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A BEHAVIOURAL STUDY OF DYNAMIC SOIL STRUCTURE INTERACTION FOR PILED RAFT FOUNDATION WITH VARIABLE SUB SOILS BY TIME HISTORY FEM MODEL

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ABSTRACT: India is the developing country and in this age of rapid urbanization, geotechnical issues in construction of tall buildings are a major problem. These act as strong barriers against the construction of tall buildings in urban areas. Piled raft foundation is the type of foundation which can be used for the construction of tall buildings safely and economically. The piled raft foundation system has recently been widely used for many structures, especially high rise buildings. In this foundation, the piles play an important role in settlement and differential settlement reduction, and thus can lead to economical design without compromising the safety of the structure. Foundation rafts are analyzed as a plate on elastic foundation with the representation of the foundation media using the Winkler idealization. The elastic constant of the Winkler springs is derived using the sub-grade modulus. Perusal of literature reveals that very few investigations were done on the effect of variable sub soil on the behavior of structures supported on pile raft foundations. So in this research, an iterative dynamic analysis was performed using SAP2000 program to carry out three dimensional time history analysis of non-linear soil-foundation-building models under a great earthquake ground motions. The interaction between the soil and structure is represented by Winkler spring model. The obtained results confirmed that the dynamic characteristics of soil structure system should be recommended for conservative nonlinear seismic response of the high building since it mitigates of earthquake hazards.

Keywords: Modulus of Sub Grade Reaction, Time History Analysis

1. INTRODUCTION

In the past few decades, there has been an increasing recognition that the use of pile groups in conjunction with the raft can lead to considerable economy without compromising the safety and performance of the foundation. Such a foundation makes use of both the raft and the piles, and is referred to here as a pile-enhanced raft or a piled raft.

Piled raft foundations provide an economical foundation option for circumstances where the performance of the raft alone does not satisfy the design requirements. Under these situations, the addition of a limited number of piles may improve the ultimate load capacity, the settlement and differential settlement performance, and the required thickness of the raft Buildings are susceptible to soil structure interaction effects due to the induced changes in the dynamic characteristics of soil during seismic excitation; particularly several buildings have been constructed on soft soil. Because of this detrimental effect, this paper aims at clarifying the soil structure interaction effect on the seismic response of buildings under strong ground motions to provide damage control and enhance the safety level of such buildings

The load and deformation characteristics of the structural and geotechnical (soil) components of the foundations of structures can affect, and in some cases dominate, seismic response and performance. Recognizing this important fact, many structural engineers have included representations of foundation strength and stiffness in their seismic analysis models for many years. The modeling of the soil and structural parts of foundations inherently accounts for the interaction of the soil and structure.

There will also be energy losses due to internal friction of the soil. Because of these effects, the response of a structure on a soft foundation to a give earthquake excitation will, in general, be different from that of the same structure supported on a different sub soil. It is the influence of a soil structure interaction on the response of structures to earthquake motion that is the general subject of this paper.

2. BASIC CONCEPTS OF MODULAS OF SUBGRADE REACTION

The concept of spring constant was first introduced by Winkler in 1867. He modelled flexible foundation, such as raft, to stand on an independent discreet spring elements or supports. In 1955, Karl Terzaghi, in his paper ‘Evaluation of coefficients of subgrade reaction’ proposed a method to estimate the magnitude of the spring constants. His approach, also known as subgrade reaction model, was then become popular and commonly used in the design of raft foundation.

In 1955, Karl Terzaghi (Liao, 1995) published a classic paper titled ‘Evaluation of coefficients of subgrade reaction’, in which he presented recommendations for estimating the spring constants which have come to be commonly used to model the foundation sub grade in the analysis of mat foundations and other similar problems Because of the complexity of soil behaviour, sub grade in soil-foundation interaction problems is replaced by a much simpler system called sub grade model. One of the most common and simple models in this context is Winkler hypothesis. Winkler idealization represents the soil medium as a system of identical but mutually independent, closely spaced, discrete and linearly elastic springs and ratio between contact pressure, P, at any given point and settlement, y, produced by it at that point, is given by the coefficient of sub grade reaction, *k*s (Dutta and Roy 2002).

