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Research Paper

A DYNAMIC BEHAVIOURAL STUDY OF 25 STOREY BUILDING WITH PILED RAFT FOUNDATION WITH VARIABLE SUBSOILS

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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 during earthquake 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. As the inclusion of study of soil structure interaction is very important in case of high rise building, in this paper an attempt is made to study the behaviour of 25 storey building resting on different types of subsoil with piled raft foundation system during earthquake.

Keywords: Dense sand, Settlement control, Soil structure interaction

INTRODUCTION

High rise buildings are usually founded on some form of piled foundation which is subjected to a combination of vertical, lateral and overturning forces. Combined pile-raft foundations can be a particularly effective form of foundation system for tall buildings because the raft is able to provide a reasonable measure of both stiffness and load resistance. 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 two time histories of Bhuj and El Centro earthquake were selected.

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ADVANTAGES OF PILED RAFT FOUNDATIONS

Piled raft foundations utilize piled support for control of settlements with piles providing most of the stiffness at serviceability loads, and the raft element providing additional capacity at ultimate loading. Consequently, it is enerally possible to reduce the required number of piles when the raft provides this additional capacity. In addition, the raft can provide redundancy to the piles, for example, if there are one or more defective or weaker piles, or if some of the piles encounter karstic conditions in the subsoil. Under such circumstances, the presence of the raft allows some measure of re-distribution of the load from the affected piles to those that are not affected, and thus reduces the potential influence of pile "weakness" on the foundation performance. Another feature of piled rafts, and one that is rarely if ever allowed for, is that the pressure applied from the raft on to the soil can increase the lateral stress between the underlying piles and the soil, and thus can increase the ultimate load capacity of a pile as compared to free-standing piles (Katzenbach *et al.*, 1998). A geotechnical assessment for design of such a foundation system therefore needs to consider not only the capacity of the pile elements and the raft elements, but their combined capacity and interaction under serviceability loading. The most effective application of piled rafts occurs when the raft can provide adequate load capacity, but the settlement and/or differential settlements of the raft alone exceed the allowable values. Poulos (2001) has examined a number of idealized soil profiles, and found that the following situations may be favorable:

- Soil profiles consisting of relatively stiff clays.
- Soil profiles consisting of relatively dense sands.

In both circumstances, the raft can provide a significant proportion of the required load capacity and stiffness, with the piles acting to "boost" the performance of the foundation, rather than providing the major means of support.

DESIGN PRINCIPLES

Design Issues

The following issues usually need to be addressed in the design of foundations for high-rise buildings:

1. Ultimate capacity of the foundation under vertical, lateral and moment loading combinations.
2. The influence of the cyclic nature of wind, earthquakes and wave loadings (if appropriate) on foundation capacity and movements.
3. Overall settlements.
4. Differential settlements, both within the high-rise footprint, and between high-rise and low-rise areas.
5. Structural design of the foundation system; including the load sharing among the various components of the system (for example, the piles and the supporting raft), and the distribution of loads within the piles. For this, and most other components of design, it is essential that there be close cooperation and interaction between the geotechnical designers and the structural designers.

6. Possible effects of externally-imposed ground movements on the foundation system, for example, movements arising from excavations for pile caps or adjacent facilities.
7. Earthquake effects, including the response of the structure foundation system to earthquake excitation, and the possibility of liquefaction in the soil surrounding and/or supporting the foundation.

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 v. 14 is used to model the actual work problem.

The data of the problem is as under:

• Details of The Problem

Height - 90m
Building Plane - 43.2 x 20.7m
Column Dimension – 600x600 mm
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 modelled in SAP: 2000 using shell and frame element

To check the behavior 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 □ = 0. For examples cohesive soil, saturated clays and silts.
- Cohesion less soils (□ - 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-□ soils): These are the composite soils having both cohesion and friction. So they are referred as c-□ soils. i.e., clayey sand, sandy clay, silty sand etc.

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.

