DTE Electric Company
Fermi 3 – ESBWR

Modified Subtraction Method (MSM) Control Building Benchmark Summary Report

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As a result of this program limitation, use of Modified Subtraction Method (MSM) of analysis is required to limit the number of interaction nodes to less than about 20,000. However, when using MSM, selection of additional nodes within the excavated soil volume to be declared as interaction nodes requires benchmarking of the MSM model results against the DM model results to ensure that the selected additional interaction nodes are adequate for producing reliable and accurate SSI results. The benchmarking of the MSM model of the FWSC is provided in Reference 5. A study for the benchmarking of the CB MSM model is provided in this report.

As detailed within the body of this summary report, two (2) CB MSM models denoted as MSM1 and MSM2 were selected and analyzed. All pertinent SSI analysis results from these two MSM models were benchmarked against the corresponding SSI analysis results from the CB DM model.

Based on the results of the benchmark study, it is concluded that in the combined CB and FWSC SSSI analysis, MSM model of CB corresponding to the MSM2 model will produce reliable and accurate results. In the MSM2 model of CB, in addition to the boundary nodes of excavated soil volume, the nodes at elevation 4.5 m (ground surface) and nodes at elevation -2.0 m will be declared as interaction nodes.

1.0 Introduction

Structure-Soil-Structure Interaction (SSSI) analysis of the combined Control Building (CB) and Firewater Service Complex (FWSC) models with engineered granular backfill above the top of the Bass Islands Group bedrock is performed to evaluate the effect of FWSC on the lateral soil pressures on the embedded CB walls and to demonstrate that the accelerations, forces, moments and floor response spectra (FRS) at the key locations of the CB and FWSC are bounded by the corresponding DCD responses. Considering the 50 Hz minimum required passing frequency of the SSSI model, for Direct Method (DM) of analysis, the number of interaction nodes in combined CB and FWSC model will far exceed the capacity of the SASSI2010 program which is about 20,000 interaction nodes.

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2.0 Control Building Benchmark

The benchmarking of the CB will be performed using the CB structural model provided in Reference 4 and upper bound (UB) soil rock profile provided in Reference 1, with adjustments as required such that both DM and MSM models meet the mesh dimension requirements for the passing frequency of 50 Hz. Details of the DM and MSM models are provided in the following sections.

2.1 DM Model

- Figure 1 shows a 3-D isometric view of the CB structural model. The model properties are from Reference 4.
- The basemat and the exterior walls below the grade are modeled by thin shell elements and the interior portion is modeled using lumped mass beam (stick) elements. The maximum aspect ratio of the shell elements is about 1:2.1.
- The OBE damping value of 4% is used for reinforced concrete.
- The UB soil-rock profile from Reference 1 is used in the model. The soil-rock profile properties provided in Reference 1 correspond to the acceleration time histories which include the impact of the Central and Eastern United States

(CEUS) Seismic Source Characterization (SSC) Model. The soil-rock layer thicknesses are adjusted to be capable of transmitting shear waves with at least 50 Hz frequency (thicknesses not greater than 20 percent of the corresponding layer shear wave length).

- The excavated soil-rock volume is from the elevation of the bottom of the CB basemat to the elevation of the top of the engineered granular backfill (grade).
- The excavated soil-rock volume is modeled using 8-node solid elements. To meet the SASSI2010 (Reference 3) requirements, the maximum horizontal and vertical mesh dimensions in the excavated soil-rock volume are limited to be less than 20 percent of the shear wave length of the subsurface material at frequency of 50 Hz.
- Per SASSI2010 User's Manual (Reference 3, Section A.4.2) recommendation, upper limit of 0.48 is used for the Poisson's ratio in the soil layers below groundwater level.
- The in-column acceleration time histories representing SSI FIRS for UB soil-rock profile are applied at the elevation of the bottom of the CB basemat. These acceleration time histories are from Reference 1. The acceleration time histories include the impact of the CEUS SSC Model.
- Figure 2 shows the excavated soil volume for the CB DM model.

2.2 MSM Models

Two MSM models are examined to determine the adequate number of interaction nodes which will lead to convergence of MSM SSI model results to the DM SSI model results.

In model 1, in addition to the interaction nodes in a standard Subtraction Method (SM) model, interaction nodes are added at the ground surface (Elevation 4.5 m). This model is called MSM1 model.

In model 2, in addition to the interaction nodes in the MSM1 model, interaction nodes are added at an additional elevation of -2.0 m. This model is called MSM2 model.

The soil-rock profile, layer thicknesses, and input motions in these two models are the same as those in the DM model described in Section 2.1. Figures 3 and 4 show the MSM1 and MSM2 excavated soil-rock volume models, respectively. The figures also show the additional layers which have interaction nodes in the corresponding models (layer at elevation 4.5 m in MSM1 model and layers at elevations 4.5 m and -2.0 m in MSM2 model).

2.3 Comparison of SSI Results

The following responses are calculated for each model for three directions of excitation and the results from the three models are compared:

- Transfer functions (both calculated and interpolated) at the following key locations of CB
  - CB top of foundation (basemat) (Elevation -7.4 m)
  - CB top of floor 2 slab (Elevation 4.65 m)
  - CB top of roof slab (Elevation 13.8 m)

- 5% damped floor response spectra (FRS) at the above key locations of CB
- Maximum absolute accelerations at the above key locations of CB
- Maximum forces and moments at key locations of CB
- Lateral soil pressures on the CB exterior walls below grade

2.3.1 Comparison of Transfer Functions

Figures 5 through 13 show the comparisons of transfer functions (both calculated and interpolated) from DM, MSM1, and MSM2 models at the key locations of the CB.

A review of Figures 5 through 13 shows that the transfer functions from the MSM1 and MSM2 models are almost identical to the DM model, except some differences in localized frequency ranges at the following locations:

- In Figure 7, the Z-direction transfer function at CB top of foundation, in the frequency range of 44 Hz to 50 Hz, from MSM1 model is about 5% to 25% higher than those from the DM and MSM2 models.
- In Figure 8, the X-direction transfer function at CB top of floor 2 slab, in the frequency range of 39 Hz to 43 Hz, from MSM1 model is about 5% to 9% higher than those from the DM and MSM2 models.
- In Figure 10, the Z-direction transfer function at CB top of floor 2 slab, in the frequency range of 41 Hz to 45 Hz, from MSM1 model is about 5% to 9% higher than those from the DM and MSM2 models.
- In Figure 11, the X-direction transfer function at the CB top of roof slab, in the frequency range of 39 Hz to 43 Hz, from MSM1 model is about 5% to 10% higher than those from the DM and MSM2 models.
- In Figure 13, the Z direction transfer function at the CB top of roof slab, in the frequency range of 41 Hz to 45 Hz, from the MSM1 model is about 5% to 9% higher than those from the DM and MSM2 models.

These small differences in the transfer functions are in localized frequency ranges and do not have any significant impact on the responses (response spectra, maximum accelerations, and forces/moments) from the three models.

2.3.2 Comparison of Floor Response Spectra (FRS)

Figures 14 through 22 show the comparisons of 5% damped FRS from the DM, MSM1, and MSM2 models at the key locations of the CB.

A review of the FRS shows that the FRS from the MSM1 and MSM2 models are almost identical to the corresponding FRS from the DM model.

2.3.3 Comparison of Maximum Absolute Accelerations

The comparisons between the maximum absolute accelerations in the X-, Y-, and Z-directions at key locations of the CB from the DM, MSM1, and MSM2 models are provided in Table 1. The maximum differences between the results from DM and MSM1 models are 0.85% for X-direction acceleration, 0.71% for Y-direction acceleration, and 0.50% for the Z-direction acceleration. The maximum differences between the results from DM and MSM2 models are 0.88% for X-direction acceleration, 0.48% for Y-direction acceleration, and 0.49% for the Z-direction acceleration.

The above comparisons show that the maximum absolute accelerations from both MSM1 and MSM2 models are almost same as those from DM model. The maximum difference is less than 1%, which is insignificant.

2.3.4 Comparison of Maximum Forces and Moments

The comparisons between the maximum forces and moments in the X-, Y-, and Z-directions (from X-, Y-, and Z-direction input motions, respectively) at the basemat of CB stick from the DM, MSM1, and MSM2 models are provided in Table 2. The maximum differences between the results from DM and MSM1 models are 0.27% for X-direction forces and moments, 0.24% for Y-direction forces and moments, and 0.69% for the Z-direction forces and moments. The maximum differences between the results from DM and MSM2 models are 0.22% for X-direction forces and moments, 0.07% for Y-direction forces and moments, and 0.95% for the Z-direction forces and moments.

The comparisons between the maximum forces and moments in the X-, Y-, and Z-directions (from X-, Y-, and Z-direction input motions, respectively) at the floor 2 slab of CB from the DM, MSM1, and MSM2 models are provided in Table 3. The maximum differences between the results from DM and MSM1 models are 0.36% for X-direction forces and moments, 0.10% for Y-direction forces and moments, and 0.31% for the Z-direction forces and moments. The maximum differences between the results from DM and MSM2 models are 0.36% for X-direction forces and moments, 0.12% for Y-direction forces and moments, and 0.09% for the Z-direction forces and moments.

The above comparisons show that the maximum forces and moments from both MSM1 and MSM2 models are almost same as those from DM model. The maximum difference is less than 1%, which is insignificant.

2.3.5 Comparison of Lateral Soil Pressures

The lateral soil pressure diagrams calculated for the north, south, east, and west exterior walls from the DM, MSM1, and MSM2 models are shown in Figures 23 to 26. The maximum percent differences between MSM1 and DM models and between MSM2 and DM models are less than 8%.

