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

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Revision History

Revision	Page	Description
0	All	Initial Issue
1	All	Issued to document revisions of the methodology used for seismic response analyses and enhancements made to the structural models; sections 1, 2.0-2.4, 3.0-3.3, 4.1, and 6. Other sections were not completely updated and may be out of date.

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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 8.3).

Table of Contents

List of Tables ... iii
List of Figures ... iv
List of Appendices ... vi
List of Acronyms ... viii
1.0 Introduction and Purpose ... 1
1.1 Description of A/B ... 2
2.0 Methodology for Development of A/B FE Models ... 2
2.1 Structural Geometry ... 2
2.2 Material Properties ... 7
2.3 Dynamic FE Structural Model ... 7
2.3.1 Structural Discretization and Finite Element Types ... 7
2.3.2 Modeling of Dynamic Stiffness ... 8
2.3.3 Equivalent Dynamic Mass ... 9
2.3.4 Modeling of Equipment ... 9
2.4 Detailed FE Structural Model ... 20
2.5 Lumped-Mass Stick Model ... 25
3.0 Validation of A/B Dynamic Models ... 31
3.1 1g Static Verification Analysis Results ... 31
3.2 Modal Analysis Results and Mesh Size Verification ... 36
3.3 Validation of Model Translation from ANSYS to SASSI ... 40
3.4 Validation of Lumped Mass Stick Model ... 42
4.0 Soil Structure Interaction Analysis ... 44
4.1 Methodology ... 44
4.2 Results of Lumped Mass Stick Model SSI Analyses ... 44
4.2.1 Maximum Forces and Moments ... 45
4.2.2 Maximum Relative Displacements ... 45
4.2.3 Maximum Absolute Accelerations ... 45
4.2.4 Basement In-Structure Response Spectra ... 45
4.2.5 Seismic Horizontal Sliding Shear and Vertical Force Demands ... 46
4.3 Results of Dynamic FE Model SSI Analyses ... 59
5.0 Static and Dynamic Analysis of Detailed FE Structural Model of A/B ... 62
5.1 Loads and Load Combinations for Seismic Structural Integrity Evaluation of A/B ... 62
5.1.1 Dead Loads (D) ... 62
5.1.2 Live Loads (L) ... 62
5.1.3 Static Ground Water (F) ... 62
5.1.4 Static Lateral Earth Load (H) ... 63
5.1.5 SSE Loads (E_{ss}) ... 63
5.1.6 Other Applicable Load Cases ... 63
5.1.7 Load Combinations ... 63
5.2 Response Spectrum Analysis Methodology ... 67
5.2.1 Determination of the Input Response Spectrum ... 67
5.2.2 Boundary Conditions for Response Spectrum Analysis ... 67
5.2.3 Combined Modal Responses: Lindley-Yow Method ... 67
5.3 Static and Response Spectrum Analysis Results ... 72
5.3.1 Base Shear ... 72
5.3.2 Structural Demands of Main Structural Components ... 72
5.4 Structural Integrity Evaluation Methodology ... 73
5.5 Structural Integrity Evaluation Results ... 74
6.0 Stability Evaluation of A/B ... 83
6.1 Stability Evaluation Methodology ... 83

7.0 Conclusion 84
8.0 References 85

List of Tables

Table 2.1-1 A/B Main Dimensions and Properties 3
Table 2.3-1 Z-coordinates of Slabs in A/B Model (Bottom to Top) 9
Table 2.3-2 X-coordinates of Walls/Columns in A/B Model (North to South) 10
Table 2.3-3 Y-coordinates of Walls/Columns in A/B Model (West to East) 11
Table 2.3-4 Stiffness Reduction for Walls with Opening(s) 12
Table 2.5-1 Centroid and Center of Rigidity and Mass Locations of Stick Model 26
Table 2.5-2 Lumped Masses and Mass Moments-of-Inertia of Stick Model 26
Table 2.5-3 Section Properties of the Beam Elements of the Lumped-Mass Stick Model 27
Table 3.1-1 Mass Distribution of FE Models 31
Table 3.1-2 Mass Properties of FE Models 31
Table 3.2-1 Frequencies of Dominant Modes (Hz) 37
Table 4.2-1 Matrix of SSI Analysis of A/B 47
Table 4.2-2 A/B Stick Model – Maximum Seismic Sliding Shear Demand (kips) 47
Table 5.1-1 Load Combinations and Load Factors for Concrete Structures 64
Table 5.1-2 A/B Structural Integrity Concrete Load Combinations 65
Table 5.3-1 Seismic Base Shear Seismic Force 72
Table 5.5-1 Typical Wall Element Forces 75
Table 5.5-2 Typical Wall Required Reinforcement 75
Table 5.5-3 Typical Structural Demands 82

List of Figures

Figure 2.1-1 US-APWR Site Layout 4
Figure 2.1-2 Typical Plan (Basement) 5
Figure 2.1-3 A/B Typical Elevation 6
Figure 2.3-1 A/B Dynamic FE Model 15
Figure 2.3-2 A/B Dynamic FE Model, Beams and Columns 15
Figure 2.3-3 A/B Dynamic FE Model Basemat 16
Figure 2.3-4 A/B Dynamic FE Model Intermediate Floor 16
Figure 2.3-5 A/B Dynamic FE Model First and Intermediate Floor 17
Figure 2.3-6 A/B Dynamic FE Model Second and Intermediate Floor 17
Figure 2.3-7 A/B Dynamic FE Model Third and Intermediate Floor 18
Figure 2.3-8 A/B Dynamic FE Model Fourth Floor and Roofs 18
Figure 2.3-9 Isometric View of SASSI FEM A/B Model 19
Figure 2.4-1 A/B Detailed FE Model 21
Figure 2.4-2 A/B Detailed FE Model, Beams and Columns 21
Figure 2.4-3 A/B Detailed FE Model Basemat 22
Figure 2.4-4 A/B Detailed FE Model Intermediate Floor 22
Figure 2.4-5 A/B Detailed FE Model First and Intermediate Floor 23
Figure 2.4-6 A/B Detailed FE Model Second and Intermediate Floor 23
Figure 2.4-7 A/B Detailed FE Model Third and Intermediate Floor 24
Figure 2.4-8 A/B Detailed FE Model Fourth Floor and Roofs 24
Figure 2.5-1 SASSI Lumped Mass Stick Model of the A/B in the XZ plane 28
Figure 2.5-2 SASSI Lumped Mass Stick Model of the A/B in the YZ plane 29
Figure 2.5-3 Isometric View of SASSI Lumped Mass Stick Model of A/B 30
Figure 3.1-1 N-S 1g Static Analysis of FE Models at NE Corner 32
Figure 3.1-2 E-W 1g Static Analysis of FE Models at NE Corner 32
Figure 3.1-3 N-S 1g Static Analysis of FE Models at NW Corner 33
Figure 3.1-4 E-W 1g Static Analysis of FE Models at NW Corner 33
Figure 3.1-5 N-S 1g Static Analysis of FE Models at SE Corner 34
Figure 3.1-6 E-W 1g Static Analysis of FE Models at SE Corner 34
Figure 3.1-7 N-S 1g Static Analysis of FE Models at SW Corner 35
Figure 3.1-8 E-W 1g Static Analysis of FE Models at SW Corner 35
Figure 3.2-1 N-S Dynamic Properties of A/B Models 38
Figure 3.2-2 E-W Dynamic Properties of A/B Models 38
Figure 3.2-3 Vertical Dynamic Properties of A/B Models 39
Figure 3.3-1 N-S Transfer Functions, Dynamic FE Model 40
Figure 3.3-2 E-W Transfer Functions, Dynamic FE Mode 41
Figure 3.4-1 Transfer Function Amplitudes for NS Response of Roof 42
Figure 3.4-2 Transfer Function Amplitudes for EW Response of Roof 43
Figure 4.2-1 Stick Model – Max. Axial Force 48
Figure 4.2-2 Stick Model – Max. N-S Shear Force 49
Figure 4.2-3 Stick Model – Max. E-W Shear Force 50
Figure 4.2-4 Stick Model – Max. Torsion Moment 51
Figure 4.2-5 Stick Model – Max. Moment about N-S axis 52
Figure 4.2-6 Stick Model – Max. Moment about E-W axis 53
Figure 4.2-7 Stick Model – Max. Displacements Relative to Basemat Bottom Center 54
Figure 4.2-8 Stick Model – Max. Absolute Accelerations 55
Figure 4.2-9 7%-Damped ISRS at Basemat – N-S Direction 56

Figure 4.2-10 7%-Damped ISRS at Basemat – E-W Direction 57
Figure 4.2-11 7%-Damped ISRS at Basemat – Vertical Direction 58
Figure 4.3-1 Dynamic FE Model – Max. Displacements Relative to Free-Field Surface 60
Figure 4.3-2 Dynamic FE Model – Max. Displacements Relative to Basemat Bottom Center. 61
Figure 5.2-1 N-S 7% Damped ISRS at Top of A/B Basemat 68
Figure 5.2-2 E-W 7% Damped ISRS at Top of A/B Basemat..... 69
Figure 5.2-3 Vertical 7% Damped ISRS at Top of A/B Basemat..... 69
Figure 5.2-4 Modified N-S Response Spectrum for Response Spectrum Analysis 70
Figure 5.2-5 Modified E-W Response Spectrum for Response Spectrum Analysis..... 70
Figure 5.2-6 Modified Vertical Response Spectrum for Response Spectrum Analysis..... 71
Figure 5.5-1 Selected Exterior Wall: Vertical Cut Out-of-plane Moment DCR 76
Figure 5.5-2 Selected Exterior Wall: Horizontal Cut Out-of-plane Moment DCR 77
Figure 5.5-3 Exterior walls: Vertical Cut Out-of-plane Shear DCR..... 78
Figure 5.5-4 Exterior Walls: Horizontal Cut Out-of-plane Shear DCR..... 78
Figure 5.5-5 Selected Ground Slab: E-W Direction Cut Out-of-plane Moment DCR 79
Figure 5.5-6 Selected Ground Slab: N-S Direction Cut Out-of-plane Moment DCR 80
Figure 5.5-7 Ground Slabs: E-W Direction Cut Out-of-plane Shear DCR..... 81
Figure 5.5-8 Ground Slabs: N-S Direction Cut Out-of-plane Shear DCR..... 81

List of Appendices

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

Appendix A was not included in revision 1. This Appendix will be updated and included in future revisions of this report when the applicable analysis is complete.

