Transactions of the **14th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 14), Lyon, France, August 17-22, 1997

K08/5

Effect of soil parameters on the seismic response of a 3-D frame structure

Ghosh A.K., Agrawal M.K., Patnaik R., Bhargava K.
Bhabha Atomic Research Centre, India

ABSTRACT

The seismic response of a structure depends on the characteristics of the ground motion, surrounding soil and the structure itself. The present paper attempts to investigate the influence of various soil parameters viz. shear wave velocity of soil, soil damping and effective soil mass on the seismic behaviour of a 3-D frame structure on raft foundation. Normalized structural responses have been presented to identity the regimes where soil structure interaction is significant. The issue of conservatism of the response calculated on the basis of fixed base condition has also been discussed in the paper.

INTRODUCTION

The response of a structure during an earthquake depends on various parameters; the nature of earthquake excitation, foundation soil and the structure itself. The structure and the foundation soil form a combined dynamic-response mechanism and there may be significant feedback from the vibrating structure into the soil resulting in soil-structure interaction.

Various authors have proposed various models of soil-structure interaction and simplified criteria to account for or ignore the soil structure interaction. The effect of soil-structure interaction is analysed by introducing spring and dashport or impedance function to represent soil behaviour [1]. Some authors [2] have suggested comparison of the frequency of the superstructure (considered as a rigid mass) supported on soil spring with the dominant frequency of a fixed base structure. A comparison of fundamental frequencies of the fixed base and interacting structures can be used to justify the fixed base assumption [3].

In this paper, an attempt has been made to examine the effects of various soil parameters, e.g. soil stiffness, soil damping and effective soil mass on the distribution of natural frequencies of the structure and seismic structural responses. The conservatism of the analysis based on fixed base condition has also been studied. The case studies have been carried out for a 3-D frame structure. A typical illustration is shown in Fig. -1.

THEORY

The governing differential equation for the dynamic response of the structure together with soil by using a finite element formulation can be written as

$$[M]\{\ddot{X}\} + [C]\{\dot{X}\} + [K]\{X\} = [M]\{1\}\ddot{U}g \qquad \text{--(1)}$$

Where the symbols have their usual meanings.

MODELLING

Model of Structure

The columns and floor beams are modelled as 3-D beam elements. Floor slabs are modelled as quadrilateral plane stress elements. The raft foundation is modelled as a thin plate and shell element incorporating membrane and bending effects. The structural and material properties of the structure shown in Fig.-1 are defined in Table-1.

The analysis for two different case studies are presented. The first case study has been carried out for the structure with raft foundation (Fig.- 1) by considering or ignoring effective soil mass and equivalent modal damping (RE) or constant modal damping (RM),the second case study has been carried out for a framed structure with isolated footings [7]. The structure considered is similar to the structure shown in fig.-1, but having two storey with 2x2 grid.

Soil Model

The various soil parameters are assumed to be frequency independent. Soil structure interaction effects are modelled by considering simple spring dashpot models derived from the linear elastic half space theory.

Frequency independent soil spring constants for rectangular foundation, for vertical, horizontal, rocking and twisting motions are calculated as per reference [4]. Material damping in soil is estimated as per reference [5] for various shear wave velocities of soil and the estimate of frequency independent radiation damping in soil and effective soil mass vibrating with the structure is considered as per reference [6].

NUMERICAL ANALYSIS

Ground Motion

The analysis has been done for the ground motion shown in Fig.-3 [3]. The analysis is based on the response spectrum method. The seismic input includes two horizontal and the vertical components of the ground motion in combination. The spectral values for the two horizontal ground motions are the same and that for vertical ground motion is 0.67 times the value for horizontal motion. Exponential Interpolation of ground response spectral acceleration has been done for a particular mode to find the spectral ordinate corresponding to the equivalent damping for that mode.

Analysis Procedure

The analysis has been carried out considering a wide range of shear wave velocity of soil (Vs), covering the values commonly encountered from 60 m/sec. to 4000 m/sec. The soil damping comprising of internal damping and radiation damping varies with the different soil conditions. The present analysis considers the effect of soil damping and the structural responses have been calculated on the basis of equivalent modal damping. Here, it should be noted that the equivalent modal damping for a particular mode is restricted to 20% of critical damping [2]. The structural responses due to individual modes are combined as per SRSS rule. A comparison of results have also been made for the structural responses on the basis of fixed modal damping value of 5%.

