

APPENDIX 2C

SEISMIC LATERAL EARTH PRESSURES

This appendix describes seismic analyses used to calculate the lateral earth pressures on the exterior walls below grade of the AP600 nuclear island.

Seismic lateral earth pressures are obtained from the 2D SASSI computer program analyses of the nuclear island. The lateral earth pressures obtained from the 2D SASSI analyses are adjusted for three-dimensional effects to include the following:

- Effect of torsional motion of the nuclear island
- Local distribution of the lateral earth pressure behind the walls at the corners and at locations of cross walls ("box effect")

Analyses are performed in the East-West and North-South directions and include the effects of the adjacent turbine, annex, and radwaste buildings.

2C.1 2D SASSI Analysis for Seismic Lateral Earth Pressures

2C.1.1 Analysis Method

Two-dimensional seismic soil-structure interaction analyses are performed to obtain the lateral earth pressures on the exterior walls below grade of the AP600 nuclear island using representative two-dimensional stick models of the nuclear island structures and basemat models. The analyses are performed using the computer program SASSI described in Section 2A.5 of Appendix 2A.

2C.1.2 Structural Models

Two-dimensional lumped mass stick models of the AP600 nuclear island structures suitable for the two-dimensional soil-structure interaction analysis were developed from the three-dimensional lumped mass stick models described in subsection 3.7.2.3. Two-dimensional lumped mass stick models were developed for the coupled auxiliary and shield buildings, the steel containment vessel, and the containment internal structures.

2C.1.3 SASSI Foundation Models

The same foundation model and procedures presented in Section 2A.5 of Appendix 2A were used to represent the basemat and side walls of the nuclear island. The SASSI foundation model in the X-Z plane is shown in Figures 2A-25 and 2A-26. The SASSI foundation model in the Y-Z plane is presented in Figures 2A-27 and 2A-28.

2C.1.4 Representation of Adjacent Structures

The structures adjacent to the nuclear island are the annex building (east side of the nuclear island), turbine building (approximately 16 feet north), and the radwaste building (south). The foundations of these buildings were represented by rigid elements. The weight of each building was distributed among the respective foundation nodes.

2C.1.5 Input Motion

The analysis was performed in the North-South and East-West directions using the H1 and H2 components of time history developed in subsection 3.7.1. The control motions were defined at the finished grade at elevation 100' in the free-field.

2C.1.6 Soil Properties

Based on parametric studies using the various soil profiles, the following four profiles were identified as governing profiles for seismic lateral earth pressures:

- Hard rock
- Soft rock
- Soft-to-medium soil with parabolic shear modulus distribution (sandy soils)
- Soft soil

2C.1.7 2D SASSI Analyses Results

Results of the analyses for seismic lateral earth pressures on the exterior walls below grade for the four soil profiles listed in subsection 2.C.1.6 are presented in Tables 2C-1 through 2C-4. Results are given for the nuclear island structures alone and also for the nuclear island structures in combination with the adjacent annex, turbine, and radwaste buildings.

2C.2 Effect from Torsional Motion of the Nuclear Island

The seismic lateral earth pressures determined as described in Section 2C.1 are adjusted to account for the torsional motion of the nuclear island structures. The adjustment factor is obtained by adding the relative displacements due to torsion of the nuclear island (calculated in the three-dimensional analyses) to the two-dimensional results. The adjustment factors are shown in Table 2C-5 and are calculated as described below:

The displacement of one end of the exterior wall relative to the other end is calculated from the time history results of the 3D SASSI analyses described in Section 3.7.2 for each elevation. The maximum relative displacement (δ_c) is calculated at each elevation.

The maximum displacement of the end wall relative to the free field (δ_{2D}) is obtained from the 2D SASSI analyses at each elevation.

The lateral earth pressures in the 2D SASSI analyses are a function of the relative displacement of the end wall and the free-field.