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 site-independent SSI analyses provide the seismic response of the A/B in terms of maximum seismic displacements relative to the free field motion, absolute accelerations, in-structure response spectra (ISRS) at the top of the basemat, 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. The member stress demands that are calculated from the static and response spectrum analyses (RSA) are used for evaluation of the structural integrity of A/B under load combinations associated with seismic design loads. The structural seismic demands obtained from the RSA are compared to seismic demands computed from the SSI analysis to confirm the adequacy of the results of the seismic structural evaluation of the A/B. The results of the SSI analyses for base force and moment reactions serve as the input for the evaluation of the seismic stability of the building.

The seismic evaluation of the A/B 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 8.1) and (2) ANSYS response spectrum analyses (RSA) that provide seismic demands on the A/B structural members. 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 define the ground motion for the standard design of the A/B.

The site-independent SSI analyses of the A/B are performed for eight generic soil profiles using two types of models representing the dynamic properties of the A/B structure: (1) a dynamic finite element (FE) model; and (2) a lumped mass stick model. The SSI analyses of A/B dynamic FE model provide the maximum absolute accelerations of A/B, maximum seismic displacements of the A/B relative to the free field ground motion and 7% damped ISRS at the top of the A/B basemat that is used as input for the ANSYS RSA. The ACS SASSI results for stresses at selected members obtained from the SSI analyses of dynamic FE model are compared with the corresponding results from the ANSYS RSA of the detailed model. The comparison serves to demonstrate that the seismic stress demands used for structural evaluation are conservative.

The site-independent SSI analyses of the A/B lumped mass stick model provide base force and moment reactions that serve as input for the evaluation of A/B seismic stability for the eight generic soil conditions. The lumped mass stick model is developed with sufficient degrees of freedom to accurately capture responses at major modes of vibration of the A/B structure that characterize the global response of the A/B structural mass. This ensures that the site-independent SSI analyses of lumped mass stick model provide adequate results for the reaction forces and moments at the base of the model. The energy of the input seismic excitation in the lumped mass stick model is distributed in fewer major modes of vibration than that of the FE model where the structural response close to the lumped mass stick model major mode of vibration is usually characterized by multiple modes of vibration with similar

frequencies. In fact, the lumped mass stick model forces the response of these multiple modes of vibration of the FE model to be in phase that results in overestimated global seismic response of the A/B structure. The results for maximum base reactions obtained from the SSI analyses of lumped mass stick model are compared with those obtained from the SSI analyses of dynamic FE model to verify that they are adequate for use as input for the A/B global stability evaluations.

The dynamic FE model and lumped mass stick model used for seismic response analyses both consider a reduced stiffness of the AB shear wall structure due to cracking of the concrete elements and the higher SSE material damping levels.

A detailed FE model of the A/B is used for static and response spectra analyses to obtain static and dynamic demands of the structural members of A/B. In order to be able to provide more accurate stress results and capture the effects of member offsets, the FE mesh and the geometry of the detailed FE model are more refined than that of the dynamic FE model used for seismic response analyses.

1.1 Description of A/B

As shown on Figure 2.1-1, The A/B is located west of the 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 8.8). Large openings in walls and slabs are included in the model, but small openings are no 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’-0”/ 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)	241,391 kips
Total Foundation Area	31,900 ft^2
Equivalent Uniform Bearing Pressure of Foundation	7.57 ksf

Security-Related Information – Withheld Under 10 CFR 2.390

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 shear wall type of structure consisting of 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 8.3).

- 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

The SSE damping ratios used for structural material damping in the seismic response analyses per DCD Table 3.7.3-1(a) (Reference 8.3) are consistent with the reduced (cracked concrete) level of stiffness considered to address effects of concrete cracking as described in Section 2.3.2.1.

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 with bearing connections structures at SSE stress level per Reg. 1.61 (Reference 8.13)

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 three layers of solid elements representing 9'-11" thick basemat. At the top of the basemat and the bottom of interior and exterior walls, the shell elements are extended into solid elements that represent the basemat. The extended shell elements share the same nodes with the solid elements but material densities are assigned to be zero. This modeling approach enables transfer of moments from the walls to the basemat. The interior walls are modeled with shell element's center planes located approximately at the centerlines 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 geometry, attributes, and FE mesh of the A/B Dynamic FE Model are created in ANSYS and then converted into ACS SASSI format. In order to ensure an appropriate transfer of high frequency seismic waves through the soil-structure interface, the maximum element sizes in the horizontal direction is set to 9 feet. Figure 2.3-1 through Figure 2.3-8 show the Dynamic FE Model of A/B.

2.3.2 Modeling of Dynamic Stiffness

2.3.2.1 Consideration of Concrete Cracking Effects

In accordance with the methodology in Section 4.5.1 of MHI TR MUAP 10001 (Reference 8.1) for consideration of concrete cracking in the analyses of US APWR Category I buildings, the SSI analyses of A/B consider reduced (cracked concrete) stiffness represented by 50% of the above listed nominal uncracked stiffness of the reinforced concrete members and higher SSE damping ratios per DCD Table 3.7.3-1(a) (Reference 8.3). The consideration of reduced stiffness is based on the premise that the main purpose of the site-independent SSI analyses is to provide input for the evaluation of the A/B reinforced concrete structure, stability of the building and the gap between the buildings. The design of the reinforced concrete shear wall structures is based on the ultimate capacity of the reinforced concrete sections that addresses code stress limits corresponding to reduced cracked concrete stiffness properties and higher SSE material damping levels as discussed in Regulatory Position C.1.2 of RG 1.61 (Reference 8.13). Likewise, the stability evaluations are also based on consideration of ultimate conditions. The lower stiffness of the reinforced concrete members amplifies the deformations of the A/B structure and thus provides higher values for the seismic displacement of the building relative to ground motion.

There are slabs in the A/B that are supported by steel beams placed under the slab. Since the actual construction detail does not warrant a full transfer of horizontal shear force between the slab and the steel beam, the FE model does not consider these slabs as composite sections. The beam elements representing the steel members and the shell elements representing the reinforced concrete slabs have coincident nodes that allow the transfer of vertical shear force between the two components but it does not reflect a larger moment of inertia for out of plane bending of a fully composite section.

The FE model does not consider the stiffness of removable wall panels whose effect on the response of the building is secondary. The mass of these wall panels have been appropriately lumped in the model.

2.3.2.2 Reduction of Stiffness for Structural Openings

The Dynamic and Detailed FE models do not explicitly model smaller 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. The ANSYS analyses that provide the reduction factors used to adjust the stiffness of the walls with openings are conducted on walls which stiffness reduced by 50% to account for the effects of concrete cracking. Therefore, the stiffness of the FE shell elements are adjusted such that the model of

wall with openings reflects the reduction of stiffness due to concrete cracking and wall openings.

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 8.5, 8.6 respectively). In addition, a 50 psf dead load is applied on all walls and slabs to account for miscellaneous minor equipment, piping, and raceways. The concrete density is adjusted to consider the additional equivalent seismic mass. The total weight of the A/B 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.8.10),

