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# Seismic Analysis of Pile Foundation in Liquefiable Soil

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*Abstract:* **In seismic prone areas where water table is at low level from the ground level, piles support the structure. Due to pore water pressure, soil gets saturated and behaves as a suspension solid which is unable to bear the load. Many pile supported structures collapsed in major earthquakes due to liquefaction as the liquefiable soil gets saturated and lose their stiffness and shear strength. Soil behaves like a fluid which moves laterally due to the inertia load results in continuous movement of liquefiable soil. Research shows that, liquefaction should be considered while designing the pile; however this work is not significantly done. Building on the work of other researchers, linear time history analysis is carried out by finite element software SAP2000 considering liquefiable and non liquefiable soils. Modeling consists of building model (G+9, G+12, and G+ 15) which are supported on pile foundation surrounded by soil. The provision of soil is fulfilled by assigning the particular stiffness properties to pile in lateral direction. An earthquake ground motion record for Northridge and El Centro is applied to the structure. Based on the comparison of the liquefied and non liquefied soil structures considering the parameters like pile length and loading on superstructure, the structural response of piles such as moments in piles, joint displacement and shear induced in lateral direction of pile is studied. Ultimately, it can be seen that the effect of liquefiable soil is a great concern and it affects the interacting parameters as compared to non liquefiable soils. The analytical results indicate that the results obtained due to liquefiable soil on piles are quite different than that of non liquefiable soil.**

*Keywords:* **seismic analysis, pile foundation, liquefaction, shear strength**

## 1. INTRODUCTION

Liquefaction is the most dominant factor in the seismic prone area in world due to which many of the pile supported structure get collapsed during the major earthquakes. Piles which support the superstructure damaged not only due to axial load as well as the inertia load while earthquake. If liquefiable soil is present in the soil strata, then it behaves like the suspension solid and exerts additional force on the pile leads to failure of pile.

Seismic analysis in liquefiable soil of the pile foundation has been carried out by many researchers but it has not done significantly. Past earthquakes studies revealed that, most of the structures collapsed due to liquefaction. Due to pore water pressure, saturated soil loses its shear strength and stiffness which unable to bear any kind of load and act as a thick fluid. The design method should ensure that yield stress limit should not cross by stresses in the pile in any point during the earthquake and also during liquefaction process. While designing pile, the effect of liquefaction should be considered which can be estimate by seismic analysis. In order to get proper understanding of the behavior of piles in terms of various observations such as moments in piles, shear induced in lateral direction of pile as well as joint displacement, analysis is carried out by comparing liquefiable soil model with non liquefiable soil model. The buckling of the pile takes place when end bearing pile embedded in soil strata of different layers having various stiffness and strength. Due to liquefaction, soil loses its stiffness and strength of the soil, so pile acts as long slender column and suspension solid around the pile exerts more stress than the yield stress which causes increase in lateral deflection, formation of plastic hinge [1] as shown in Figure1.

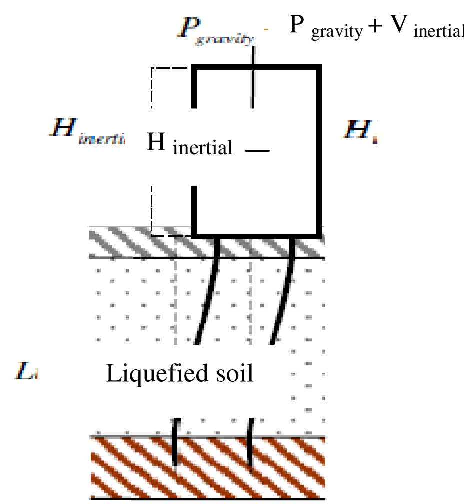



**Fig. 1- Lateral deflection due to liquefaction**

R.S. Meera et. al. tried to analyzed and predicted flexural behaviour of axially and laterally loaded pile foundations under liquefied soil conditions. The prediction was done by comparing the theoretical and observed values in the field [2]. Vijay Puri and Shamsher Prakash discussed the method of pile design and the behaviour of pile in liquefiable soil in lateral spreading ground and concluded that the lateral displacement and bending moment increases due to liquefaction during earthquake [3]. V. S. Phanikanth et al. studied the soil pile structure interaction in presence of liquefiable soil by considering the stiffness degradation effects for a range of earthquakes with different amplitudes, mean time periods, and different durations of earthquakes and the kinematic response then compared with field observations of actual earthquake which shows the significant effect of the liquefaction on the structure [4].