The lateral earth pressure including torsional motion is taken as the lateral earth pressure from the 2D SASSI analyses increased by an adjustment factor. There is no adjustment at the midpoint of the wall. The adjustment factor at the corners is equal to 1 plus half the maximum relative displacement of the corners divided by the maximum two-dimensional relative deflection ($1 + 0.5 \delta_c / \delta_{2D}$). The adjustment factor is linear between the midpoint of the wall and the corners.

2C.3 Local Distribution of Lateral Earth Pressure

The seismic lateral earth pressures determined as described in Section 2C.1 are also adjusted to account for local distribution of the seismic soil pressure at the corners. The adjustment factors are obtained using static analyses of a simplified three-dimensional model of the nuclear island below grade together with the soil around the walls and basemat. The structural model is shown in Figure 2C-1 and the soil model is shown in Figure 2C-2. The elastic soil properties are compatible with the properties used in the soil structure interaction analyses. The model extends sufficiently to eliminate the far-field boundary effects.

The analyses are performed using the computer program BSAP (Reference 1). For each soil case analyzed, the shear force at elevation 100' obtained from the 2D SASSI analyses is applied as a static load to the model and the stresses in the soil elements behind the wall are computed. Analyses are performed for the following soil cases:

- Hard rock
- Soft rock
- Soft-to-medium soil, with parabolic shear modulus distribution (sandy soils)
- Soft soil

The relative soil pressures behind the walls for the four soil cases are shown in Table 2C-6. These analyses are intended to show the distribution of the lateral earth pressures rather than actual magnitudes, which are better calculated in the 2D SASSI analyses described previously. The results of these analyses show the following behavior:

- Lateral earth pressures are higher opposite the interior walls and floor slabs than opposite the middle of the wall panels. The difference is greater for the harder sites. This effect is also apparent in the 2D SASSI results of Tables 2C-1 through 2C-4 where the pressures are higher opposite the floor slabs at elevations 82.5' and 100'.
- Lateral earth pressures are higher at the corner than at the middle of the wall panels. For the harder soils these pressures are similar in magnitude to those opposite the interior walls. For the soft soil the pressures are about 60 percent higher than opposite the interior walls. This increased pressure only occurs over one element, that is, a length of about 6 feet.

The relative lateral earth pressure results are used to adjust the two-dimensional seismic pressures (Section 2C.1.7) at the corners for the design of the exterior walls. The two-dimensional seismic lateral earth pressures are increased by the ratio of the pressure at the corner divided by the pressure at the adjacent interior wall. The adjustment factors are shown in Table 2C-7.

No adjustment is made to the lateral earth pressures due to the effect of the interior walls. This is conservative for the design of the exterior wall since the redistribution reduces the bending moments and shear forces in the wall which spans between the interior walls and the floor slabs.

2C.4 References

1. Bechtel Corporation, "User's and Theoretical Manual for Computer Program BSAP (CE800)," Revision 12, 1991.

Table 2C-1

**SEISMIC LATERAL EARTH PRESSURES (KSF)
NUCLEAR ISLAND STRUCTURES ALONE
NORTH-SOUTH (X) SHAKING**

Elev. (ft)	Layer No.	Hard Rock		Soft Rock		Soft-to-Medium Soil		Soft Soil	
		South Side	North Side	South Side	North Side	South Side	North Side	South Side	North Side
97.5	1	19.69	19.91	6.54	6.62	3.75	3.84	6.69	6.71
92.5	2	2.31	2.35	1.12	1.11	1.76	1.70	2.52	2.41
87.5	3	1.33	1.43	2.28	2.27	1.06	1.22	2.41	2.41
82.5	4	6.42	6.45	3.90	3.92	1.56	1.83	4.52	4.54
77.5	5	5.78	5.86	2.74	2.76	0.87	0.93	1.50	1.50
72.5	6	0.72	0.64	1.26	1.26	2.11	2.07	6.71	6.78
68.25	7	3.19	3.27	1.43	1.43	1.60	1.57	4.27	4.37
63.5	8	2.58	2.63	2.20	2.19	2.74	2.75	6.31	6.28