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	Roof 2
101’-0”	1212	Roof 3

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
-104.75	AA1**	
-91.791	AA2**	
-82.5	BA	North Interior Wall
-70.916	BA1**	
-59.5	CA	North Interior Wall
-49.666	CA1**	
-44.75	CA2**	
-39.833	CA3**	
-30	DA	North Interior Wall
-18.166	DA1**	
-15	DA2**	
-9.833	DA3**	
0	EA	Center of the Building
9.333	EA1**	
15	EA2**	
20.5	EA3**	
30	FA	South Interior Wall
37.417	FA1**	
45	FA2**	
50.083	FA3**	
60	GA	South Interior Wall
69.917	GA1**	
75	GA2**	
82.583	GA3**	
90	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	1A3**	
-25.167	2A	West Interior Wall
-13.167	2A1**	
0	3A	Center of the Building
8.5	3A1**	
17	4A	East Interior Wall
28.917	4A1**	
39	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 (Elev. -26'-4") NS														
NS_1A_B1FB1FM_DA_EA	16.58	30.00	3.33	4.00	6.67	8.50	--	--	--	0.782	0.718	178599	0.0040	3.48
NS_1A1_B1FB1FM_BA1_CA1	16.58	21.25	1.00	7.42	3.00	16.58	13.09	3.00	16.58	0.718	0.718	186272	0.0033	1.00
NS_2A1_B1FB1FM_BA1_DA	16.58	40.92	2.17	1.08	3.00	6.67	--	--	--	0.935	0.917	235894	0.0045	2.19
NS_2A1_B1FB1FM_EA3_HA	16.58	69.50	2.17	9.25	3.00	16.58	10.92	3.00	16.58	0.560	0.468	111179	0.0039	2.37
NS_3A_B1FB1FM_CA_DA	16.58	29.50	1.67	25.17	4.33	16.58	--	--	--	1.000	1.000	259555	0.0040	1.67
NS_3A_B1FB1FM_HA_JA	16.58	34.17	3.33	1.67	6.33	8.33	--	--	--	0.820	0.772	194416	0.0041	3.44
NS_4A1_B1FB1FM_CA_DA	16.58	29.50	1.00	1.67	3.33	6.67	--	--	--	0.899	0.866	220502	0.0044	1.02
NS_4A1_B1FB1FM_DA3_FA	16.58	39.83	3.50	1.75	3.33	16.58	--	--	--	0.915	0.818	200660	0.0040	3.70
NS_5A_B1FB1FM_DA3_FA	16.58	39.83	2.17	12.34	3.33	6.67	35.16	3.00	6.67	0.923	0.903	231949	0.0043	2.19
NS_5A2_B1FB1FM_DA_EA	16.58	30.00	2.33	1.67	3.00	16.58	--	--	--	0.898	0.749	177679	0.0038	2.55
NS_6A_B1FB1FM_EA_FA	16.58	30.00	3.33	1.50	6.67	8.50	--	--	--	0.783	0.715	177451	0.0039	3.49
NS_1A1_B1FMF1F_BA_BA1	16.58	11.58	1.75	7.16	3.00	6.67	--	--	--	0.766	0.722	181837	0.0049	1.80
NS_1A1_B1FMF1F_BA1_CA1	16.58	21.25	1.75	7.42	3.00	6.67	18.42	3.00	6.67	0.870	0.860	221936	0.0050	1.76
NS_4A_B1FMF1F_DA3_FA	12.00	39.83	3.17	16.66	2.50	6.00	22.33	2.50	6.00	0.939	0.895	226990	0.0048	3.24
NS_4A1_B1FMF1F_AA2_BA	12.00	9.29	2.25	1.13	3.00	6.67	--	--	--	0.683	0.588	141650	0.0042	2.42
NS_4A1_B1FMF1F_DA3_FA	12.00	39.83	3.50	1.75	3.33	12.00	--	--	--	0.915	0.837	207908	0.0045	3.66
NS_4A1_B1FMF1F_FA_HA	12.00	60.00	2.00	1.67	3.00	6.67	31.00	3.00	6.67	0.901	0.855	216038	0.0051	2.05
NS_5A_B1FMF1F_AA_CA	12.00	55.58	2.33	1.75	3.00	12.00	--	--	--	0.945	0.899	227622	0.0050	2.39
NS_5A_B1FMF1F_FA_HA	12.00	60.00	2.00	1.67	3.00	6.67	31.00	3.00	6.67	0.901	0.855	216038	0.0051	2.05
NS_5A2_B1FMF1F_DA1_EA	12.00	18.17	2.33	15.00	3.00	6.67	--	--	--	0.839	0.735	178699	0.0046	2.49
GSLAB (Elev. 3'-7") NS														
NS_1A_F1FF2F_AA_EA	26.25	115.08	3.33	32.67	19.67	14.00	87.50	6.67	8.50	0.830	0.761	189298	0.0044	3.48
NS_2A_F1FF1MF_DA3_EA3	12.17	30.33	2.50	1.25	3.00	6.67	--	--	--	0.904	0.878	224563	0.0050	2.54
NS_2A_F1FF1MF_HA_JA	12.17	34.17	4.00	27.92	3.00	6.67	--	--	--	0.914	0.886	226435	0.0048	4.06
NS_4A1_F1FF1MF_EA3_GA2	12.17	54.50	4.17	54.50	3.00	6.67	--	--	--	1.033	1.046	273431	0.0049	4.14
NS_4A1_F1FF1MF_GA2_JA	12.17	49.17	2.67	42.83	3.00	6.67	--	--	--	0.940	0.926	238585	0.0051	2.69
NS_5A_F1FF1MF_DA3_FA	12.17	39.83	2.50	1.21	3.00	6.67	--	--	--	0.927	0.914	235715	0.0051	2.52
NS_5A_F1FF1MF_FA_HA	12.17	60.00	3.08	65.33	3.00	6.67	--	--	--	1.000	1.000	259560	0.0050	3.08
NS_5A3_F1FF1MF_DA3_EA	12.17	9.83	1.50	7.83	2.00	12.17	--	--	--	1.000	1.000	259565	0.0048	1.50
NS_5A3_F1FF1MF_EA_EA2	12.17	15.00	2.17	6.33	2.50	12.17	--	--	--	0.833	0.833	216300	0.0046	2.17
NS_5A3_F1FF1MF_EA2_FA2	12.17	30.00	2.67	5.96	2.50	12.17	19.92	2.50	12.17	0.774	0.450	89036.6	0.0035	3.50
NS_5A3_F1FF1MF_FA2_GA2	12.17	30.00	2.67	6.25	2.50	12.17	20.58	2.50	12.17	0.806	0.484	97306.2	0.0036	3.44
NS_5A3_F1FF1MF_GA2_HA	12.17	15.00	2.67	6.30	2.50	12.17	--	--	--	0.833	0.833	216300	0.0045	2.67
NS_5A3_F1FF1MF_HA_HA2	12.17	21.67	1.67	5.33	2.50	12.17	12.67	2.50	12.17	0.769	0.769	199661	0.0045	1.67
NS_6A_F1FF1MF_CA_JA	12.17	183.67	3.33	6.67	8.33	8.50	173.33	6.67	8.50	0.954	0.939	241916	0.0048	3.36
NS_4A_F1MFF2F_DA3_EA3	14.08	30.33	2.00	1.33	3.00	6.00	19.16	3.00	6.00	0.817	0.773	195215	0.0049	2.06
NS_4A_F1MFF2F_EA3_FA1	14.08	16.92	3.33	13.92	3.00	6.00	--	--	--	1.000	1.000	259525	0.0048	3.33
NS_4A_F1MFF2F_FA1_FA3	14.08	12.67	2.83	1.17	3.00	6.00	--	--	--	0.781	0.711	176148	0.0045	2.97
NS_4A_F1MFF2F_FA3_GA1	14.08	19.83	2.00	19.83	3.00	6.00	--	--	--	1.077	1.151	308736	0.0053	1.93
NS_4A_F1MFF2F_GA1_HA2	14.08	41.75	2.42	17.08	3.00	6.00	22.58	3.00	6.00	0.933	0.904	231180	0.0050	2.45
NS_4A_F1MFF2F_HA2_JA	14.08	12.50	2.00	1.21	3.00	6.00	--	--	--	0.778	0.710	176024	0.0048	2.09

