SSI ANALYSIS IN DYNAMIC DOMAIN FOR STRUCTURES RESTING ON ROCK MEDIA

K Y Dalal[1], Ajit Deshmukh[2], E.Ramkumar[3]
[1] Deputy General Manager, Tata Consulting Engineers Ltd, Mumbai, INDIA - 400083.
[2] Manager, Tata Consulting Engineers Ltd, Mumbai, India.
[3] Asst. Manager, Tata Consulting Engineers Ltd, Mumbai, India.
E-mail of corresponding author: kydalal@tce.co.in, asdeshmukh@tce.co.in, eramkumar@tce.co.in

ABSTRACT

As per ASCE 4-98, any material with a shear wave velocity of 1,100 m/s is called as rock for the purpose of defining ground input motion. Further, the same standard specifies that a fixed-base support may be assumed in modeling structures for seismic response analysis when the frequency obtained assuming a rigid structure supported on soil springs representing the soil supporting medium is more than twice the dominant frequency obtained from a fixed base analysis of the flexible structure representation. However, even if both the criteria are satisfied, in light of too many uncertainties involved in SSI analyses and also a section of literature suggesting that such an approach of ignoring SSI may not always be conservative, it is deemed necessary to incorporate the effects of the interaction of superstructure with raft / footings and to go for SSI analysis in dynamic domain. A sensitivity analysis for structural response to dynamic and static loading is envisaged for study of the variation in rock-stiffness properties viz. deformation modulus of rock-medium. The range of 0.5G-G-2G is considered for dynamic loading.

INTRODUCTION:

SSI denotes the phenomenon of coupling between a structure and its supporting medium (soil or rock) during an earthquake. Conventional structural design methods neglect the SSI effects. Neglecting SSI is reasonable for light structures in relatively stiff soil such as low rise buildings and simple rigid retaining walls. The effect of SSI, however, becomes prominent for heavy structures resting on relatively soft soils for example nuclear power plants and high-rise buildings on soft soil.

ASCE 4-98 states that fixed base condition may be assumed for soil-structure systems when the site soil conditions behave in a rock like manner to reduce computational efforts. In general shear wave velocity of 1100 m/s or greater warrants a fixed base analysis.

In the present paper dynamic analysis results considering soil structure interaction and fixed base analysis are compared. The structure considered for the case study is measuring approximately 48.800 m (X-Direction) x 19.800 m (Z- direction) in plan and 36.130 m (Y –direction) m high. Structure considered is frame type RCC structure with shear walls.

FINITE ELEMENT MODEL:

The finite element analysis is performed using ANSYS software. X-Z plane represents the plan for the 3D model. Y Axis is positive in upward vertical direction. S.I. units are used. Beams and columns are modeled by using uniaxial element with tension, compression, torsion and bending capabilities. The walls and foundations are modeled by using an isoparametric 8 noded shell element. Both these elements have six degrees of freedom at each node. Masses are lumped using point elements.

MATERIAL PROPERTIES:

The structure is R.C.C. Structure and has grade of concrete, M30 (Characteristic compressive strength of concrete is 30 N/mm^2). The young's modulus is considered based on the expression $E_{concrete} = 5000 \sqrt{fck}$, where fck is the characteristic compressive strength of concrete. Poisson's ratio considered for concrete is 0.2. Material damping ratio for concrete considered for the analysis is 0.07.