2.3.6 Summary of Response Comparisons

The comparisons of responses in Sections 2.3.1 through 2.3.5, from the MSM1 and MSM2 models with the DM model, show that the responses from both MSM1 and MSM2 models match well with the corresponding responses from DM model, except the transfer functions at some localized frequencies from the MSM1 model differ from the corresponding transfer functions from DM model (differences up to 25%). The transfer functions from the MSM2 model are almost identical to the corresponding transfer functions from the DM model. Hence, in the combined CB and FWSC SSSI analysis, MSM model of CB corresponding to MSM2 model is recommended.

3.0 Conclusions

Structure-Soil-Structure Interaction (SSSI) analysis of the combined Control Building (CB) and Firewater Service Complex (FWSC) models with engineered granular backfill above the top of the Bass Islands Group bedrock is performed to evaluate the effect of FWSC on the lateral soil pressures on the embedded CB walls and to demonstrate that the accelerations, forces, moments and floor response spectra (FRS) at the key locations of the CB and FWSC are bounded by the corresponding DCD responses. Considering the 50 Hz minimum required passing frequency of the SSSI model, for Direct Method (DM) of analysis, the number of interaction nodes in combined CB and FWSC model will far exceed the capacity of the SASSI2010 program which is about 20,000 interaction nodes.

As a result of this program limitation, use of Modified Subtraction Method (MSM) of analysis is required to limit the number of interaction nodes to less than about 20,000. However, when using MSM, selection of additional nodes within the excavated soil volume to be declared as interaction nodes requires benchmarking of the MSM model results against the DM model results to ensure that the selected additional interaction nodes are adequate for producing reliable and accurate SSI results. The benchmarking of the MSM model of the FWSC is provided in Reference 5. A study for the benchmarking of the CB MSM model is provided in this report.

As detailed within the body of this summary report, two (2) CB MSM models denoted as MSM1 and MSM2 were selected and analyzed. All pertinent SSI analysis results from these two MSM models were benchmarked against the corresponding SSI analysis results from the CB DM model.

Based on the results of the benchmark study, it is concluded that in the combined CB and FWSC SSSI analysis, MSM model of CB corresponding to the MSM2 model will produce reliable and accurate results. In the MSM2 model of CB, in addition to the boundary nodes of excavated soil volume, the nodes at elevation 4.5 m (ground surface) and nodes at elevation -2.0 m will be declared as interaction nodes.

4.0 References

1. DTE Electric Company Letter No. 2013-MEP-F3COLA-0021, "Soil Profile and Acceleration Time Histories Based Upon the Central and Eastern United States Seismic Source Characterization Model," February 14, 2013.

2. ESBWR Design Control Document, Tier 2, Revision 9, December 2010.

3. SASSI2010 Version 1.0 User's Manual, "A System for Analysis of Soil-Structure Interaction," Farhang Ostadan and Nan Deng, May 2012.

4. DTE Electric Company Letter No. 2012-MEP-F3COLA-0083, Transmittal of Verified ESBWR Seismic Model Information, December 10, 2012.

5. Modified Subtraction Method (MSM) Firewater Service Complex Benchmark Summary Report, SL-011863 Revision 0, May 21, 2013.

Table 1: Comparison of Maximum Absolute Accelerations between DM, MSM1, and MSM2 Models

(a) Maximum seismic accelerations (units of g)

	DM			MSM1			MSM2		
Location	X_x	Y_y	Z_z	X_x	Y_y	Z_z	X_x	Y_y	Z_z
CB top of basemat Node 410	0.2272	0.1815	0.1863	0.2268	0.1810	0.1865	0.2270	0.1812	0.1863
CB top of floor 2 slab Node 460	0.2245	0.2672	0.2856	0.2264	0.2691	0.2846	0.2244	0.2678	0.2860
CB top of roof slab Node 500	0.4088	0.4109	0.3410	0.4075	0.4113	0.3427	0.4074	0.4100	0.3416

(b) Comparison of MSM maximum seismic accelerations to DM values

	$\left\lvert\frac{MSM1-DM}{DM}\right\rvert\times 100$			$\left\lvert\frac{MSM2-DM}{DM}\right\rvert\times 100$		
Location	X_x	Y_y	Z_z	X_x	Y_y	Z_z
CB top of basemat Node 410	0.18%	0.26%	0.11%	0.09%	0.09%	0.11%
CB top of floor 2 slab Node 460	0.85%	0.71%	0.35%	0.88%	0.48%	0.49%
CB top of roof slab Node 500	0.32%	0.10%	0.50%	0.02%	0.32%	0.32%

Table 2: Comparison of Maximum Forces and Moments at CB foundation between DM, MSM1, and MSM2 Models

(a) Maximum seismic forces and moments at CB foundation (units of MN and MN-m)

Load Dir.	DM			MSM1			MSM2		
	X	Y	Z	X	Y	Z	X	Y	Z
P2 (F_X)	53.87	--	--	53.79	--	--	53.89	--	--
P3 (F_Y)	--	62.19	--	--	62.05	--	--	62.19	--
P1 (F_Z)	--	--	34.00	--	--	34.24	--	--	34.32
M2 (M_X)	--	451.40	--	--	451.89	--	--	451.69	--
M3 (M_Y)	399.72	--	--	400.80	--	--	400.60	--	--

(b) Comparison of MSM seismic forces and moments to DM values at CB foundation

Load Dir.	$\left\lvert\frac{MSM1-DM}{DM}\right\rvert\times 100$			$\left\lvert\frac{MSM2-DM}{DM}\right\rvert\times 100$		
	X	Y	Z	X	Y	Z
P2 (F_X)	0.15%	--	--	0.04%	--	--
P3 (F_Y)	--	0.24%	--	--	0.00%	--
P1 (F_Z)	--	--	0.69%	--	--	0.95%
M2 (M_X)	--	0.11%	--	--	0.07%	--
M3 (M_Y)	0.27%	--	--	0.22%	--	--

Table 3: Comparison of Maximum Forces and Moments at CB floor 2 between DM, MSM1, and MSM2 Models

(c) Maximum seismic forces and moments at CB floor 2 slab (units of MN and MN-m)

Load Dir.	DM			MSM1			MSM2		
	X	Y	Z	X	Y	Z	X	Y	Z
P2 (F_X)	19.00	--	--	18.93	--	--	18.93	--	--
P3 (F_Y)	--	19.94	--	--	19.96	--	--	19.92	--
P1 (F_Z)	--	--	21.98	--	--	22.05	--	--	22.00
M2 (M_X)	--	158.97	--	--	158.97	--	--	158.77	--
M3 (M_Y)	167.79	--	--	167.20	--	--	167.20	--	--

(d) Comparison of MSM seismic forces and moments to DM values at CB floor 2 slab

Load Dir.	$\left\lvert\frac{MSM1-DM}{DM}\right\rvert \times 100$			$\left\lvert\frac{MSM2-DM}{DM}\right\rvert \times 100$		
	X	Y	Z	X	Y	Z
P2 (F_X)	0.36%	--	--	0.36%	--	--
P3 (F_Y)	--	0.10%	--	--	0.10%	--
P1 (F_Z)	--	--	0.31%	--	--	0.09%
M2 (M_X)	--	0.00%	--	--	0.12%	--
M3 (M_Y)	0.35%	--	--	0.35%	--	--