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)
Second Floor (25'-3")_NS														
NS_1A_F2FF3F_HA_JA	20.83	34.17	2.67	4.83	8.00	8.50	--	--	--	0.780	0.758	193883	0.0047	2.71
NS_1A2_F2FF3F_HA_JA	20.83	34.17	1.67	3.00	8.67	34.91	--	--	--	0.762	0.719	181434	0.0035	1.72
NS_2A1_F2FF3F_DA_EA	20.83	30.00	1.00	2.00	6.67	8.50	--	--	--	0.793	0.786	202905	0.0058	1.00
NS_2A1_F2FF3F_EA_HA	20.83	90.00	1.00	43.16	6.67	8.50	80.83	6.67	8.50	0.931	0.910	233340	0.0059	1.01
NS_3A_F2FF3F_DA_FA	20.83	60.00	2.67	9.33	6.67	8.50	41.83	6.67	8.50	0.794	0.778	199913	0.0048	2.69
NS_3A_F2FF3F_FA_HA1	20.83	70.83	2.67	13.17	6.67	8.50	--	--	--	0.913	0.904	233385	0.0050	2.68
NS_5A3_F2FF3F_EA_GA	20.83	60.00	1.00	11.83	6.67	8.50	41.83	6.67	8.50	0.897	0.885	228091	0.0058	1.01
NS_5A3_F2FF3F_GA_HA1	20.83	40.83	1.00	11.17	6.67	8.50	--	--	--	1.000	1.000	259560	0.0059	1.00
NS_6A_F2FF3F_CA_DA	20.83	29.50	2.67	6.67	6.67	8.50	--	--	--	0.788	0.781	201714	0.0048	2.68
NS_6A_F2FF3F_HA_JA	20.83	34.17	2.67	22.08	8.00	8.50	--	--	--	0.780	0.753	191817	0.0047	2.72
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	0.797	0.797	206768	0.0053	1.00
NS_4A_F3FF3MF_HA1_JA	12.17	23.33	1.17	8.33	6.67	6.83	--	--	--	1.079	1.195	326287	0.0055	1.11
NS_1A2_F3FF4F_DA3_FA	26.58	39.83	1.33	33.50	5.00	6.67	--	--	--	0.906	0.855	215600	0.0056	1.37
NS_6A_F3FF4F_CA_DA	26.58	29.50	2.67	6.67	6.67	8.50	--	--	--	0.806	0.840	222807	0.0050	2.61
NS_6A_F3FF4F_HA_JA	26.58	34.17	2.67	21.00	9.33	9.00	--	--	--	0.756	0.741	190551	0.0048	2.69
Fourth Floor and Beyond (76'-5"_101'-0")_NS														
NS_5A_F4FRoof1_HA_JA	13.67	34.17	1.75	27.17	3.33	6.83	--	--	--	0.906	0.877	224175	0.0053	1.78
NS_6A_F4FRoof1_HA_JA	13.67	34.17	0.83	24.50	6.00	9.00	--	--	--	0.823	0.727	177366	0.0057	0.89
NS_6A_F4FRoof3_CA_DA	25.08	29.50	0.83	6.67	6.67	9.00	--	--	--	0.796	0.812	212967	0.0062	0.82
Basemat (el.-26'-4")_EW														
EW_BA_B1FB1FM_1A_4A	16.58	80.67	2.67	1.67	3.00	6.67	73.00	3.00	6.67	0.933	0.932	241662	0.0051	2.67
EW_BA_B1FB1Fm_4A_5A	16.58	22.00	2.67	17.33	3.00	6.67	--	--	--	0.878	0.832	210113	0.0049	2.74
EW_BA1_B1FB1FM_2A1_4A	16.58	31.00	3.50	1.08	3.33	16.58	--	--	--	0.888	0.765	184194	0.0043	3.77
EW_CA_B1FB1FM_1A3_2A1	16.58	19.83	2.67	1.25	6.58	16.58	--	--	--	0.668	0.668	173408	0.0037	2.67
EW_CA_B1FB1FM_2A1_4A1	16.58	42.92	2.67	1.08	3.33	16.58	--	--	--	0.920	0.853	213201	0.0047	2.77
EW_CA2_B1FB1FM_5A1_6A	16.58	12.67	1.00	0.50	3.33	6.67	--	--	--	0.865	0.774	190144	0.0055	1.06
EW_DA3_B1FB1FM_1A_1A2	16.58	18.38	1.08	1.67	3.00	6.67	--	--	--	0.854	0.798	200388	0.0056	1.12
EW_DA2_B1FB1FM_5A2_6A	16.58	7.75	1.08	1.67	3.00	6.67	--	--	--	0.854	0.798	200388	0.0052	1.12
EW_EA_B1FB1Fm_1A_1A2	16.58	18.38	1.00	1.67	3.00	6.67	--	--	--	0.856	0.798	200186	0.0058	1.04
EW_HA_B1FB1FM_4A1_5A	16.58	10.08	2.50	1.25	3.00	6.67	--	--	--	0.731	0.694	175583	0.0046	2.57
EW_AA2_B1FMF1F_1A_4A	12.00	80.67	2.58	1.67	3.00	6.67	76.00	3.00	6.67	0.963	0.962	249364	0.0051	2.59
EW_BA_B1FMF1F_4A_5A	12.00	22.00	2.67	1.67	2.00	6.67	18.67	3.33	12.00	0.912	0.869	220163	0.0042	2.73
EW_BA1_B1FMF1F_2A1_4A	12.00	31.00	3.50	1.08	3.33	12.00	--	--	--	0.888	0.795	195118	0.0044	3.70
EW_FA_B1FMF1F_2A_2A1	12.00	12.00	3.33	1.67	3.00	6.67	--	--	--	0.755	0.668	163045	0.0042	3.54
EW_HA_B1FMF1F_4A1_5A	12.00	10.08	2.50	1.25	3.00	6.67	--	--	--	0.708	0.614	148410	0.0042	2.68
EW_CA3_B1FF1F_1A1_2A1	28.58	39.00	2.50	16.17	3.00	28.58	36.00	3.00	28.58	0.846	0.846	219627	0.0046	2.50

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")_EW														
EW_CA_F1FF1MF_1A_4A	12.17	80.67	2.67	35.17	10.00	12.00	67.33	10.00	8.33	0.873	0.734	174839	0.0040	2.91
EW_CA_F1FF1MF_4A_5A	12.17	22.00	2.67	19.00	3.00	6.83	--	--	--	1.000	1.000	259503	0.0049	2.67
EW_CA2_F1FF1MF_5A2_6A	12.17	7.75	1.00	1.00	3.33	16.25	--	--	--	1.000	1.000	259605	0.0035	1.00
EW_DA3_F1FF1MF_5A_5A1	12.17	8.67	2.42	4.83	3.00	12.17	--	--	--	0.654	0.654	169712	0.0037	2.42
EW_DA3_F1FF1MF_5A1_6A	12.17	12.67	1.50	18.17	3.00	12.17	--	--	--	0.862	0.720	170721	0.0043	1.64
EW_GA_F1FF1MF_1A_2A	12.17	37.67	2.00	30.33	3.33	6.67	--	--	--	0.913	0.883	225418	0.0051	2.03
EW_GA1_F1FF1MF_4A_4A1	12.17	11.92	4.17	1.75	3.00	12.17	--	--	--	0.748	0.748	194216	0.0039	4.17
EW_HA_F1FF1MF_1A_2A	12.17	37.67	2.00	30.33	3.33	6.67	--	--	--	0.913	0.883	225418	0.0051	2.03
EW_FA_F1MFF2F_2A_2A1	14.08	12.00	3.33	9.17	2.00	14.08	--	--	--	0.830	0.518	106263	0.0035	4.22
EW_HA_F1MFF2F_2A_2A1	14.08	12.00	3.33	1.67	3.33	6.67	--	--	--	0.736	0.685	171492	0.0044	3.46
Second Floor (25'-3")_EW														
EW_CA_F2FF3F_5A_6A	20.83	30.67	2.50	10.33	3.00	6.67	--	--	--	0.918	0.923	240289	0.0052	2.49
EW_CA2_F2FF3F_5A2_6A	20.83	17.08	1.00	1.00	3.33	6.83	--	--	--	0.803	0.633	145997	0.0054	1.13
EW_DA_F2FF3F_1A_3A	20.83	62.83	2.67	52.17	6.67	8.50	--	--	--	0.902	0.897	232254	0.0050	2.67
EW_EA_F2FF3F_3A_6A	20.83	69.67	1.00	59.66	6.67	8.50	--	--	--	0.912	0.897	231018	0.0060	1.01
EW_JA_F2FF3F_4A_6A	20.83	52.67	3.33	27.33	3.00	7.17	--	--	--	0.951	0.939	242142	0.0050	3.35
Third Floor (50'-2")_EW														
EW_CA2_F3FF4F_5A2_6A	26.58	22.00	1.00	1.00	3.33	6.83	--	--	--	0.890	0.770	185886	0.0057	1.08
EW_HA2_F3FF4F_4A_5A	26.58	22.00	1.00	1.00	3.33	6.83	--	--	--	0.890	0.770	185886	0.0057	1.08
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	--	--	--	0.874	0.883	230382	0.0054	1.74
EW_DA_F4FRoof3_5A_6A	25.08	30.67	1.75	3.33	13.58	20.08	--	--	--	0.557	0.557	144592	0.0039	1.75