The analysis is carried out in finite element software (SAP 2000) with modeling of liquefiable and non liquefiable soil modeling consist of superstructure supported on pile foundation surrounded by the soil of different layer.

## 2. OVERVIEW OF MODELING

For the purpose of analysis, superstructure supported on pile foundation has been modeled considering loading on superstructure and the depth of pile as the interacting parameter. Three building model G+9, G+12 and G+15 are modeled in order to get the variation in loading of the superstructure. Concrete pile having length 15m is to be provided with spacing of the pile 3x3 m in either direction as shown in Figure 2. Spacing of the pile is kept same for all three models to see the effect of axial as well as the inertia loading and the kinematic loading due to liquefiable soil which surrounds the pile.

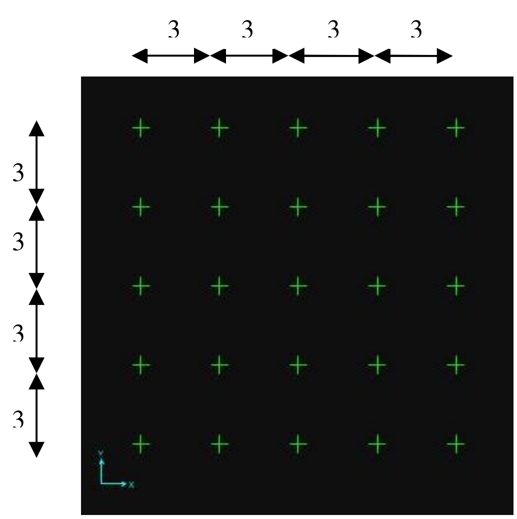



**Fig. 2- Spacing of piles in meters (plan view)**

## 3. ANALYTICAL MODEL OF PILE FOUNDATION

Modeling of pile foundation and the superstructure is approximated using finite element software SAP 2000. Superstructure consists of the three buildings each are varying as per modeling and the slab is modeled as the linear thin shell element which is subjected to the live load of 3 kN/m$^2$ also In general, piles are model as the frame column element as the pile is susceptible to buckling. Pile is considered as the end bearing pile embedded in soil strata and hinge support is provided at the bottom. Concrete (M25) piles are used for the pile. Table 1 show the properties used in the modeling.

**TABLE 1: Properties of the structure**

| Properties | Specifications |
|---|---|
| Size of beam | 230x230 mm |
| Size of column | 230x300 mm |
| Slab thickness | 110 mm |
| Diameter of pile | 450 mm |
| Length of pile | 15m |
| Young's modulus of concrete | 25x10$^9$ N/mm$^2$ |
| Height of story | 2.9 m |

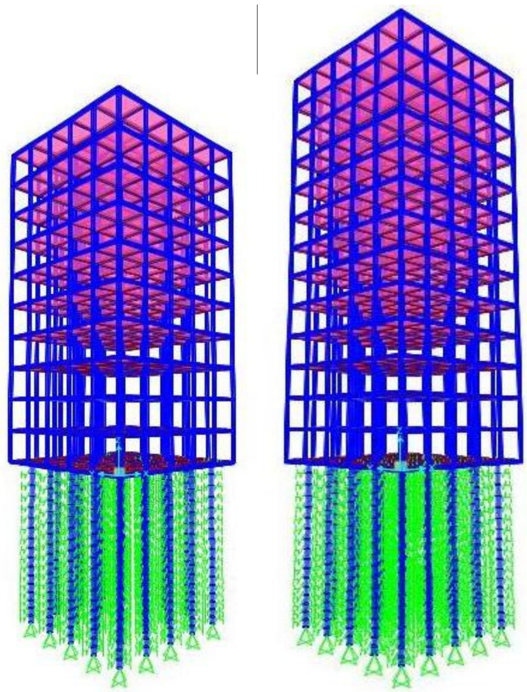
In liquefaction, stiffness of soil plays important role which is surrounded to pile are assign by spring stiffness in both longitudinal as well as lateral direction. For non liquefied soil, spring stiffness provided with no liquefaction whereas, for liquefiable soil imparts kinematic force during earthquake with very low stiffness which is 1/1000 times stiffness as that of non liquefiable soil stiffness. Table 2 presents the soil stiffness properties which are use in the modeling.

