# Combined Effect of Soil Structure Interaction and Infill Wall Stiffness on Building_- A Review

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**Abstract--The present study makes an attempt to show the effect of flexibility and rigidity of foundation in earthquake analysis of structure by the considering the combined effect of soil structure interaction and infill wall stiffness of building. For superstructure G+3 simple rectangular building is considered for seismic analysis. The infill wall is replaced by equivalent diagonal member. The total work is divided into two parts. In first part the manual analysis is done in X direction and in second part the analysis is done with ANSYS software. The more emphasis has given on manual earthquake analysis by using model superposition response method as per IS 1893-2002 (part-II) the stiffness of soil is calculated by the formulae as per the FEMA 356. After studying this behavior it is found that base shear decreases in seismic analysis of superstructure by considering the effect of soil structure interaction in X direction.**

***Keywords: soil structure interaction, infill wall, base shear, soil stiffness***



## 1. INTRODUCTION

The soil response analyses is one of the most important aspects of earthquake engineering, as it will determine the ground motion that will be experienced at the top of soil without the presence of a structure or the so-called free field response. The analysis involves estimation of the seismologic characteristics of the region, and determination and modeling of the soil profile and its dynamic characteristics. Further, it accounts for the multiple reflections and refractions that will occur at the soil layer interfaces as the seismic waves propagate though the soil deposits. Although special purpose computer programs exist for this purpose, the validity of the results depend greatly on how accurate dynamic soil properties are estimated, which in spite the improvements in the in situ testing, is still a challenging task. In the present study, no soil amplification analysis was performed; rather, they considered accelerograms were used directly to excite the structure

The analysis of fundamental SSI effects is well established and some computer programs can be used for SSI analysis of even complicated models. It should also be pointed out that while the analysis of SSI effects has been focused mainly on the investigation in terms of deformation and force the SSI effects may have a significant influence on the structural performance, the performance-based design procedures currently in use are still inadequate to account for these effects on the inelastic structural response. A number of damage models have been developed for evaluation of the structural performance,but usually assuming the structure as rigidly supported.

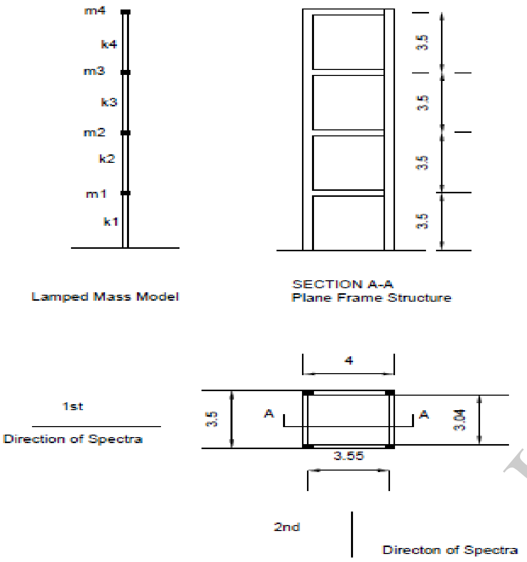
## 2. NOTATION

| | |
|---|---|
| B | Damping coefficient |
| D | Depth of foundation |
| d | Depth of footing at outer edge |
| E | Modulus of Elasticity of soil |
| F | Force in an energy dissipation unit |
| G | Shear modulus |
| g | Acceleration due to gravity |
| H | Average story height |
| I | Moment of Inertia |
| K | Soil spring stiffness, stiffness matrix |
| Kh | Spring constants for horizontal cases |
| ku | Linear soil spring stiffness |
| L | Length of footing |
| m | Mass of oscillating body |
| N | Number of layers |
| P | Force |
| U | Total acceleration |
| u | Independence function |
| $\theta$ | Independence function |
| U1 | Acceleration due to kinematic interaction |
| u1 | Linear displacement |
| U2 | Acceleration due to dynamic interaction |
| uf | Free translation relative to ground motion |
| y1 | Model linear displacement |
| yg | Ground acceleration |
| $\mu$ | Coefficient of friction |
| $\gamma$ | Poissions ratio of soil |
| $\rho$ | Mass density |
| f | frequency |

| | |
|---|---|
| T | Fundamental natural period |
| Ø | Mode shape |
| pk | Modal participation factor |
| mk | Modal mass |
| Qlk | Design lateral force |
| kx,sur | Translation stiffness along x- axis (foundation at surface) |
| ky,sur | Translation stiffness along y- axis (foundation at surface) |
| kz,sur | Translation stiffness along z- axis (foundation at surface) |
| kxx | Rocking stiffness along x- axis (foundation at surface) |
| kyy | Rocking stiffness along y- axis (foundation at surface) |
| kzz | Rocking stiffness along z- axis |

## 3. MATHEMATICAL FORMULATION(MANUALLY)

For the mathematical calculation of base shear of building as shown in fig




By using response spectrum method as per IS 1893-2002 part-II

Step-I Calculation of lumped masses to various floor levels roof /floor = mass of infill + mass of column +mass of beam in longitudinal and transverse direction of that floor + mass of slab + imposed load on that floor if permissible

** 50% of Imposed load, if imposed load is greater than 3 kN/m2

Step- II : Frame considering the stiffness of infill

The frame considered in previous section is again analyed by considering the stiffness of infill walls. The is modelled as equivalent diagonal strut.