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

Figure 1: Front View of 25 Storey Building with Pile Length l = 15 m

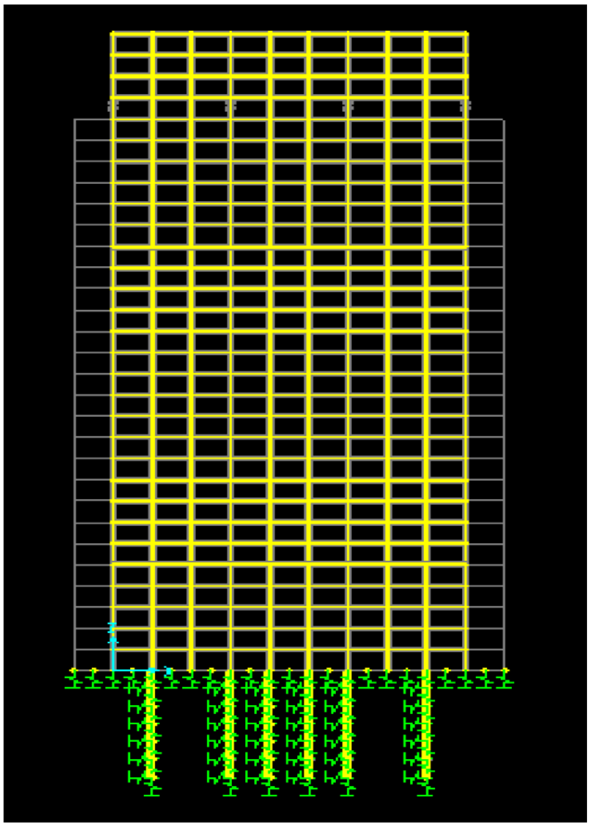
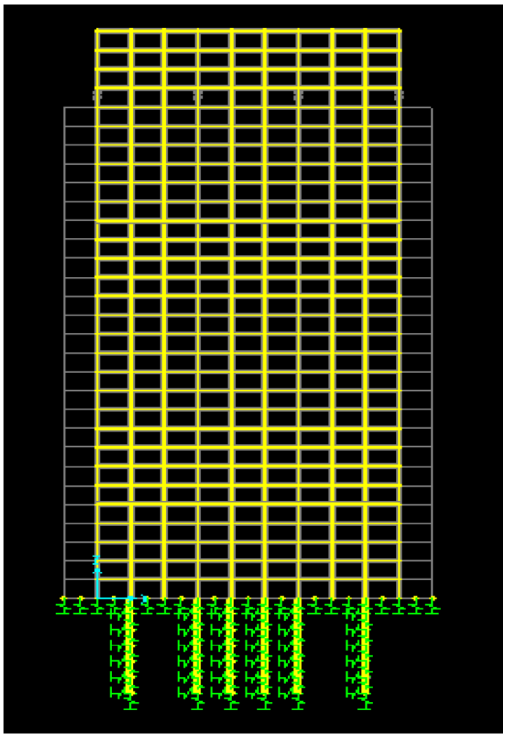
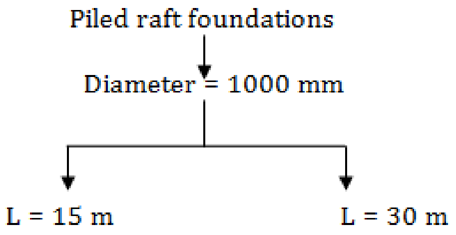


Figure 2: Front View of 25 Storey Building with Pile Length l = 30 m



Variation of Length of Piles Studied for Research



computer model with a finite number of mass less members and a finite number of node (joint) displacements that will simulate the behavior 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.

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

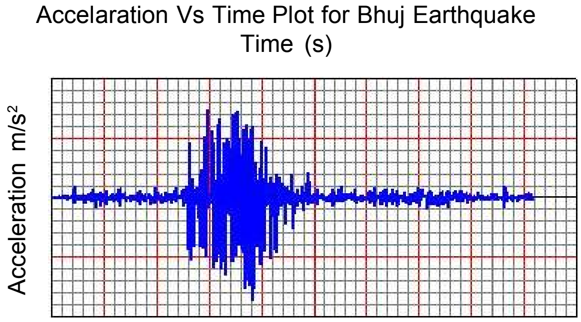
1. Bhuj Earthquake:

   Date: 26/1/2001, time: 8:46:42

   Magnitude: 7.2, duration: 109 s

   PGA: 0.24 g

Figure 3: Accelogram for Bhuj Earthquake, 26/1/2000



2. El Centro Earthquake:

   Date: 19/5/19 40, time: –

   Magnitude: 6.7, duration: 40 s

   PGA: 0.319

Figure 4: Accelogram for El Centro Earthquake, 19/5/1940

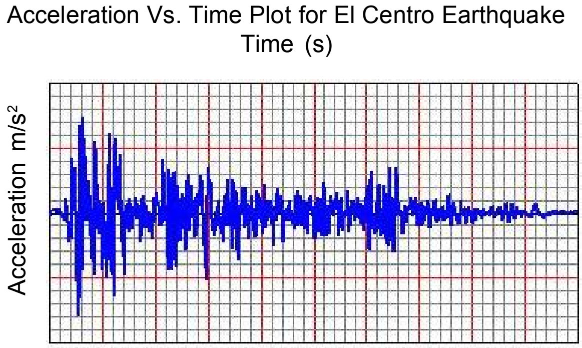


Table 1: Summary of All the Accelograms

S. No.	Name of Earthquake	Date	Duration (s)	Magnitude (M)	PGA (g)
1.	Bhuj	26/1/2001	109 s	7.2	0.38
2.	El Centro	19/5/1940	40 s	6.7	0.31