**TABLE 2: Soil stiffness properties**

| Sr No. | Soil Strata | Unit weight (kN/m$^2$) | Stiffness (kN/m) |
|---|---|---|---|
| 1 | Soft silty clay | 19.1 | 6.3 |
| 2 | Soft clayey silt | 18.2 | 8.1 |
| 3 | Black clayey soil | 18 | 13.5 |
| 4 | Yellowish clayey soil | 19 | 17.4 |
| 5 | Medium dense silty sand | 19.4 | 21.3 |

Individual pile has been provided instead of the group pile, because the performance of large diameter pile is better than small diameter group piles due to provision of sufficient skin friction. As diameter of the pile increases, the stiffness of the pile section increases and many of the static and dynamic instabilities disappear.

The assignment of soil stiffness in lateral direction produces the effect of the soil strata which supports soil and provides skin friction so as to support superstructure.



(a) (b)

**Fig. 3: 3D Model in SAP 2000**
**(a) G+9 (b) G+12 with soil stiffness**

3D modeling of the pile foundation with soil stiffness is as shown in figure 3 presents the analytical model of G+9 and G+12. In other words, soil stiffness is provided to impart the skin friction to piles.

For the analysis input data consisted of time histories of Northridge earthquake recorded at Arleta and Nordhoff fire station as shown in figure 3 and Imperial Valley earthquake–EL CENTRO as in figure 4.

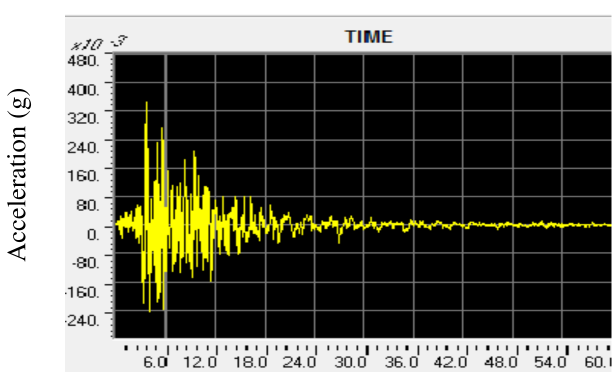



**Fig. 3. Northridge Earthquake**

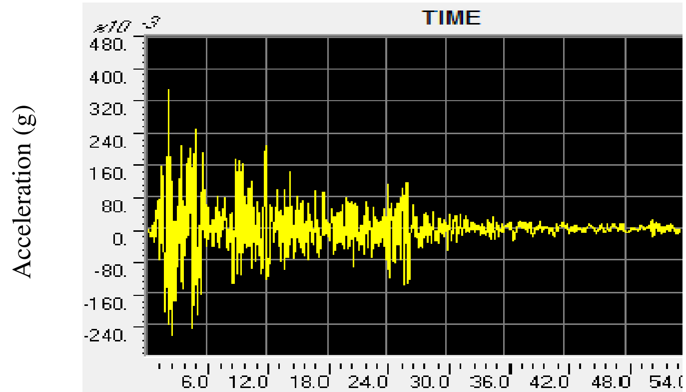



**Fig. 4: Imperial valley earthquake**

## 4. RESULTS AND DISCUSSION

Pile foundation in liquefiable soil was analyzed considering the change in loading of the superstructure subjected to the time history analysis. The free vibration analysis has been carried out before the time history analysis in order to know the fundamental time period and the frequency of the modes. As three superstructures have different loading their time period varies as per the stiffness. The number of modes used for response evaluations is recommended in several seismic codes to include at least 90% of the participating mass for each principal horizontal direction. The time period and the mode shapes for G+15 building is as shown in the table 3

**TABLE 3: Natural time period of G+15 building**

| Mode No. | Liquefied soil layer | Non liquefied soil layer |
|---|---|---|
| 1 | 1.51 | 1.4790 |
| 2 | 1.062 | 1.0427 |
| 3 | 0.3942 | 0.3863 |

Above table shows that, as time period of the liquefied soil layer structure is increases than non liquefied soil structure it shows that the liquefied soil structure has less stiffness.

It analyses that, liquefied pile with low stiffness in range 1/1000 than non-liquefied pile which are supports G+9, G+12, G+15 building. The models are then compared with non-liquefied pile and the results are compared in the responses. i.e. moments and shear force within the pile and the graphical results are as shown below.

The graphical results shows that, the moments in the pile are increased in case liquefied soil layer and moments are directly proportional with the height of building as building height increases moments also increase. it has seen that the change in bending moment occurs at the junction of liquefied and non liquefied soil layer , the liquefied layer is provided at the 60 - 70 % of total pile length. (Fig No. 5,6,7.).

