A DYNAMIC BEHAVIORAL STUDY OF STRUCTURE WITH PILED RAFT FOUNDATION BY TIME HISTORIES FINITE ELEMENT MODEL

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ABSTRACT

A piled raft foundation is a combination of a shallow foundation and a deep foundation with the best characteristics of each of its components. The piled raft foundation is a composite construction consisting of three bearing elements, piles, raft and subsoil. Unlike the traditional design of foundation where the load is carried either by the raft or by the piles, in the design of a piled raft foundation the load share between the piles and the raft is taken into account. In this foundation the piles usually are not required to ensure the overall stability of the foundation but to reduce the magnitude of settlements, differential settlements and the resulting tilting of the building and guarantee the satisfactory performance of the foundation system. The bearing behaviour of a piled raft foundation is characterized by complex soil-structure interactions (Katzenbach et al. 1998). The modelling of these interactions requires a reliable and powerful analysis tool, such as the Finite Element Method in combination with a realistic constitutive law. Different researches have been realized investigations about the numerical modelling of piled rafts with FE analysis and different constitutive models. The present research combines the 3D modelling with a modern and realistic constitutive model. An increasing number of structures, especially tall buildings are founded on piled rafts (O'Neil et al. 1996; Katzenbach et al. 2000, Poulos 2001). For this reason, it is important to develop a methodology to study the bearing behaviour of piled rafts. In this paper different parameters of piled raft foundation like diameter of the piles, thickness of rafts, are discussed. It is incorporated with computational modelling of piled raft foundation.

Key Words: Soft Soils, Time History Analysis

I 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.

Thus this is fundamentally different from foundation application where the piles or shafts are placed beneath the entire foundation and are assumed to carry all loads. An additional unique aspect of the piled - raft concept is that the deep-foundation elements are sometimes designed to reach their ultimate geotechnical axial compressive capacity under service loads. The piled-raft concept has also proven to be an economical way to improve the serviceability of foundation performance by reducing settlements to acceptable levels. This paper sets out the effect of subsoil types on the behaviour of tall building, with attention being focused on piled raft foundation systems. Some of the advantages of piled rafts are outlined, and then effect of subsoil on the behaviour of tall building was checked by time history analysis. For this three time histories of Bhuj and El Centro and yermo earthquake were selected.

1.1 History of Piled Raft Foundations

The piled raft foundation consists of three load-bearing elements: piles, raft and subsoil. According to their stiffness, the raft distributes the total load transferred from the structure as contact pressure below the raft and load over each of the piles. In conventional foundation design, it has to be shown that either the raft or the piles will support the building load with adequate safety against bearing capacity failure and against loss of overall stability. In piled raft foundation, the contributions of the raft and piles are taken into consideration to verify the ultimate bearing capacity and the serviceability of the overall system. Several studies of analyzing piled rafts have been reported in the literature. The approaches can be divided into simplified analytical methods and numerical methods such as finite element methods, boundary element methods or hybrid methods, all with various assumptions and constitutive laws.

Randolph (1994) presented new analytical approaches for the design of pile groups and piled raft foundations to focus on the settlement issue rather than the capacity. An equivalent pier analogue of pile groups and piled raft was proposed as the most direct method of estimating the stiffness of the foundation. Design principles were introduced for piled rafts with the aim of minimizing differential settlements by optimal location of the piles beneath the raft. Russo (1998) presented an approximate numerical method for the analysis of piled raft foundation, in which the raft is modelled as a thin plate and the piles as interacting non-linear springs. Both the raft and the piles are interacting with the soil which is modelled as an elastic layer. Two sources of non-linearity are accounted for: the unilateral contact at the raft-soil interface, and the non-linear load-settlement relationship of the piles. Both theoretical solutions and experimental results were used to verify that, despite the approximations involved, the proposed method of analysis can provide satisfactory solutions in both linear and non-linear range.

Prakoso and Kulhawy (2001) analyzed piled raft foundation using simplified linear elastic and nonlinear plane strain finite element models. The effects of raft and pile group system geometries and pile group compression capacity were evaluated on the average and differential displacements, raft bending moments, and pile butt load ratio. The results were synthesized into an updated, displacement-based, design methodology for piled rafts.

Poulos (2001) demonstrated three different stages of design for piled raft foundation. In the first stage, the effects of the number of piles on load capacity and settlement are assessed through an approximate analysis. The second stage is a more detailed examination to assess where piles are required. The third is a detailed design phase in which a more refined analysis is employed to confirm the optimum number and location of the piles. Procedures for estimating the necessary geotechnical parameters are also described.