Starting with the pioneering work of McClelland and Focht (1958), beam-on nonlinear Winkler foundation (BNWF) models have been used for many years for analyzing the response of foundations, most notably piles, for static loads (Matlock, 1970; Cox et al., 1974) and dynamic loads (Penzien, 1970; Nogami et al., 1992; Boulanger et al., 1999). Key advantages of these models over continuum formulations lies in their ability to describe soil-structure interaction phenomena by one-dimensional nonlinear springs distributed along the soil-foundation interface. It is well-known that the modulus of the springs (also known as modulus of sub-grade reaction) is not uniquely a soil property, but also depends on foundation stiffness, geometry, frequency, response mode, and level of strain. A limitation of the approach relates to its one-dimensional nature. A spring responds only to loads acting parallel to its axis, so loads acting in a perpendicular direction have no effect on the response of the spring.

In this model the sub grade soil assumes to behave like infinite number of nonlinear elastic springs that the stiffness of the spring is named as the modulus of sub grade reaction .Nonlinear springs for shallow foundations have been used in conjunction with gapping and damper elements by Allotey and Naggar (2003 and 2007) as well as Raychowdhury and Hutchinson (2009).

The direct method to estimate the modulus of sub grade reaction is plate load test that it is done with 30-100 cm diameter circular plate or equivalent rectangular plate (Reza & Janbaz, 2008). In general, the methods of determination of ks can be classified as: [3]

1- Plate load test (Dutta and Roy 2002; Bowles 1998),
2- Consolidation test (Dutta and Roy 2002; Bowles 1998),
3- Triaxial test (Dutta and Roy 2002),
4- CBR test (Nascimento and Simoes 1957) and
5- Empirical and theoretical relations that are proposed by researchers (Bowles 1998; Elachachi *et al.* 2004).

Because of the limitation of available data and the uncertainty of soil condition, it was also roposed to use the empirical equations.

Vesic $$k_s = \frac{0.65\,E_s}{B\,(1-\upsilon_s^2)}\ \sqrt[12]{\frac{E_s B^4}{EI}}$$

The Vesic’s equation clearly shows that the modulus of sub grade reaction depends not only on the width of the foundation, B, but also on the elastic parameters of soils, Es and µs, and on the shape factor of the foundation, Ip.

Table:- 1 Range of modulus of subgrade reaction $\boldsymbol{K_s}$
Use values as guide and for comparison when using approximate equations[1]

Soil		$\boldsymbol{K_s}$, kN/m^3
Loose sand		48000 – 16000
Medium dense sand		9600 – 80000
Dense sand		64000 – 128000
Clayey medium dense sand		32000 – 80000
Silty medium dense sand		24000 – 48000
Clayey soil		
200<	$\boldsymbol{q_a \le 200\ kPa}$	12000 – 24000
	$\boldsymbol{q_a \le 800\ kPa}$	24000 – 48000
	$\boldsymbol{q_a > 800\ kPa}$	> 48000

After broader idea of sub soil type’s discussion, three major group of soil are selected for subsoil for the actual work problem. They are classified as under

The sub soils selected are c-soils- ϕ soils and ϕ soils. As c – soils the clayey soils with sub grade modulus 30000 kN/m^3, as c- ϕ 48000 kN/m^3 and as ϕ – soils medium dense sand with 70000 kN/m^3 modulus of sub grade reaction were selected and the further analysis was carried out and various outputs are compared for different sub soils as mentioned in above discussions.

Table :-2Values or value ranges for Poisson's ratio	
Type of soil	***μ***
Clay, saturated	*0.4 - 0.5*
Clay, unsaturated	0.1 - 0.3
Sandy clay	0.2 - 0.3
Silt	0.3 - 0.35
Sand. gravelly sand	0.1 - 1.00
commonly used	0.3 - 0.4
Rock	0.1 - 0.4 (depends somewhat on type of rock)
Loess	0.1-0.3
Ice	0.36
Concrete	0.15
Steel	0.33

2. PROBLEM STATEMENT

Foundation along with surrounding soil is considered for analysis. For analysis the building along with foundation was modelled as frame and shell element consisting of 9049 and 3305 elements. The Discretization of shell element was done at the rate of 1.2m x 1.2m with 0.3m of sub mesh