Table 2C-2

**SEISMIC LATERAL EARTH PRESSURES (KSF)
NUCLEAR ISLAND STRUCTURES ALONE
EAST-WEST (Y) SHAKING**

Elev. (ft)	Layer No.	Hard Rock		Soft Rock		Soft-to-Medium Soil		Soft Soil	
		East Side	West Side	East Side	West Side	East Side	West Side	East Side	West Side
97.5	1	17.12	17.36	8.24	8.36	3.70	3.75	7.75	7.65
92.5	2	2.24	2.27	0.75	0.78	3.09	3.13	4.46	4.42
87.5	3	0.85	0.90	1.63	1.71	2.05	2.17	2.00	2.28
82.5	4	4.05	4.19	3.39	3.45	1.61	1.64	0.55	0.58
77.5	5	3.73	3.77	2.76	2.80	2.77	2.73	1.54	1.01
72.5	6	0.77	0.80	0.92	0.93	1.73	1.79	1.17	1.74
68.25	7	2.89	3.14	0.57	0.56	1.31	1.19	0.78	0.68
63.5	8	1.86	1.87	0.79	0.77	1.49	1.61	5.24	5.97

Table 2C-3

**SEISMIC LATERAL EARTH PRESSURES (KSF)
NUCLEAR ISLAND STRUCTURES COMBINED WITH TURBINE and RADWASTE
BUILDINGS
NORTH-SOUTH (X) SHAKING**

Elev. (ft)	Layer No.	Hard Rock		Soft Rock		Soft-to-Medium Soil		Soft Soil	
		South Side	North Side	South Side	North Side	South Side	North Side	South Side	North Side
97.5	1	19.69	19.91	2.44	7.55	2.03	4.53	3.87	5.00
92.5	2	2.31	2.35	0.73	1.45	3.23	2.85	2.79	3.63
87.5	3	1.33	1.43	1.13	2.90	6.00	6.77	3.67	4.83
82.5	4	6.42	6.45	2.12	4.34	1.11	3.63	5.29	5.86
77.5	5	5.78	5.86	1.72	2.67	2.52	3.43	1.71	2.32
72.5	6	0.72	0.64	0.86	1.20	3.57	1.47	5.31	4.92
68.25	7	3.19	3.27	0.84	1.32	2.56	3.02	4.96	6.09
63.5	8	2.58	2.63	1.71	1.77	3.40	2.25	4.52	4.84

Table 2C-4

**SEISMIC LATERAL EARTH PRESSURES (KSF)
NUCLEAR ISLAND STRUCTURES COMBINED WITH ANNEX BUILDING
EAST-WEST (Y) SHAKING**

Elev. (ft)	Layer No.	Hard Rock		Soft Rock		Soft-to-Medium Soil		Soft Soil	
		East Side	West Side	East Side	West Side	East Side	West Side	East Side	West Side
97.5	1	17.12	17.36	2.18	7.36	0.83	5.04	1.53	8.88
92.5	2	2.24	2.27	0.79	1.00	1.25	2.28	1.99	2.58
87.5	3	0.85	0.90	1.69	1.91	3.04	1.87	1.07	2.06
82.5	4	4.05	4.19	1.47	3.70	1.13	1.33	1.65	0.84
77.5	5	3.73	3.77	1.17	3.01	2.06	3.14	1.17	1.09
72.5	6	0.77	0.80	0.43	1.16	1.73	1.65	1.65	1.5
68.25	7	2.89	3.14	0.76	2.87	0.73	1.23	1.65	1.81
63.5	8	1.86	1.87	0.71	1.33	2.05	2.23	5.10	5.33

Table 2C-5

**SEISMIC LATERAL EARTH PRESSURES
MAXIMUM ADJUSTMENT FACTORS for TORSIONAL MOTION**

Elevation (ft)	Soft Rock		Soft-to-Medium Soil	
	North-South	East-West	North-South	East-West
100	1.26	1.26	1.18	1.22
82.5	1.30	1.19	1.11	1.20

Table 2C-6 (Sheet 1 of 4)