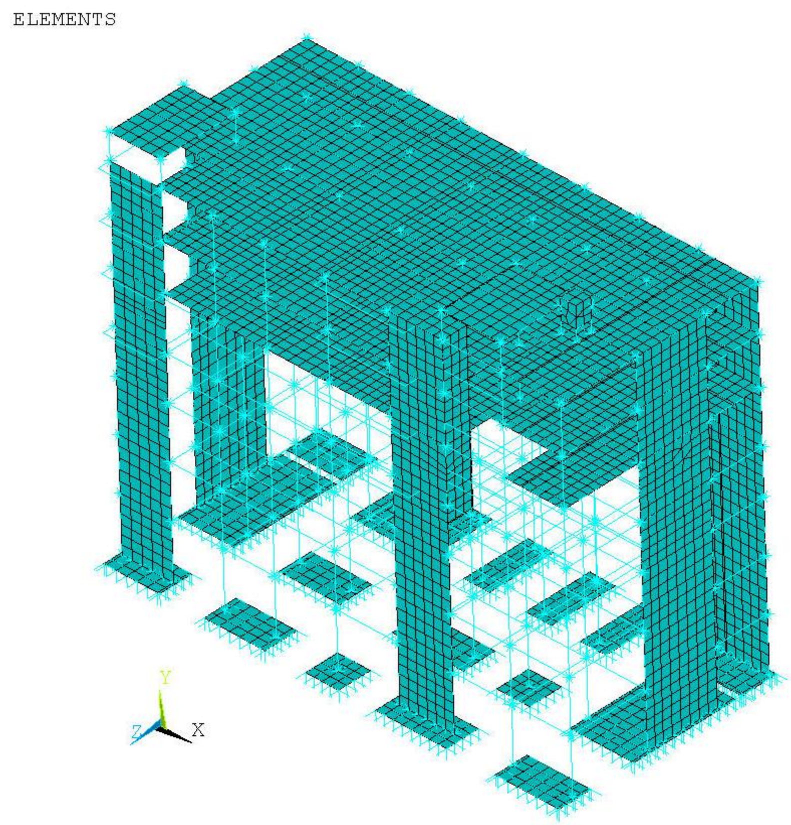

Fig. 1: Finite Element model.

BOUNDARY CONDITIONS:

The structure is analysed for two different boundary conditions

(a) With Fixed base approach

All foundation nodes are assigned with fixed support conditions i.e. all the six degrees of freedom are restrained at supports.

(b) Soil structure interaction approach

The support nodes are provided with translational springs. The spring stiffness is calculated based on impedance function formulation as stated in ASCE 4-98. Embedment effect of soil around the structural elements is not considered in this approach.

Shear wave velocity considered for spring stiffness is 1100 m/s. Density of foundation material considered as 2650 kg/m^3.

Soil springs are modeled at raft base using three translational springs using the following expression [2]

$$K_x = 2\,(1+\upsilon_s)\,G_s\,\beta_x\,\sqrt{BL} \tag{1}$$

$$K_y = [G_s / (1-\upsilon_s)]\,\beta_z\,\sqrt{BL} \tag{2}$$

Where,

K_x =Spring constant in the horizontal direction

K_y = Spring constant in the verticall direction

G_s = Shear Modulus of the soil medium

υ_s = Poisson's ratio of the soil medium

β_x, β_z are geometric coefficients and are functions of L/B obtained as per ASCE :4-98.

B= width of foundation perpendicular to the direction of horizontal excitation

L= Length of foundation in the direction of horizontal excitation

The spring stiffness at each node is arrived at by the following expressions:

$$(k_x)_i = (K_x)(A_i/A) \tag{3}$$

$$(k_y)_i = (K_y)(A_i/A) \tag{4}$$

Where A is the base area and A_i is the contributory area around each node. Material damping ratio for soil springs considered for the analysis is 0.07.

ANALYSIS FOR SEISMIC RESPONSE:

As a pre-requisite of obtaining the dynamic response of structure, a modal analysis is carried out as free-vibration analysis. Response for seismic loading is obtained using application of response spectra in three orthogonal directions independently. Then modal responses obtained on application of spectrum loading are combined using standard modal combination rule (Ten percent grouping method) to obtain final responses at the level of elemental stress resultants.

Free vibration Analysis

In free vibration analysis, un-damped natural frequencies and mode-shapes are obtained. Contribution of each mode in each of the three orthogonal directions is obtained as mode participation factor and modal mass.

Purpose of the analysis is to arrive at number of significant modes of the structure. The mode frequencies provide information on dynamic characteristics of the structural system.

Response Spectrum Input

Response spectra are the frequency-wise seismic peak response acceleration values for various damping ratios. These are applied at the supports for determining the response of the elements of the structure. The free field spectral acceleration versus frequency (refer Fig: 2) is used as input response spectrum. The response spectrum is used independently in NS (X), EW(Z) and Vertical (Y) directions for this purpose. Same spectra are used for NS and EW directions. A vertical motion response spectrum is used with two third (2/3) as multiplier on acceleration values of those for horizontal direction spectrum. Using the set of a spectral acceleration, mode-participation factor and frequency, the mode coefficient is computed.