Reul (2004) compared the bearing behaviour of a single pile, a freestanding pile group and a piled raft in overconsolidated clay by means of three-dimensional finite-element analysis, and demonstrated the influences of pile-pile interaction and pile-raft interaction. As a result of pile–raft interaction the skin friction was shown to increase with an increase in load or increase in settlement. It was also shown that under practically relevant loads, the piles of a piled raft do not reach their ultimate bearing capacity.

Sanctis and Mandolini (2006) proposed a simple criterion to evaluate the ultimate vertical load of a piled raft from the separate ultimate capacities of its components (the raft and the pile group) based on both experimental evidence and three dimensional finite-element analyses. The proportion of the load taken by the raft at failure is typically less than unity, depending on the pile layout and geometry. The ultimate capacity of the piled raft is at least 80% of the sum of the ultimate capacities of the separate components.

II PRESENT WORK

The foundations that designers are most likely to consider first for major structures on deep deposits of clay or sand are reinforced concrete rafts. Rafts spread the load from columns and load bearing walls over the widest possible area. Generally settlement consideration are the most important determinants of the final design and only in cases of extremely heavy structures must the possibility of bearing capacity failures can be seriously examined. To limit the settlement to the allowable value the practice is to use pile foundations.

The deep foundation elements (piles or shafts) are only placed beneath portions of a foundation and are intended to carry only a portion of the superstructure load. Thus this is fundamentally different from foundation application where the piles or shafts are placed beneath the entire foundation and are assumed to carry all loads. An additional unique aspect of the piled raft concept is that the deep foundation elements are sometimes designed to reach their ultimate geotechnical axial compressive capacity under service loads. After completion of verification process, finite element software SAP 2000 was used to model the actual work problem.

The data of the problem is as under:-

To check the behaviour of above building with piled raft foundation in soft soil, three different types of soils are considered. They are classified as under:-

- **Purely cohesive soils(C-soils):-** these soils are the soils which exhibit cohesion but the angle of shearing resistance $\phi = 0$. For examples cohesive soil, saturated clays and silts.
- **Cohesion less soils (ϕ - soils):-** these soils are the soils which do not have cohesion and they derive the strength from the intergranular friction. They are also referred as cohesion less soil i.e. sands and gravels.
- **Cohesive-cohesion less soils (c-ϕ soils):-** These are the composite soils having both cohesion and friction. So they are referred as c- ϕ soils. I .e clayey sand, sandy clay, silty sand etc.

2.1 Details of the Problem

Height of the building - 90m

Building Plane - 43.2 x 20.7m

Column Dimension – 600mm x 600mm

Beam Dimension – 250mm x 600mm

Shear Wall Thickness – 300mm

- **Spacing of Piles**

At edge: - 8.6 m

At centre: - 4.3 m

Total piles: - 36 No

- **Foundation Data**

Piled raft foundation

Analyse Type – Flexible approach (Winkler's model)

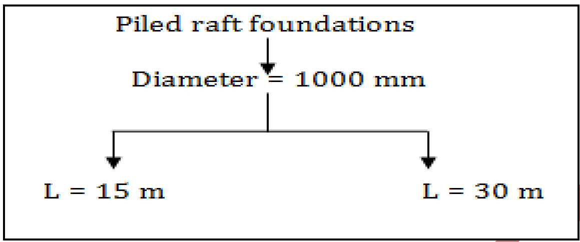
Thickness of raft –1 m

Area of raft – 1050.45 m^2

Pile Diameter: – 1000 mm,

Pile length – 15 m and 30m

This Building was modeled in **SAP: 2000** using shell and frame element.



