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Structure Soil Structure Interaction Effects: Seismic Analysis of Safety Related Collocated Concrete Structures

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ABSTRACT

The Process, Purification and Stack Buildings are collocated safety related concrete shear wall structures with plan dimensions in excess of 100 feet. An important aspect of their seismic analysis was the determination of structure soil structure interaction (SSSI) effects, if any.

The SSSI analysis of the Process Building, with one other building at a time, was performed with the SASSI computer code for up to 50 frequencies. Each combined model had about 1500 interaction nodes. Results of the SSSI analysis were compared with those from soil structure interaction (SSI) analysis of the individual buildings, done with ABAQUS and SASSI codes, for three parameters: peak accelerations, seismic forces and the in-structure floor response spectra (FRS). The results may be of wider interest due to the model size and the potential applicability to other deep soil layered sites.

Results obtained from the ABAQUS analysis were consistently higher, as expected, than those from the SSI and SSSI analyses using the SASSI. The SSSI effect between the Process and Purification Buildings was not significant. The Process and Stack Building results demonstrated that under certain conditions a massive structure can have an observable effect on the seismic response of a smaller and less stiff structure.

INTRODUCTION

Process Building, Purification Building and Stack Building are adjacent safety related structures in K area at a U. S. Department of Energy (DOE) facility at the Savannah River Site (SRS). Structural analysis and evaluation for natural phenomena hazards (NPH) effects on the building structures was required for a project at SRS. New DOE missions at SRS have given rise to the continuing utility for these nearly fifty years old massive reactor buildings. The buildings were qualified for the performance category 3 (PC3) NPH effects using criteria to comply with the current DOE orders [DOE 420.1 1996] and an associated standard [DOE-STD-1020 1996].

An important aspect of the seismic analysis consisted of the determination of the structure soil structure interaction (SSSI) effects, if any, between the collocated buildings. Soil structure interaction (SSI) analysis of the individual buildings was first performed. The SSSI effect was determined by comparing results of the SSI analysis for sets of two buildings with those for the individual building. This paper summarizes results of

the SSSI effects between the Process and Purification Buildings, and between Process and Stack Buildings.

BUILDING DESCRIPTIONS

The layout of the three buildings is shown in Fig. 1.

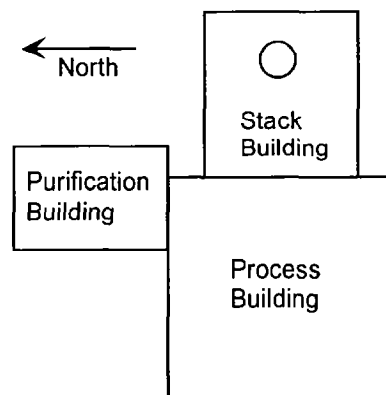


Fig. 1 Layout of Building Structures

The 105-K Area Process Building is a massive reinforced concrete structure supported approximately 40 feet below the finished grade. The Building has a reinforced concrete basemat foundation of varying thickness with the main foundation mat thickness of 10 feet. The approximate foundation dimensions are 240 feet along the east west direction and 220 feet along the north south direction. A portion of the Process Building rises approximately 148 feet above the finished grade level.

The Purification Building lies north east of the Process Building and is separated from the Process Building by a 1-inch expansion joint above the grade level. Its 3.5 feet thick basemat is separated from the Process Building basemat by a distance of approximately one foot. The Purification Building basemat dimensions are 75 feet east west by 105 feet north south at a depth of 14 feet below grade.

The Stack Building lies east of the Process Building and is separated from the Process Building by a 1-inch expansion joint above the grade level. Its 7 feet thick basemat is separated from the Process Building basemat by a distance of approximately 15 feet. The Stack Building basemat dimensions are 135 feet east west by 100 feet north south at a depth of 14 feet below the finished grade level.

COMPUTER CODES

SSI analysis was performed using the SASSI [Lysmer 1988] and ABAQUS [ABAQUS 1998] computer codes. Typically the three dimensional building model used in the SASSI code incorporates eccentricities and is attached to a relatively rigid box that represents the building below grade. The three dimensional building model used in the ABAQUS code is attached to springs and dashpots that represent the embedded foundation effects for the average soil properties consistent with the design basis seismic motion. The above ground structural representation of the buildings is identical in SASSI and ABAQUS models. The three dimensional models were developed using standard engineering procedures following guidelines established by ASCE [ASCE 4 1986].

The ABAQUS models were used for comparison and trending purposes. The ABAQUS analyses demonstrated that the upper bound (UB) forces are higher than the corresponding forces using the best estimate (BE) and lower bound (LB) soil profiles.

SSSI effects were evaluated through a parametric study using the upper bound soil properties, for which only a relatively crude model of the soil medium was required. Because of

realistic limitations of CRAY computational storage and analysis time it was not feasible to analyze the three buildings simultaneously.

SOIL DATA

The rock level at the site is more than 1000 feet below grade.

Input Ground Motion

The facility specific PC3 design basis horizontal free field input spectra for 5 percent damping is given in Fig. 2. For the purposes of this analysis the vertical motion is conservatively considered equal to the horizontal.