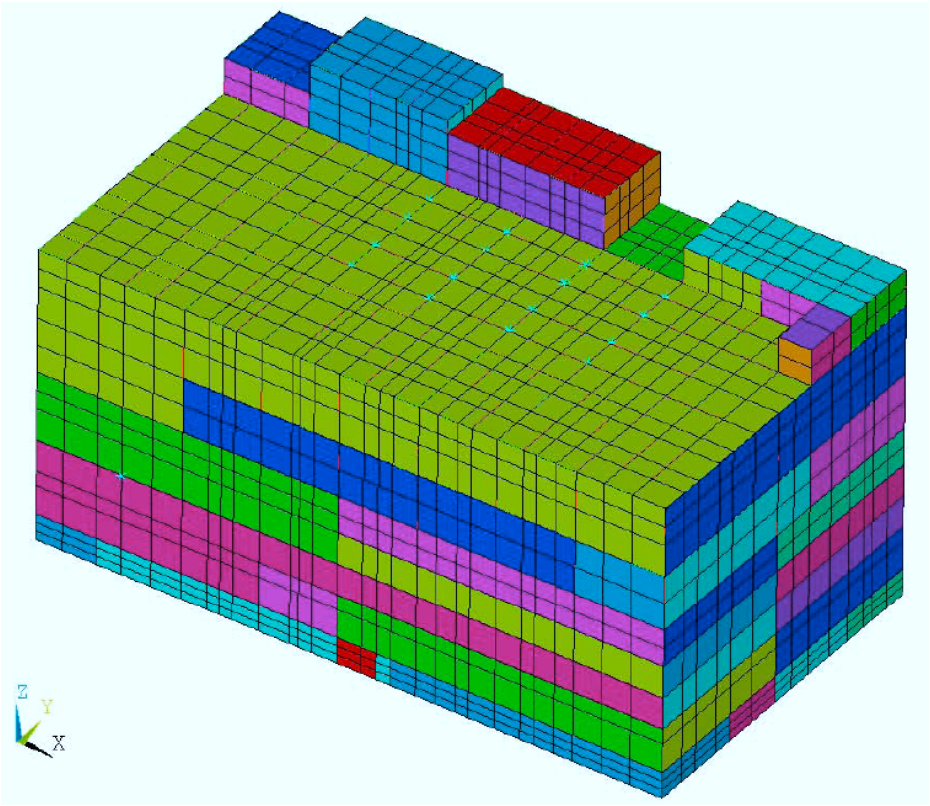

Figure 2.3-1 A/B Dynamic FE Model

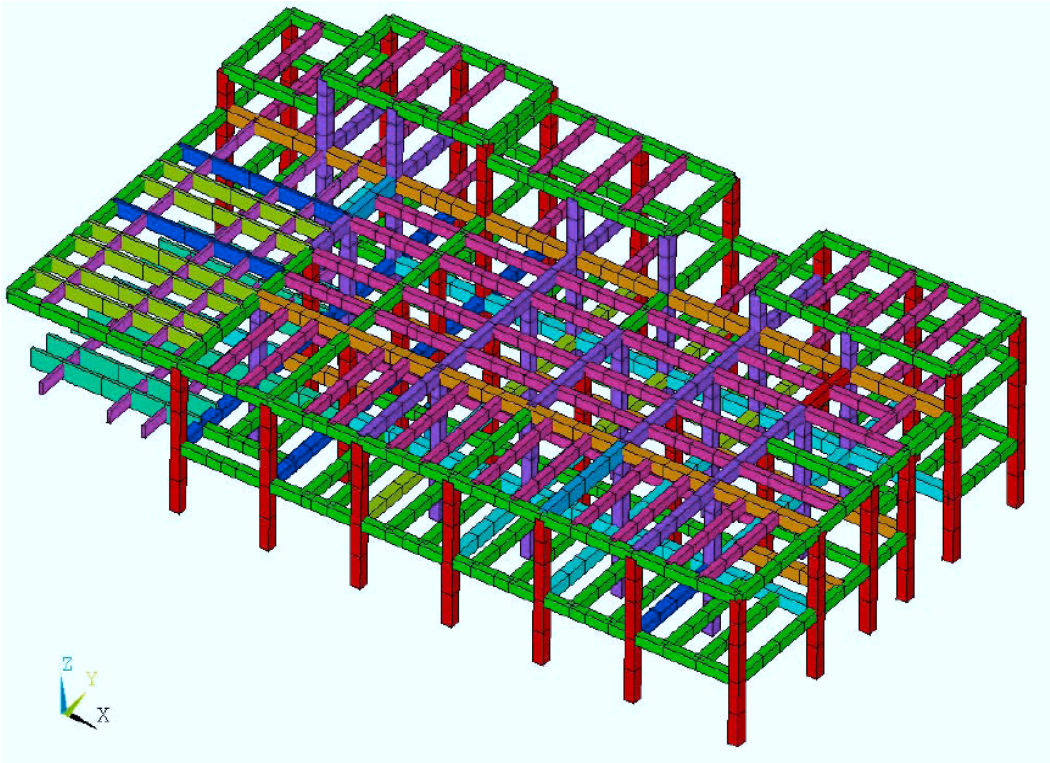

Figure 2.3-2 A/B Dynamic FE Model, Beams and Columns

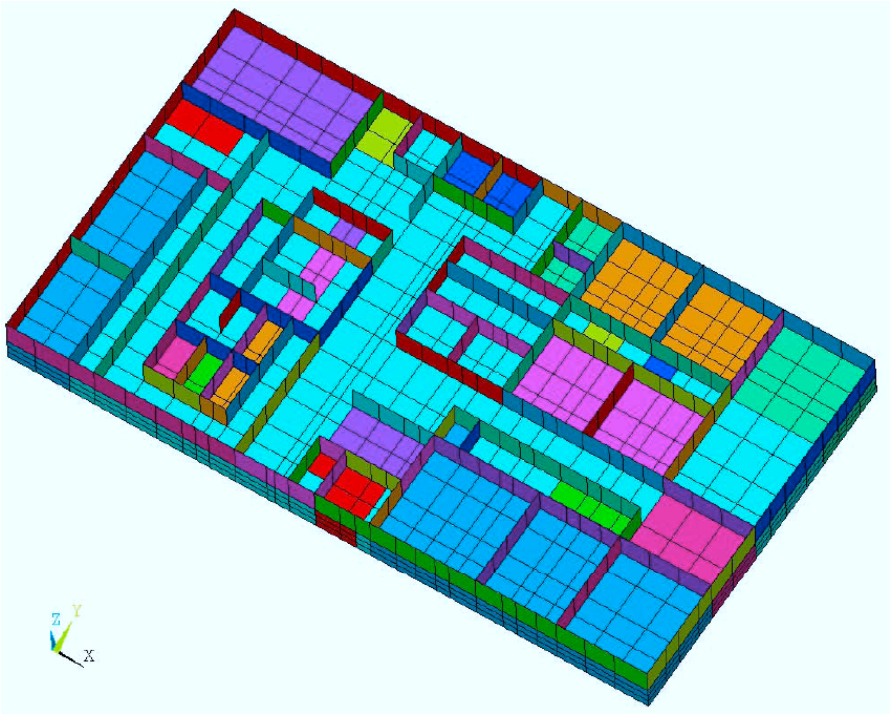

Figure 2.3-3 A/B Dynamic FE Model Basemat

(Elev. -26'-4")

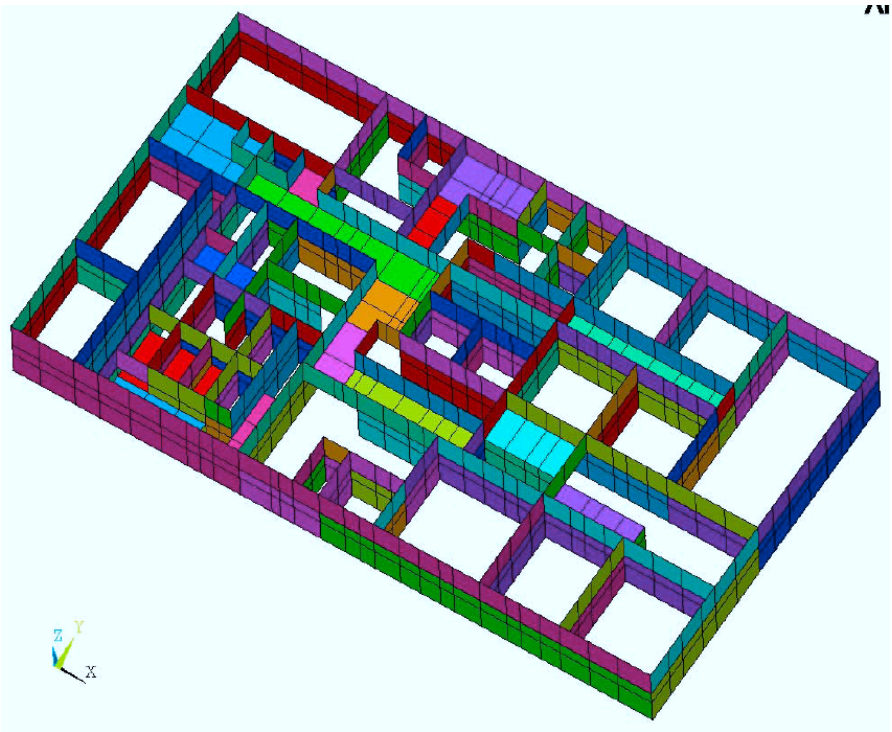

Figure 2.3-4 A/B Dynamic FE Model Intermediate Floor

(Elev. -14'-4" & -8'-7")

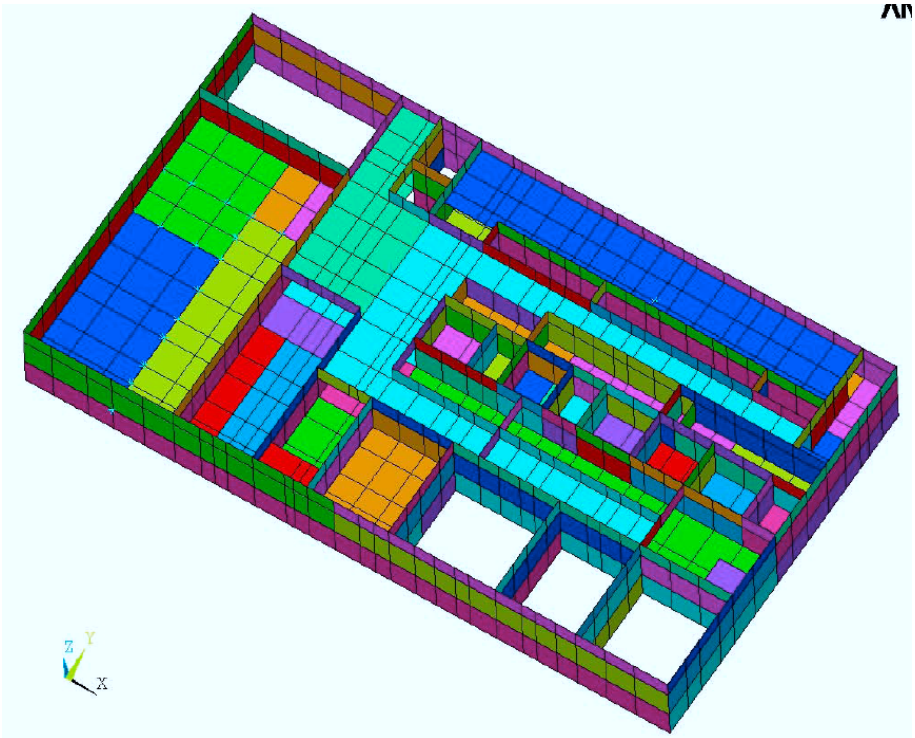

Figure 2.3-5 A/B Dynamic FE Model First and Intermediate Floor

(Elev. 3'-7" & 15'-9")

