SEISMIC RESPONSE OF HIGH RISE STRUCTURE DUE TO THE INTERACTION BETWEEN SOIL AND STRUCTURE

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ABSTRACT

In this paper the responses of the high rise structure due to the interaction between soil and structure are analysed. In this study, a 14 storeyed moment resisting building with 4 basement floors under different boundary conditions subjected to earthquake loading is analysed. Building is designed according to is 456 & is 800 codes and it is assumed to be located in seismic zone ii according to is 1893 2002 code. Both the structure & the soil are modelled & analysed using Etabs software and linear analysis is done using response spectrum method. Building is analysed under following different boundary conditions 1) fixed base without soil-structure interaction 2) fixed base with soil-structure interaction 3) pile foundation without soil-structure interaction.4) pile foundation with soil-structure interaction. Here results are focused on base shear, time period, storey drifts, and maximum storey displacement. Soil-structure interaction alters the response characteristics of a structure because of massive and stiff nature of structure and often soil softness. Due to this base shear, time period , storey drifts, and maximum storey displacement increased .and also as depth of foundation increases all the above said response factors increases due the increase in contact area between soil and structure. Hencesoil-structure interaction effects need to be considered while designing buildings for its better performance.

Key words
Soil structure interaction, base shear, time period, response spectrum, tall buildings

1. Introduction

All the civil engineering structures involve some type of structural element with direct contact with ground. When the external forces such as earthquakes act on these systems neither the structural displacements nor the ground displacements are independent of each other. The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is termed as **soil-structure interaction (SSI).**

Conventional structural design methods neglect the SSI effects. Neglecting SSI is reasonable for light structures in relatively stiff soil such as low rise buildings and sample rigid retaining walls. The effect of SSI, however, becomes prominent for heavy structures resting on relatively soft soils for example nuclear power plants, high-rise buildings and elevated-highways on soft soil.

Damage sustained in recent earthquakes, such as the 1995 Kobe earthquake, have also highlighted that the seismic behavior of a structure is highly influenced not only by the response of the superstructure, but also by the response of the foundation and the ground as well.

1.2Effect of soil-structure interaction on structural response

Dr.Sushmapulikanthi, Prof.Pradeepkumarramancharla (2013) [1] observed that there is two-times increase in the acceleration response of the top floor while considering the sfsi over fixed base analysis for nonlinear case of buildings supported on pile foundation under transient loading. **Kraus &D.dzakic (2013) [2]** analysed 3,7 & 10 storey 3 bay reinforced concrete frames using time history analysis. A parametric investigation was carried out assuming 2 cases. A) Building is conventional fixed at the ground level. B) Building is founded on flexible base represented by Winkler springs. C) Results shows that models with soil have much higher values of story drifts, especially when the soil is modelled using winkler springs.**S.Hamidrezatabaiefar, Behzadfatahia and Bijansamali (2012) [3]** analysed structures under two different boundary conditions: (i) fixed-base (ii) flexible-base. Performance levels of the building frames change from life safe to near collapse in soil class ee which is dangerous and safety threatening. As a result, considering SSI effects in seismic design of moment resisting building frames resting on soil classes de and ee according to australian standard as1170.4 is essential.**Behzadfatahi , S. Hamid Reza tabatabaifar , Aslan S. Hokmabadi , BijanSamali (2012) [4]** observed that by decreasing the bedrock depth, lateral deflections of the moment resisting building frames decreases. Therefore, the conventional design procedure excluding SSI is no longer adequate to guarantee the structural safety for the mentioned frames.**Hamid Reza Tabatabaiefar, Bijansamali, and Behzadfatahi (2010) [5]** analysed 3 bay 10 storey moment resisting building frame, resting on shallow foundation, is selected in conjunction with a clayey soil, representing subsoil class Ee, as classified in the as 1170.4. The structural sections are designed after applying dynamic nonlinear time history analysis. Fully nonlinear dynamic analysis under influence of different earthquake records is conducted for fixed & flexible base conditions. It is observed that the maximum later storey drifts of the structures resting on soft soil deposit substantially increase when the SSI is considered. It is concluded that the conventional structural analysis methods assuming fixed-base structures is no longer adequate to guarantee the structural safety. **MuberraEserAydemir (2009) [6]** investigated the seismic behaviour of multi storeyed structures considering soil structure interaction effects. 3,6 and 9 storeyed plane frames were modelled according to Turkish seismic design code. Incremental dynamic analyses were performed on these models using 64 ground motions recorded on different site conditions. The strength reduction factor values considering soil structure interaction are almost always lower than the strength reduction factor value given in codes for design for all sample buildings investigated.