The graph also shows that, the shear force remains constant in the liquefied soil layer throughout the pile length. Which can be considered as critical condition as their may be absence of skin friction due to suspension solids occurs by liquefaction. (Fig No. 8,9,10.). also it has seen that the shear force is maximum liquefied layer.

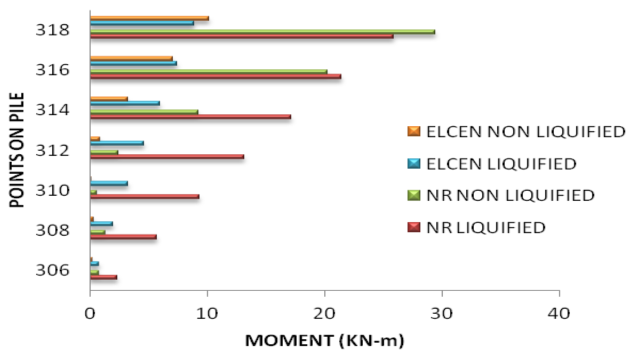



**Fig. 5. Moments in pile of G+9 building**

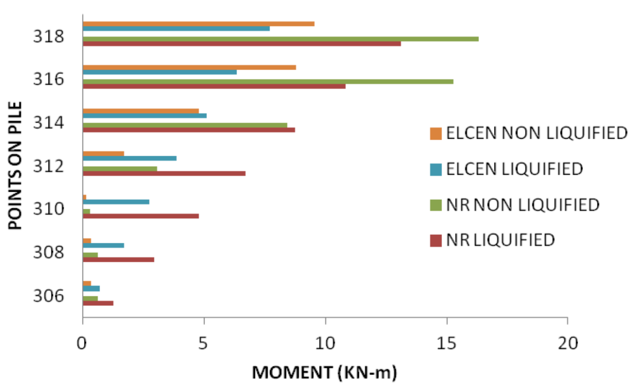



**Fig. 6. Moments in pile of G+12 building**

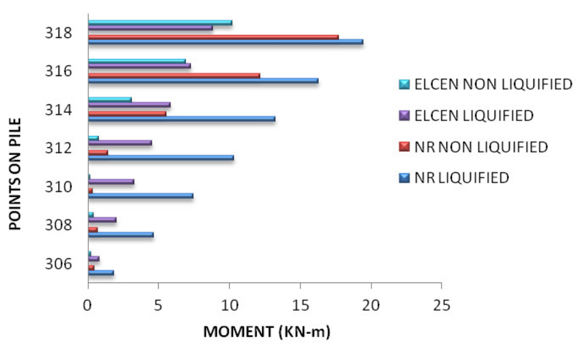



**Fig. 7. Moments in pile of G+15 building**

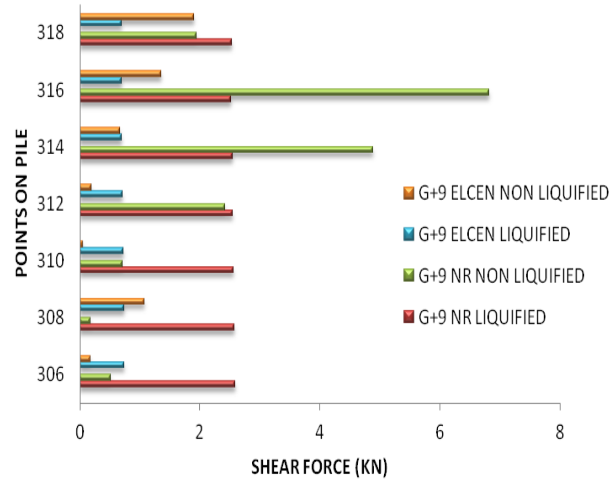



**Fig. 8. Shear in pile of G+9 building**

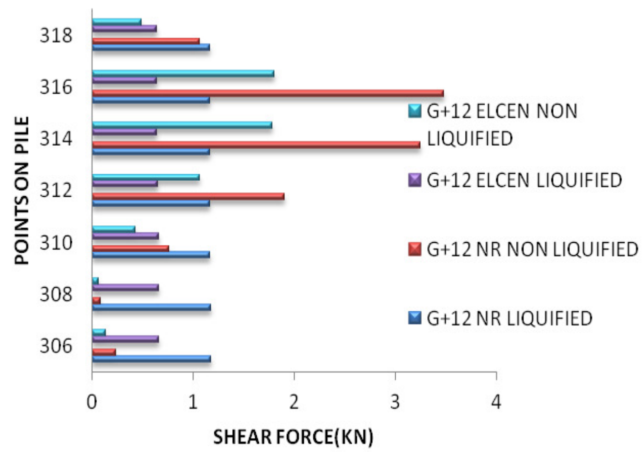



**Fig. 9. Shear in pile of G+12 building**

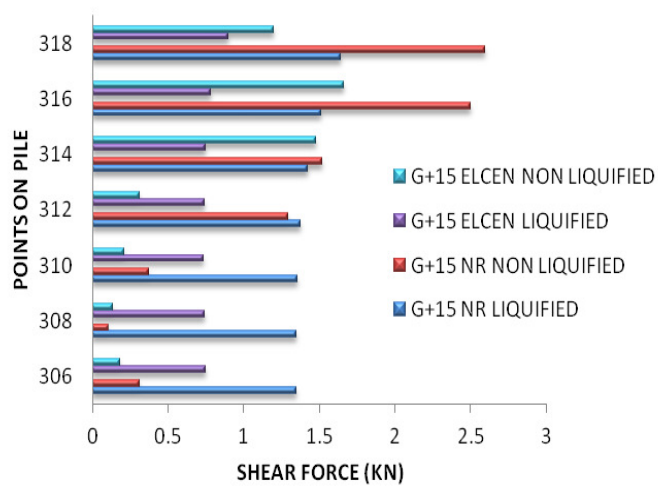



**Fig. 10. Shear in pile of G+15 building**

## 5. CONCLUSION

The time history analysis is carried out for G+9, G+12,G+15 building with the liquefied and non liquefied soil layer and the results present the conclusions are as follows:

1. The moments are maximum in liquefied soil layer but these values of moments are never considered in the design of pile but we should consider the liquefaction effect from point of view of earthquake.

2. The change in moments occurs at the junction of liquefied and non liquefied soil layer.

3. Shear force is constant throughout the pile length in liquefied layer which is critical condition.

4. The joint displacements in case of liquefied layer is maximum due to the movement of non liquefied soil layer overlying liquefied soil layer.

## REFERENCES

[1] Rajib sarkar, Shubhomay Bhattacharya, B.K. Maheshwari, “Seismic Requalification of Pile Foundations in Liquefiable Soils”, Indian geotechnical journal, SPRINGER, April 2014, Vol 42, No. 2, p.p 183-195.