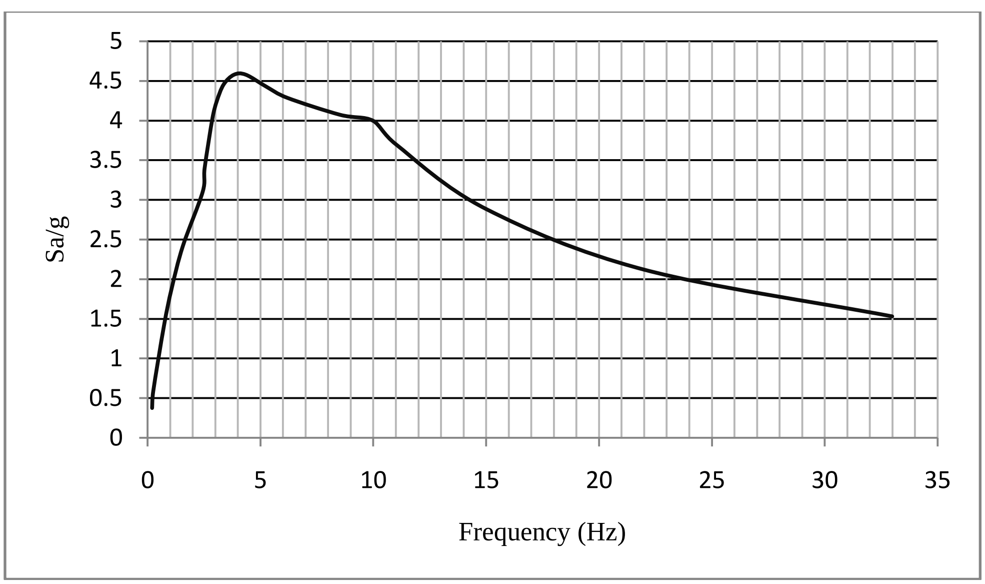

Fig. 2: Response spectrum for 7% damping.

COMPARISON OF RESULTS:

From Free vibration Analysis cumulative mass participation values are obtained for both SSI analysis and Fixed base analysis for each direction. Higher mass participations values are observed for the SSI model.