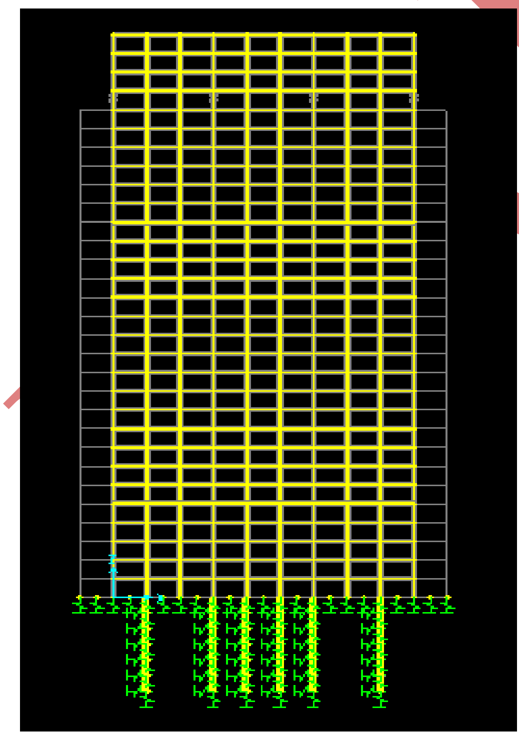


Fig:1 Front view of 25 storey building with pile length l = 15 m

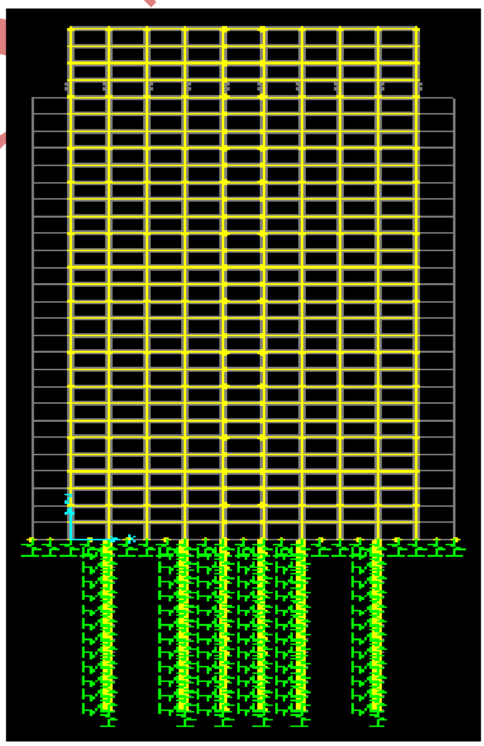


Fig:2 Front view of 25 storey building with pile length l = 30 m

Based on above soil types the Winkler's model (beams of elastic foundation) approach is adopted and foundation analysis was carried out for different combination of pile and raft dimensions.

In the following sections cohesion less soil is considered dense sand and cohesive soil is considered as loose clay. The combinations of raft and pile dimensions adopted for the analysis are as under

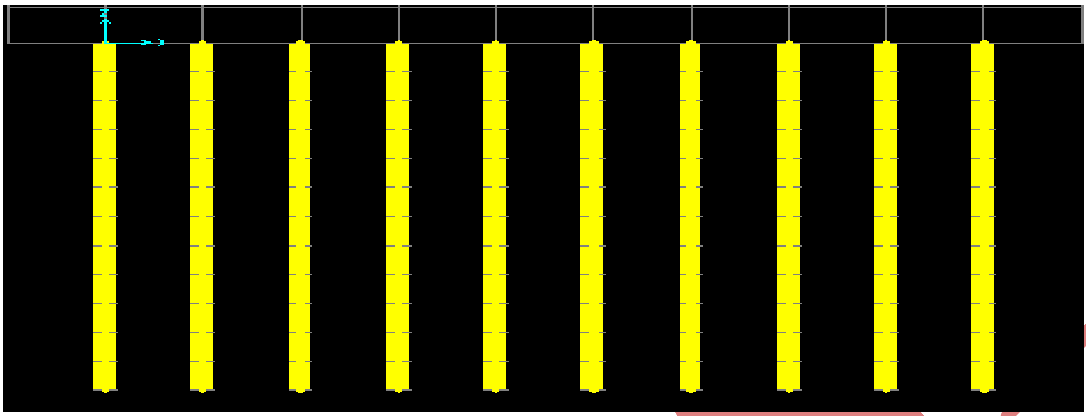


Fig:3 Front view of piles d=1000 mm

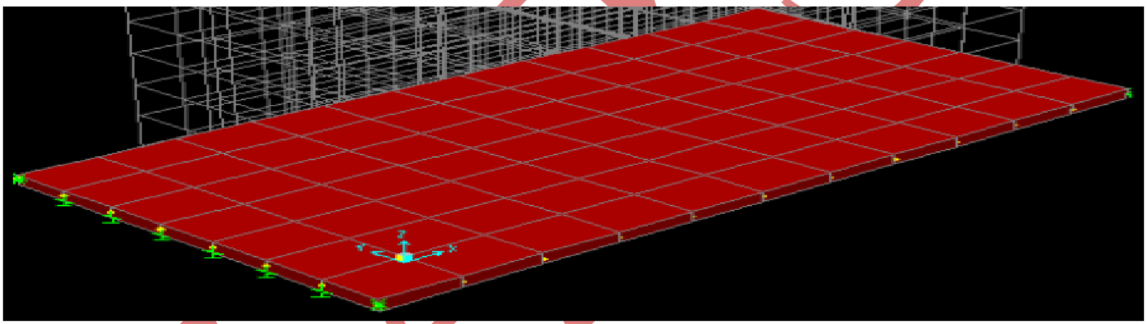


Fig:4 3-D view of raft, t = 1 m

Foundation along with surrounding soil is considered for analysis. The layering effect of soil is also considered. For analysis the building along with foundation was modeled as frame and shell element. Spring elements are used to represent the effect of soil for analysis.

