

Seismic Evaluation of Multistorey Building Considering the Effect of Soil Structure Interaction

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Abstract

The effect of soil structure interaction is generally ignored in the seismic analysis of the multistory buildings. In most of the cases fixed base assumption is accepted which in general not accurate. Soil flexibility causes lengthening of the natural periods due to overall decrease in stiffness as the lateral stiffness of the building depends on the compressibility of the soil. This leads to a subsequent variation in the natural periods of the system which may considerably influence the seismic response of the building. Thus the effect of soil-structure interaction should be considered in buildings which are located in earthquake prone areas. Reinforced concrete frame buildings with unreinforced brick masonry infill walls are generally analyzed and designed as bare frames, without considering the strength and stiffness contributions of infills.

Keywords: *Soil structure interaction, Etabs, Brick masonry, nonlinear-pushover analysis, lateral displacement, Base shear, natural period.*

INTRODUCTION

Soil-Structure Interaction (SSI)

The interaction of a structure's base or foundation with the surrounding soil. When a structure, such as a building, bridge, dam, or tower, is constructed on or within the ground, it imparts loads onto the soil, and the soil, in turn, exerts reaction forces back onto the structure. The way the structure behaves and reacts can be greatly affected by this interaction between the

structure and the earth under various loading conditions, such as seismic events, dynamic forces from machinery, or environmental loads.

The relative interaction in-between the structure and soil involves two primary types: kinematic interaction and inertial interaction. Kinematic interaction refers to the relative movement in-between structure and soil surrounding, encompassing displacements and rotations of both structure and soil mass. It accounts for the deformation of the soil caused by the structural movement and its influence on the overall relative response of the system.

Experience from the past earthquakes has revealed that much loss of life and property, results due to inadequacy and faulty practices in seismic design of structures. The present work is the comparative research of behavior of building models subjected to soil structure interaction for different soil types also the attempt to understand the lateral load resistance behaviour of building with and without unreinforced brick masonry wall. The analysis has been carried out using ETABS software.

Masonry infill: Analysis of the building-structure damage from strong earthquake reveals many instances in the presence of masonry infill has advantageously affected the lateral resistance of reinforced-concrete multistoried structure. Although the infill panel significantly enhances both stiffness and strength of the frame, their contribution is not taken in to consideration because of the lack of knowledge of the composite behavior of the frame and infill. **Equivalent Diagonal Strut:** The study of the interaction of infill with frames has been investigated by employing sophisticated analyses like finite element analysis or theory of elasticity. But due to uncertainty in defining the interface conditions between the infill with the frames, an analysis method may be better acceptable. The most common approximations of infill walls in the basis of equivalent diagonal strut i.e. the system is modelled as a braced frame and infill walls as web element.

The geometric and material properties of the equivalent diagonal strut are required for conventional braced frame analysis to determine the increased stiffness of the infill- frame. The geometric properties of strut are of effective width and thickness of strut.

ELTA EFFECT: Any structure with elements subject to an axial load will experience the nonlinear phenomenon known as P-Delta.

METHODOLOGY

DESIGN PROCEDURE

In this study three, six and nine storeyed buildings are studied which are modelled for three different soil types namely soft, medium and stiff. The effect of unreinforced brick masonry infill walls are also studied for the same building. The gravity and seismic load combinations given in IS 1893 (Part 1): 2002 are considered. The present study also investigates the performance based seismic evaluation using the nonlinear pushover analysis method. Modeling and analysis are carried out in ETABS Nonlinear version software. The stiffness of equivalent soil springs are calculated as per ATC-40. The results are obtained in the form of natural period, lateral displacement and base shear and are compared.

Table No.1 Details of the Building

Structure	OMRF
No. of storey	G+2, G+5 and G+8
Storey Height - Ground storey	4.80 m
- Upper Storey	3.60 m
Type of building use	RCC
Type of building use	Official
Seismic Zone	III
Material Properties	
Young's modulus of Ms concrete, E	25.0x 10 ⁸ kN/m ²
Grade of concrete	M20
Grade of Steel	Fe415
Density of reinforced concrete	25 kN/m
Modulus of elasticity of brick masonry	2100 *10 ³ N/m
Density of brick masonry	20kN/m ³
Thickness of slab	0.120m
Member Properties	
Beam Size (3-Storey)	0.25 x 0.50 m
Column size (3-Storey)	0.25 x 0.50 m
Column size (3-Storey) for seismic Design	0.30x.75m
Column size (3-Storey) for gravity Design	0.25 x 0.50 m
Beam Size (6-Storey)	0.25 x 0.50 m
Column size (3-Storey) for seismic Design	0.375*0.60m
Column size (3-Storey) for gravity Design	0.45*0.75
Beam Size (9-Storey)	0.25 x 0.50 m
Column size (3-Storey) for seismic Design	0.45*0.75m
Column size (3-Storey) for gravity Design	0.45*0.90m
Thickness of Wall	0.25m

