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# Effect of Soil Structure Interaction On The Dynamic 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. Thus the change in natural period due to effect of soil structure interaction may be an important issue from the viewpoint of design considerations.*
***Keywords –*** *Stiffness, Partial fixity, Flexibility, soil structure interaction*

## 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. 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

## II. 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 on frames considering different types of soil.
3. To study the effect of soil structure interaction on frames with shears walls..

## III. 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. Shear walls in the frames.
4. Analysis by using STAAD-PRO 2008

## IV. 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.

## V. IDEALIZATION OF STRUCTURE

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. 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 10 storey building frame with infill wall modeled as 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.

3 bay x 3 bay building frames with 10 storeys 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 bays x 3 bay building is taken as 6 m for central bay and 6 mt for the two side bays. For all the buildings the dimensions of reinforced concrete column are taken as 600x600 mm and for beam it is 200x600 mm. Similarly thickness for roof and floor is taken as 150mm and their corresponding dead load is directly applied on the beam. The brick infill with thickness 150 mm. 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.

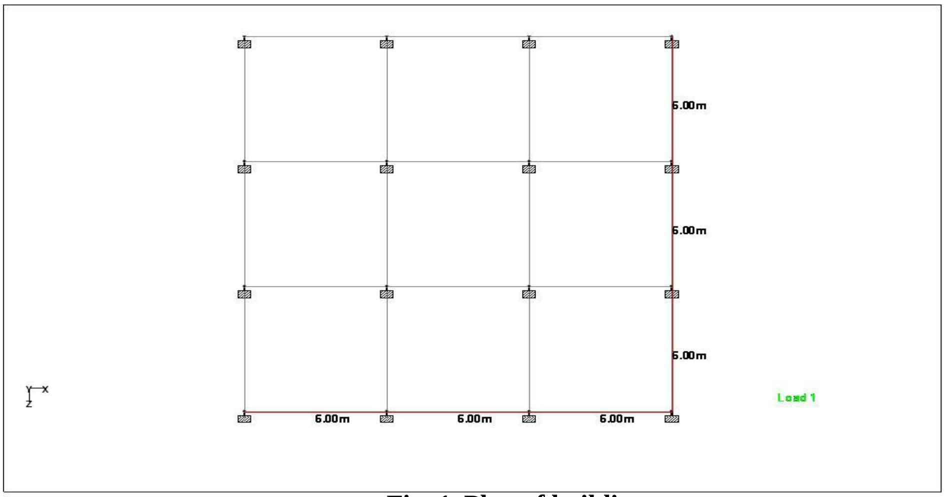


**Fig. 1. Plan of building**

## VI. IDEALIZATION OF SOIL

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.

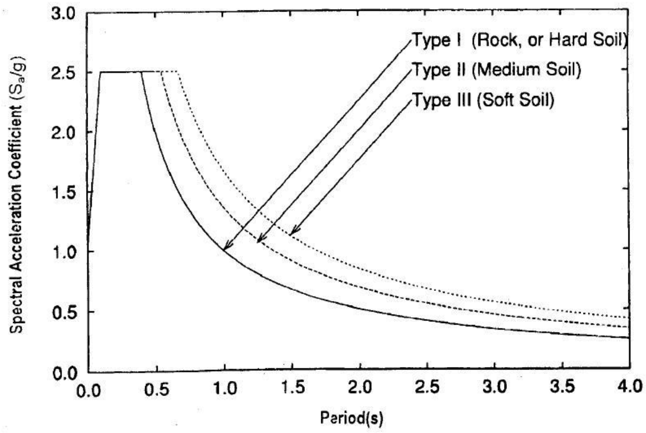


**Fig. 2** Response spectra for rock and soil sites for 5% damping (IS1893 Fig. 2)

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. Hence to make the analysis most 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