Numerical Results

Table- 2 and Fig.- 2 present eigenvalues for first few modes. Table- 3 present the equivalent modal damping ratios for few modes.

For brevity, only few typical results are presented in the paper. Table- 4 present the comparison of structural responses for the cases `RE' and `RC'. Fig.- 4 presents normalised maximum structural displacement against Vs. Figures 5 presents normalised maximum column bending moment against Vs.

Discussion of Results

Drawing an analogy with a single degree of freedom structure the effective stiffness (Ke) in case R can be approximated as

$$(1/Ke) = (1/Kss) + (1/Kr) + (1/Ks) \qquad \text{--- (2)}$$

where Kss, Kr and Ks are the stiffness of superstructure, raft and soil respectively. With increasing Vs (hence, increasing Ks) the effect of soil stiffness diminishes. Thus the effective stiffness approaches an asymptotic value with increasing Vs. Hence, the seismic response (i.e. displacement, moment) can also be expected to approach asymptotic value with increasing Vs.

Comparison of fig.-5 and fig.-6 shows the fixed-base assumption is not always a conservative approach for designing the structure particularly at lower shear wave velocity . As the shear wave velocity increases , the dynamic interaction of structure with soil also come down and therefore, response of structure slowly approaches to the fixed-base results, i.e. towards normalised one.

For the present case study, it is seen that the addition of effective soil mass vibrating with superstructure does not affect structural response (see table-2 to 4).

In Table- 5 a comparison of normalised frequencies has been made as per reference [2]. An empirical relationship has been prescribed to consider the conservation of fixed base analysis. As per this the results are conservative when the ratio of the frequency (Rf) is equal to or greater than 2.

$$Rf = \omega \;/\; \omega_f \geq \quad 2 \qquad \text{------(3)}$$

where the symbols have their usual meanings. As per the results shown in Table- 5 , the ratio Rf at shear wave velocity Vs= 550M/sec. is more than two for both the cases but the normalised result for the case-2 from fig.-6 shows the maximum bending moment is more than unity , i.e. in the case -2 even at a frequency ratio greater than two, the fixed base analysis is not conservative.

CONCLUSIONS

Following conclusions are drawn, based on the present case study.

1. The first few natural frequencies of vibration for the structure are found to approach asymptotic value with increasing Vs of soil medium. The variation in frequencies of vibration is seen to be significant for higher modes.

2. The effective soil mass has a negligible influence on the structural response.

3. Soil damping plays an important role in bringing down the structural response,the effect being more pronounced at lower Vs of soil medium.

4. Neglecting the structure - foundation- soil- interaction for a structure could result in significant under estimation of structural displacements and forces.

5. It is seen that various criteria to ignore soil-structure interaction and carry out analysis with a fixed-base assumption depend on case specific parameters and as such conservatism of the fixed-base analysis cannot be generalised.

REFERENCES :

1. USNRC 1981, Soil Structure Interaction : The status of current Analysis Methods and Research Report NUREG/CR-1780.

2. ASCE-ASCE Standard 4-86, 1995.

3. USNRC, 1982 Standard Review Plan 3.7.2, NUREG 800, US Nuclear Regulatory Commission.

4. Arya S.C., M.W. O'Neill, G. Pineus 1979 (Design of structures and foundations for vibrating machines) [Book] Gulf Publishing Company Houston.

5. Newmark, N.M. E. Rosenblueth, 1971 (Fundamentals of Earthquake Engineeriong) Prentive Hall, Englewood Cliffs, N.J.

6. Whitman, R.V. F.E. Richart, Jr. 1967 Design procedures for Dyanmically loaded foundations (Soil Mechanics and Foundations Division) SM6 169-193.

7. Patnaik, R. , et al, " Effect of Foundation Conditions on the Seismic Response of a Space Frame; BARC/1994/I/010,1994.