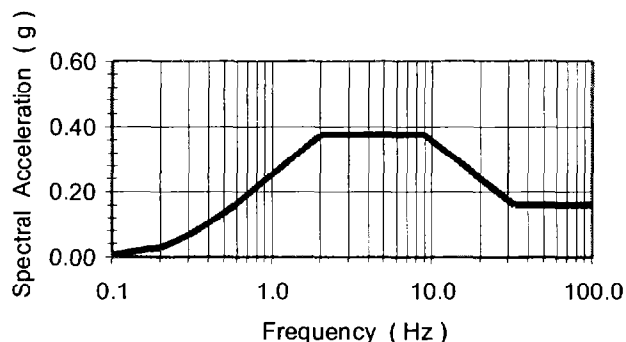


Fig.2 Input Spectra

Facility specific dynamic soil profile is given in Table 1 which includes elevations (El) and average shear wave velocity, V_s . Soil types B and C refer to Tobacco Road, and Dry Branch, Santee or Congree formations, respectively.

Table 1 Dynamic Soil Profile

El. from-to Feet	Type /soil	Poisson Ratio	Unit Wt. lb./cft	V_s ft/sec
270-225	B	0.30	120	1435
225-210	B	0.30	117	1186
210-180	C	0.47	124	1149
180-150	C	0.47	120	1124
150-125	C	0.47	115	1080
125-110	C	0.47	125	1313
110-70	C	0.47	125	1431

The variation of the soil shear modulus with soil strain is given by $G/G_{max} = 1/(1 + (e/e_r))$, where
 G is shear modulus corresponding to the shear strain of e ,
 G_{max} is the low strain or the maximum shear modulus, which is equal to $(V_s^2 \times \text{mass density of soil})$,
 V_s is the shear wave velocity of the soil, and
 e_r is the reference strain which is equal to 0.044 and 0.077 for formations B and C, respectively.

The variation of soil damping ratio (%) with respect to the soil shear strain, e , is given in Table 2 for the two soil types B and C.

Table 2 Variation of Soil Damping (%) with Shear Strain

Shear Strain	For Soil		Shear Strain	For Soil	
	Type B	Type C		Type B	Type C
1E-5	0.625	0.825	5E-3	1.747	1.470
1E-4	0.625	0.825	1E-2	2.790	2.108
2E-4	0.647	0.835	2E-2	4.605	3.281
3E-4	0.670	0.846	3E-2	6.139	4.336
5E-4	0.717	0.871	5E-2	8.614	6.162
1E-3	0.835	0.936	1E-1	12.799	9.605
2E-3	1.070	1.070	2E-1	17.425	13.951
3E-3	1.300	1.205	3E-1		16.68

Three statistically independent acceleration time histories whose response spectra envelop the free field PC3 design basis spectra are generated. Iterated soil properties for the design basis seismic input were determined using the computer code SHAKE [Idriss 1992]. Properties of soil elements in SASSI, and the spring and damping values in ABAQUS models are based on the iterated or high strain soil properties. The average upper bound (UB) shear wave velocity for the top 100 feet of soil was about 1500 feet/sec.

Geological Origins

The Coastal Plain stratigraphic section, which includes the SRS, is divided into several geological formations and groups based principally on age and lithology. For the structures under consideration all soils in the top two hundred feet, considered explicitly, are Tertiary sediments. In the top two hundred feet two soil types are encountered as shown in Tables 1 and 2: B and C. Type B refers to the Tobacco Road formation whereas Type C refers to Dry Branch, Santee, Warley Hill and Congree formations. Within individual soil types B and C certain properties vary with formations;

however, the variations of the normalized shear modulus and of damping with shear strain remain the same as indicated in Tables 1 and 2.

BUILDING MODELS

Significant structural properties of the Process Building are given in Table 3. Moments of inertia are given in $1E6 \text{ ft}^4$. The shear areas and moments of inertia between two elevations are given in the table in the row for the higher elevation. Area for shear in north south direction is shown under N-S, and the moment of inertia resisting the corresponding moment is shown under E-W. The weight of the structure is input as mass at elevations shown in the table; members are considered weightless. Torsional moments of inertia and the mass moments of inertia are not given in the table.

Table 3 Structural Properties of the Process Building

Elevation feet	Area, feet ²		Moment of Inertia		Mass kip-sec ² /foot
	N-S	E-W	N-S	E-W	
148	83	83	.03	.03	13
130	83	83	.03	.03	11
125	180	165	.12	.14	7
120	180	165	.12	.14	15
110	180	165	.12	.14	28
91	314	342	.49	.31	143
66	763	1293	11.1	1.21	378
48	634	2353	20.0	0.84	518
34	2303	3417	33.3	5.47	715
15	2496	3494	35.7	3.58	642
0	4590	3742	75.3	20.1	1708
-14	4590	3742	75.3	20.1	5050
-40					4097

The Process Building model is schematically shown in Fig. 3. The SASSI impedance model of the Stack Building has 1360 interaction nodes, 960 soil elements and 728 shell elements. The SASSI seismic analysis model for the Process Building has 1392 nodes, 960 soil elements, 26 beam elements, 728 shell elements, and 124 spring elements. The spring elements, not shown in Fig. 3, are added to rigidly connect the building stick below grade to the embedded box.