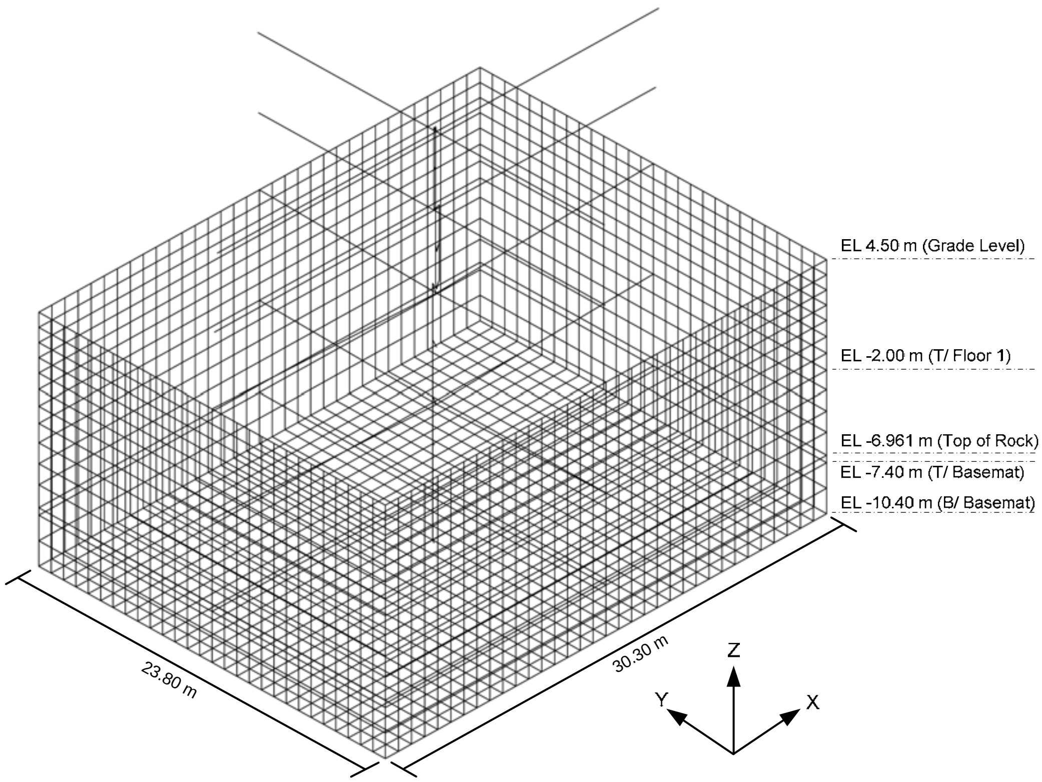


Figure 1: 3-D Isometric View of the CB SASSI2010 Structural Model

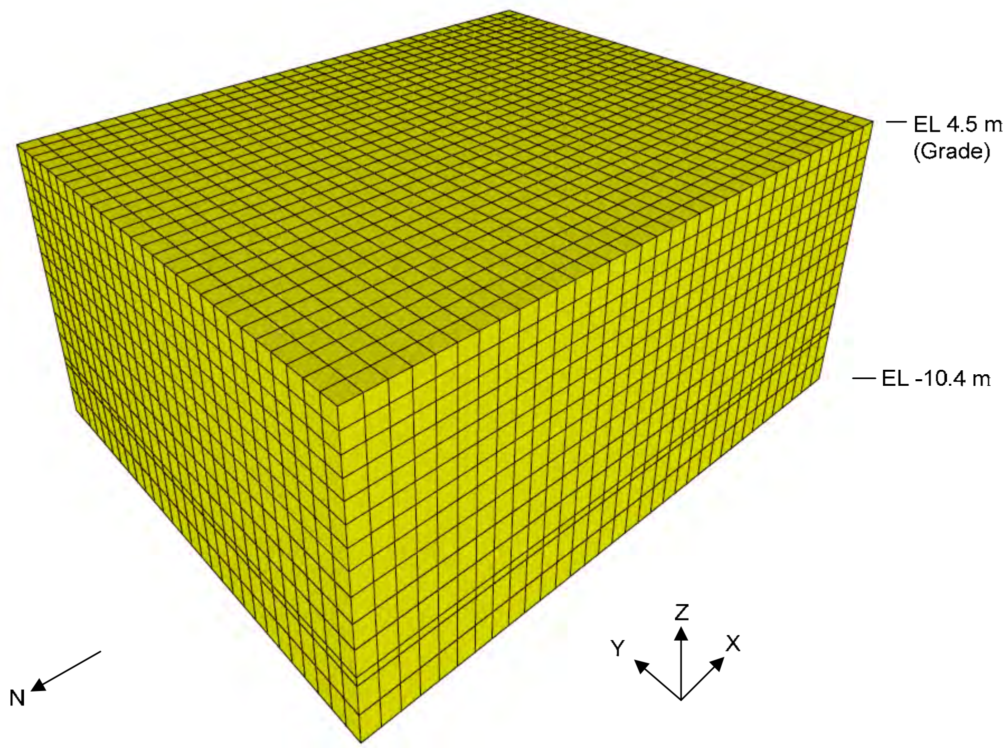


Figure 2: Excavated Soil-Rock Volume of the CB DM Model (all nodes are interaction nodes)

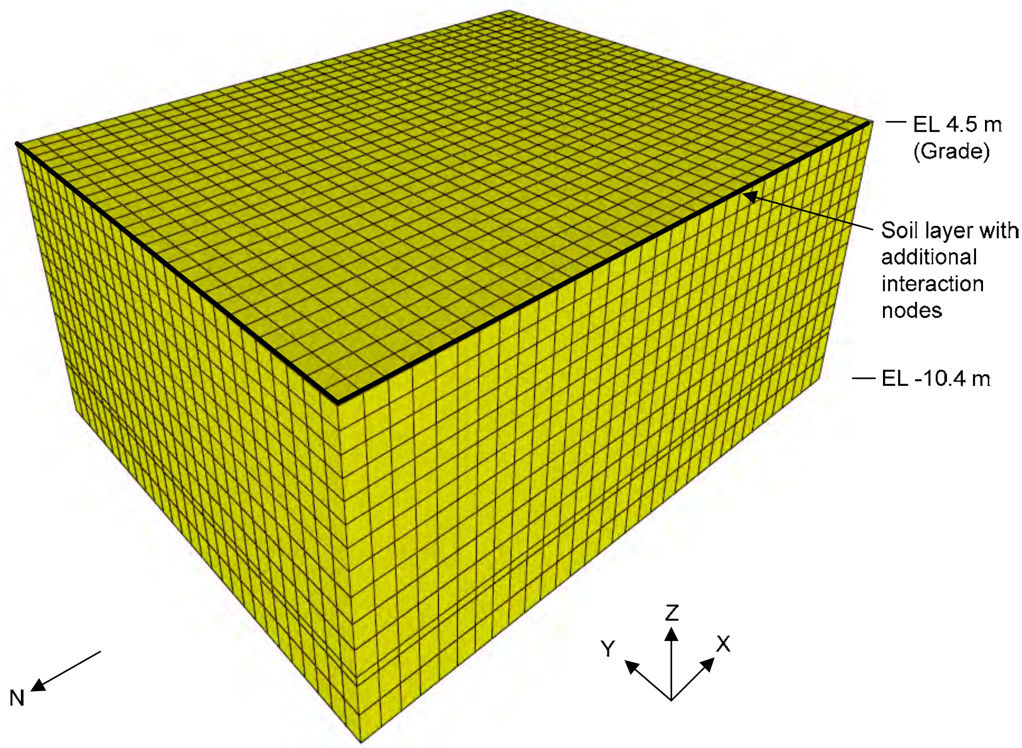


Figure 3: Excavated Soil-Rock Volume for CB MSM1 Model

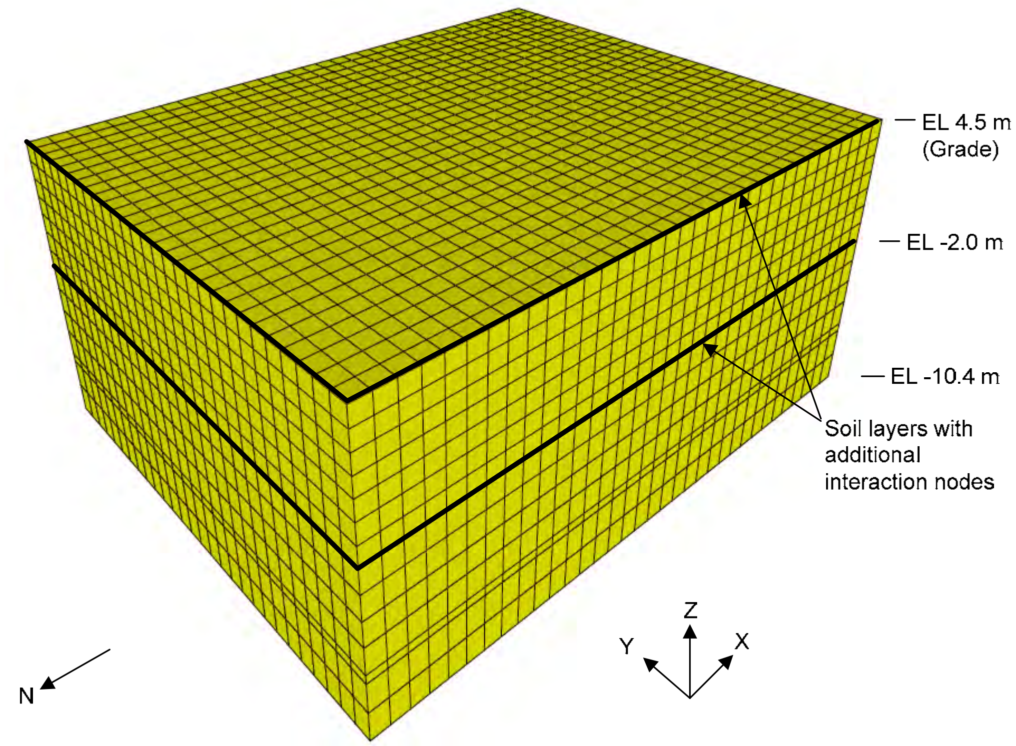


Figure 4: Excavated Soil-Rock Volume for CB MSM2 Model

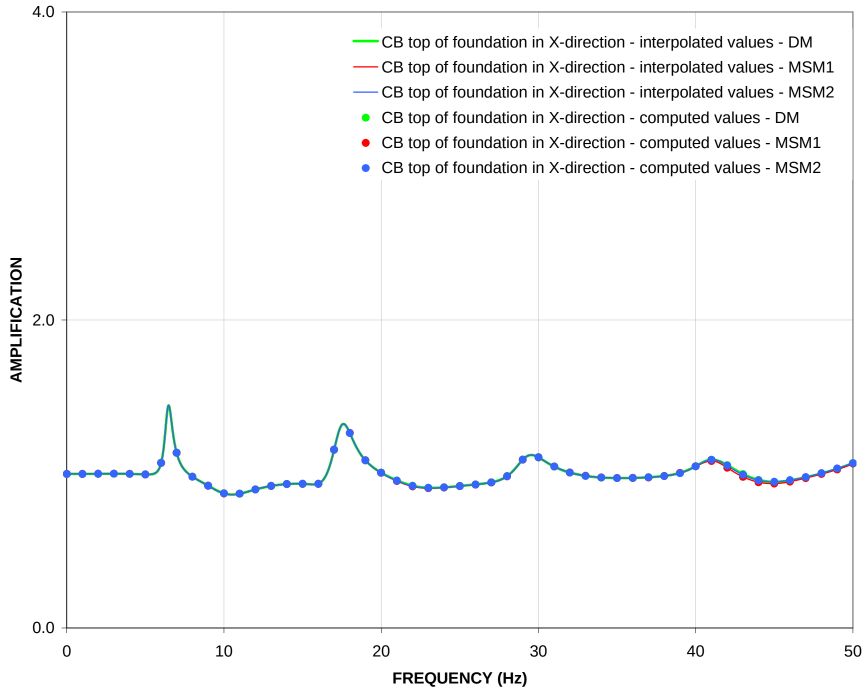


Figure 5: X-Direction DM, MSM1, and MSM2 Transfer Functions CB top of foundation (EL -7.4 m)