Considering soil-structure interaction makes a structure more flexible and thus, increasing the natural period of the structure compared to the corresponding rigidly supported structure. Moreover, considering the SSI effect increases the effective damping ratio of the system. The smooth idealization of design spectrum suggests smaller seismic response with the increased natural periods and effective damping ratio due to SSI.With this assumption, it was traditionally been considered that SSI can conveniently be neglected for conservative design. In addition, neglecting SSI tremendously reduces the complication in the analysis of the structures which has tempted designers to neglect the effect of SSI in the analysis

1.3 Objectives of the thesis

The principal objective of this thesis is to find the responses of the tall building due to soil structure interaction effects. In order to achieve this building models are designed usingEtabs software by varying different parameters of the building and soil conditions. And analysed the response of the building due to earthquake for corresponding conditions.Work of this type is extremely important because there is very little data that is available to validate the importance of SSI effects on buildings. Especially there is no clear comparison of the responses like base shear, time period, storey drift, storey displacement between with and without soil-structure interaction for the tall building including basement with normal foundation and also with pile foundation.

2. MODEL NO. 1 FIXED BASE WITHOUT SOIL STRUCTURE INTERACTION

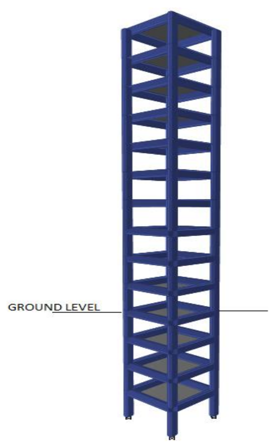


Fig 1: model with fixed base without soil structure interaction

In this model a single bay 14 storeyed R.C.Building with 4 basements is considered in the analysis. Base of all columns are fixed. Soil is not considered in the analysis. Building is modelled and analysed using etabs software 13.2.1 version. Details of the structure, loads and earthquake parameters considered are given in table 1, 2, 3 and 4.

2.1 Building details

Table 1: materials

Sl. No.	Materials used	Type
1.	Concrete	M20
2.	Steel	HYSD 500

Table 2: Structural details

Sl. No.	Elements	Dimensions	Unit
1.	Building dimensions	5x5	Meters
2.	All column size	300x600	mm
3.	All beam size	300x600	mm
4.	Slab thickness	150	mm
5.	Wall thickness	230	mm
6.	Storey height	3	Meters
7.	No of columns in each storey	4	Number
8.	No of beams in each storey	4	Number
9.	Total height of the building	42	Meters

Table 3: Loads considered

Sl. No.	Load type	Load	Unit
1.	**At the basement**		
	A)floor finish	2.5	kN/m^2
	B)live load	3	kN/m^2
	C)wall load	11.04	kN/m
2.	**From ground floor to 9th floor**		
	A)floor finish	1.5	kN/m^2
	B)live load	2	kNm^2
	C)wall load	11.04	kNm
3.	**At the terrace**		
	A)floor finish	2.4	kNm^2
	B)live load	1.5	kN/m^2
	C)wall load	3	kNm