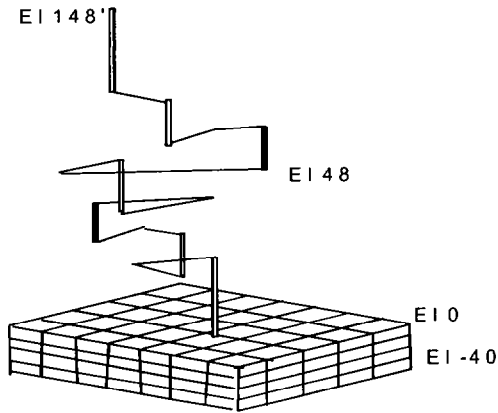


Fig. 3 Process Building Model

Similarly significant structural properties for the Purification Building are given in Table 4 with notations of Table 3. The moments of inertia of 100 E6 ft⁴ are taken to represent rigid flexural behavior. The areas represent realistic shear wall contributions for the two directions.

Table 4 Structural Properties of the Purification Building

Elevation feet	Area, feet ²		Moment of Inertia		Mass kip-sec ² /foot
	N-S	E-W	N-S	E-W	
47	467	134	100.	100.	138
13	640	241	100.	100.	208
0	458	134	100.	100.	164
-12					73

The Purification Building model is schematically shown in Fig. 4. The SASSI impedance model of the Purification Building has 96 interaction nodes, 35 soil elements and 94 shell elements. The SASSI seismic analysis model of the Purification Building has 110 nodes, 35 soil elements, 9 beam elements and 94 shell elements.

Similarly significant structural properties for the Stack Building are given in Table 5 with notations of Table 3 except that the mass of the stack is represented by member weights.

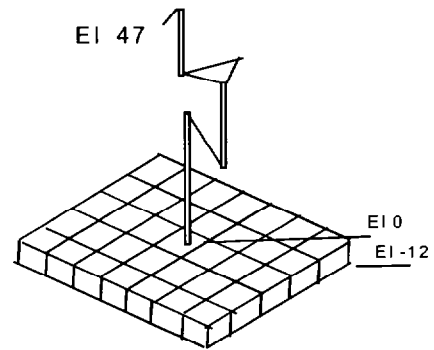


Fig. 4 Purification Building Model

Table 5 Structural Properties of the Stack Building

Elevation feet	Area, feet ²		Moment of Inertia		Mass kip-sec ² /foot
	N-S	E-W	N-S	E-W	
200	15	15	1.06	1.06	
195	15	15	1.08	1.08	
185	16	16	1.11	1.11	
175	16	16	1.15	1.15	
165	20	20	1.49	1.49	
155	23	23	1.82	1.82	
145	23	23	1.87	1.87	
135	24	24	1.93	1.93	
125	24	24	2.0	2.0	
115	24	24	2.05	2.05	
105	27	27	2.28	2.28	
95	30	30	2.35	2.35	
85	34	34	2.73	2.73	
75	37	37	2.99	2.99	
65	40	40	3.18	3.18	
55	992	1104	1080	1910	106
-7.5					41

The Stack Building model is schematically shown in Fig. 5. The SASSI impedance model of the Stack Building has 160 interaction nodes, 63 soil elements and 158 shell elements. The SASSI seismic analysis model for the Stack Building has 180 nodes, 63 soil elements, 18 beam elements, 158 shell elements and 124 spring elements. The spring elements, not shown in Fig. 5, are added to rigidly connect the building stick below grade to the embedded box.

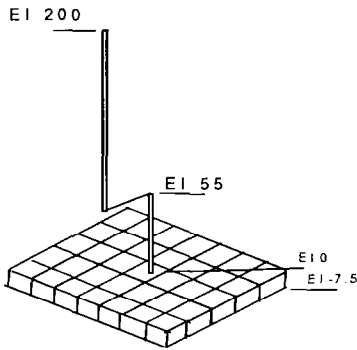


Fig. 5 Stack Building Model

Process and Purification Buildings

SASSI seismic analysis models for the Process and Purification Buildings described earlier are combined together to form a combined SSSI model. The combined model has 1520 nodes including 1474 interaction nodes, 995 soil elements, 35 beam elements, 822 shell elements and 124 spring elements. The model has few more nodes than the earlier two models combined together because it has some extra soil nodes. The combined SSSI model for the Process and Purification Buildings is shown in Fig. 6.

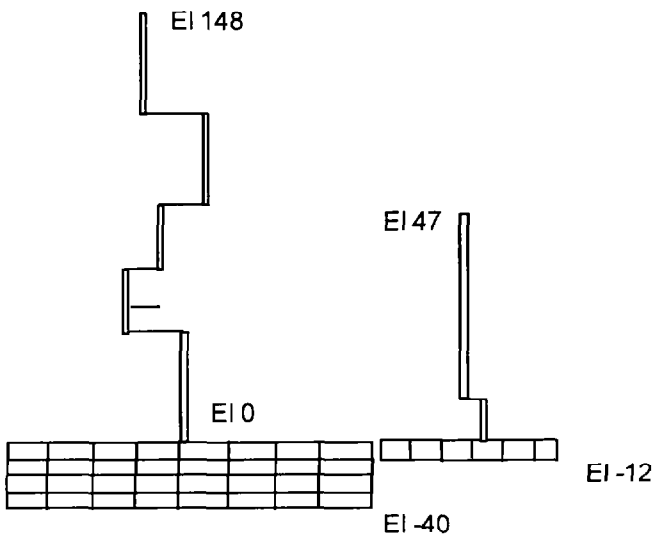


Fig. 6 SSSI Model for Process and Purification Buildings

Process and Stack Buildings

SASSI seismic analysis models for the Process and Stack Buildings described earlier are combined together to form a combined SSSI model. The combined model has 1578 nodes including 1526 interaction nodes, 1023 soil elements, 44 beam elements, 886 shell elements and 124 spring elements. The model shows few more nodes than the earlier two models combined together because it has some extra soil nodes. The combined SSSI model for the Process and Stack Buildings is shown in Fig. 7.