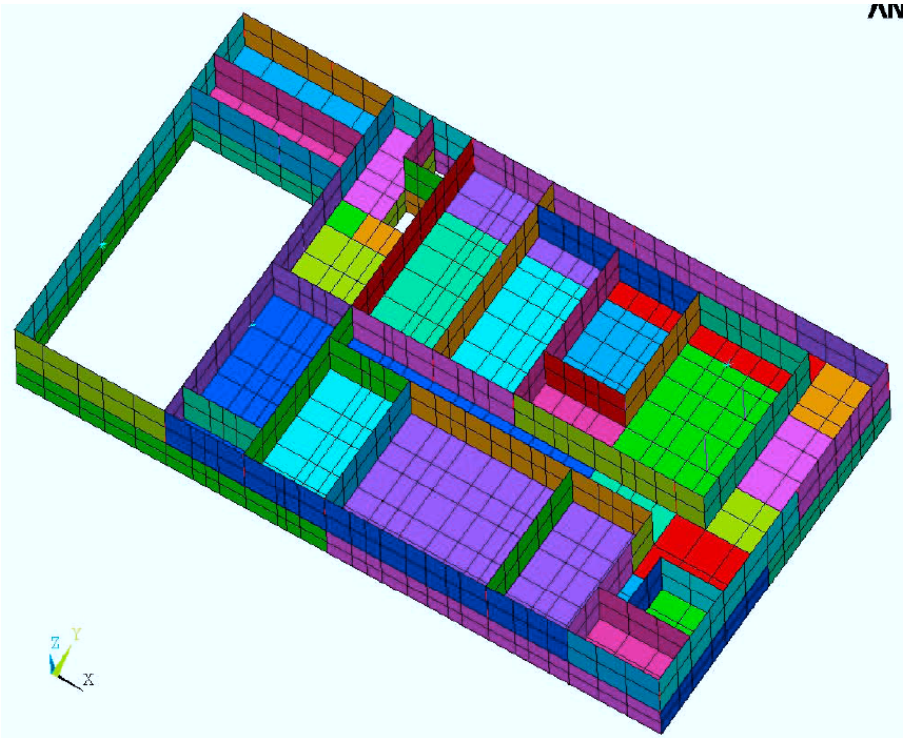

Figure 2.3-6 A/B Dynamic FE Model Second and Intermediate Floor

(Elev. 25'-3" & 33'-5")

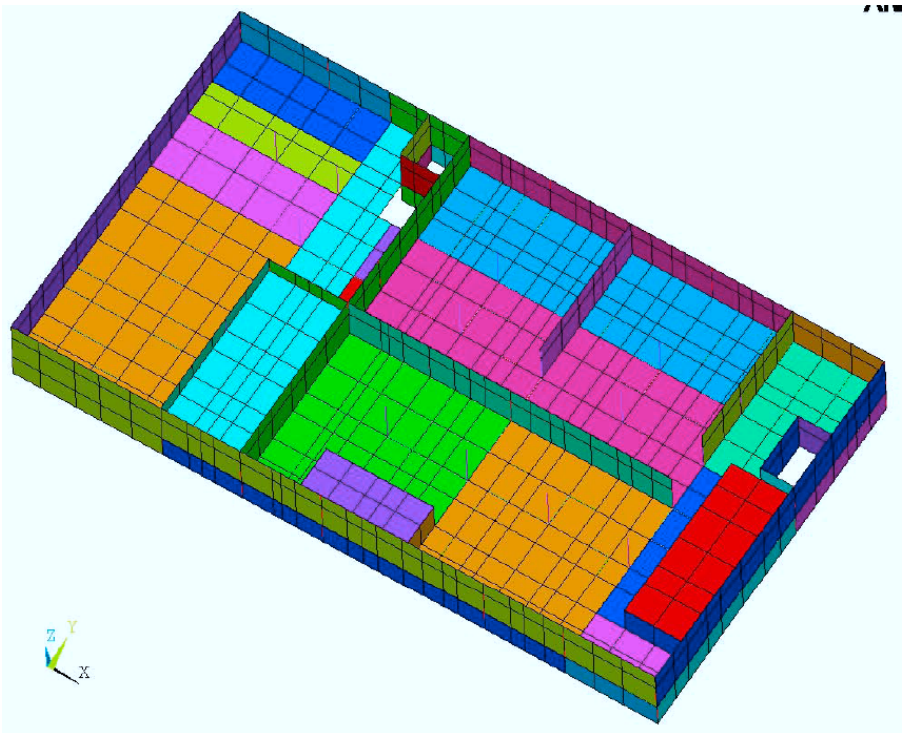

Figure 2.3-7 A/B Dynamic FE Model Third and Intermediate Floor

(Elev. 50'-2" & 61'-6")

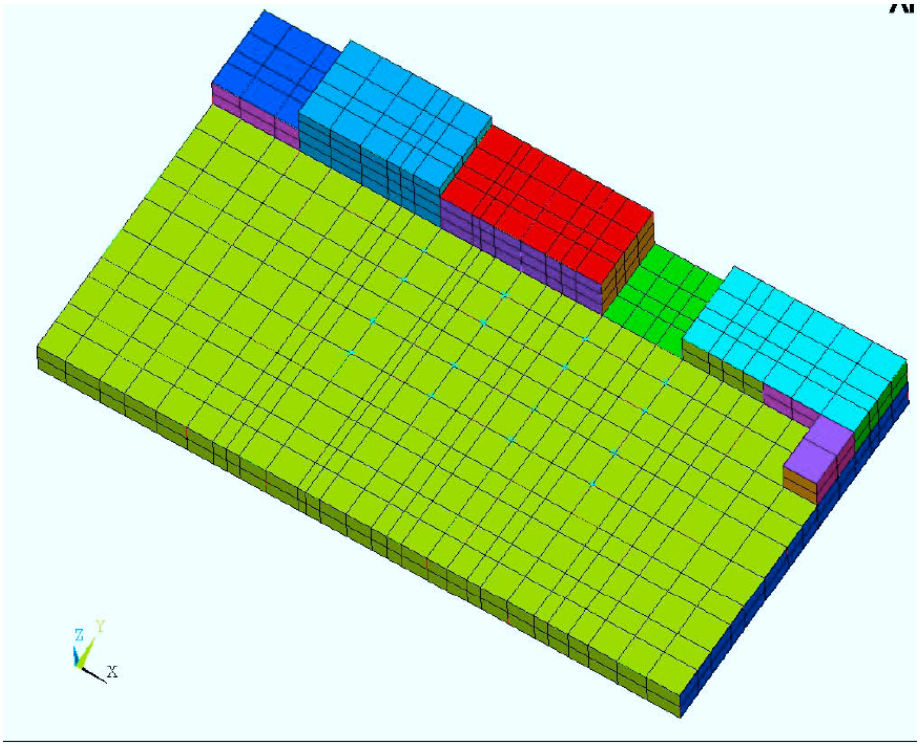

Figure 2.3-8 A/B Dynamic FE Model Fourth Floor and Roofs

(Elev. 76'-5", 89'-7", 96'-0" & 101'-0")

