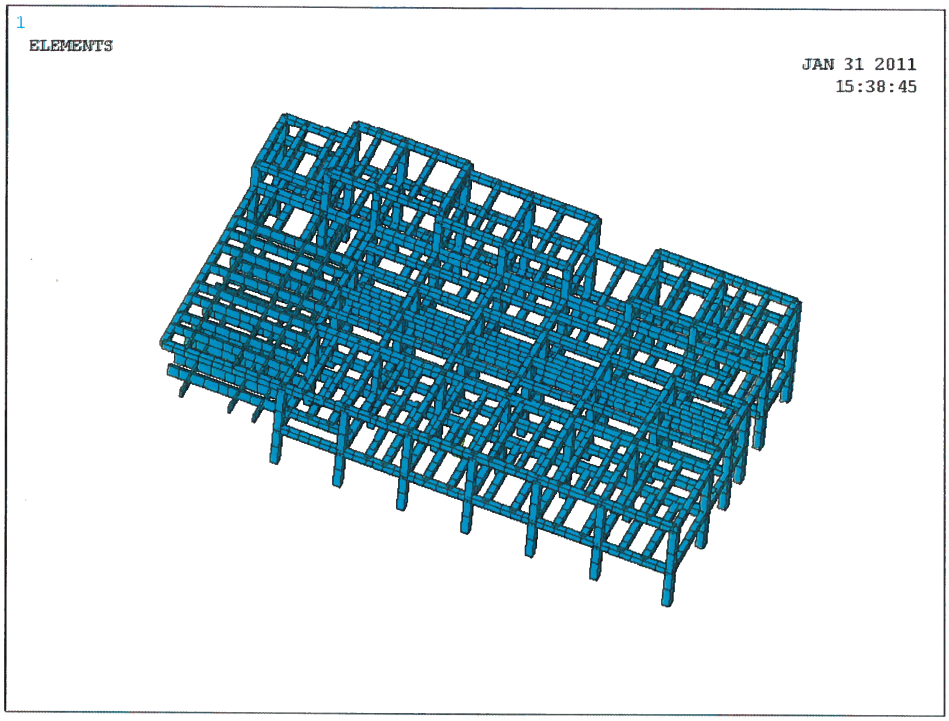


Figure 2.3-2 9-ft Mesh Dynamic FE Model, Beams and Columns

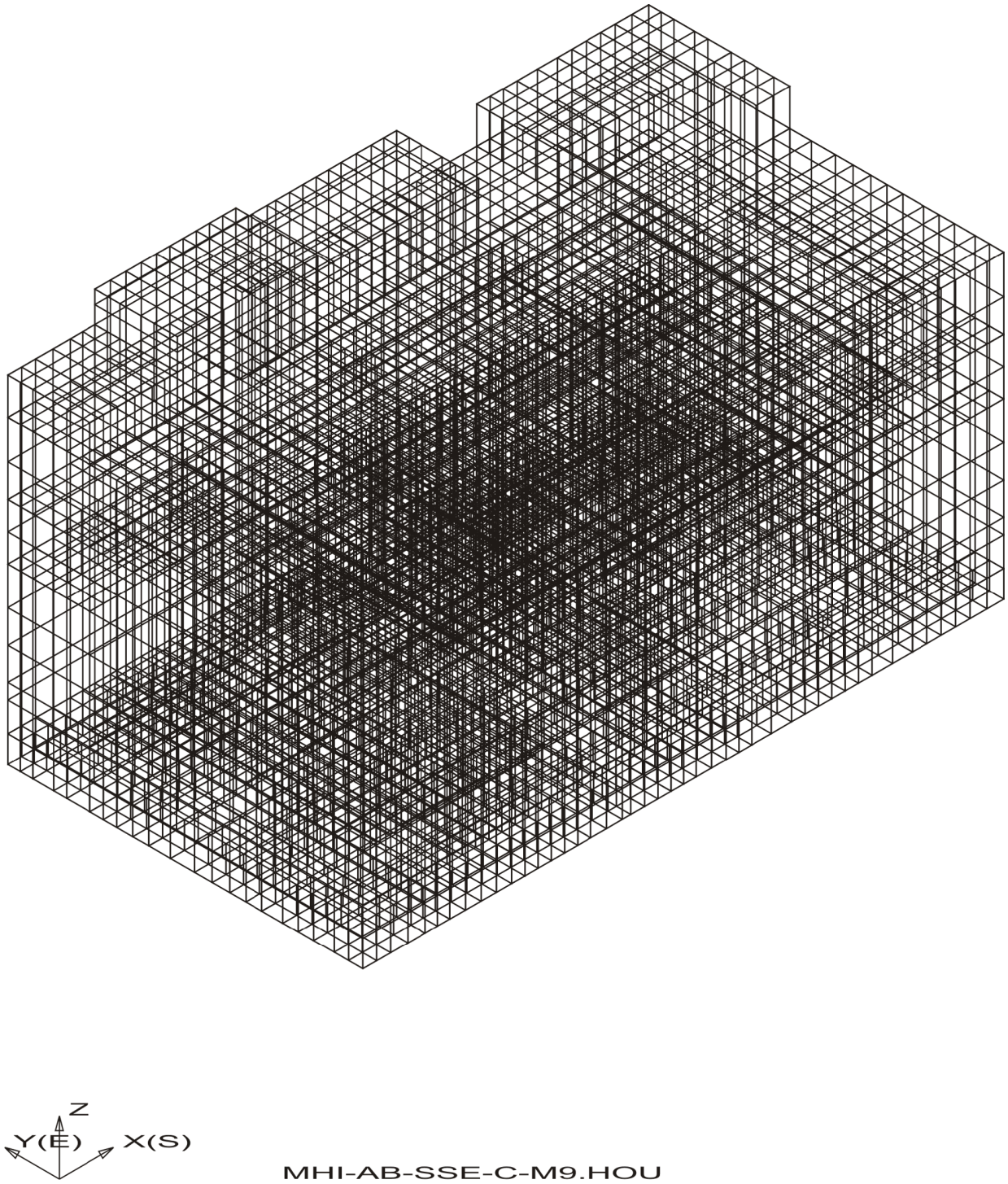


Figure 2.3-3 Isometric View of SASSI FEM A/B Model (9 ft mesh)

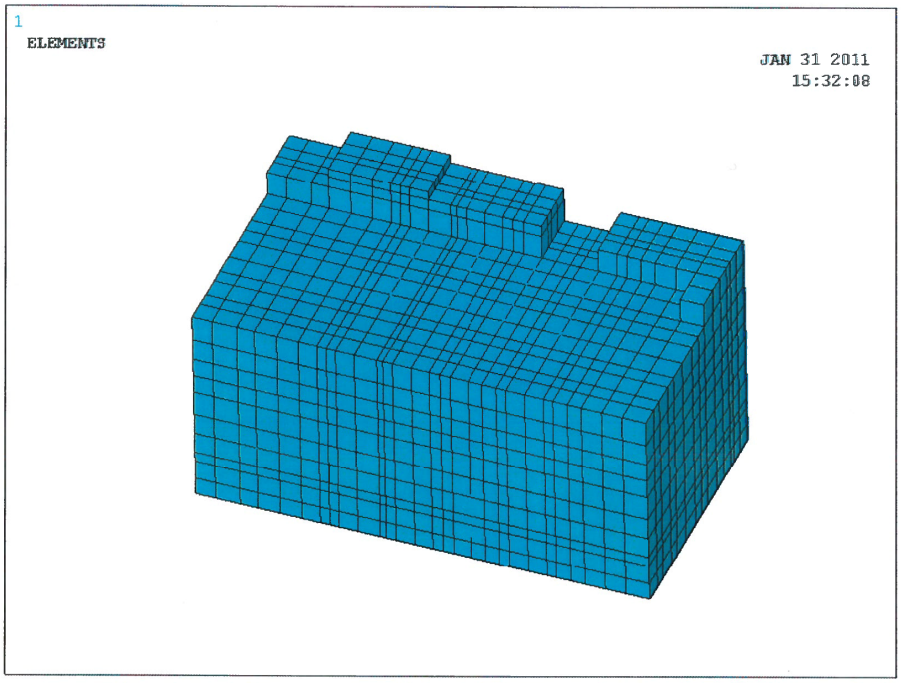


Figure 2.3-4 13-ft Mesh Dynamic FE Model

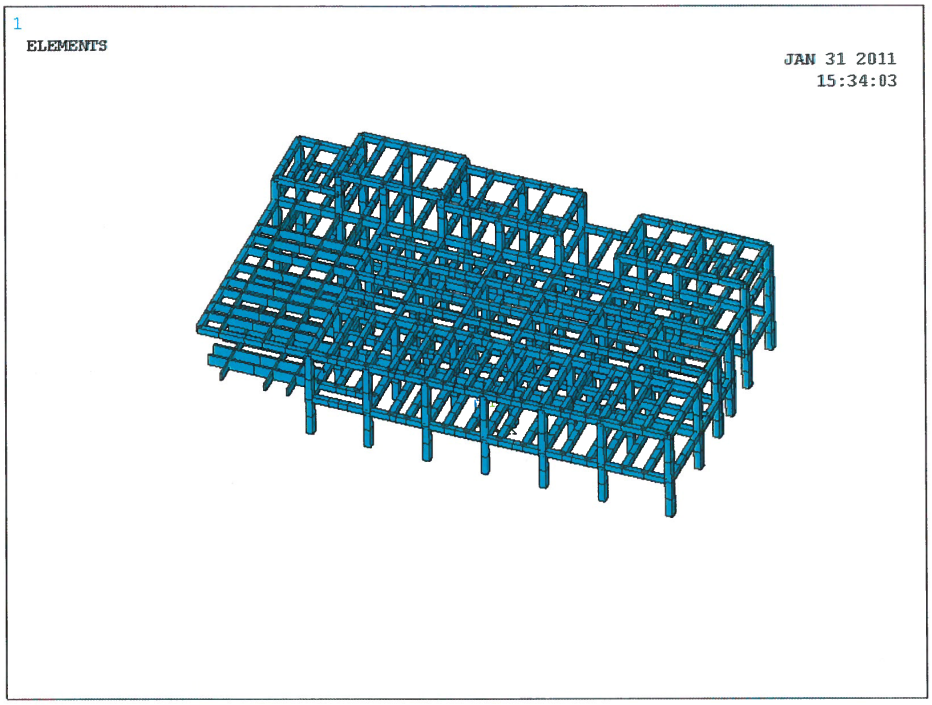


Figure 2.3-5 13-ft Mesh Dynamic FE Model, Beams and Columns

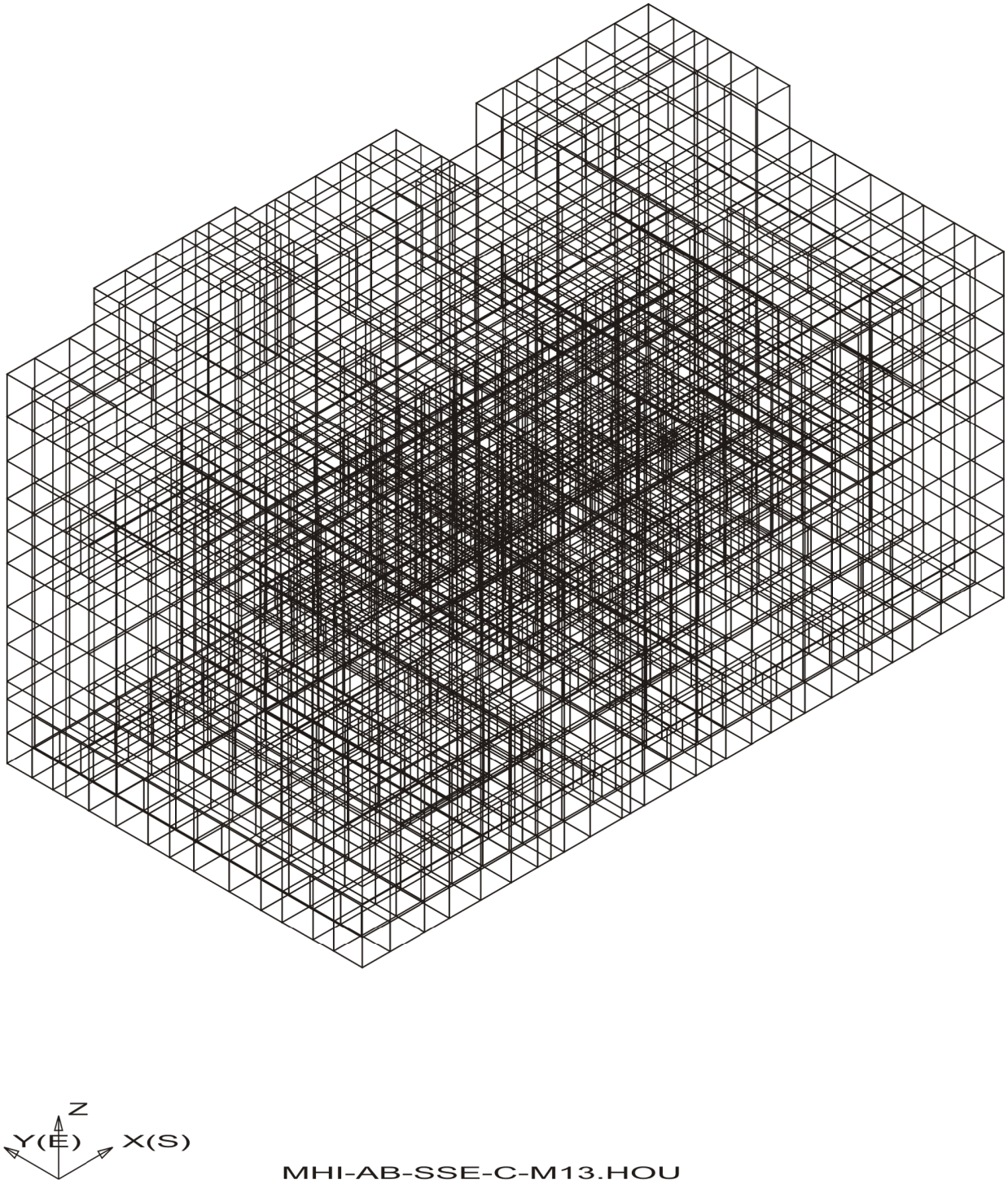


Figure 2.3-6 Isometric View of SASSI FEM A/B Model (13 ft mesh)

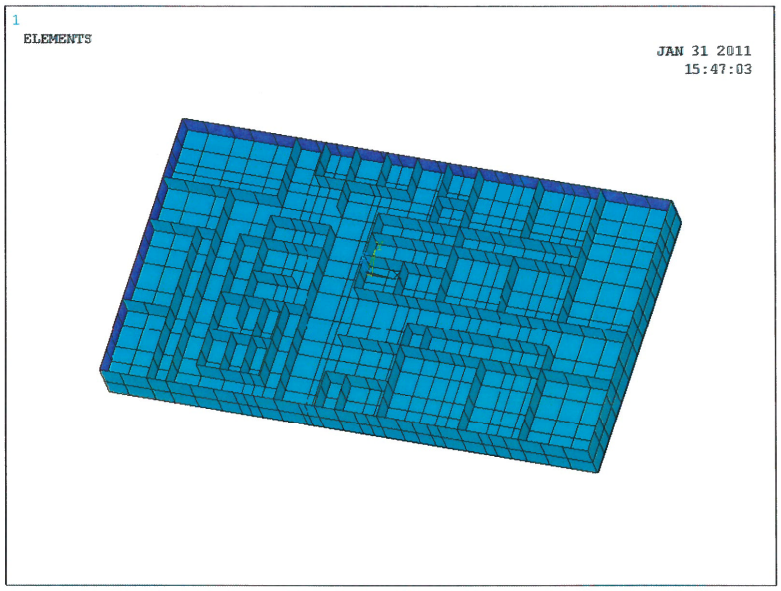


Figure 2.3-7 13 ft Mesh Dynamic Model Basemat
(Elev. -26'-4")

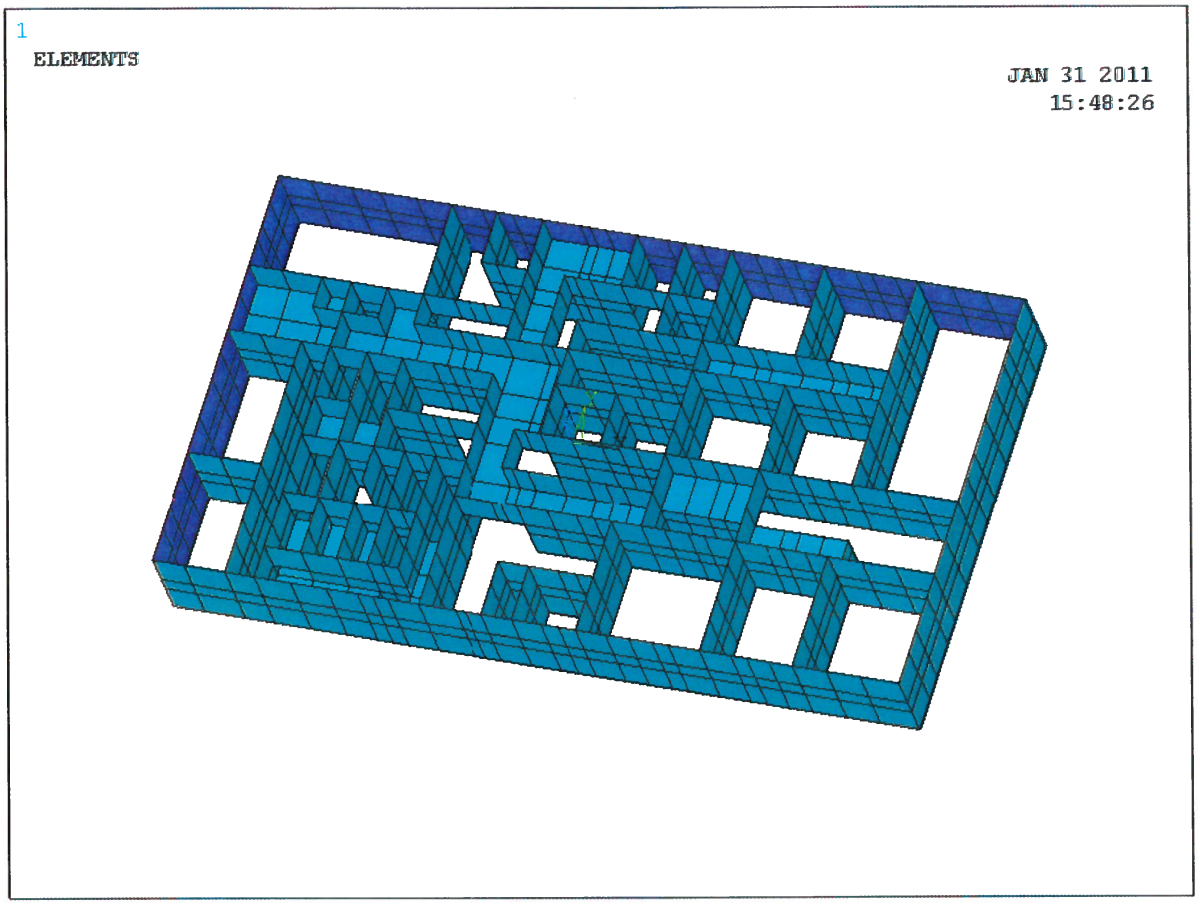


Figure 2.3-8 13 ft Mesh Dynamic Model Intermediate Floor (Elev. -14'-4" & -8'-7")

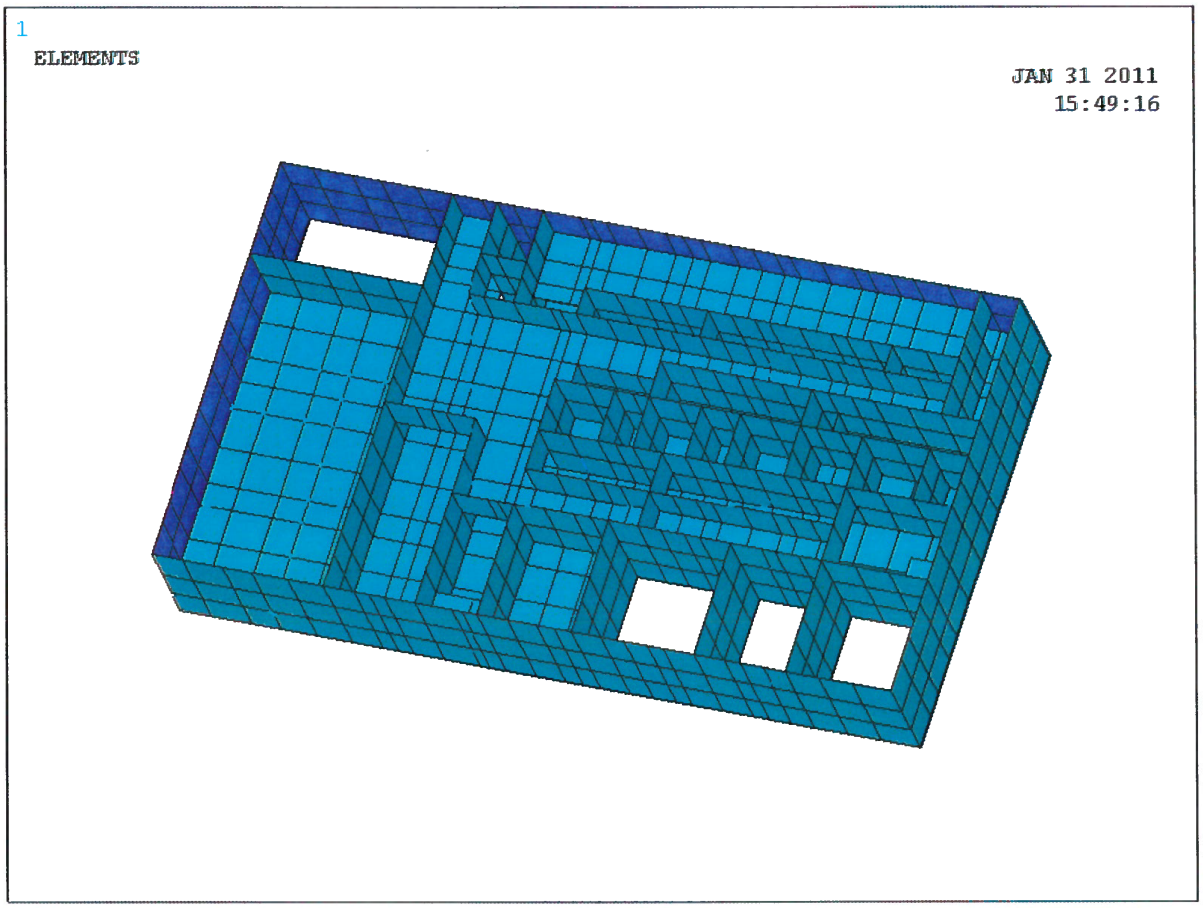


Figure 2.3-9 13 ft Mesh Dynamic Model First Floor and Intermediate Floor (Elev. 3'-7" & 15'-9")

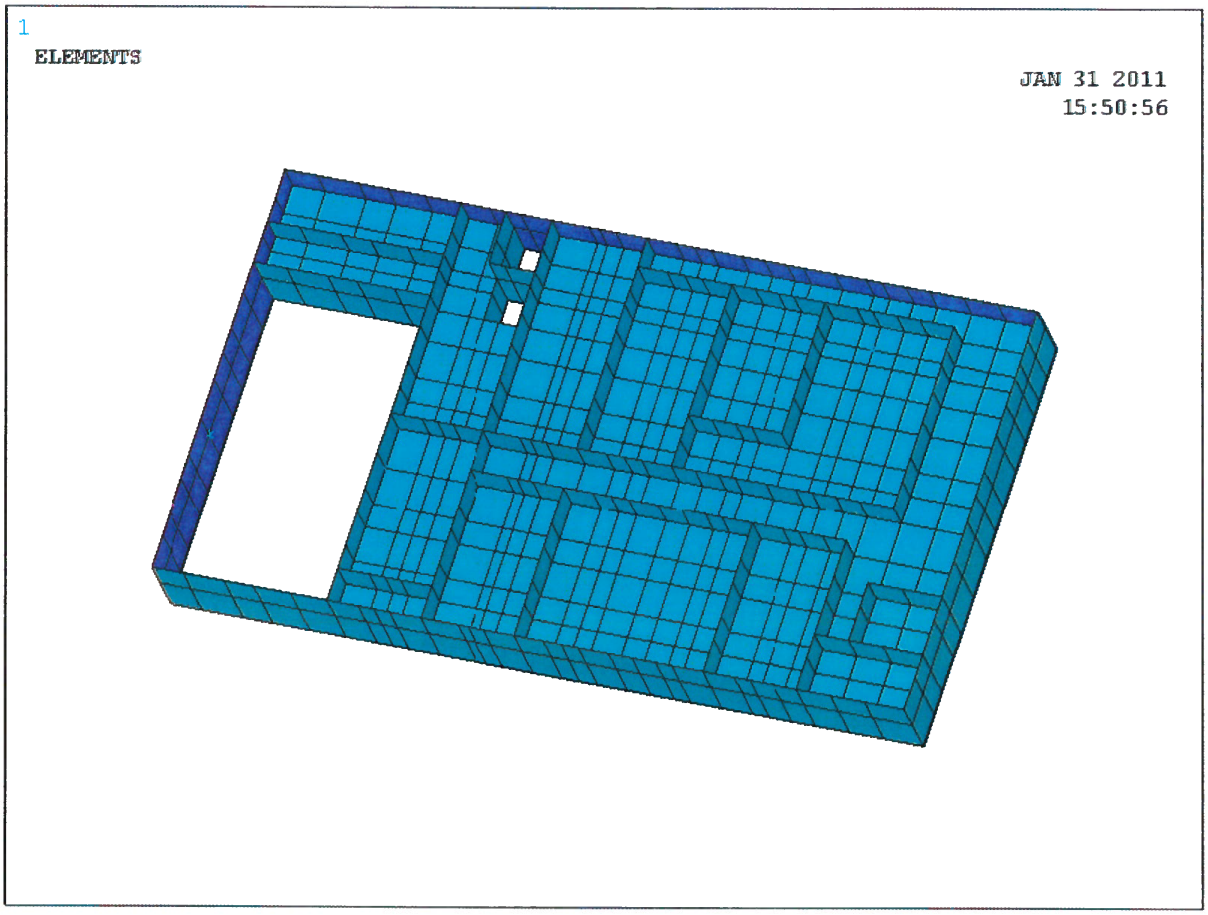


Figure 2.3-10 13 ft Mesh Dynamic Model Second and Intermediate Floor (Elev. 25'-3" & 33'-5")

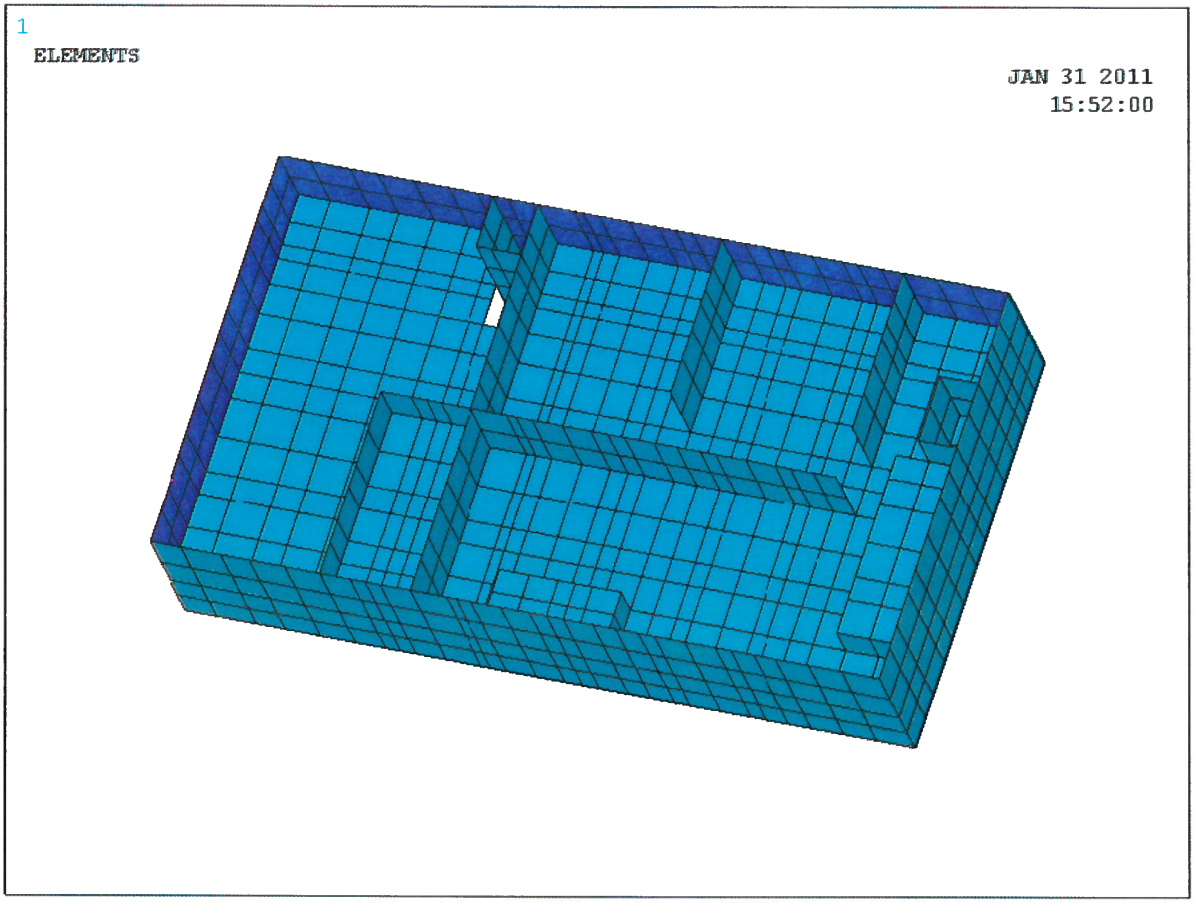


Figure 2.3-11 13 ft Mesh Dynamic Model Third and Intermediate Floor (Elev. 50'-2''& 61'-6")

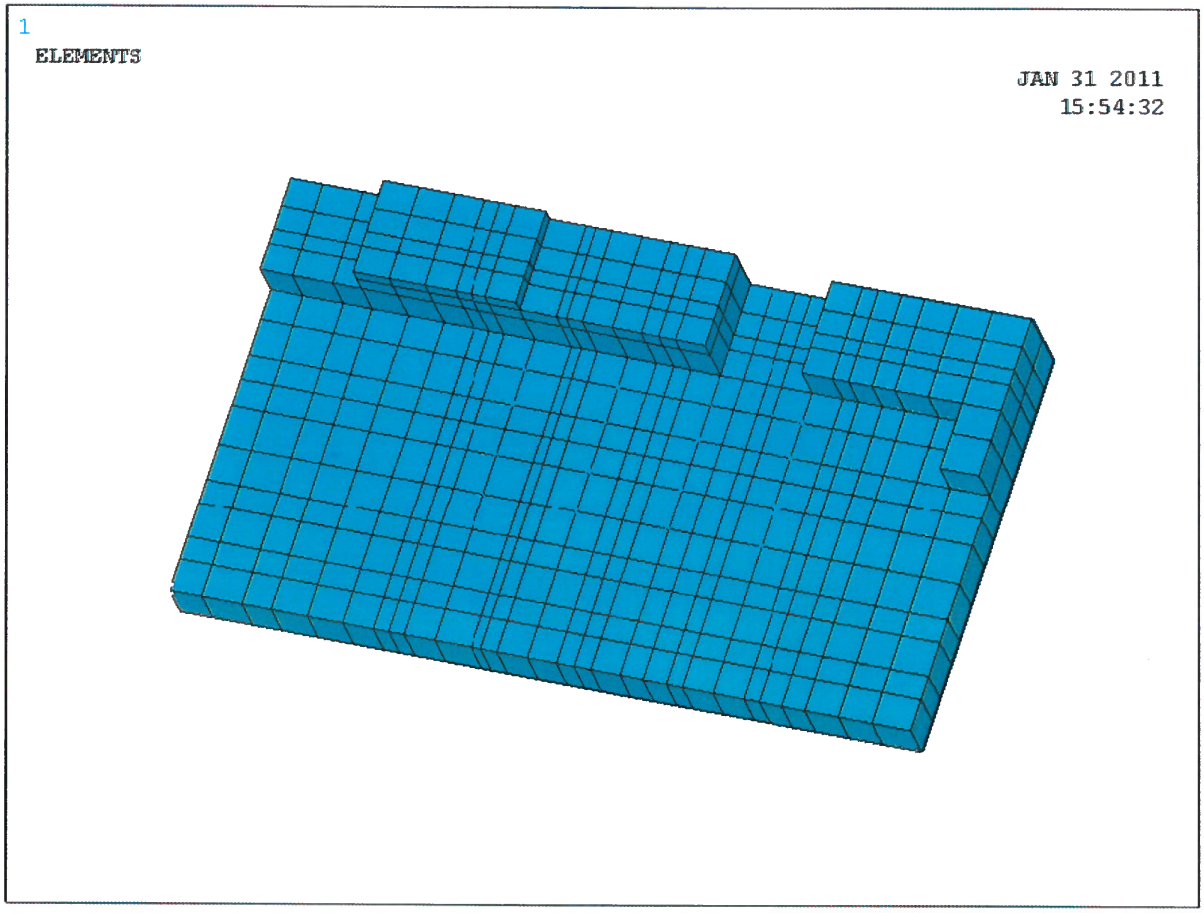


Figure 2.3-12 13 ft Mesh Dynamic Model Fourth Floor and Roofs (Elev. 76'-5'', 89'-7'', 96'-0'' & 101'-0'')

Note: Figures 2.3-7 to 2.3-12 for 13 ft mesh are not repeated for 9 ft mesh.

2.4 Detailed FE Structural Model

The detailed FE model is developed using ANSYS to calculate seismic and static load demands on the structural members that serve as basis for the evaluation of the overall structural integrity of the A/B. Figure 2.4-1 and Figure 2.4-2 present the detailed FE model. The FE model is developed as described in Section 2.1 and 2.2 above and further refined to provide additional precision in analysis. The nominal FE mesh size is set to 5 feet to provide additional refinement needed for the stress evaluations.

The structural integrity evaluation considers loads and load combinations associated with safe shutdown earthquake (SSE) event. All applicable static loads that act in conjunction with the SSE loads are applied to the detailed FE model to calculate static load demands on structural members. Static and dynamic soil pressures on the exterior walls of the basement that are in contact with soil are calculated using procedure and parameters that are specified in MHI TR MUAP-10006 (Reference 7.2). The seismic design demands are obtained from a response spectrum analysis of the detailed FE model as described in Section 4.2 below. The SSE design load demands are combined with the static load demands in the design load combinations specified in Table 3.8.4-3 of US-APWR DCD.