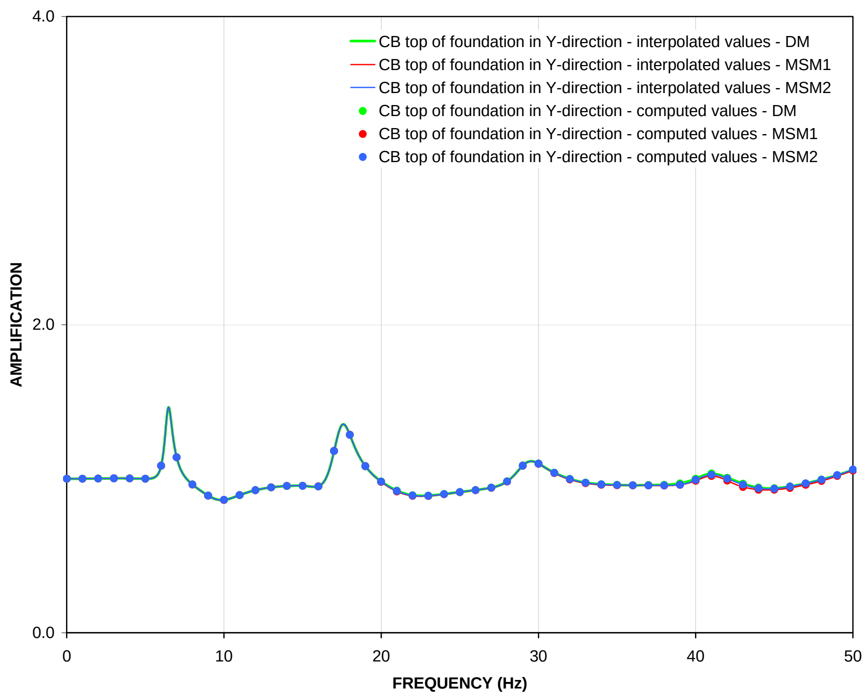


Figure 6: Y-Direction DM, MSM1, and MSM2 Transfer Functions CB top of foundation (EL -7.4 m)

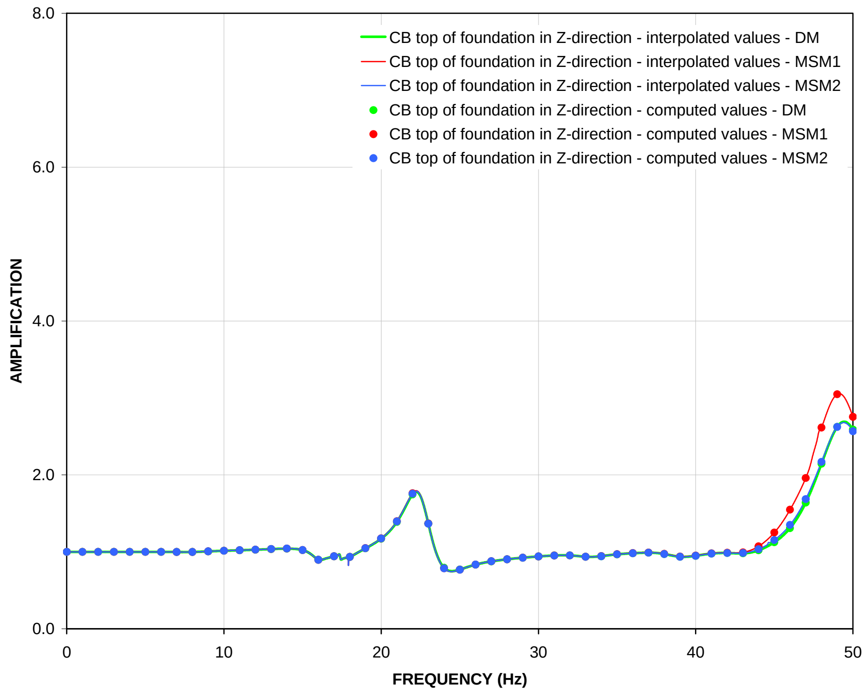


Figure 7: Z-Direction DM, MSM1, and MSM2 Transfer Functions CB top of foundation (EL -7.4 m)

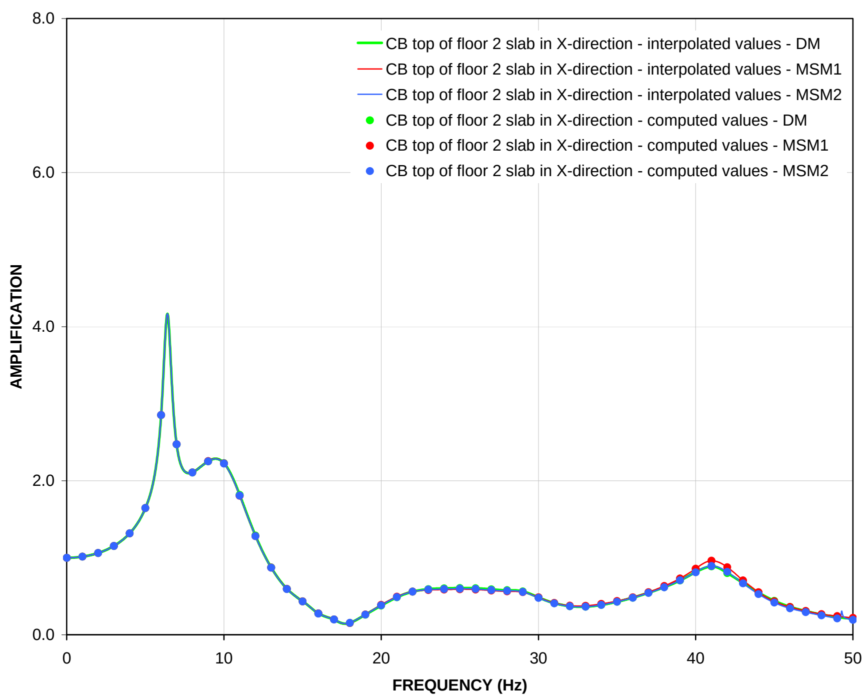


Figure 8: X-Direction DM, MSM1, and MSM2 Transfer Functions CB top of floor 2 slab (EL 4.65 m)

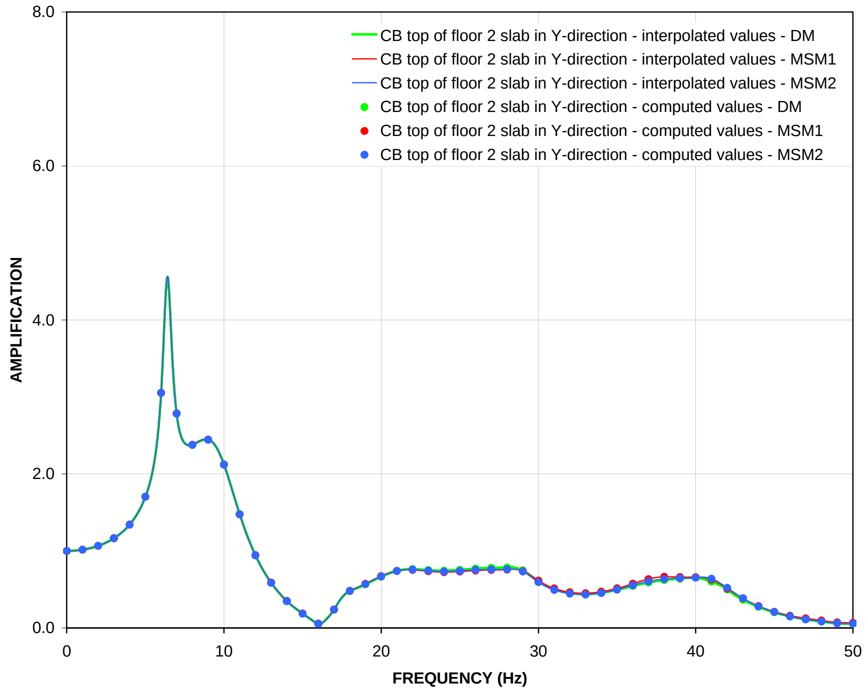


Figure 9: Y-Direction DM, MSM1, and MSM2 Transfer Functions CB top of floor 2 slab (EL 4.65 m)

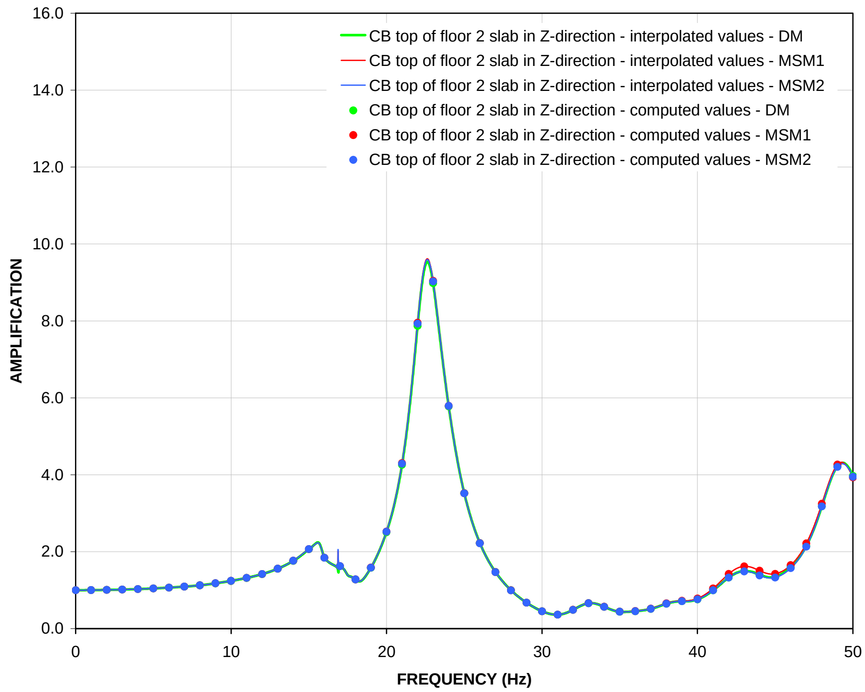


Figure 10: Z-Direction DM, MSM1, and MSM2 Transfer Functions CB top of floor 2 slab (EL 4.65 m)

