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# Effect of Soil Structure Interaction on Seismic Analysis of Structure

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***Abstract :*** *The supporting soil influences the behaviour of the structure due to its ability to deform. The fixed support neglects all these deformations. The response of the structure with flexible foundation has been done in this study.The difference in behaviour between fixed and flexible support structure if not taken into account could lead to inaccuracy in assessing the structural safety. Multistoried buildings with isolated footing resting on medium and stiff soil is considered. Response spectrum analysis is done to consider the seismic forces. The analysis of the buildings is carried out in SAP 2000. All the soil parameters required which defines the classification of soil has been together computed from IS 1893(II) and FEMA- 356(2000). The soil considered has been modelled by equivalent springs in all six degrees of freedom. This process is simpler than the direct method and should be effectively used with known soil properties to consider the SSI effects. The influence of different soil conditions, number of stories, type of footing has been taken to observe the change in the structural behaviour of the structure. It was observed that the time period and lateral deflection of building was increased from fixed to both flexible support . There was marginal changein the base shear and mode shape of the structure. The response of the structure obtained using both square and rectangular footing is same. A constant trend was observed in percentage change of time period with increasing number of stories.*

## 1. INTRODUCTION

Common practice of analysis and design of buildings is to assume the base of building to be conventionally fixed, whereas in reality supporting soil influences the structural response by allowing movement due to its natural ability to deform. Failure of the structures in past earthquakes with neglecting the effect of soil showed the importance of considering soil-structure interaction in the seismic analysis of structures. The seismic response of structures due to the effect of soil flexibility depends on both the soil property and structural property. The overall stiffness of the structural system is decreased and hence, may increase the natural period of the system. The extent of fixity offered by soil at the base of the structure depends on the load transferred fromthe structure to the soil as the same decides the type and size of foundation to be provided. Such an interdependent behaviour between soil and structure regulating the overall response is referred to as soil structure interaction.

In reality the structure and the foundation have mass and when there is acceleration acting on mass inertial forces will be developed. This inertial force will try to move the soil underneath the structure and when the soil is compliant the forces transmitted to it by the foundation will produce foundation movement i.e. displacement and rotation at the soil foundation interface.Secondly, with the seismic wave propagation,scattering, diffraction, reflection and refraction of the seismic waves at the soil foundation interface takes place, changing the nature of ground motion at that point. These effects are known as kinematic interaction effects.

There are two methods of implementing soil structure interaction. First is the direct method in which the soil, structure and foundation is represented as a continuum and modelled together using finite element method. The ground motion is specified as free field motion and is applied at all boundaries. Second method is the substructure method in which soil material properties are used for incorporation of springs to represent the stiffness at the soil foundation interface. Sub-structure method is computationally more efficient than the direct method as most of the disadvantages of thedirect method can be removed, if the substructure method is employed.

## 2. LITERATURE REVIEW

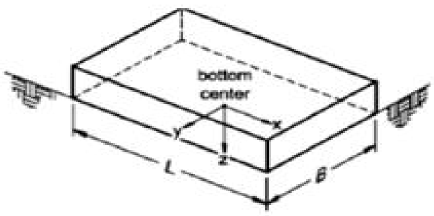
Some important study of soil structure interaction includes: Tabatabaiefar et al.focussed on the effect of flexibility of the foundation support and various design parameters affected by it. The soil modelling was done by 2D plane strain grid element with viscous boundaries as per the direct method. A ten storey frame resting on shallow foundation with three different soils were taken. The ratios of the base shear of the flexible-base to the fixed-base in all models are less than 1 in both elastic and inelastic cases for all the earthquake considered. Comparing interstorey drifts, hard soil did not differ much to fixed model. But, the interstory drifts of the flexible-base model resting on medium and soft changed drastically. The natural period increased from fixed to flexible model indicating the displacements tends to increase Dutta, S. C., et al.(2003)did a detailed investigation on lateral natural period, seismic base shear and fundamental torsional to lateral period ratio considering SSI on frames on raft foundation.The stiffnesses of equivalent soil spring decrease with decrease in shear modulus and increase with sizes of foundation. Withtwo contradictory effects, the spring stiffness maximizes in case of medium clay. They carried the work on modified lateral stiffness to get same base shear with fixed based condition as obtained by SSI effects.Liu.,et al. (2012) used the pushover method for the nonlinear seismic analysis of soil-structure interaction (SSI) system. They found out that the structural period, damping and vibration, mode shapes of the soil-structure interaction system are quite different to that of fixed support.Four different soils based on shear wave velocity has been classified. It was found that in nonlinear stage, SSI can decrease the capacity curves. The softer the foundation soil is, the more the curves get reduced. SSI can increase structural displacement and inter-story drift of bottom floor.