Table - 1

Structural and Material Properties

for the structure (Unit: KN-M)

Structure			Concrete		
Columns	:	0.4 x 0.4	Grade	:	M20
Floor beams	:	0.25 x 0.4	Modulus of Elasticity	:	0255E08
Floor slab thk:		0.15			
Raft	:	9.4 x 9.4	Poission's ratio	:	0.15
			Weight density:		25.0

Table-2

Comparison of Natural Frequencies of Vibration
(Frequency in Hz)

Vs (M/Sec)	60		1100		4000	
Mode no.	RM	RWM	RM	RWM	RM	RWM
1	0.96	0.97	1.41	1.41	1.42	1.42
2	0.96	0.97	1.41	1.41	1.42	1.42
3	1.44	1.44	1.61	1.61	1.61	1.61
5	3.50	3.57	4.29	4.29	4.29	4.29
7	4.06	3.98	7.12	7.12	7.12	7.12
10	5.61	5.74	9.31	9.31	9.31	9.31

RM : effective soil mass considered

RWM: effective soil mas neglected

Table - 3

Equivalent Modal damping Ratios (% of critical damping)

Vs (M/Sec.)	60		550		1100		4000	
Mode no.	REM	REWM	REM	REWM	REM	REWM	REM	REWM
1	5.75	5.75	5.98	5.98	5.54	5.54	5.09	5.09
2	6.13	6.11	5.92	5.92	5.50	5.50	5.09	5.09
4	63.83*	45.65*	5.45	5.45	5.24	5.24	5.04	5.04
6	12.68	23.54*	5.15	5.15	5.05	5.05	5.01	5.01
7	23.55*	26.60	5.11	5.11	5.03	5.03	5.01	5.00
8	12.61	25.29*	5.09	5.09	5.03	5.03	5.00	5.00
9	6.79	23.35*	5.09	5.09	5.04	5.04	5.00	5.01
10	23.02*	16.02	5.07	5.07	5.03	5.03	5.01	5.01

* Values restricted to 20% of critical damping in analysis.

Table- 4 : Comparison of Structural Responses (Unit KN-M)

Vs=1100M/Sec	RE		RM	
Response Location	REM	REWM	RCM	RCWM
Displacement Elevation=20M	0.111	0.111	0.115	0.115
Column Moment EL=0.0M	347.1	347.0	360.9	360.8
Column Axial Force EL=0.0M	59.1	59.62	62.15	62.17
Beam Moment EL = 5M	215.7	215.6	224.5	224.3

Table-5 : Comparison of value Rf

Vs (M/Sec)	60.0	550.0	1100.0	4000.0
Case				
Case-1	2.52	23.04	46.05	167.64
Case-2	1.45	13.29	26.58	96.65

Table-6: Table of legend

Soil Mass / Damping	Considered	Ignored
Equivalent Modal Damping	REM	REWM
Constant Damping	RCM	RCWM

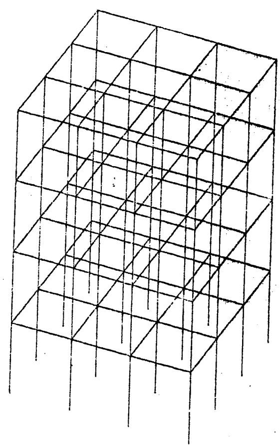

Fig.-1

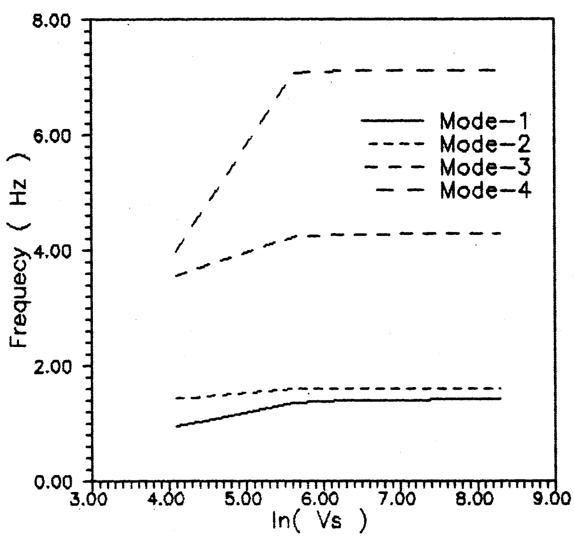

Fig.-2 : Natural Frequency of Vibration for case-1 (RWM)