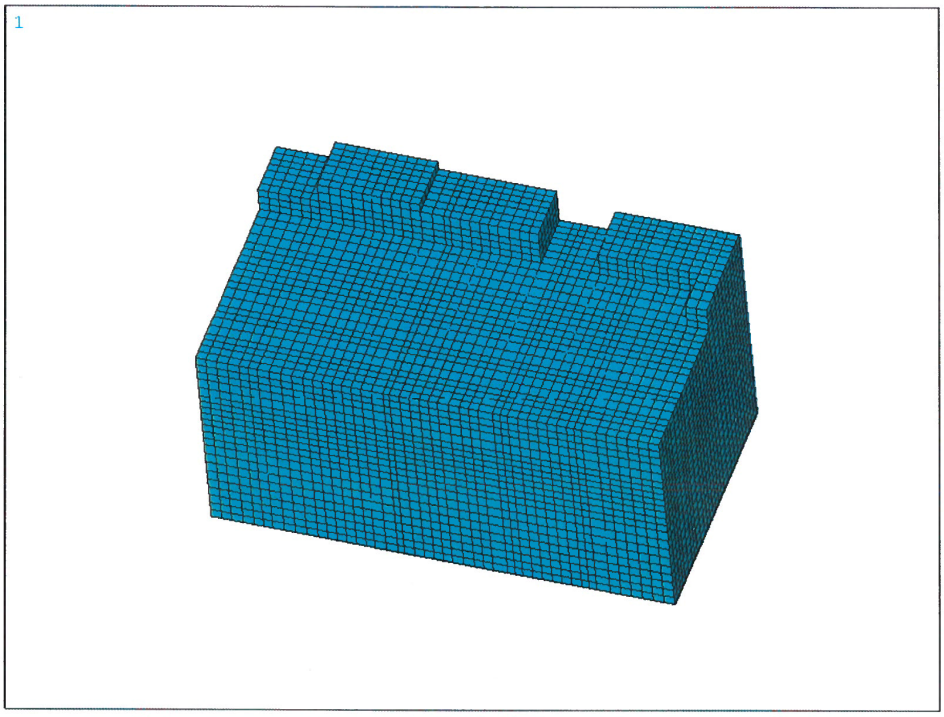


Figure 2.4-1 Detailed FE Model

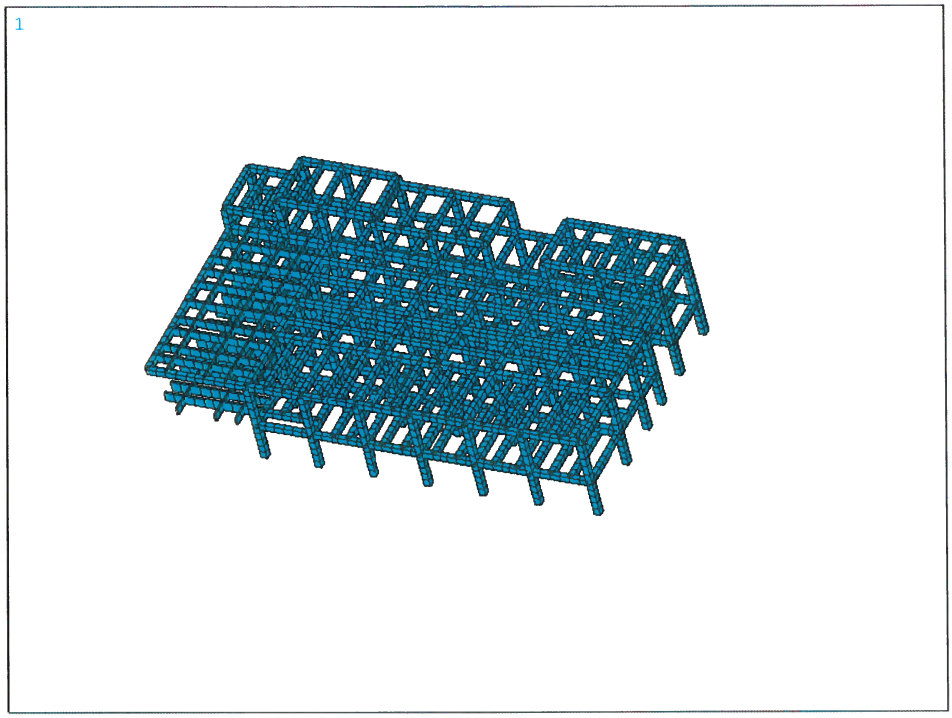


Figure 2.4-2 Detailed FE Model, Beams and Columns

2.5 Lumped-Mass Stick Model

The seismic soil-structure interaction (SSI) analyses of A/B are performed directly using the dynamic FE structural model of A/B developed as described in Section 2.3. However, to facilitate the selection of critical generic site profiles that controls the maximum seismic response parameters, a simplified three-dimensional (3-D) lumped-mass beam-stick model of the A/B structure is also developed for use in SSI analyses performed for all eight generic site profiles. The results of SSI analyses using the simplified lumped-mass stick model are used for identifying the critical generic site profiles that are to be considered in the more refined SSI analyses using the dynamic FE model directly.

The simplified lumped-mass beam-stick model is developed from the dynamic FE model of the A/B structure described in Section 2.3. For the lumped-mass stick model, the inertial properties of the structure tributary to each floor elevation are lumped at each floor elevation. The lumped-mass nodes at different major elevations are denoted as BM (base of the A/B structure), AB01 (first floor), AB02 (second floor), AB03 (third floor) and AB04 (roof of the structure). The following calculation steps are performed to develop the model properties of the lumped-mass stick model of the A/B:

1. Calculate the masses and mass-moments-of-inertia and location of the center of mass (CM) at each major floor elevation;

2. Calculate the shear rigidities (shear areas and torsional-moment-of-inertia) and associated location of the center of shear rigidity (CR or shear center) of the structural elements for each story in-between two consecutive lumped-mass elevations;

3. Calculate for each story the location of the centroid (center of axial area and bending rigidities) and associated axial area and bending rigidities (area-moments-of-inertia).

The locations of CM, CR, and centroid computed for each floor elevation are summarized in Table 2.5-1.

Table 2.5-2 provides the computed lumped masses and mass-moments-of inertia. The basement mass (BM) does not include the mass of the basemat slab, which is modeled as shell elements with the appropriate dimensions and density.

Table 2.5-3 presents the section rigidities of the generalized beam elements of the stick model. The simplified lumped-mass beam-stick model developed for A/B is shown schematically in Figure 2.5-1.

As shown in Figure 2.5-1, the basemat thickness is modeled with a rigid stick having three nodes located at the top, middle, and bottom of the basemat. The masses of the walls and equipment supported on the basemat tributary to the basement are lumped at the middle node of the basemat.

Figure 2.5-3 presents an isometric view of the complete lumped-mass SASSI stick model.

Table 2.5-1 Centroid and Center of Rigidity and Mass Locations of Stick Model

Nodal ID (Elev.)	Centroid		Center of Rigidity		Center of Mass	
	X(ft)	Y(ft)	X(ft)	Y(ft)	X(ft)	Y(ft)
Bottom (-36.25')-BM	118.758	60.274	118.758	60.274		
BM (-31.292')					118.60	58.80
BM-B1F	118.758	60.274	118.758	60.274		
B1F (-26.333')						
B1F-AB01	118.70	67.23	120.31	58.87		
AB01 (3.583')					106.32	66.15
AB01-AB02	119.49	64.59	121.59	79.34		
AB02 (30.167')					133.82	69.29
AB02-AB03	106.11	66.35	106.22	66.35		
AB03 (50.167')					120.08	62.62
AB03-AB04	114.13	70.16	114.13	70.04		
AB04 (76.417')					119.50	75.40

Note: The origin of reference of all the centers location is the North-West corner of the building at the intersection of gridlines 1A and AA. The positive X-axis points to South and the positive Y-axis points to East.

Table 2.5-2 Lumped Masses and Mass Moments-of-Inertia of Stick Model

Nodal ID (Elev.)	Translational Mass (Weight)			Mass (Weight) Moment-of-Inertia		
	X (N-S) (kip)	Y (E-W) (kip)	Z (Vertical) (kip)	XX (about NS) (kip-ft^2)	YY (about EW) (kip-ft^2)	ZZ (about vert) (kip-ft^2)
BM (-31.292')	32,547	32,547	32,547	5.91E+07	1.732E+08	2.249E+08
AB01 (3.583')	54,530	54,530	54,530	4.129E+07	1.405E+08	1.756E+08
AB02 (30.167')	38,820	38,820	38,820	5.684E+07	8.365E+07	1.442E+08
AB03 (50.167')	30,840	30,840	30,840	1.662E+07	4.692E+07	8.821E+07
AB04 (76.417')	20,190	20,190	20,190	2.172E+07	4.263E+07	9.250E+07

Note: The properties at BM do not include the 239.25'×133.33'×9.917' basemat (47,453 kips) which was modeled with plate-shell elements having a density of 0.15 kips/ft3.

Table 2.5-3 Section Properties of the Beam Elements of the Lumped-Mass Stick Model

Nodal ID (Elev.)	Axial Area (ft^2)	Shear Area		Torsion J (ft^4)	I_{xx} (about the NS axis) (ft^4)	I_{yy} (about the EW axis) (ft^4)
		X (NS) (ft^2)	Y (EW) (ft^2)			
Bottom-B1F (-36.25' to -26.333')	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid
B1F-AB01 (-26.333' to 3.583')	6750.0	3290.0	3120.0	2.00E+07	4.75E+06	1.03E+07
AB01-AB02 (3.583' to 30.167')	4900.0	2800.0	2090.0	1.72E+07	3.64E+06	8.73E+06
AB02-AB03 (30.167' to 50.167')	3260.0	1640.0	1620.0	1.70E+07	4.16E+06	1.22E+07
AB03-AB04 (50.167' to 76.417')	2330.0	1320.0	1020.0	1.31E+07	2.42E+06	1.06E+07

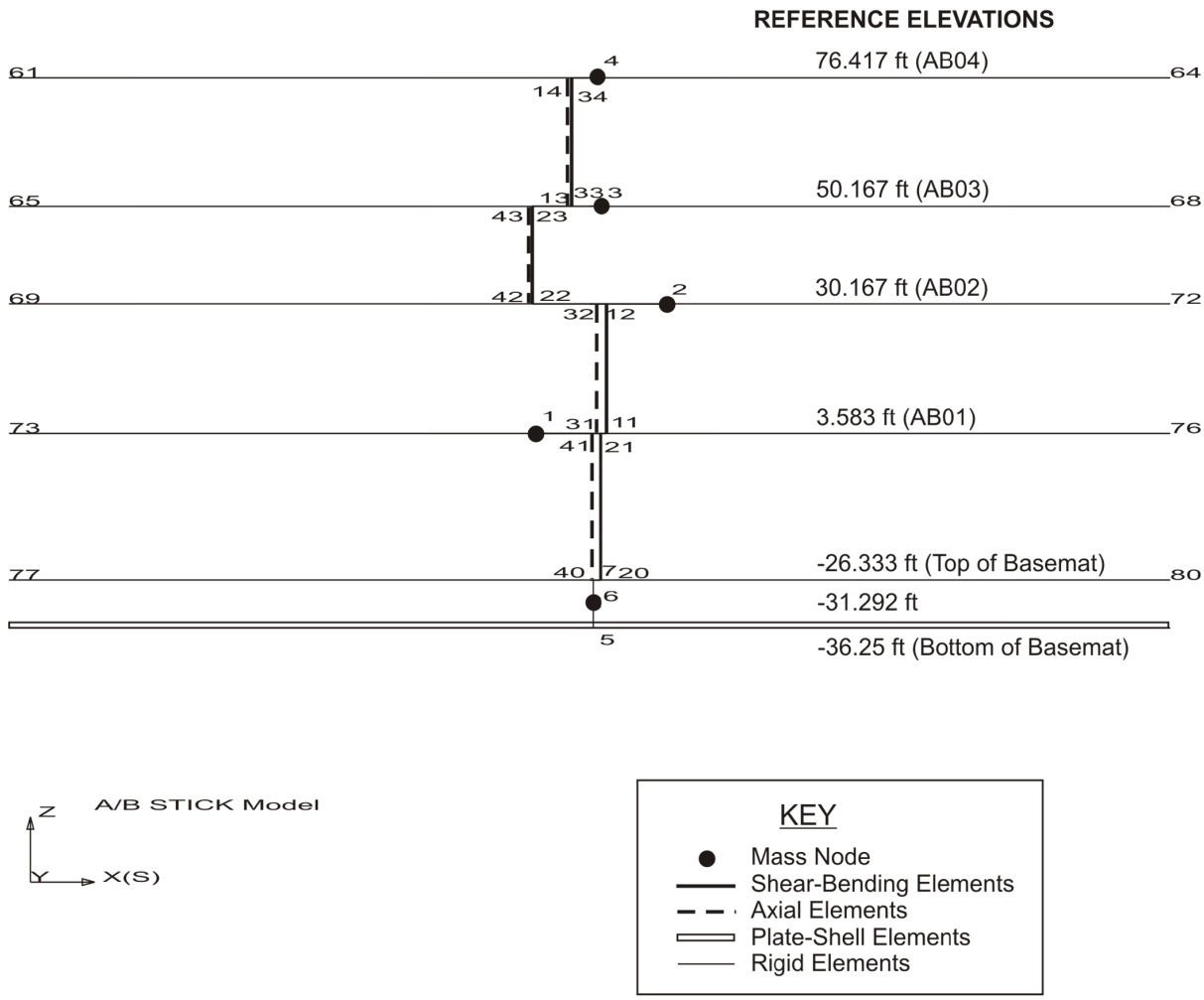


Figure 2.5-1 SASSI Lumped Mass Stick Model of the A/B in the XZ plane

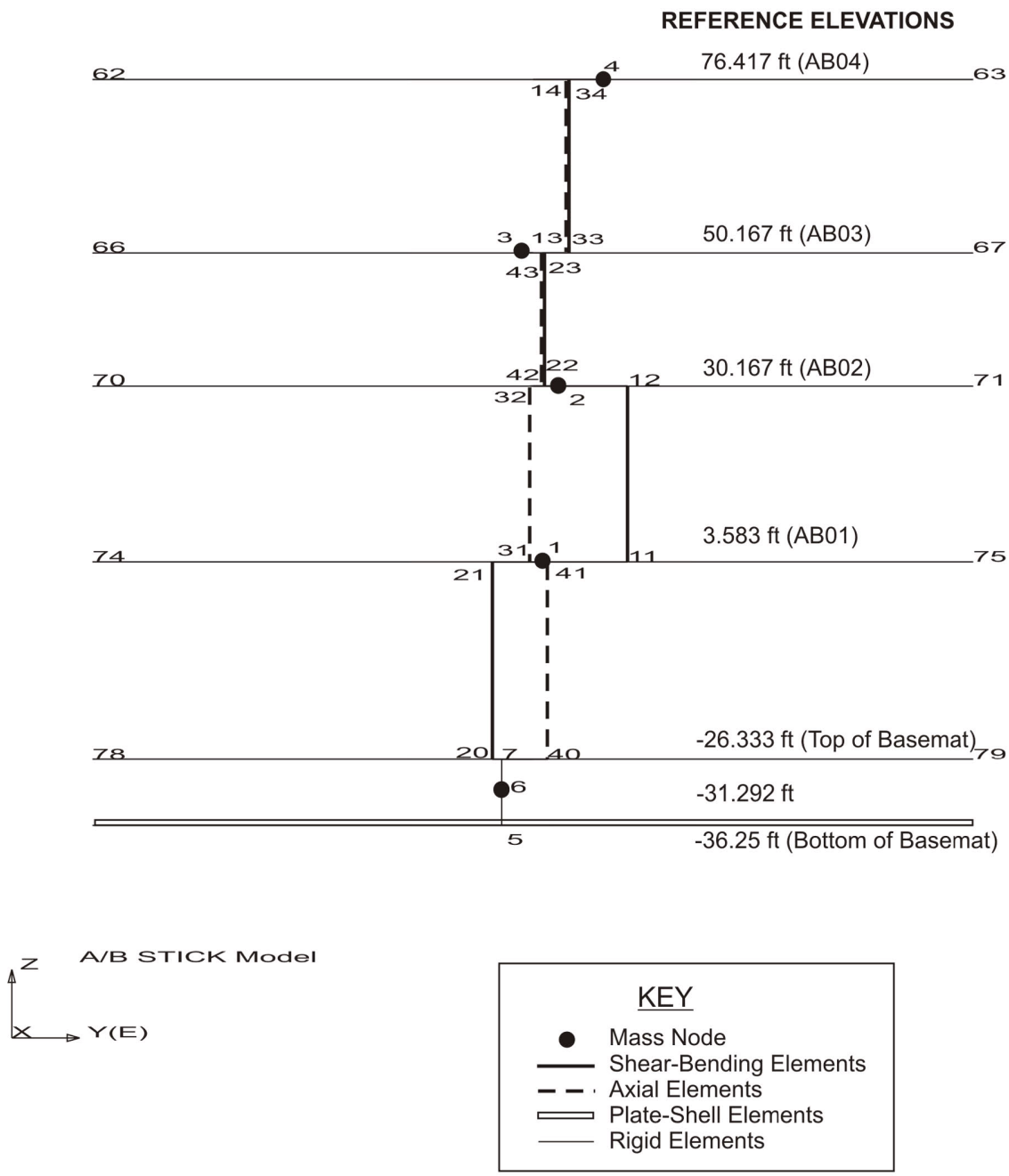


Figure 2.5-2 SASSI Lumped Mass Stick Model of the A/B in the YZ plane

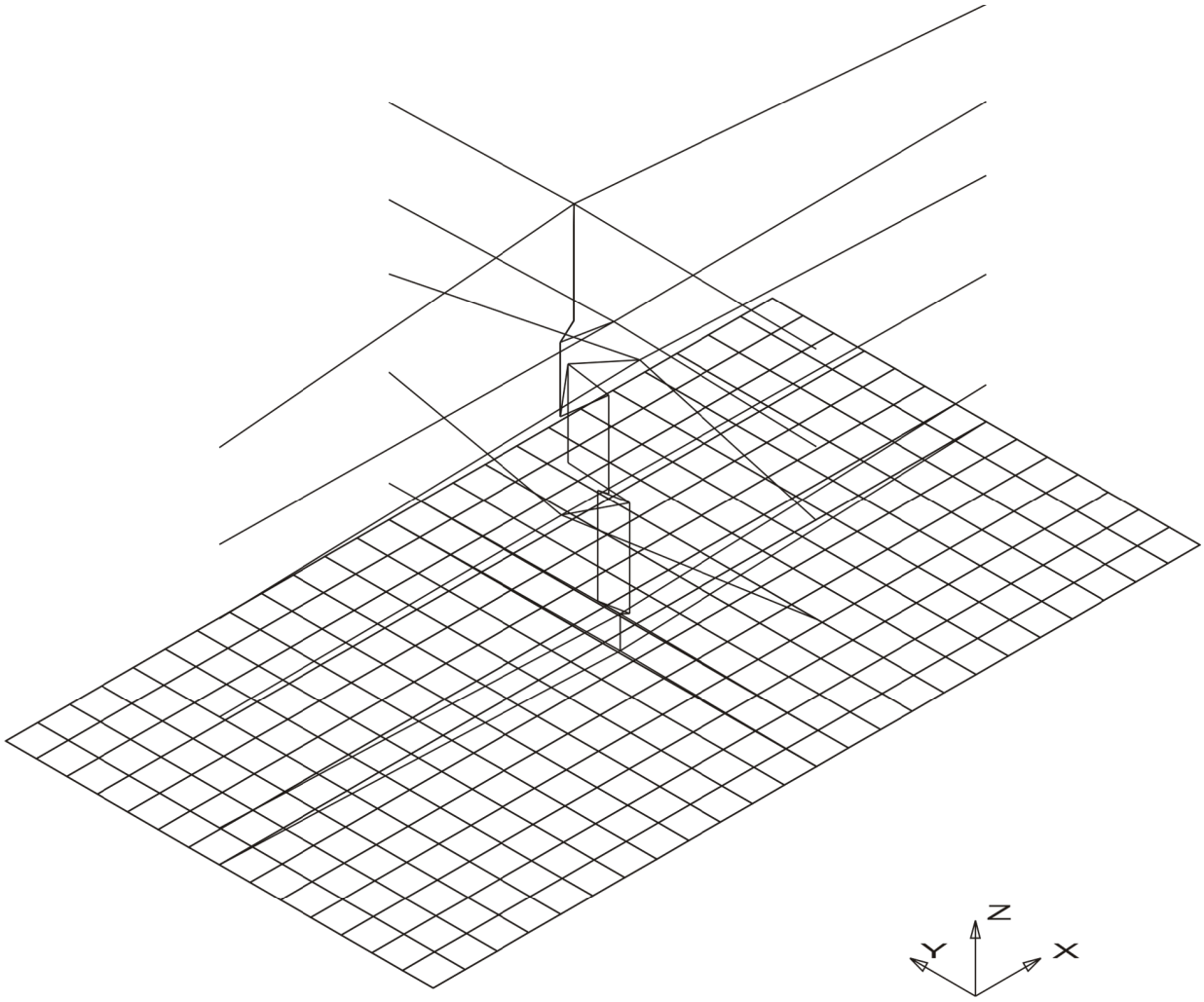


Figure 2.5-3 Isometric View of SASSI Lumped Mass Stick Model of A/B

3.0 VALIDATION OF A/B DYNAMIC MODELS

3.1 1g Static Verification Analysis Results

The mass and stiffness properties of all FE models are compared to ensure the validity of the models. The seismic mass associated with each major floor elevation is calculated for each of the three FE models and then compared with each other in Table 3.1-1 and Table 3.1-2.

ANSYS static analyses of the three different FE models are performed by establishing fixed boundary conditions at the base of the models and applying 1g static load. The results of these 1-g static analyses for deflections at selected nodes are compared with each other in Figures 3.1-1 through 3.1-3 which confirms that the three models are consistent and properly represent the mass and stiffness properties of the A/B.

Table 3.1-1 Mass Distribution of FE Models

Location	Weight (10^3 kips)			(2)/(3) Ratio
	(1)	(2)	(3)	
	Dynamic FE Model (9-ft mesh)	Dynamic FE Model (13-ft mesh)	Detailed FE Model	
Roof	3.99	3.99	3.82	105%
Fourth Floor	16.14	16.14	15.84	102%
Third Floor	30.77	30.72	28.64	107%
Second Floor	38.81	38.81	36.62	106%
Ground Floor	56.61	56.61	55.58	102%
Base Mat	79.99	79.99	78.14	102%

Table 3.1-2 Mass Properties of FE Models

Model	Mass Center Coordinates (ft)			Mass Inertia about Center of Mass (kip-ft^2)		
	Xc	Yc	Zc	IXX	IYY	IZZ
(1) 9-ft_Mesh Dynamic FE Model	5.09	4.48	9.18	2.06E+07	4.50E+07	4.76E+07
(2) 13-ft_Mesh Dynamic FE Model	5.09	4.48	9.17	2.05E+07	4.49E+07	4.75E+07
(3) Detailed Static Model	5.05	4.93	9.18	1.98E+07	4.32E+07	4.55E+07
Ratio (2)/(3)				104%	104%	105%

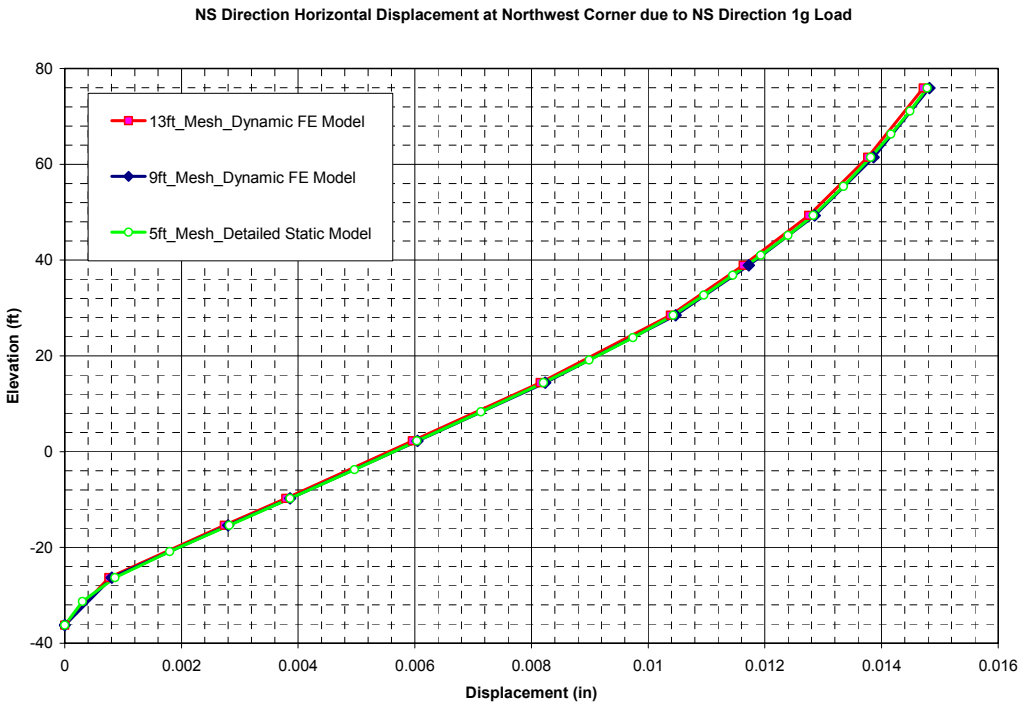


Figure 3.1-1 N-S 1g Static Analysis of FE Models

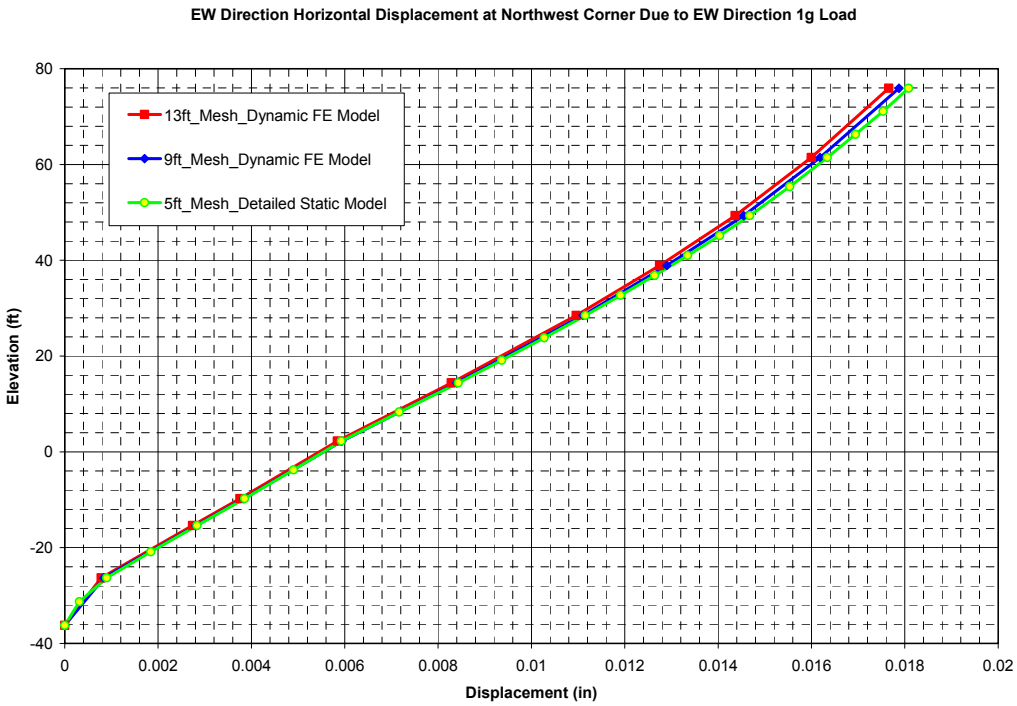


Figure 3.1-2 E-W 1g Static Analysis of FE Models

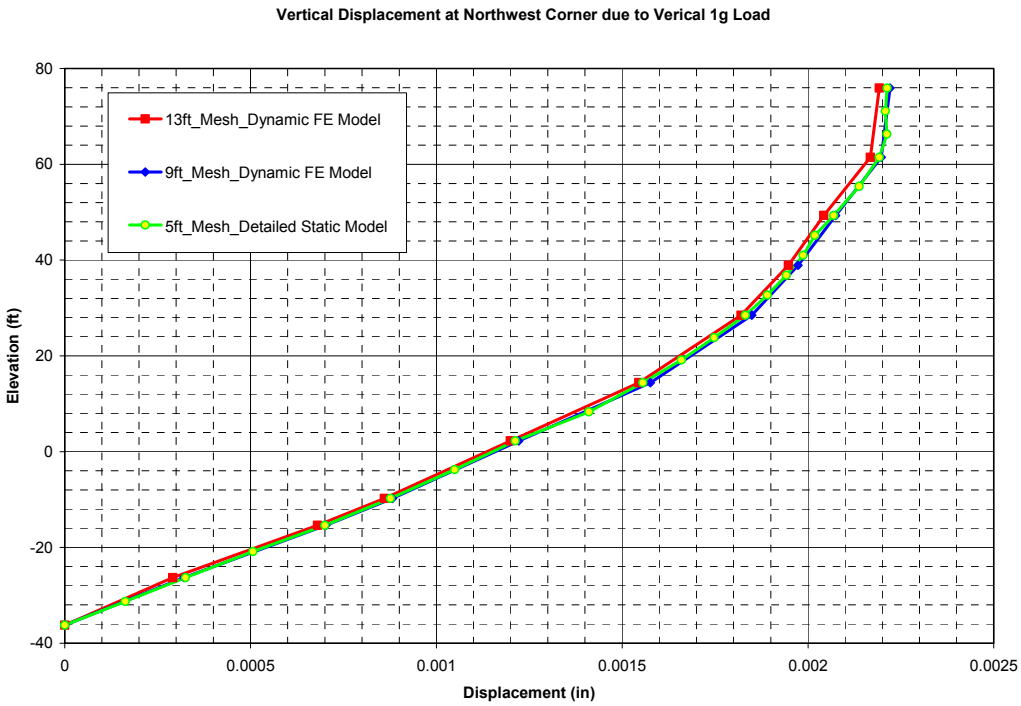


Figure 3.1-3 Vertical 1g Static Analysis of FE Models

3.2 Modal Analysis Results and Mesh Size Verification

Modal analyses of the three different FE models are performed in ANSYS with fixed boundary conditions established at the base of the A/B basemat. Table 3.2-1 summarizes the results of the modal analyses of the three different FE models for the dominant natural frequencies in horizontal N-S and E-W directions. The results of the modal analyses for cumulative mass participation are plotted as function of frequency in Figure 3.2-1, Figure 3.2-2 and Figure 3.2-3 for the N-S, E-W and vertical directions. The conformity of the dominant-mode frequencies obtained from the modal analyses of the three FE models and the cumulative mass fraction plots indicates the models properly capture the dynamic behavior of the A/B and that no further refinement of the mesh is required for the two dynamic FE models.