Material properties:- Grade of concrete :- M35 Poisson's ratio(μ) :- as per the soil Type of pile :- friction pile Section of pile :- circular section
Details of The Problem Height - 90m Building Plane - 43.2 x 20.7m Column Dimension – 600mm x 600mm Beam Dimension – 250mm x 600mm Shear Wall Thickness – 300mm
Foundation Data Piled raft foundation Analyse Type – Flexible approach (Winkler's model) Thickness of raft –1 m , Area of raft – 1050.45 m^2 Pile Diameter, 1000 mm. Pile length (l)– 15m, 30m Spacing between piles :- 4.3 m atcentre,8.6 at edge Total no of piles:- 36 nos

A time history analysis was carried out using El Centro earthquake and bhuj earthquake time history time history as shown in fig. 2-3

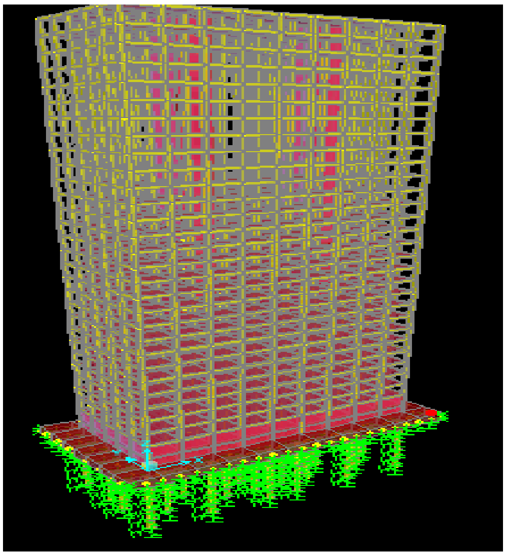

Fig:1 25 storey building supported on piled raft foundation

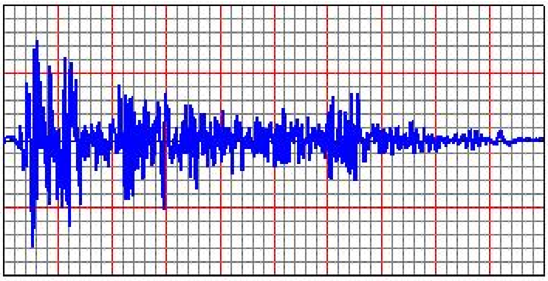

Fig:2 A time history of El Centro earthquake

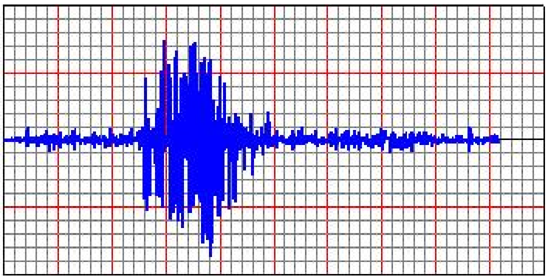

Fig:3 A time history of bhuj earthquake

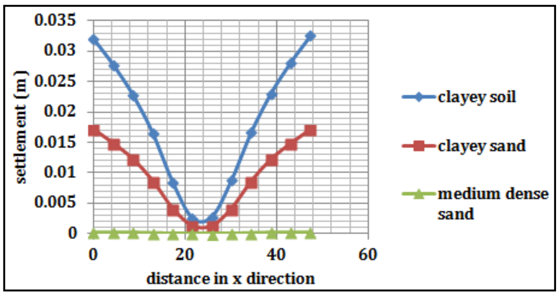

Fig: 4 Settlement of raft in z direction for El Centro earth quake (l = 15 m)

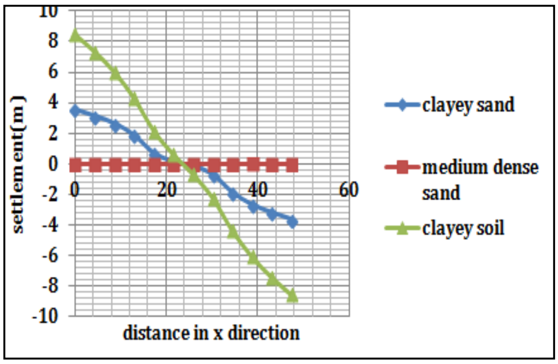

Fig: 5For bhuj earthquake settlement in z direction (l = 30 m)