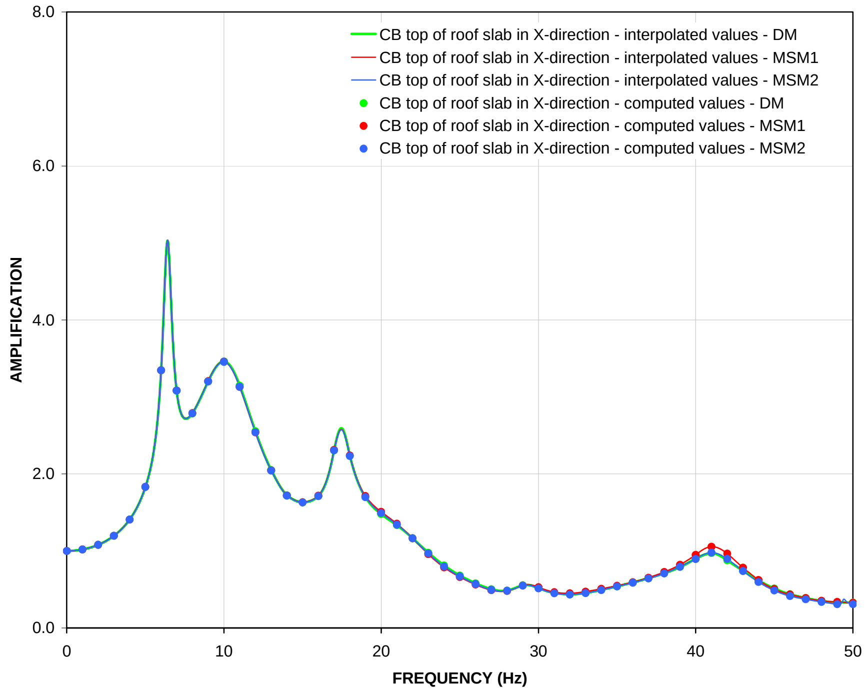


Figure 11: X-Direction DM, MSM1, and MSM2 Transfer Functions CB top of roof slab (EL 13.8 m)

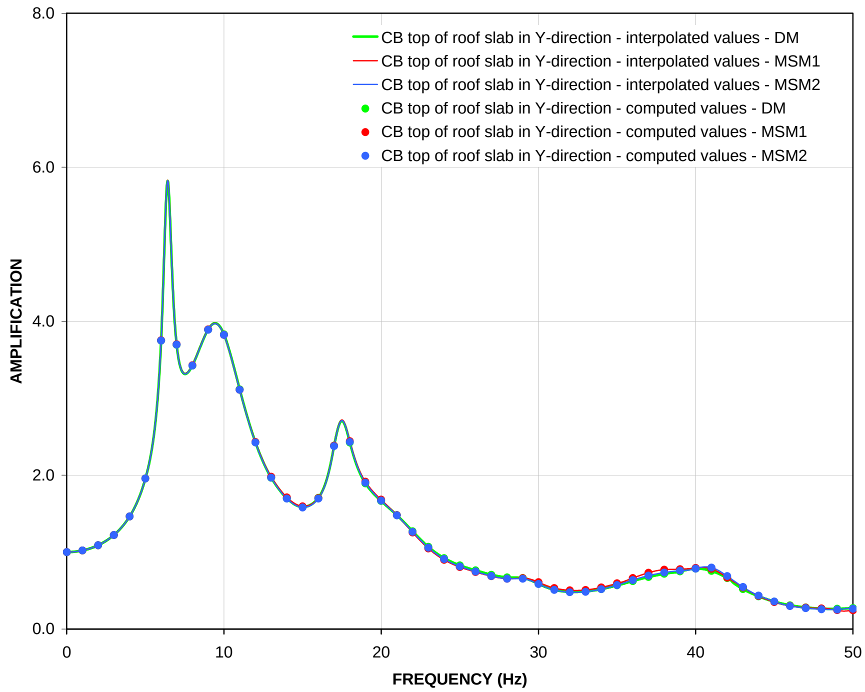


Figure 12: Y-Direction DM, MSM1, and MSM2 Transfer Functions CB top of roof slab (EL 13.8 m)

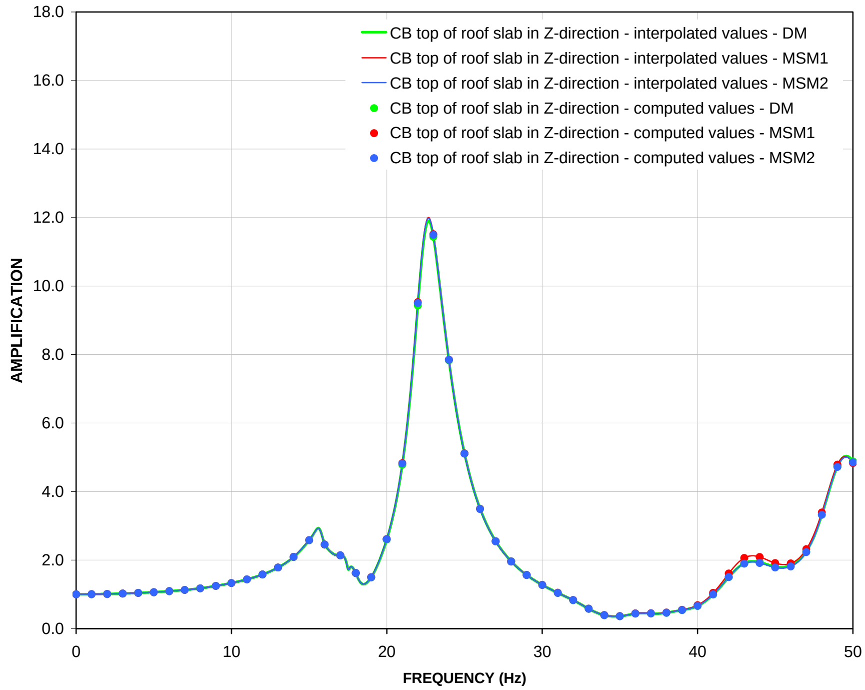


Figure 13: Z-Direction DM, MSM1, and MSM2 Transfer Functions CB top of roof slab (EL 13.8 m)

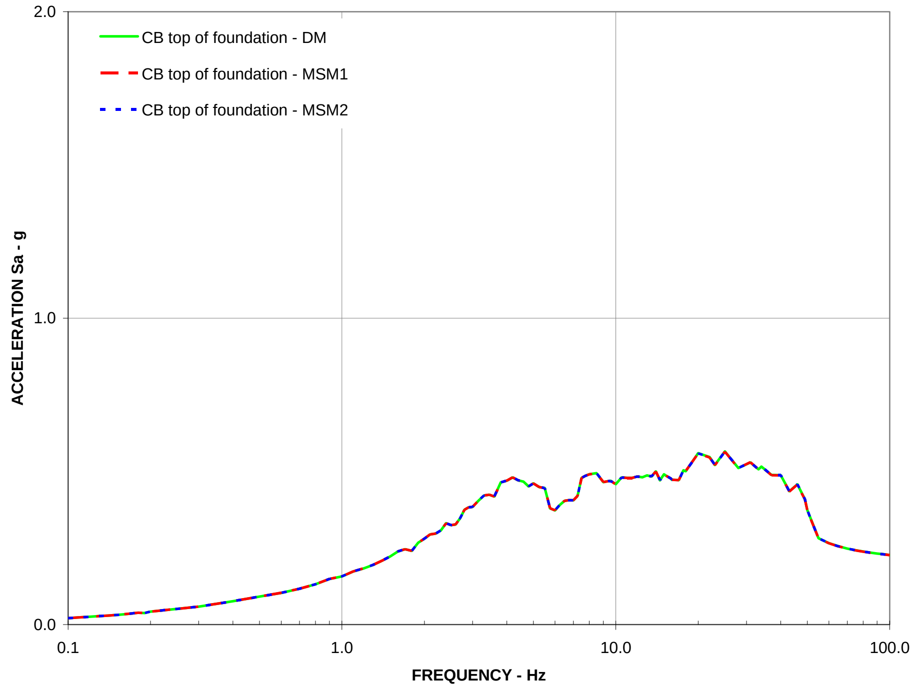


Figure 14: X-Direction DM, MSM1, and MSM2 5% Damped Response Spectra CB top of foundation (EL -7.4 m)