Assumed Dead Load Intensities	
Roof finishes	2kN/m ²
Floor Finishes	1kN/m ²
Live Load Intensities	
Roof	1.5 kN/m
Floor	3.0 kN/m
Earthquake LL on slab as per clause 7.3.1 and 7.3.2 of IS: 1893 -2002	
Roof	0
Floor	0.25 x 3.0 =0.75kN/m

Table No.2 Input data of all the building models for equivalent static analysis

Zone	III
Zone factor, Z (Table 2)	0.16
Importance factor, I (Table 6)	1.00
Response reduction factor, R (Table 7)	3.0
Damping ratio	5% (for RC framed

Natural Period Time:

As per IS 1893: -2002, clause: 7.6.1, the approximate fundamental natural period of vibration (T_a), in seconds, for moment-resisting frame building without and with brick infill panels are calculated using empirical equations as given below respectively.

$$T=0.075xh^{0.75} \text{ (For RC frame building without brick infill)}$$

$$T= 0.09xh / \sqrt{d}$$

h = height of building in meter and

d = base dimension of the building at plinth level, in meter along the considered direction of lateral load.

Equivalent Static Method: The design horizontal seismic coefficient and seismic weight of the structure are used to calculate the overall design lateral force or design base shear along any principal direction.

i) Determination of base shear (VB) of the building.

$$VB=A_h \times W$$

where, W= seismic weight of building

$A_h= Z-I-S_a / 2-R-g$ [any of the structure with $T \leq 0.1s$, the value of A_h will not be taken less than whatever be the value of (I/R)].

ii) Lateral distribution of design base shear: Using a parabolic distribution equation, the design base shear V_B is then distributed along the height of the building:

$$Q_i = V_B W_i * h_i^2 / \sum_{i=1}^n (W_i * h_i^2)$$

Q_i = lateral force Design at i^{th} floor

W_i = Seismic weight of i^{th} floor

H_i = Height of floor measured from base.

TARGET DISPLACEMENT: It is possible to determine the Target Displacement, or the maximum displacement the structure is anticipated to experience throughout the design event.

$$\Delta = C_1 C_2 C_3 C_4 S_a * (T_e^2 / 4\pi^2) * g \dots \dots \dots \text{Refer (ATC-440)}$$

MODELING AND ANALYSIS

Defining the slab sections: While defining the type of behaviour of wall and slab sections in the ETABS there are three options available, namely, shell type, membrane type, and plate type behaviour. Shell-type behaviour means that both in-plane membrane stiffness and out-of-plane plate bending stiffness are provided for the section. Membrane-type behaviour means that only in-plane membrane stiffness is provided for the section. Plate-type behaviour means that only out-of-plane plate bending stiffness is provided for the section.

The shear modulus G for a soil is related to the modulus of elasticity E and Poisson's ratio ν , by relation.

$$G = E / (2(1 + \nu))$$

Table 3 Soil Parameters Considered

Type of Clay	S.B.C of soil (kN/m ²)	Young's Modulus (kN/m ²)	Poisson's ratio	Shear Modulus (kN/m ²)
Soft	120	15000	0.45	5172.41
Medium	160	50000	0.45	17241.37
Stiff	250	200000	0.45	68965.51

The method for simulating and determining the stiffness of equivalent soil springs along the different degrees of freedom has been established by ATC-440.

The individual distributed stiffness intensities are calculated by dividing the uncoupled total embedded stiffness by the corresponding area of contact for translational stiffness parameters and by moment of inertia for rotational stiffness parameters, after which the surface stiffness factors are multiplied with stiffness of embedment factors to account for the effects of the depth of bearing. Individual distributed stiffness intensity values obtained above are multiplied with the relevant regions to generate the final stiffness with the proper units (kN/m for translational stiffness and KN/radian for rotational stiffness).

The formulae to obtain the stiffness of equivalent springs along many degrees of freedom are tabulated.