The analysis was carried out in the form of time period for all three soil conditions which is as under.

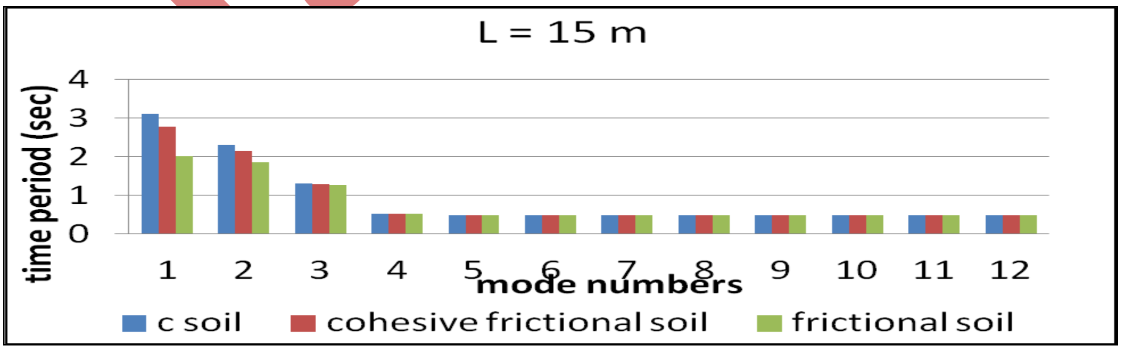


Fig:5 Mode Number Vs Time Period L = 15 M

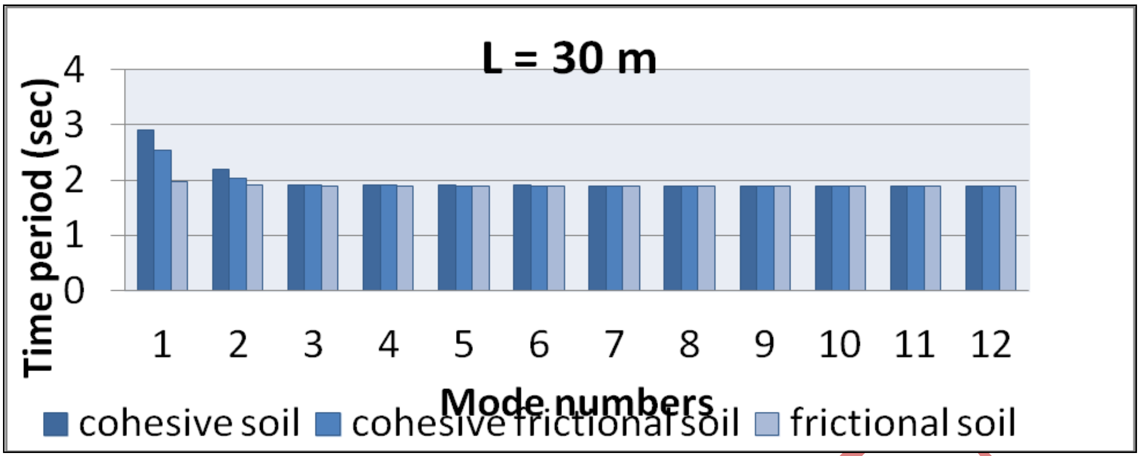


Fig: 6 mode number Vs time period l = 15 m

As shown in above figures, the structure with cohesive soil behave with more time period for first 3 modes as in case of cohesive soils, the conditions turns to more flexible and time period is increased for both pile lengths.