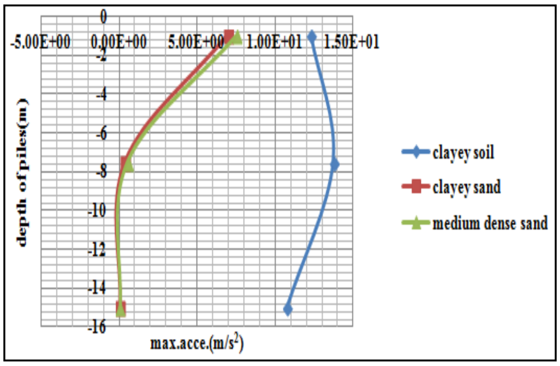

Fig: 6 Maximum acceleration for bhuj earthquake. l = 15 m

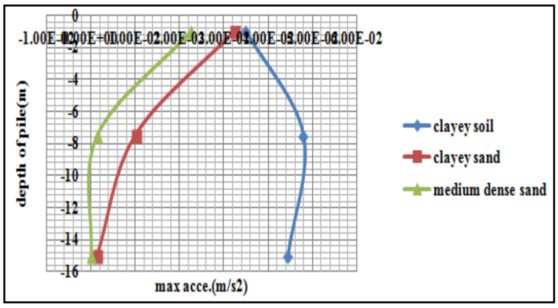

Fig:7 Maximum acceleration for El Centro earthquake. l = 15 m

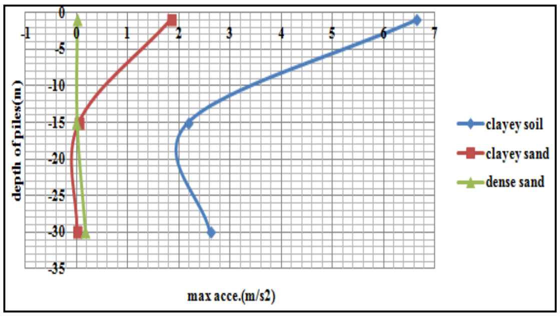

Fig: 8 Maximum acceleration for Bhuj earthquake. l = 30 m

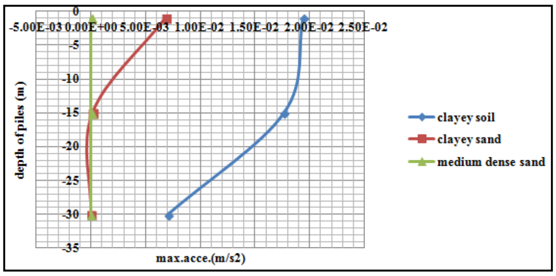

Fig: - 9 Maximum acceleration for El Centro earthquake. l = 30 m

4. ANALYSIS AND RESULTS

1) settlement in raft

For El Centro earth quake c soil gives settlement in the range of 22 to 32 mm where as c-ϕ soil gives it in the range of 12 to 17 mm which shows reduction of 45 to 55 % and ϕ soil gave 1 mm to 2 mm which shows reduction of 99% structure remain steady in all sub soil conditions because settlement within permissible limits (65 to 100 mm for raft IS; 1904-1966) and for l = 30 m , c-ϕ shows reduction of 65 to 70 % and ϕ soil shows reduction of 99% structure remain steady in all sub soil conditions because settlement within permissible limits (65 to 100 mm for raft IS;1904-1966 where as for Bhuj earthquake, structure fails for all sub soils for l= 15 m.

For l = 30 m pile length, structure remains safe for all sub soil conditions and φ soil gave very good performance for El Centro earthquake and for Bhuj earthquake ,structure remains safe only for φ soil.

2) Maximum acceleration

From fig 6-9 of maximum accelerations, it was observed that structure with medium dense sand gave minimum accelerations in both time histories and c soil gave maximum acceleration at different pile depths which show the flexible behavior of c soil.

5. CONCLUSIONS

For medium duration earthquake the ϕ soil behaves in desired manner. The settlement and displacement of raft gets reduced in considerable extent of and for short duration earthquake these results are even more effective considering all the three specified sub soil types. This exhibits excellent behavior of medium dense sand (ϕ) soil as subsoil.

The frequency of occurrence of longer duration earthquake with high PGA is relatively very less but for medium to low duration earthquake it is very frequent. In that way performance of dense sand or medium dense sand as a sub soil results in reduced settlement and displacement to a considerable extent as compared to c and c-ϕ soil.

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