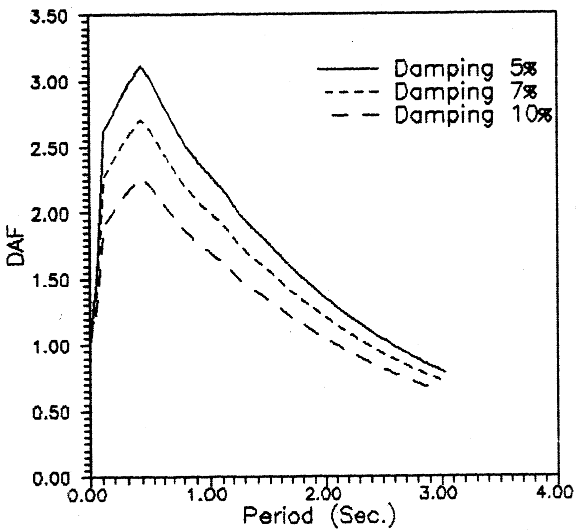

Fig.—3: Response Spectra

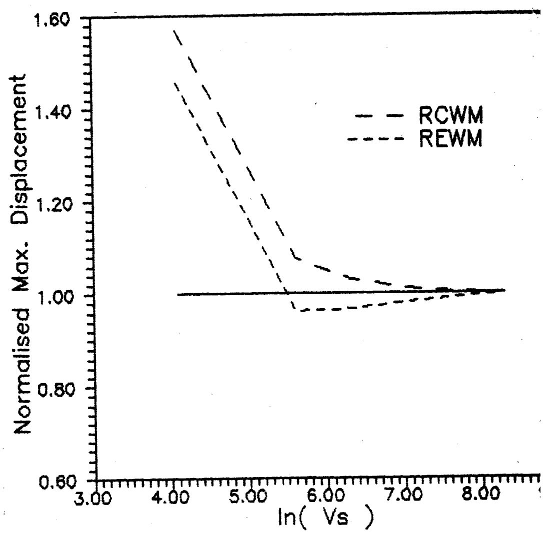

Fig.—4: Normalised Max. Displacemei

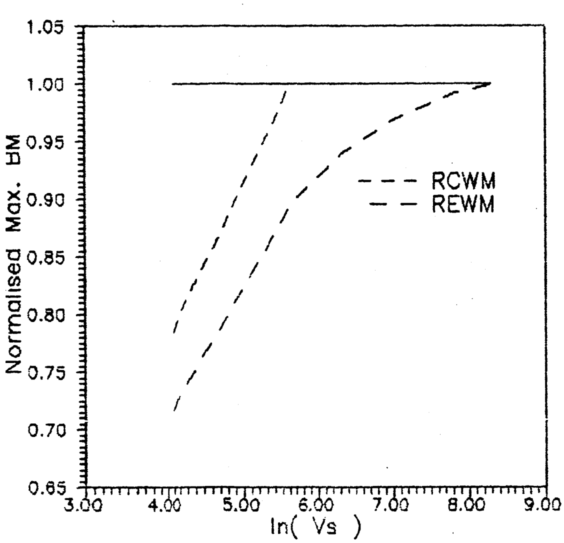

Fig.—5: Normalised Max. Column BM

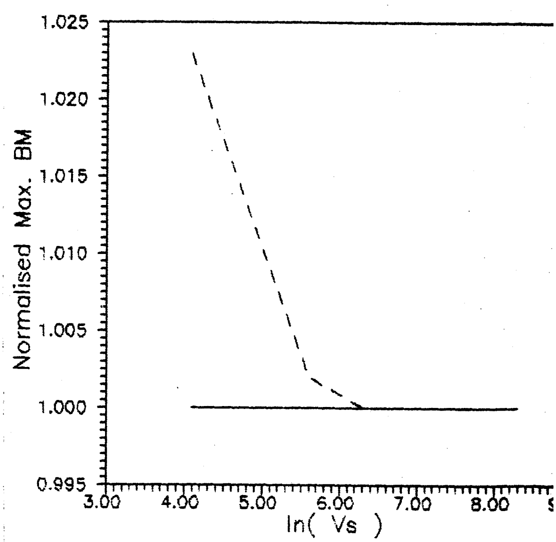

Fig.—6: Normalised Max. Column BM (Co