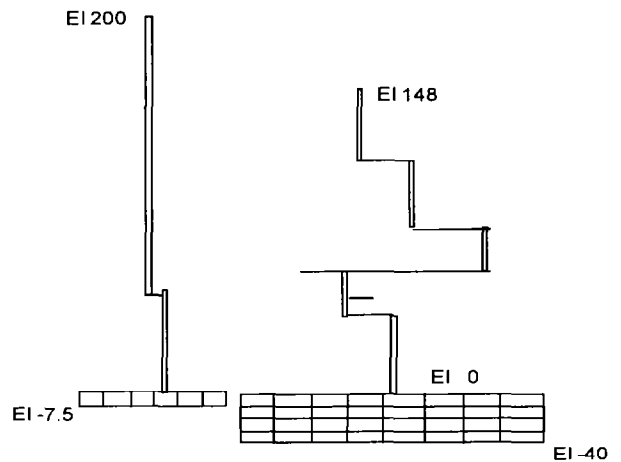


Fig. 7 SSSI Model for Process and Stack Buildings

SASSI ANALYSIS

The SASSI models for individual and combined buildings are analyzed frequency by frequency, or for a set of frequencies. Results of various frequencies are combined together by running the COMBINE module of the SASSI. MOTION and STRESS modules of the SASSI are run to obtain transfer functions, peak accelerations, stress resultants and response spectra at critical locations of the buildings, for three mutually orthogonal directions.

Transfer functions were carefully reviewed in order to make sure that amplification has not occurred for frequencies in between the frequency values initially considered. Intermediate values of frequency were added as needed. Typically the final analysis was performed for 30 to 50 frequencies.

A comparison of the results of the SSI and SSSI models is provided in this paper. Three parameters were investigated as a measure of the SSSI effect, primarily by computing the ratio of the parameter from the SASSI analysis of the combined model to that from the SSI analysis of the individual building. The parameters are the peak acceleration at a floor level, seismic force such as shear force, axial force or bending moment at a floor level, and the in-structure floor response spectra (FRS).

Peak acceleration at an elevation is the maximum absolute value obtained from the acceleration time history at the elevation, for the analysis under consideration, and approximates the large frequency acceleration or the zero period acceleration associated with the floor response spectra at that elevation.

PROCESS AND PURIFICATION BUILDINGS

Peak Accelerations

A comparison of peak accelerations at various elevations from the SSI model of the Process Building alone, using SASSI and ABAQUS codes, and the combined SASSI model of the Process and Purification Buildings is provided in Table 6. Ratios for the east west (E-W) and vertical excitations are similar to those for the north south (N-S) excitations shown for various elevations in the table.

Table 6 N-S Peak Accelerations (g) for Process Building

Elev. Feet	SSSI	SSI	N-S Ratio SSSI/SSI	ABAQUS SSI
148	.604	.574	1.05	0.99
91	.322	.319	1.01	0.51
48	.22	.227	0.97	0.31
0	.152	.153	0.99	0.19
-40	.139	.139	1.00	0.16

Similar comparison of peak accelerations for the Purification Building is given in Table 7.

Table 7 N-S Peak Accelerations (g) for Purification Building

Elev. Feet	SSSI	SSI	N-S Ratio SSSI/SSI	ABAQUS SSI
47	.207	.211	.98	.267
13	.164	.178	.92	.222
0	.158	.161	.98	.209
-12	.159	.151	1.05	.162

The ratio for the north south peak accelerations, for the north south seismic event, varies between 0.97 to 1.05 for the Process Building (Table 6) and between 0.92 to 1.05 for the Purification Building (Table 7). Thus the effect of SSSI is not significant on north south accelerations, and the buildings are essentially decoupled in the north south direction.

The ratio for the east west peak accelerations, not shown in the tables, varies between 0.99 to 1.04 for the Process Building and between 0.93 to 1.00 for the Purification Building. Thus the effect of SSSI is not significant on east west accelerations also and the buildings are decoupled.

The ratio for the vertical peak accelerations, not shown in the tables, varies between 0.97 to 1.01 for the Process Building and between 1.14 to 1.18 for the Purification Building. Therefore, there is some effect of SSSI on the Purification Building response but this has insignificant impact on the overall results.

Seismic Loads

A comparison of seismic loads for the north south seismic event, from the model of the Process Building alone (SSI analysis), and the combined model of the Process and Purification Buildings (SSSI analysis) both using SASSI code, is provided in Table 8.

