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"Dynamic Soil Structure Interaction Analysis for Piled Raft Foundation"

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Abstract— Damages caused by recent earthquakes have pointed out that the seismic behaviour of a structure is highly influenced not only by the response of the super structure but also by the response of the foundation and ground as well. The effect of SSI becomes prominent for heavy structures resting on relatively soft soils. The main focus of the present investigation is to evaluate the seismic performance of the fifteen storey, reinforced concrete building with piled raft foundation using linear time history analysis by finite element based software SAP 2000. The various results such as time period, displacements, base shear and settlements are compared and the effect of piled raft foundation behaviour is evaluated.

Keywords— *soil structure interaction, SAP 2000, piled raft foundation, linear time history analysis.*

I. INTRODUCTION

Damages caused by recent earthquakes have pointed out that the seismic behaviour of a structure is highly influenced not only by the response of the super structure but also by the response of the foundation and ground as well. Considerable progress has been made in understanding the nature of earthquake and how they could cause structural damages. The investigation on the energy transfer mechanism from soil to buildings during earthquakes is critical for the seismic design of multi-storey buildings and upgrading existing structures. Hence it is necessary to study the soil structure interaction effects while determining the behaviour of the structures.

Soil structure interaction is a special field of earthquake engineering. It concerns the wave propagation in a coupled system. Neglecting SSI is reasonable for light structures in relatively stiff soil such as low rise buildings and simple rigid retaining walls. The effect of SSI becomes prominent for heavy structures resting on relatively soft soils for example nuclear power plants, high-rise buildings and elevated highways on soft soil.

The raft foundation and piled raft foundation are used to support structure and the frame structure is assumed as moment resisting bare frame for the analysis. The loads from super structure are carried through raft foundation and transferred to the soil beneath. The differential settlement and displacements are considerably reduced by providing raft foundation. Piled raft foundation is a special form of raft foundation in which sharing of loads takes place and works better in reducing the settlements and displacements. The superstructure, foundation and soil mass are considered as a single unit and analyzed using finite element method (FEM). The structure foundation system is placed in three different types of soil namely hard, medium and soft, analyzed using finite element based software SAP 2000 version-14.0.0.

Seismic response of superstructure on soft soil considering soil-pile-structure interaction was proposed by the Hokmabadi A.S., Fatahi B and Samali B in the year 2007. They concluded that the soil structure interaction induces significant increase in the lateral deflections and inter-story drift of the structure both with shallow and deep foundations in comparison with the fixed base structures using FLAC3D software. S.A Rasal, Chore H.S and P.A Dode in the year 2010 observed the interaction of frame with pile foundation for three storied frame comprises of two bays. The effect of different pile diameters was evaluated on the response of superstructure through a parametric study. The response of the superstructure considered includes the displacement of the frame.

Effect of Piled Raft Design on High-Rise Building Considering Soil Structure Interaction was studied by R. R. Chaudhari and Dr K. N. Kadam in the year 2013. In this paper they were concluded that soil structure interaction has been found to be significantly affecting the performance of structure using ANSYS software. A dynamic behavioural study of 25 storey building with piled raft foundation with variable sub soils was examined by Shukla S J, Desai A K and Solanki C H in the year 2013. They were concluded that piled raft foundation with dense sand type of subsoil was a very good

combination for good bearing behaviour of the structure using SAP 2000 software.

II. PRESENT WORK

A. Methodology

1. Collection of detailed information regarding Bhuj earthquake ground motion.
2. Collection of information on shear wave velocity to calculate the dynamic properties of various soils (IBC 2006, soil classification).
3. Check the effect of presence of soft soil in the site condition
4. The numerical method such as Finite Element Method is used to model the soil, foundation-system.
5. Soil structure interaction effect of fifteen storey RC frame with raft and piled raft foundations are analyzed by linear time history analysis using Finite element based software SAP 2000.
6. Interpretation of results.

B. Objectives

1. The present work focuses on the analysis of soil structure interaction effect of 15 storey special moment resisting reinforced concrete bare frame for the following cases of analysis.
   (i) Without subsoil i.e. without soil structure interaction (fixed case)
   (ii) With subsoil condition i.e. soil structure interaction analysis for different soil condition with raft foundation. (Shallow foundation)
   (iii) With subsoil condition i.e. soil structure interaction analysis for different soil condition with piled raft foundation. (Combination of shallow and deep foundations)
2. The comparative studies between rafts and piled rafts are done for different soil conditions such as hard, dense and soft soils.
3. Dynamic analysis by linear time history method is carried out for all the models. The structural response for the different input parameters are carried out by various studies.