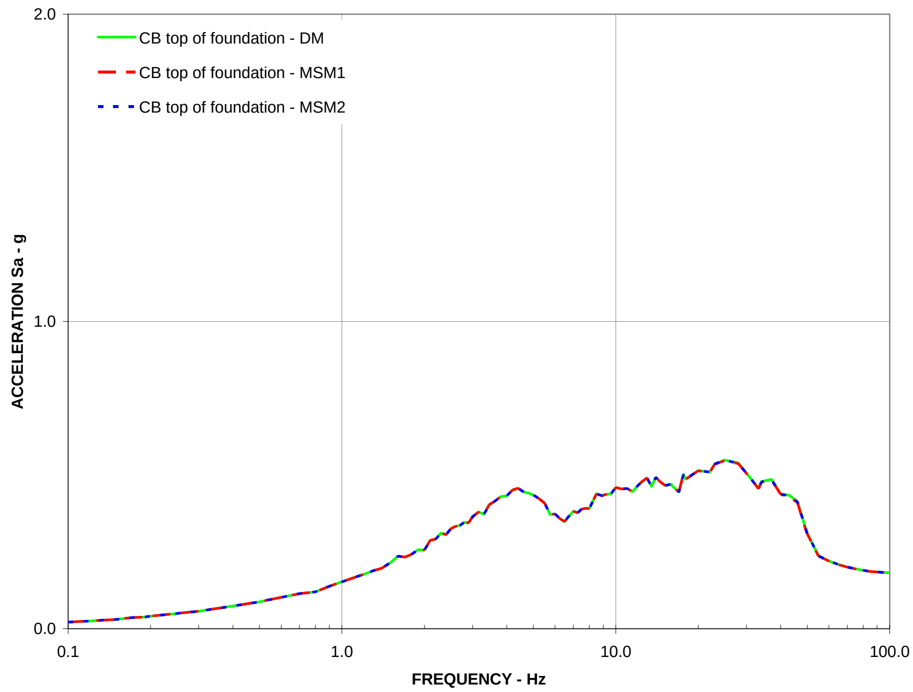


Figure 15: Y-Direction DM, MSM1, and MSM2 5% Damped Response Spectra CB top of foundation (EL -7.4 m)

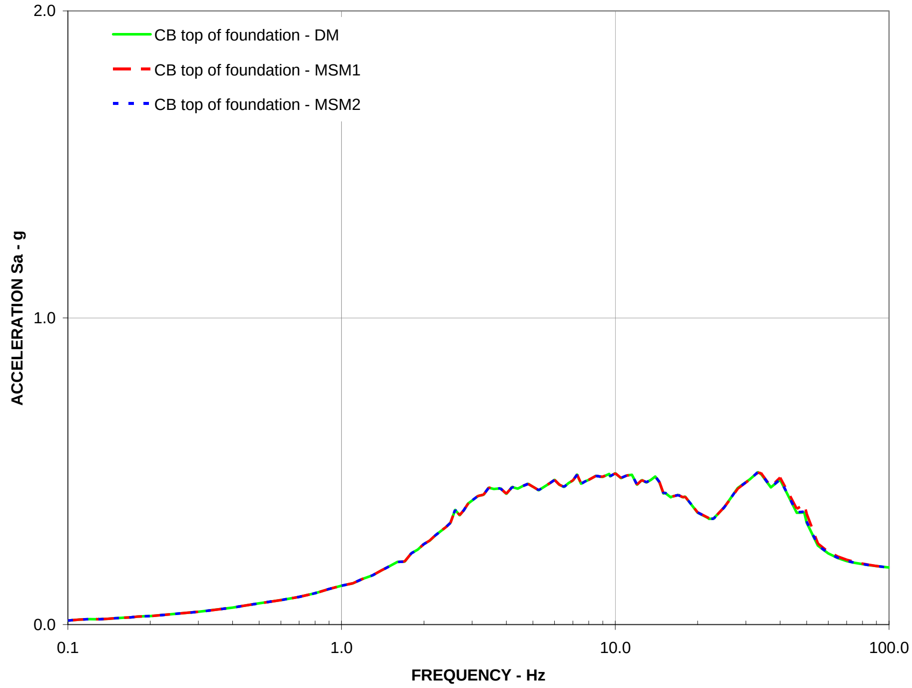


Figure 16: Z-Direction DM, MSM1, and MSM2 5% Damped Response Spectra CB top of foundation (EL -7.4 m)

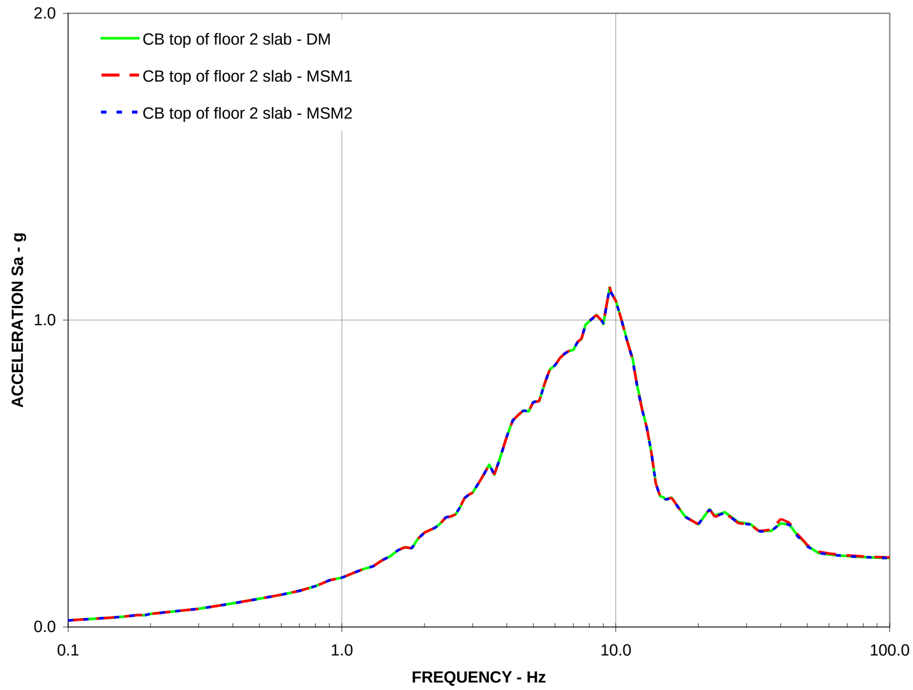


Figure 17: X-Direction DM, MSM1, and MSM2, 5% Damped Response Spectra CB top of floor 2 (EL 4.65 m)

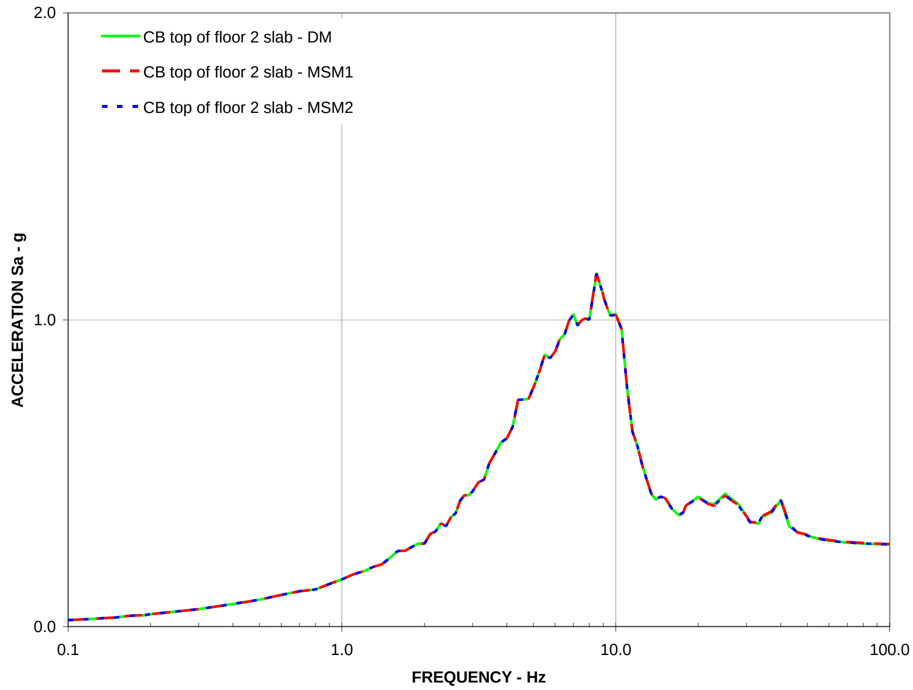


Figure 18: Y-Direction DM, MSM1, and MSM2, 5% Damped Response Spectra CB top of floor 2 (EL 4.65 m)

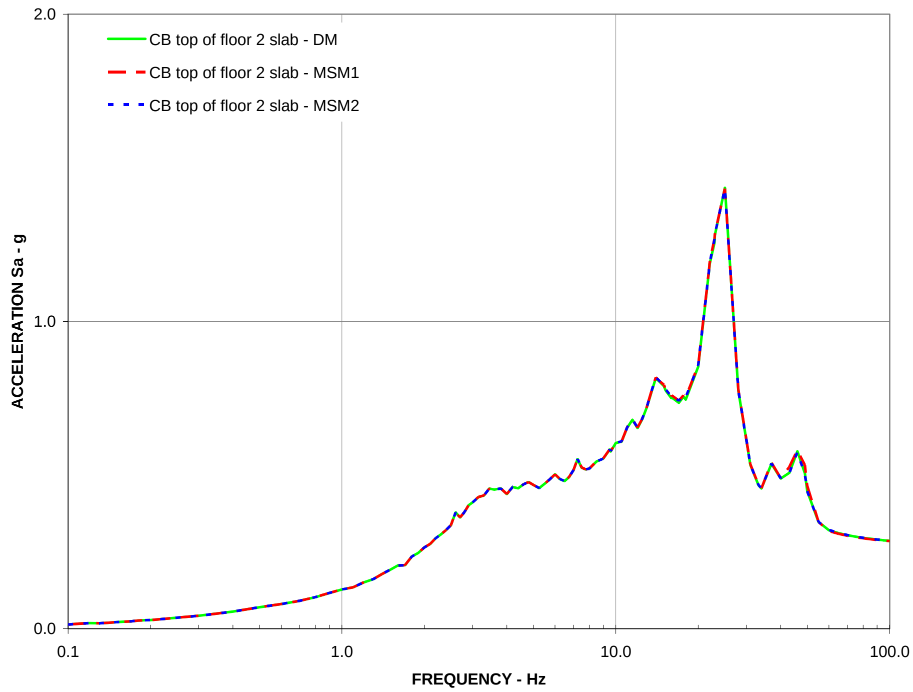


Figure 19: Z-Direction DM, MSM1, and MSM2, 5% Damped Response Spectra CB top of floor 2 (EL 4.65 m)