**SEISMIC LATERAL EARTH PRESSURES
RELATIVE DISTRIBUTION OF SOIL PRESSURES BEHIND WALLS**

HARD ROCK

Elev. (ft)	Top Element Number (See Figure 2C-2)									
	10	9	8	7	6	5	4	3	2	1
97.5	4.74	3.55	7.43	7.87	5.20	8.80	8.92	5.72	9.36	9.59
92.5	2.14	0.30	3.23	3.14	0.31	3.62	3.58	0.28	3.80	3.75
87.5	1.24	0.42	2.44	2.47	0.66	2.89	2.90	0.78	3.10	3.19
82.5	0.87	0.40	1.67	1.71	0.64	2.03	2.04	0.75	2.22	2.26
77.5	0.45	0.06	0.78	0.76	0.07	0.92	0.91	0.09	1.00	1.02
72.5	0.27	0.03	0.35	0.32	0.07	0.38	0.37	0.09	0.40	0.42
67.5	0.15	0.13	0.05	0.12	0.35	0.18	0.22	0.45	0.24	0.23

Notes:

1. First vertical double line represents the corner. The other vertical double lines represent interior cross walls (see Figure 2C-1, Sheet 2).
2. The horizontal double lines represent floor slabs (see Figure 2C-1, Sheet 1).

Table 2C-6 (Sheet 2 of 4)

**SEISMIC LATERAL EARTH PRESSURES
RELATIVE DISTRIBUTION OF SOIL PRESSURES BEHIND WALLS**

SOFT ROCK

Elev. (ft)	Top Element Number (See Figure 2C-2)									
	10	9	8	7	6	5	4	3	2	1
97.5	6.26	4.79	5.81	5.87	5.02	5.99	6.03	5.19	6.11	6.47
92.5	3.50	1.28	2.88	2.87	1.50	2.93	2.94	1.51	2.94	3.45
87.5	2.76	1.42	2.32	2.33	1.51	2.34	2.34	1.52	2.33	2.75
82.5	2.24	1.23	1.82	1.81	1.28	1.79	1.80	1.28	1.78	2.02
77.5	1.63	0.64	1.14	1.15	0.66	1.09	1.09	0.64	1.06	1.26
72.5	1.36	0.51	0.84	0.98	0.40	0.69	0.67	0.32	0.62	0.75
67.5	1.48	0.87	0.89	0.76	0.51	0.59	0.54	0.35	0.48	0.52

Notes:

1. First vertical double line represents the corner. The other vertical double lines represent interior cross walls (see Figure 2C-1, Sheet 2).
2. The horizontal double lines represent floor slabs (see Figure 2C-1, Sheet 1).

Table 2C-6 (Sheet 3 of 4)

**SEISMIC LATERAL EARTH PRESSURES
RELATIVE DISTRIBUTION OF SOIL PRESSURES BEHIND WALLS
SOFT-TO-MEDIUM SOIL**

Elev. (ft)	Top Element Number (See Figure 2C-2)									
	10	9	8	7	6	5	4	3	2	1
97.5	4.15	3.03	3.31	3.20	3.12	3.23	3.26	3.14	3.28	3.32
92.5	2.71	1.37	1.89	1.76	1.52	1.78	1.80	1.49	1.8	1.94
87.5	3.10	1.91	2.21	2.11	1.91	2.10	2.11	1.88	2.11	2.24
82.5	2.75	1.55	1.87	1.76	1.56	1.73	1.73	1.52	1.72	1.84
77.5	2.75	1.43	1.81	1.73	1.43	1.67	1.66	1.36	1.64	1.79
72.5	2.61	1.38	1.71	1.59	1.31	1.50	1.48	1.21	1.45	1.55
67.5	3.00	2.00	2.01	1.84	1.71	1.73	1.70	1.59	1.66	1.69

Notes:

1. First vertical double line represents the corner. The other vertical double lines represent interior cross walls (see Figure 2C-1, Sheet 2).
2. The horizontal double lines represent floor slabs (see Figure 2C-1, Sheet 1).