III. MODELLING AND ANALYSIS

In the present study fifteen storeys RC moment resisting frame is modeled using SAP2000 with different cases such as fixed base, with raft foundation, with piled raft foundation. These three cases are considered in hard, dense and soft soils, analyzed by linear time history analysis by inputting the Bhuj earthquake data (2001).

A. Cross sectional and material properties

1. Grade of concrete - 25, 30
2. Building plan - (4 × 12) m
3. Beam size - (0.5 × 0.5) m
4. Column size - (0.7 × 0.7) m
5. Thickness of slab - 0.1 m
6. Each storey height - 3 m
7. Number of storey - 15
8. Total height of building - 45 m
9. Each bay width in x and y direction - 4 m
10. Elastic modulus of hard soil - (1.5×10^7) kN/m2
11. Elastic modulus of medium soil - (2.5×10^6) kN/m2
12. Elastic modulus of soft soil - (4.02×10^4) kN/m2

B. Finite element modelling

The numerical method such as finite element method is implemented to analyze coupled system as a whole single unit. This finite element method of analysis helps in discretizes the particular domain into number of iso-parametric elements with different degree of freedom and gives accurate results. All the frame systems are modeled as a 3D frame using SAP2000 Software package. The raft and piled raft foundations are modeled as solid elements with finite meshing by finite element method. The soil depth is considered upto 30m and boundaries are restricted to 15m from the frame structure in all the four sides and the soil mass is modeled by elastic continuum method.