III DYNAMIC ANALYSIS

All real physical structures behave dynamically when subjected to loads or displacements. The additional inertia forces, **from Newton's second law**, are equal to the mass times the acceleration. If the loads or displacements are applied very slowly, the inertia forces can be neglected and a static load analysis can be justified. Hence, dynamic analysis is a simple extension of static analysis. In addition, all real structures potentially have an infinite number of displacements. Therefore, the most critical phase of a structural analysis is to create a computer model with a finite number of mass less members and a finite number of node (joint) displacements that will simulate the behaviour of the real structure. The mass of a structural system, which can be accurately estimated, is lumped at the nodes. Also, for linear elastic structures, the stiffness properties of the members can be approximated with a high degree of confidence with the aid of experimental data. However, the dynamic loading, energy dissipation properties and boundary (foundation) conditions for many structures are difficult to estimate. This is always true for the cases of seismic input or wind loads. To reduce the errors that may be caused by the approximations summarized in the previous paragraph, it is necessary to conduct many different dynamic analyses using different computer models, loading and boundary conditions. This ground acceleration is descritized by numerical values at discrete time intervals. Integration of this time acceleration history gives velocity history, integration of which in turn gives displacement history.

3.1 Nonlinear Time History Analysis For 25 Storeys Building With Different Time Histories

To check the behavior of the building with different earth quake with different duration and magnitude were adopted the details of these all time histories are as under

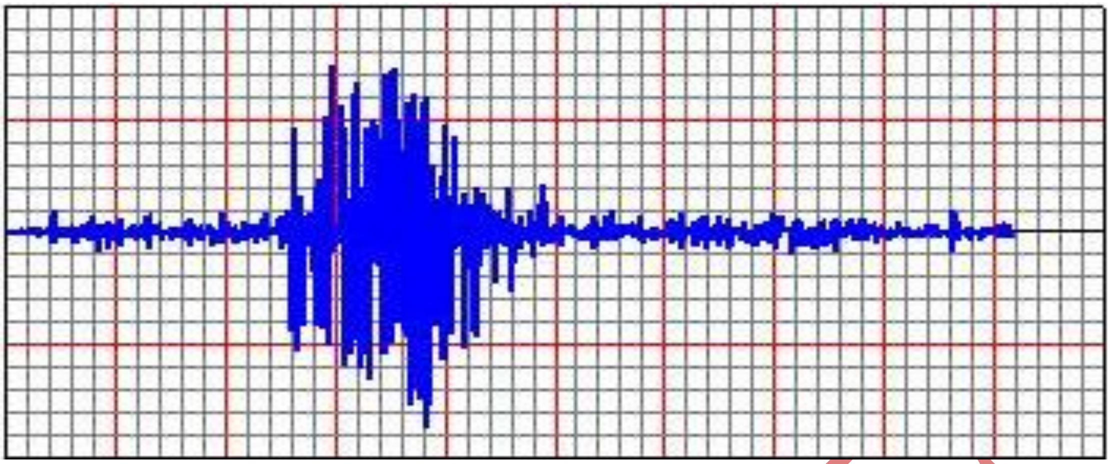


Fig: 7 Accelogram for bhuj earthquake, duration 109 sec.

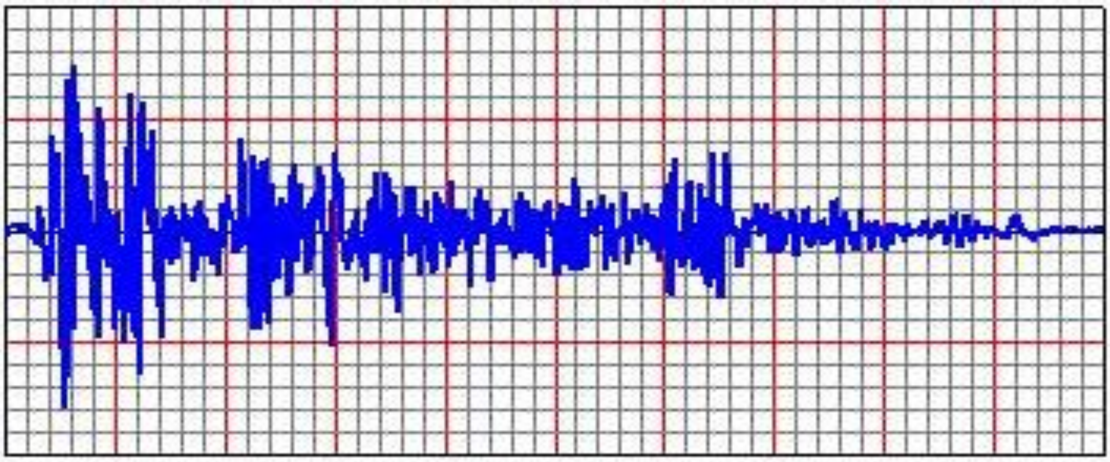


Fig: 8 Accelogram for El Centro earth quake, duration 40 sec.