Table 2C-6 (Sheet 4 of 4)

**SEISMIC LATERAL EARTH PRESSURES
RELATIVE DISTRIBUTION OF SOIL PRESSURES BEHIND WALLS**

SOFT SOIL

Elev. (ft)	Top Element Number (See Figure 2C-2)									
	10	9	8	7	6	5	4	3	2	1
97.5	6.21	4.45	4.87	4.68	4.55	4.72	4.76	4.57	4.78	4.84
92.5	3.75	1.82	2.46	2.27	1.99	2.29	2.32	1.93	2.31	2.47
87.5	3.64	2.13	2.45	2.27	2.12	2.25	2.26	2.06	2.26	2.36
82.5	3.20	1.76	2.04	1.85	1.74	1.82	1.83	1.67	1.81	1.90
77.5	3.04	1.64	1.99	1.81	1.65	1.76	1.77	1.56	1.74	1.83
72.5	2.99	1.67	1.98	1.76	1.65	1.71	1.71	1.54	1.68	1.72
67.5	3.51	2.34	2.44	2.25	2.23	2.20	2.20	2.16	2.18	2.18

Notes:

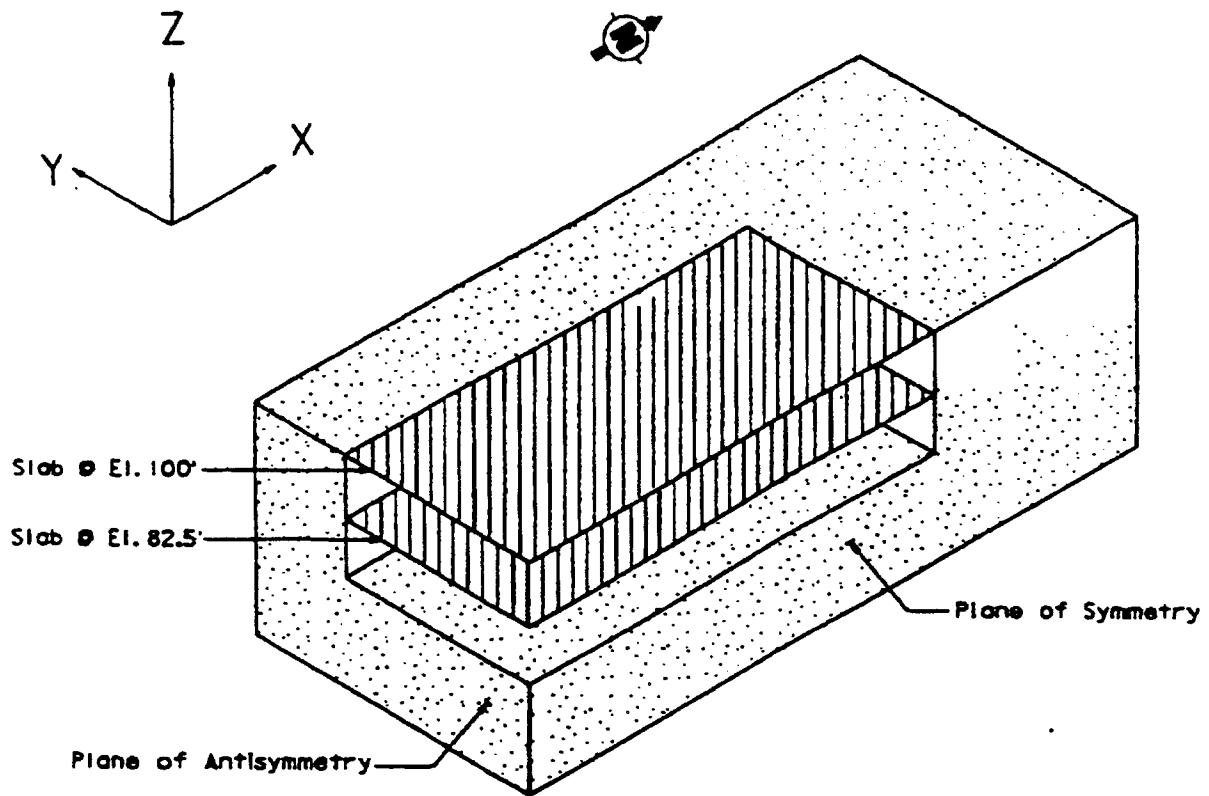
1. First vertical double line represents the corner. The other vertical double lines represent interior cross walls (see Figure 2C-1, Sheet 2).
2. The horizontal double lines represent floor slabs (see Figure 2C-1, Sheet 1).

