Effect of Soil Structure Interaction on The Seismic Behavior of Buildings

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Abstract- *A common design practice for dynamic loading assumes the building to be fixed at their bases. In reality the supporting soil medium allows movement to some extent due to its property to deform. This may decrease the overall stiffness of the structural system and hence may increase the natural periods of the system, such influence of partial fixity of structures at foundation level due to soil flexibility intern alters the response. Such an interdependent behavior of soil and structure regulating the overall response is referred to as soil structure interaction. This effect of soil flexibility is suggested to be accounted through consideration of springs of specified stiffness.*

Keywords- Modulus of sub grade reaction, Modulus of elasticity of soil, spring stiffness, Design base shear.

I. INTRODUCTION

In the last three decades, the effect of SSI on earthquake response of structures has attracted an intensive interest among researchers and engineers. Most of these researches focus on theoretical analysis, while less has been done on the experimental study. The interaction among the structure, foundation and soil medium below the foundation alter the actual behavior of the structure considerably as obtained by the consideration of the structure alone. Flexibility of soil medium below foundation decreases the overall stiffness of the building frames resulting in an increase in the natural period of the system.

Soil-Structure Interaction (SSI) is a collection of phenomena in the response of structures caused by the flexibility of the foundation soils, as well as in the response of soils caused by the presence of structures. Analytic and numerical models for dynamic analysis typically ignore SSI effects of the coupled in nature structure-foundation-soil system. It has been recognized that SSI effects may have a significant impact especially in cases involving heavier structures and soft soil conditions.

A parametric study is carried out for determining the lengthened lateral natural period of building frame due to incorporation of the effect of soil structure interaction. Also the effect of infill with and without opening and the various other parameters on the natural period has been studied. The study includes the building with isolated footing on soft, medium and hard soil and comparison between the natures of change in lateral natural period has been presented. Such a study may help to provide guidelines to assess more accurately the seismic vulnerability of building frames and may be useful for seismic design.

OBJECTIVE OF STUDY

1. To study the effect of soil structure interaction on infill frame and bare frame.
2. To study the effect of soil structure interaction by varying the number of storey's in the building frame.
3. To study the effect of soil structure interaction on the dynamic behavior of building by considering different types of soil.

SCOPE OF STUDY

The present study is limited to the following considerations,

1. Three type of soil namely soft, medium and hard.
2. A brick masonry infill panel.
3. Analysis by using E TAB.

II. METHODOLOGY

RESPONSE SPECTRUM METHOD

The response spectrum represents an interaction between the ground acceleration and the structural system, by an envelope of several different ground motion records. For the purpose of the seismic analysis the design spectrum given in fig 2 of IS1893 (part1)-2002 is used. This spectrum is based on strong motion records of eight Indian earthquakes. Following procedure is generally used for the spectrum analysis.

i) Select the design spectrum
ii) Determine the mode shapes and period of vibration to be included in the analysis.
iii) Read the level of response from the spectrum for the period of each of the modes considered.

iv) Calculate the participation of each mode corresponding to the single degree of freedom response read from the curve.
v) Add the effects of modes to obtained combined maximum response.
vi) Convert the combined maximum response into shears and moments for use in design of the structures.
vii) Analyze the building for the resulting moments and the shear in the same manner as the static loads.

The code suggests that the number of modes to be used in the analysis should be such that the total masses of all loads considered is at least 90% of the total seismic mass. If the natural frequencies differ from each other by10%, then the modes are considered as closely spaced. And the peak response quantities are combined using Complete Quadratic Combination (CQC) method. If the modes are not closely spaced then Square Root of Sum of Squares (SRSS) method is used. If there were few closely spaced modes, then it suggest the use of Sum of Absolute Values (ABSSUM) method and rest of the mode could be combined using CQC method. In the present study CQC method is used.

III. MODELING METHOD

To study the dynamic behavior of building structure while considering the effect of soil structure interaction, building frame is modeled as 3D space frame using standard two nodded frame element with two longitudinal degrees of freedom and one rotational degree of freedom at each node. To analyze the infill using finite element method, modeling requires breaking it down into a series of plate elements, each plate is four nodded rectangular plate element with two traditional degrees of freedom at each node. An opening of required dimension can be provided while modeling the building in the software E TAB. At the interface of infill and frame, the infill element and the frame element are given same nodes.

The idealized form of a typical 3 bay x 3 bay 6 storey building frame (up to GL) with infill wall modeled as a plate is represented schematically in fig 1. The present study also considers bare frame to see how correctly the influence of soil structure interaction on dynamic behavior can be predicted. This may give an idea about the error, which one should liable to commit if this popular but grossly inaccurate approach is invoked.