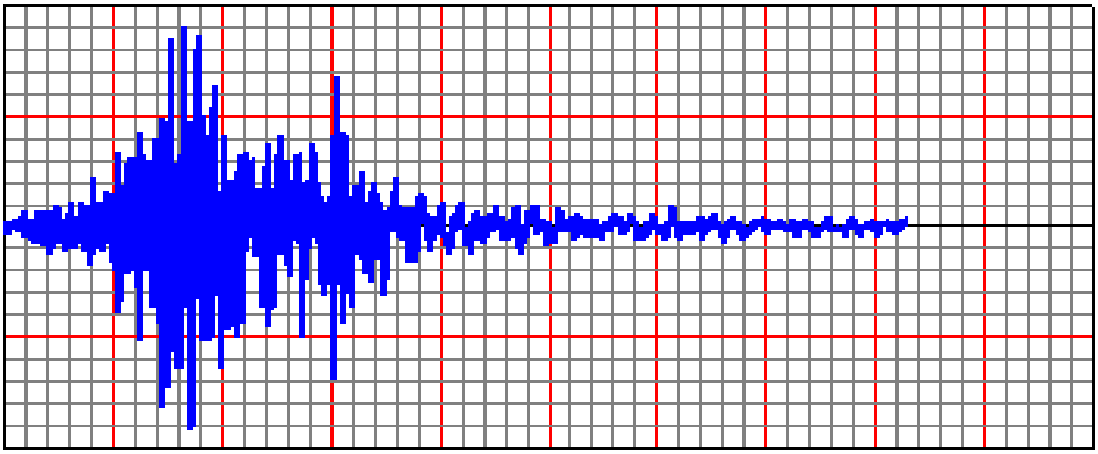


Fig: 9 Accelogram for yermo earth quake, duration 12 sec.