## 3. PRESENT STUDY

In the work presented in this paper the incorporation of the soil foundation stiffness has been done for the buildings resting on the shallow foundation. The movement of the foundation is considered in two perpendicular horizontal directions, one vertical direction and the rotations of the same about these three directions. For the building with isolated footing, three translational springs along three directions and three rotational springs about those mutually perpendicular axes are put together to simulate the effect of soil flexibility, as suggested in well accepted literature (Gazetas) as shown in table 1and table 2. It has been observed that the stiffness of the spring are dependent on the frequency of the forcing function though stiffness properties are frequency independent. This frequency dependence is incorporated by multiplying theequivalent spring stiffness by a frequency dependent factor. However some studies suggest that this stiffness can be considered as frequency independent with good results. Hence the effect of such multiplication factor is not, in general, considered in studies.

Table 1. Stiffness of foundation at surface

| Degrees Of Freedom | Stiffness of foundation at Surface |
|---|---|
| Translational along x - axis | $K_x = \frac{GB}{2-\mu}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 1.2\right]$ |
| Translational along y - axis | $K_y = \frac{GB}{2-\mu}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 0.4\frac{L}{B} + 0.8\right]$ |
| Translational along z - axis | $K_z = \frac{GB}{1-\mu}\left[1.55\left(\frac{L}{B}\right)^{0.75} + 0.8\right]$ |
| Rocking about x - axis | $K_{xx} = \frac{GB^3}{1-\mu}\left[0.4\left(\frac{L}{B}\right) + 0.1\right]$ |
| Rocking about x - axis | $K_{yy} = \frac{GB^3}{1-\mu}\left[0.47\left(\frac{L}{B}\right)^{2.4} + 0.034\right]$ |
| Rocking about x - axis | $K_{zz} = GB^3\left[0.53\left(\frac{L}{B}\right)^{2.45} + 0.51\right]$ |




Orient axis L ≥ B.

fig.1. Orientation of the footing

The above stiffness is at only surface level. These stiffness are to be modified by the correction factor for embedment depth as shown in table 2

Table 2 : Correction factor

| Degrees Of Freedom | Correction Factor for Embedment |
|---|---|
| Along x - axis | $\beta_x = \left(1 + 0.21\sqrt{\frac{D}{B}}\right).\left[1 + 1.6\left(\frac{hd(B+L)}{BL^2}\right)^{0.4}\right]$ |

| | |
|---|---|
| Along y - axis | $\beta_y = \left(1 + 0.21\sqrt{\frac{D}{B}}\right) . \left[1 + 1.6\left(\frac{hd(B+L)}{BL^2}\right)^{0.4}\right]$ |
| Along z - axis | $\beta_z = \left[1 + \frac{1}{21}\frac{D}{B}\left(2 + 2.6\frac{B}{L}\right)\right] . \left[1 + 0.32\left(\frac{d(B+L)}{BL}\right)^{2/3}\right]$ |
| Rocking about x - axis | $\beta_{xx} = 1{+}2.5\frac{d}{B}\left[1 + \frac{2d}{B}\left(\frac{d}{D}\right)^{-0.2}\sqrt{\frac{B}{L}}\right]$ |
| Rocking about x - axis | $\beta_{yy} = 1{+}1.4\left(\frac{d}{L}\right)^{0.6}\left[1.5 + 3.7\left(\frac{d}{L}\right)^{1.9}\left(\frac{d}{D}\right)^{-0.6}\right]$ |
| Rocking about x - axis | $\beta_{zz} = 1{+}2.6\left(1 + \frac{B}{L}\right)\left(\frac{d}{B}\right)^{0.9}$ |