Line load on beams (wall load) = 0.23x (3-0.6) x20=11.04 kN/m

Table no. 4: earthquake parameters

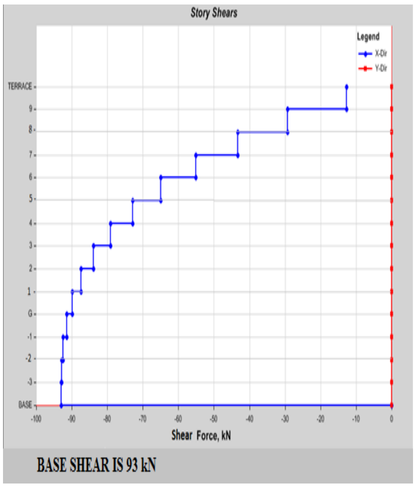
Sl. No.	Factors	Symbol	Values
1.	Zone	Z	II
2.	Importance factor	I	1
3.	Response reduction factor	R	3
4.	Time period	T	1.69 seconds
5.	Soil type		Medium

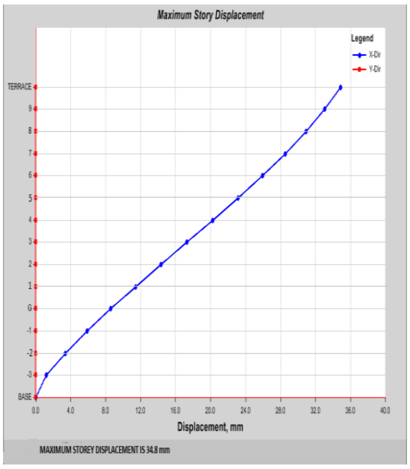
Time period,t=0.09h/√ (d) =1.69 seconds

where, h=42 m

d=5 m

2.2 response of the building





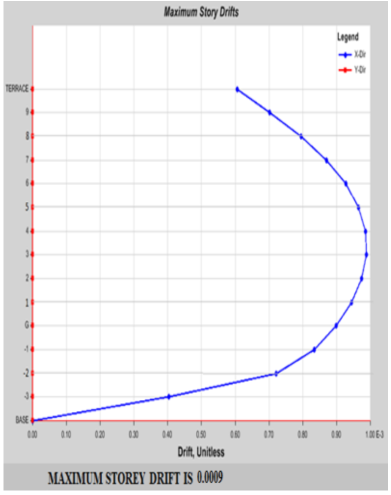


Figure 2: shear force at different storeysfigure 3: displacement at different storeysfigure 4: drifts at different storeys

Figure 2 gives the graph of shear force at different stories, it shows that there is increase in shear force from top storey to bottom storey and shear force at the base is 93 kN which is maximum. Figure 3 gives the graph of lateral displacements at different storeys and it shows that there is increase in displacement from bottom storey to top storey and maximum displacement at the top storey is 34.8 mm. Figure 4 shows the variation of storey drifts, maximum storey drift is 0.0009.

Table 5: response of the building

Sl.no.	Parameter	Values	Units
1.	Time period	2.69	Seconds
2.	Base shear	93	Kn
3.	Maximum storey displacement	34.8	Mm
4.	Maximum storey drift	0.0009	No unit

Table 5 shows the response of the building due to earthquake without considering soil-structure interaction.