Table 3.2-1 Frequencies of Dominant Modes (Hz)

		Dynamic FE Model, 13-ft Mesh	Dynamic FE Model, 9-ft Mesh	Detailed FE Model, 5ft Mesh
N-S Direction	Mode 1	8.1	8.0	8.1
	Mode 2	16.7	16.7	16.9
E-W Direction	Mode 1	6.7	6.7	6.7
	Mode 2	12.7	12.7	13.1

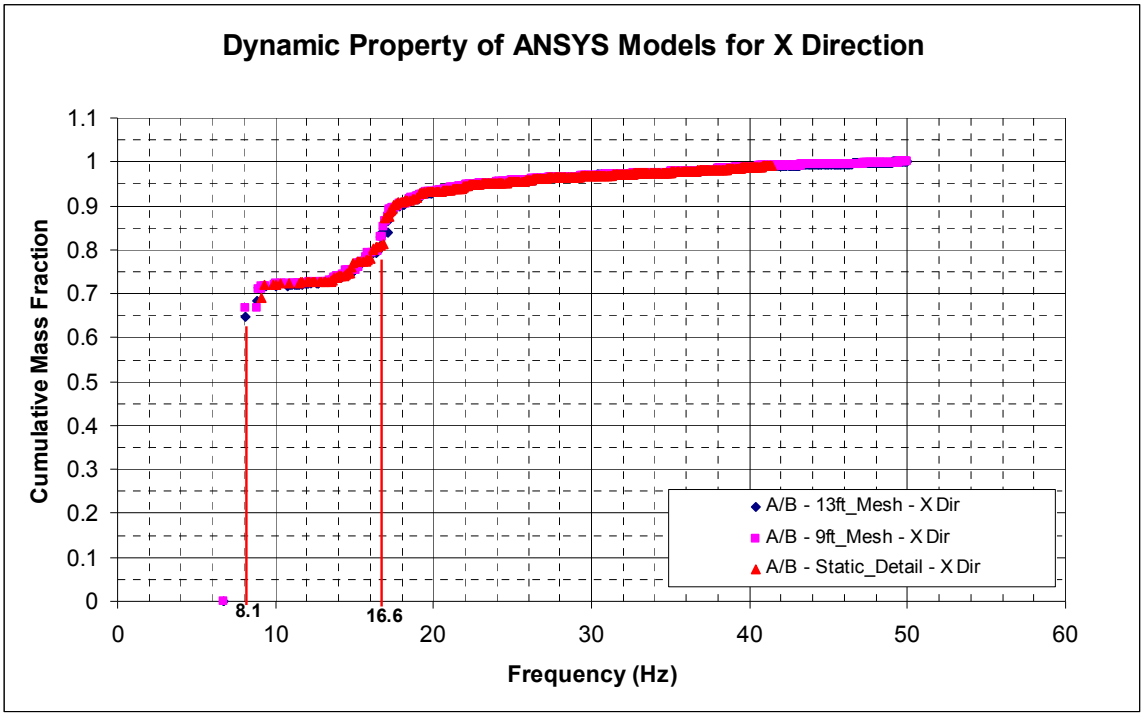


Figure 3.2-1 N-S Dynamic Properties of A/B Models

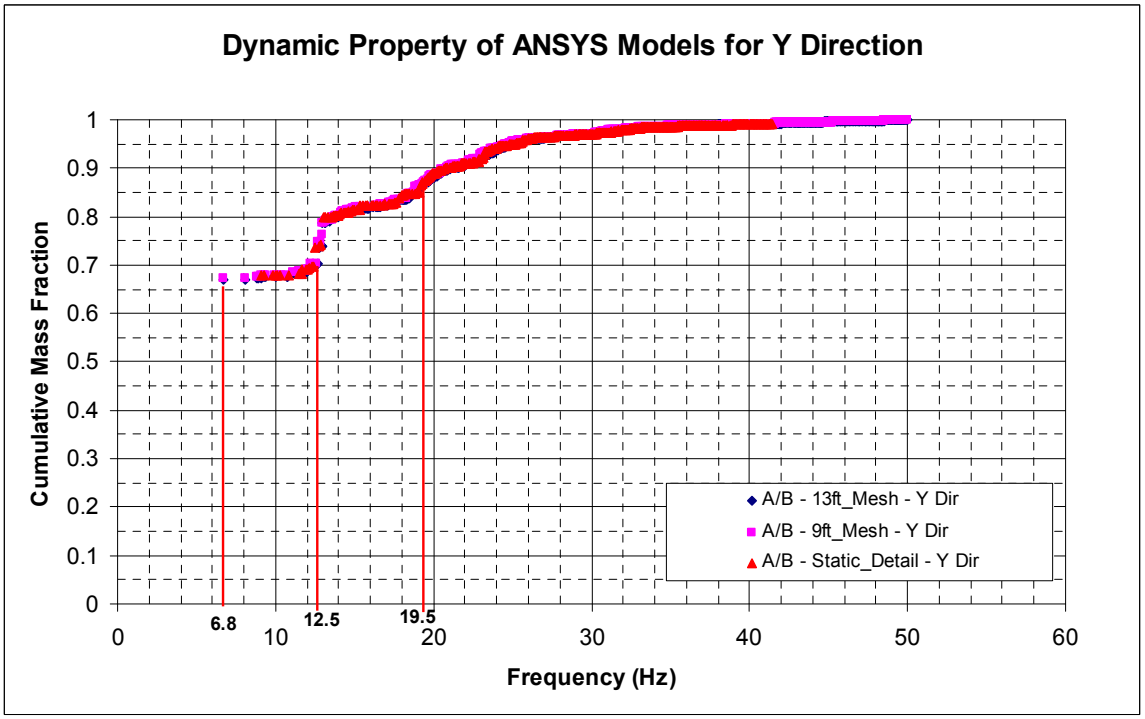


Figure 3.2-2 E-W Dynamic Properties of A/B Models

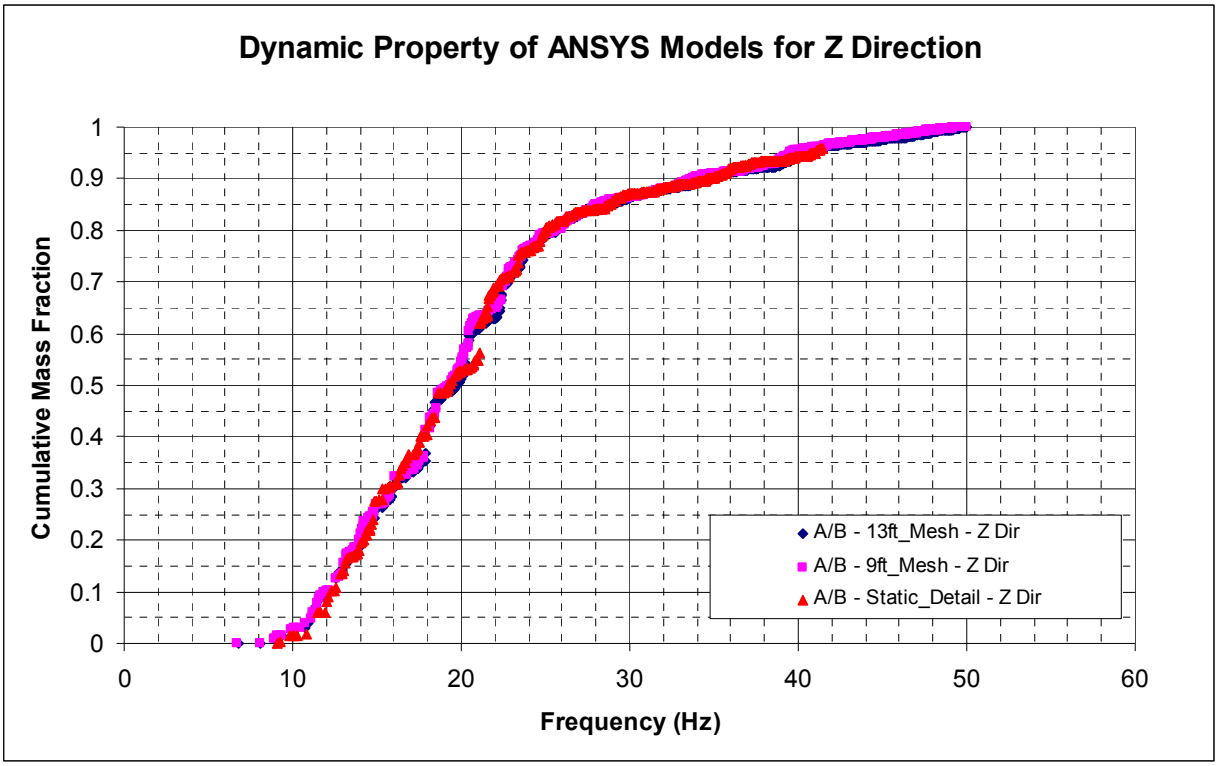


Figure 3.2-3 Vertical Dynamic Properties of A/B Models

3.3 Validation of Model Translation from ANSYS to SASSI

An SSI analysis is performed in ACS SASSI with the dynamic FE model (13-ft mesh) resting on the surface of an elastic half-space with high stiffness that approximates fixed-base conditions. Figure 3.3-1 and Figure 3.3-2 present the results of the validation SASSI analyses for acceleration transfer functions at selected locations. These figures show that the peak amplifications of the transfer functions occur at or close to the values of the dominant frequencies shown in Table 3.3-1 and Figure 3.2-1 and Figure 3.2-2, which indicates that the translation of the A/B dynamic FE model into SASSI format is accurate.

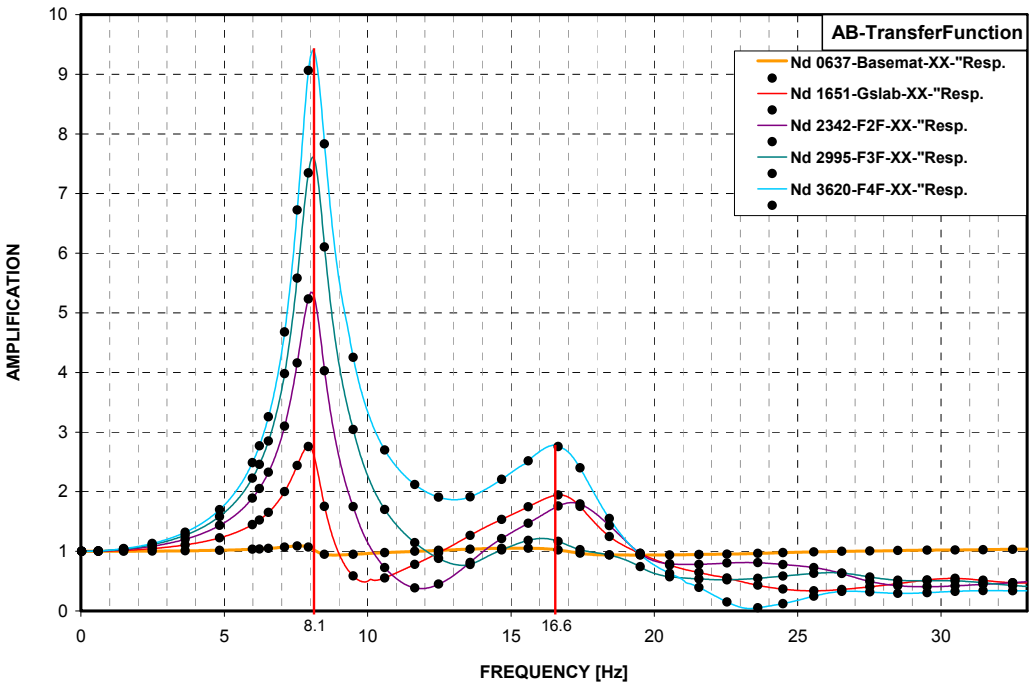


Figure 3.3-1 N-S Transfer Functions, 13-ft Mesh Dynamic FE Model

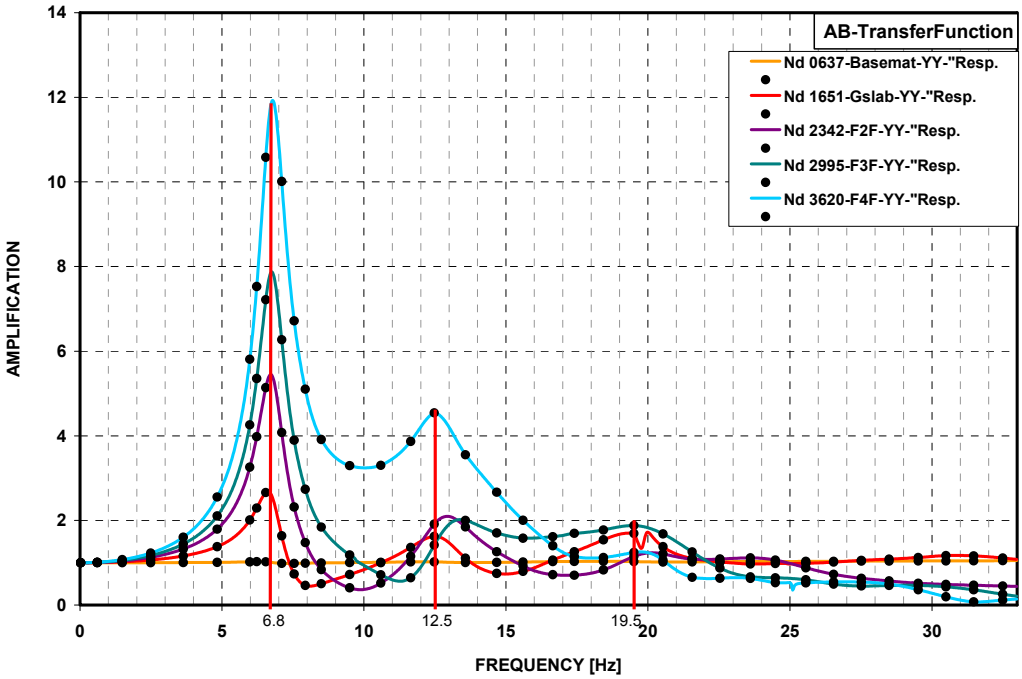


Figure 3.3-2 E-W Transfer Functions, 13-ft Mesh Dynamic FE Mode

3.4 Validation of Lumped Mass Stick Model

In order to verify that the simplified lumped-mass stick model developed as described in Section 2.5 is dynamically equivalent to the dynamic FE model of the A/B, the fixed-base dynamic properties of the lumped-mass stick model are correlated with the fixed-base dynamic properties of the SASSI FE models. The correlation is made by comparing the horizontal (NS and EW) seismic response transfer functions computed from equivalent fixed-base SSI analyses of the lumped-mass stick model and the SASSI FE models resting on the surface of very stiff elastic half-space using SASSI. These transfer functions computed from the lumped-mass stick model at selected locations of A/B are compared with the corresponding transfer functions computed from the dynamic FE model (13-ft mesh). Figure 3.4-1 and Figure 3.4-2, respectively, compare the transfer function amplitudes computed for the horizontal NS and EW seismic responses at the roof elevation (El. 75.9 ft). As indicated from these figures, the correlation between the dynamic properties of the fixed-base lumped-mass stick model and that of the fixed-base FE model are reasonable for the fundamental-mode responses.

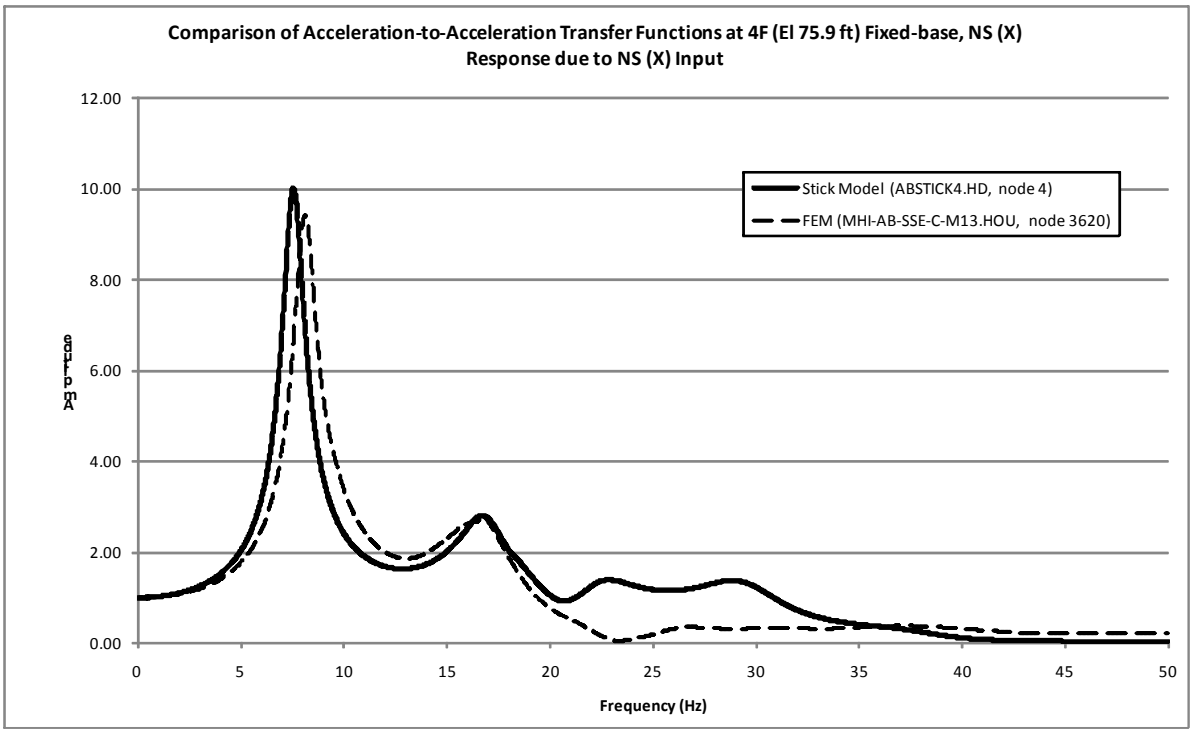


Figure 3.4-1 Transfer Function Amplitudes for NS Response of Roof

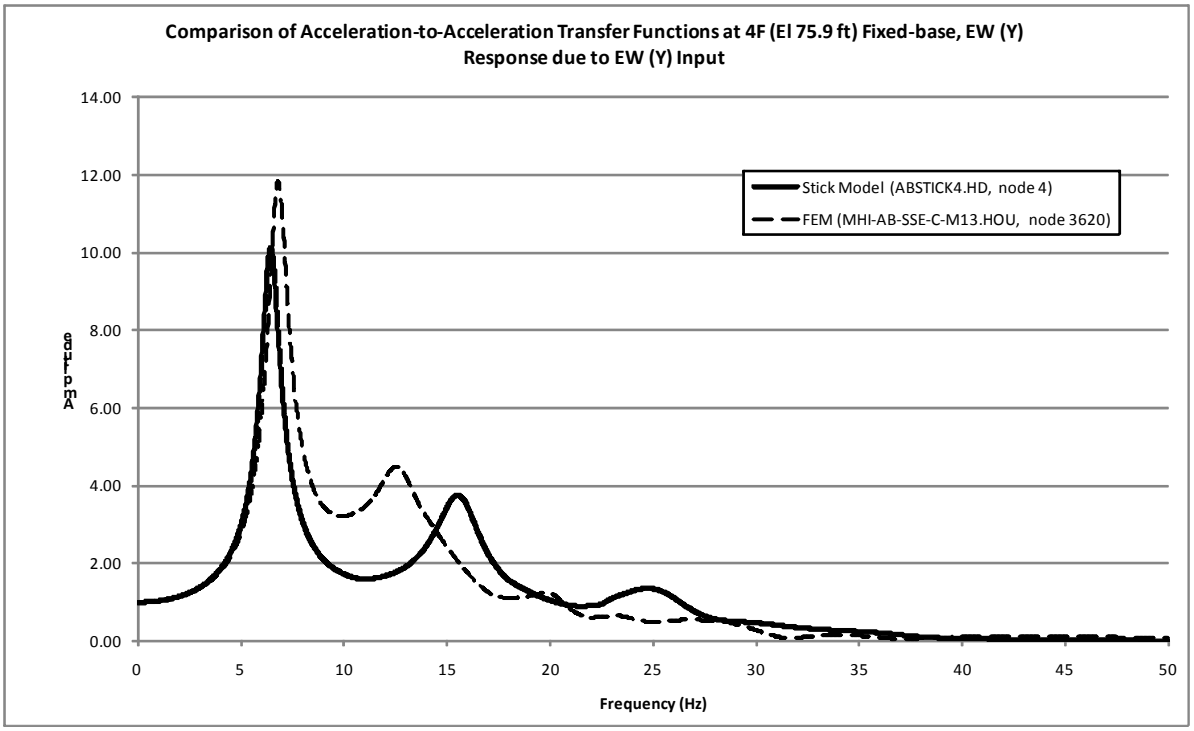


Figure 3.4-2 Transfer Function Amplitudes for EW Response of Roof

4.0 SOIL STRUCTURE INTERACTION ANALYSIS

4.1 Methodology

Seismic SSI analyses of the A/B are performed using SASSI for the eight generic site profiles described in MHI TR MUAP-10006 (Reference 7.2) that have been considered for the standard plant design. Consistent with the site-independent SSI analyses performed for the R/B Complex and PS/B, the SSI analyses of the A/B consider the A/B foundation as resting on the surface of the generic site profiles. Thus, the SSI system of the A/B structure is modeled in SASSI as a surface-supported structure and SSI analyses are carried for the eight generic site profiles.

To facilitate the SSI analysis, SASSI analyses are carried out in two stages: first and second stage. The first-stage SSI analyses are carried out using the simplified lumped-mass stick model supported on the surface of the eight generic site profiles considered, namely, (1) 270(m/s)-200 (ft), (2) 270-500, (3) 560-100, (4) 560-200, (5) 560-500, (6) 900-100, (7) 900-200, and (8) 2032-100. From these analyses, the critical maximum seismic response parameters, such as the maximum absolute accelerations, maximum displacements relative to structural base, maximum global structural response shears and moments, and in-structure response spectra at the top of basemat are computed for the SSI analyses of the stick model. These response results provide a basis for identifying a critical subset of the generic site profiles that control the maximum seismic response parameters. The in-structure response spectra (ISRS) computed at the top of the basemat for all eight generic site profiles provide the basis for development of the seismic acceleration input spectra for the response spectrum analysis of the detailed FE model described in Section 5.2.

After the critical subset of the eight generic site profiles is identified, the second-stage SSI analyses are performed using SASSI for the FE dynamic models of the A/B structure resting on the surface of the identified critical generic site profiles.

Table 4.2-1 provides a summary of the dynamic models, site profiles, number of frequencies of analyses and cut-off frequency of analyses used for the different SSI analyses presented in this report. The horizontal size of the FE mesh of the basemat is also presented in the table together with the maximum frequency of the waves that can be transmitted through the soil-foundation interface based on the criterion that the basemat FE size is not more than 20% of the minimum wave length.

4.2 Results of Lumped Mass Stick Model SSI Analyses

The SASSI model used in the first-stage SSI analyses of the lumped-mass stick model is shown in Figure 2.5.3. In the model, the stick model is rigidly connected to the basemat modeled as flat shell finite elements. The base of the stick model where it connects to the FE model of the basemat is linked to the center of each perimeter wall that is structurally connected to the basemat. To obtain seismic response values at the extreme edge locations of each floor or roof, massless rigid arms modeled using massless rigid beam elements are used to connect the nodes at the extreme edge locations to the CM node of each floor or roof. The CSDRS-compatible acceleration time-histories prescribed at the surface of the generic site profiles considered are used as the seismic input. SASSI analyses are performed with each individual direction of seismic input separately and the 3-D seismic response of the stick model are calculated. Co-directional maximum seismic responses generated from the seismic inputs in the three directions are combined on time-history square-root-of-the-sum-of-squares (SRSS) basis.

The results obtained from the first-stage SASSI analyses of the lumped-mass stick model are summarized below.

4.2.1 Maximum Forces and Moments

The combined maximum seismic response axial, NS and EW shear forces and the maximum torsional and bending moments about the NS and EW axes obtained from SRSS combinations of the maximum seismic responses generated from the three individual directions (horizontal NS and EW and vertical) of seismic input for all eight generic site profile cases considered are shown in Figures 4.2-1 through 4.2-6.

From the results shown in these figures, one can identify that the maximum global structure seismic response forces and moments obtained from the SSI analyses of the eight generic site profiles are dominated (controlled) by the site profiles 900-100, 900-200, and 2032-100.

4.2.2 Maximum Relative Displacements

Figure 4.2-7 presents the combined maximum NS, EW and vertical displacements of the A/B structure relative to the bottom center of the basemat. The maximum values presented in Figure 4.2-7are envelopes of the maximum response values obtained at the center of mass and four extreme edge nodes on each floor elevation. The vertical displacements at the basemat are not zero because they include the envelope of the edge nodes of the basemat. At the edge nodes, there are vertical displacements caused by rocking of the basemat due to horizontal input. As indicated in this Figure 4.2-7, the maximum relative displacements of the structure are controlled by the softest generic site profiles, namely, 270-200 and 270-500.

4.2.3 Maximum Absolute Accelerations

The combined maximum seismic response absolute accelerations in the horizontal NS and EW and vertical directions obtained are summarized in Figure 4.2-8. Similar to the maximum relative displacements presented above, the maximum absolute acceleration values presented in Figure 4.2-8 are envelopes of the maximum response values obtained at the center of mass and four extreme edge nodes on each floor elevations. The results shown in Figure 4.2-8 indicate that the maximum acceleration response values are controlled by the generic site profiles 900-100 and 2032-100.

4.2.4 Basement In-Structure Response Spectra

In-structure (acceleration) response spectra (ISRS) are computed for the response motions at the basemat center and four extreme-edge nodes. Figure 4.2-9, Figure 4.2-10, and Figure 4.2-11, respectively, show the 7%-damped horizontal NS and EW, and vertical ISRS computed that are envelopes of responses at the five nodes on the basemat for all eight generic site profile cases.

4.2.5 Seismic Horizontal Sliding Shear and Vertical Force Demands

The combined maximum seismic horizontal NS and EW sliding shear forces and the vertical forces computed at the bottom of the basemat for all eight generic site profile cases are summarized in Table 4.2-2. In this table, the time instances at which the maximum forces occur are also identified.

Table 4.2-1 Matrix of SSI Analysis of A/B

Structural Model	Basemat FE Mesh Size (ft)	Generic Soil Profile	Max. Wave Passage Freq. (Hz)	Total Number of Freq. of Analyses	Cut-off Freq. of Analyses (Hz)
Lumped Mass Stick Model	10.0	270-200	26.0	67	50
	10.0	270-500	24.8	69	50
	10.0	560-100	31.8	66	50
	10.0	560-200	31.0	69	50
	10.0	560-500	34.0	68	50
	10.0	900-100	68.1	71	50
	10.0	900-200	64.7	71	50
	10.0	2032-100	142.5	70	50
Dynamic FE Model	8.92 (max)	270-500	27.9	45	50
	13.17 (max)	900-100	51.7	45	50
	13.17 (max)	900-200	49.2	45	50
	13.17 (max)	2032-100	108.2	45	50

Table 4.2-2 A/B Stick Model – Maximum Seismic Sliding Shear Demand (kips)

Generic Site Profile	Direction		
	X (NS) Sliding Shear (time of maximum in seconds)	Y (EW) Sliding Shear (time of maximum in seconds)	Z (Vertical) Base Force (time of maximum in seconds)
270-200	93,200 (8.390)	96,700 (7.865)	82,200 (9.035)
270-500	87,300 (8.395)	93,500 (7.865)	76,000 (7.850)
560-100	102,600 (9.280)	100,100 (8.365)	94,300 (8.730)
560-200	88,900 (10.095)	98,800 (8.545)	94,300 (7.845)
560-500	90,800 (10.085)	90,200 (7.850)	91,900 (7.840)
900-100	122,300 (10.765)	112,200 (7.830)	114,500 (8.700)
900-200	118,800 (10.770)	115,700 (7.840)	92,800 (9.015)
2032-100	126,300 (7.340)	100,600 (8.310)	91,600 (8.640)
Envelope Value Site Profile Case	126,300 2032-100	115,700 900-200	114,500 900-100