Table 8 N-S Seismic Loads for Process Building

Elev. Feet	SSSI Shears (E3 kips)	SSI Shears (E3 kips)	Ratio	SSSI Moments (E3 kip-ft)	SSI Moments (E3 kip-ft)	Ratio
148						
91	0.72	0.73	0.99	16.2	16.4	0.99
48	2.55	2.56	1.0	100	102	0.98
0	8.16	7.83	1.04	308	303	1.02
-40	24.7	24.4	1.01	1229	1211	1.01

Similar comparison of seismic loads for the Purification Building is given in Table 9.

Table 9 N-S Seismic Loads for Purification Building

Elev. Feet	SSSI Shears (E3 kips)	SSI Shears (E3 kips)	Ratio	SSSI Moments (E3 kip-ft)	SSI Moments (E3 kip-ft)	Ratio
47						
13	.926	.935	.99	34.4	33.2	1.04
0	2.07	2.13	.97	64.7	62.2	1.04
-12	2.73	2.95	.93	102	97	1.05

The ratio for the north south shear forces, for the north south seismic event, varies between 0.97 to 1.04 for the Process Building and between 0.93 and 0.99 for the Purification Building. That is, the effect of SSSI is not significant on the north south shear forces. The ratios for the moment are slightly less than those for the corresponding shears. Thus Process Building and Purification Buildings are decoupled in the north south direction.

Similarly the ratio for the east west shear forces, not shown in the tables, varies between 0.97 to 1.02 for the Process Building and between 0.91 and 0.93 for the Purification Building. Therefore, SSSI reduces the response of the Purification Building to some extent.

The ratio for the vertical loads, for a vertical seismic event, not shown in the tables, varies between 1.01 to 1.03 for the Process Building and between 1.10 and 1.12 for the Purification Building. That is, SSSI gives slightly increased loads for the Purification Building for the vertical excitation.

Floor Response Spectra

For the horizontal north south (N-S) earthquake, a comparison between the FRS, at El. 48 and 148, for the Process Building alone (SSI analysis) with that from the combined model of the Process and Purification Buildings (SSSI analysis), is shown in Fig. 8. The SASSI code is used in both analyses.

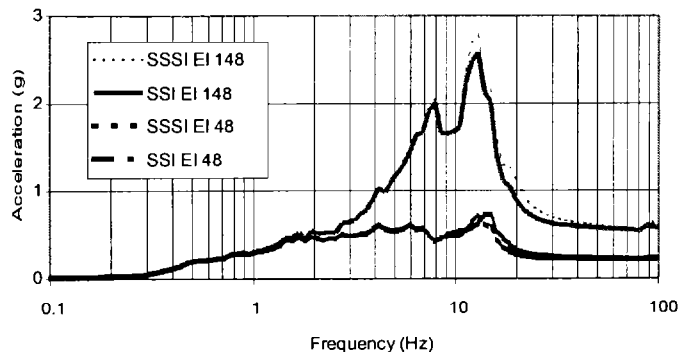


Fig. 8 N-S FRS for Process Building El. 48 and 148 .

The FRS at El. 0 and -40 feet are not shown because there is hardly any difference between the spectra at these elevations obtained from the SSI and SSSI analyses.

Similar comparison of FRS at El. 0 and 47 of the Purification Building is shown in Fig. 9.

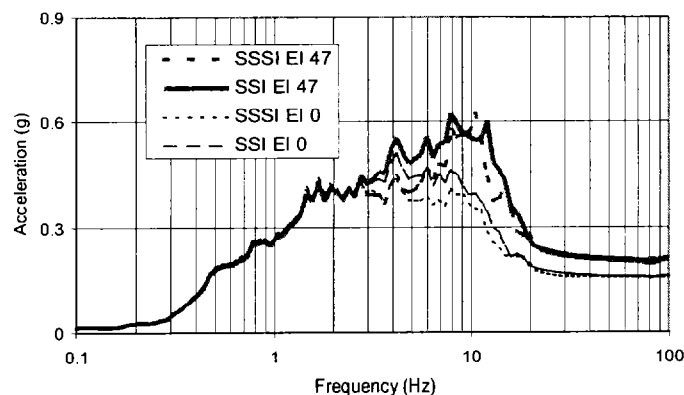


Fig. 9 N-S FRS for Purification Building El. 0 and 47

Fig. 8 and 9 indicate that the effect of SSSI in the north south direction is not significant.

For the horizontal east west (E-W) earthquake, a comparison between the FRS, at El. 40 and 148, for the Process Building alone (SSI analysis) with that from the combined model of the

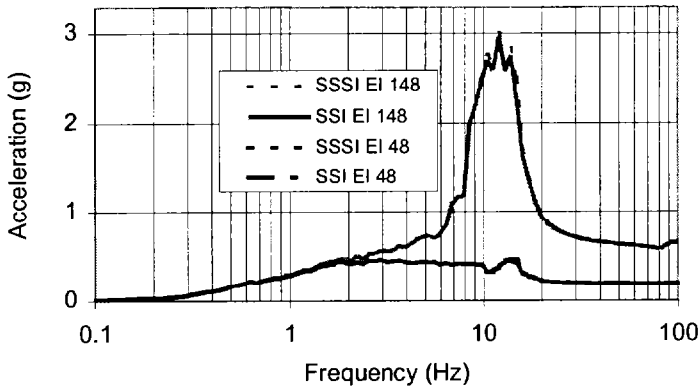


Fig. 10 E-W FRS for Process Building El. 48 and 148

Process and Purification Buildings (SSSI analysis) is shown in Fig. 10. The SASSI code is used in both analyses.