Table 2C-7

**SEISMIC LATERAL EARTH PRESSURES
ADJUSTMENT FACTORS FOR BOX EFFECTS
EXTERIOR WALLS BELOW GRADE**

Adjustment Factors for Box Effect

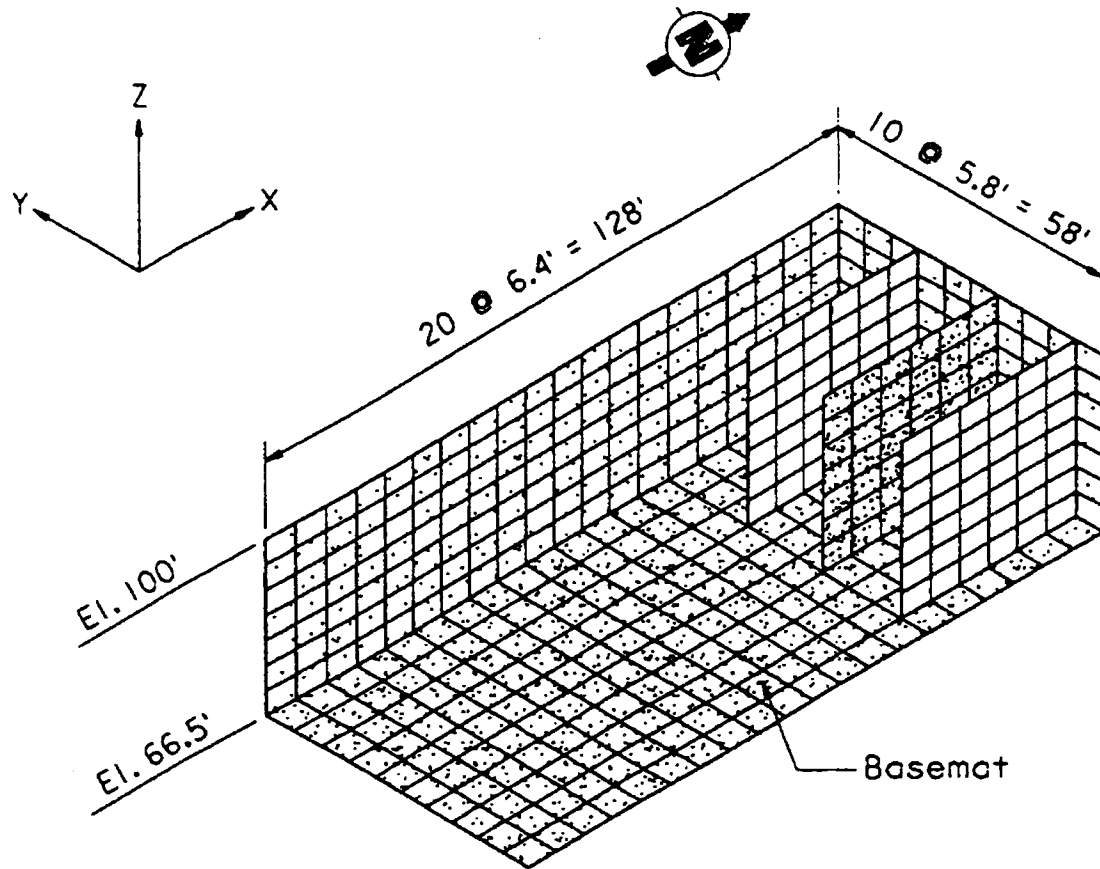
Elevation Range (ft)	Hard Rock	Soft Rock	Parabolic 1.0 x G_{max}	Soft Soil
66.5 to 70.0	1.76	1.79	1.56	1.50
70.0 to 75.0	1.00	1.49	1.58	1.60
75.0 to 80.0	1.00	1.42	1.55	1.60
80.0 to 85.0	1.00	1.23	1.52	1.65
85.0 to 90.0	1.00	1.19	1.44	1.54
90.0 to 95.0	1.00	1.22	1.48	1.59
95.0 to 100.0	1.00	1.07	1.27	1.30