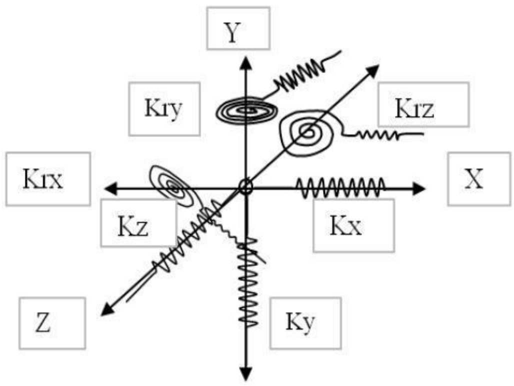


Fig. 3 Idealization arrangement at a typical column square foundation strip and equivalent soil spring junction

**Table 1**. Spring stiffness for square footing along various degrees of freedom

| **Degrees of freedom** | **Stiffness of equivalent soil spring** |
|---|---|
| Vertical Ky | 4.54Gb/(1-µ ) |
| Horizontal (lateral direction) Kx | 9Gb/(2-µ ) |
| Horizontal (longitudinal direction) Kz | 9Gb/(2-µ ) |
| Rocking (about the longitudinal) Krx | 0.45Gb3/(1-µ) |
| Rocking (about the lateral) Krz | 0.45Gb3/(1-µ) |

| | |
|---|---|
| Torsion Kry | 8.3Gb3 |

Note: „b‟ is half width of a square foundation

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,

$$G=120\ N^{0.8}\ t/ft2 \quad (1)$$

$$G=12666\ N^{0.8}\ KN/m2 \quad (2)$$

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 STAAD PRO 2008. All isolated footings are assumed to be square in shape.

**Table 2.** Types of soil and their parameters

| Sr. No. | Type of soil | N value | Shear Modulus in KN/m2 |
|---|---|---|---|
| 1. | Soft | 3 | 30502.57 |
| 2. | Medium | 6 | 53018.07 |
| 3. | Hard | 30 | 192458.23 |

## VII. RESULTS OF ANALYSIS

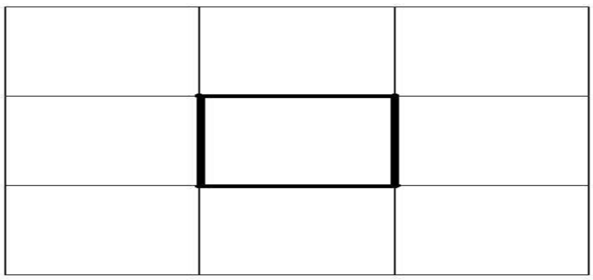

Fig. 4. Frame considering for soft soil (Structure B)

**Table 3 Analysis results for soft soil (Structure B)**

| Case No. | Storey | Max Reaction in KN | Max.Displacement of top storey In mm | Frequency In Cyc/sec. | Period In Sec. | Base shear in KN |
|---|---|---|---|---|---|---|
| Without SSI | G+10 | 6269 | 54 | 0.530 | 1.8 | 302 |
| | | | | 0.530 | 1.8 | |
| | | | | 0.690 | 1.4 | |
| | | | | 0.608 | 1.4 | |
| With SSI | G+10 | 5000 | 94 | 0.443 | 2.2 | 266 |
| | | | | 0.443 | 2.2 | |
| | | | | 0.640 | 1.5 | |

**Table No. 4** Summary of displacement and base shear for Soft Soil (Without SSI)

| CASE | Structure B | | Structure C | | Structure D | | Structure E | |
|---|---|---|---|---|---|---|---|---|
| | Max. Displ.mm | Base shear kN | Max. Displ.mm | Base shear kN | Max. Displ.mm | Base shear kN | Max. Displ.mm | Base shear kN |
| Infill wall without considering itsstiffness | 54 | 302 | 55 | 309 | 62 | 335 | 72 | 301 |
| Infill wall considering its stiffness | 43 | 423 | 51 | 356 | - | - | - | - |
| Shear wall considering its stiffness | 40 | 436 | 50 | 375 | 55 | 356 | 42 | 404 |