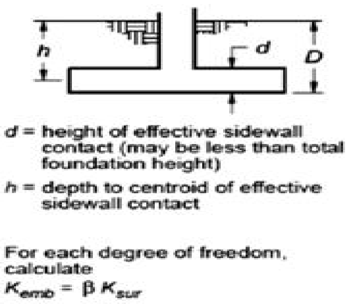



fig. 2. Correction embedment

## 4. STRUCTURE IDEALISATION AND BUILDING DATA

Multistoried building frame with fixed and flexible base subjected to seismic force were analysed under different soil conditions like stiff, medium and compared the responses.The building is first analysed for all the load combinations as per IS 1893 (I) : 2002 and the percentage of rebar is kept in between 2% - 2.5%.

Table 3 : Building Data

| |
|---|
| Type of structure : RCC Multi storied frame |
| Seismic zone : V |
| Response reduction factor : 3 |
| Importance factor : 1 |
| Number of storeys : 6,7,8,9,10,11 |
| Height of each floor : 4m |
| Height of first floor : 5.5m |
| Imposed load on floors : 4 kN/m$^2$ |
| Live Roof : 1.5 kN/m$^2$ |
| Floor Finish on all floors : 1 kN/m$^2$ |
| Materials : M25, Fe415(Beam, Column) |
| Depth of the slab : 150mm |
| Unit weight of RCC : 25kN/m$^3$ |
| Type of soil : Medium Soil (N=18, N=14) |
| Response spectra : IS 1893(I) 2002 |
| Depth of foundation : 1.5m |

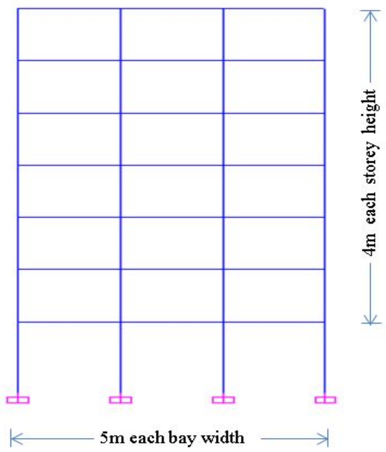



fig. 3.Elevation of the seven storeyed building

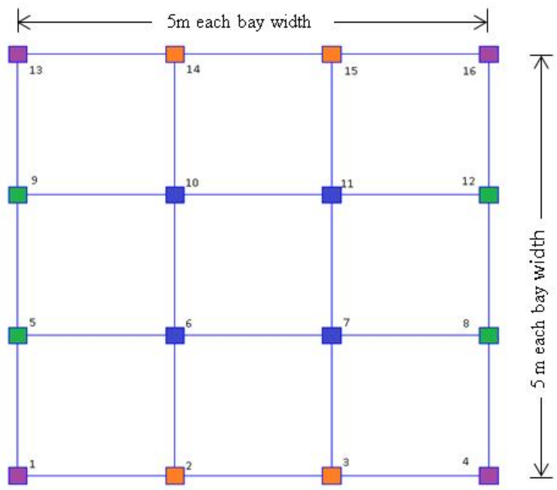



fig. 4. Plan of Seven Storeyed building

Table 4 : Section size

| Group | Column no. | Section size for 7 Storeyed building |
|---|---|---|
| I | 1,4,13,16 | 0.38m X 0.38m |
| II | 2,3,14,15 | 0.36m X 0.48m |
| III | 5,8,9,12 | 0.36m X 0.48m |
| IV | 6,710,11 | 0.46m X 0.46m |
| Beam Size | | 0.3m X 0.41m |

## 5. IDEALISATION AND MODELLING OF SOIL

In the present work the fixed support has been replaced by the soil stiffness as per Gazetas equations. Six different stories of building have been taken to observe the change in the responses of the structure. The calculation for the parameters of the soil were obtained from FEMA 356. As per the guidelines available, the different type of soils were classified by various parameters such as shear wave velocity, (N) no. of blows to be applied in STP., density, shear modulus.