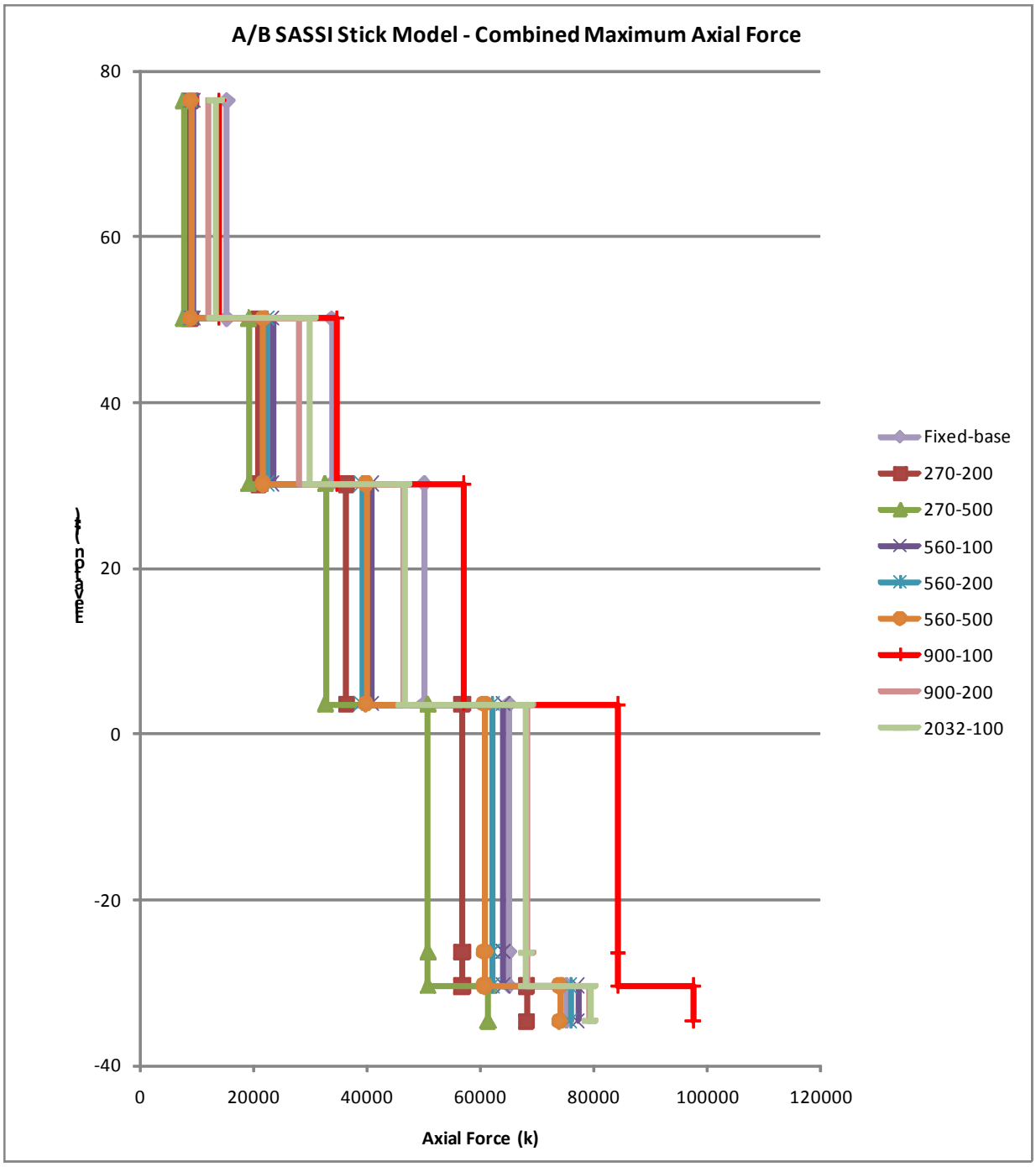


Figure 4.2-1 Stick Model – Max. Axial Force

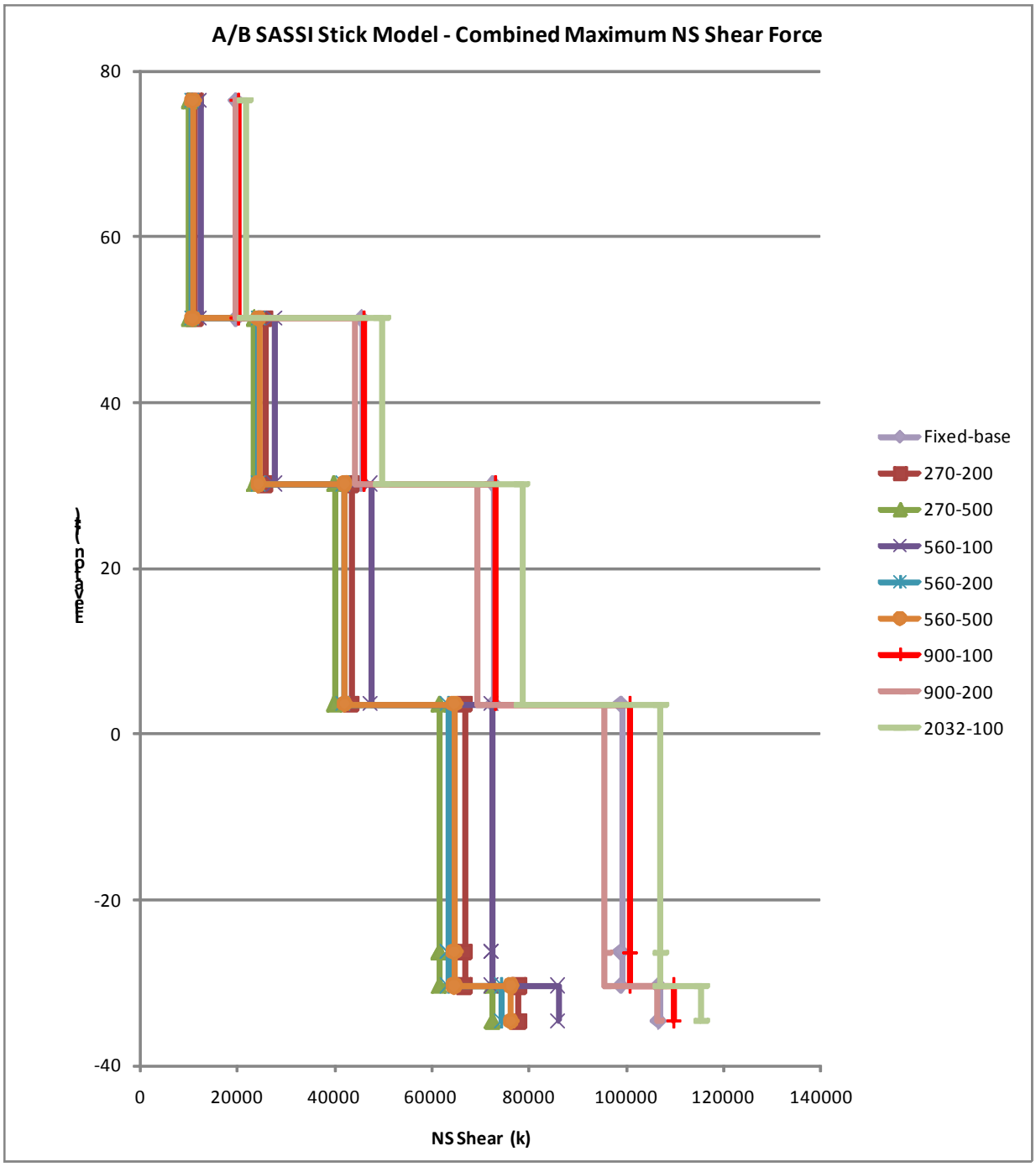


Figure 4.2-2 Stick Model – Max. N-S Shear Force

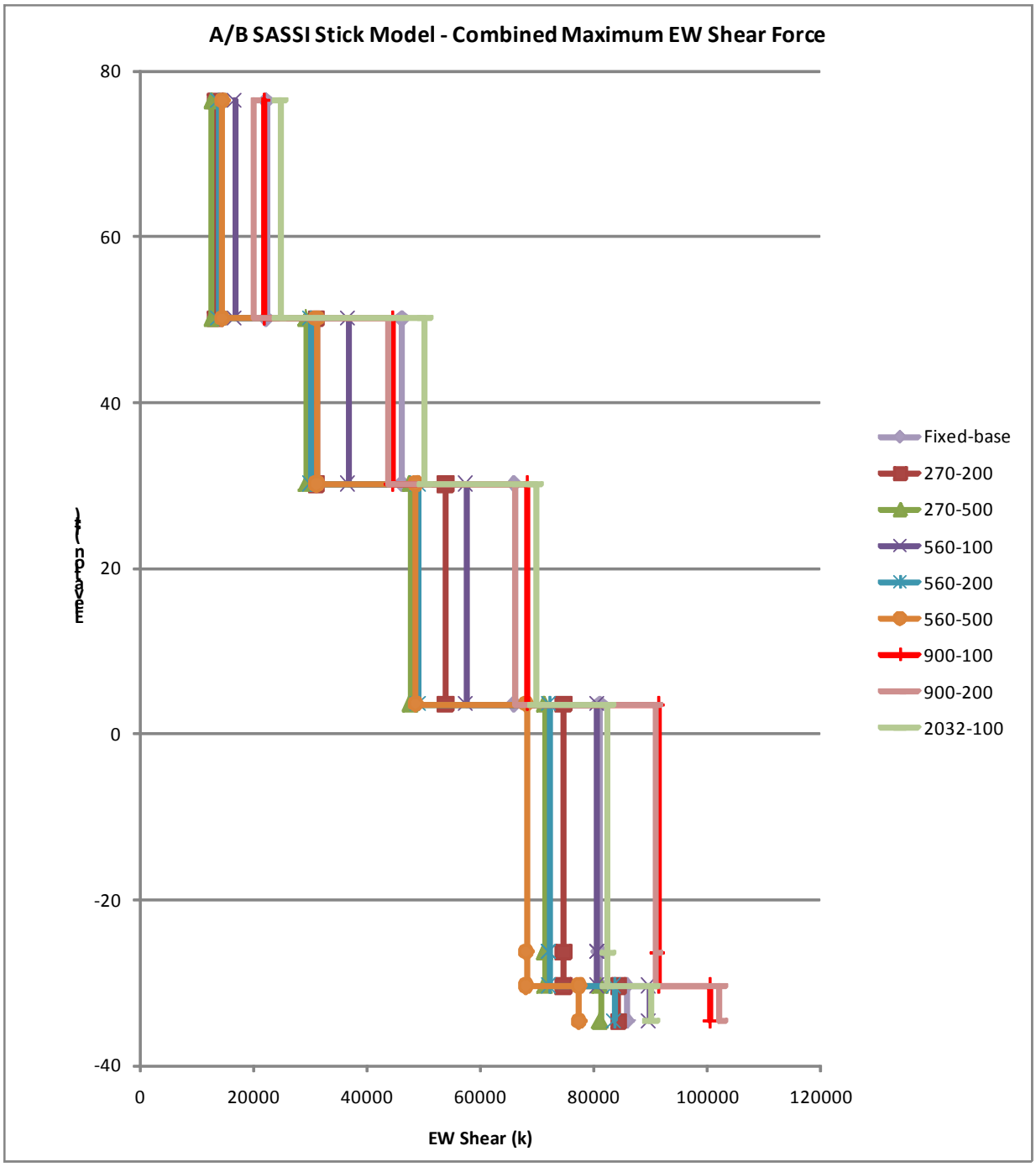


Figure 4.2-3 Stick Model – Max. E-W Shear Force

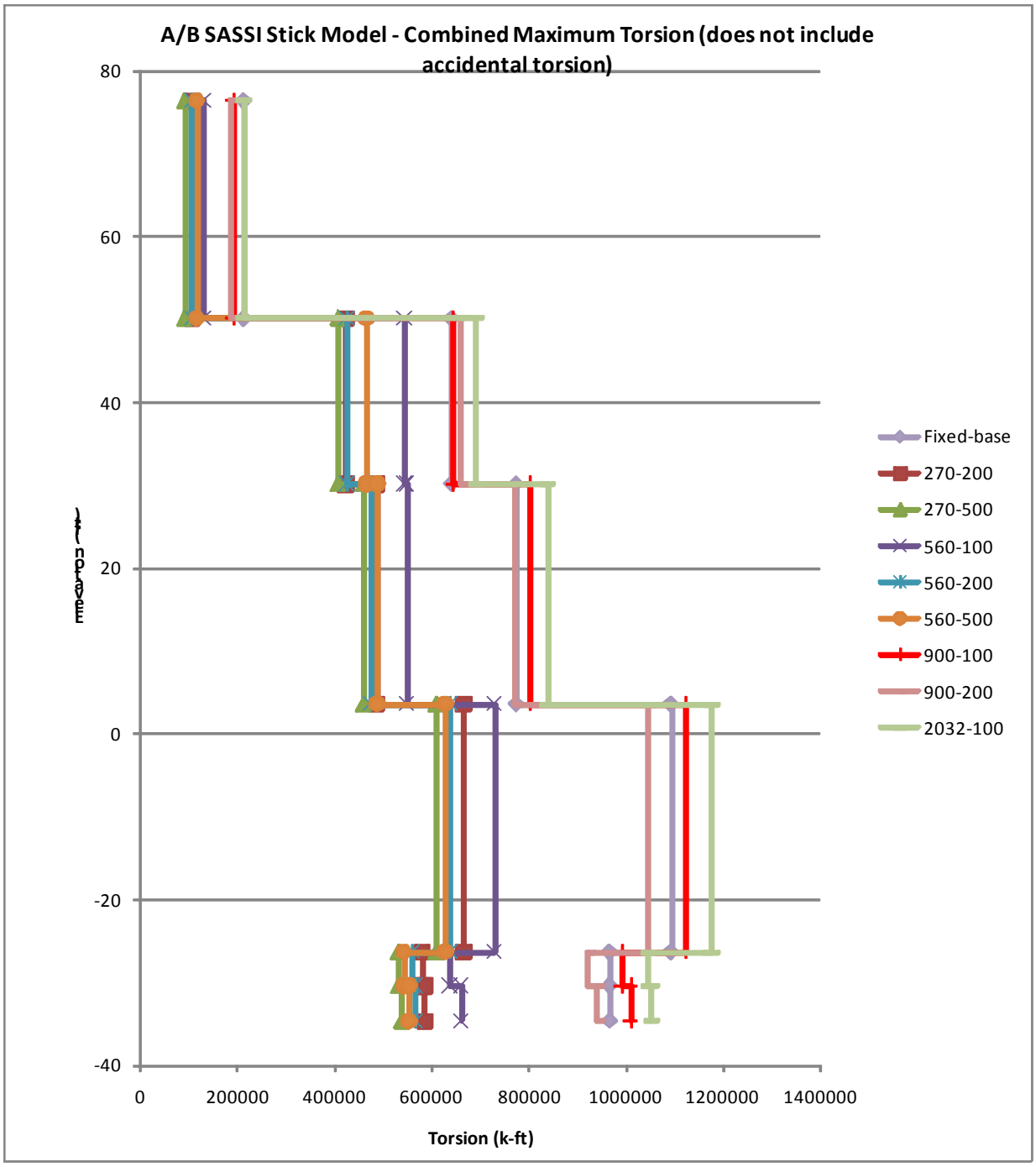


Figure 4.2-4 Stick Model – Max. Torsion Moment

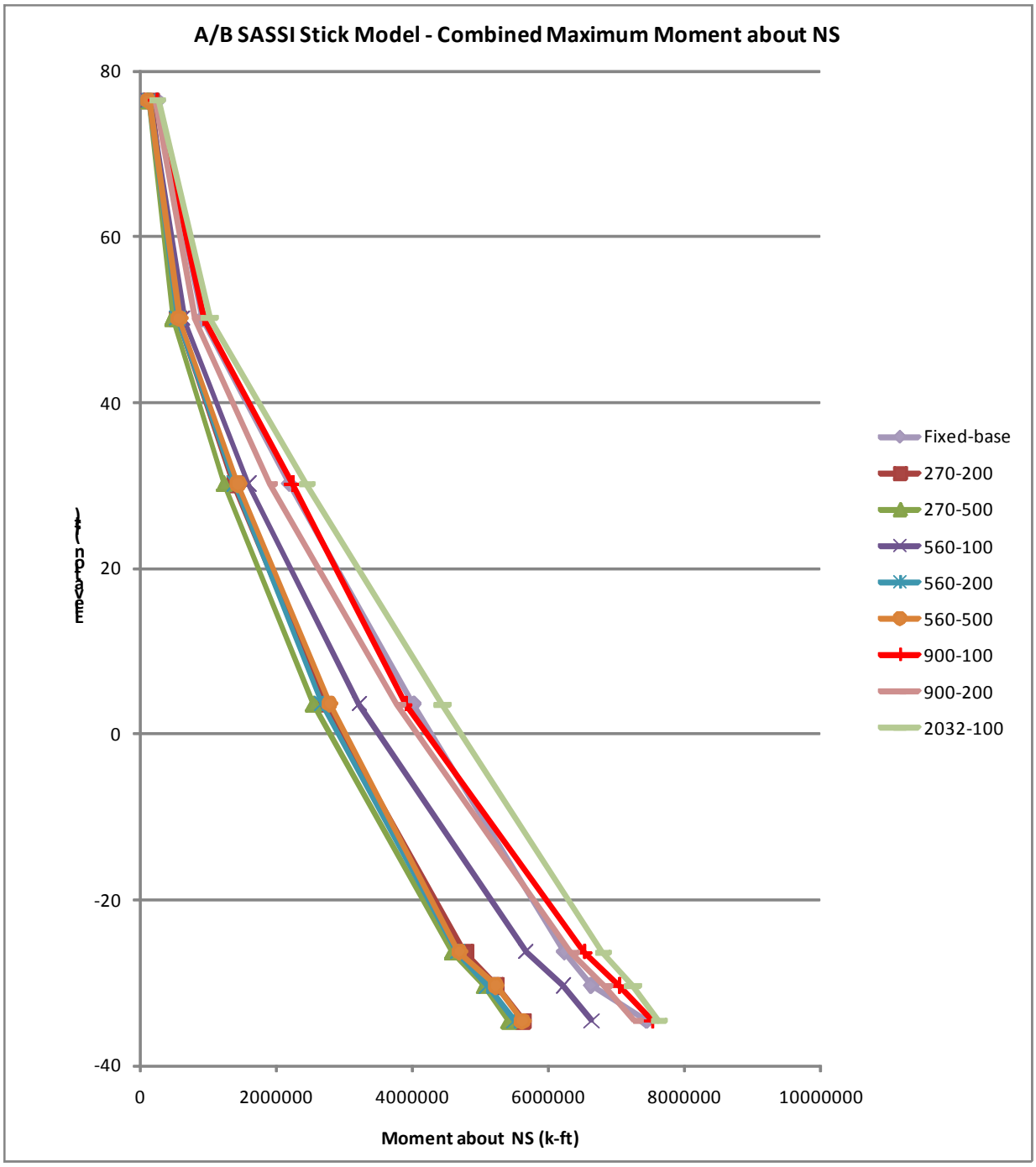


Figure 4.2-5 Stick Model – Max. Moment about N-S axis

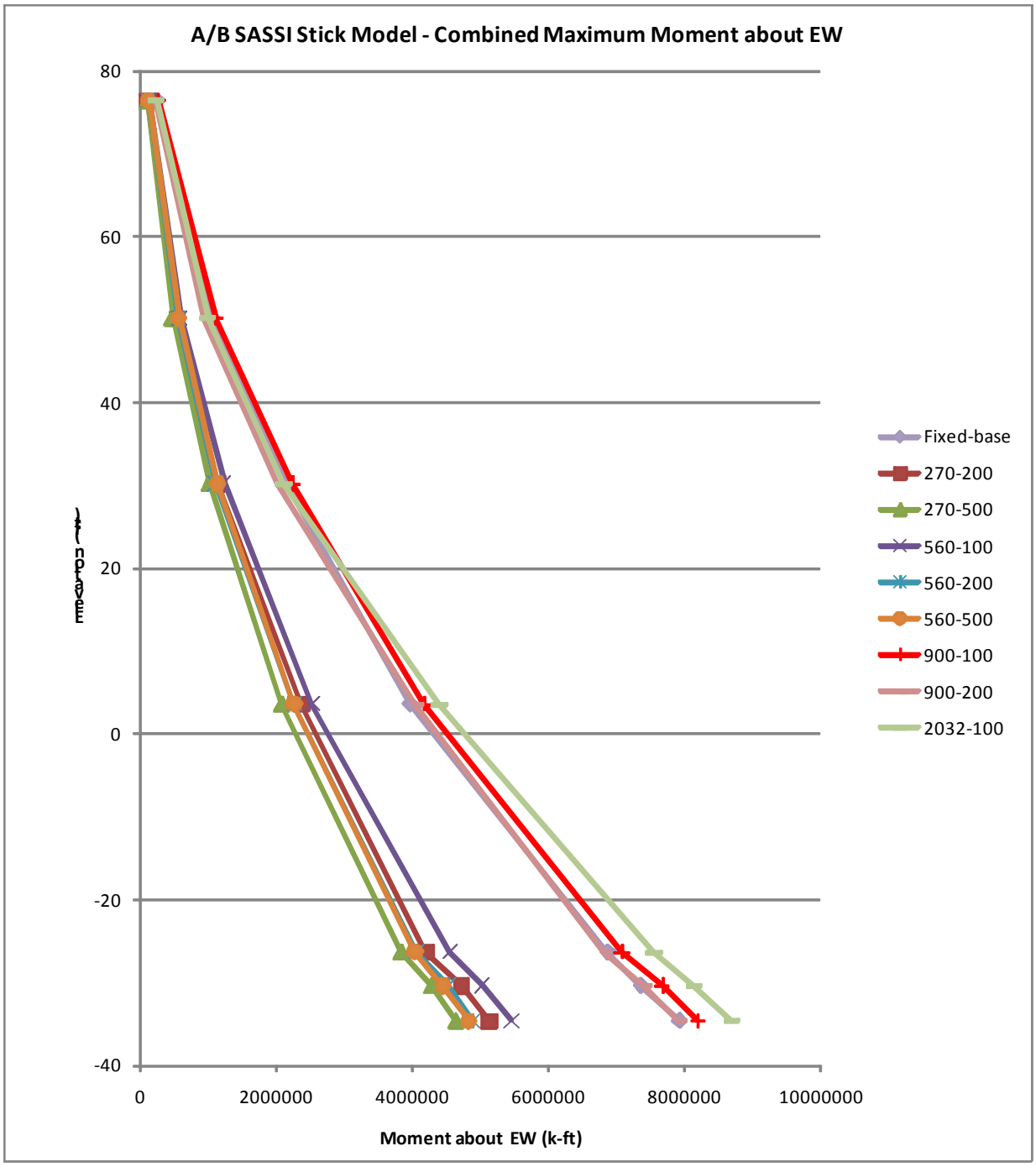


Figure 4.2-6 Stick Model – Max. Moment about E-W axis

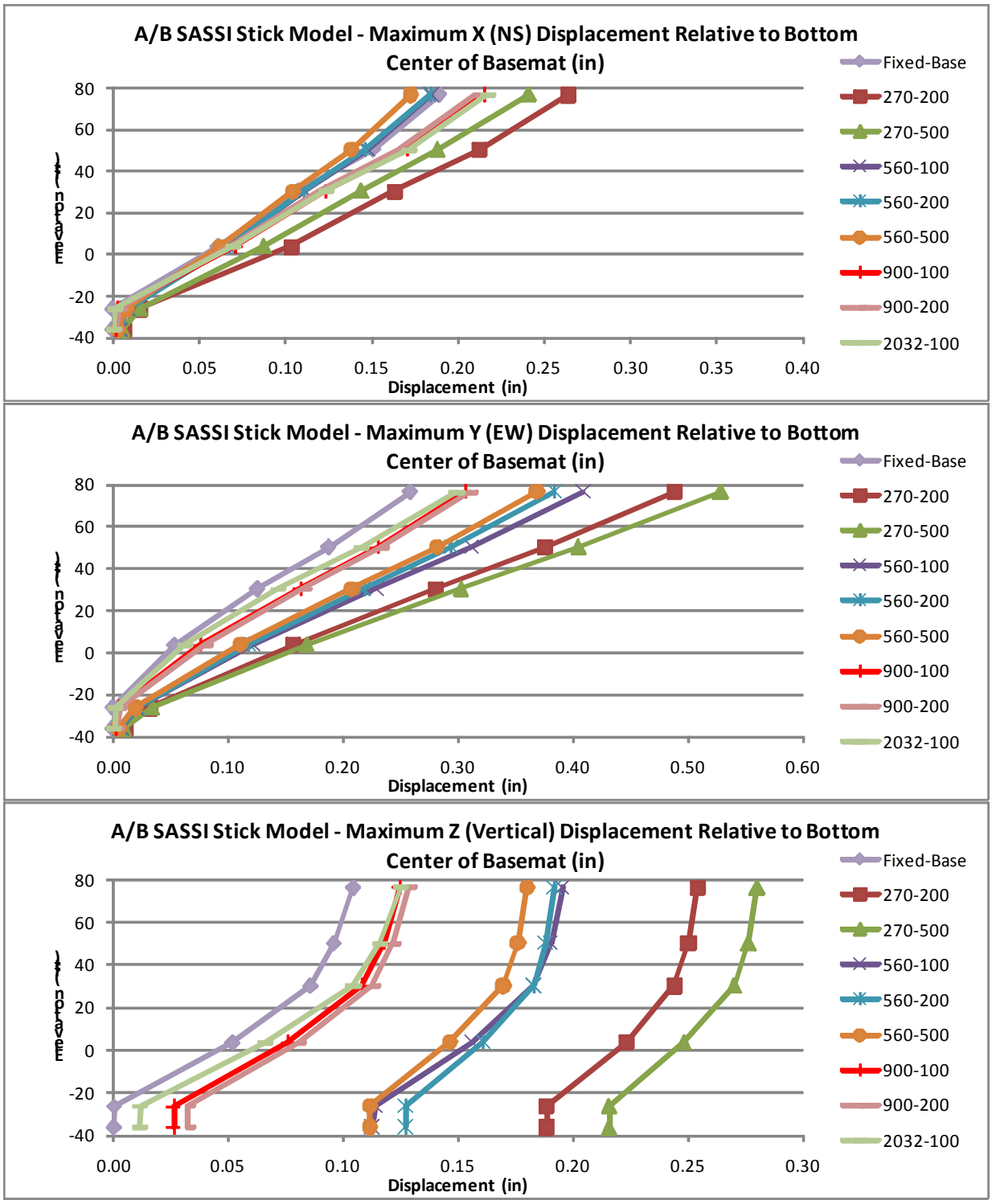


Figure 4.2-7 Stick Model – Max. Displacements Relative to Basemat Bottom Center

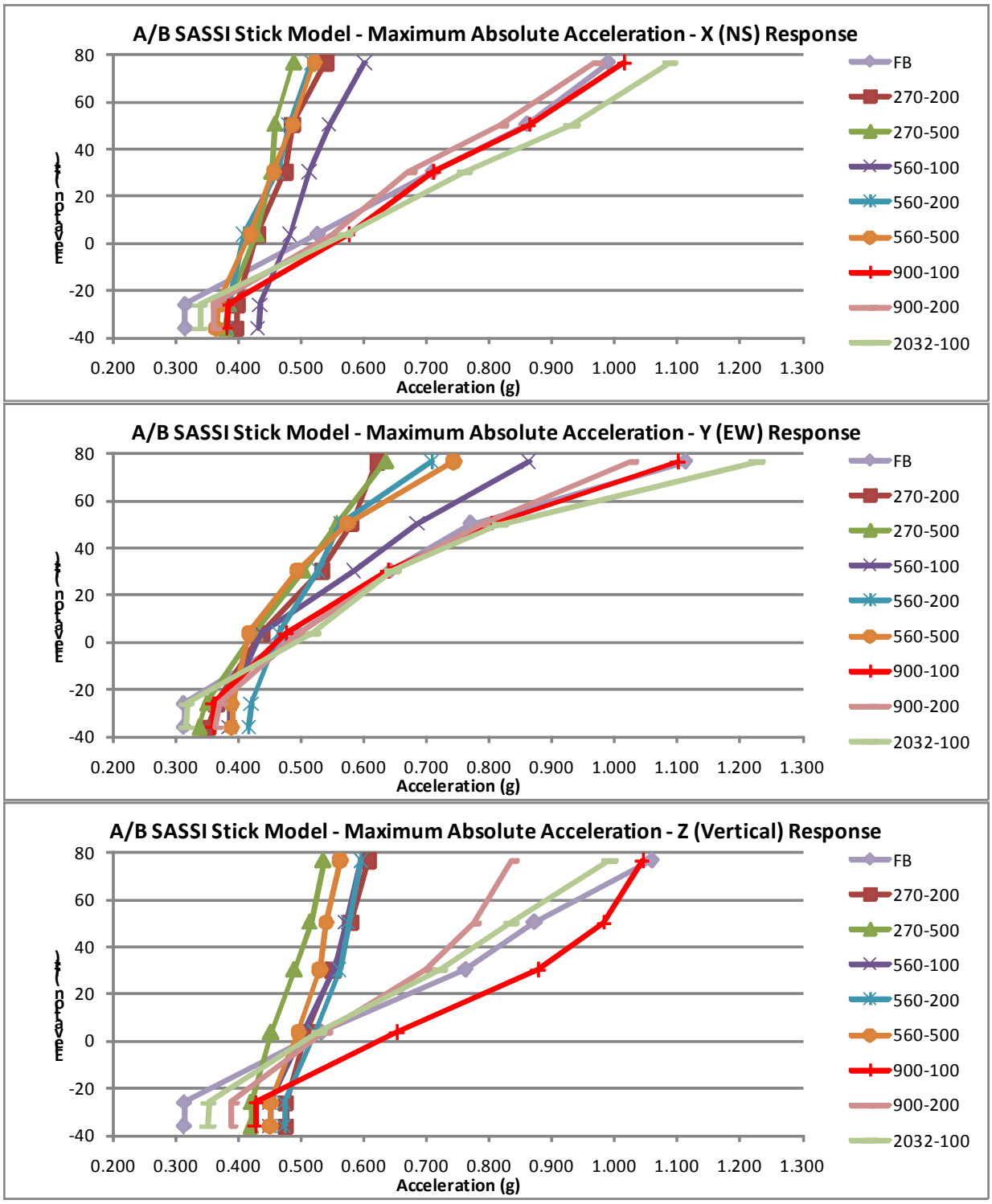


Figure 4.2-8 Stick Model – Max. Absolute Accelerations

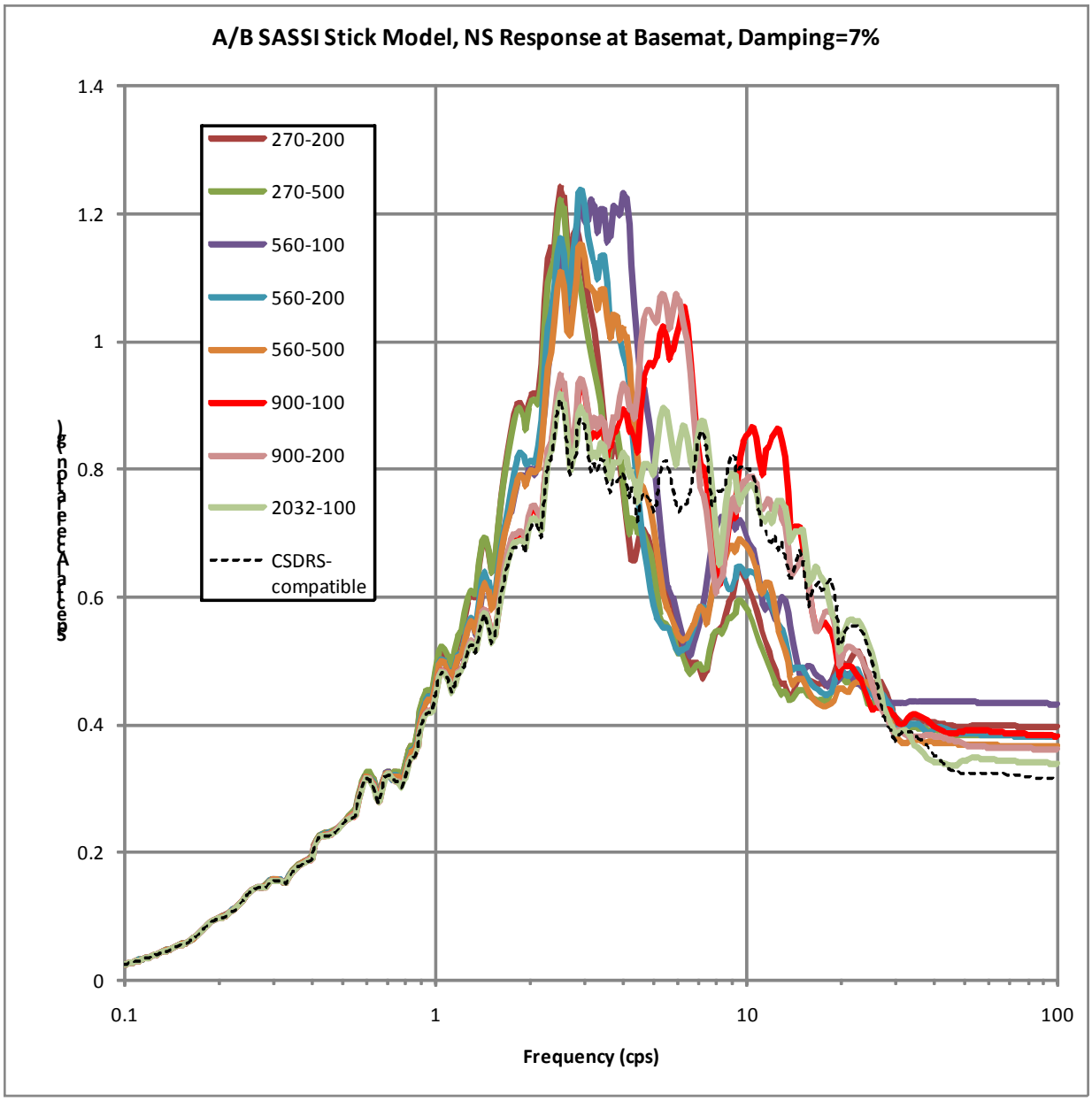


Figure 4.2-9 7%-Damped ISRS at Basemat – N-S Direction

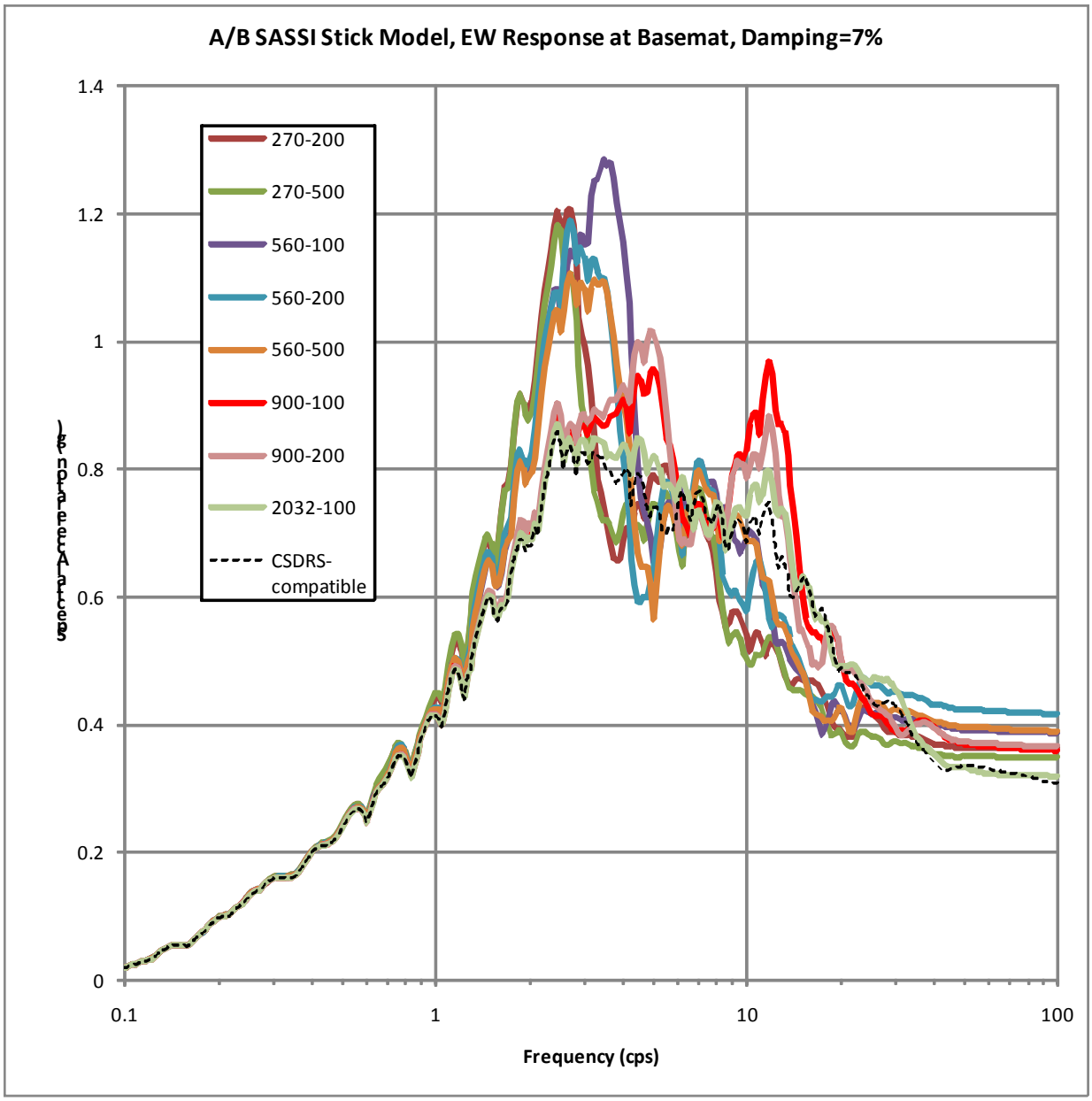


Figure 4.2-10 7%-Damped ISRS at Basemat – E-W Direction

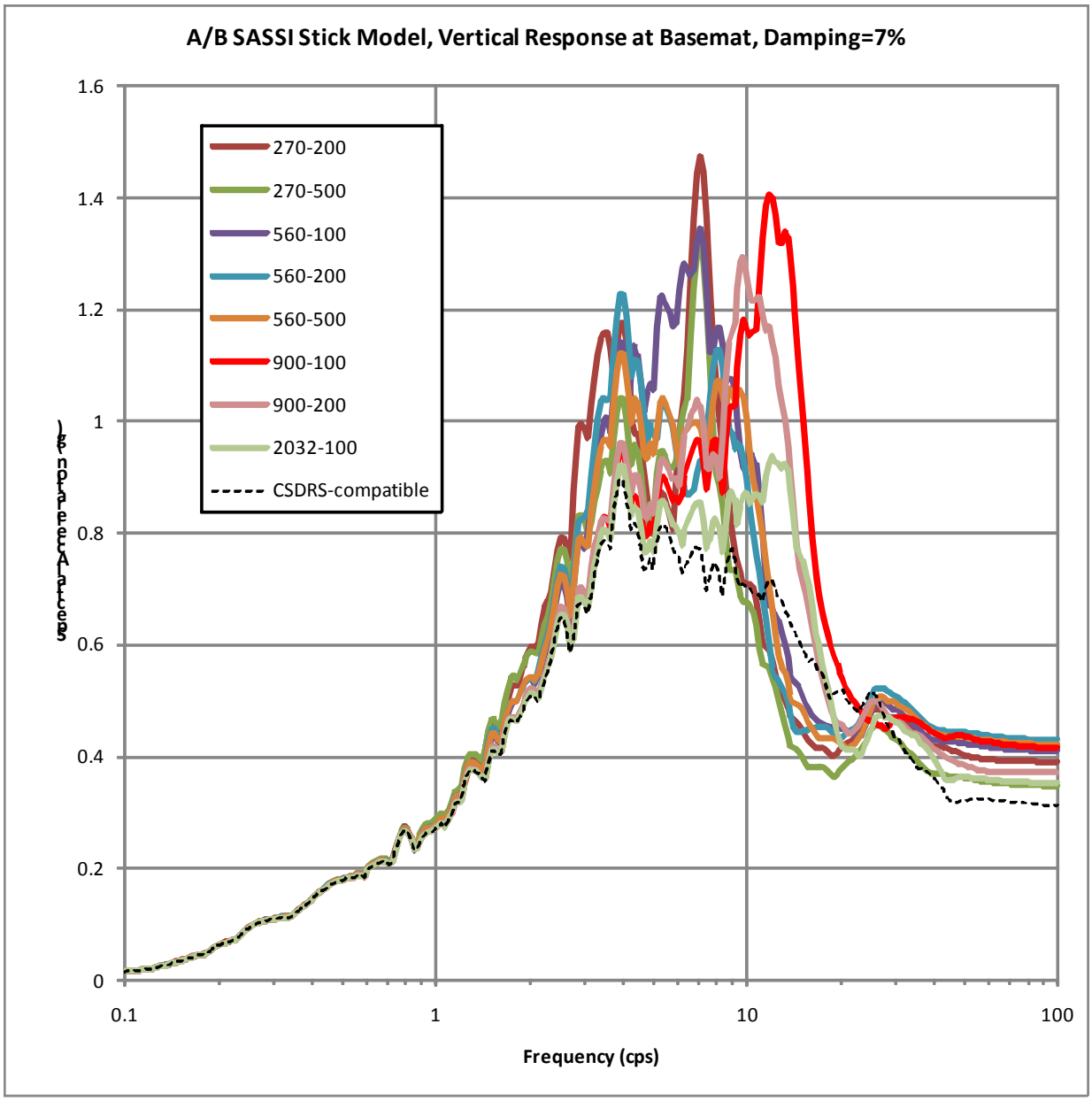


Figure 4.2-11 7%-Damped ISRS at Basemat – Vertical Direction

4.3 Results of Dynamic FE Model SSI Analyses

From the critical maximum seismic response results obtained from the first-stage SSI analyses performed using the lumped-mass beam-stick model presented above, up to four critical generic site profiles that control the critical maximum seismic response values are identified. These four site profiles identified are (a) 270-500, (b) 900-100, (c) 900-200, and (d) 2032-100.

The site profiles 900-100, 900-200, and 2032-100 are selected based upon the maximum forces and moments (Figures 4.2-1 through 4.2-6) and maximum absolute accelerations (Figure 4.2-8). The maximum displacements relative to the basemat bottom center (Figure 4.2-7) show that site profile 270-200 controls in the North-South direction and site profile 270-500 controls in the East-West and vertical directions. Since the displacements of the A/B will ultimately be used to evaluate the seismic gap between the A/B and the R/B and the A/B and the Ac/B, the 270-500 site profile was chosen for the second-stage analysis because the R/B is on the East side of the A/B and the Ac/B is on the West side of the A/B. The results of the SSI analyses also indicate that the displacements are largest in the East-West direction.

The second-stage SSI analyses are performed using SASSI with the dynamic FE models (9-ft mesh and 13-ft mesh for the basemat) of the A/B structure supported on the surface of the four critical generic site profiles identified above as the SSI models. These SASSI models are shown in Figure 2.3-1 through Figure 2.3-3 for the 9-ft-mesh model, which is used for the critical 270-500 site profile case, and in Figure 2.3-4 through Figure 2.3-12 for the 13-ft-mesh model, which is used for the critical 900-100, 900-200, and 2032-100 site profile cases.

Using these refined SASSI FE models, SSI responses in terms of the maximum seismic response displacements relative to the structural base (at the bottom center of the basemat) and relative to the free-field ground surface where the seismic input motion is prescribed, are extracted. Figure 4.3-1 presents the results of maximum seismic displacements relative to the free-field ground motion and Figure 4.3-2 presents the results of the maximum seismic response displacements relative to the structural base. These results are obtained from the SASSI analyses performed using the dynamic FE models of A/B for the four critical generic site profiles identified.

Comparison of the relative displacements with respect to the structural base shown in Figure 4.3-2 obtained from the SASSI analyses of the FE models for the four controlling site profile cases with the corresponding relative displacements shown in Figure 4.2-7 obtained from the SASSI analyses of the lumped-mass stick model shows that the maximum displacement response values obtained from the FE models are quite consistent with, but slightly higher than, the corresponding results obtained from the lumped-mass stick model. As with the stick model results, the vertical displacements at the base have a large rocking component (vertical displacement at the basemat edge due to horizontal input). Figure 4.3-1 shows that the maximum displacement relative to the free-field ground surface is 0.92 inches in the East-West direction.