ANALYSIS AND OBSERVATION

Displacement of the Structure in x Direction for Various Time Histories L = 15 m

Figure 5: Displacement in x Direction for El Centro Earthquake = 15 m

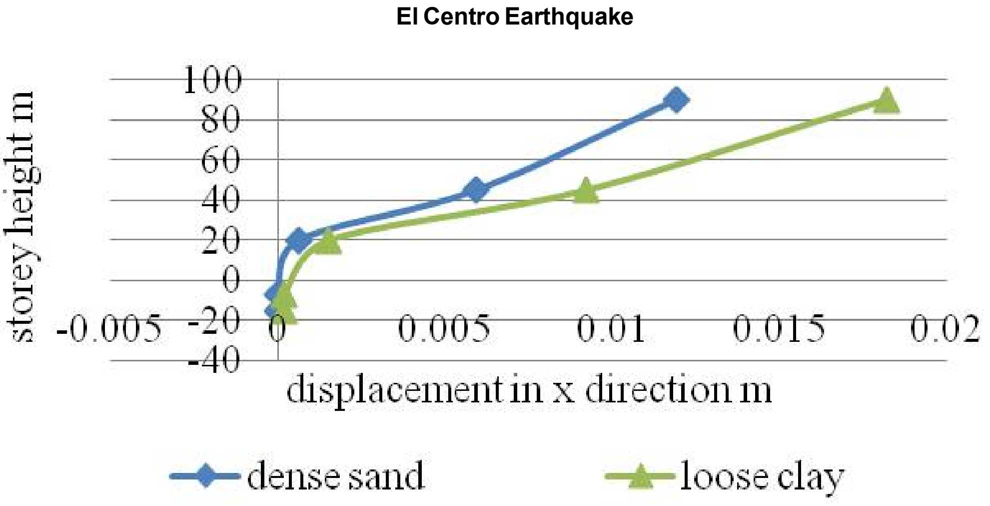
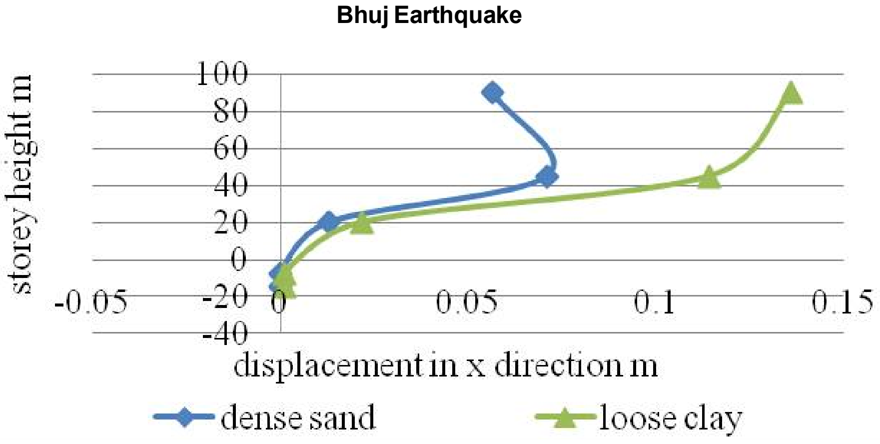