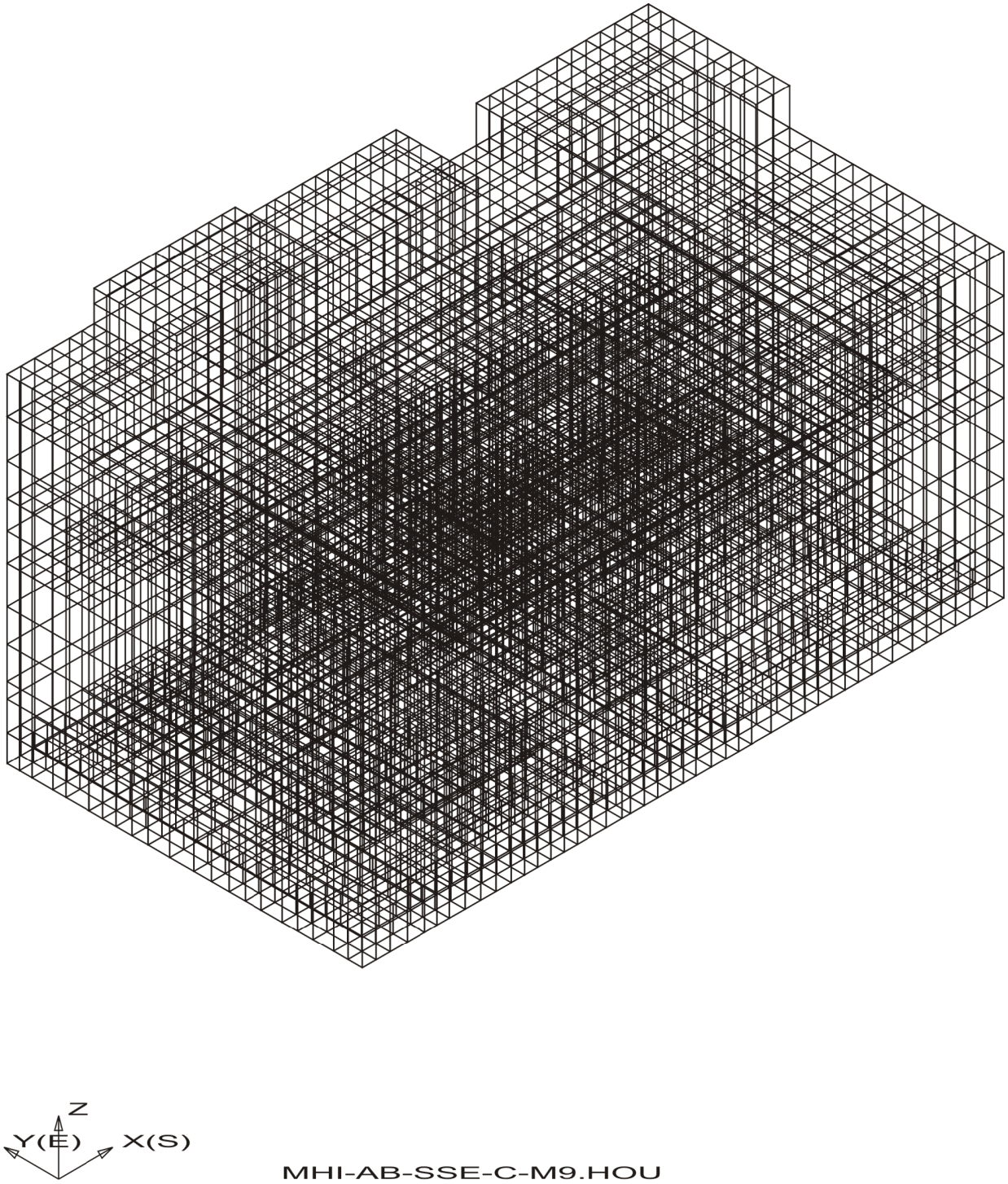

Figure 2.3-9 Isometric View of SASSI FEM A/B Model

Figure 2.3-9 was not updated in revision 1 and may be out of date. This data will be updated in future revisions of this report when the applicable analysis is complete.

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 through Figure 2.4-8 present the Detailed FE Model. The Detailed 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 the 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 procedures and parameters that are specified in MHI TR MUAP-10006 (Reference 8.2). The seismic design demands are obtained from a response spectrum analysis of the detailed FE model as described in Section 4.2. 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 (Reference 8.3).

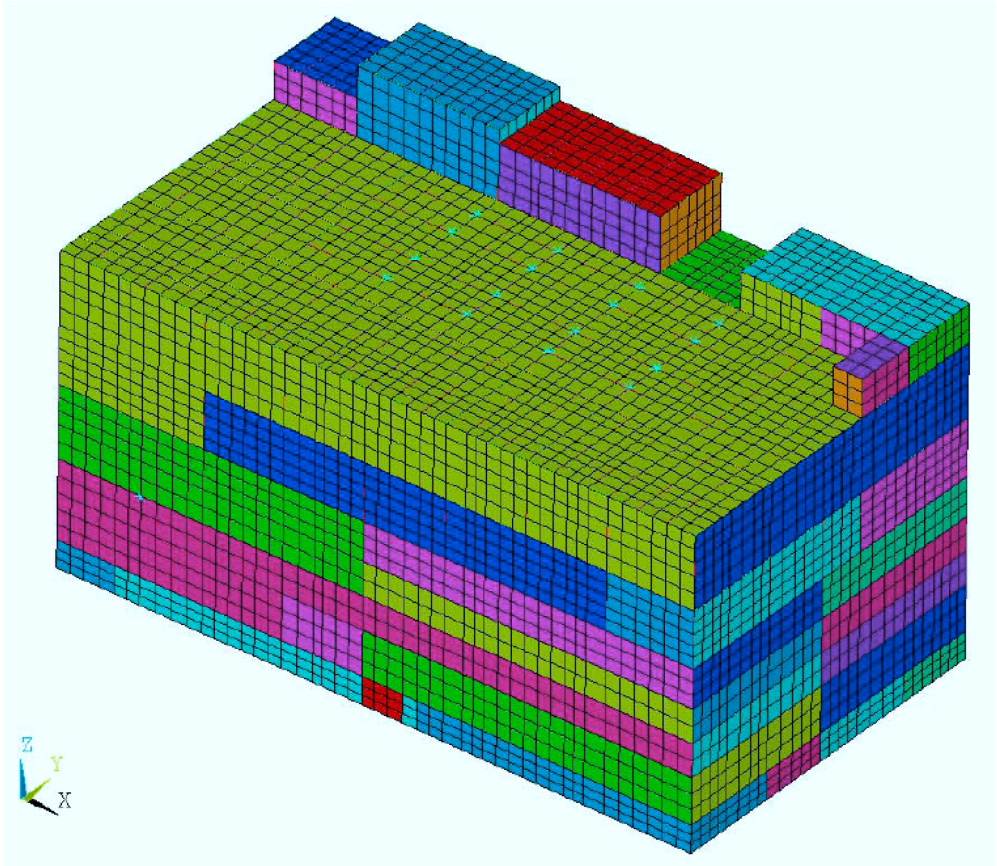

Figure 2.4-1 A/B Detailed FE Model

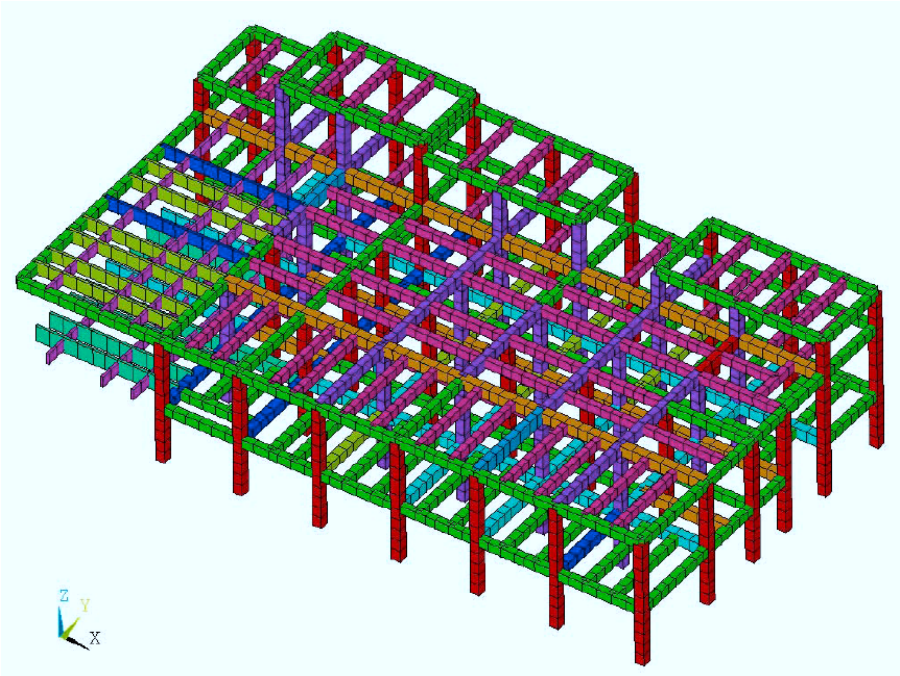

Figure 2.4-2 A/B Detailed FE Model, Beams and Columns

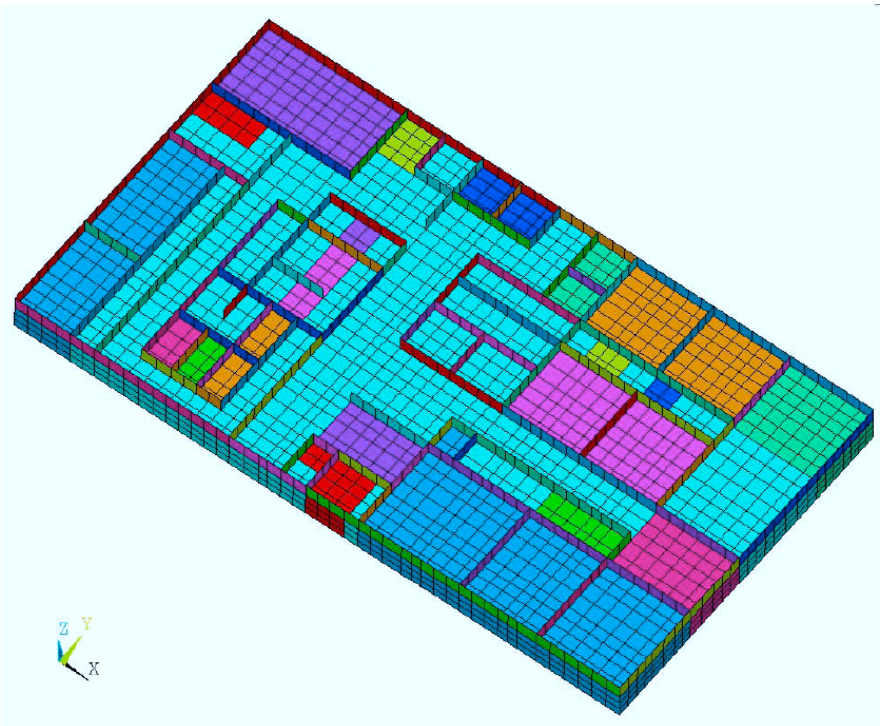

Figure 2.4-3 A/B Detailed FE Model Basemat

(Elev. -26'-4")

Figure 2.4-4 A/B Detailed FE Model Intermediate Floor

(Elev. -14'-4" & -8'-7")