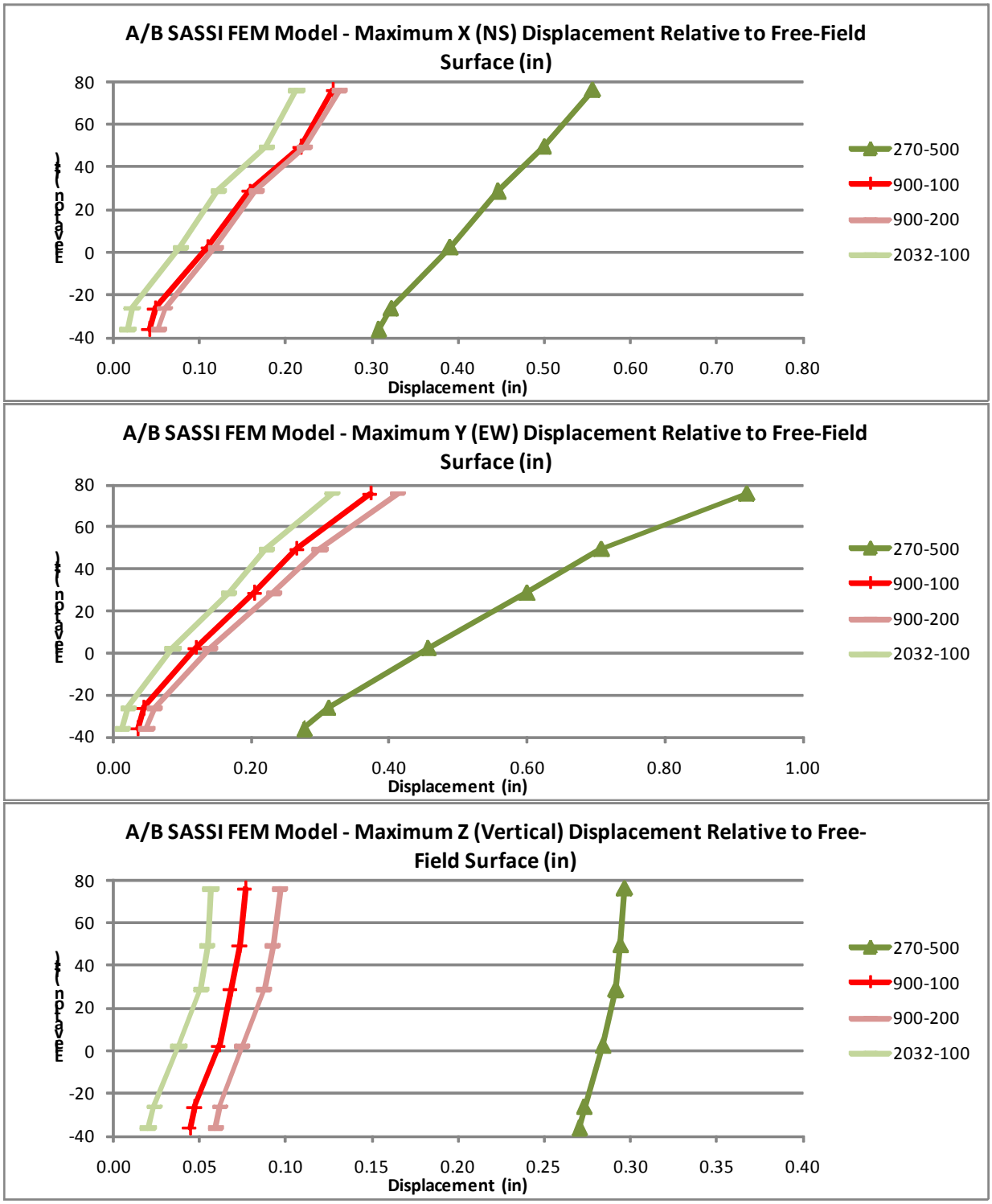


Figure 4.3-1 Dynamic FE Model – Max. Displacements Relative to Free-Field Surface

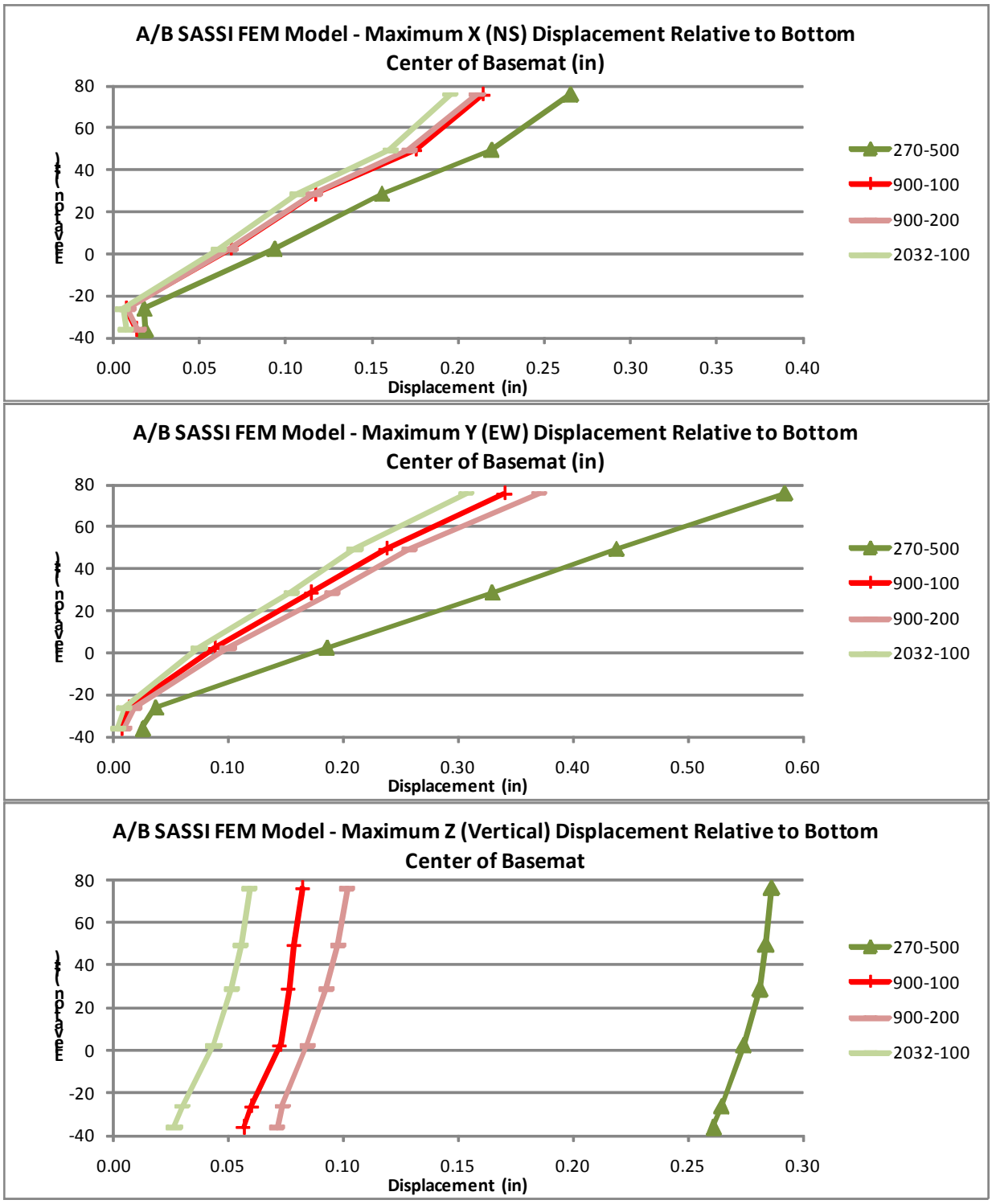


Figure 4.3-2 Dynamic FE Model – Max. Displacements Relative to Basemat Bottom Center

5.0 STATIC AND DYNAMIC ANALYSIS OF DETAILED FE STRUCTURAL MODEL OF A/B

A structural integrity evaluation is performed of the A/B based on structural demands calculated from ANSYS static and response spectrum analyses of the detailed FE model. The structural demands due to applicable static and seismic design loads and design load combinations on main representative shear walls and slabs of the building are checked against design allowables in order to evaluate the overall structural integrity of the A/B.

5.1 Loads and Load Combinations for Seismic Structural Integrity Evaluation of A/B

The structural integrity evaluation considers loads and load combinations associated with an SSE seismic event as listed below. All applicable A/B loads are applied to the detailed FE model.

5.1.1 Dead Loads (D)

Dead loads include the weight of structures (D1) such as slabs, roofs, decking, framing (beams, columns and walls), and the weight of permanently attached major equipment (D2) such as tanks, machinery, cranes, elevators, etc. MHI report N0-EHB0032, “Component Weight List Auxiliary Building” (Reference 7.6) provides the foot prints and weights of major pieces of equipment in the A/B.

5.1.2 Live Loads (L)

Live loads are the loads imposed by the use and occupancy of the building/structure.

Building Floor (L_1) MHI report N0-EHB0031, “Load Distribution Auxiliary Building” (Reference 7.5) provides live loads P2 (loads of piping, duct, tray, conduit, platform equipped to component and support) and live loads P3 (floor load during periodic inspection where positions and weights vary) and some P1 (component load) dead loads not listed in the component weight list (Reference 7.6) for the structural evaluation and design of buildings.

Roof Snow/Live (L_2) The roof is conservatively designed for uniform snow live load of 75 50 psf per Table 1 of the SDC (Reference 7.9). Consistent with DC/COL-ISG-7 (Reference 7.15), this load represents the 100-year snowpack maximum snow weight including the contributing portion of either extreme frozen winter precipitation event or extreme liquid winter precipitation event. The roof design live load is 40 psf. Roof live load is not added to roof snow load when evaluating the design load combinations.

5.1.3 Static Ground Water (F)

A static ground water pressure (F) acting on the structures during normal operation is included in the analysis. Table 2.0-1 of Chapter 2 of the DCD (Reference 7.3) identifies that the maximum groundwater level is 1 ft. below grade. However, to simplify the calculations, the groundwater level is conservatively taken as at grade level for determination of hydrostatic pressure.

5.1.4 Static Lateral Earth Load (H)

A static at rest earth pressure (H) acting on the structures during normal operation is included in the analysis. Soil properties are taken from MHI TR MUAP-10006 (Reference 7.2).

Table 2.0-1 of Chapter 2 of the DCD (Reference 7.3) identifies that the maximum groundwater level is 1 ft. below grade. However, to simplify the calculations, the groundwater level is conservatively taken as being at grade level for determination of hydrostatic pressure and static earth pressure.

5.1.5 SSE Loads (E_{ss})

SSE Loads are defined as the loads generated by the SSE specified for the plant. This includes dynamic soil pressures (E_{ds}) on exterior walls that contact with surrounding backfill and member forces (E_{ss}) derived from the RSA analyses. It also includes accidental torsion (E_t).

Dynamic soil pressures are taken from Table 4-12 of MHI TR MUAP-10006 (Reference 7.2). Member forces are derived from RSA analyses performed on the A/B detailed model per Section 5.2. The ISRS input for the RSA analyses considers SSI amplified effects. The ISRS is provided by the seismic soil-structure interaction (SSI) analysis per Section 4.0.

SRP Acceptance Criteria 1.A.iii of Section 3.7.2 of NUREG 800 (Reference 7.10) requires consideration of torsional, rocking and translation responses of site structures and their foundations. SRP Acceptance Criteria 11 of Section 3.7.2 also requires consideration of an accidental torsion that is based on an additional eccentricity of ±5% of the maximum building lateral dimension. Therefore, in addition to the earthquake forces derived from RSA analyses, the effects of accidental torsion is also considered. A torsion moment equal to the larger of the torsions resulting from the product of the base shears times 5% of the building dimension that is perpendicular to the direction of the base shear force is applied to the analytical model.

5.1.6 Other Applicable Load Cases

Liquid (F) Hydrostatic loads are based on the water volumes within the various pits during normal operations. No significant pits are located in the A/B.

Normal Pipe Reactions (R_o) The normal operating environment inside and outside the R/B is specified in Table 6 of the SDC. Since the change in temperature (ΔT) of the reference temperature of 70° F and normal operating temperatures are not excessive, this load is not considered in the structural integrity evaluation.

Normal Operating Thermal (T_o) Pipe and equipment reactions during normal operation or shutdown conditions are based on the most critical transient or steady state condition. These loads produce primarily local effects and will not be addressed in structural integrity evaluation.

Accident Loads (P_a, T_a, R_a, Y_r, Y_j, Y_m) These loads will not be addressed in structural integrity evaluation

5.1.7 Load Combinations

Concrete structures are designed in accordance with ACI-349 (Reference 7.16), and the provisions of RG 1.142 (Reference 7.14) where applicable, with the load combinations and load factors provided in Table 5.1-1. Load combinations #1, 4, and 8 are applicable for the structural integrity evaluation at this stage. Future revision of this report will includes evaluation for all the applicable load cases and combinations. Table 5.1-2 provides the load combinations considered in the ANSYS analysis and evaluation.

Table 5.1-1 Load Combinations and Load Factors for Concrete Structures

LOAD COMBINATIONS AND FACTORS(1),(2)												
ACI 349 Load Combination:		1	2	3	4	5	6	7	8	9	10	11
Load Type												
Dead	D	1.4	1.4	1.4	1.0	1.0	1.0	1.0	1.0	1.05	1.05	1.05
Liquid	F	1.4	1.4	1.4	1.0	1.0	1.0	1.0	1.0	1.05	1.05	1.05
Live	L	1.7	1.7	1.7	1.0	1.0	1.0	1.0	1.0	1.3	1.3	1.3
Earth	H	1.7	1.7	1.7	1.0	1.0	1.0	1.0	1.0	1.3	1.3	1.3
Design pressure	P_d											
Normal Pipe reactions	R_o	1.7	1.7	1.7	1.0	1.0				1.3	1.3	1.3
Normal thermal	T_o				1.0	1.0				1.2	1.2	1.2
Wind	W			1.7								1.3
OBE	E_{ob}		NA					NA			NA	
SSE	E_{ss}				1.0				1.0			
Tornado	W_t					1.0						
Accident pressure	P_a						1.4	1.15	1.0			
Accident thermal	T_a						1.0	1.0	1.0			
Accident thermal pipe reactions	R_a						1.0	1.0	1.0			
Pipe rupture reactions	Y_r							1.0	1.0			
Jet impingement	Y_j							1.0	1.0			
Pipe Impact	Y_m							1.0	1.0			

Notes:
1. Design per ACI-349 Strength Design Method for all load combinations.
2. Where any load reduces the effects of other loads, the corresponding coefficient for that load is taken as 0.9 if it can be

Table 5.1-2 A/B Structural Integrity Concrete Load Combinations

		L01	L02	L06	L07	L08	L12	L11	L13	L15	L16	L17	L18	L19	L20	L21	L22
		Dead Loads		Liquid Loads	Live Loads		Earth Pressure	SSE Dynamic Soil Pressure		SSE RSA Seismic Load						SSE Accidental Torsion	
		Self Weight	Equipment Loads	Ground Water	Floor LL Roof Snow/LL	Piping LL	Static	E-W	N-S	N-S +	N-S -	E-W +	E-W -	Vertical +	Vertical -	+	-
Load Combo		D_1	D_2	F_3	L_1	L_2	H_1	E_{ds1}	E_{ds1}	E_{ss1}	E_{ss2}	E_{ss3}	E_{ss4}	E_{ss5}	E_{ss6}	E_{t+}	E_{t-}
ABConcLC01	1.4D+1.4F+1.7L+1.7H	1.4	1.4	1.4	1.7		1.7										
ABConcLC02	1.4D+1.4F+1.7L+1.7H	1.4	1.4	1.4		1.7	1.7										
ABConcLC03	1.4D+1.4F+1.7L+1.7H	1.4	1.4	1.4			1.7										
ABConcLC04	1.4D+1.4F+1.7L+1.7H	1.4	1.4	1.4	1.7	1.7	1.7										
ABConcLC05	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0	0.4	1.0	1.0		0.4		0.4		1.0	
ABConcLC06	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0	0.4	1.0	1.0		0.4			0.4	1.0	
ABConcLC07	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0			0.4	0.4		1.0	
ABConcLC08	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0			0.4		0.4	1.0	
ABConcLC09	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0	0.4			1.0	0.4		0.4		1.0	
ABConcLC10	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0	0.4			1.0	0.4			0.4	1.0	
ABConcLC11	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0				1.0		0.4	0.4		1.0	
ABConcLC12	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0				1.0		0.4		0.4	1.0	
ABConcLC13	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.4	0.4		1.0		0.4		1.0	
ABConcLC14	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.4	0.4		1.0			0.4	1.0	
ABConcLC15	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0	1.0			0.4	1.0		0.4		1.0	
ABConcLC16	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0	1.0			0.4	1.0			0.4	1.0	
ABConcLC17	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0		0.4	0.4			1.0	0.4		1.0	
ABConcLC18	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0		0.4	0.4			1.0		0.4	1.0	
ABConcLC19	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0				0.4		1.0	0.4		1.0	
ABConcLC20	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0				0.4		1.0		0.4	1.0	
ABConcLC21	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0	0.4	0.4	0.4		0.4		1.0		1.0	
ABConcLC22	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0		0.4	0.4			0.4	1.0		1.0	
ABConcLC23	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0	0.4			0.4	0.4		1.0		1.0	
ABConcLC24	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0				0.4		0.4	1.0		1.0	
ABConcLC25	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0	0.4	0.4	0.4		0.4			1.0	1.0	
ABConcLC26	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0		0.4	0.4			0.4		1.0	1.0	
ABConcLC27	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0	0.4			0.4	0.4			1.0	1.0	
ABConcLC28	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0				0.4		0.4		1.0	1.0	
ABConcLC29	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0	0.4	1.0	1.0		0.4		0.4			1.0
ABConcLC30	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0	0.4	1.0	1.0		0.4			0.4		1.0
ABConcLC31	1.0D+1.0F+1.0L+1.0H+1.0E_{ss}	1.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0			0.4	0.4			1.0

Table 5.1-2 A/B Structural Integrity Concrete Load Combinations (continued)

		L01	L02	L06	L07	L08	L12	L11	L13	L15	L16	L17	L18	L19	L20	L21	L22
		Dead Loads		Liquid Loads	Live Loads		Earth Pressure	SSE Dynamic Soil Pressure		SSE RSA Seismic Load						SSE Accidental Torsion	
		Self Weight	Equipment Loads	Ground Water	Floor LL Roof Snow/LL	Piping LL	Static	E-W	N-S	N-S +	N-S -	E-W +	E-W -	Vertical +	Vertical -	+	-
Load Combo		D_1	D_2	F_3	L_1	L_2	H_1	E_{ds1}	E_{ds1}	E_{ss1}	E_{ss2}	E_{ss3}	E_{ss4}	E_{ss5}	E_{ss6}	E_{t+}	E_{t-}
ABConcLC32	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0			0.4		0.4		1.0
ABConcLC33	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0	0.4			1.0	0.4		0.4			1.0
ABConcLC34	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0	0.4			1.0	0.4			0.4		1.0
ABConcLC35	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0				1.0		0.4	0.4			1.0
ABConcLC36	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0				1.0		0.4		0.4		1.0
ABConcLC37	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.4	0.4		1.0		0.4			1.0
ABConcLC38	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.4	0.4		1.0			0.4		1.0
ABConcLC39	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0	1.0			0.4	1.0		0.4			1.0
ABConcLC40	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0	1.0			0.4	1.0			0.4		1.0
ABConcLC41	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0		0.4	0.4			1.0	0.4			1.0
ABConcLC42	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0		0.4	0.4			1.0		0.4		1.0
ABConcLC43	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0				0.4		1.0	0.4			1.0
ABConcLC44	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0				0.4		1.0		0.4		1.0
ABConcLC45	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0	0.4	0.4	0.4		0.4		1.0			1.0
ABConcLC46	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0		0.4	0.4			0.4	1.0			1.0
ABConcLC47	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0	0.4			0.4	0.4		1.0			1.0
ABConcLC48	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0				0.4		0.4	1.0			1.0
ABConcLC49	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0	0.4	0.4	0.4		0.4			1.0		1.0
ABConcLC50	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0		0.4	0.4			0.4		1.0		1.0
ABConcLC51	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0	0.4			0.4	0.4			1.0		1.0
ABConcLC52	$1.0D+1.0F+1.0L+1.0H+1.0E_{ss}$	1.0	1.0	1.0	1.0	1.0	1.0				0.4		0.4		1.0		1.0
ABConcLC53	1.05D+1.05F+1.3L+1.3H	1.05	1.05	1.05	1.3	1.3	1.3										

Notes:

D_1 Self Weight of Elements

D_2 Dead Load (Includes permanently attached equipment, tanks, machinery, cranes, elevators, etc.)

F_3 Fluid Load (Lateral and upward pressure due to high water table)

L_1 Live Load (Building floor loads)

L_2 Live Load (Piping Live Load)

H_1 Earth Pressure (Static)

E_{ds1} Dynamic Soil Pressure Safe Shutdown Earthquake (E-W direction Earthquake)

E_{ds2} Dynamic Soil Pressure Safe Shutdown Earthquake (N-S direction Earthquake)

E_{ss1} Safe Shutdown Earthquake (N-S) Response (Positive)

E_{ss2} Safe Shutdown Earthquake (N-S) Response (Negative)

E_{ss3} Safe Shutdown Earthquake (E-W) Response (Positive)

E_{ss4} Safe Shutdown Earthquake (E-W) Response (Negative)

E_{ss5} Safe Shutdown Earthquake (Vertical) Response (Positive)

E_{ss6} Safe Shutdown Earthquake (Vertical) Response (Negative)

E_{t+} Accidental Torsion due to SSE (positive rotation)

E_{t-} Accidental Torsion due to SSE (negative rotation)

5.2 Response Spectrum Analysis Methodology

The seismic inertial forces for the structural integrity evaluation on structural members are obtained from the response spectrum analysis (RSA) of the detailed FE model with the effective seismic mass and fixed boundary conditions set at the base of A/B structure. An RSA is performed for each orthogonal seismic input motion (N-S, E-W, and Vertical). No uplift is assumed at the base and will be further confirmed/verified during the basic design of the basemat.

5.2.1 Determination of the Input Response Spectrum

In order to conservatively account for the amplification of the structural response due to soil structure interaction effects, the acceleration response spectra used as input for the response spectrum analysis (RSA) are obtained as follows:

Step 1: Perform SSI analyses on the A/B stick model described in Section 2.4 above for all eight generic soil profiles.

Step 2: The Acceleration Responses Spectrum (ARS) for 7% damping ratio at edges and center of top surface of basemat due to three directions of the earthquake are combined using the rule of Square Root of the Sum of Square (SRSS) to account for cross directional earthquake effects.

Step 3: Envelope SRSS combined ARS for 7% damping ratio at edges and center of basemat top surface for the eight soil profiles.

Step 4: Generate ISRS for 7% damping ratio at basemat top surface by applying 15% peak broadening and 5% increase in magnitude of the response to the enveloped ARS obtained from Step 3. The resulting ISRS in Figure 5.2-1 through Figure 5.2-3 are used as input base excitation spectra for the RSA analysis.

Step 5: ISRS generated at Step 4 are verified by SSI analyses performed on A/B dynamic FE model for the four critical soil cases as described in Section 4.3.

5.2.2 Boundary Conditions for Response Spectrum Analysis

The response spectrum analysis (RSA) considers a fixed-base condition by setting a fixed boundary condition at each node at the bottom of the basemat. The response spectrum analysis considers SSI affects through use of the broadened input acceleration response spectrum generated by SSI analysis described above. The fixed nodes do not allow the basemat to deflect and therefore not all applicable seismic forces are captured for the basemat slab. The response of the basemat is not considered in this structural integrity evaluation and will be evaluated during the finial basic design.

5.2.3 Combined Modal Responses: Lindley-Yow Method

The response from each individual mode is combined by Lindley-Yow method per Regulatory Position 1.3.2 of RG 1.92, Rev. 2 (Reference 7.19). The ISRS obtained from the SSI analyses are modified per Reg. 1.92 for modal combinations using Lindley-Yow method. Figure 5.2-4 through Figure 5.2-6 present the Lindley-Yow modified response spectra that are used as input for the response spectrum analysis (RSA). The periodic response portion of the Lindley-Yow method is implemented by using ANSYS “Grouping Method” and the rigid response

portion is implemented by using “Static ZPA Method” per Regulatory Position 1.4.2 of RG 1.92, Rev. 2. The directional effect from each direction is combined by 100-40-40 method.

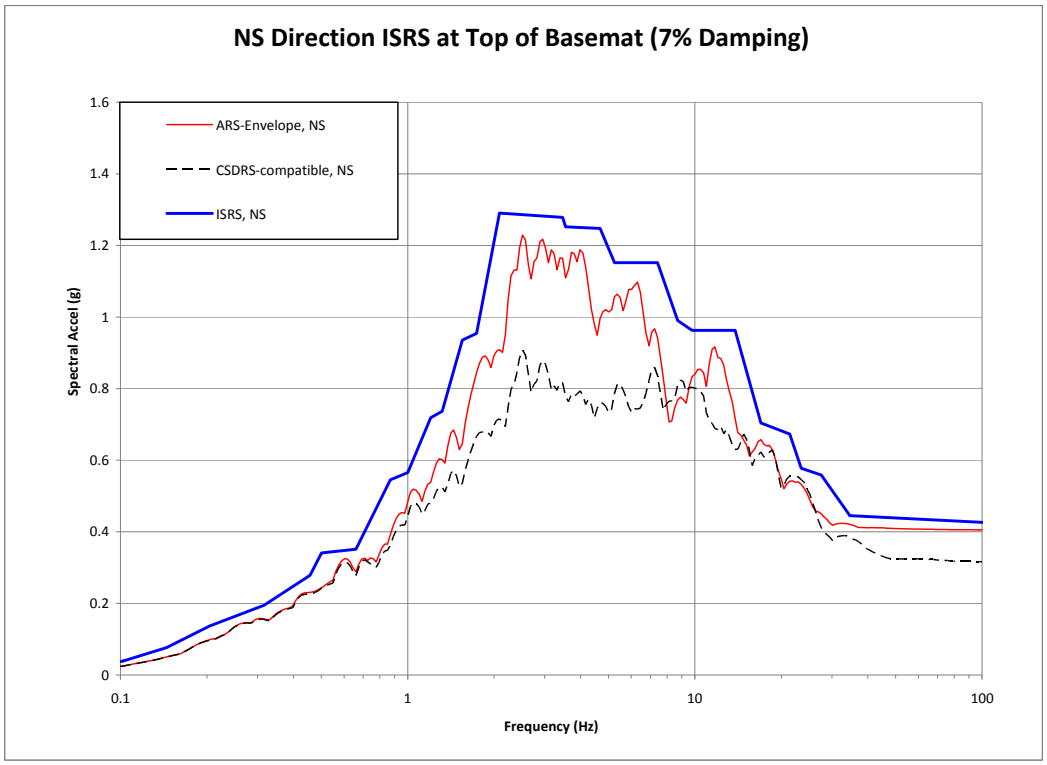


Figure 5.2-1 N-S 7% Damped ISRS at Top of A/B Basemat

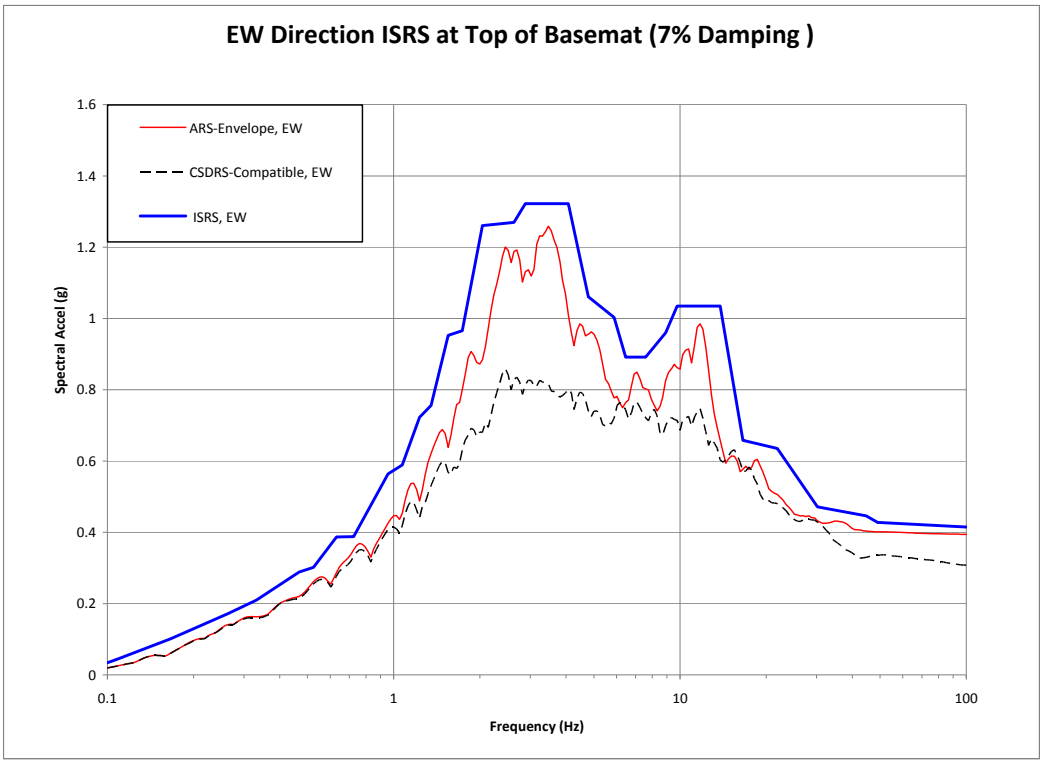


Figure 5.2-2 E-W 7% Damped ISRS at Top of A/B Basemat

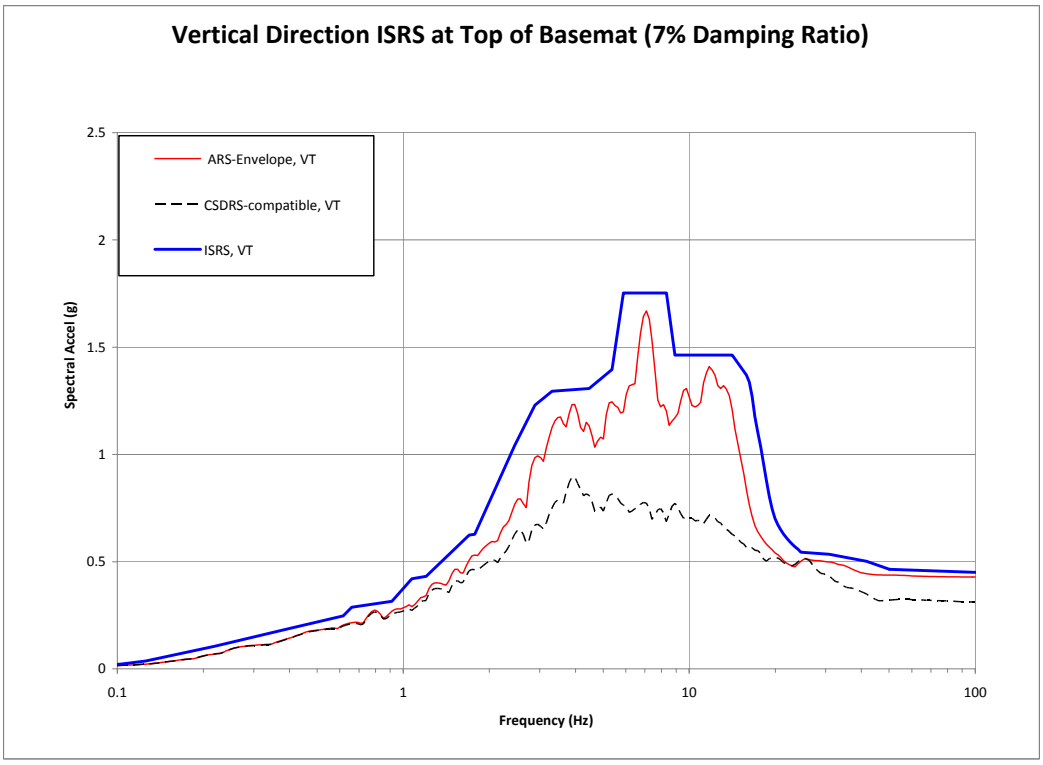


Figure 5.2-3 Vertical 7% Damped ISRS at Top of A/B Basemat

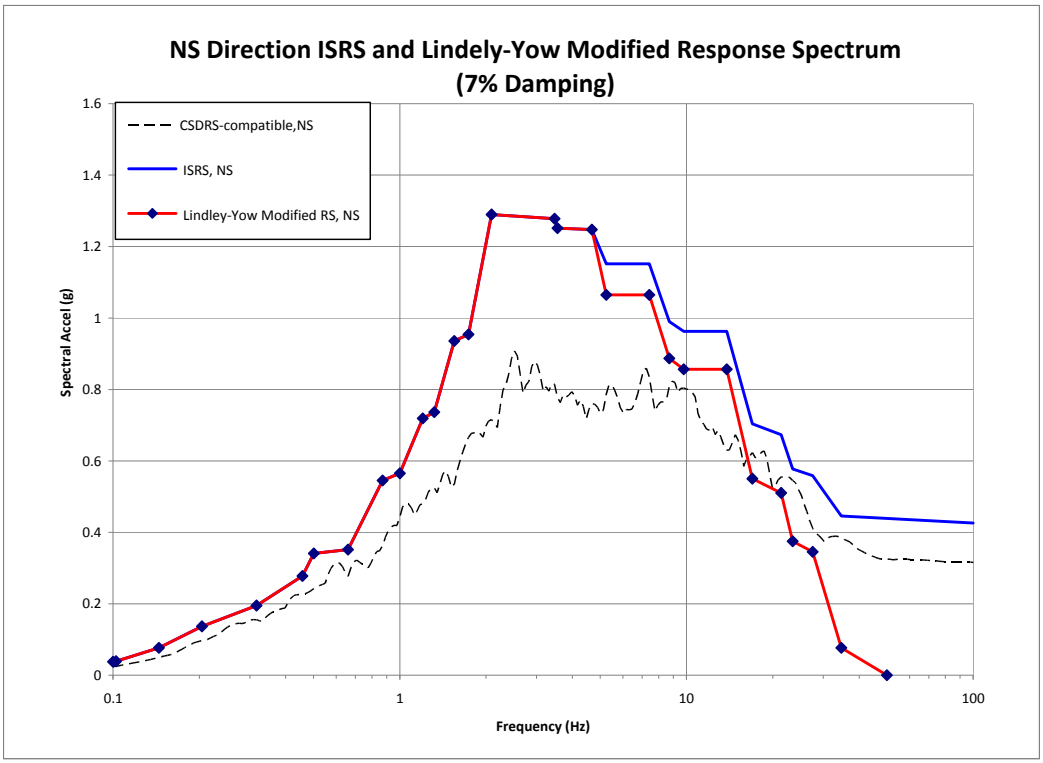


Figure 5.2-4 Modified N-S Response Spectrum for Response Spectrum Analysis

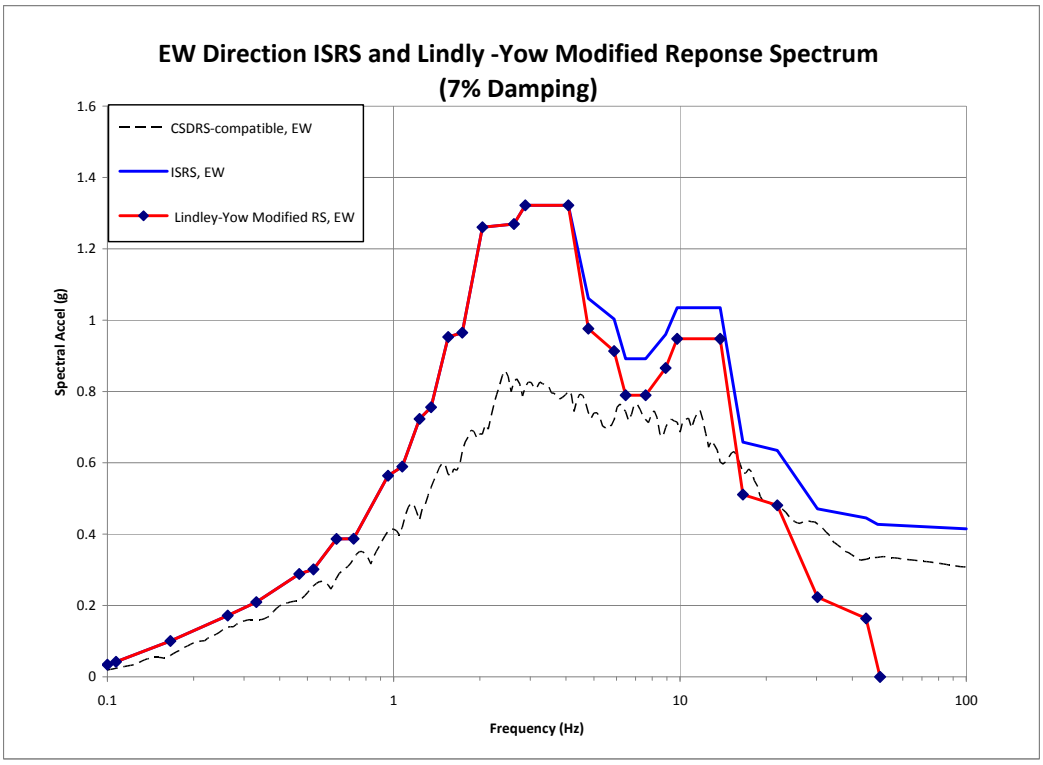


Figure 5.2-5 Modified E-W Response Spectrum for Response Spectrum Analysis

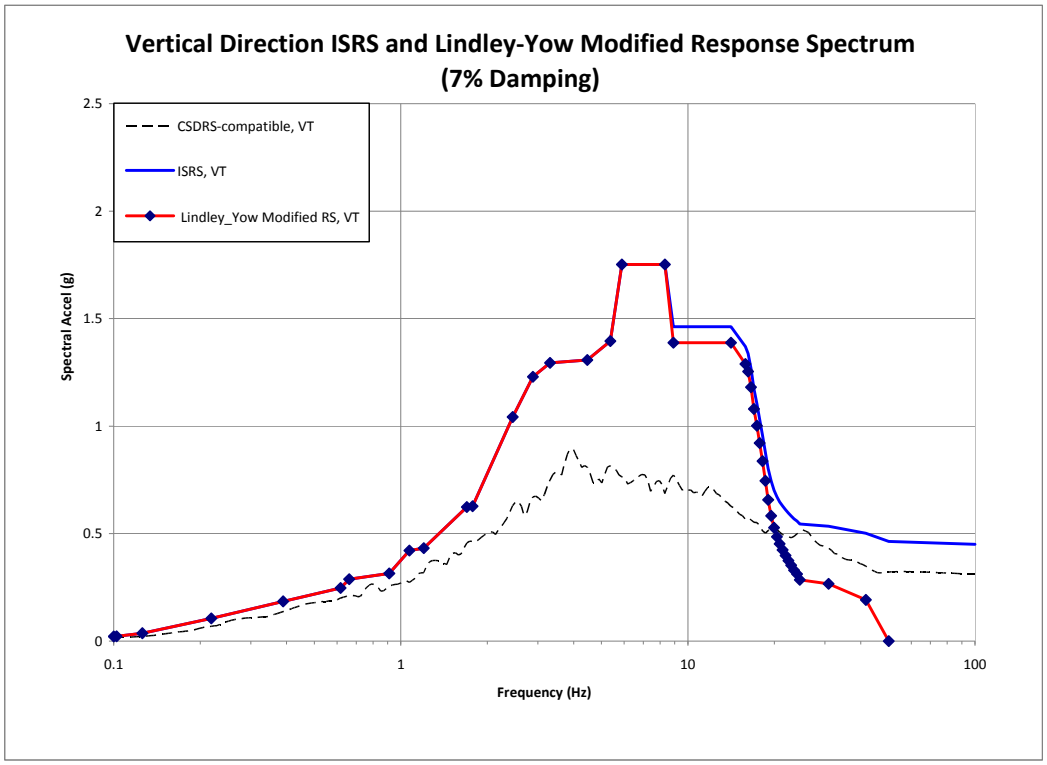


Figure 5.2-6 Modified Vertical Response Spectrum for Response Spectrum Analysis

Note: The Lindley-Yow's curve representing the periodic response only and needs to be combined with rigid response from static ZPA.