3.2 Analysis and Results of Dynamic Loading

i) Settlement of raft in z direction l = 15 m

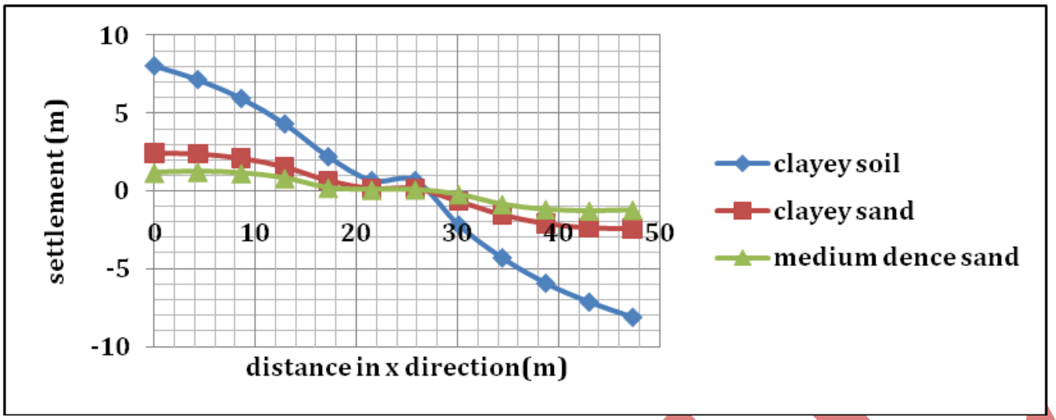


Fig: 10 For Bhuj earthquake l = 15 m

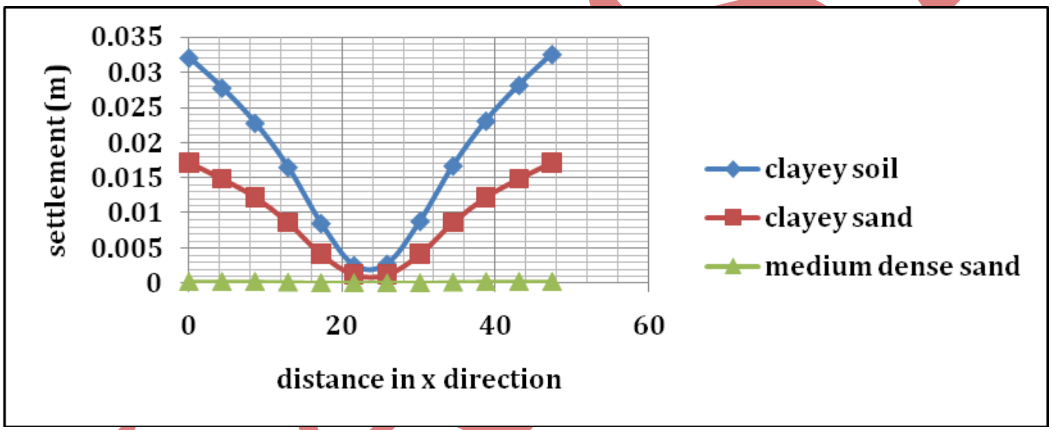


Fig: 11 For El Centro earth quake l = 15 m

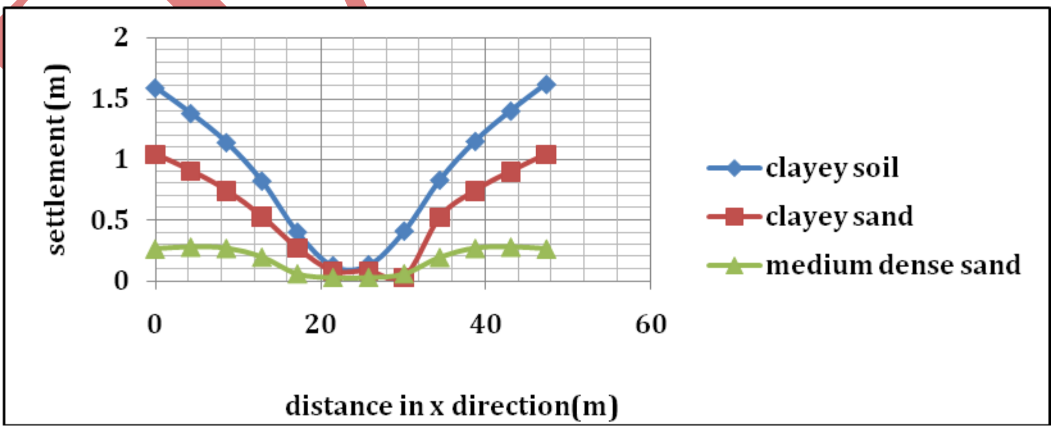


Fig: 12 For yermo earthquake l = 15 m

ii) Settlement of raft in z direction l = 30m

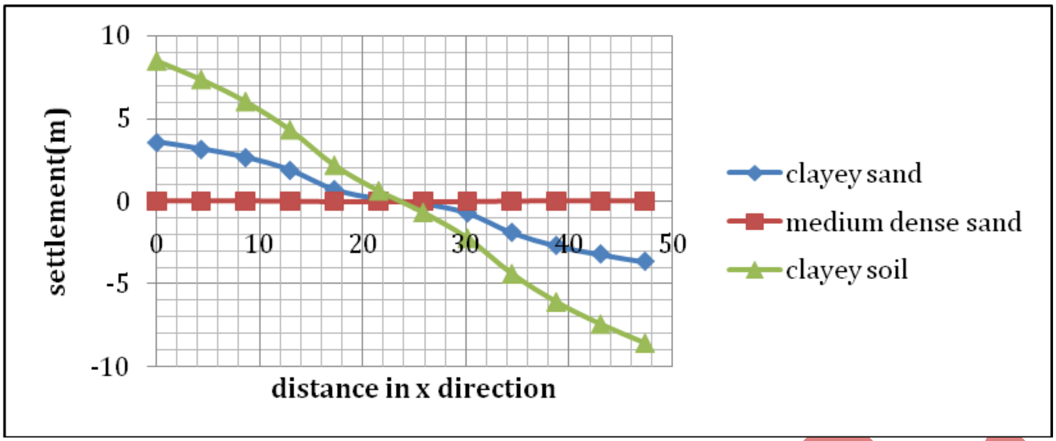


Fig: 13 For bhuj earthquake settlement in z direction l = 30 m

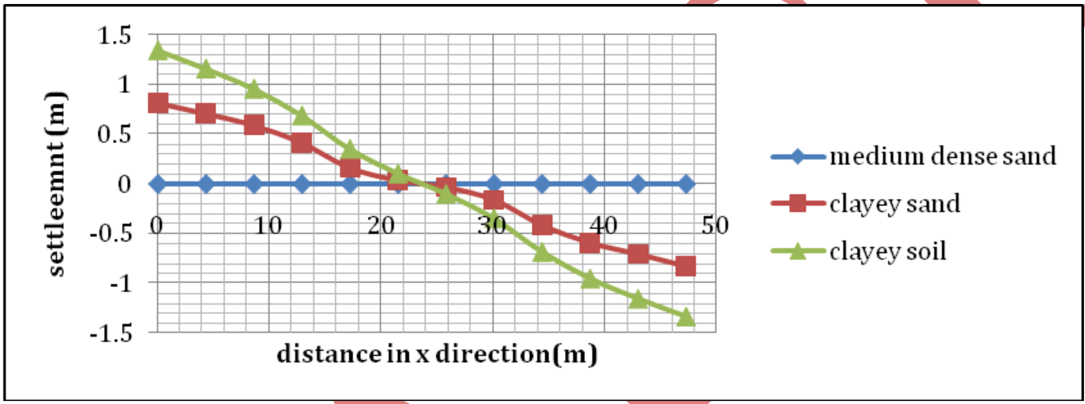


Fig : 14 For yermo earthquake settlement in z direction l = 30 m

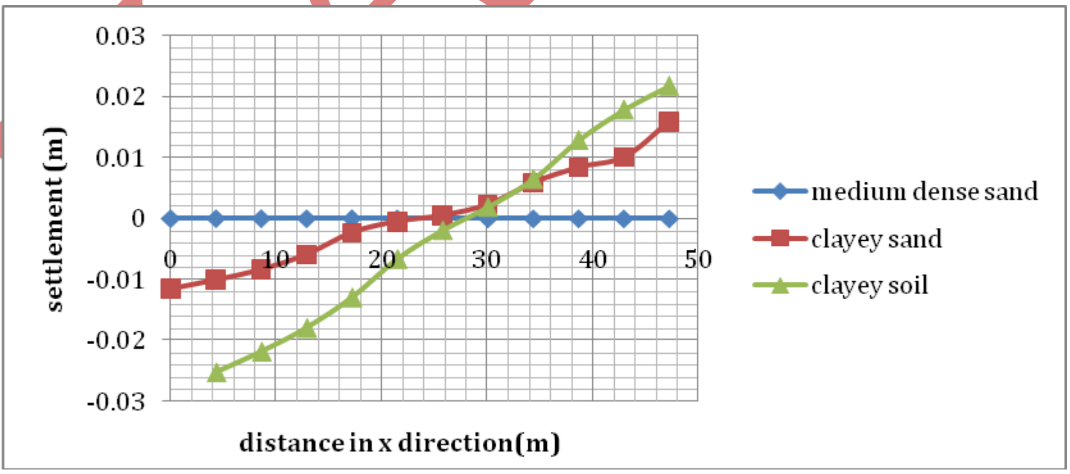


Fig: 15 For El Centro earthquake settlement in z direction l = 30 m

As from above fig amongst all applied time histories, structure is under safer condition for all subsoil variation for El Centro earthquake where as for yermo earthquake and bhuj earthquake building is under safe condition for medium dense sand sub soil.

In more for El Centro earthquake clayey sand reduce the settlement up to 55 % and medium dense sand reduce the settlement maximum up to 99% with compare to clayey soil.

IV DISCUSSION AND CONCLUSIONS

In this research work the analysis was carried out for 25 storey building with 3 different types of sub soil: - medium dense sand (ϕ-soil), clayey sand(c- ϕ soil) and clayey soil(c-soil). The FEM modelling was carried out with Winkler's approach with different elastoplastic spring which represents soil elements with different modulus of subgrde reaction and study was carried out for time history analysis.

