Earthquake Response of Multi Storey Buildings Under Different Soil Conditions

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Abstract— ***Earthquake is an endogenous natural hazard which occurs sudden without warning and destruction takes place during short duration of time. Most loss of life and property during an earthquake comes from total or partial collapse of buildings. While countries like U.S.A and Japan are constructing earthquake resistant structures, not much awareness has been created in developing countries like India on these aspects. Major metropolitan cities in India located in seismic regions, have registered enormous growth in population resulting in huge urban sprawl with major construction activities. When an earthquake occurs seismic waves propagate through different soil / rock media and when they reach the foundation, the structure vibrates. When structures are subjected to excitation, it is normally assumed that the structure is fixed at the base neglecting the influence of soil below it. This assumption leads to larger variation in the assessment of overall response under seismic loads.***

In the present study, a part of Amaravathi, capital of the state Andhra Pradesh, India, where many high rise buildings are expected to come in future, is chosen as study area. A nine storied building, with two soft stories; one cellar for parking and the other a function hall in fifth floor and when it rests on different types of soil, seismic analysis is carried out using MATLAB software for obtaining fundamental time periods, base shear and displacement parameters. The results are compared with the results of those obtained when fixed base condition is assumed. Results indicate that Soil – Structure Interaction influencies considerably on response parameters like base shears and displacements; particularly when structures built on loose soils.

Keywords— *Soil-Structure Interaction, Shear wave velocity, Spring constant, Time period, Base shear and Displacement*

I. INTRODUCTION

Though the land, air and water of the planet earth provides cradle for the existence of life and growth of civilization, sometimes they cause disasters in the form of earthquakes, volcanoes, wind storms and floods resulting in large scale loss of life and property.

A spurt in the related professional activities in India during recent times shows that 1993 Killari, 2001 Bhuj and 2004 Indonesia earthquakes have significantly enhanced the awareness among the engineering community towards the earthquake problem. However, there is a need to channelize various aspects in earthquake resistant design problems and must be implemented before the interest fades away. The response of structures against earthquake induced vibrations is a function of the nature of foundation soil/rock, form, size, construction quality and the duration & characteristics of the ground motion.

The dynamic inter-relationship between the response of the structure and the characteristics of the soil/rock below the foundation is commonly referred as Soil- Structure Interaction (SSI). This interaction phenomenon is principally affected by the mechanism of energy exchanged between the soil and the structure.

In general, it can be concluded that buildings rest on stiff soils/rock behave well during an earthquake compared to when they rest on soft or loose soils.

II. SOIL – STRUCTURE INTERACTION

Most of the civil engineering structures involve some type of structural elements in direct contact with the ground. When the external forces, such as earthquakes, act on these systems, neither the structural displacements nor the ground displacements, are independent of each other. The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is termed as Soil Structure Interaction (SSI) [1]. Conventional structural design methods neglect the SSI effects. Neglecting SSI is reasonable for light structures resting on 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, high-rise buildings and elevated water tanks resting on soft soil.

III. SOIL/ROCK CLASSIFICATION IN STUDY AREA

The study area is covered by different types of geomorphic units / landforms [2]. The seismic response of similar building behaves differently in different soil units during an earthquake. Assuming the chosen building rests on different soil / rock units, the study area is classified into seven types as given below for carrying out the analysis.

Type S1 – Clay, Soft and Silty clay
Type S2 – Loose gravel and Fine sand
Type S3 – Dense & Medium sand
Type S4 – Weathered rock
Type S5 – Semi weathered rock
Type S6 – Fractured rock
Type S7 – Hard rock

The analysis is also carried out considering with and without the stiffness of infill walls between columns in the direction of earthquake force as given below:

Case 1 – Considering infill wall stiffness between columns while calculating total stiffness of each storey.

Case 2 – Without considering infill wall stiffness between columns while calculating total stiffness of each storey.