Table 4 Stiffness of equivalent soil springs along various degrees of freedom

Stiffness Parameter	Rigid Plate stiffness at Surface, K_i
Vertical Translation, K_i (kN/m)	$\frac{GL}{1-\nu} \left[0.73 + 1.54 \left(\frac{B}{L} \right)^{0.75} \right]$
Horizontal Translation, $K_{Y'}$, (kN/m) (towards long side)	$\frac{GL}{2-\nu} \left[2 + 2.5 \left(\frac{B}{L} \right)^{0.85} \right]$
Horizontal Translation, $K_{X'}$, (kN/m) (toward shorter side)	$\frac{GL}{2-\nu} \left[2 + 2.5 \left(\frac{B}{L} \right)^{0.85} \right] - \frac{GL}{0.75-\nu} \left[0.1 \left(1 - \frac{B}{L} \right) \right]$
Rotation, $K_{\theta x}$ (kN/radian) (about x axis)	$\frac{G}{1-\nu} I_x^{0.75} \left(\frac{L}{B} \right)^{0.25} \left(2.4 + 0.5 \frac{B}{L} \right)$
Rotation, $K_{\theta y}$ (kN/radian) (about y axis)	$\frac{G}{1-\nu} I_y^{0.75} \left[3 \left(\frac{L}{B} \right)^{0.15} \right]$

Table 5 Stiffness of equivalent soil springs along various degrees of freedom

Stiffness Parameter	Embedment Factors, η_i
Vertical Translation, η_z	$\left[1 + 0.095 \frac{D}{B} \left(1 + 1.3 \frac{B}{L} \right) \right] \left[1 + 0.2 \left(\frac{2L + 2B}{LB} d \right)^{0.67} \right]$
Horizontal Translational, η_y , (towards long side)	$\left[1 + 0.15 \left(\frac{2D}{B} \right)^{0.5} \right] \left\{ 1 + 0.52 \left[\frac{\left(D - \frac{d}{2} \right) 6(L + B)d}{BL^2} \right]^{0.4} \right\}$
Horizontal Translational, η_x (towards short side)	$\left[1 + 0.15 \left(\frac{2D}{L} \right)^{0.5} \right] \left\{ 1 + 0.52 \left[\frac{\left(D - \frac{d}{2} \right) 6(L + B)d}{LB^2} \right]^{0.4} \right\}$
Rotation, $\eta_{\theta x}$, (about X axis)	$1 + 2.52 \frac{d}{B} \left(1 + \frac{2d}{B} \left(\frac{d}{D} \right)^{-0.20} \left(\frac{B}{L} \right)^{0.50} \right)$
Rotational $\eta_{\theta y}$	$1 + 0.92 \left(\frac{2d}{L} \right)^{0.60} \left(1.5 + \left(\frac{2d}{L} \right)^{1.9} \left(\frac{d}{D} \right)^{-0.60} \right)$

Example Building Studied: Study reinforced concrete moment resisting frame building of three storied, six storied and nine storied are considered. The plan layout of all storied buildings with bare frame, with open first storey and unreinforced brick infill walls in the upper storey and for the retrofitted models for which unreinforced brick infill walls are provided only in the corners. The bottom storey height is kept 4.8m and a typical height of 3.6m is kept for all the other storeys in all the buildings. The building is deliberately kept symmetric in both the orthogonal directions in plan to avoid torsional response under pure lateral forces. The building is to be considered which is located in the seismic zone III and intended for office use.

Model I-Building is supported on the soft clay and has no walls in the first storey and one full brick masonry wall in the upper storeys and the building is modelled as bare frame; however, the masses of the walls are included.

Model II - Building is supported on the medium clay and has no walls in the first storey and one full brick masonry wall in the upper storeys and the building is modelled as bare frame; however, the masses of the walls are included. Model III-Building is supported on the stiff clay and has no walls in the first storey and one full brick masonry wall in the upper storeys, and the building is modelled as bare frame; however, the masses of the walls are included.

Model IV - Building is supported on the soft clay and has no walls in the first storey and one full brick masonry wall in the upper storeys; however, stiffness and masses of the walls are considered.

Model V-Building is supported on the stiff clay and has no walls in the first storey and one full brick masonry wall in the upper storeys, however stiffness and masses of the walls are considered.

Model VI - Building is supported on the medium stiff clay and has no walls in the first storey and one full brick masonry wall in the upper storeys; however, stiffness and masses of the walls are considered.