- In area of research work for static gravitational loading, it was observed that for the first 3 modes, c soil gives highest time period and ϕ soil gives lowest time period. As c soil reflects more flexibility and structure behaves with more flexibly.

In case of dynamic analysis, three time histories were applied at the base of the footing with different duration and PGA. In which bhuj time history was with highest time period and highest PGA where as El-centro time history was with lowest duration and lowest PGA. The results and observations of above analysis are as under:-

- **Settlement in raft**

- **For bhuj earth quake**:-c soil gives settlement in the range of 7 to 8 m where as c-ϕ soil gives it in the range of 1.5 to 2 m which shows reduction of 65 to 75 % though structure fails in this two sub soil conditions because of excessive settlement beyond permissible limits (65 to 100 mm for raft IS;1904-1966) where as ϕ soil gave 90 mm to 100 mm settlement which was on the verge of failure.
- **For yermo earth quake**:-c soil gives settlement in the range of 1.5 to 1.6 m where as c-ϕ soil gives it in the range of 0.5 to 1 m which shows reduction of 35 to 40 % and ϕ soil gave 5 mm to 270 mm which shows reduction of 75 to 85 % though structure fails in all sub soil conditions because of excessive settlement beyond permissible limits (65 to 100 mm for raft IS;1904-1966)
- **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)

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