5.3 Static and Response Spectrum Analysis Results

5.3.1 Base Shear

The seismic forces for the structural evaluation from each response spectrum analysis (RSA) are applied to the structural members/element as seismic loads with separate load cases for each orthogonal direction: N-S, E-W, and vertical. The shear forces from each RSA analysis are summed to obtain the base shear in each direction. A summary of the total seismic base shear force at the top of the base mat from the effect of each directional response are combined by SRSS and the results are given in Table 5.3-1. The total base shears as shown on Table 5.3-1 are used to determine accidental torsions as applied forces in the static analysis.

5.3.2 Structural Demands of Main Structural Components

The structural demands for the main shear walls and slabs are determined for the load combinations described in Section 5.1.6, which include SSE loads. The applicable element forces are extracted from the static analysis for each shear wall and slab. The demand–to-capacity ratios are determined in Section 5.5.

Table 5.3-1 Seismic Base Shear Seismic Force

Base Shear at Top of Basemat By SRSS the RSA results in N-S, E-W and Vertical Direction (Kips)			
Base Shear direction	Seismic Input Direction	Base shear from source excitation alone	Base shear with combined directional effect by SRSS
N-S	N-S	128,467	134,908
	E-W	25,996	
	Vertical	25,204	
E-W	N-S	21,483	117,006
	E-W	110,347	
	Vertical	26,201	

5.4 Structural Integrity Evaluation Methodology

The structural integrity of several representative shear walls and slabs is evaluated to determine if their capacity is adequate to resist the seismic demands calculated from the static and response spectrum analyses of the detailed FE model. The structural demands and the geometry of these walls and slabs are input to concrete design programs“wall.exe” and “slab.exe” . The program calculates the member demand-to-capacity ratios and provides the necessary rebar arrangement to resist the demands. To facilitate the process, several additional ANSYS macros were developed. The programs are described in Appendix A.

5.5 Structural Integrity Evaluation Results

Exterior walls at column line 1A and the first floor slabs are selected as representative members for structural Integrity evaluation. Exterior wall segment along column line AA between column lines 1A and 6A, from elevation -26'-4" to elevation 2'-3" has been selected to check the shear capacity of the exterior walls. Table 5.5-1 provides the forces of selected elements from the ANSYS analysis for this typical wall.

The required reinforcement due to out-of-plane bending moments and in-plane forces are calculated by program "WALL" and is shown in Table 5.5-2. Similarly, the required reinforcement due to out-of-plane bending moments and out-of plane shear force in slabs are calculated by program "SLAB". These required reinforcements are calculated in element level and are defined as "Demands".

In order to demonstrate the results of the integrity evaluation, the above mentioned "Demands" need to be compared against the "Capacity" of the components. The capacity for each item of demands is defined below:

- Out-of-plane Bending Capacity for Walls and Slab:

  The capacity is based on the designer's selection of the reinforcement in each of the two orthogonal directions. This is really a "design capacity" instead of an absolute capacity. For the comparison with the demand, the basis of the capacity is stated in this report.

- Out-of-plane Shear Capacity for Walls and Slab:

  The capacity is based on concrete strength of the section cut without the consideration of shear reinforcement. It is essentially a "design capacity" as well since the capacity can be increased if the shear reinforcement is to be added by design engineer.

- In-plane Shear Capacity for Walls:

  The capacity is the maximum code allowed capacity for the wall section. For walls with the length of l_w, thickness of t, concrete strength of fc' and reduction factor of Φ (=0.6), the design strength allowed by ACI 349-01 is $\phi 10\sqrt{f_c^{'}} * (l_w * t)$ which includes the strength contributed by shear reinforcement. This is a "true capacity" not a "design capacity".

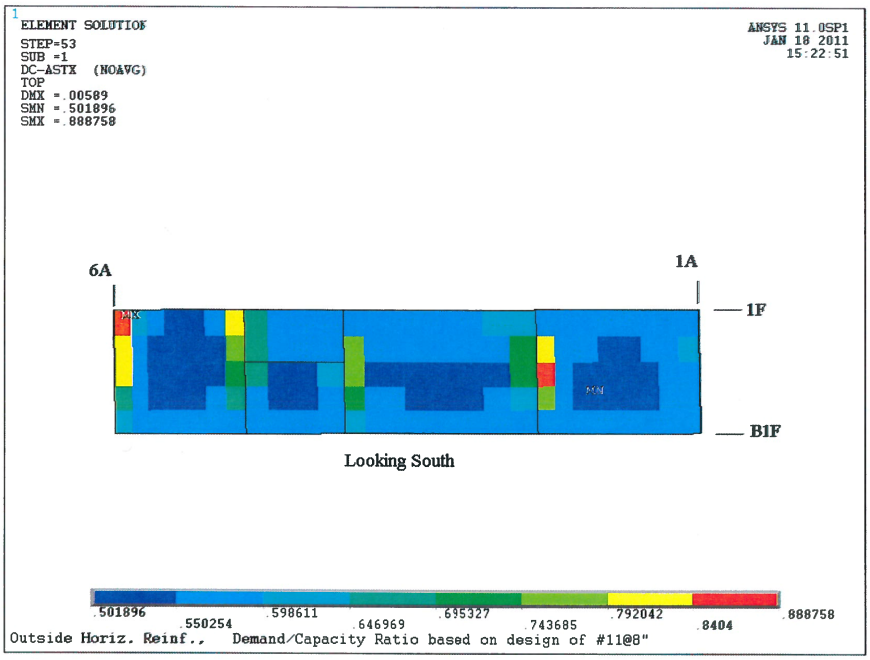
The demand/capacity ratio for in-plane shear, out-of plane shear (horizontal and vertical directions), out of plane bending (horizontal and vertical directions) are summarized in Table 5.5-3. The demand/capacity ratios are shown in the contour plots in Figures 5.5-1 to 5.5-8. All the DCRs are less than 1 with the exception of out-of-plane shear in horizontal cut in shear wall along Column Line AA (See Figure 5.5-4). In order to reduce the DCRs, there are a few options, including increasing wall thickness, adding boundary beams or adding shear reinforcement. A more extensive check of the remaining walls will be provided in the future revision of the report.

Table 5.5-1 Typical Wall Element Forces

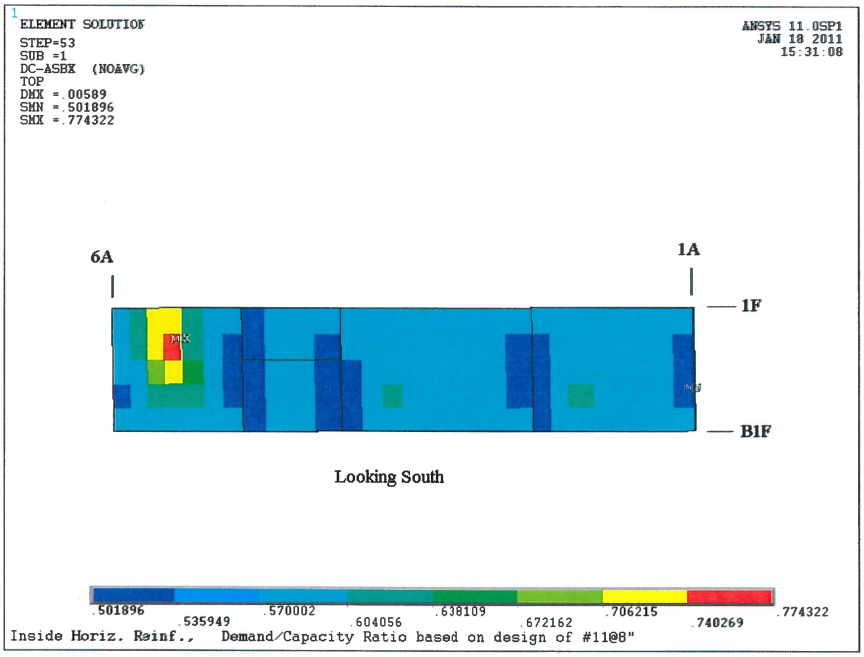
Element	Load Case	In-plane Base Shear (kips)	Nx (kip/ft)	Ny (kip/ft)	Nxy (kip/ft)	Mx (kip-ft/ft)	My (kip-ft/ft)	Mxy (kip-ft/ft)
3057	13	14613.4	4.11	9.19	112.41	193.24	-0.45	8.0
3410	37	12895	-2.99	213.0	99.19	38.65	38.14	61.06
4141	20	14080	-30.2	-270.1	108.3	-189.1	-132.8	-1.56
3411	29	9334	-10.6	165.1	71.8	0.46	-21.8	47.1

Table 5.5-2 Typical Wall Required Reinforcement

Element	Load Case	ASTX (in^2/ft)	ASBX (in^2/ft)	ASTY (in^2/ft)	ASBY (in^2/ft)
3057	13	1.417	0.576	0.768	0.768
3410	37	0.85	0.768	2.63	2.19
4141	20	0.576	1.06	1.304	1.75
3411	29	0.768	0.805	1.699	2.226

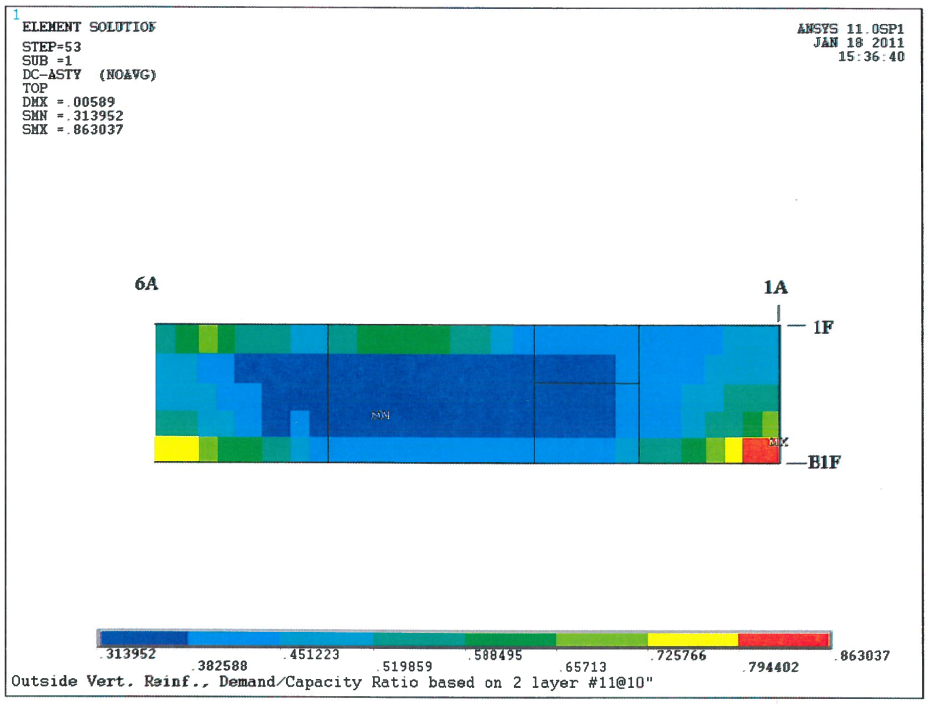


Outside Layer Moment Demand/Capacity for Walls in Column AA between B1F to 1F

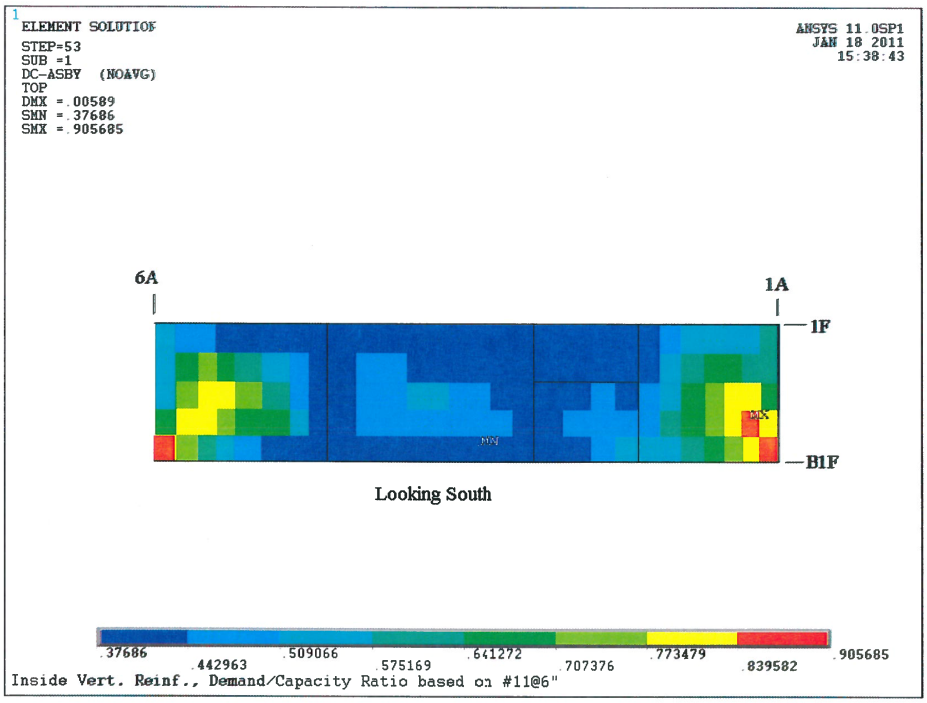


Inside Layer Moment Demand/Capacity for Walls in Column AA between B1F to 1F

Figure 5.5-1 Selected Exterior Wall: Vertical Cut Out-of-plane Moment DCR



Outside Layer Moment Demand/Capacity for Walls in Column AA between B1F to 1F



Inside Layer Moment Demand/Capacity for Walls in Column AA between B1F to 1F

Figure 5.5-2 Selected Exterior Wall: Horizontal Cut Out-of-plane Moment DCR

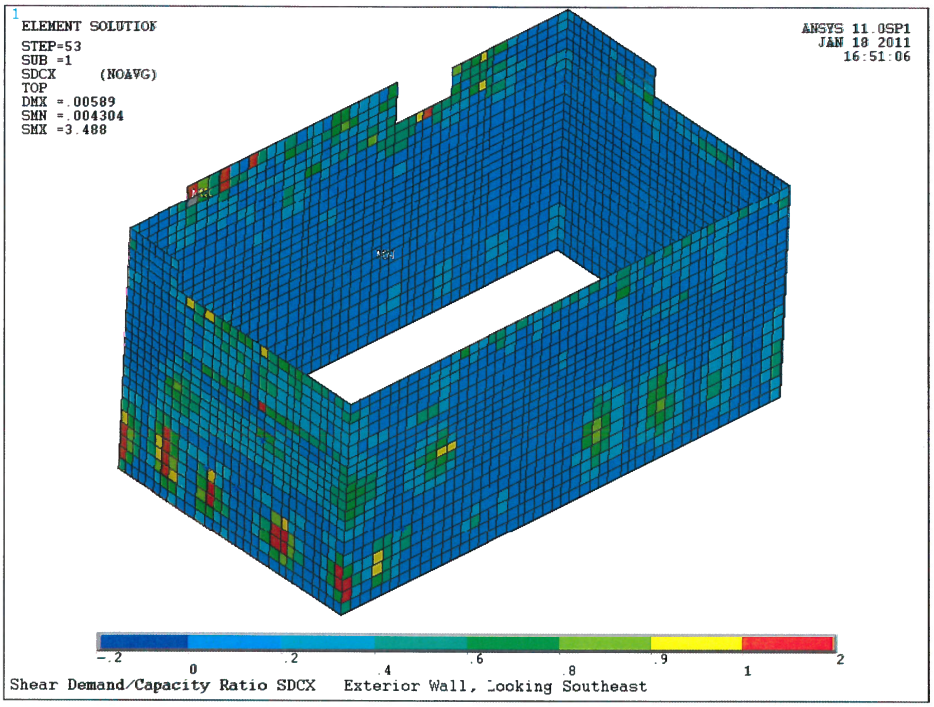


Figure 5.5-3 Exterior walls: Vertical Cut Out-of-plane Shear DCR

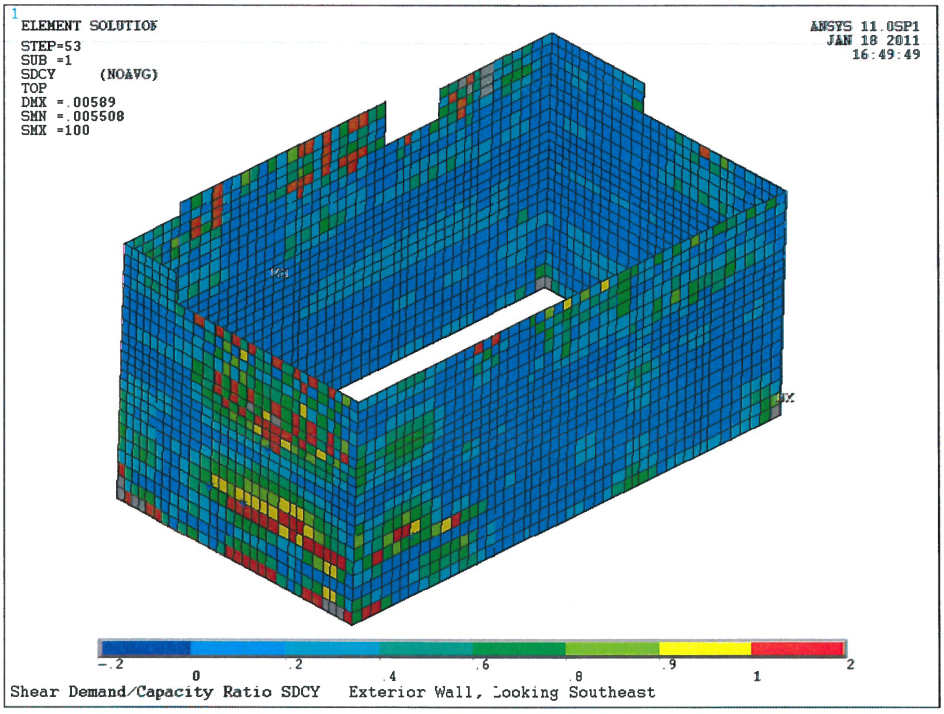
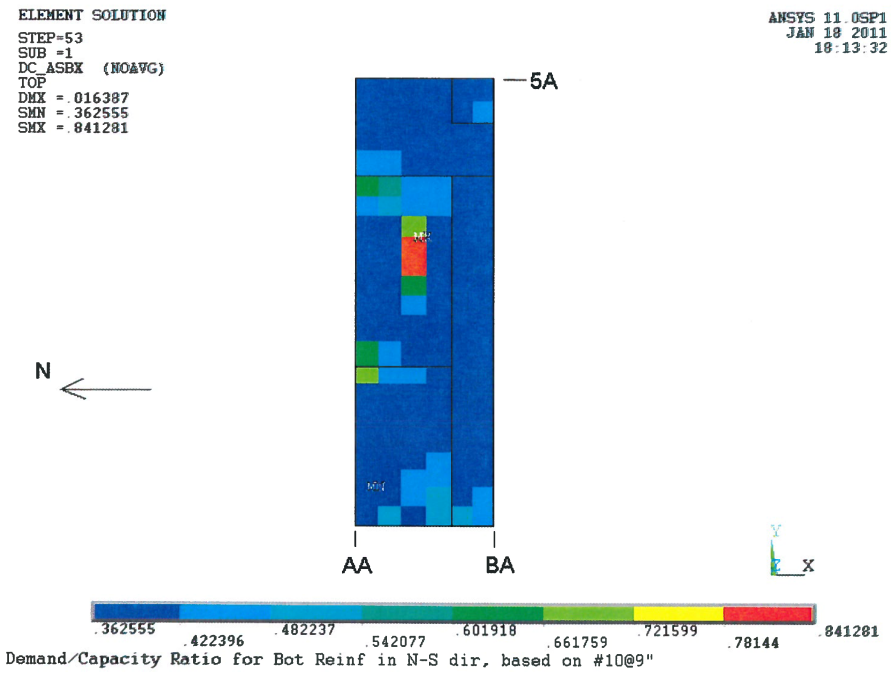
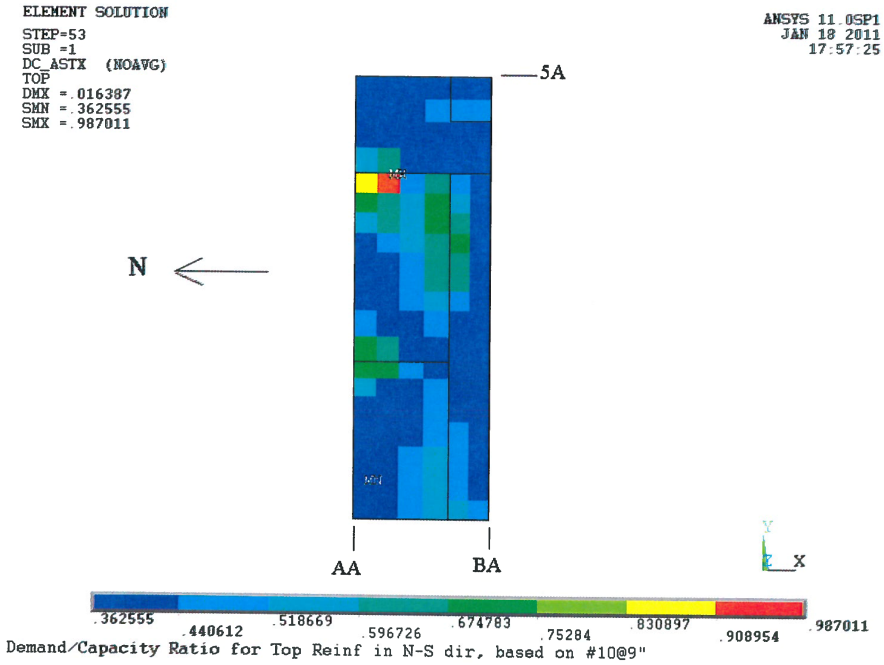


Figure 5.5-4 Exterior Walls: Horizontal Cut Out-of-plane Shear DCR

Note: All wall sections not within distance "d" from the interfacing interior walls or floor slabs (not shown) have D/C ratio less than 1. The shear capacity is based on the concrete strength, ΦV_n alone.

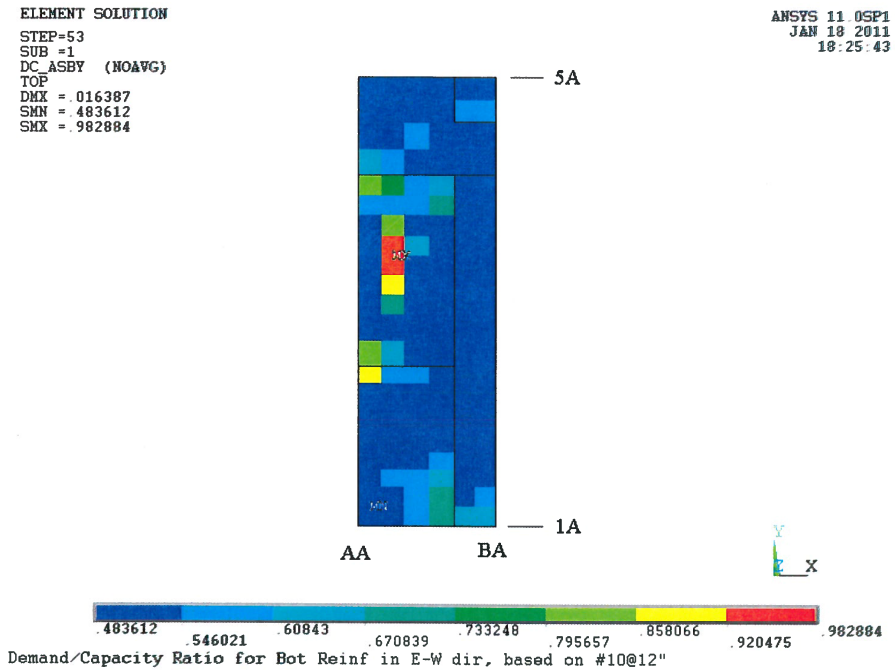


DCR for N-S Bottom Reinforcement at North End of 1st Floor Slab

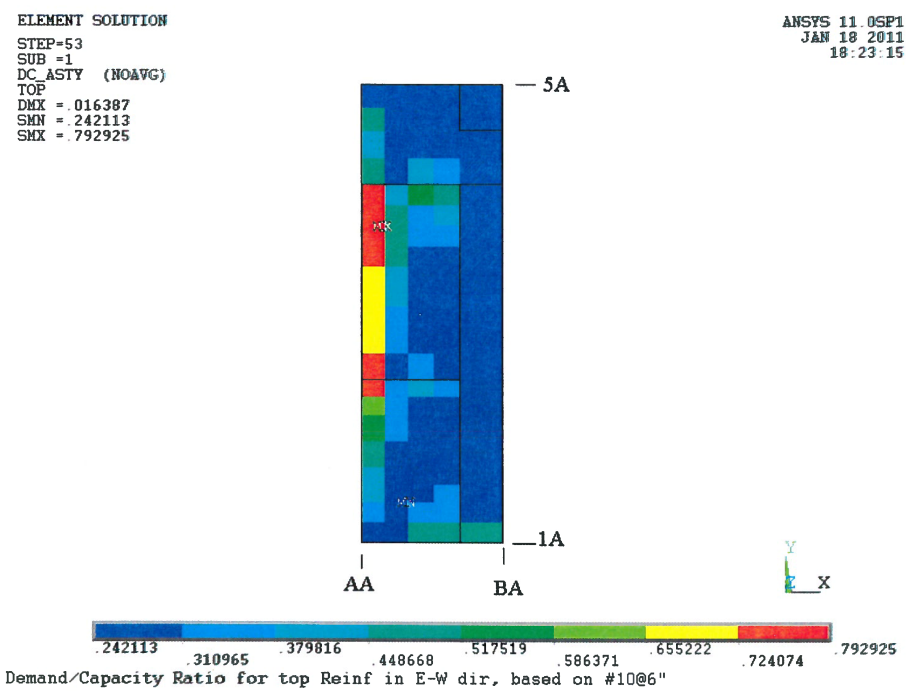


DCR for N-S Top Reinforcement at North End of 1st Floor Slab

Figure 5.5-5 Selected Ground Slab: E-W Direction Cut Out-of-plane Moment DCR



DCR for E-W Bottom Reinforcement at North End of 1st Floor Slab



DCR for E-W Top Reinforcement at North End of 1st Floor Slab

Figure 5.5-6 Selected Ground Slab: N-S Direction Cut Out-of-plane Moment DCR

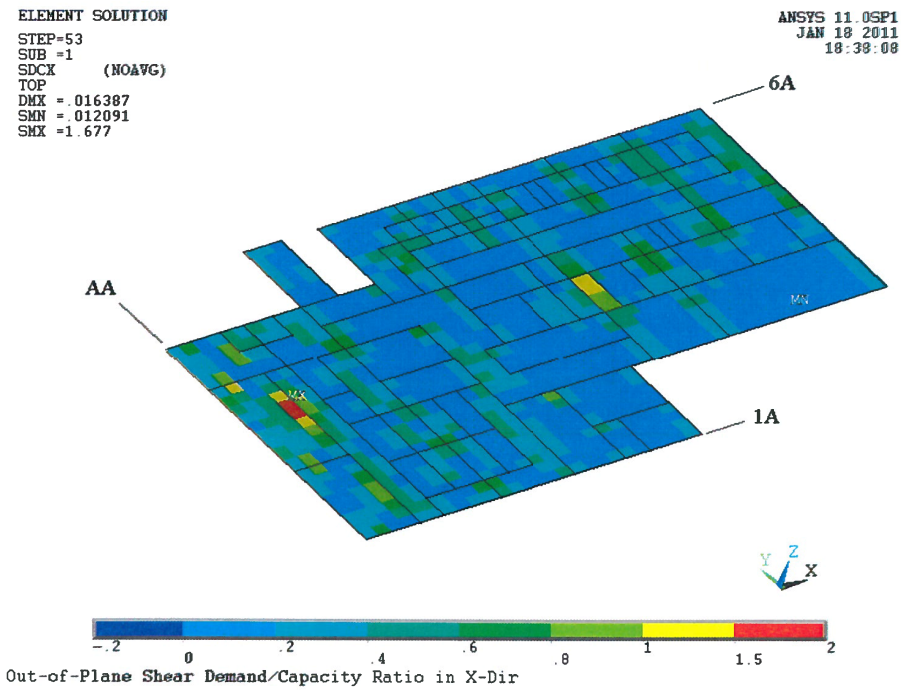


Figure 5.5-7 Ground Slabs: E-W Direction Cut Out-of-plane Shear DCR

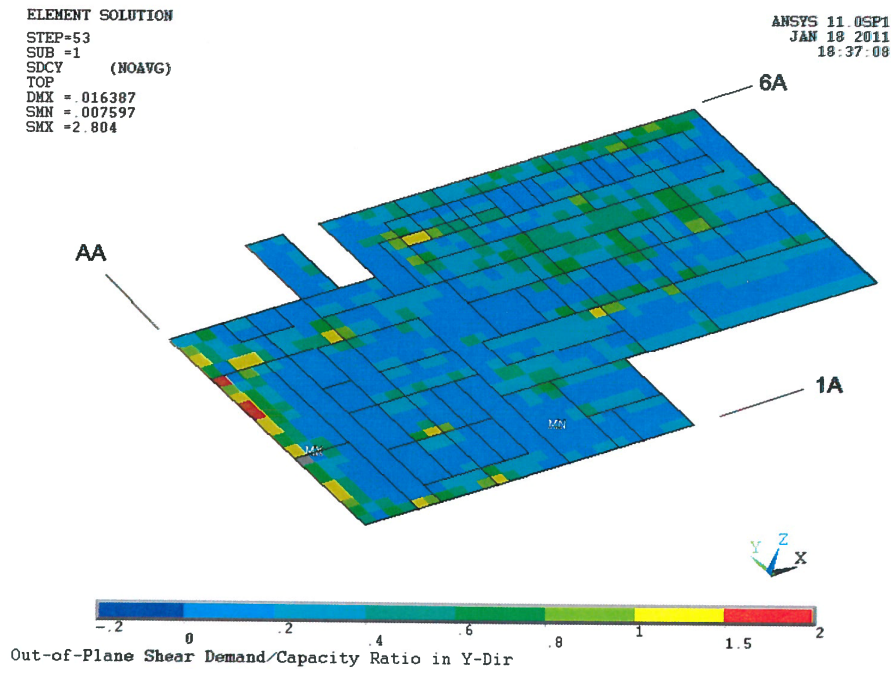


Figure 5.5-8 Ground Slabs: N-S Direction Cut Out-of-plane Shear DCR

Note: All slabs sections not within “d” distance from the face of the interfacing walls have DCR < 1.0
Shear capacity is based on concrete strength, ΦV_n, alone.