IV. SEISMIC ANALYSIS

A. *Structure Model*

In the present study, a nine storied building with lower storey for parking, fifth floor as function hall (two soft stories) and the remaining seven stories for commercial and residential purpose, resting on seven different types of homogeneous soils, is chosen for the study. Analysis is also carried out when the structure is assumed to be fixed at the base and results are compared. The dimensions and properties of the structural elements of the building are presented in Tables 1 (a) and 1 (b). The size of the building is 32m x 15m in plan and consists of 8 bays in X – direction and 3 bays in Z – direction, and the plan of the building is shown in Fig. 1.

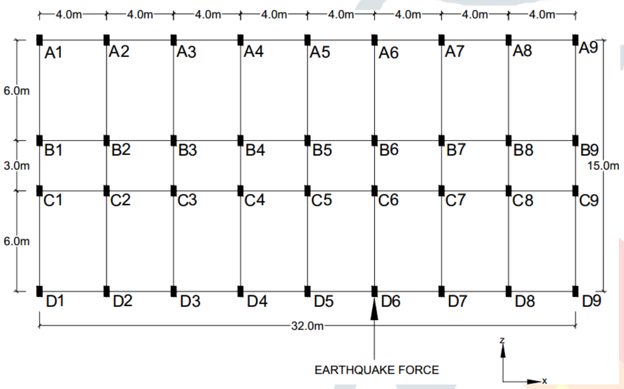


Fig. 1 Plan of the building

Table - 1 (a) Preliminary Data for the analysis

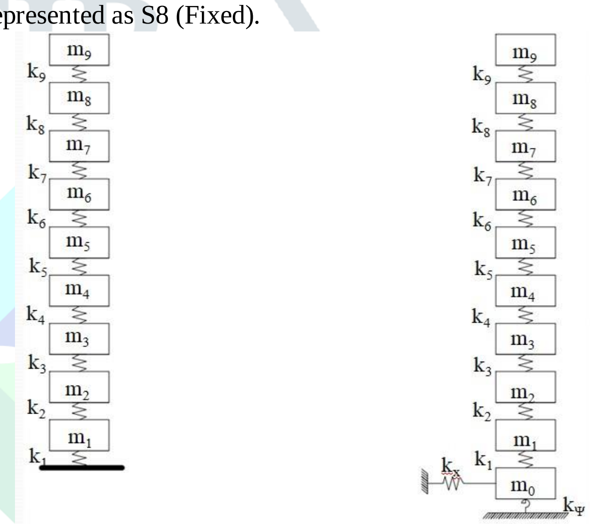
Parameter	Dimensions
Height of the building	30.6 m
Height of each storey	3.2 m
Height of function hall	5.0 m
Number of stories	9 (2 soft stories)
Column size for 1-4 floors	0.30 x 0.60 m
Column size for 5-9 floors	0.23 x 0.50 m
Longitudinal beams	0.23 x 0.40m
Transverse beams	0.23 x 0.50 m
Plinth beams	0.30 x 0.40 m
Slab thickness	0.12 m
Exterior wall thickness	0.23 m
Interior wall thickness	0.115 m
Parapet wall height	0.90 m

Table - 1 (b) Property of Materials & Gravity Loads

Property of material	Loads
Grade of concrete	M_{20}
Grade of steel	Fe415
Unit weight of RCC	25 kN/m^3
Unit weight of brick work	19 kN/m^3
Live load (floor)	4.00 kN/m^2
Live load (terrace)	1.50 kN/m^2
Floor finish	1.50 kN/m^2
Terrace finish	1.50 kN/m^2
Earthquake zone	III

Mathematical Model

The masses are lumped at each storey level and equivalent stiffness value of all columns with and without infill walls as Case 1 & Case 2 in each storey are represented as spring at that storey level. Fig. 2 (a) represents the mathematical model of the building when it is assumed to be fixed at the base and SSI [3] & [4] effect is neglected. This type of model is represented as S8 (Fixed).