C. Figures

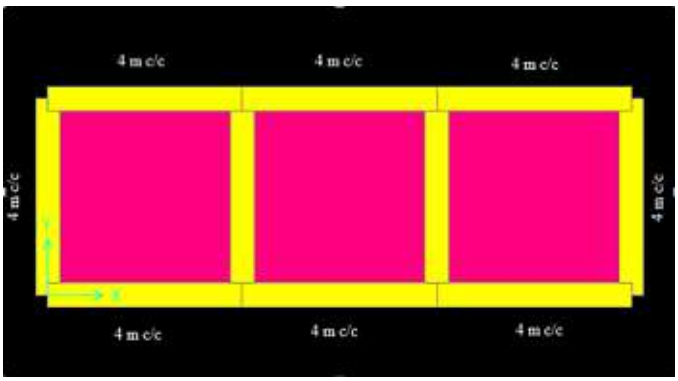

Figure 1: Building plan

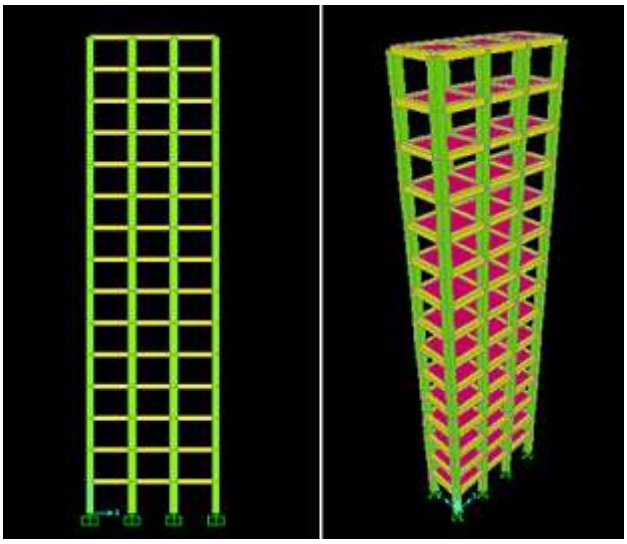

Figure 2: Fixed base model

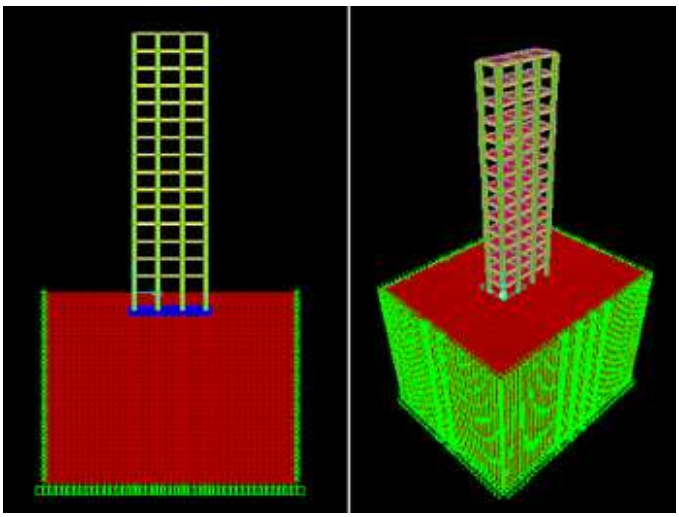

Figure 3: Fifteen storey building with raft foundation

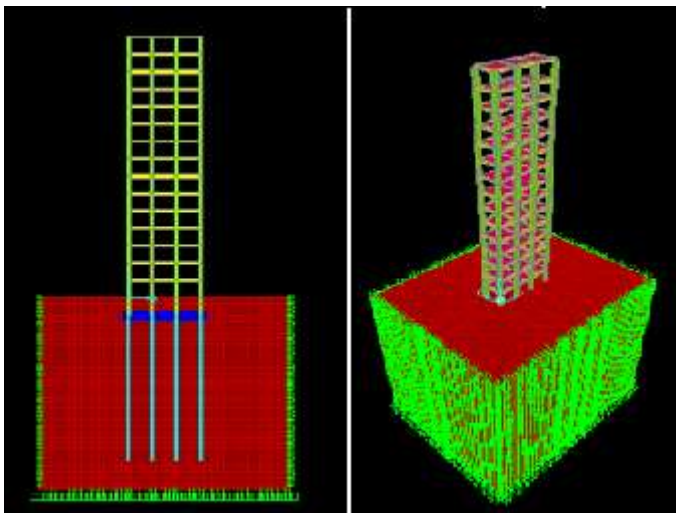

Figure 4: Fifteen storey building with piled raft foundation

IV. RESULTS AND DISCUSSION

A. *Variation of maximum displacement*

The displacements of building are very high in building resting on soft soil with raft foundation. The piled raft foundation reduces the displacement very much compared to raft foundation. The displacements of building in hard and dense soil are almost similar with both raft and piled raft foundations. The results and variations are tabulated in table 1 and shown in figure 5. The displacement in soft soil with raft foundation is 270.7mm which can be reduced to 93.9mm by piled raft foundation.

A. Table 1 Percentage variation in displacement

Building type	Soil type	Maximum displacement (mm)		% variation in maximum displacement
		Without SSI	With SSI	
Bare frame with Fixed base	-	47.5	-	-
Bare frame with Raft foundation	Hard	-	50.4	6.1
	Dense		53.2	12
	Soft		270.7	469.89
Bare frame with Piled raft foundation	Hard	-	50.4	6.1
	Dense		53.1	11.79
	Soft		93.9	97.68

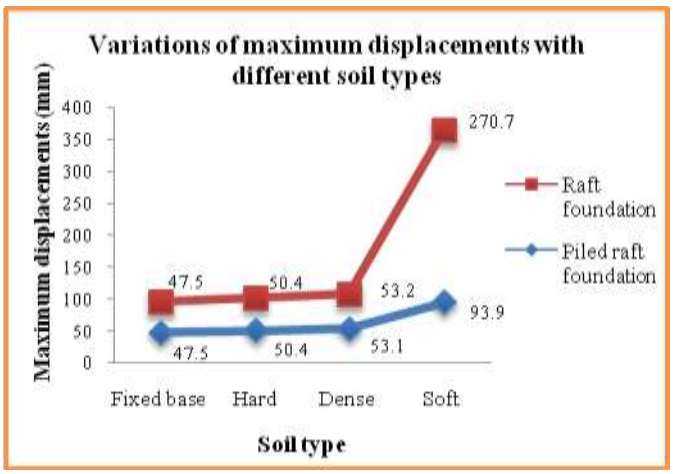

Figure 5: Variation of maximum displacements with soil structure interaction effects

B. *Variation of base shear*

The base shear of building is very high in building resting on soft soil. It indicates that more disturbances at the base of building and it depend upon the underlying soil condition. The results and variations are tabulated in table 2 and shown in figure 6.