A 3 bay x 3 bay building frames with 2, 4, 6, 8, 10, 12 storey's on isolated footing have been considered. The height of each storey is taken as 3.6 mt and the longitudinal and transverse dimensions of 3 bay x 3 bay building is taken as 3.5 m for central bay and 5 mt for the two side bays. For all the buildings the dimensions of reinforced concrete column are taken as 400x400 mm and for beam it is 300x500 mm. Similarly thickness for roof and floor is taken as 120mm and their corresponding dead load is directly applied on the beam. All the above dimensions were arrived on the basis of the design following the respective Indian code for design of reinforced concrete structure .However, these design data are believed to be practicable and hence, do not affect the generality of the conclusion.

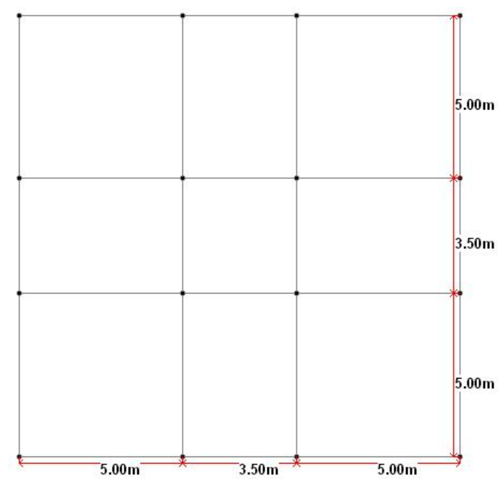

Fig. 1 Plan of the building

IV. STRUCTURAL PARAMETERS GOVERNING SEISMIC BEHAVIOUR

Flexibility of soil medium below foundation may appreciably alter the natural periods of any building. It usually causes to elongate time period of structure. It is observed (from the fig 2) that soft soil amplifies ground motion more than that of hard soil.

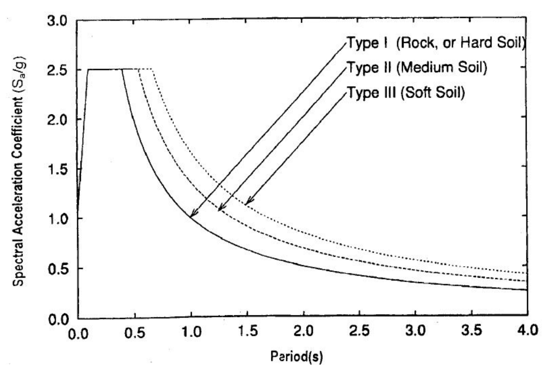

Fig. 2 Response spectra for rock and soil sites for 5% damping (IS1893 Fig. 2)

The flexibility of soil is usually modeled by inserting springs between the foundation member and soil medium. While modeling, the number of degree of freedom should be selected carefully considering the objective of the analysis. During earthquake a rigid base may be subjected to a displacement in six degrees of freedom, and therefore resistance of soil can be expressed by the six corresponding resultant force components. general, translations of foundation in two mutually perpendicular principle horizontal directions and vertical direction as well as rotation of the same about these three directions are considered in this study. In this project, for isolated footing below each column, three translation springs along two horizontal and one vertical axis, together with three rotational springs about those mutually perpendicular axes, have been attached (as shown in Fig 3) to simulate the effect of soil flexibility.

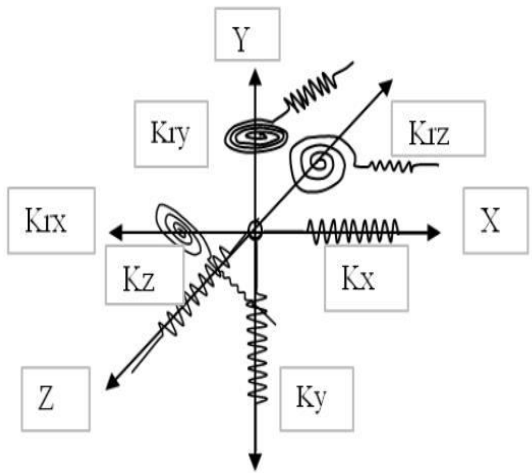

Fig. 3 Idealization arrangement at a typical column square Foundation strip & equivalent soil spring junction

Table 1. Spring stiffness for square footing along various Degree

Degrees of freedor	**Stiffness of equivalent soil spring**
Vertical Ky	$4.54Gb/(1-\mu)$
Horizontal (lateral direction) Kx	$9Gb/(2-\mu)$
Horizontal (longitudinal direction) Kz	$9Gb/(2-\mu)$
Rocking (about the longitudinal) Krx	$0.45Gb3/(1-\mu)$
Rocking (about the lateral) Krz	$0.45Gb3/(1-\mu)$
Torsion Kry	8.3Gb3

To obtain the values of spring stiffnesses of the springs for hard, medium and soft soil, value of shear modulus (G) of soil have been estimated using the following empirical relationship,