Model VII Building is supported on soft clay having one full brick masonry walls only in the corners of the first storey and one full brick masonry wall in the upper storeys; however, stiffness and masses of the walls are considered. Model VIII - Building is supported on medium stiff clay having one full brick masonry walls only in the corners of the first storey and one full brick masonry wall in the upper storeys; however, stiffness and masses of the walls are considered.

Model IX - Building is supported on stiff clay having one full brick masonry walls only in the corners of the first storey and one full brick masonry wall in the upper storeys; however, stiffness and masses of the walls are considered.

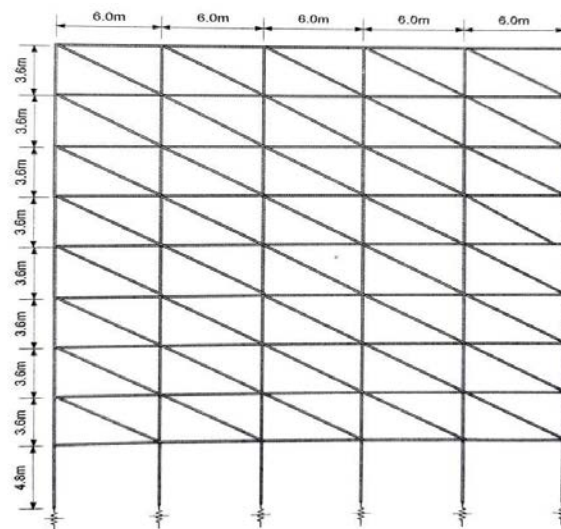


Fig 2: Elevation of the Nine storeyed building models with SEDS.

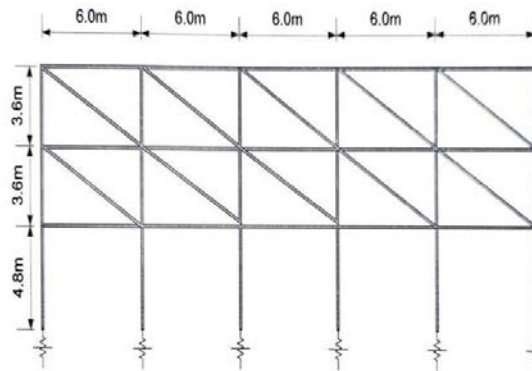


Fig 2: Elevation of the three storeyed building models with SEDS.

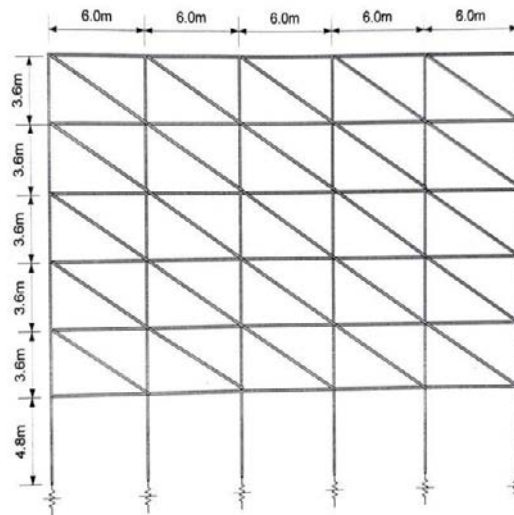


Fig 3: Elevation of the SIX storeyed building models with SEDS.

Table-6. Fundamental natural period for three storied building models.

Model Number	Fundamental natural Period in seconds			
	Gravity load combination		Seismic load combination	
	Codal	Analysis	Codal	Analysis
I	0.483	2.059	0.483	1.673
II	0.483	1.914	0.483	1.497
III	0.483	1.867	0.483	1.433
IV	0.197	1.778	0.197	1.416
V	0.197	1.613	0.197	1.219
VI	0.197	1.579	0.197	1.179
VII	0.197	0.899	0.197	0.842
VIII	0.197	0.780	0.197	0.730
IX	0.197	0.698	0.197	0.669

Table-7. Fundamental natural period for SIX storied building models.

Model Number	Fundamental natural Period in seconds			
	Gravity load combination		Seismic load combination	
	Codal	Analysis	Codal	Analysis
I	0.782	3.345	0.782	2.693
II	0.782	2.293	0.782	2.202
III	0.782	2.231	0.782	1.953
IV	0.374	2.329	0.374	1.898
V	0.374	1.358	0.374	1.264
VI	0.374	1.268	0.374	1.132
VII	0.374	1.588	0.374	1.510
VIII	0.374	0.602	0.374	0.589
IX	0.374	0.481	0.374	0.463

Table-8. Fundamental natural period for NINE storied building models.