The mass matrix [M] for lumped plane frame model is

$$M = \begin{bmatrix} M1 & 0 & 0 & 0 \\ 0 & M2 & 0 & 0 \\ 0 & 0 & M3 & 0 \\ 0 & 0 & 0 & M4 \end{bmatrix}$$

Column stiffness of storey

$$k = \frac{12EI}{L^3}$$

Stiffness of infill is determined by modeling the infill as an equivalent diagonal strut in which, width of strut ,

$$W = \frac{1}{2}\sqrt{\alpha_h^2 + \alpha_l^2}$$

$$\alpha_h = \frac{\pi}{2}\left[\frac{E_f I_c h}{2E_m t \sin 2\theta}\right]^{\frac{1}{4}}$$

$$\alpha_l = \pi\left[\frac{E_f I_b l}{E_m t \sin 2\theta}\right]^{\frac{1}{4}} \qquad \theta = \tan^{-1}\frac{h}{l}$$

Where,

$E_f$ =elastic modulus of frame material N/m$^2$

$E_m$ =elastic modulus of frame material N/m$^2$

t = thickness of infill wall mm

h = height of infill wall m

l = length of infill wall

$I_c$ = moment of inertia of column

$I_b$ = moment of inertia of beam m$^4$

$$\text{Stiffness of infill is } = \frac{AE_m}{l_d}(\cos\theta)^2$$

For the frame with two bays there are two struts participating in each direction total lateral stiffness of each storey

Stiffness matix [k]=

$$K = \begin{bmatrix} k_1 + k_2 & -k_2 & 0 & 0 \\ -k_2 & k_2 + k_3 & -k_3 & 0 \\ 0 & -k_3 & k_3 + k_4 & -k_4 \\ 0 & 0 & -k_4 & k_4 \end{bmatrix}$$

For the above stiffness and mass matrix, eigen values and Eigen vectors are work out as follows

$$|K - \omega^2 m|_{=0}$$

$$k/m = \omega_n^2$$

the mode shapes corresponding to each natural frequency is determined from the equation

$$\begin{bmatrix} 2K-\omega^2 m & -k_2 & 0 & 0 \\ -k_2 & 2K-\omega^2 m & -k_3 & 0 \\ 0 & -k_3 & 2K-\omega^2 m & -k_4 \\ 0 & 0 & -k_4 & K-\omega^2 0.575m \end{bmatrix} \begin{Bmatrix} \emptyset_1 \\ \emptyset_2 \\ \emptyset_3 \\ \emptyset_4 \end{Bmatrix} = 0$$

Step –III Mode Shapes

Eigen vectors (mode shapes):

$$\{\emptyset\} = \{\emptyset_1 \quad \emptyset_2 \quad \emptyset_3 \quad \emptyset_4\}$$

Step –IV Determination of modal participation factor

The modal participation factor

$$P_k = \frac{\sum_{i=1}^{n} \omega_i \O_{ik}}{\sum_{i=1}^{n} \omega_i \O_{ik}^2}$$

Step –V Determination of modal mass

$$m_k = \frac{\left(\sum_{i=1}^{n} \omega_i \O_{ik}\right)^2}{g\left(\sum_{i=1}^{n} \omega_i \O_{ik}^2\right)}$$

Where

G= acceleration due to gravity

$\O_{ik}$ = mode shape coefficient at floor ith

$$m_1 = \frac{\left(g \sum_{i=1}^{4} \omega_1 \O_{i1}\right)^2}{g\left(\sum_{i=1}^{n} \omega_1 \O_{i1}^2\right)}$$

Step –VI Determination of lateral forces at each floor at each mode

The design lateral force is given by($Q_{ik}$) at floor i in mode $Qik = A_k \O_{ik} p_k W_i$

The design horizontal seismic coefficient $A_h$, for various mode are

$$Ahk = \frac{Z}{2}\frac{I}{R}\frac{S_{ak}}{g}$$

$$\frac{S_a}{g} = \begin{cases} 1 + 15\,T & 0.00 \le T \le 0.10 \\ 2.5 & 0.10 \le T \le 0.40 \\ 1.00/\,T & 0.40 \le T \le 4.00 \end{cases}$$