Figure 6: Displacement in x Direction for Bhuj Earthquake, l = 15 m

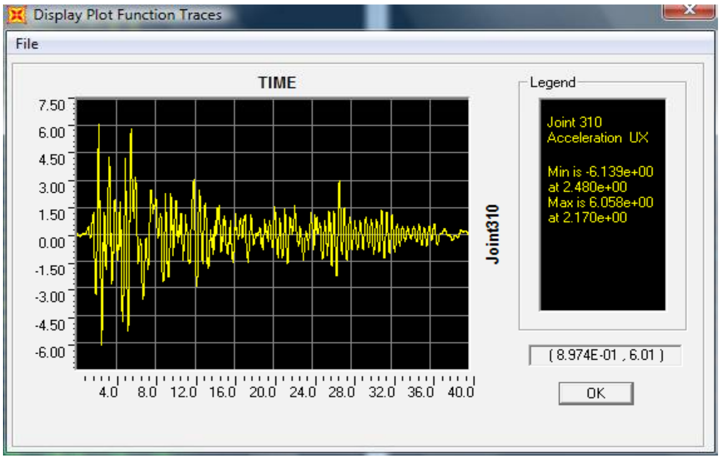


From all above results it was observed that cohesion less soil (dense sand) with l = 15 shows very good behaviour for various responses of applied time histories. And it gives less displacement in **x** direction.

Acceleration Response of the Structure for El Centro Earthquake for l = 15 m Cohesion Less Soil and Cohesive Soil

From all above graphs it was observed that, for cohesion less soil, maximum acceleration for all selected points was less and time period was also less for cohesion less soil (dense sand).Overall piled raft foundation with cohesion less soil like dense sand is a very good combination for the reasonable behaviour of the structure in earthquake. Some of above result was generated for the case L = 30 m which are as under.

Figure 7: Acceleration Response for Cohesion Less Soil on Top of the Structure

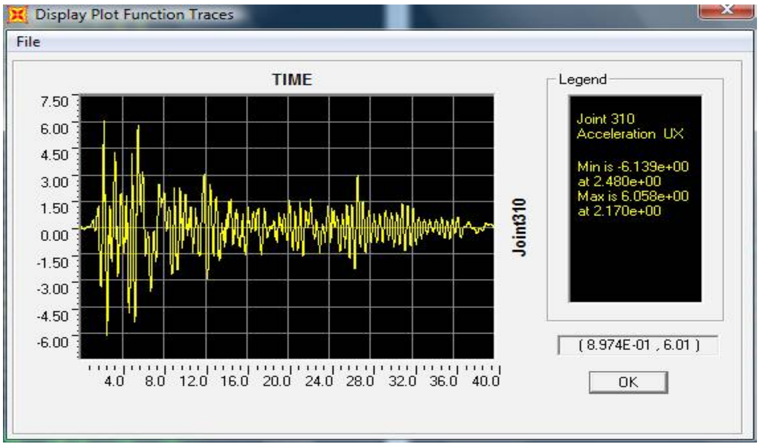


```
Joint 310
Acceleration UX

Min is -6.139e+00
at 2.480e+00
Max is 6.058e+00
at 2.170e+00
```

(8.974E-01 , 6.01)

Figure 8: Acceleration Response for Cohesive Soil on Top of the Structure

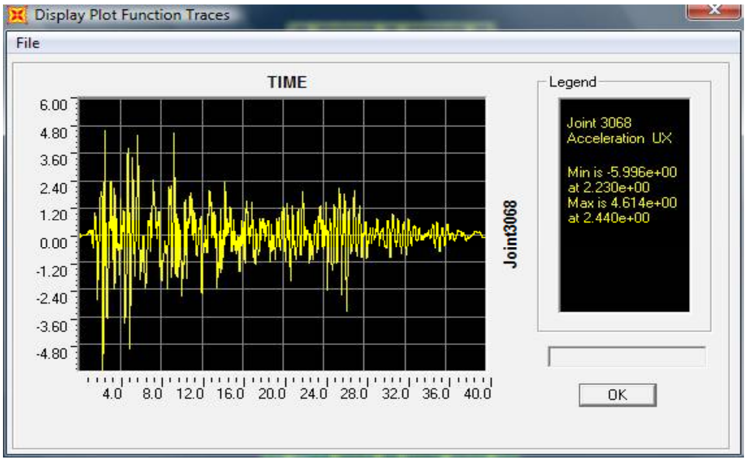


```
Joint 310
Acceleration UX

Min is -6.139e+00
at 2.480e+00
Max is 6.058e+00
at 2.170e+00
```

(8.974E-01 , 6.01)