B. Table 2 Percentage variation in base shear

Building type	Soil type	Base shear (kN)		% variation in base shear
		Without SSI	With SSI	
Bare frame with Fixed base	-	137.85	-	-
Bare frame with Raft foundation	Hard	-	358.43	160.01
	Dense		453.10	229.34
	Soft		793.84	475.87
Bare frame with Piled raft foundation	Hard	-	358.43	160.02
	Dense		454.32	229.58
	Soft		793.84	475.87

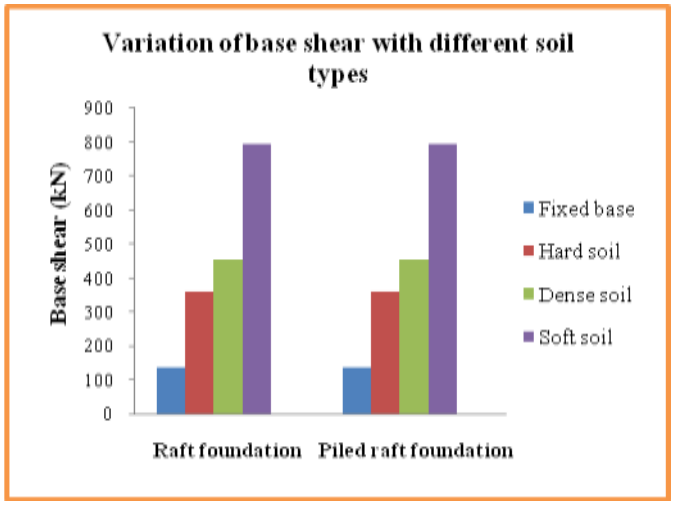

Figure 6: Variation of base shear of building with soil structure interaction effects.

C. *Variation of natural period*

The study shows that natural period increases with soil flexibility by the incorporation of soil structure interaction when compared to fixed base model. In soft soil the natural period is decreased considerably with piled raft foundation compared to raft foundation. The results and variations are tabulated in table 3 and shown in figure 7.

C. Table 3 Percentage variation in natural period

Building type	Soil type	Natural period (sec)		% variation in natural period
		Without SSI	With SSI	
Bare frame with Fixed base	-	1.5233	-	-
Bare frame with Raft foundation	Hard	-	1.5604	2.43
	Dense		1.5988	4.96
	Soft		2.2345	46.69
Bare frame with Piled raft foundation	Hard	-	1.5604	2.43
	Dense		1.5975	4.87
	Soft		1.906	25.12

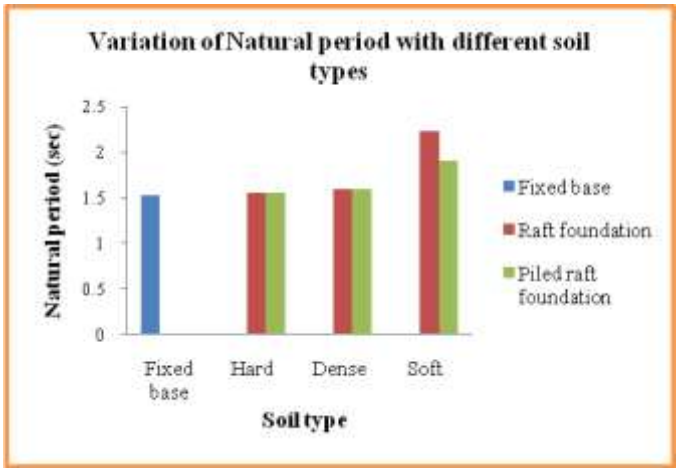

Figure 7: Variation of natural period of building with soil structure interaction effects.

D. *Variation of settlement*

The raft settlement is higher for building resting on soft soil with raft foundation compared to building resting on soft soil with piled raft foundation. The raft settlement is 12.3 mm in raft foundation and 2.3 mm for building resting on piled raft foundation.

V. CONCLUSION:

The soil structure interaction effects in hard and dense soil are almost same with raft and piled raft foundation. The soil structure interaction effect in soft soil is more and the building vibrates longer with raft foundation than piled raft foundation. The base shear and displacements are increases with incorporation of soil flexibility. The base shear is mainly depends upon the soil condition. The displacement in soft soil can be reduced much more by providing piled raft foundation than raft foundation. The raft settlement can be reduced considerably with piled raft foundation and settlement of pile is within the permissible limit.

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Indian standard codes

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[3] IS: 875 – 1987 - Code of Practice for Design Loads (other than Earthquake) for Buildings and Structures, Part 1: Dead Loads, Part 2: Imposed Loads, Bureau of Indian Standards, New Delhi.