Step VII Determination of storey shear forces in each mode

$$V_{ik} = \sum_{i=i+1}^{n} Qik$$

Step VIII Determination of storey shear forces due to all modes

$V_1=[(V_{11})^2+(V_{12})^2+(V_{13})^2+(V_{14})^2]^{0.5}$

Step IX Determination of lateral forces at each storey

Final base shear at each floor

$F_4$ at roof floor

$F_3$ at third floor = $V_3$- $V_4$

$F_2$ at second floor = $V_2$- $V_3$

$F_1$ at first floor = $V_1$- $V_2$

Total Base shear = $F_1$+ $F_2$ + $F_3$ + $F_4$

*3.1Calculation of soil parameters*

The stiffness is calculated by as per the guidelines of FEMA - 356 by considering the elastic parameters of soil dimensions of foundations the main elastic parameters is required is shear modulus which is calculated by

$$G = \frac{E}{2(1+\gamma)}$$

Where E= modulus of elasticity kN/m2

For the group –I soil (soft clay, firm and stiff clay, silty sand and loose sand)

For the stiffness of soil the following formulae to be used from FEMA356

| Degree of freedom | Stiffness of the foundation at surface |
|---|---|
| Translation along x-axis | $Kx, sur = \frac{GB}{2-\upsilon}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 1.2\right]$ |
| Translation along y-axis | $Ky, sur = \frac{GB}{2-\upsilon}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 0.4\frac{L}{B} + 0.8\right]$ |
| Translation along z-axis | $Kz, sur = \frac{GB}{1-\upsilon}\left[1.55\left(\frac{L}{B}\right)^{0.75} + 0.8\right]$ |
| Rocking along x-axis | $Kxx, sur = \frac{GB^3}{1-\upsilon}\left[0.4\left(\frac{L}{B}\right) + 0.1\right]$ |
| Rocking along y-axis | $Kyy, sur = \frac{GB^3}{1-\upsilon}\left[0.47\left(\frac{L}{B}\right)^{2.4} + 0.034\right]$ |
| Torsion about z-axis | $Kzz, sur = GB^3\left[0.53\left(\frac{L}{B}\right)^{2.45} + 0.51\right]$ |



*3.2 Formulation of Problems*

**Table 3.1 :** Constants which are considered for calculation

| Sr. No. | Constant | Values | Remarks |
|---|---|---|---|
| 1 | Z | 0.1 | Structure assumed in Zone II |
| 2 | I | 1.5 | Importance Factor |
| 3 | R | 3 | Response Reduction Factor |
| 4 | M-25 | | Grade of Concrete |
| 5 | Fe-500 | | Grade of Steel |

*3.3 Response Spectrum Analysis*

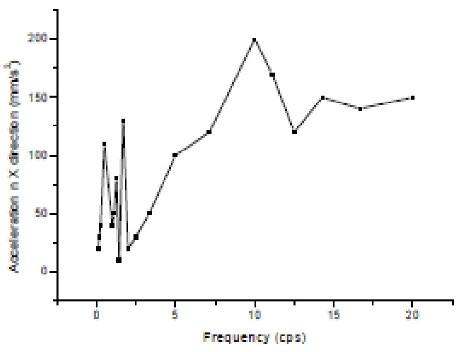


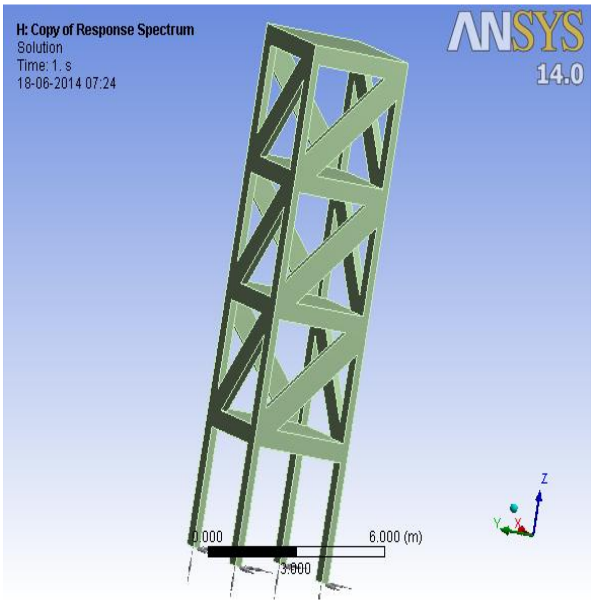

Figure. 2.4 Response Spectrum of Bhuj Earthquake (2001) in X direction[2]

4.ANALYSIS BY ANSYS

**Proposed building Models with SSI**

Model 1: building without SSI effect and infill wall.


Model 2: building with SSI effect and infill wall.




5. RESULTS & DISCUSSION

The study of effect of soil structure interaction with infill wall stiffness is more effective on base shear calculation of building Here one type of soil group is to be considered and along X direction is considered for analysis This study will be show decrease in the base shear by considering effect of SSI

6.FUTURE WORK

The further study shows that the effect of SSI will be the major parameter affecting the calculation of base shear calculation. The different model will considered with infill wall considerations for the analysis and conclusion will be made. High rise complicated geometrical building for rigorous analysis is going to be considered In present study only one type of soil strata is considered beneath the structure which is rarely possible, so the study has been prolonged for layered soil media. For this study only response spectrum method is considered, time history method can be used

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