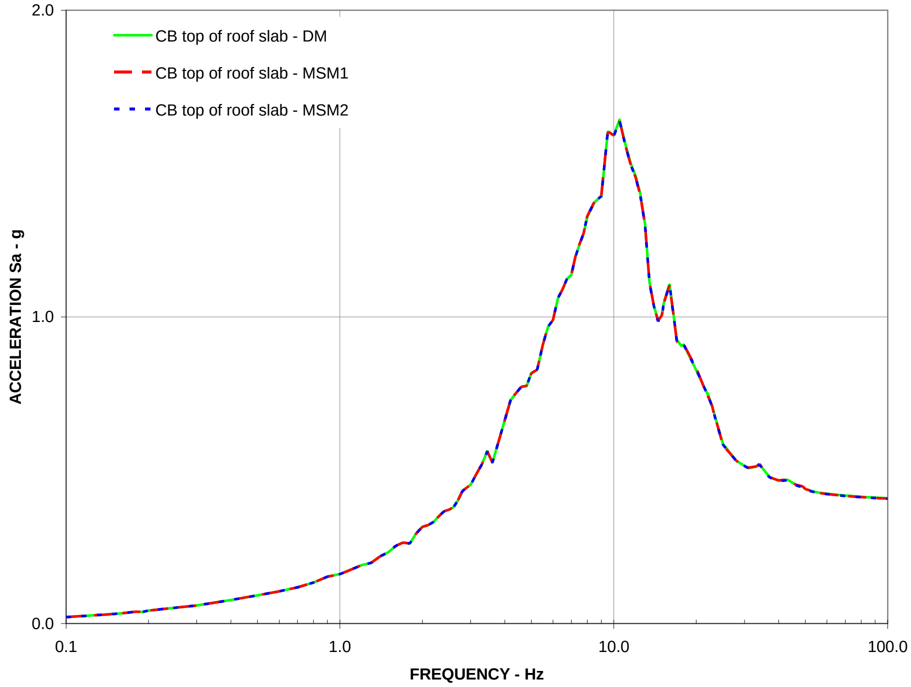


Figure 20: X-Direction DM, MSM1, and MSM2, 5% Damped Response Spectra CB top of roof slab (EL 13.8 m)

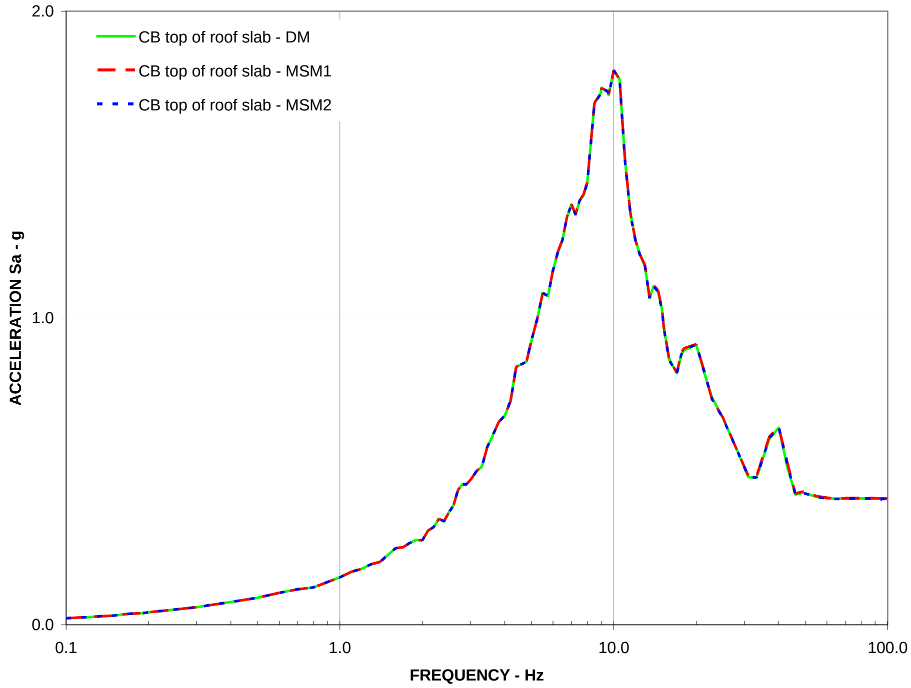


Figure 21: Y-Direction DM, MSM1, and MSM2, 5% Damped Response Spectra CB top of roof slab (EL 13.8 m)

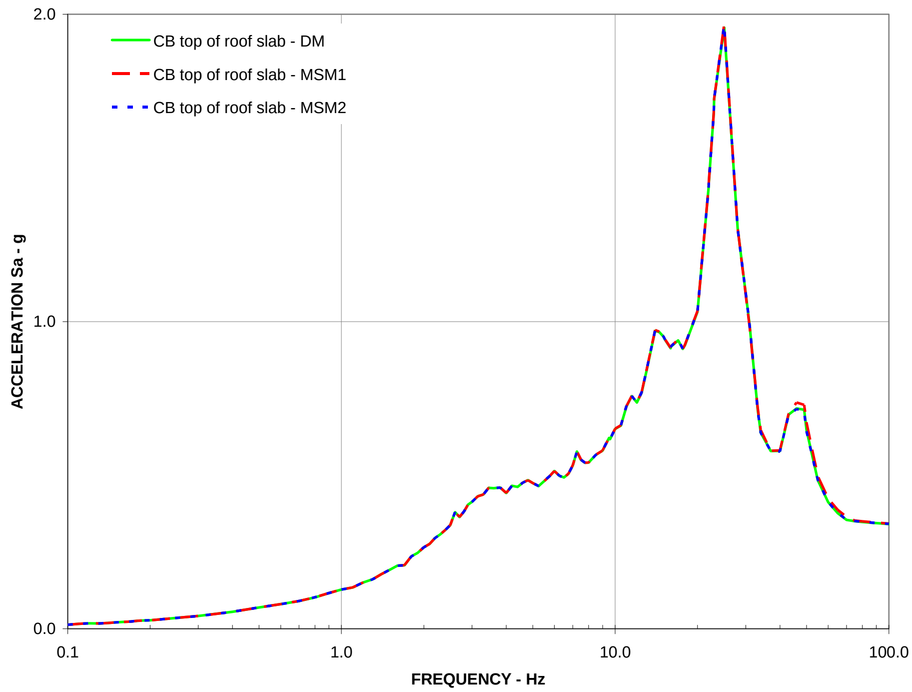
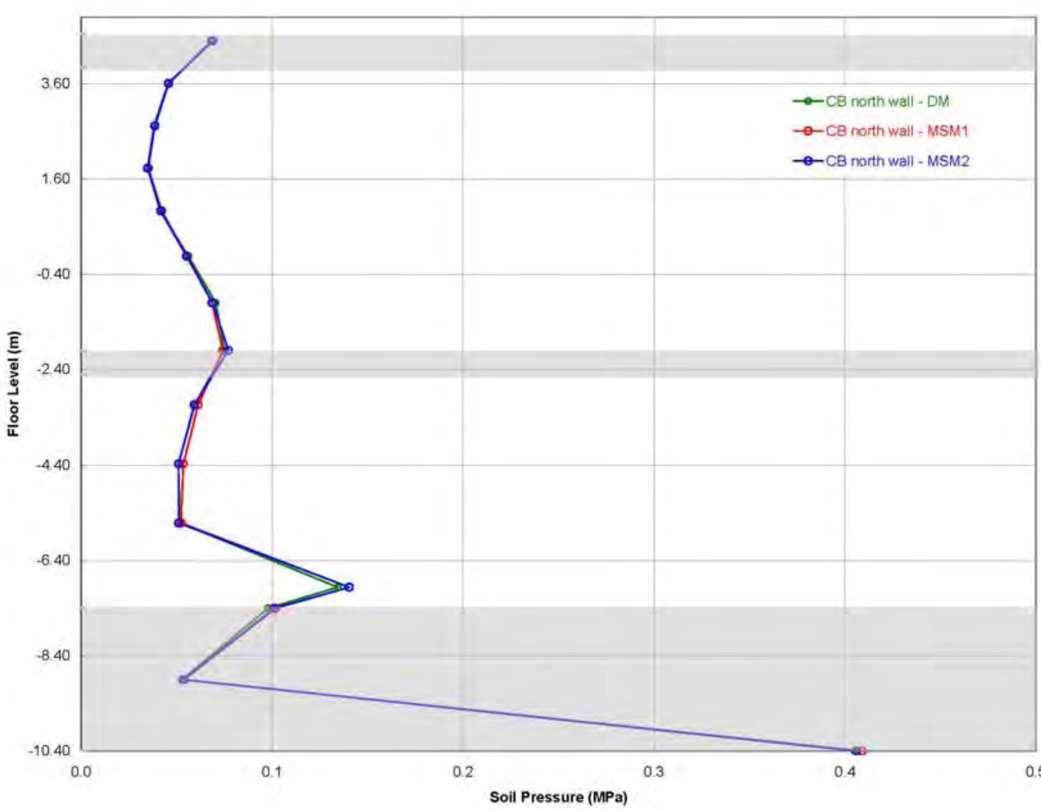