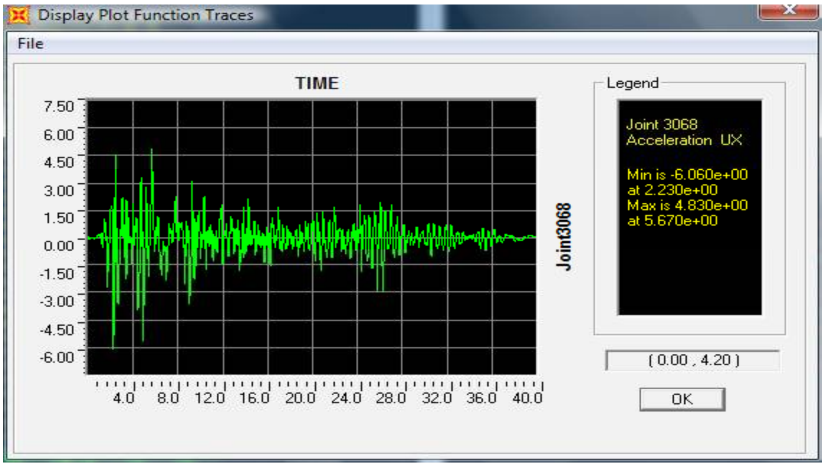
Figure 9: Acceleration Response for Cohesive Less Soil at Middle of the Structure



```
Joint 3068
Acceleration UX

Min is -5.996e+00
at 2.230e+00
Max is 4.614e+00
at 2.440e+00
```

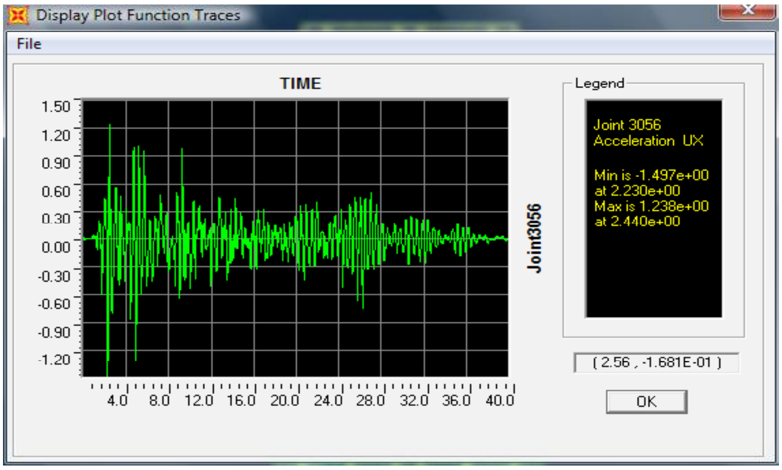
Figure 10: Acceleration Response for Cohesion Soil at Middle of the Structure



```
Joint 3068
Acceleration  UX

Min is -6.060e+00
at 2.230e+00
Max is 4.830e+00
at 5.670e+00
```

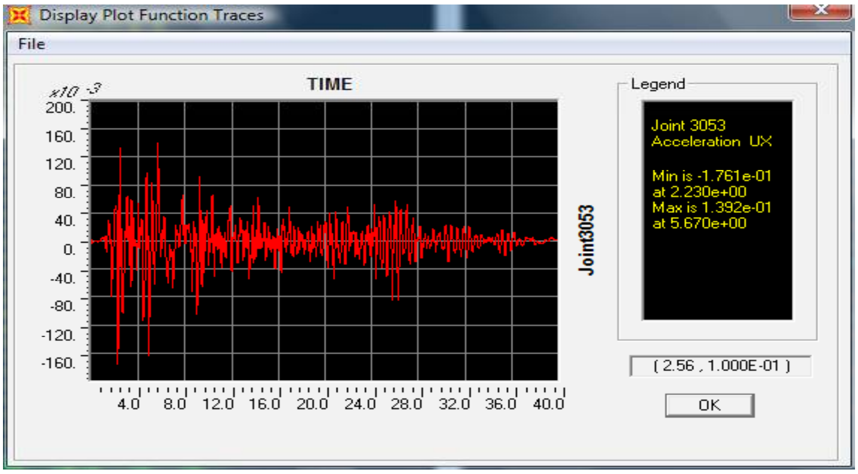
Figure 11: Acceleration Response for Cohesive Less Soil at Bottom of the Structure



```
Joint 3056
Acceleration  UX

Min is -1.497e+00
at 2.230e+00
Max is 1.238e+00
at 2.440e+00
```