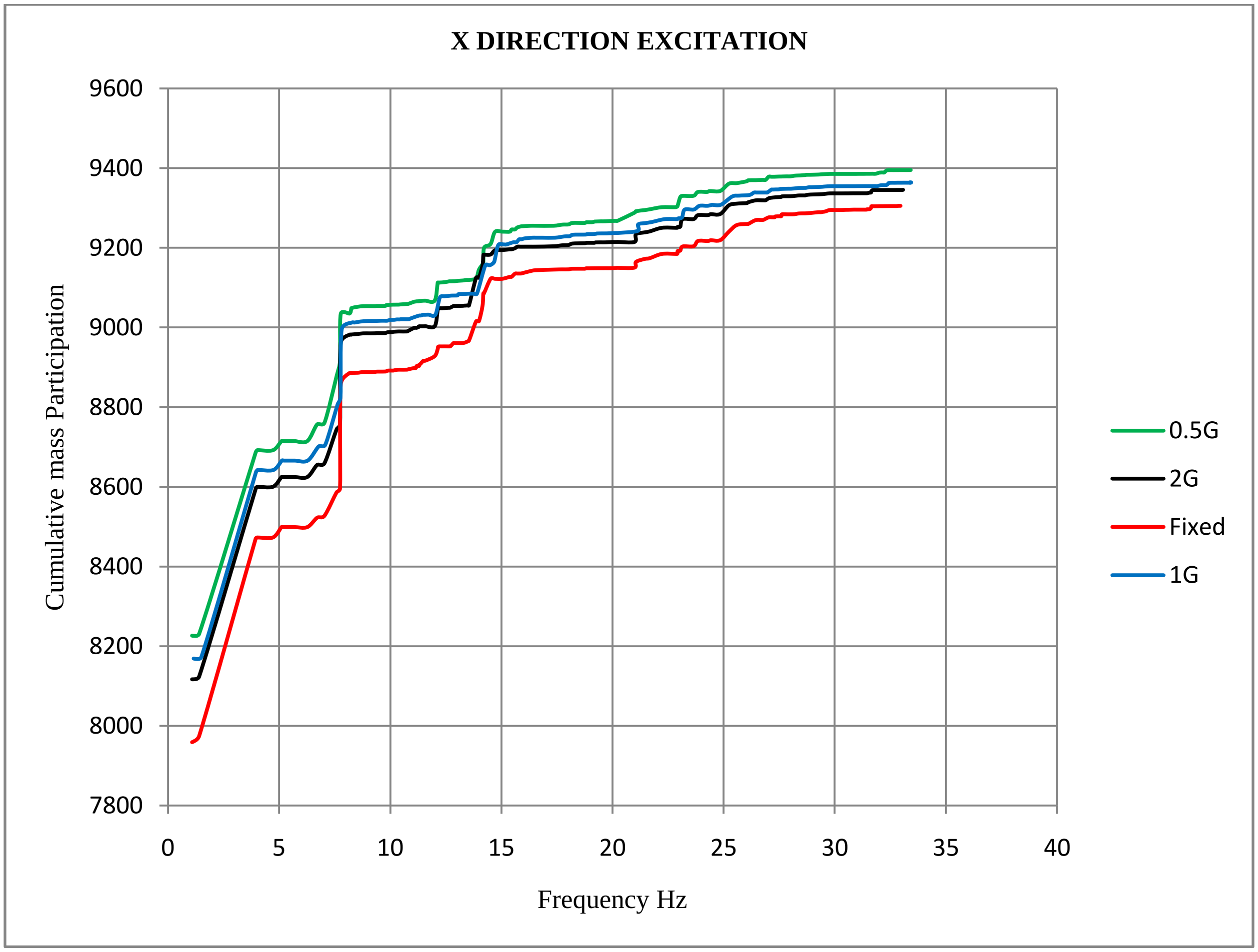

Fig. 3: Mass Participation results for X direction excitation.