**Table No. 5** Summary of displacement and base shear for Soft Soil (Wit SSI)

| CASE | Structure B | | Structure C | | Structure D | | Structure E | |
|---|---|---|---|---|---|---|---|---|
| | Max. Displ.mm | Base Shear kN | Max. Displ.mm | Base Shear kN | Max. Displ.mm | Base Shear kN | Max. Displ.mm | Base Shear kN |
| Infill wall without considering itsstiffness | 94 | 266 | 83 | 268 | 108 | 289 | 103 | 261 |
| Infill wall considering its stiffness | 76 | 323 | 82 | 306 | - | - | - | - |
| Shear wall considering its stiffness | 74 | 291 | 76 | 296 | 83 | 296 | 79 | 304 |

**Table No.6.** Summary of periods and frequency for Soft Soil (Without SSI)

| CASE | Structure B | | Structure C | | Structure D | | Structure E | |
|---|---|---|---|---|---|---|---|---|
| | Period sec | Freq. cyc/sec | Period sec | Freq. cyc/sec | Period sec | Freq. cyc/sec | Period sec | Freq. cyc/sec |
| Infill wall without considering its stiffness | 0.53<br>0.53<br>0.69 | 1.8<br>1.8<br>1.4 | 0.44<br>0.44<br>0.52 | 2.2<br>2.2<br>1.9 | 0.54<br>0.54<br>0.77 | 1.9<br>1.9<br>1.4 | 0.45<br>0.45<br>0.55 | 2.1<br>2.1<br>1.8 |
| Infill wall considering | 0.62<br>0.63 | 1.59<br>1.57 | 0.57<br>0.57 | 1.7<br>1.7 | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| its stiffness | 0.63 | 1.57 | 0.87 | 1.4 | | | | |
| Shear wall considering its stiffness | 0.75<br>0.84<br>0.84 | 1.3<br>1.1<br>1.1 | 0.57<br>0.57<br>0.87 | 1.7<br>1.7<br>1.4 | 0.57<br>0.57<br>0.87 | 1.7<br>1.7<br>1.4 | 0.65<br>0.65<br>0.80 | 1.5<br>1.5<br>1.2 |

**Table No.7.** Summary of periods and frequency for Soft Soil (Wit SSI)

| CASE | Structure B | | Structure C | | Structure D | | Structure E | |
|---|---|---|---|---|---|---|---|---|
| | **Period sec** | **Freq. cyc/sec** | **Period sec** | **Freq. cyc/sec** | **Period sec** | **Freq. cyc/sec** | **Period sec** | **Freq. cyc/sec** |
| Infill wall without considering its stiffness | 0.44<br>0.44<br>0.64 | 2.2<br>2.2<br>1.5 | 0.37<br>0.37<br>0.48 | 2.7<br>2.7<br>2.2 | 0.40<br>0.40<br>0.60 | 2.3<br>2.3<br>1.5 | 0.37<br>0.37<br>0.50 | 2.6<br>2.6<br>1.9 |
| Infill wall considering its stiffness | 0.44<br>0.44<br>0.57 | 2.2<br>2.2<br>1.7 | 0.42<br>0.42<br>0.88 | 2.3<br>2.3<br>1.4 | - | - | - | - |
| Shear wall considering its stiffness | 0.43<br>0.40<br>0.53 | 2.4<br>2.4<br>1.8 | 0.40<br>0.40<br>0.60 | 2.3<br>2.3<br>1.5 | 0.42<br>0.42<br>0.60 | 2.3<br>2.3<br>1.8 | 0.45<br>0.45<br>0.66 | 2.2<br>2.2<br>1.4 |

## CONCLUSIONS

1. The study shows that consideration of different parameter such as soil structure interaction, types of soil, stiffness of infill walls, and location of walls influences time period, displacement and base shear of building frame considerably. Hence it is important to consider to all these parameters in the analysis of structures.
2. Shear walls located in the central part of the multistoried building gives lesser displacement and more base shear compared to other locations.

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