(a) Fixed Base Condition (b) Soil Structure Interaction
Fig. 2 Building Model

B. *Soil Model*

Modeling of soil requires representation of basic parameters of soil like, shear wave velocity, mass density, Poisson's ratio and shear modulus and the values are worked out as suggested by Whitmen and Richart [5]. The values of these parameters are presented in Table 2. The structure is assumed to rest on a uniform elastic half-space and soil spring approach is used to model the soil-structure interaction. Soil model is represented in terms of stiffness of soil, mass of the footing & damping ratio. Since the structures are usually designed for gravity loads, only the springs in horizontal and rocking[6] modes are considered in the analysis. In the present study, rectangular type of footing is adopted for the building. The mathematical model considering SSI effect is shown in Fig. 2(b).

Table-2 Types and Properties of Soil or rock

Type	Description of soil	Bearing Capacity of soil (kN/m^2)	Shear wave velocity V_s (m/sec)	Mass density ρ (kN – Sec^2) m4	Poisson's ratio (ν)	Shear modulus $G= \rho V_s^2$ (kN/m^2 x 10^5)
S1	Clay, Soft and, Silty clay	13	60	1.70	0.45	0.06
S2	Loose gravel and Fine sand	15	100	1.80	0.45	0.18
S3	Dense & Medium sand	250	150	1.85	0.4	0.42
S4	Weathered rock	30	400	1.90	0.33	3.04
S5	Semi weathered rock	350	1250	2.10	0.30	32.81
S6	Fractured rock	400	2000	2.50	0.30	100.00
S7	Hard rock	500	2700	2.60	0.30	189.54

Table - 3 (a) Equivalent stiffness and Damping coefficient values of soil springs

Description of parameter	Building with rectangular footing
Horizontal stiffness, k_x (kN/m)	$2(1+\nu)\, G\beta_x (BL)^{1/2}$
Rocking stiffness, k_Ψ (kN-m)	$\frac{G}{1-\nu}\beta_\Psi BL^2$

k_x = Horizontal stiffness of soil in kN/m, k_Ψ = Rocking stiffness of soil in kN-m,β_x & β_Ψ are constants suggested by Whitmen & Richart as shown in Fig-3.,B is the width of the footing in the direction of horizontal excitation and L is the length of the footing in the direction of horizontal excitation.

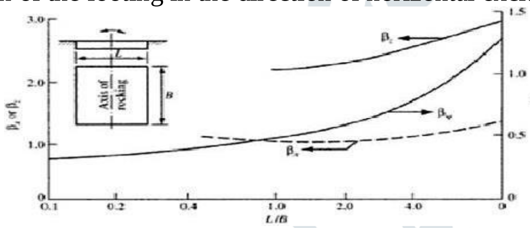


Fig. 3 Constants for rectangular footings (Whitman and Richart) 1967

Based on the work done by Whitman and Richart as presented in Table 3(a), the horizontal stiffness & Rocking stiffness of the soil springs are obtained when they rest on different types of soil and the results are presented in Table-3(b). The variation of horizontal and rocking stiffness values with shear wave velocity is shown in Fig. 4

Table - 3 (b) Horizontal & Rocking Stiffness values of soil or rock

Type of soil or rock	Stiffness values	
	K_x (kN/m x 10^6)	K_Ψ (kN.m x 10^6)
S1	2.09	25.74
S2	5.3	56.76
S3	10.9	65
S4	69.9	305
S5	721	1133
S6	2200	3390
S7	3630	4308

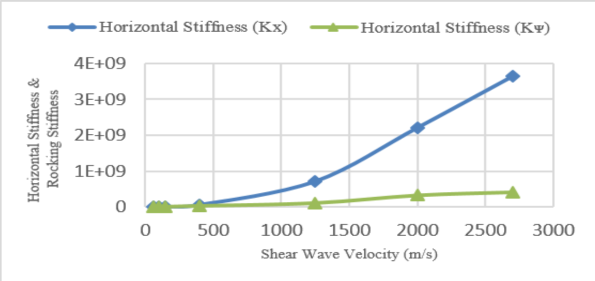


Fig. 4 Variation of Horizontal & Rocking stiffness values of soil

V. Method Of Seismic Analysis

A. Free Vibration Analysis

Using free vibration analysis[7], fundamental natural frequencies and time periods are obtained when similar structure rests on different types of soils and the results are presented in Tables 4. The graphical representation of these values are shown in Figs. 5 and 6.