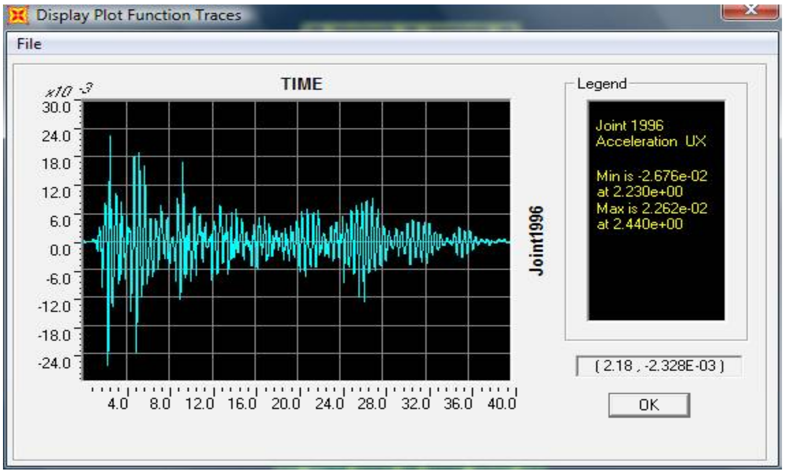
Figure 12: Acceleration Response for Cohesive Soil at Bottom of the Structure



```
Joint 3053
Acceleration  UX

Min is -1.761e-01
at 2.230e+00
Max is 1.392e-01
at 5.670e+00
```

Figure 13: Acceleration Response for Cohesion Less Soil on Top of the Foundation

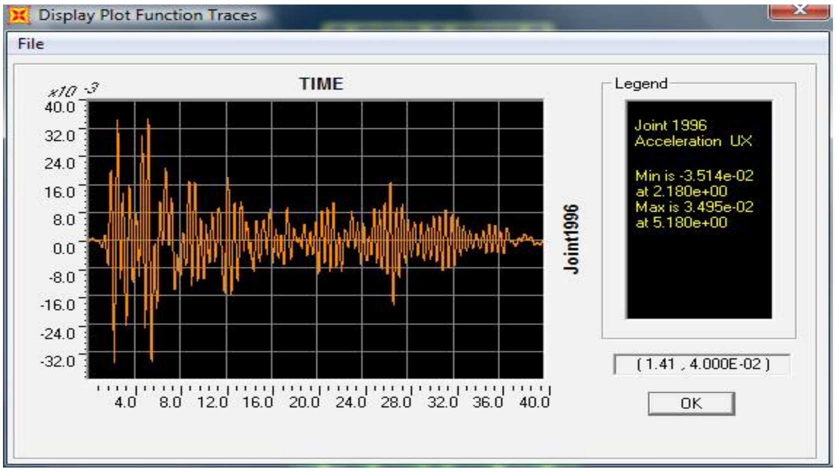


Joint 1996
Acceleration UX

Min is -2.676e-02
at 2.230e+00
Max is 2.262e-02
at 2.440e+00

(2.18 , -2.328E-03)

Figure 14: Acceleration Response for Cohesion Soil on Top of the Foundation

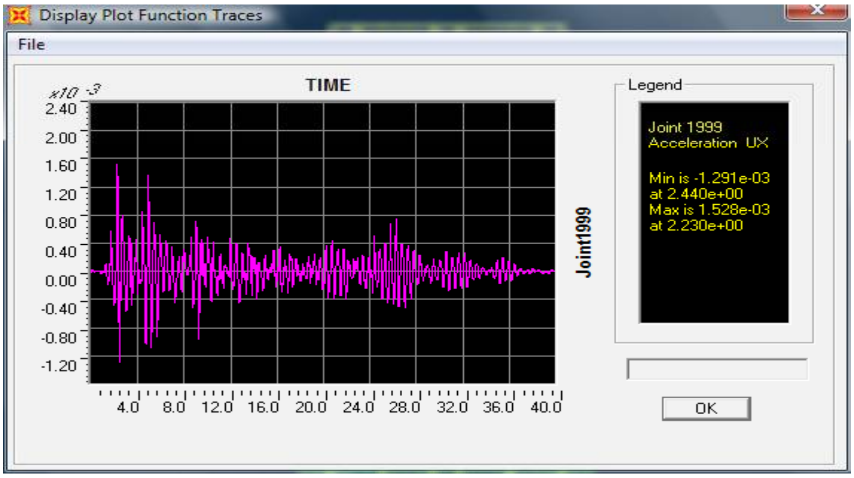


Joint 1996
Acceleration UX

Min is -3.514e-02
at 2.180e+00
Max is 3.495e-02
at 5.180e+00

(1.41 , 4.000E-02)