The FRS at El. 0 and -40 feet are not shown because there is hardly any difference between the spectra obtained at these elevations from the SSI and SSSI analyses.

Similar comparison of FRS at El. 0 and 47 of the Purification Building is shown in Fig. 11. Again, the effect of SSSI is not significant in the east west direction.

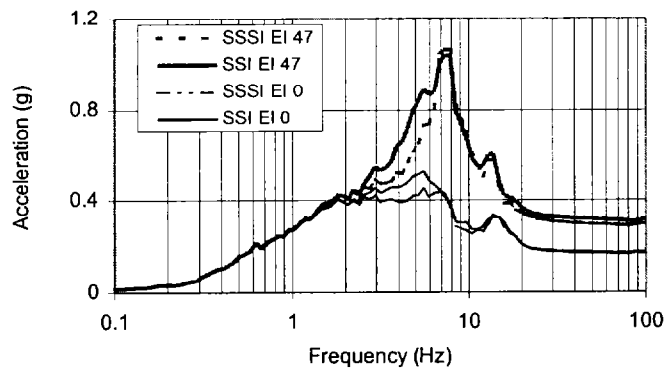


Fig. 11 E-W FRS for Purification Building El. 0 and 47

For the vertical (V) earthquake, a comparison between the FRS, at El. -40 and 148, for Process Building alone (SSI analysis) with that from the combined model of the Process and Purification Buildings (SSSI analysis), is shown in Fig. 12.

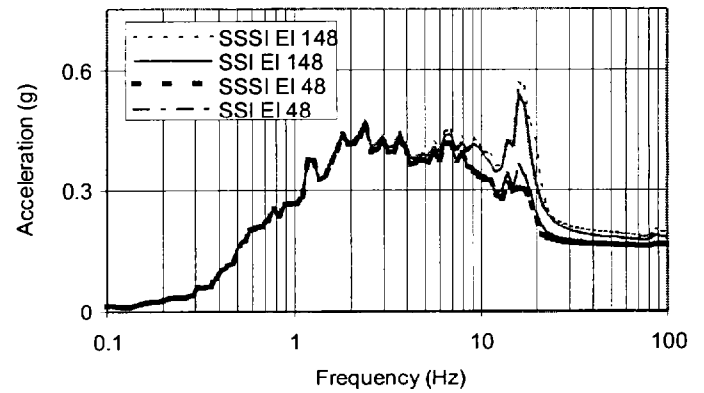


Fig. 12 V FRS for Process Building El. 48 and 148

The SASSI code is used in both analyses.

Similar comparison of FRS at El. 0 and 47 of the Purification Building is shown in Fig. 13. The SSSI effect in the vertical direction is not significant.

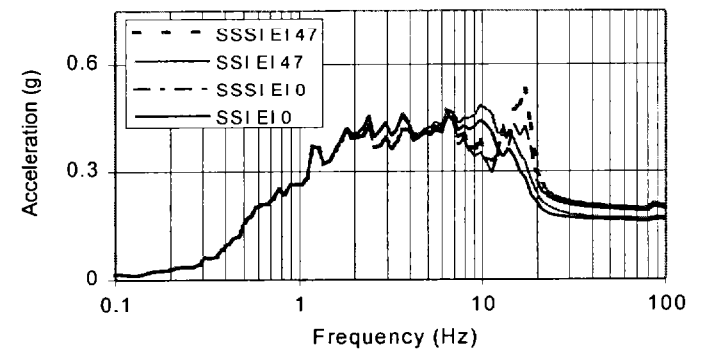


Fig. 13 V FRS for Purification Building El. 0 and 47

Summary of Results

For this parametric study, SSSI effects between the Process and Purification Buildings are not significant. The results obtained from the ABAQUS analyses are consistently higher than the corresponding results obtained from the SSI analysis of the individual building and SSSI analysis of the combined buildings.

PROCESS AND STACK BUILDINGS

Peak Accelerations

A comparison of peak accelerations at various elevations from the SSI model of the Process Building alone, using ABAQUS and SASSI codes, and the combined SASSI model of the Process and Stack Buildings is provided in Table 10.

Table 10 N-S Peak Accelerations (g) for Process Building

Elev. Feet	SSSI	SSI	N-S Ratio SSSI/SSI	ABAQUS SSI
148	.551	.574	0.99	.99
91	.316	.319	0.99	.51
48	.221	.227	0.97	.31
0	.152	.153	0.99	.19
-40	.141	.139	1.01	.16

Similar comparison of peak accelerations for the Stack Building is given in Table 11.

Table 11 N-S Peak Accelerations (g) for Stack Building

Elev. Feet	SSSI	SSI	N-S Ratio SSSI/SSI	ABAQUS SSI
200	.776	.762	1.02	1.02
165	.410	.409	1.00	.53
55	.184	.196	0.94	.24
0	.167	.156	1.07	.20
-7.5	.165	.151	1.09	.20

The ratio for the north south peak accelerations, for the north south seismic event, varies between 0.96 to 1.02 for the Process Building and between 0.94 to 1.07 for the Stack Building. Thus the effect of SSSI is not significant on north south accelerations, and the buildings are essentially decoupled.