The shear modulus of soil depending upon shear velocity and mass density is expressed as

$$G = \rho v^2$$

where G : N/m$^2$ , $\rho$: Kg/m$^3$ and $v$ : m/s.

Table 5 :Clasiification of soil

| Type of soil | Medium(N=18) | Medium(N=14) |
|---|---|---|
| **Notation** | N18 | N14 |
| **Shear wave velocity (m/s)** | 210 | 180 |
| **Mass density (Kg/m$^3$)** | 1900 | 1850 |
| **Shear modulus(MPa)** | 84 | 60 |
| **Poisson ratio(μ)** | 0.39 | 0.39 |
| **N** | 18 | 14 |

The notations for the two soils is only for this study. For the medium soil with N=14, the footing is designed for safe bearing capacity of 200kN/m$^2$. Here square footing is used, so L = B in every case. For soil with N=18, the SBC of soil is increased.

All the calculated parameters for only seven storeyed building are presented here for proper understanding.Same procedure is to be applied for other buildings.

Table 6: Footing dimensions

| Column no. | Square Footing size (m$^2$) | Depth of footing (mm) | Governing Load Combination |
|---|---|---|---|
| 1,4,13,16 | 1.85m x 1.85m | 350 | 1.2(DL+LL±EL) |
| 2,3,14,15 | 2.4m x 2.4m | 430 | 1.5(DL+LL) |
| 5,8,9,12 | 2.4m x 2.4m | 430 | 1.5(DL+LL) |
| 6,7,10,11 | 3.2m x 3.2m | 580 | 1.5(DL+LL) |

The length and depth of footing is obtained after analysis with all the load combinations. Whenearthqaukeload combination is considered, the safe bearing capacity of soil for isolated footing is increased by 20%.

The translational stiffness in all the three directions and rotational stiffness in all these three directions as per Gazetas with the embedded correction factors for embedded stiffness at the depth of foundation for seven storeyed building is shown in table 7.

Table 7 : Soil Stiffness

| Direction | Embedded Soil Stiffness(kN/m) | |
|---|---|---|
| | Medium(N18) | Medium(N14) |
| $K_Z$ x $10^3$ | 942 | 697 |
| $K_X$ x $10^3$ | 1182 | 866 |
| $K_Y$ x $10^3$ | 1182 | 866 |
| $K_{XX}$ x $10^3$ | 1321 | 1048 |
| $K_{YY}$ x $10^3$ | 1540 | 1227 |
| $K_{ZZ}$ x $10^3$ | 2354 | 1874 |

The above values are shown only for soil foundation stiffness below columns under group II. The soil foundation embedded stiffness for all other groups is calculated in similar manner using the footing geometry and soil properties. The first mode is only coming to be effective. So, the results are shown only for the first mode.

Table 8 : Time Period comparision

| Fixed Support | Along X - Direction | |
|---|---|---|
| | N18 soil | N14 soil |
| $t_1$= 1.911 sec | $t_1$= 1.926 sec | $t_1$= 1.9318 sec |
| $\phi_1 = \begin{Bmatrix} 1 \\ 1.78 \\ 2.49 \\ 3.09 \\ 3.56 \\ 3.88 \\ 4.05 \end{Bmatrix}$ | $\phi_1 = \begin{Bmatrix} 1 \\ 1.77 \\ 2.46 \\ 3.05 \\ 3.52 \\ 3.84 \\ 4.01 \end{Bmatrix}$ | $\phi_1 = \begin{Bmatrix} 1 \\ 1.77 \\ 2.46 \\ 3.05 \\ 3.52 \\ 3.84 \\ 4.01 \end{Bmatrix}$ |