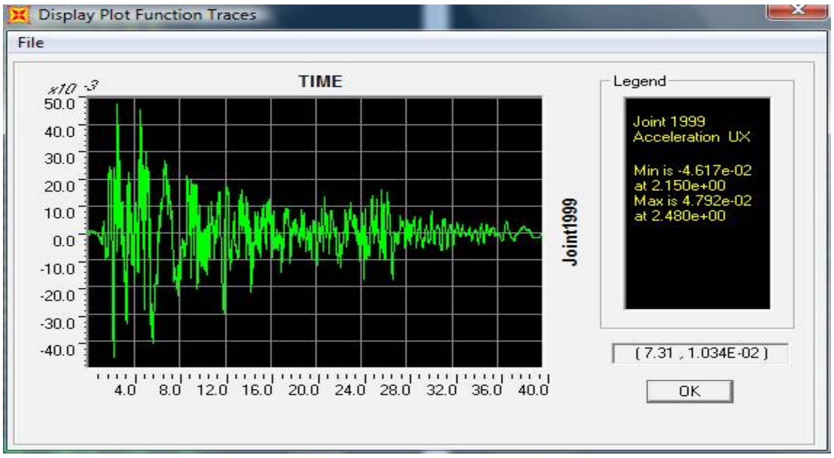
Figure 15: Acceleration Response for Cohesion Less Soil at Middle of the Foundation



Joint 1999
Acceleration UX

Min is -1.291e-03
at 2.440e+00
Max is 1.528e-03
at 2.230e+00

Figure 16: Acceleration Response for Cohesion Soil at Middle of the Foundation

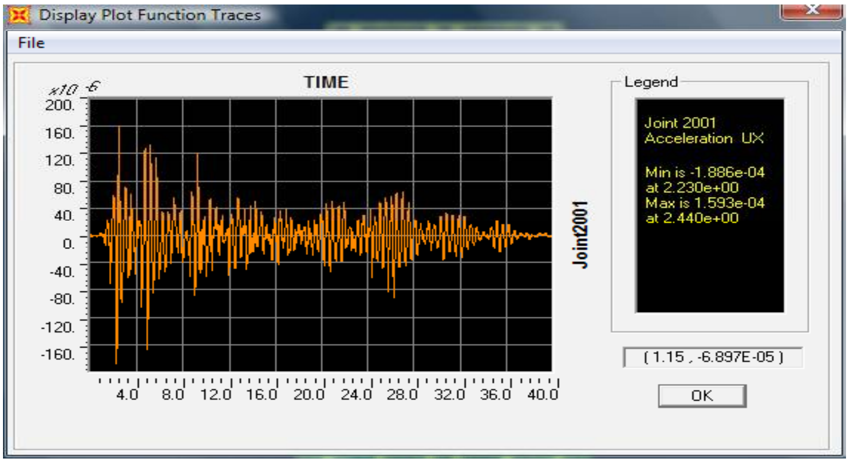


Joint 1999
Acceleration UX

Min is -4.617e-02
at 2.150e+00
Max is 4.792e-02
at 2.480e+00

(7.31 , 1.034E-02)

Figure 17: Acceleration Response for Cohesion Less Soil at Bottom of the Foundation

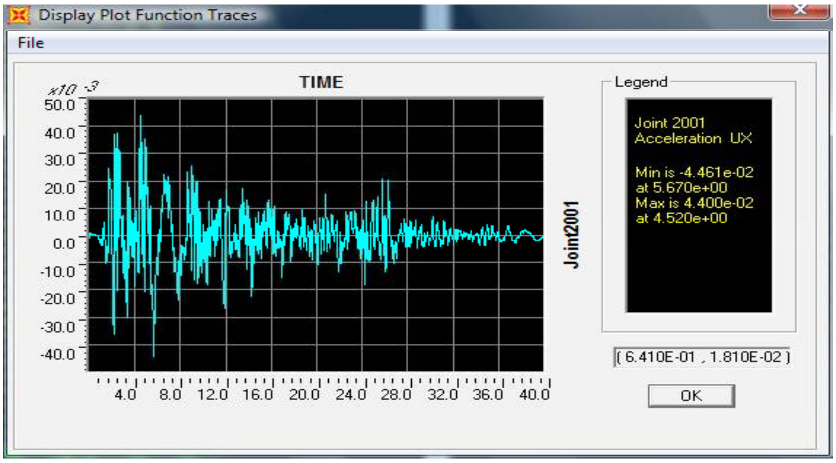


Joint 2001
Acceleration UX

Min is -1.886e-04
at 2.230e+00
Max is 1.593e-04
at 2.440e+00

(1.15 , -6.897E-05)