Table 5.5-3 Typical Structural Demands

Location of Components	Items	Demand/Capacity Ratio	Reference Figure
Wall in Column Line AA Between B1F and 1F	Wall In-plane-shear	0.617	NA
Wall in Column Line AA above and below 3rd floor	Wall out-of-plane shear (Horizontal)	1< DCR <2 for wall above and below 3rd floor	Figure 5.5.3
Wall in Column Line AA Between B1F and 1F	Wall out-of-plane shear (Vertical)	< 1 for all wall sections not within the “d” distance of the interfacing walls	Figure 5.5.4
Wall in Column Line AA Between B1F and 1F	Wall out-of-plane bending Vertical Cut	< 0.89	Figure 5.5.1
Wall in Column Line AA Between B1F and 1F	Wall out-of-plane bending Horizontal Cut	< 0.91	Figure 5.5.2
1st Floor Slab	E-W direction cut out-of-plane shear	<1.0 for slab not within the “d” distance from wall surface	Figure 5.5.7
1st Floor Slab	N-S direction cut out-of-plane shear	<1.0 for slab not within the “d” distance from wall surface	Figure 5.5.8
1st Floor Slab	E-W direction cut out-of-plane bending	< 0.99 for #10@9” top and bottom reinforcement	Figure 5.5.5
1st Floor Slab	N-S direction cut out-of-plane bending	<0.98 for #10@6” top and #10@12” for bottom	Figure 5.5.6

6.0 CONCLUSION

This report documents the methodology, the models and the results of the SSI analyses and structural integrity evaluation of selected major walls and slabs of the A/B to confirm that the major wall and slab thicknesses are adequate.

Sections 2.5 and 2.3, respectively, present the description and validation of the lumped-mass stick model and dynamic FE used for SSI analyses. The detailed FE models used for static and RSA are described and validated as presented in Section 2.4.

The dynamic properties of the A/B model are presented in Section 3.2. The results of the SSI analyses of lumped-mass stick model for eight generic soil profiles and dynamic FE models for three selected critical soil profiles are presented in Section 4.2 and 4.3, respectively. The SSI analyses of A/B dynamic FE model yield maximum seismic horizontal displacements relative to the free field are on the order of 0.6” and 0.9” for NS and EW direction, respectively (Figure 4.3-1). TR MUAP-10006 Table 4-3 (Reference 7.2) shows that R/B EW direction displacement relative to the free field at node NW 03, which is at about same elevation as A/B roof level, is on the order of 1.1”. NS direction displacement relative to free field at roof level of PS/B is on the order of 0.37” (Reference 7.2, Table 4-4). A/B is located at west to R/B and north to PS/B. The buildings are separated by 4” wide gap. Conservatively assuming that the two adjacent buildings move toward each other during an earthquake, the minimum net gap between A/B and R/B will be 4”-(0.9”+1.1”) = 2.0”, between A/B and PS/B will be 4”-(0.6”+0.37”)=3.03” Therefore, the 4” gap is wide enough to accommodate earthquake induced deflections between A/B and R/B, A/B and PS/B. In future revision of this report, the maximum seismic displacements will be combined with non-seismic horizontal displacements that are due to possible tilting of A/B and effects of adjacent buildings and/or construction tolerances to check if the gaps between the A/B and adjacent structures are adequate.

Structural static and seismic demands are obtained by applying fixed boundary condition at bottom of basemat without consideration of uplift. The seismic base shear and vertical forces are presented in Section 5.3. The demand to capacity ratios (DCR) for selected members are presented in Section 5.5. The structural integrity evaluation of selected major structural components demonstrates the major structural components, namely, exterior walls and major floor slabs, have adequate thickness for an SSE event based on the analysis summarized in this report. The wall along Column Line AA may require additional shear reinforcement or increase of wall thickness locally to accommodate out-of-plane shear. This is to be determined during the detailed design of the building.

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APPENDIX A

ANSYS Post-Processors for Concrete Slabs and Walls

ANSYS POST-PROCESSORS FOR CONCRETE SLABS AND WALLS

Reinforcement design for the concrete walls and slabs in the Auxiliary Building (A/B) was performed using FORTRAN routines “wall.exe” and “slab.exe”, respectively. To facilitate the process, multiple additional ANSYS macros and routines were developed. The following is a description of the post-processors, the theoretical basis for design of reinforced concrete members and the methodology for execution of the design using the postprocessors.

Key Features

The key features inherent in these post-processors are summarized as follows.

- Works Only with ANSYS SHELL181 Elements.
- ANSYS Input Units Must be *feet* and *kips.*
- User Must Specify *Element Coordinate Systems* in Directions of the Intended Placement of Reinforcing Steel.
- Design Is Based on Provisions of ACI 349-01 “Code Requirements for Nuclear Safety Related Concrete Structures” [(1)].
- Program Checks Minimum Reinforcement in Accordance with Section 7.12 of ACI 349-01.
- Program Determines Area of Reinforcing Steel for Out-of-Plane Bending Combined With In-Plane Axial Loads.
- Program Checks Out-of-Plane (Transverse) Shears with In-Plane Axial Loads.
- Program Determines Area of Reinforcing Steel for In-Plane Shear in Shear Walls in Accordance with Chapter 21 of ACI 349-01 [(1)]. In-Plane Shear in Slabs Incorporated in Axial Load and Combined with Out-of-Plane Bending.
- Program Does Not Consider Slenderness Effects on Wall Capacities.
- Program Identifies Controlling Load Case Numbers.

(1) The wall.exe and slab.exe programs perform evaluation of concrete walls and slabs based on ACI 349-01. Regulatory Guide 1.142 advocates the use of the latest edition of ACI 349. In most respects ACI 349-01 is very much similar to or the same as ACI 349-06. The primary difference is in section 9.3.4 of ACI 349-01 where the limit on shear capacity of shear walls is overly conservative. ACI 349-06 removes these restrictions on shear wall capacity. In the wall.exe program, the phi factor of 0.85 taken from ACI 349-06 is used to calculate shear capacity instead of the phi factor of 0.60 required in ACI 349-01. Appendix C, “Alternative Load and Strength Reduction Factors” of ACI 349-06 is used to maintain load factor compatibility with ACI 349-01.

Theoretical Basis for Performing Reinforced Concrete Design

The out-of-plane flexural (Mx, My) and twisting (Mxy) moments can be combined to produce the largest (principal) bending moment Mn:

$$Mn(\theta) := Mx\cdot(\cos(\theta))^2 + My\cdot(\sin(\theta))^2 - Mxy\cdot\sin(2\cdot\theta)$$

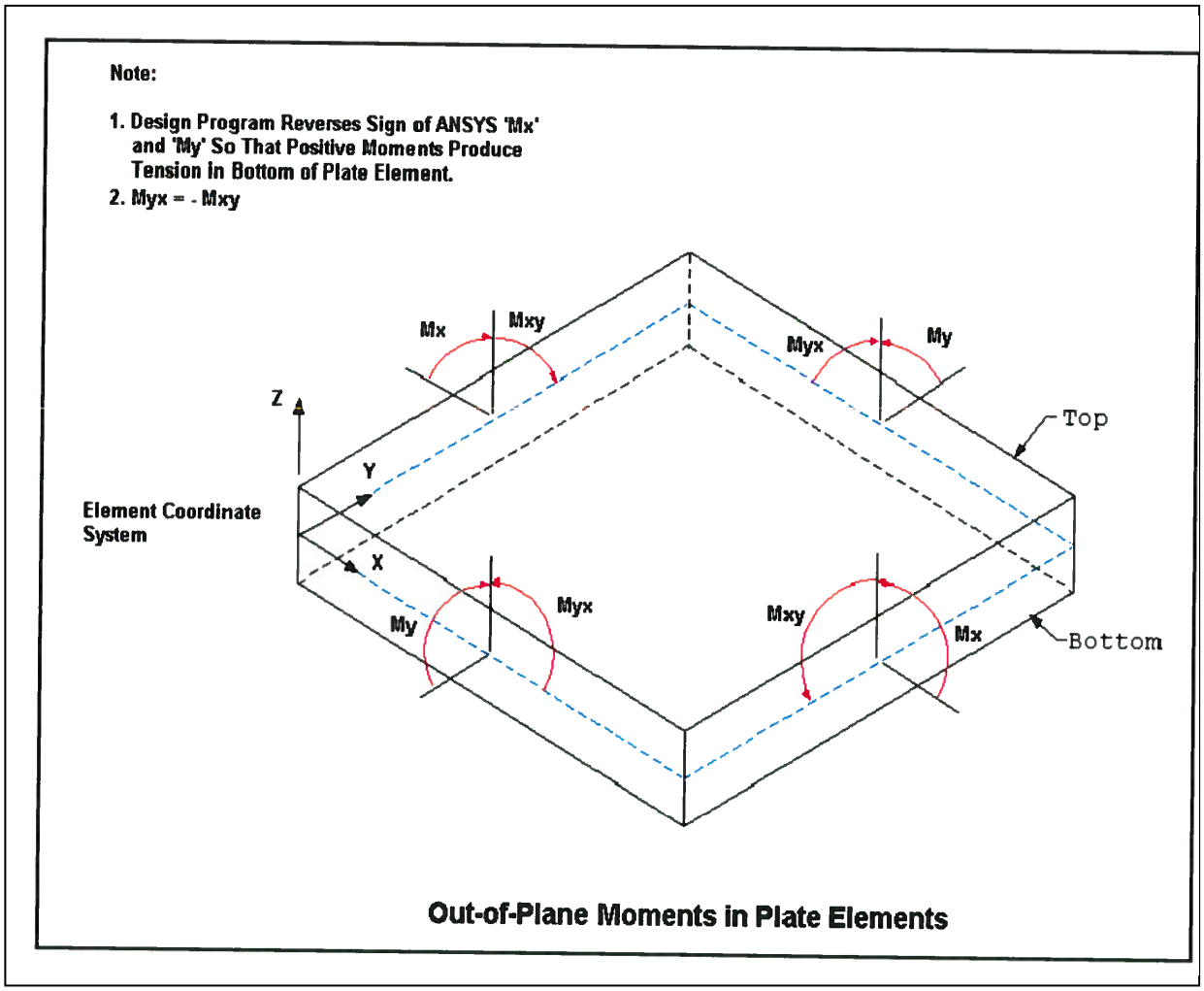
along the principal direction defined by the angle:

$$\tan(2\cdot\theta p) := \frac{2\cdot Mxy}{My - Mx}$$

The effect of in-plane forces Nx, Ny, Nxy must be superimposed on the effect of moments Mx, My and Mxy, in order to calculate the required reinforcement. Since the in-plane forces have their own principal direction defined by the angle:

$$\tan(2\cdot\theta p) := \frac{2\cdot Nxy}{Ny - Nx}$$

which is different, in general, from the principal direction of the moments, it is difficult to assess the most critical orientation. In lieu of a more complicated theoretical development, a simplified, yet conservative approach is to increase the bending moments Mx and My, as indicated below.



Bottom Steel

$Mx^* = Mx + |Mxy|$; $My^* = My + |Mxy|$

1) If Mx^* and My^* both >= 0, done.

2) If $Mx^* < 0$, then

$Mx^* = 0$; $My^* = My + |Mxy^2/Mx|$

If My^* >= 0, done. Else $My^* = 0$.

3) If $My^* < 0$, then

$My^* = 0$; $Mx^* = Mx + |Mxy^2/My|$

If Mx^* >= 0, done. Else $Mx^* = 0$.

Top Steel

$Mx^* = Mx - |Mxy|$; $My^* = My - |Mxy|$

1) If Mx^* and My^* both <= 0, done.

2) If $Mx^* > 0$, then

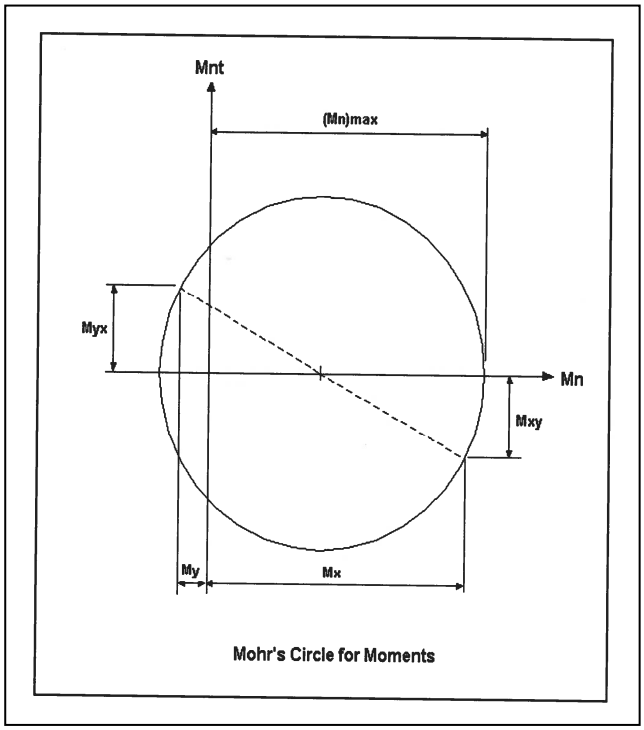
$Mx^* = 0$; $My^* = My - |Mxy^2/Mx|$

If My^* <= 0, done. Else $My^* = 0$.

3) If $My^* > 0$, then

$My^* = 0$; $Mx^* = Mx - |Mxy^2/My|$

If Mx^* <= 0, done. Else $Mx^* = 0$.



The maximum and minimum axial forces are:

$$(Nn)max=(Nx+Ny)/2 +(((Nx-Ny)/2)^2 + (Nxy)^2)^{1/2}$$

$$(Nn)max=(Nx+Ny)/2 -(((Nx-Ny)/2)^2 + (Nxy)^2)^{1/2}$$

For wall design, the flexural demands are (Mx*, Nx) and (My*, Ny). The effect of Nxy is excluded from flexural considerations, as it is addressed separately in the design of in-plane shear per ACI 349-01 sections 11.10, 11.12 and 21.6. The flexural and in-plane shear reinforcements are added together to arrive at the total wall reinforcement.

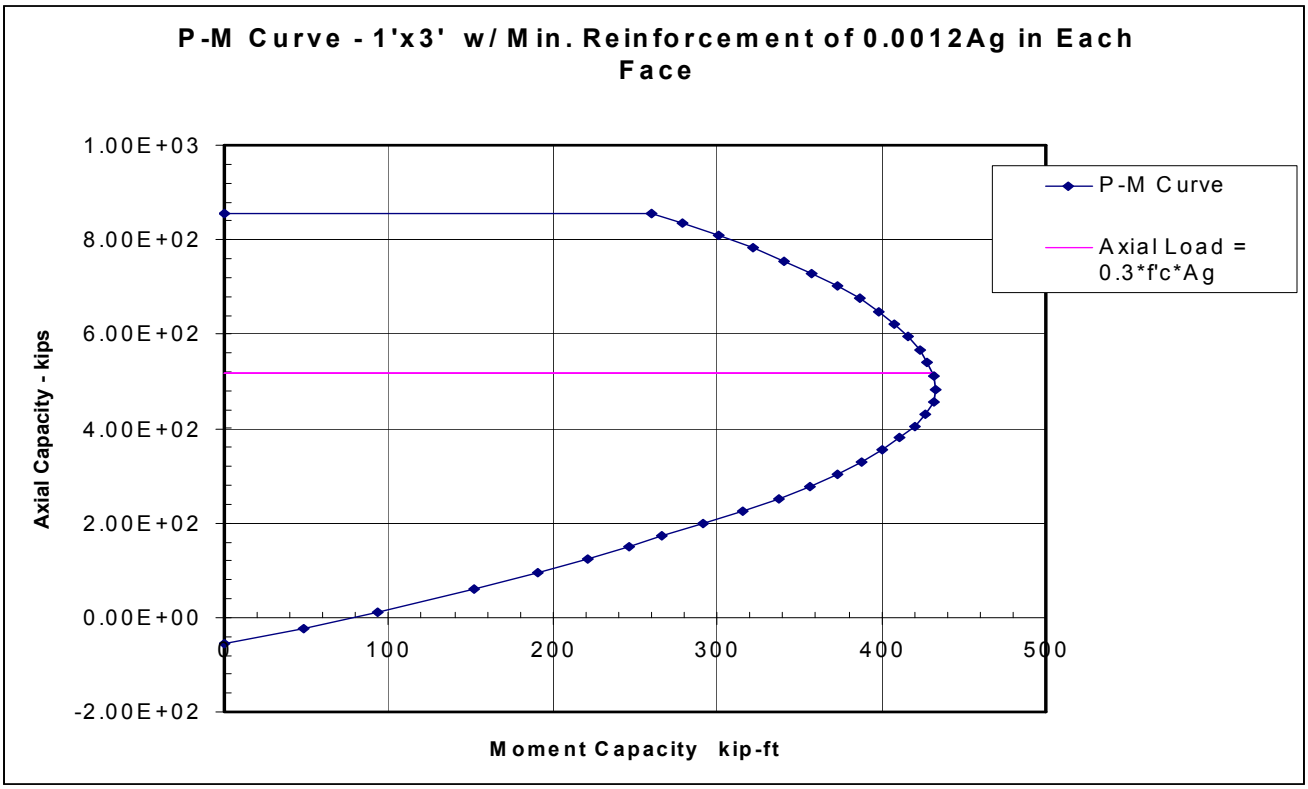
For slab design, the flexural demands are (Mx*, (Nn)max) and (My*, (Nn)max). Since slab design does not address in-plane shear separately, the effect of (Nxy) is implicitly considered by using (Nn)max.

The interaction between axial force and the modified moment Mx* or My*, is obtained as for an ordinary rectangular column. A typical P-M interaction diagram is shown below. From this diagram, the demand/capacity (D/C) ratio of the proposed wall/slab (of a given thickness and reinforcement) is obtained; if unsatisfactory, the reinforcement and/or thickness can be increased until the D/C becomes less than one.

Once a satisfactory (i.e. D/C<1) reinforcement has been determined for the selected wall thickness, as described above, additional reinforcement must be provided to account for the effect of a shear force acting in the plane of the wall (Nxy), calculated per the requirements of ACI 349-01 Section 11.10, 11.12, 21.6. Whereas the axial-flexural reinforcement is based on the forces and moments acting on a particular finite element, the shear reinforcement must be

based on the total shear force acting on an entire wall or wall segment, in accordance with ACI 349.

Axial Load – Moment Interaction Diagram:



Execution Methodology

The following is a list of the steps taken to determine slab reinforcement requirements using these programs in conjunction with ANSYS.

1. Create element components in ANSYS for each slab for which reinforcement requirements are to be calculated, based on the groupings identified in drawings and markups.
2. Set pointers in ANSYS to the set of load combinations for which slab design is to be executed.
3. Execute the ANSYS macro “Slab_sr” to obtain element stress resultants NX, NY, NXY, MX, MY, and MXY for each element in the slab component and for each load combination considered. For the slab design, the output file name for this step is of the form “slab component name.Forces”. The reinforced concrete design parameters (i.e., f’c, fy, top and bottom cover dimensions) are incorporated in this file.
4. Execute “slab.exe” with the input file “*.Forces” created in step 3. The output file is of the form “slab component name.Reinf” which contains calculated required flexural/axial reinforcement in each element of the slab. Element shear strength and demanding transverse shear forces are also calculated. Abridged files that contain only the appropriate portion of the output are also generated for creation of flexural/axial reinforcement and transverse shear demand/capacity plots. The controlling load case numbers are identified for each element item.
5. The list of slab components in “SlabComp.TXT” is looped through steps 3 and 4 to have all the slabs processed. Abridged files “SlabBendReinf.out” and “SlabShearReinf.out” created in step 4 that contain calculated flexural/axial reinforcement and transverse shear demand and strength for the elements of all the slabs are then read in to establish element tables, i.e., “ASTX” (required area of reinforcement in top face, X-direction), “ASBX” (bottom face, X-direction), “ASTY” (top face, Y-direction), “ASBY” (bottom face, Y-direction), “SDCX” (transverse shear demand/capacity, element X face), and “SDCY” (element Y face). ANSYS database RBSlabReinf.db is saved and can be resumed later to create contour plots for these element tables.

Post-processing of shear walls follows similar steps but is more involved. The following is a list of the steps taken to determine shear wall reinforcement requirements.

1. Create element components in ANSYS for each wall for which reinforcement requirements are to be calculated, based on the groupings identified in drawings and markups. The list of wall components is put in “WallComp.TXT”. These walls are designated as “regular walls” in the following discussion. In addition, another set of wall components is created such that in-plane shear can be uniformly distributed across an entire wall. These larger so-called “in-plane shear walls” consist of continuous wall segments of same or similar thicknesses and located between floor slabs in a common vertical plane. In case of an in-plane shear wall composed of wall segments of different thicknesses, a minimum or major wall thickness is used.
2. Set pointers in ANSYS to the set of load combinations for which wall design is to be executed.
3. In-plane shear walls are processed first. Execute the ANSYS macro “Wall_sr” to obtain element stress resultants NX, NY, NXY, MX, MY, and MXY for each element in the wall component and for each load combination considered. It also extracts shear wall height and length as well as total in-plane shear at the top and bottom of the wall for each load combination. Element in-plane shear NXY are all set to zero. For the wall design, the output file name for this step is of the form “wall component name.Forces”. The reinforced concrete design parameters (i.e., f’c, fy, top and bottom cover dimensions) are incorporated in this file.
4. Execute “wall.exe” with the input file “*.Forces” created in step 3. The output file is of the form “wall component name.Reinf” which contains calculated required flexural/axial reinforcement, shear strength and demanding transverse shear forces in each element of the wall. The maximum required overall horizontal and vertical in-plane shear reinforcement in the wall are

also calculated. However, when the in-plane concrete allowable shear strength, i.e., 8 $A_{cv}\sqrt{f'_c}$, is exceeded, a large value of required in-plane shear reinforcement is assigned indicating the wall thickness needs to be increased. The original input and output format of the FORTRAN routine are modified such that manual intervention is not needed. Abridged files that contain only the appropriate portion of the output are also generated. The controlling load case numbers are identified for each element item. The required in-plane shear reinforcements are saved in a separate output file.

5. The list of in-plane shear wall components in “WallCompIPS.TXT” is looped through steps 3 and 4 to have all the walls processed. Abridged files “WallBendIPSReinf.out” and “WallInShReinf.out” are created that contain calculated flexural/axial and in-plane shear reinforcements for all the in-plane shear walls, respectively. These two output files are then read in to store required in-plane shear reinforcements in element tables, i.e., “ASH” (required area of in-plane horizontal shear reinforcement), “ASV” (required area of in-plane vertical shear reinforcement).
6. Regular walls are processed next. Following the same step 3 as described above, element stress resultants are obtained and saved in the output file “*. Forces” with which “wall.exe” is then executed. The output file is also of the form “wall component name.Reinf” which contains calculated required flexural/axial reinforcement (in-plane shear reinforcement separate), shear strength and demanding transverse shear forces in each element of the wall. However, in-plane horizontal and vertical shear reinforcement calculated for the regular wall are replaced by the elemental maximums from those obtained in step 5 for the in-plane shear walls. Note that the calculated flexural/axial reinforcement and in-plane shear reinforcement are independent. The total required reinforcement is the sum of both as done in step 7.
7. The list of regular wall components in “WallComp.TXT” is looped through step 6 to have all the walls processed. Abridged files “WallBendReinf.out” and “WallShearReinf.out” are formed to contain calculated flexural/axial and in-plane shear reinforcements, respectively. These two output files are then read in to establish element tables, i.e., “ASTX” (total required area of reinforcement in top face, X-direction), “ASBX” (bottom face, X-direction), “ASTY” (top face, Y-direction), “ASBY” (bottom face, Y-direction), “SDCX” (transverse shear demand/capacity, element X face), and “SDCY” (element Y face). The calculated wall in-plane shear reinforcement requirements stored in element tables ASH and ASV are added by placing equal amount of steel in each face to the corresponding flexural/axial requirements to obtain the total required flexural/axial reinforcements. ANSYS database RBWallReinf.db is saved and can be resumed later to create contour plots for these element tables.