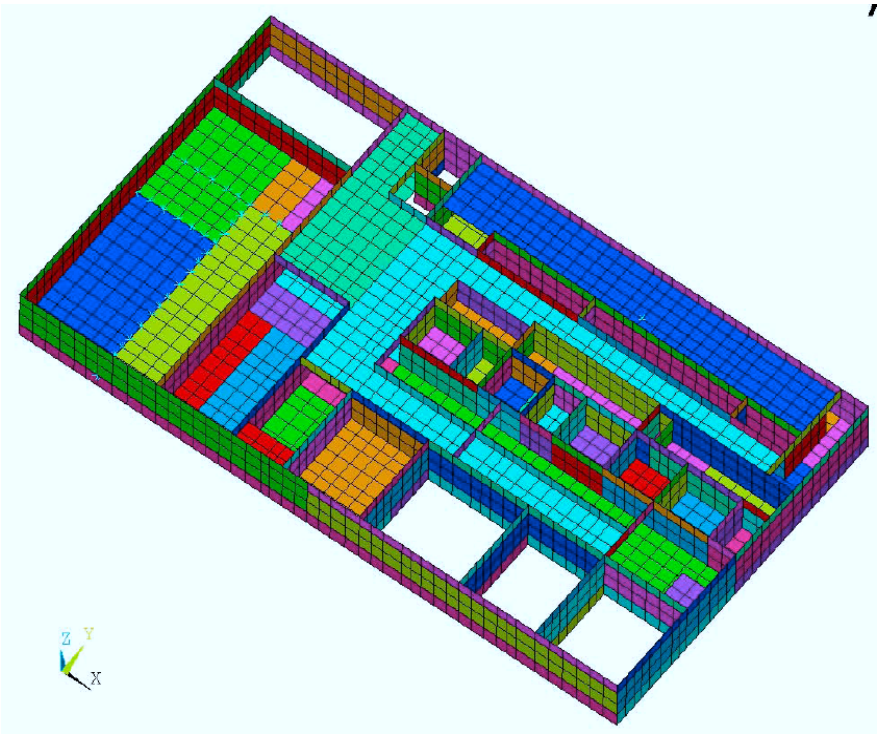

Figure 2.4-5 A/B Detailed FE Model First and Intermediate Floor

(Elev. 3'-7" & 15'-9")

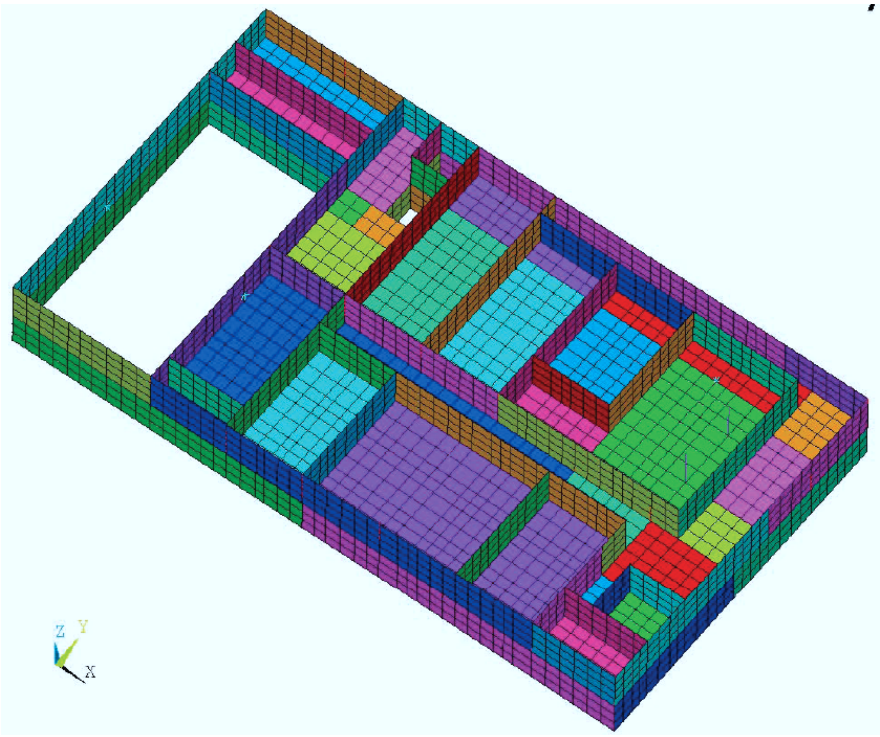

Figure 2.4-6 A/B Detailed FE Model Second and Intermediate Floor

(Elev. 25'-3" & 33'-5")

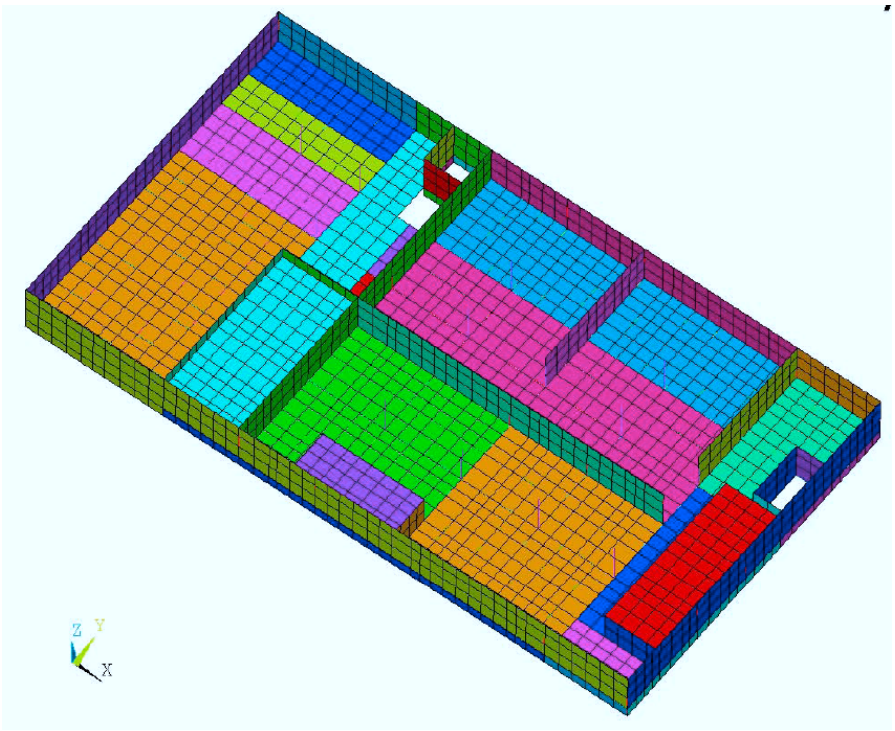

Figure 2.4-7 A/B Detailed FE Model Third and Intermediate Floor

(Elev. 50'-2" & 61'-6")

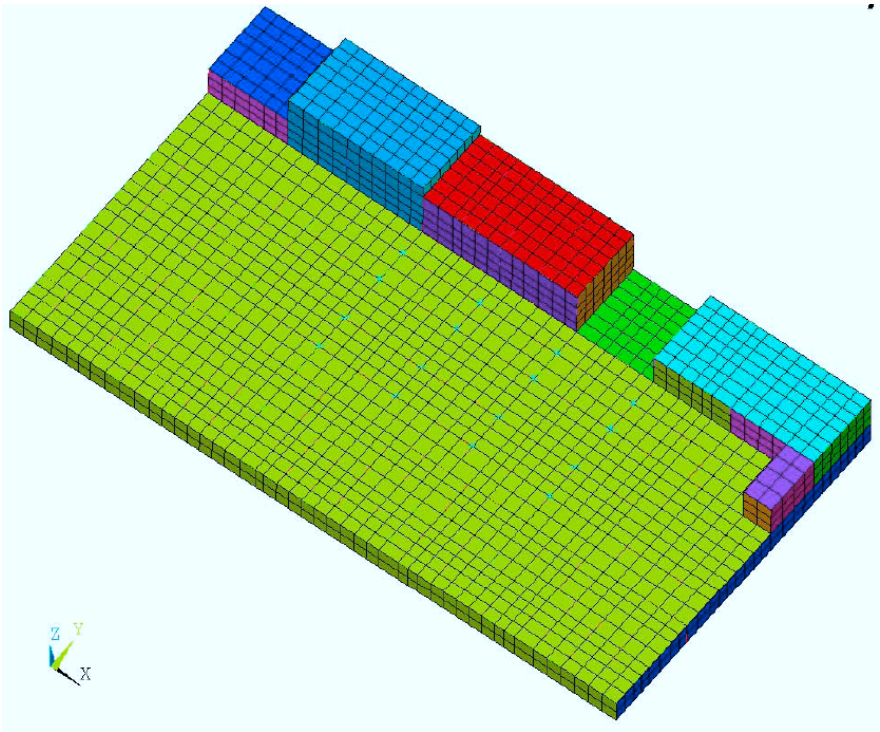

Figure 2.4-8 A/B Detailed FE Model Fourth Floor and Roofs

(Elev. 76'-5", 89'-7", 96'-0" & 101'-0")

2.5 Lumped-Mass Stick Model

Section 2.5 was not completely updated in revision 1 and may be out of date. This data will be updated in future revisions of this report when the applicable analysis is complete.

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 calculation of base reaction forces a three-dimensional (3-D) lumped-mass beam-stick model of the A/B structure is also developed. Site-independent SSI analyses are performed on the lumped mass stick model for all eight generic site profiles. These analyses provide results for time histories of stick member forces and moments as well as the time histories of the nodal accelerations at the basemat that are used as input for evaluation of seismic stability of the building

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