Table 9 : Building Forces comparision

| Load Combination | 1.5(DL+EL) | | 1.2(DL+LL+EL) | |
|---|---|---|---|---|
| Forces | Base Shear (kN) | Lateral Deflection (mm) | Base Shear (kN) | Lateral Deflection (mm) |
| Fixed Support | 871 | 74.7 | 697 | 59.8 |
| Medium N18 Soil | 865 | 75.4 | 690 | 60.3 |
| Medium N14 Soil | 860 | 75.6 | 680 | 60.5 |

The above results and table are presented for seven storeyed building only. In the same manner, all the parameters calculated and obtained is calculated for the remaining buildings (6,8,9,10,11-storied building).

The results for remaining buildings is presented in the form of charts.

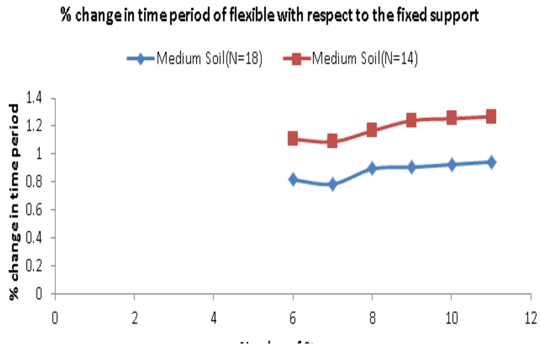



fig. 5. Percentage time period change variation

From the above chart of fig, 5.with the buildings which have been considered, it can be observed that the percentage change in time period is maximum for medium soil(N14) and minimum for the soil with (N=18). Further it can be observed that for both the type of soil the percentage change for the time period is coming out to be constant with the increase in the number of storeys.

In fig. 6 it can be observed the percentage change in lateral deflection for load case 1.5(DL+EL) is maximum for medium soil(N14). As the no. of storeys are increased for the building on both the type of soil, the trend observed for both the soil is not specific except for increasing nature.

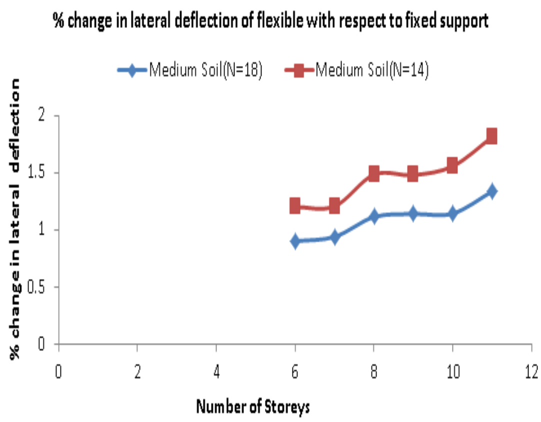



fig. 6. Percentage change lateral deflection variation

## 6. CONCLUSION

It has been observed that the time period is changed for different soil conditions or foundation flexibility and base shear is decreased from fixed to flexible foundation. The axial force is found to increase from fixed to flexible foundation and the column end moment is uncertain on increasing or decreasing nature. The response of the structure may vary from structure to structure.

The above results are for square footing, when the type of footing was taken as rectangular footing, there was no change or negligible change in the results.

In this work, the building is designed to keep rebar percentage in the range 2% - 2.5%. But it was also studied that if same column size is used for all the possible storeys of building keeping it in structural safety, then the percentage change in the time period is obtained in the reducing nature, i.e. the effect ofsoil structure interaction is reduced with increasing no. of stories.

With the buildings considered in this study, it has been observed that the percentage change in time period is maximum for medium soil(N14) and minimum for the soil with (N=18). Further it can be observed that for both the type of soil the percentage change for the time period is coming out to be constant with the increase in the no. of storeys. The percentage change in lateral deflection for load case 1.5(DL+EL) is maximum for medium soil(N14). As the no. of storeys are increased for the building on both the type of soil, the trend observed for both the soil is not specific except for increasing nature.

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