3. MODEL NO. 2: FIXED BASE WITH SOIL-STRUCTURE INTERACTION

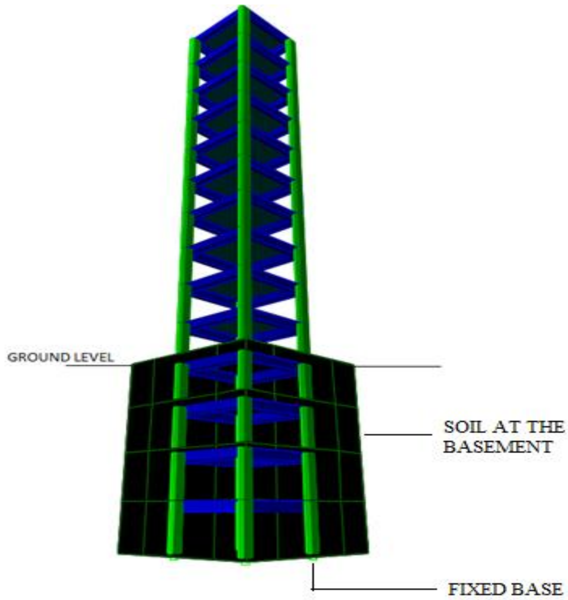


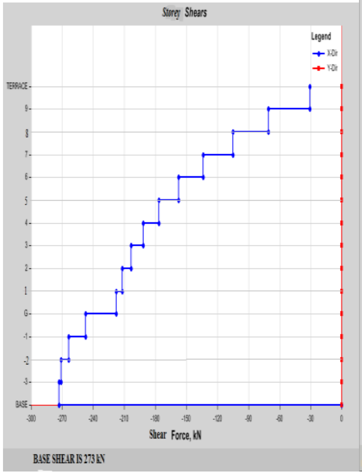
Figure 5: model with fixed base with soil-structure interaction

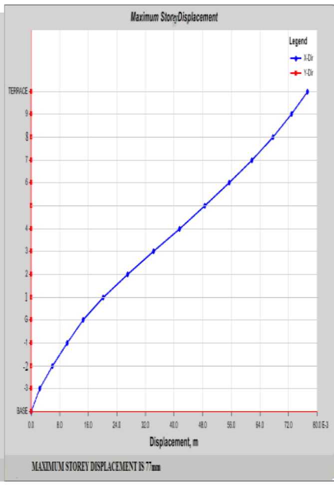
In this model single bay 14 storeyed R.C.Building with 4 basements is considered in the analysis. Base of all columns are fixed. Soil at the basement, upto a distance of 2 meters from the centre of the columns around the building and upto bottom of the columns are considered. Both the soil and the structure are modelled and analysed using Etabs software. Soil details assumed at the basement is shown in table 6. Soil below the basement level is not considered.All other parameters such as building materials used, building structural details, loads, earthquake parameters are same as considered in model no. 1 (table 1, 2, 3, 4)

Table6: soil details assumed at the basement

Sl.no.	Soil details	Values	Units
1.	Soil type	Medium	
2.	Weight density	20	Kn/m^3
3.	Modulus of elasticity	1,20,000	Kn/m^2
4.	Poison's ratio	0.25	
5.	Shear modulus	48,000	Kn/m^2

3.1 Response of the building





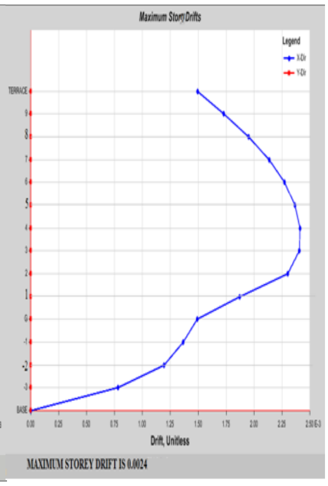


Figure 6: Shear force at different storeysfigure 7: Displacement at different storeys figure 8: Drifts at different storeys

Figure 6 gives the graph of shear force at different stories, it shows that there is increase in shear force from top storey to bottom storey and shear force at the base is 273 kn which is maximum. Figure 7 gives the graph of lateral displacements at different storeys and it shows that there is increase in displacement from bottom storey to top storey and maximum displacement at the top storey is 77 mm. Figure 8 shows the variation of storey drifts, maximum storey drift is 0.0024.

Table no. 7: Responses of the building

Sl.no.	Parameter	Values	Units
1.	Time period	2.753	Seconds
2.	Base shear	273	Kn
3.	Maximum storey displacement	77	Mm
4.	Maximum storey drift	0.0024	No unit

Table 7 shows the response of the building due to earthquake considering soil-structure interaction. It can be clearly seen that there is increase in time period, base shear, maximum storey displacement, maximum storey drift as compared to model no 1, i.e., model without considering soil-structure interaction. (Refer table 5)