1/4 Model - Box Effect

Figure 2C-1 (Sheet 1 of 2)

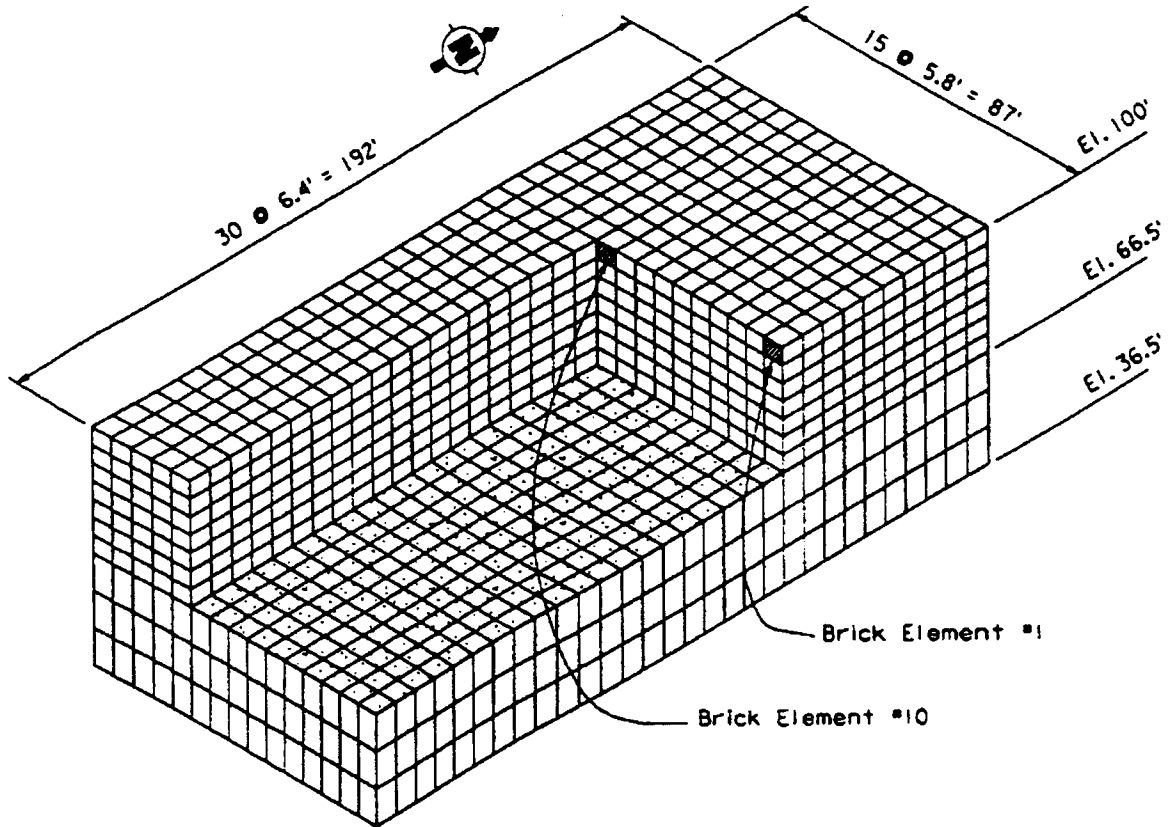
Model for Calculating Box Effects



1/4 Model - Box Effect

Figure 2C-1 (Sheet 2 of 2)

Model for Calculating Box Effects



1/4 Model - Box Effect

Figure 2C-2

Soil Model for Calculating Box Effects