G=120 N 0.8 t/ft2 (1)

G=12666 N 0.8 KN/m2 (2)

Where, N= Number of blows to be applied in Standard Penetration Test (SPT) of the soil; and the poisons ratio (μ) of the soil has been taken to be equal to 0.5 for all types of clay. N is taken as 3, 6, and 30 for soft, medium and hard soil respectively. The details of different soil parameters are tabulated in table 2. Safe Bearing Pressure is assumed for footing placed at depth 1.4 mt below ground level. Since the stiffnesses of spring used to represent the soil flexibility are highly sensitive to the size of footing below which they are attached to, dimensions of various footing have been very rigorously computed separately based on Safe bearing capacity to have an exhaustive idea. The load carried by each column is obtained from the response spectrum analysis using E TAB. All isolated footings are assumed to be square in shape.

Table 2. Types of soil and their parameters

No.	**Type of Soil**	**N Value**	**Shear Modules in KN/m^2**
1.	Soft	3	30502.57
2.	Medium	6	53018.07
3.	Hard	30	192458.23

V. ANALYSIS RESULTS

Table 3. Percentage change in lateral natural periods for infill frame.

Storey considered	**Soil type**	**Natural period(sec) Without considering soil flexibility**	**Natural period(sec) With considering soil flexibility**	**% change in natural periods**
2	HARD	0.1179	0.1291	9.5
	MEDIUM	0.1179	0.1491	26.45
	SOFT	0.1179	0.1594	35.2
4	HARD	0.1802	0.1993	10.6
	MEDIUM	0.1802	0.2352	30.5
	SOFT	0.1802	0.2533	40.59
6	HARD	0.26659	0.2975	11.61
	MEDIUM	0.26659	0.3487	30.79
	SOFT	0.26659	0.3749	40.61
8	HARD	0.34584	0.3919	13.307
	MEDIUM	0.34584	0.4663	34.82
	SOFT	0.34584	0.4986	44.18
10	HARD	0.45756	0.5166	12.91
	MEDIUM	0.45756	0.6126	33.88
	SOFT	0.45756	0.6500	42.06
12	HARD	0.61471	0.6834	11.18
	MEDIUM	0.61471	0.7969	29.64
	SOFT	0.61471	0.8402	36.68

Table 4 Percentage change in lateral natural periods for bare frame

Storey considered	Soil type	Natural period(sec) Without considering soil flexibility	Natural period(sec) With considering soil flexibility	% change in natural periods
2	HARD	0.3754	0.3774	0.54
	MEDIUM	0.3754	0.3813	1.58
	SOFT	0.3754	0.3835	2.17
4	HARD	0.68736	0.6905	0.45
	MEDIUM	0.68736	0.6963	1.3
	SOFT	0.68736	0.6995	1.76
6	HARD	1.00585	1.0100	0.41
	MEDIUM	1.00585	1.0177	1.18
	SOFT	1.00585	1.0218	1.59
8	HARD	1.33278	1.3396	0.51
	MEDIUM	1.33278	1.3524	1.47
	SOFT	1.33278	1.3590	1.97
10	HARD	1.6704	1.6794	0.54
	MEDIUM	1.6704	1.6968	1.58
	SOFT	1.6704	1.7060	2.13
12	HARD	2.02089	2.0310	0.5
	MEDIUM	2.02089	2.0506	1.47
	SOFT	2.02089	2.0605	1.96

VI. CONCLUSION

In the present study, the effect of soil structure interaction on the dynamic characteristics of structure with brick infill and bare frame has been studied. Some of the conclusions that can be drawn from the results tabulated in previous tables are

1. The study shows that consideration of effect of soil structure interaction influences time period and base shear of building frame. Thus evaluation of these parameters without considering soil structure interaction causes significant error in seismic design, as seismic response is found to be sensitive to soil structure interaction.
2. Incorporating effect of soil flexibility, seismic response (time period) experiences an increase for buildings with lesser number of stories having short period (up to 0.35 sec). However, seismic response generally decreases due to influence of soil structure interaction for medium to high rise buildings
3. If the effect of infill brick wall is not considered while studying the seismic behavior of building frames, the effect of soil structure interaction on seismic response is found to be insignificant.

ACKNOWLEDGMENT

I express my deepest gratitude to my project guide Principal and Prof. Dr. U. B. Kalwane, Dr. D. Y. Patil School of Engineering & Technology, whose encouragement, guidance and support from the initial to the final level enabled me to develop an understanding of the subject. Besides, I would like to thank to Dr. Sunil M. Rangari, Head of the Civil Engineering Department, Dr. D.Y.Patil School of Engineering & Technology for providing their invaluable advice and for providing me with an environment to complete my project successfully. Finally, I take this opportunity to extend my deep appreciation to my family and friends, for all that they meant to me during the crucial times of the completion of my project.

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