Model Number	Fundamental natural Period in seconds			
	Gravity load combination		Seismic load combination	
	Codal	Analysis	Codal	Analysis
I	1.047	4.172	1.047	3.731
II	1.047	3.818	1.047	3.604
III	1.047	2.897	1.047	2.842
IV	0.552	3.190	0.552	2.385
V	0.552	2.425	0.552	1.957
VI	0.552	1.253	0.552	1.022
VII	0.552	2.365	0.552	1.965
VIII	0.552	1.795	0.552	1.308
IX	0.552	1.271	0.552	0.593

This are the fundamental natural periods for buildings resting on soft, medium and stiff soils are tabulated. Table 9 shows the percentage reduction in natural periods for bare frame model resting on medium and stiff soil with that of on soft soil. Table 10 shows the percentage reduction in natural periods for soft storey resting on medium and stiff soil with that of soft

soil and the table 11 shows the percentage reduction in natural periods for soft storey resting on medium and stiff soil with that of soft soil.

The building models supported on soft soil, analytical time period obtained are more than for the same buildings supported on medium and stiff. This could be due to the variation in the soil stiffness.

Table-9. Percentage reduction in natural periods for models II and III with that of Model

I

Model No.	Three Storeyed		Six Storeyed		Nine Storey	
	Gravity Load	Seismic Load	Gravity Load	Seismic Load	Gravity Load	Seismic Load
II	7.04%	10.52%	31.45%	18.23%	8.48%	3.40%
III	9.32%	14.34%	33.30%	27.47%	30.56%	23.82%

Table-10. Percentage reduction in natural periods for models V and VI with that of Model

IV

Model No.	Three Storeyed		Six Storeyed		Nine Storey	
	Gravity Load	Seismic Load	Gravity Load	Seismic Load	Gravity Load	Seismic Load
II	9.28%	13.91%	41.69%	33.40%	23.98%	17.94%
III	11.19%	16.73%	45.55%	40.35%	60.72%	57.12%

Table-11. Percentage reduction in natural periods for models IX and VIII with that of

Model VII

Model No.	Three Storeyed		Six Storeyed		Nine Storey	
	Gravity Load	Seismic Load	Gravity Load	Seismic Load	Gravity Load	Seismic Load
II	13.23%	13.30%	62009%	60.99%	24.10%	33.43%
III	22.23	20.54%	69071%	69.33%	46.25%	69.82%

Effect of Infill : it is observed that bare frame buildings are more vulnerable during the earthquake. This is because in bare frame buildings stiffness of the infill is not considered.

However, in case of soft storey there is significant decrease in lateral displacement compared to bare frame buildings. In case of retrofitted buildings in which one full brick masonry wall only at the corners are provided and the stiffness of the same is considered, lateral displacement is even less than soft storey buildings.

For the buildings with different heights, model I, II and III shows abrupt change in lateral displacements, which indicates stiffness irregularity due to open ground storey and bare frame consideration. However, lateral displacement profile is smooth for remaining models. The lateral displacement along longitudinal and transverse directions is reduced by 40 to 50% for soft storey as compared to bare frame buildings.

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CONCLUSION

- The fundamental natural period of the building varies inversely with stiffness of the soil. The natural period of the buildings resting on stiff soil is 45-50% less as compared to the same building resting on soft soil.
- The lateral displacement of the buildings due to seismic force varies inversely with stiffness of soil. The lateral displacement for the building on soft soil is more compared to the same building resting on medium and stiff soil.
- The soil flexibility directly affects the lateral displacement of the building at the base.
- As the stiffness of soil increases base shear of the buildings decreases. The base shear of the building on stiff soil is less than that on the soft soil.

- The inter storey drift changes drastically for bare frame compared to soft storey and retrofitted models. It is obtained that inter storey drift in top storey for bare frame models is more compared to soft storey models. But due to soft storey at the ground floor, irregularity of stiffness is obtained resulting which the storey drifts in first storey more than bare frame structures.
- The performances of the building with bare frame supported on all three types of soil are within the collapse prevention range. However, the performance of the soft storey and retrofitted buildings are improved and found to be within life safety range.
- The target displacements obtained by analysis when compared with that of those obtained by expression given in ATC-440 found to be lesser for the collapse- prevention as well as life safety levels for all the building models.

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