Table - 4 Results for Free Vibration Analysis

Type of soil or rock	Time period (sec)		Frequency (Hz)	
	Case-1	Case-2	Case-1	Case-2
S1	1.65	1.84	0.6	0.54
S2	1.10	1.34	0.9	0.75
S3	0.63	1.26	1.57	0.79
S4	0.41	0.93	2.38	1.07
S5	0.38	0.85	2.59	1.16
S6	0.35	0.836	2.81	1.19
S7	0.34	0.834	2.90	1.198
S8(Fixed)	0.33	0.82	2.97	1.21

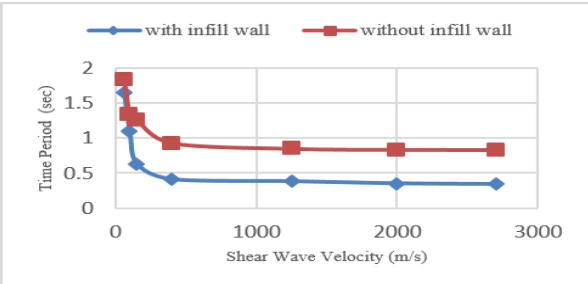


Fig. 5 Time period Vs Shear wave velocity

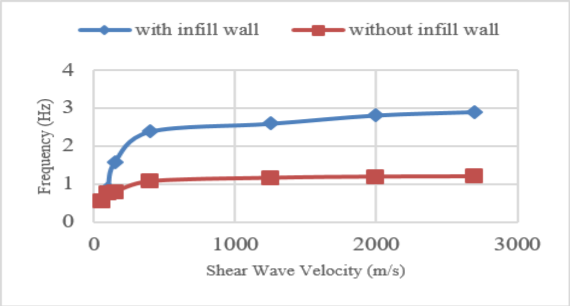


Fig. 6 Natural frequency Vs Shear wave velocity

B. Earthquake Response of the Structure

Using seismic coefficient method of analysis as given in IS 1893 (2002)[8], the base shears and storey displacements are worked out and these results are compared with the results obtained from fixed base condition. The base shear and displacement parameters are worked out when the structure is located in seismic zones III and the results are represented in Tables 5 & 6 and graphical representation of these values are shown in Figs. 7(a) & (b) and 8.

Table - 5 Results for Earthquake response of the structure

Type of soil or rock	Base shear at base of the structure (kN)		Base shear absorbed by the soil (kN)	
	Case-1	Case-2	Case-1	Case-2
S1	181	220	335	238
S2	210	221	258	171
S3	254	182	158	133
S4	289	193	80	46
S5	291.36	201	57	13.34
S6	301.89	190.35	19	6.88
S7	302.53	190.41	9.43	6.88
S8(Fixed)	302.71	191.90	-	-

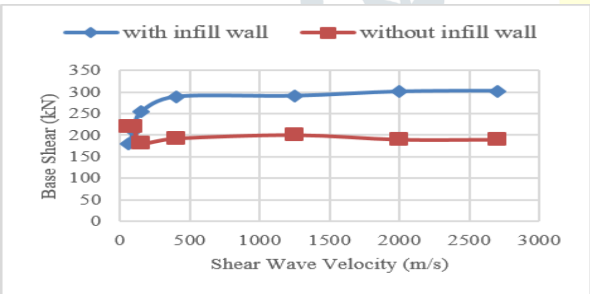


Fig. 7(a) Maximum base shear at base of the structure Vs Shear wave velocity

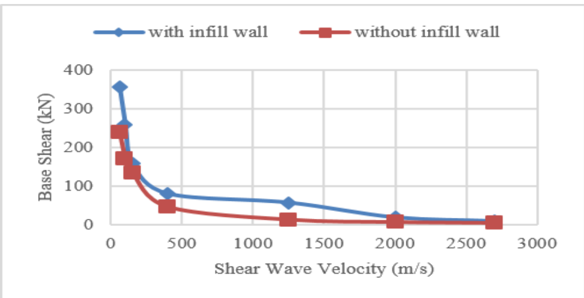


Fig. 7(b) Base shear absorbed by the soil Vs Shear wave velocity

Table - 6 Results of Displacement values

Type of soil or rock	Total displacement (mm)	
	Case-1	Case-2
S1	12.9	14
S2	9	10.8
S3	4.7	8.3
S4	2.5	5.3
S5	2.43	4.79
S6	1.9	3.98
S7	1.8	3.95
S8(Fixed)	1.7	3.90