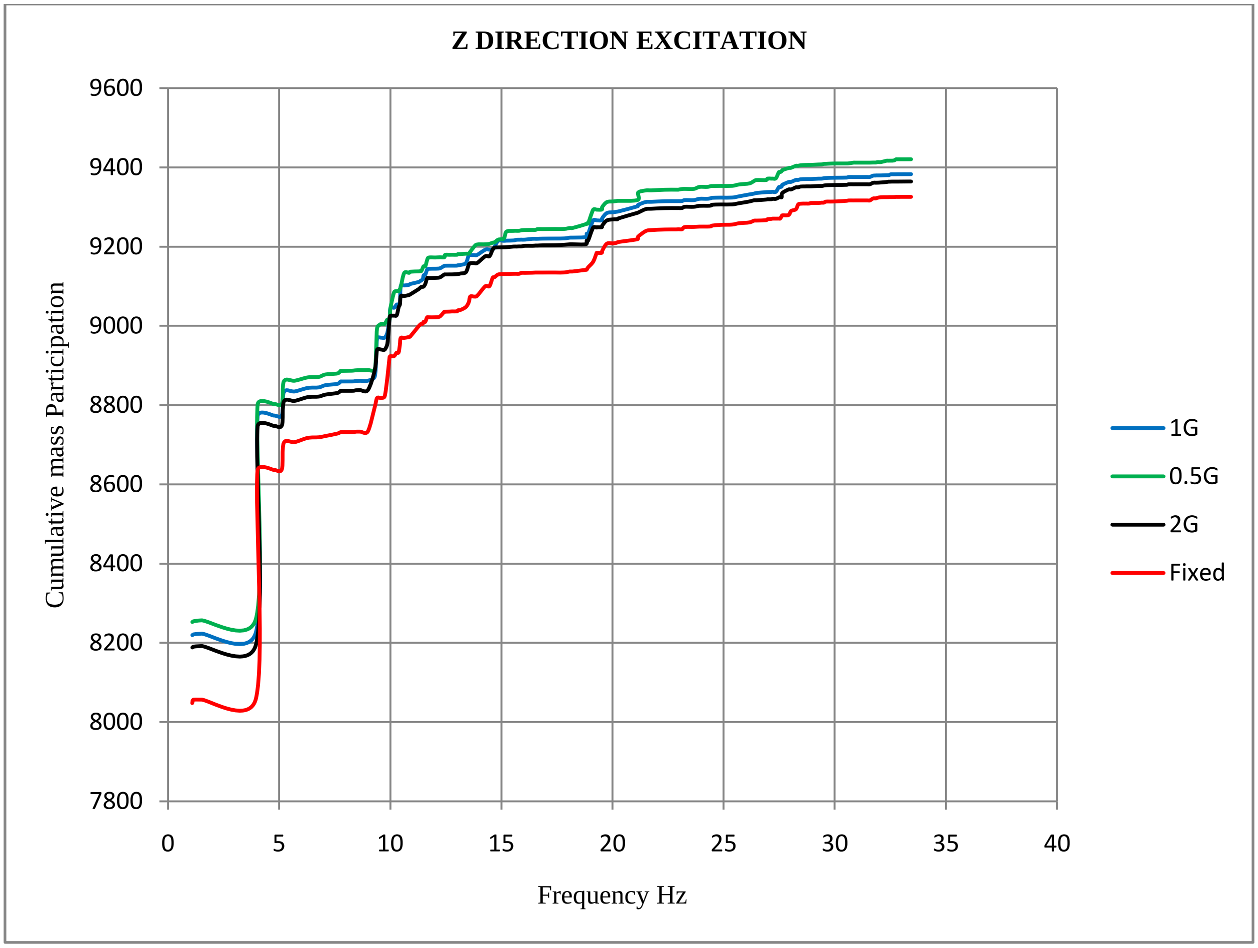

Fig. 4: Mass Participation results for Z direction excitation.

Table 1: Frequency comparison for fixed base and SSI analysis.

Mode	**Frequency(Hz)**			
	Fixed base approach	**SSI approach**		
		0.5G	**G**	**2.0G**
1	1.28826	1.03768	1.09131	1.1398
2	1.32993	1.08798	1.15162	1.20287
3	1.83031	1.408	1.50231	1.5864
4	4.00302	3.95005	3.9563	3.96106
5	4.10296	4.01775	4.0276	4.03438
6	4.84584	4.72773	4.74033	4.74888
7	5.16567	5.11297	5.11997	5.12566
8	5.32019	5.19872	5.2119	5.22206
9	5.79551	5.68806	5.6991	5.70727
10	6.37356	6.2718	6.28374	6.29235
11	6.99102	6.7163	6.78162	6.82991
12	7.23477	7.04311	7.07498	7.10096

Mode	Frequency(Hz)			
	Fixed base approach	SSI approach		
		0.5G	G	2.0G
13	7.78724	7.59165	7.62762	7.65328
14	7.84251	7.74552	7.75989	7.76932
15	8.01691	7.77919	7.81424	7.84847
16	8.4119	8.16779	8.27126	8.28357
17	8.80276	8.2473	8.37395	8.51035
18	8.9305	8.26535	8.45633	8.59686
19	9.05718	8.54846	8.65112	8.73552
20	9.43872	8.78386	8.99119	9.13136
21	9.67896	9.10225	9.30562	9.41943
22	9.7475	9.33036	9.40408	9.47667
23	9.96988	9.39184	9.58253	9.70409
24	10.1768	9.53643	9.74776	9.8844

Table 2: Mass Participation comparison for fixed base and SSI analysis.