The ratio for the east west peak accelerations, not shown in the tables, varies between 0.98 to 1.06 for the Process Building and between 1.0 to 1.15 for the Stack Building. Thus there is a minor SSSI effect on the acceleration response of the Stack

Building during the east west seismic event.

The ratio for the vertical peak accelerations, not shown in the tables, varies between 0.99 to 1.06 for the Process Building and between 0.97 to 1.04 for the Stack Building. Therefore, the effect of SSSI is not significant on the vertical accelerations of the Process and Stack Buildings, using SASSI.

Seismic Loads

A comparison of seismic loads for the north south seismic event, from the model of the Process Building alone (SSI analysis), and the combined model of the Process and Stack Buildings (SSSI analysis), both using the SASSI code, is provided in Table 12.

Table 12 N-S Seismic Loads for Process Building

Elev. Feet	SSSI SSI		Ratio	SSSI SSI		Ratio
	Shears (E3 kips)			Moments (E3 kip-ft)		
148						
91	0.70	0.73	0.96	15.6	16.4	0.95
48	2.51	2.56	0.98	98.9	102	0.97
0	8.01	7.83	1.02	302	303	1.02
-40	24.5	24.4	1.00	1194	1211	0.99

A similar comparison of seismic loads for the east west seismic event for the Stack Building is given in Table 13. The load ratios for the east west direction are significantly higher than those for the north south direction.

Table 13 E-W Seismic Loads for Stack Building

Elev. Feet	SSSI SSI		Ratio	SSSI SSI		Ratio
	Shears (E3 kips)			Moments (E3 kip-ft)		
200						
165	.02	.01	1.14	0.07	0.06	1.19
145	.13	.12	1.07	3.7	3.4	1.10
55	.32	.25	1.26	18.4	18.1	1.01
-7.5	2.59	2.53	1.03	165	148	1.12

The ratio for the north south shear forces, for the north south seismic event, varies between 0.95 to 1.02 for the Process Building and between 0.91 and 1.03 for the Stack Building.

That is, the effect of SSSI is not significant on the north south shear forces. Thus the Process and Stack Buildings are decoupled in the north south direction.

Similarly the ratio for the east west shear forces varies between 0.96 to 1.04 for the Process Building and between 1.02 and 1.30 for the Stack Building. At the bottom of the Stack Building even with the high shear force ratio, the ratio for the corresponding bending moments is only 1.01. That is, the effect of SSSI is not significant in the east west direction.

The ratio for the vertical loads, for a vertical seismic event, varies between 1.01 to 1.06 for the Process Building and between 0.95 and 1.03 for the Stack Building. That is, the effect of SSSI is not significant in the vertical direction.

Floor Response Spectra

For the horizontal north south earthquake, a comparison between the FRS, at El. 48 and 148, for the Process Building alone (SSI analysis) with that from the combined model of the Process and Stack Buildings (SSSI analysis), is shown in Fig. 14. The SASSI code is used in both analyses.

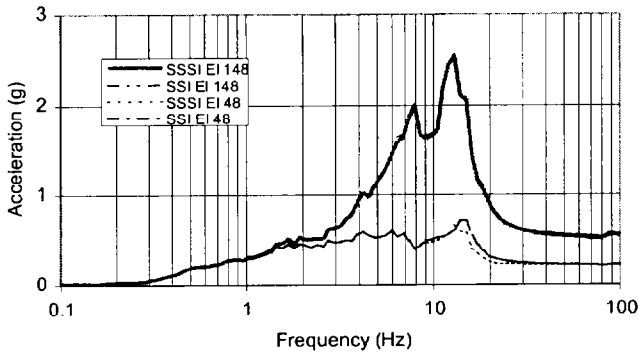


Fig. 14 N-S FRS for Process Building El. 48 and 148

The FRS at El. 0 and -40 feet are not shown because there is hardly any difference between the spectra at these elevations obtained from the SSI and SSSI analyses.

A similar comparison of FRS at El. -7.5 and 200 of the Stack Building is shown in Fig. 15. The effect of SSSI in the north south direction is not significant.

As expected there is significant amplification at the stack frequency of about 2 Hz and a less amplification at the structural frequency of about 8 Hz of the Stack Building.

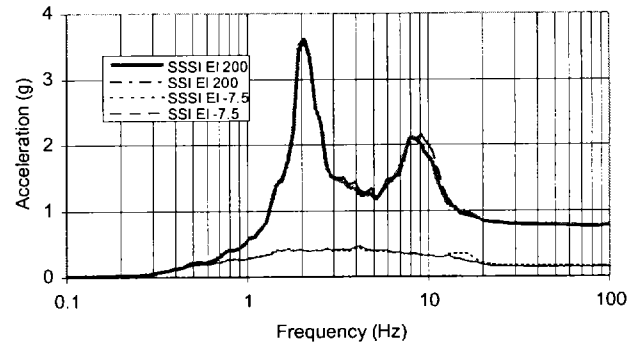


Fig. 15 N-S FRS for Stack Building El. -7.5 and 200

For the horizontal east west earthquake, a comparison between the FRS, at El. 48 and 148, for the Process Building alone (SSI analysis) with that from the combined model of the Process and Stack Buildings (SSSI analysis), is shown in Fig. 16. The SASSI code is used in both analyses.