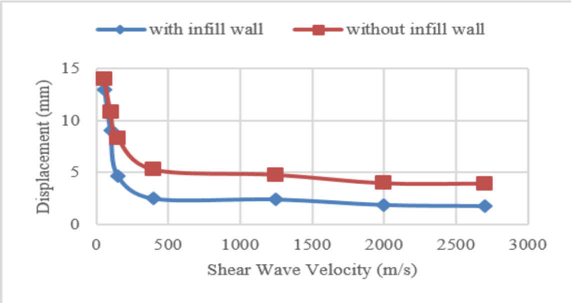


Fig. 8 Maximum Displacement Vs Shear wave velocity

CONCLUSION

1) Time periods of the structure decrease with the increase in soil stiffness from loose soil to stiff soil and so the natural frequency will increase with increase in soil stiffness.
2) Time period of the structure also decreases when stiffness of infill walls is considered.
3) The displacements of structure increases with the decrease of soil stiffness, particularly in loose soils and this is mainly attributed due to the contribution from rocking effect.
4) From the present study, it can be concluded that structures resting on hard rock or firm soil behave well during earthquakes when compared to the structures resting on loose soils.
5) From many failure examples and the results of present analysis, SSI effect shall be considered while analyzing high rise structures resting on loose soil.
6) It is noticed that shear wave velocity influences significantly on the change in shear modulus of soil and hence the horizontal & rocking stiffness values increase exponentially from loose soil to hard rock.
7) Base shear absorbed by the soil increase with decrease of the soil stiffness.
8) It is observed that total displacement increase with soil stiffness varying from 12.9 mm in case of loose soil to 1.8 mm in case of hard rock.
9) It is also observed that the displacement considering Soil-Structure Interaction in case of hard rock (1.80 mm) is almost same as in the case of fixed base condition (1.70 mm). Hence SSI effect may be neglected in case of structures rest on hard rock; however, when structures rest on loose soils, SSI effect need to be considered.

REFERENCES

[1] Shehata E.Abdel Raheem, Mohamed M. Ahmed and Tarek M.A.Alazrak, “Soil-Structure Interaction effects on seismic response of multi-story buildings on raft foundation”, Journal of Engineering a Sciences Assiut University Faculty of Engineering vol.42, No. 4, pp 905-930, July 2014.

[2] S.R.K.Reddy, et al, “Terrain evaluation and influence of soil-structure interaction on seismic response of structures in urban environs” proc of 3rd International conference (2006)Venice, Italy, pp235-242.

[3] Vidya.V, B. K. Raghu Prasad and Amarnath.K, “Seismic response of high rise structure due to interaction between soil & structure”, International journal of Research in Engineering and Applied Sciences, Volume 5. Issue 5-May-2015

[4] Ketan Bajaj, JiteshT Chavda, Bhavik M Vyas, “Seismic behavior of buildings on different types of soil”.

[5] Whitman R V & Richart F.E, “Design procedures for dynamically loaded foundation engg. Division, ASCE93, 1967, pp161-191.

[6] David J. Dowrick (1996) “Earth-quake Resistant Design for Engineers and Architects”. John Wiley & Sons, New York.

[7] Pankaj Agarwal and Manish Shrikhande (2014), "Earthquake Resistant Design of Structures", PHI Learning Private Limited, Delhi (2006).

[8] Bureau of Indian Standards IS 1893 (Part I): 2002. Criteria for earthquake resistant design of structures. Part I General provisions and Buildings, 2002