Figure 22: Z-Direction DM, MSM1, and MSM2, 5% Damped Response Spectra CB top of roof slab (EL 13.8 m)



Note: The shaded areas show the thickness of the basemat and the floor slabs

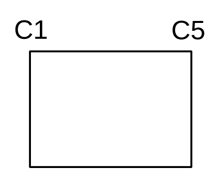
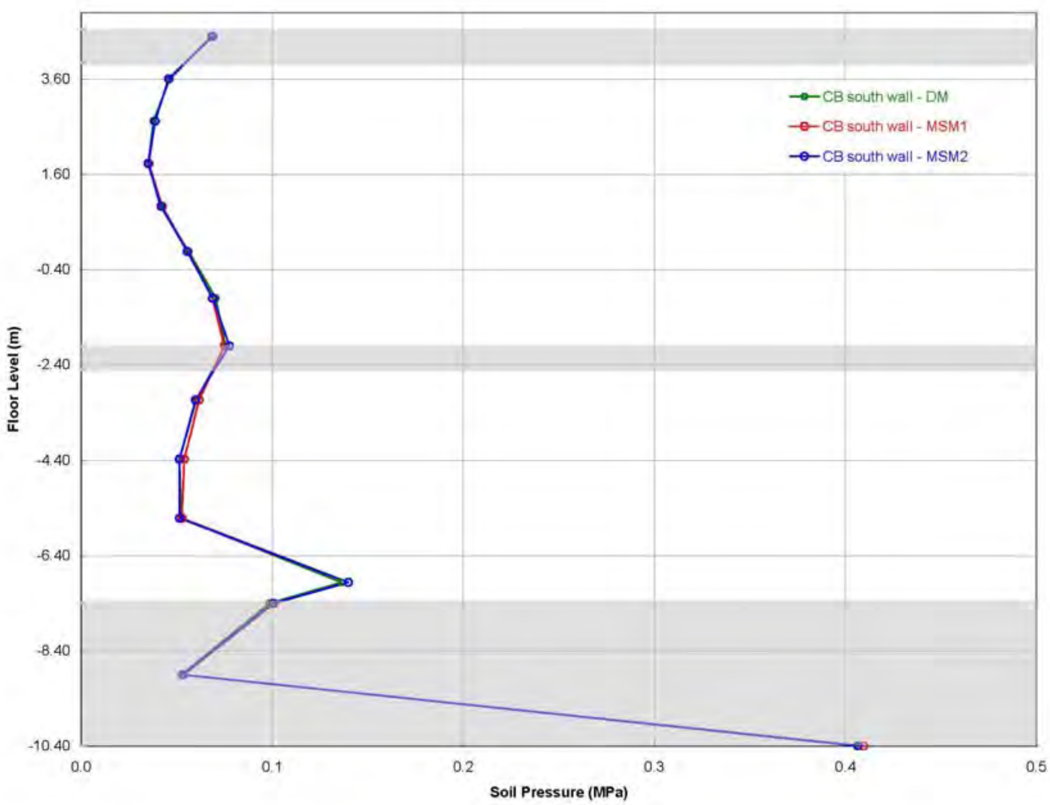


Figure 23: DM, MSM1, and MSM2 lateral soil pressure on CB north exterior wall (C1)



Note: The shaded areas show the thickness of the basemat and the floor slabs

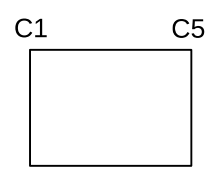
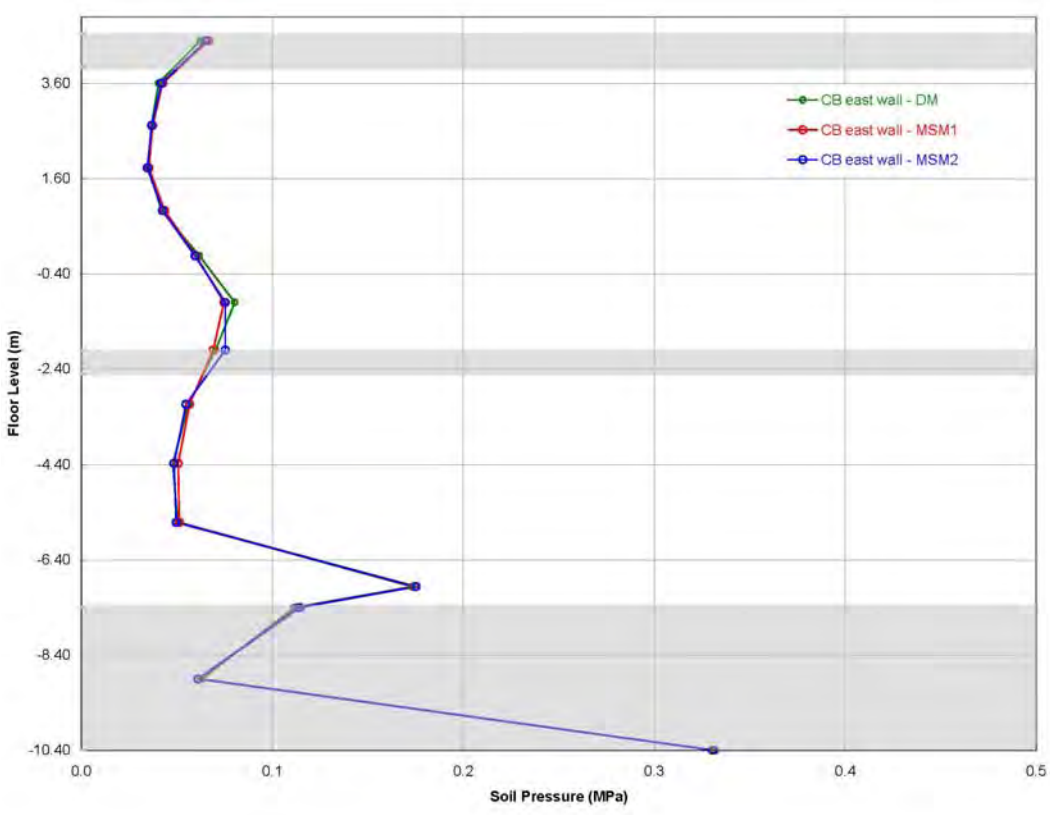


Figure 24: DM, MSM1, and MSM2 lateral soil pressure on CB south exterior wall (C5)



Note: The shaded areas show the thickness of the basemat and the floor slabs

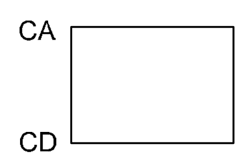
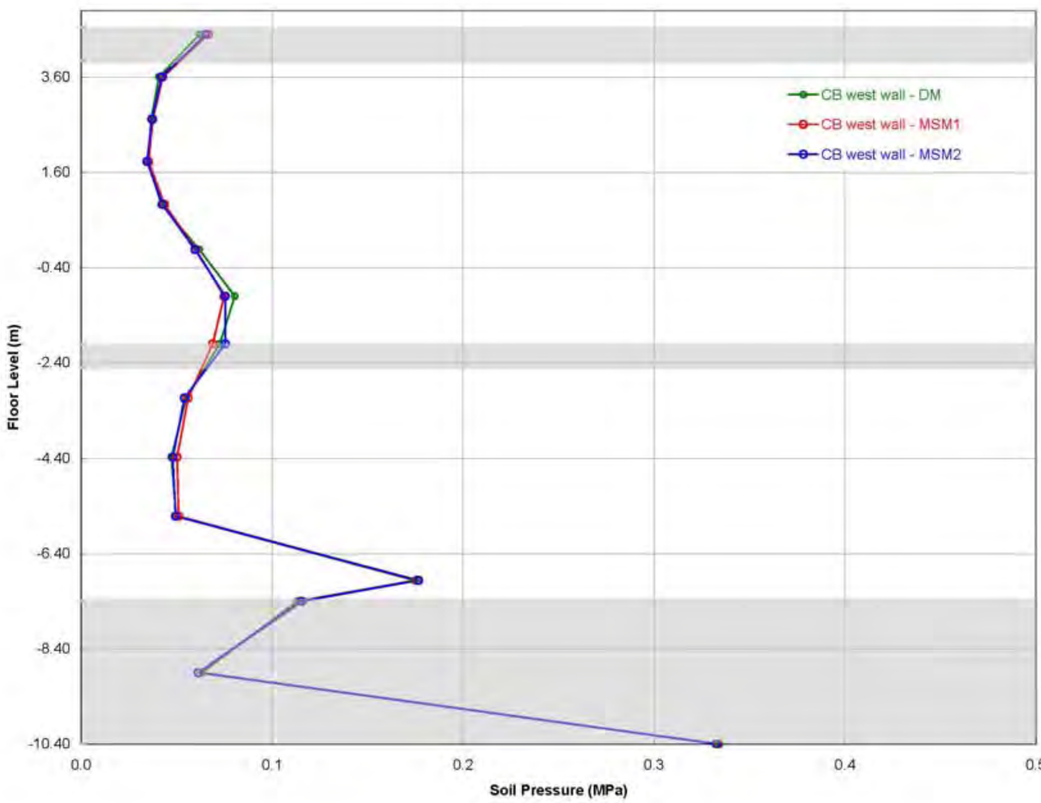


Figure 25: DM, MSM1, and MSM2 lateral soil pressure on CB east exterior wall (CA).



Note: The shaded areas show the thickness of the basemat and the floor slabs

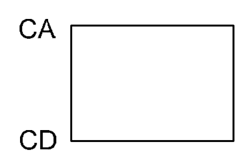


Figure 26: DM, MSM1, and MSM2 lateral soil pressure on CB west exterior wall (CD).