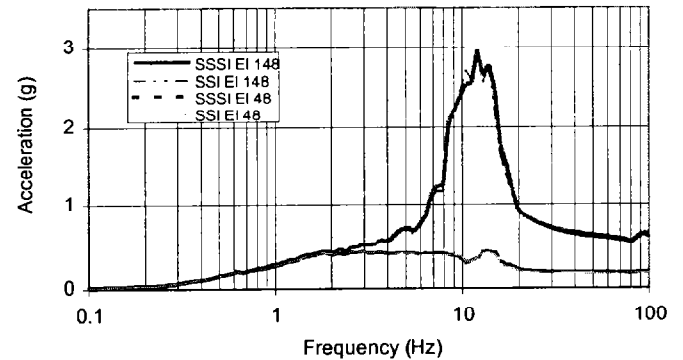


Fig. 16 E-W FRS for Process Building El. 48 and 148

Similar comparison of FRS at El. -7.5 to 200.0 of the Stack Building is shown in Fig. 17.

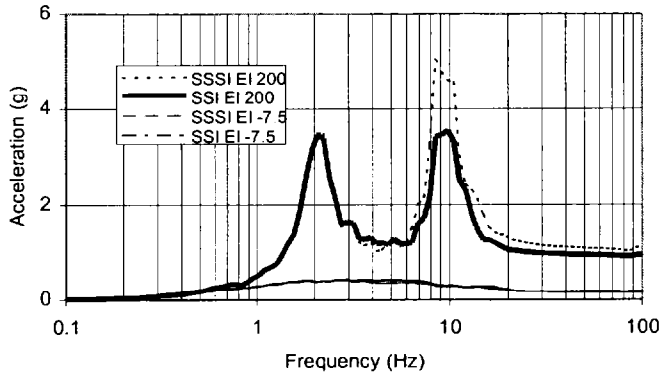


Fig. 17 E-W FRS for Stack Building El. -7.5 and 200

It is observed that in the east west direction SSSI has an effect on the Stack Building FRS; that is, the Stack Building is driven by the Process Building in the east west direction. However the influence of the “shadow” or rocking effect is localized in that the stress resultants are not significantly increased.

For the vertical earthquake, a comparison between the FRS, at El. 48 to 148, for Process Building alone (SSI analysis) with that from the combined model of the Process and Stack Buildings (SSSI analysis), is shown in Fig. 18.

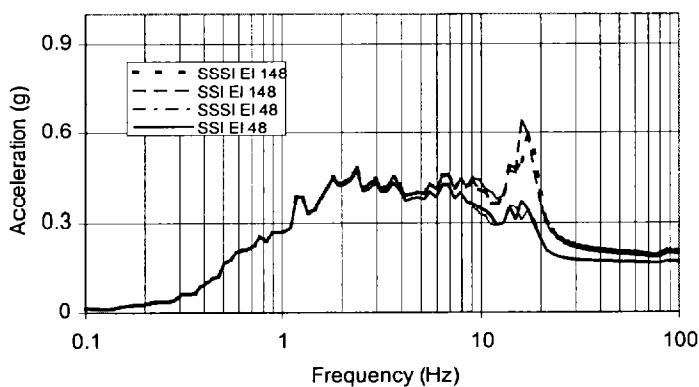


Fig. 18 V FRS for Process Building El. 48 and 148

A similar comparison of FRS at El. -7.5 to 200.0 of the Stack Building is shown in Fig. 19. The SSSI effect in the vertical

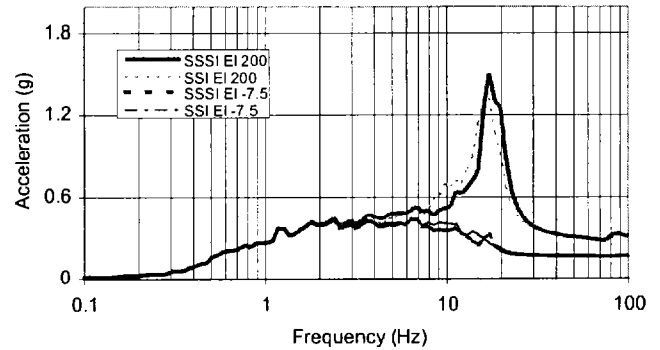


Fig. 19 V FRS for Stack Building El. 7.5 and 200

direction is not significant.

Summary of Results

For this parametric study SSSI effects between the Process Building and the Stack Building are not significant. Even where there is some effect, the SSI and SSSI results are significantly lower than the corresponding ABAQUS results, which are used in the structural evaluation of the buildings.

CONCLUSIONS

There is no significant structure soil structure interaction (SSSI) effect between the Process and Purification Buildings.

For the north south or vertical earthquakes there is no significant SSSI effect between the Process Building and Stack Buildings.

For the east west earthquake the Stack Building is driven by the Process Building by imparting a rocking motion. However the effect is localized to a frequency of about 8.5 Hz, and the forces at the base of the stack, and below, are only slightly increased due to the SSSI effect.

Thus the structure soil structure interaction between the Process and Stack Buildings in the east west direction is observable but not significant.

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