4. MODEL NO. 3: BUILDING WITH PILE FOUNDATION WITHOUT SOIL-STRUCTURE INTERACTION

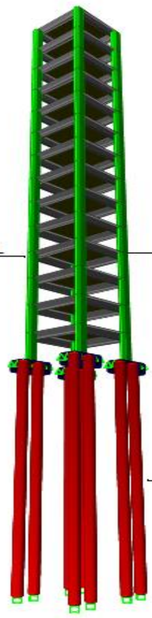


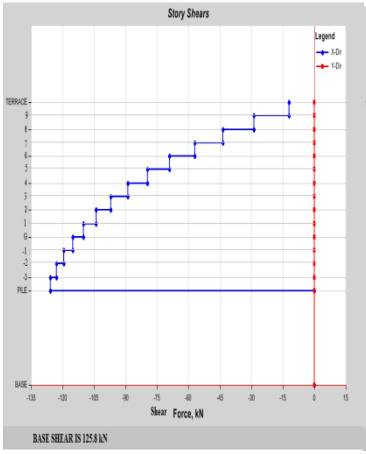
Figure 9:building with pile foundation without soil-structure interaction

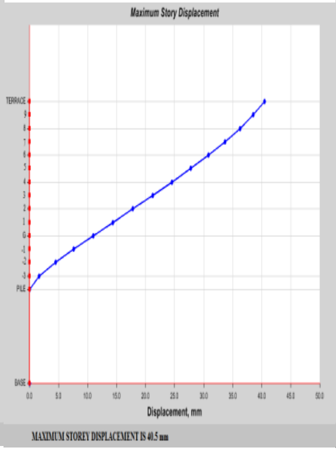
In this model single bay 14 storeyed R.C.Building with 4 basements is considered. Building structural details, loads, earthquake parameters are same as that of model no. 1. (table 1, 2, 3, 4). Additionally pile foundation is designed for this building. Pile foundation details are given in table 8. Only structure is modelled and analysed without soil.

Table 8: Pile foundation details

Sl.no .	Pilefoundation details	Dimensions	Units
1.	No of piles for each column	2	Number
2.	Pile diameter	0.6	M
3.	Length of the pile	21	M
4.	Pile cap dimensions	2.7 x 1.2	M
5	Pile cap depth	1	M
6	Material used for pile & pile cap	M20 concrete	

4.2 Response of the building





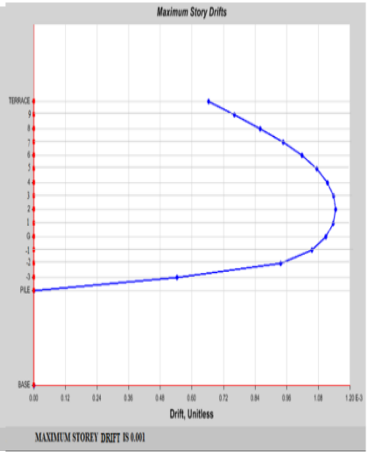


Figure 10: shear force at different storeysfigure 11: displacement at different storeysfigure 12: drifts at different storeys

Figure 10 gives the graph of shear force at different stories, it shows that there is increase in shear force from top storey to bottom storey and shear force at the base is 125.8kn which is maximum. Figure 11 gives the graph of lateral displacements at different storeys and it shows that there is increase in displacement from bottom storey to top storey and maximum displacement at the top storey is 40.5 mm. Figure 12 shows the variation of storey drifts, maximum storey drift is 0.001.

Table 9: Responses of the building

Sl.no.	Parameters	Values	Units
1.	Time period	2.69	Seconds
2.	Base shear	125.8	Kn
3.	Maximum storey displacement	40.5	Mm
4.	Maximum storey drift	0.001	No unit

Table 9 shows the response of the building with pile foundation due to earthquake without considering soil-structure interaction. As compared to the response of first model without pile foundation (table 5), base shear, maximum storey displacement, maximum storey drift is more for this model (table 9) due to increase in total height and weight of the structure (due to pile).