Mode	Mass Participation in X direction Excitation				Mass Participation in Z direction Excitation			
	Fixed base approach	SSI approach			Fixed base approach	SSI approach		
		0.5G	G	2.0G		0.5G	G	2.0G
1	8.61127	2.0215	2.00126	2.23783	8048	8252.75	8219.24	8187.92
2	7949.94	8224.34	8167.04	8114.42	8.65007	1.97291	1.9643	2.1914
3	15.5954	4.61389	4.31192	6.92197	0.141511	2.22623	1.7436	1.29055
4	495.457	455.369	463.567	470.996	2.18156	4.62542	4.31457	4.20774
5	3.04727	5.73259	5.41659	5.29117	575.675	539.692	544.857	550.35
6	0.054197	0.02326	0.023165	0.025523	2.03653	1.74281	1.69147	1.65848
7	25.9928	22.806	23.6092	24.4096	0.842831	1.23932	1.18369	1.2076
8	0.000255	0.000128	0.000334	0.002209	67.2491	56.093	58.2177	60.3809
9	0.000635	0.000379	0.000215	0.000149	1.7759	1.34932	1.43218	1.51694
10	0.005298	0.000143	0.00036	0.001524	10.6254	8.35541	8.82269	9.30801
11	23.6083	42.0271	35.7218	30.5222	1.66141	1.30288	1.41071	1.49766
12	4.65347	3.74912	3.93407	3.97751	3.04238	6.04548	5.43624	4.82746
13	59.288	117.61	101.049	85.5018	6.40237	2.72977	3.63818	4.42691
14	9.65492	39.6824	18.5704	12.9294	3.28488	6.33709	5.79392	5.17473
15	261.611	116.756	170.28	204.378	0.151975	0.059755	0.064755	0.134968
16	27.8299	0.539683	16.9053	19.9191	0.002174	0.413646	0.015759	0.002158
17	0.003868	10.997	0.04227	0.064322	0.171856	0.552694	0.370483	0.334566
18	0.634655	2.89742	0.578088	0.585651	1.10299	0.415314	0.920274	0.967189
19	0.310048	3.22004	1.88934	1.28553	0.078811	0.491204	0.328011	0.199451
20	1.84736	1.4295	1.47446	1.54712	0.246627	0.441597	0.389511	0.348379

Mode	Mass Participation in X direction Excitation				Mass Participation in Z direction Excitation			
	Fixed base approach	SSI approach			Fixed base approach	SSI approach		
		0.5G	G	2.0G		0.5G	G	2.0G
21	0.009121	0.108261	0.075623	0.011941	62.1351	2.64539	11.9167	51.3878
22	0.262178	0.033233	0.138164	0.225515	22.1239	102.775	94.8316	50.2515
23	0.677742	0.418217	0.433073	0.485841	0.527929	10.664	1.69523	0.613793
24	0.025821	0.000358	0.00587	0.009149	3.88337	0.375581	0.283468	0.009871

Table 3: Storey shear comparison for fixed base and SSI analysis.

Storey Level	Storey Wise Mass (Ton)	Storey Shear in X Direction in kN				Storey Shear in Z Direction in kN			
		Fixed base approach	SSI approach			Fixed base approach	SSI approach		
			0.5G	G	2.0G		0.5G	G	2.0G
16.5	243.095	230.286	208.36	214.741	219.714	228.871	203.076	209.502	214.731
14	701.286	787.545	712.56	734.384	751.389	782.707	694.49	716.468	734.35
9.5	702.503	1266.964	1146.331	1181.441	1208.798	1259.18	1117.261	1152.619	1181.386
5	1333.185	4355.408	3940.714	4061.408	4155.453	4328.651	3840.779	3962.327	4061.218
-0.05	1845.049	9355.61	8464.828	8724.085	8926.099	9298.135	8250.165	8511.255	8723.678
-4.33	1829.329	13520.713	12233.356	12608.033	12899.983	13437.65	11923.124	12300.451	12607.444
-9.33	1288.23	15274.364	13820.035	14243.308	14573.125	15180.528	13469.566	13895.833	14242.644
-14.33	1215.909	17063.827	15439.117	15911.978	16280.434	16958.997	15047.589	15523.795	15911.236
-19.63	1521.203	17806.017	16110.641	16604.069	16988.551	17696.628	15702.083	16199.002	16603.294

CONCLUSION:

Framed structure is analyzed for fixed base support condition and SSI, the frequency obtained from two analyses differ even for shear wave velocity of founding media 1100 m/s, the structural frequency obtained for SSI is lesser compare to corresponding frequency for fixed based analysis. Hence fixed base analysis will give the results on conservative side if the dominant frequencies of the structure are lesser than the frequency corresponding to peak spectral acceleration. For rigid structures, however, having dominant frequencies greater than the frequencies corresponding to the peak spectral acceleration, fixed base analysis will lead to under estimation of structural response as compare to the SSI analysis. Also with the advancement in the computer hardware technology, SSI analysis can be carried out with nominal computational efforts even for the structure founded on rock like media to get actual structural response. A sensitivity analysis for structural response can be carried out to take care of the uncertainties in SSI Analysis.

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