Figure 18: Acceleration Response for Cohesion Soil at Bottom of the Foundation



Joint 2001
Acceleration UX

Min is -4.461e-02
at 5.670e+00
Max is 4.400e-02
at 4.520e+00

(6.410E-01 , 1.810E-02)

been observed that cohesion less (dense sand) give minimum acceleration response

Displacement in x Direction for Applied Time Histories

Figure 19: Displacement in x Direction El Centro Earthquake l = 30 m

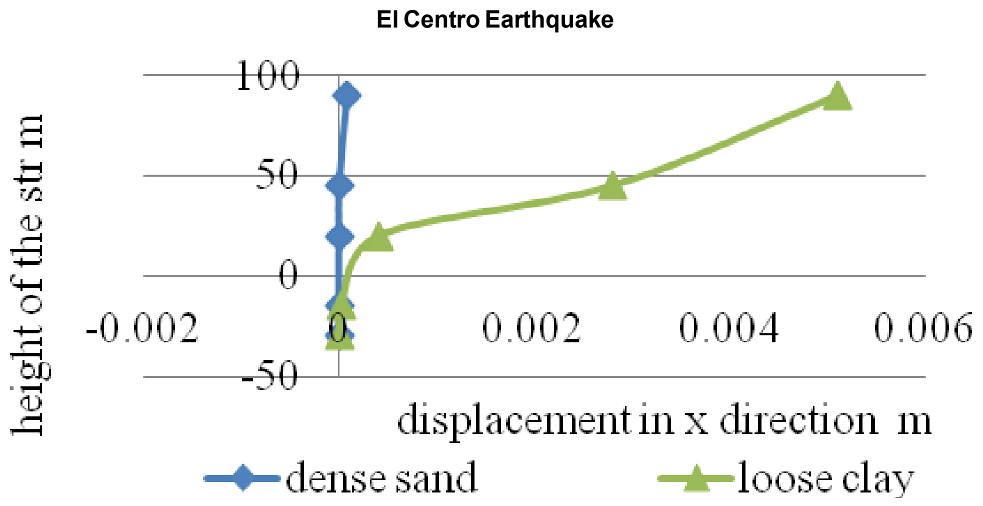
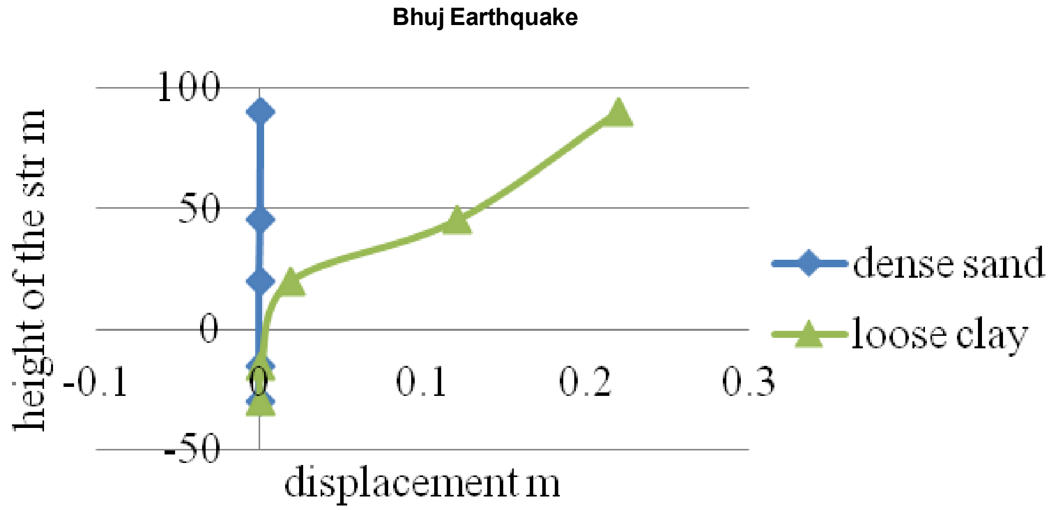


Figure 20: Displacement in x Direction Bhuj Earthquake l = 30 m



CONCLUSION

- The full scale finite element modelling of a 25 storey building supported with piled raft foundation have shown that effect of sub soil on the behavior of the structure is very significant.
- It has been observed that building supported with dense sand gives minimum displacement in x direction for both pile length l = 15 m and l = 30 m.
- For acceleration response, six numbers of points through the length of the structure have been selected and acceleration response on all the points analysed. It has

and time period for all the selected height.

- So overall it have been concluded that piled raft foundation with dense sand type of subsoil was a very good combination for good bearing behaviour of the structure.

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