5. MODEL NO. 4: BUILDING WITH PILE FOUNDATION WITH SOIL-STRUCTURE INTERACTION

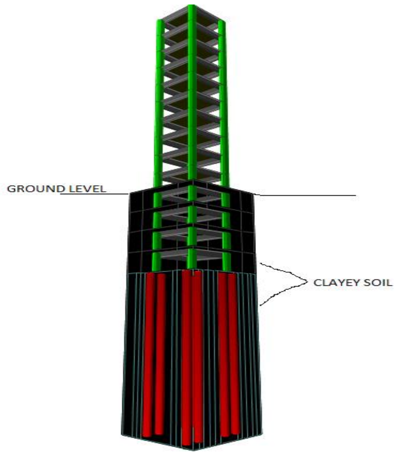


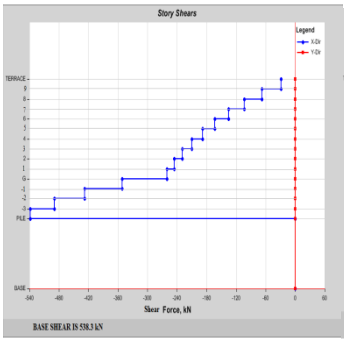
Figure 13: building with pile foundation with soil-structure interaction

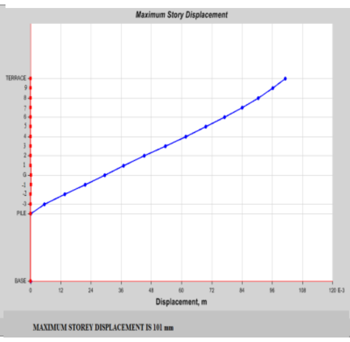
In this model soil is assumed to be rested on clayey soil. Building structural details, loads, earthquake parameters are same that of model no. 1.(table 1, 2, 3, 4) pile foundation details are sameas that of model no. 3. (table 8). Soil details are considered as shown in table 10. Soil below ground level at the basement, up to a distance of 2 meters from the centre of the columns around the building and up to bottom of the piles are considered. Soil below the pile bottom is not considered. Bottom of the pile is fixed.

Table 10: soil details assumed at the basement

Sl.no.	Soil details	Values	Units
1.	Soil type	Soft soil	
2.	Weight density	20	Kn/m^3
3.	Modulus of elasticity	E=30,000	Kn/m^2
4.	Poison's ratio	u=0.42	
5.	Shear modulus	G=10563.5	Kn/m^2

5.1 Responses of the building





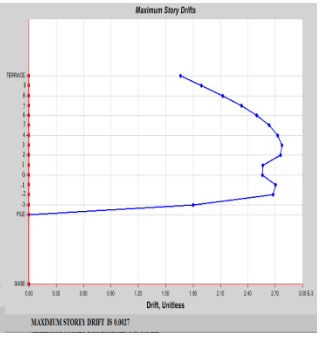


Figure 14: shear force at different storeysfigure 15 displacement at different storeysfigure 16 drifts at different storeys

Figure 14 gives the graph of shear force at different stories, it shows that there is increase in shear force from top storey to bottom storey and shear force at the base is 538.3kn which is maximum. Figure 15 gives the graph of lateral displacements at different storeys and it shows that there is increase in displacement from bottom storey to top storey and maximum displacement at the top storey is 101 mm. Figure 16 shows the variation of storey drifts, maximum storey drift is 0.0027.

Table no. 11: Responses of the building

Sl.no.	Parameter	Values	Units
1.	Time period	2.88	Seconds
2.	Base shear	538.3	kN
3.	Maximum storey displacement	101	mm
4.	Maximum storey drift	0.0027	No unit

Table 11 shows the response of the building due to earthquake considering soil-structure interaction. It can be clearly seen that there is increase in time period, base shear, maximum storey displacement, maximum storey drift as compared to model no 3, i.e., model with pile foundation and without considering soil-structure interaction. (refer table 9)

As compared to all the results , response of this model is more since soil-structure interaction is more here due increased depth of foundation, i.e., contact area of the structure with soil is more.

6. Results, discussion and Conclusions

Comparing the responses of all the models following points can be noted.

1. Time period will elongate, base shear, maximum storey displacement, maximum storey drift increase with the introduction of soil-structure interaction.
2. As the depth of the foundation increase time period , base shear, maximum storey displacement, maximum storey drift also increase since there is increase in contact area between soil and the structure
3. Since these parameters increases due to soil-structure interaction, to add stability to the structure and for better performance of the structure, soil-structure interaction effects need to be considered while designing buildings.

7. References

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