Sample Results

The following provides a sample of the results for wall reinforcement design:

```
***  NAME OF STRUCTURAL COMPONENT CONTAINING ELEMENTS: W40AB1F5

 PROPERTIES FOR REINF. CONCRETE DESIGN

 CONCRETE F'C                      =   4.000 KSI
 REBAR FY                          =  60.000 KSI
 DIST. TO C.G. REINF. (BOT)        =   3.000 INCHES
 DIST. TO C.G. REINF. (TOP)        =   3.000 INCHES
 CAPACITY FACTOR                   =   0.900
 WALL SHEAR PHI FACTOR             =   0.850
 WALL IN-PLANE SHEAR SCALE FACTOR  =   1.000
 WALL THICKNESS                    =   3.333 FT
 WALL HEIGHT                       =  16.583 FT
 WALL LENGTH                       = 130.000 FT

***  NAME OF STRUCTURAL COMPONENT CONTAINING ELEMENTS: W40AB1F5

 MAXIMUM PLATE ELEMENT REINFORCING STEEL (SQ.IN./FT.)

 NUMBERS IN PARENTHESES ( ) INDICATE CONTROLLING LOAD CASE NO.
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NO.	THICKNESS (FT)	REINFORCING STEEL IN X-DIRECTION (TOP)	(BOT)	REINFORCING STEEL IN Y-DIRECTION (TOP)	(BOT)
2663	3.333	0.7679 (1)	0.7679 (1)	2.2926 (13)	1.7126 (13)
2664	3.333	0.7679 (1)	0.7679 (16)	2.3333 (13)	2.0863 (13)
2665	3.333	0.7679 (1)	0.7679 (1)	1.4790 (13)	2.0030 (13)
2666	3.333	0.7679 (1)	0.5759 (1)	1.5448 (13)	1.5388 (13)
2675	3.333	0.7679 (5)	0.7679 (1)	1.2801 (13)	1.6671 (13)
2676	3.333	0.7679 (1)	0.5759 (1)	1.1936 (13)	1.1936 (13)
2765	3.333	0.7679 (1)	0.7679 (1)	1.4998 (13)	0.7597 (5)
2766	3.333	0.7679 (5)	0.7679 (1)	1.6105 (13)	0.9116 (5)
2767	3.333	0.5759 (1)	0.8173 (13)	0.7431 (5)	1.4136 (13)
2768	3.333	0.5759 (1)	0.7679 (1)	0.9231 (5)	1.5289 (13)
2795	3.333	0.5759 (1)	0.7679 (1)	0.7031 (5)	1.3649 (13)
2796	3.333	0.5759 (1)	0.7679 (1)	0.8741 (5)	1.7635 (13)
2823	3.333	0.7679 (1)	0.7679 (1)	1.8366 (13)	1.1206 (5)
2824	3.333	0.7679 (1)	0.7679 (1)	2.0681 (13)	1.3486 (5)
2825	3.333	0.5759 (1)	0.7679 (1)	1.1105 (5)	1.7460 (13)
2826	3.333	0.5759 (1)	0.7679 (1)	1.3024 (5)	1.9598 (13)
2833	3.333	0.5759 (1)	0.7679 (1)	1.0511 (5)	1.9289 (13)
2834	3.333	0.5759 (1)	0.7679 (1)	1.1906 (5)	1.8912 (13)
2957	3.333	0.7679 (1)	0.7679 (1)	0.9599 (13)	0.7679 (10)
2958	3.333	0.7679 (1)	0.7679 (10)	0.8669 (13)	0.7679 (9)
2959	3.333	0.7679 (9)	0.7679 (1)	0.5759 (1)	0.8639 (13)
2960	3.333	0.9079 (13)	0.5759 (1)	0.7679 (3)	0.7679 (1)
3047	3.333	0.7959 (13)	0.5759 (1)	1.0131 (13)	0.7378 (5)
3048	3.333	0.7679 (1)	0.7679 (1)	1.2769 (13)	0.7679 (9)
3049	3.333	1.1749 (13)	0.5759 (1)	0.7679 (1)	0.7679 (1)
3050	3.333	0.7679 (1)	0.7679 (1)	0.8342 (5)	1.0889 (13)
3057	3.333	1.4169 (13)	0.5759 (1)	0.7679 (5)	0.7679 (1)
3058	3.333	0.7679 (5)	0.7679 (1)	0.5759 (1)	0.8639 (5)
3153	3.333	0.5759 (1)	0.7679 (1)	0.5759 (1)	0.8639 (13)
3154	3.333	1.0819 (13)	0.5759 (1)	0.7679 (5)	0.7679 (1)
3191	3.333	0.7679 (1)	0.7679 (1)	0.9429 (5)	0.5759 (1)
3192	3.333	0.7679 (1)	0.7679 (1)	0.9539 (13)	0.5759 (1)
3193	3.333	0.7679 (5)	0.8639 (13)	0.5759 (1)	0.8639 (5)
3194	3.333	0.5759 (1)	0.7906 (13)	0.5759 (1)	0.8639 (5)
3277	3.333	0.7679 (1)	0.7679 (10)	0.9149 (13)	0.5759 (1)
3278	3.333	0.7679 (1)	0.7679 (9)	0.9519 (13)	0.5759 (1)
3279	3.333	0.7679 (1)	0.7679 (1)	1.0019 (13)	0.5759 (1)
3280	3.333	0.5759 (1)	0.7679 (1)	0.5759 (1)	0.8639 (13)
3281	3.333	0.5759 (1)	0.7679 (1)	0.5759 (1)	0.8639 (13)
3282	3.333	0.5759 (1)	0.7813 (14)	0.5759 (1)	0.8639 (13)
3292	3.333	0.5759 (1)	0.7679 (1)	0.5759 (1)	1.0209 (13)
3293	3.333	0.5759 (1)	0.7679 (1)	0.5759 (1)	1.0419 (13)
3294	3.333	0.5759 (1)	0.7679 (1)	0.5759 (1)	0.9579 (13)
3409	3.333	1.0179 (13)	0.5759 (1)	2.0331 (37)	1.9181 (37)
3410	3.333	0.8506 (13)	0.7679 (5)	2.6324 (37)	2.1914 (37)
3411	3.333	0.7679 (1)	0.8053 (18)	1.6987 (29)	2.2259 (37)
3412	3.333	0.7679 (1)	0.7679 (1)	2.6237 (37)	1.9263 (29)
3425	3.333	0.5759 (1)	0.7679 (1)	0.5759 (1)	0.8639 (13)

3426	3.333	0.5759 (1)	0.7679 (1)	0.5759 (1)	0.9129 (13)
3556	3.333	0.8506 (13)	0.5759 (1)	0.8769 (5)	0.5759 (1)
3557	3.333	0.7679 (1)	0.7679 (1)	0.9079 (5)	0.7679 (10)
3558	3.333	1.1079 (13)	0.5759 (1)	0.7679 (1)	0.7679 (1)
3559	3.333	0.7679 (1)	0.7679 (1)	0.7679 (5)	0.8639 (5)
3566	3.333	1.2119 (13)	0.5759 (1)	0.7679 (5)	0.7679 (1)
3567	3.333	0.5759 (1)	0.7679 (1)	0.5759 (1)	0.7679 (1)
3644	3.333	0.7679 (5)	0.7679 (1)	0.8639 (5)	0.7679 (9)
3645	3.333	0.7679 (1)	0.5759 (1)	0.8639 (5)	0.7679 (10)
3646	3.333	0.5759 (1)	0.7679 (1)	0.5762 (5)	0.8639 (5)
3647	3.333	0.7679 (1)	0.5759 (1)	0.5759 (1)	0.7679 (1)
3654	3.333	1.2939 (37)	0.7679 (26)	1.5984 (37)	1.4991 (29)
3655	3.333	0.7679 (5)	0.7679 (1)	1.4997 (29)	1.8503 (37)
3658	3.333	0.5759 (1)	0.7679 (1)	0.7679 (5)	0.7679 (1)
3659	3.333	0.8639 (13)	0.5759 (1)	0.7679 (1)	0.7679 (1)
3770	3.333	0.7679 (1)	0.5759 (1)	1.1009 (5)	1.0339 (5)
3771	3.333	0.7679 (5)	0.7679 (1)	0.9163 (5)	0.8023 (5)
3772	3.333	0.7679 (1)	0.5759 (1)	0.8371 (5)	0.8639 (5)
3773	3.333	0.5759 (1)	0.7679 (1)	0.7214 (5)	0.8639 (5)
3780	3.333	0.9589 (13)	0.5759 (1)	0.8639 (5)	0.7679 (1)
3781	3.333	0.5759 (1)	0.7679 (1)	0.6129 (5)	0.8172 (5)
3892	3.333	0.7679 (1)	0.7679 (1)	1.5154 (29)	1.1544 (29)
3893	3.333	0.7679 (1)	0.7679 (10)	1.3540 (5)	1.1490 (5)
3894	3.333	0.7679 (6)	0.7679 (1)	1.0826 (29)	1.2466 (29)
3895	3.333	0.9589 (13)	0.5759 (1)	0.9475 (29)	0.9475 (29)
3922	3.333	0.5759 (1)	0.7679 (1)	0.9984 (29)	1.1124 (29)
3923	3.333	1.1059 (13)	0.5759 (1)	0.8639 (5)	0.8639 (5)
4030	3.333	0.7679 (1)	0.7679 (1)	1.7088 (37)	1.2533 (29)
4031	3.333	0.5759 (1)	0.8639 (13)	1.2255 (29)	1.4135 (37)
4035	3.333	0.5759 (1)	0.9629 (20)	1.1559 (29)	1.4789 (37)
4126	3.333	0.7679 (1)	0.7679 (1)	2.3155 (37)	1.6396 (29)
4127	3.333	0.7679 (5)	0.7679 (1)	1.9283 (37)	1.4305 (29)
4128	3.333	0.5759 (1)	0.8639 (13)	1.5537 (29)	1.9909 (37)
4129	3.333	0.5759 (1)	0.8586 (14)	1.3802 (29)	1.6209 (37)
4140	3.333	0.5759 (1)	1.0239 (20)	1.4159 (29)	1.8777 (37)
4141	3.333	0.5759 (1)	1.0589 (20)	1.3039 (29)	1.7520 (37)

*** NAME OF STRUCTURAL COMPONENT CONTAINING ELEMENTS: W40AB1F5

MAXIMUM PLATE ELEMENT TRANSVERSE SHEARS (KIPS/FT)

NUMBERS IN PARENTHESES ( ) INDICATE CONTROLLING LOAD CASE NO.
AN ASTERISK (*) NEXT TO VALUES OF PHI*VN INDICATES THAT THE ELEMENT SHEAR STRENGTH IS EXCEEDED.
ELEMENT SHEAR STRENGTH, PHI*VN, INCLUDES CAPACITY FACTOR.

NO.	THICKNESS (FT)	QX	PHI*VN (X)	QY	PHI*VN (Y)
2663	3.333	-7.79 (20)	44.17	-37.12 (13)	13.16 *
2664	3.333	6.81 (5)	43.71	-9.30 (13)	6.66 *
2665	3.333	13.73 (13)	44.32	-12.62 (13)	17.22
2666	3.333	34.31 (13)	44.70	4.35 (5)	17.23
2675	3.333	30.69 (37)	44.61	3.29 (5)	20.69
2676	3.333	57.61 (37)	44.86 *	1.57 (5)	23.16
2765	3.333	6.76 (37)	42.25	-40.26 (13)	31.91 *
2766	3.333	1.77 (37)	42.60	-54.79 (13)	28.79 *
2767	3.333	-7.78 (20)	44.78	-14.84 (13)	32.27
2768	3.333	-1.45 (20)	44.70	-21.95 (13)	28.55
2795	3.333	-19.58 (44)	44.95	4.63 (5)	30.72
2796	3.333	-3.93 (44)	44.83	5.34 (5)	27.75
2823	3.333	-3.92 (20)	44.71	-57.95 (13)	24.54 *
2824	3.333	-7.60 (20)	44.55	-51.70 (13)	19.92 *
2825	3.333	1.56 (29)	43.68	-23.76 (13)	24.72
2826	3.333	4.84 (37)	43.84	-20.38 (13)	20.85
2833	3.333	6.17 (13)	43.80	4.81 (5)	24.67
2834	3.333	15.30 (13)	44.20	4.15 (5)	22.24
2957	3.333	-8.07 (44)	44.36	-48.17 (38)	44.29 *
2958	3.333	-3.96 (20)	44.71	-16.09 (37)	35.72
2959	3.333	9.71 (13)	42.63	-24.29 (44)	50.27
2960	3.333	31.93 (13)	42.47	-3.35 (44)	50.70
3047	3.333	-5.35 (12)	44.92	5.81 (5)	30.12
3048	3.333	4.17 (37)	42.03	-15.90 (37)	33.90
3049	3.333	-37.96 (20)	44.87	11.50 (13)	38.01
3050	3.333	-19.60 (20)	44.87	-3.38 (20)	51.33
3057	3.333	-65.17 (44)	44.87 *	9.26 (5)	37.05
3058	3.333	-40.18 (44)	45.05	2.89 (5)	33.42
3153	3.333	26.49 (13)	43.02	7.33 (5)	38.02
3154	3.333	59.08 (13)	42.42 *	2.87 (5)	38.39
3191	3.333	9.44 (37)	43.03	-49.87 (18)	46.70 *
3192	3.333	6.17 (37)	43.03	-68.17 (20)	50.07 *
3193	3.333	-5.08 (20)	44.25	-23.27 (20)	49.66

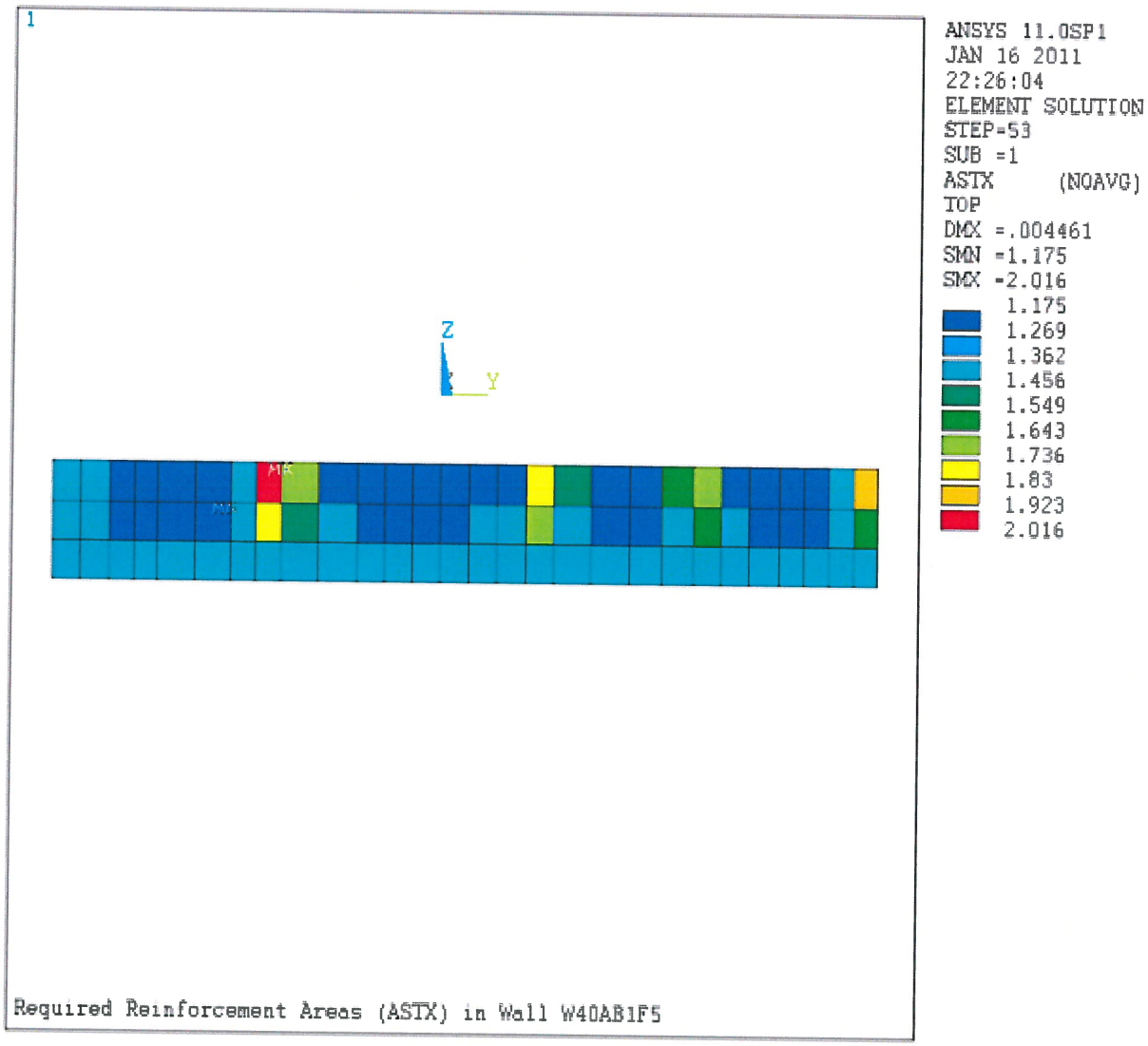
3194	3.333	-0.98 (20)	44.25	-33.34 (20)	49.86
3277	3.333	1.63 (37)	43.02	-76.32 (20)	50.26 *
3278	3.333	-3.37 (20)	44.32	-77.01 (20)	50.43 *
3279	3.333	-7.74 (20)	44.38	-70.84 (44)	50.50 *
3280	3.333	-0.30 (28)	44.26	-38.47 (20)	50.11
3281	3.333	-0.44 (28)	44.31	-38.99 (20)	50.19
3282	3.333	2.07 (13)	42.45	-35.25 (44)	50.41
3292	3.333	-2.14 (44)	44.53	9.05 (5)	41.30
3293	3.333	3.58 (13)	42.33	9.07 (5)	40.73
3294	3.333	10.26 (13)	42.68	8.82 (5)	39.68
3409	3.333	-50.68 (20)	43.99 *	44.33 (37)	13.06 *
3410	3.333	-21.26 (44)	43.85	31.50 (37)	4.83 *
3411	3.333	-29.41 (44)	43.97	-18.03 (18)	51.49
3412	3.333	-7.98 (44)	43.86	-17.21 (37)	10.43 *
3425	3.333	-17.89 (20)	44.44	7.16 (5)	40.86
3426	3.333	-7.81 (44)	44.49	8.55 (5)	41.35
3556	3.333	5.28 (37)	42.95	4.43 (5)	33.32
3557	3.333	7.67 (13)	42.85	-25.62 (44)	49.67
3558	3.333	-35.12 (20)	44.37	7.31 (13)	43.67
3559	3.333	-14.93 (20)	44.33	-5.91 (20)	49.40
3566	3.333	-61.03 (20)	44.44 *	5.59 (29)	41.07
3567	3.333	-35.41 (20)	44.53	1.73 (29)	40.51
3644	3.333	1.39 (13)	41.56	-25.80 (13)	39.30
3645	3.333	9.04 (37)	42.71	-16.44 (20)	49.52
3646	3.333	5.05 (37)	41.93	-4.15 (20)	50.72
3647	3.333	29.57 (37)	42.52	3.16 (5)	35.63
3654	3.333	-63.77 (20)	44.54 *	30.75 (37)	18.75 *
3655	3.333	-39.57 (44)	44.55	7.07 (29)	16.86
3658	3.333	6.64 (13)	42.99	18.33 (13)	41.61
3659	3.333	34.80 (13)	40.46	10.81 (13)	43.76
3770	3.333	-9.07 (20)	44.41	3.68 (29)	25.15
3771	3.333	-2.20 (20)	44.12	-16.09 (13)	36.80
3772	3.333	-31.12 (20)	44.22	10.52 (13)	36.32
3773	3.333	-10.34 (20)	44.02	2.47 (29)	30.50
3780	3.333	-41.05 (20)	43.52	7.94 (13)	38.98
3781	3.333	-13.17 (20)	44.13	12.54 (37)	39.77
3892	3.333	-5.85 (20)	44.40	-36.23 (13)	29.56 *
3893	3.333	5.55 (29)	41.35	-12.04 (13)	29.84
3894	3.333	16.26 (37)	43.04	-11.84 (13)	30.64
3895	3.333	33.69 (37)	42.22	2.29 (13)	34.24
3922	3.333	36.33 (13)	43.24	1.59 (29)	25.59
3923	3.333	62.50 (13)	43.17 *	4.38 (13)	36.74
4030	3.333	-4.91 (20)	44.51	-47.82 (37)	26.38 *
4031	3.333	6.28 (13)	43.04	-17.85 (37)	26.63
4035	3.333	16.42 (13)	43.32	-7.64 (20)	54.22
4126	3.333	6.68 (37)	42.90	-36.77 (37)	17.09 *
4127	3.333	1.76 (37)	42.25	-47.55 (37)	22.11 *
4128	3.333	-7.39 (44)	44.03	-11.14 (37)	18.69
4129	3.333	-1.85 (52)	44.01	-17.38 (37)	22.78
4140	3.333	-18.56 (44)	44.41	3.25 (29)	18.32
4141	3.333	-4.96 (44)	44.33	-9.33 (20)	55.05

*** NAME OF STRUCTURAL COMPONENT CONTAINING ELEMENTS: W40AB1F5

MAXIMUM REQUIRED WALL SHEAR REINFORCEMENT

NUMBERS IN PARENTHESES ( ) INDICATE CONTROLLING LOAD CASE NO.

HORIZONTAL REINFORCEMENT = 1.1999 SQ.IN./FT (1)
VERTICAL REINFORCEMENT = 1.1999 SQ.IN./FT (5)
NO. OF CURTAINS OF REINF. = 2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Y
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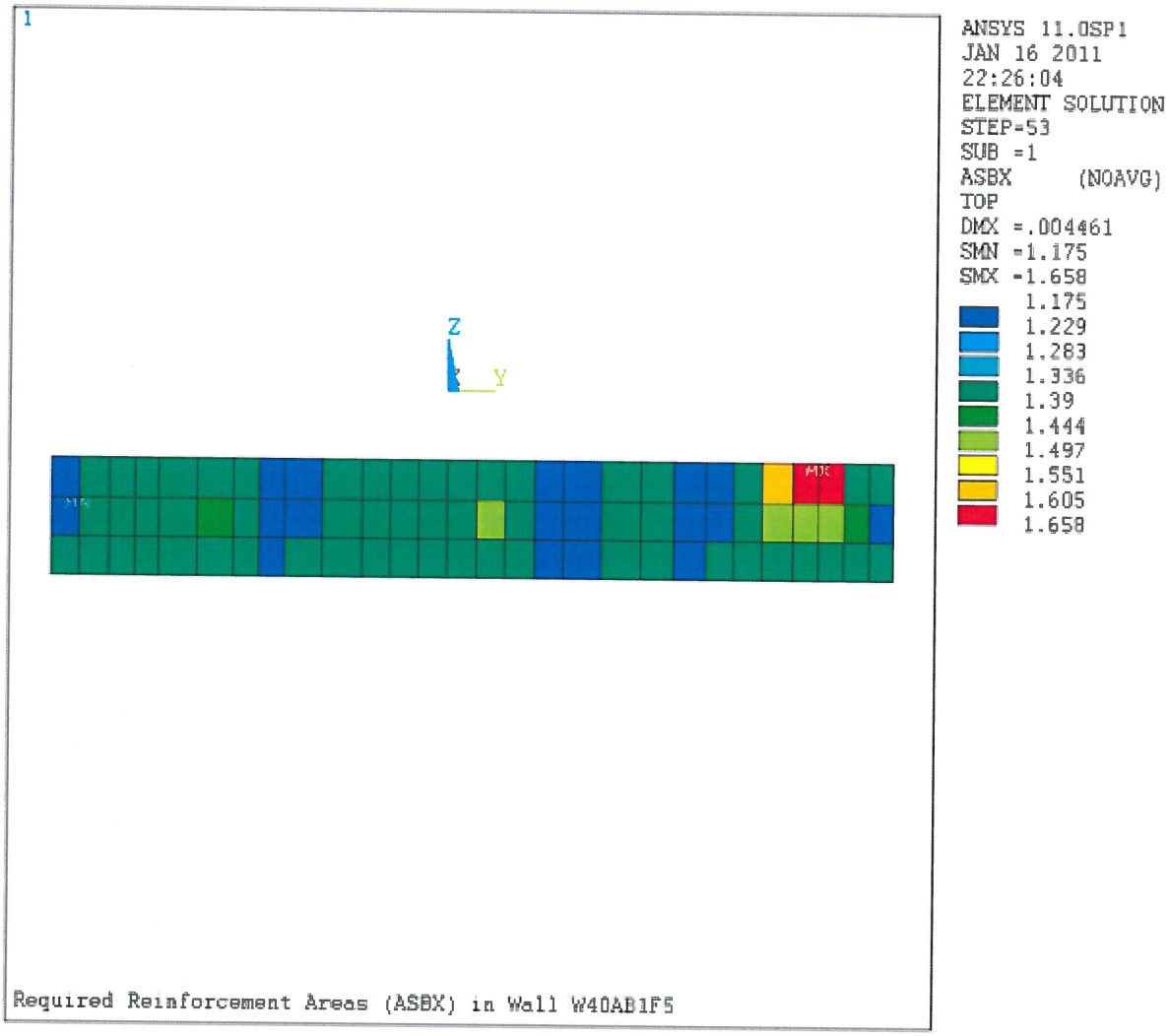
JAN 16 2011
22:26:04
ELEMENT SOLUTION
STEP=53
SUB =1
ASTX (NOAVG)
TOP
DMX =.004461
SMN =1.175
SMX =2.016
1.175
1.269
1.362
1.456
1.549
1.643
1.736
1.83
1.923
2.016
Required Reinforcement Areas (ASTX) in Wall W40AB1F5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Y
MX
MN
ANSYS 11.0SP1
JAN 16 2011
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SUB =1
ASBX (NOAVG)
TOP
DMX =.004461
SMN =1.175
SMX =1.658
1.175
1.229
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1.444
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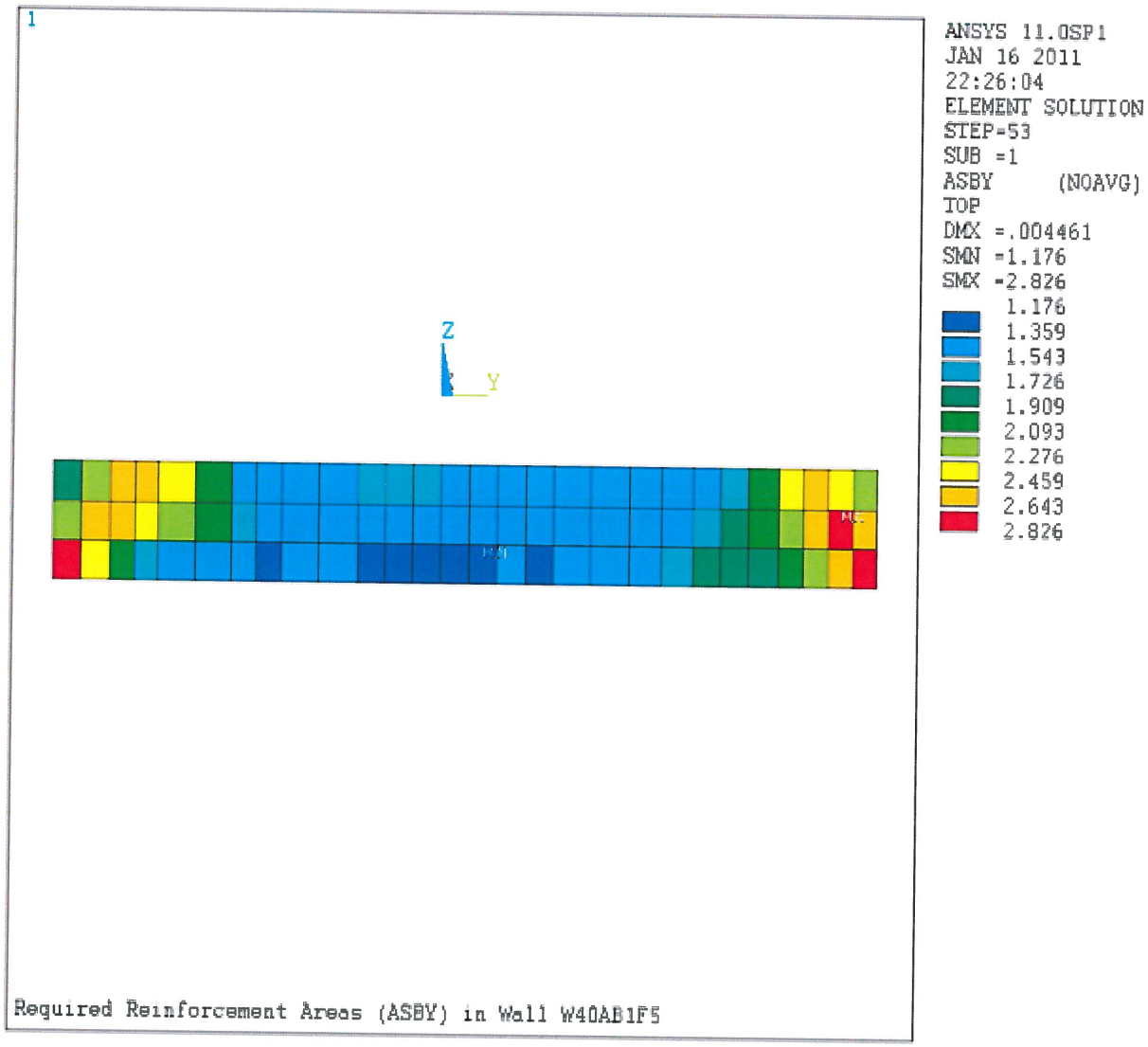
1.605
1.658
Required Reinforcement Areas (ASBX) in Wall W40AB1F5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ELEMENT SOLUTION
STEP=53
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DMX =.004461
SMN =1.176
SMX =2.826
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1.359
1.543
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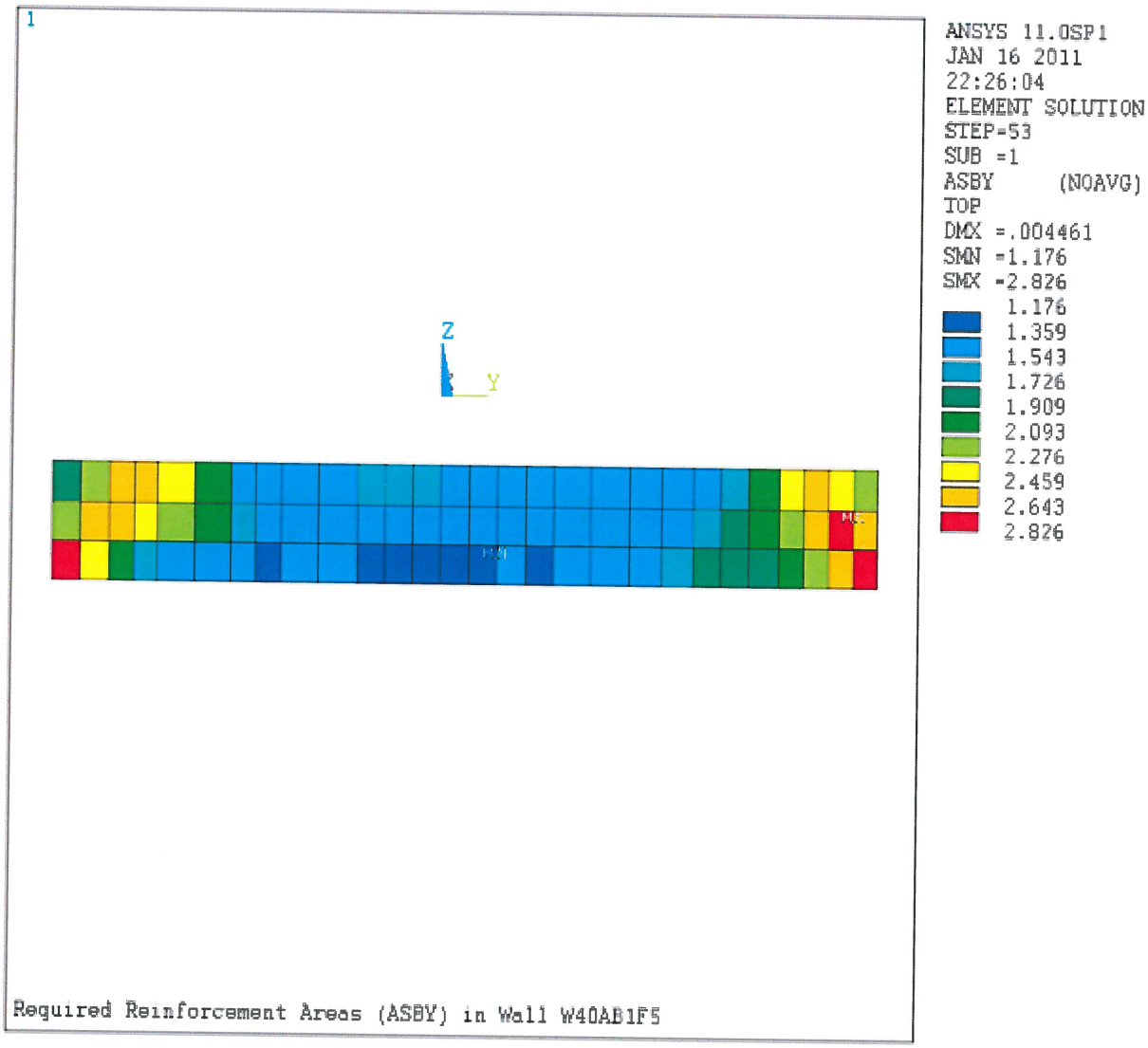
1.909
2.093
2.276
2.459
2.643
2.826
Required Reinforcement Areas (ASBY) in Wall W40AB1F5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ANSYS 11.0SP1
JAN 16 2011
22:26:04
ELEMENT SOLUTION
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SUB =1
ASBY (NOAVG)
TOP
DMX =.004461
SMN =1.176
SMX =2.826
1.176
1.359
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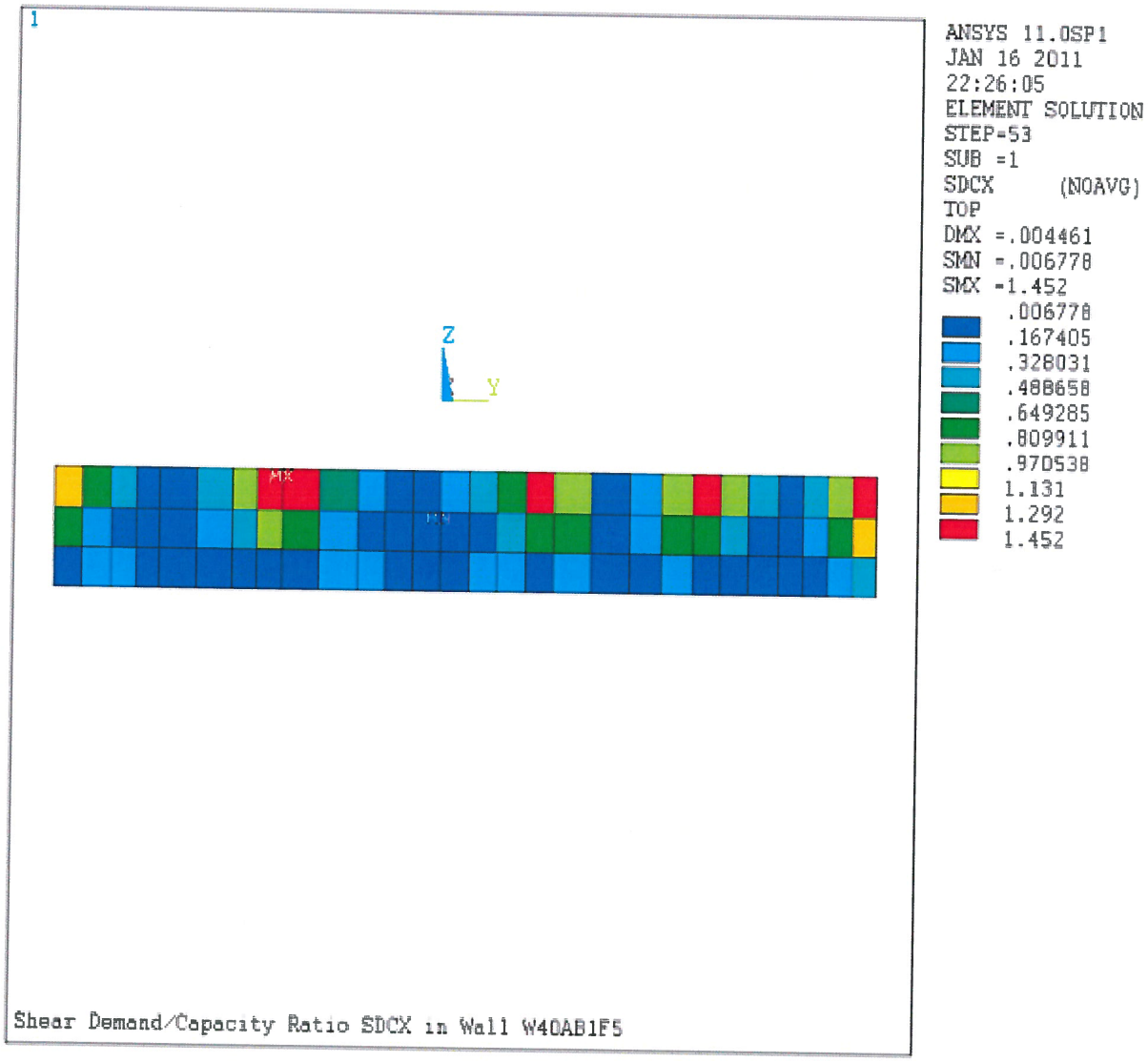
1.909
2.093
2.276
2.459
2.643
2.826
Required Reinforcement Areas (ASBY) in Wall W40AB1F5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ELEMENT SOLUTION
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SUB =1
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TOP
DMX =.004461
SMN =.006778
SMX =1.452
.006778
.167405
.328031
.488658
.649285
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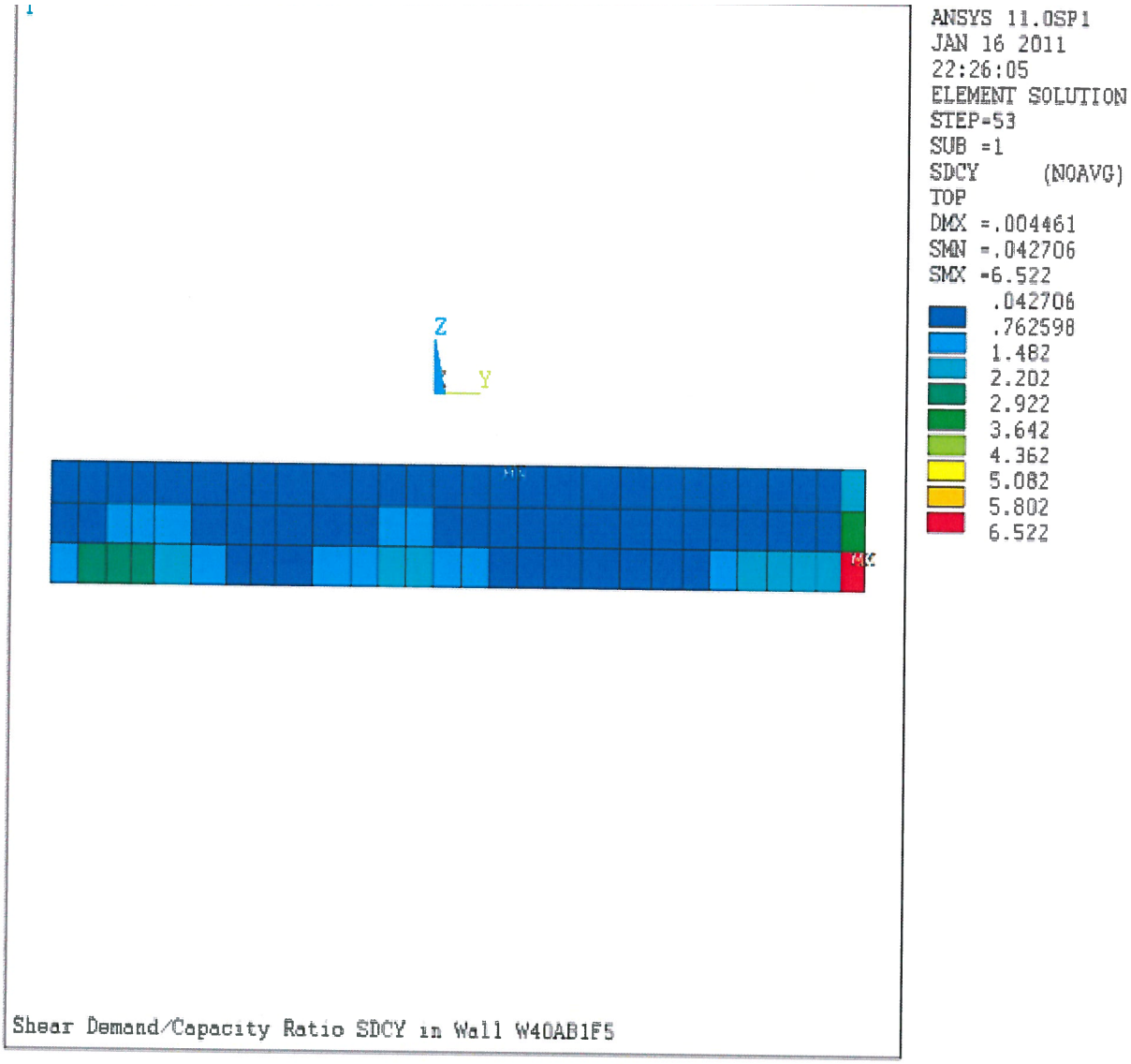
.970538
1.131
1.292
1.452
Z
Y
MX
MN
Shear Demand/Capacity Ratio SDCX in Wall W40AB1F5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JAN 16 2011
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ELEMENT SOLUTION
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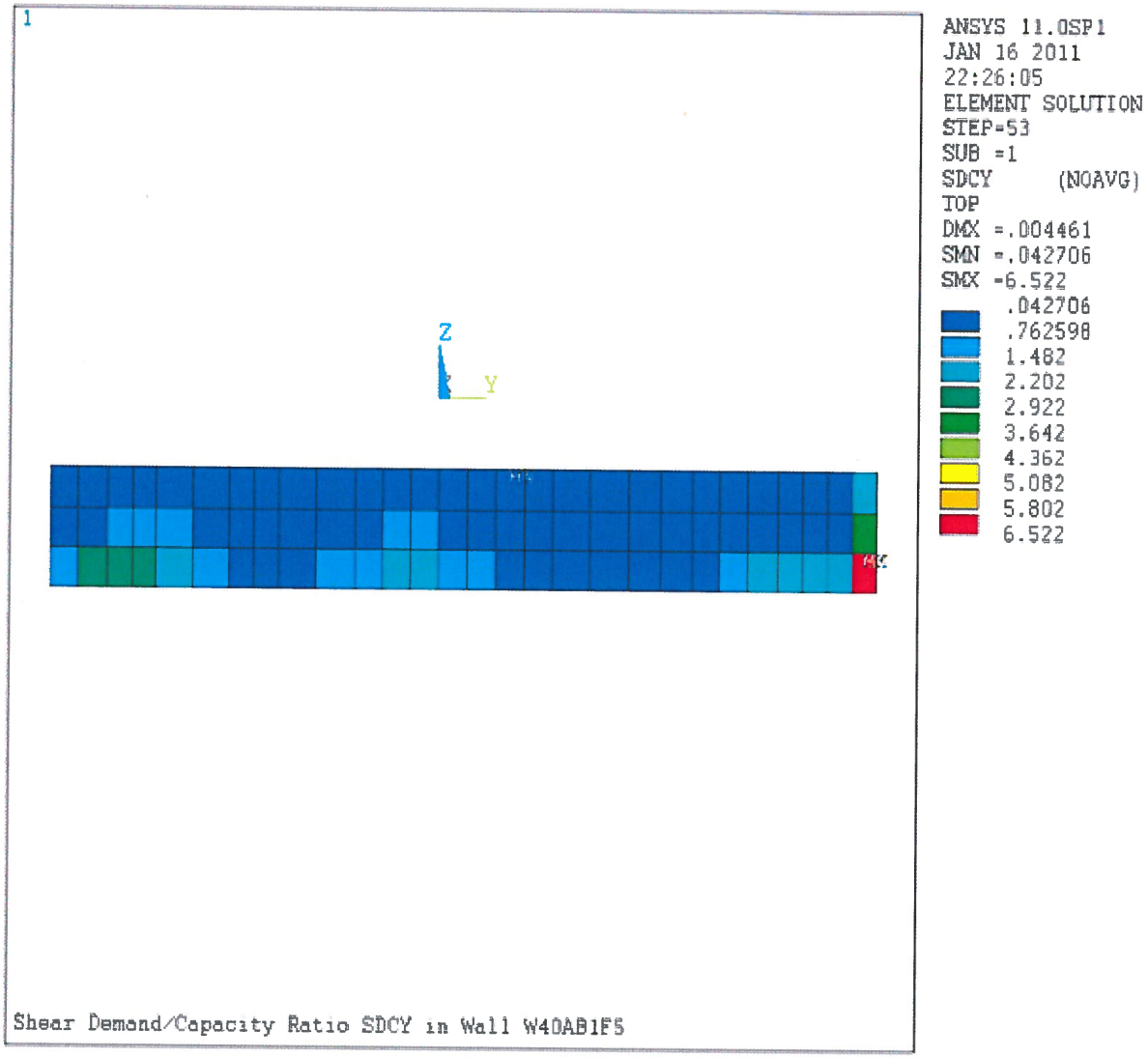
SUB =1
SDCY (NOAVG)
TOP
DMX =.004461
SMN =.042706
SMX =6.522
.042706
.762598
1.482
2.202
2.922
3.642
4.362
5.082
5.802
6.522
Z
Y
Shear Demand/Capacity Ratio SDCY in Wall W40AB1F5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Z
Y
ANSYS 11.0SP1
JAN 16 2011
22:26:05
ELEMENT SOLUTION
STEP=53
SUB =1
SDCY (NOAVG)
TOP
DMX =.004461
SMN =.042706
SMX =6.522
.042706
.762598
1.482
2.202
2.922
3.642
4.362
5.082
5.802
6.522
Shear Demand/Capacity Ratio SDCY in Wall W40AB1F5