[2] R. S. Meera K. Shanker P. K. Basudhar “Flexural response of piles under liquefied soil conditions” Geotech Geol Eng (2007) 25:409–422.

[3] Vijay K. Puri and Shamsher Prakash, “Pile Design In Liquefying Soil”, 14th World Conference Of Earthquake Engineering Beijing China, October 2008, p.p 1-8.

[4] K. Ishihara, M. Kubrinovski, “Soil Pile Interaction In Liquefied Deposit Undergoing Lateral Spreading”, 11th Danube- European conference Croatia, May 1998, p.p 1-14.

[5] V. S. Phanikanth, Deepankar Choudhury, G. R. Reddy, “Behaviour of Single Pile in Liquefied Deposits during Earthquakes”, International Journal Of Geomechanics, ASCE, August 2013, Vol 13, p.p 445-462.

[6] W. D. Liam Finn, “A Study of Piles during Earthquakes: Issues of Design and Analysis”, Bulletin of Earthquake Engineering, Springer 2005 ,Vol 3, p.p141–234.

[7] S. Bhattacharya, S. P. G. Madabhushi And M. D. Bolton, “An Alternative Mechanism Of Pile Failure In Liquefiable Deposits During Earthquakes”, 2004. Geotechnical journal, vol 54, No. 3, p.p 203–213.

[8] Assaf Klar, Sam Frydman, Rafael Baker, “Seismic Analysis Of Infinite Pile Groups In Liquefiable Soil”, Soil Dynamics and Earthquake Engineering, ELSEVIER, October 2004, p.p 565–575.

[9] Ahmed Abdelraheem Farghaly and Hamdy Hessain Ahmed, “Contribution of Soil-Structure Interaction to Seismic Response of Buildings”, KSCE Journal of Civil Engineering (2013), Vol 17, No.5, p.p 959-971

[10] Vijay K. Puri and Shamsher Prakash, “Pile Design In Liquefying Soil”, 14th World Conference Of Earthquake Engineering Beijing China, October 2008, p.p 1-8

[11] Shin’ichiro Mori, Atsunori Numata And Baoqi Guan, “Damage To A Pile Foundation Due To Liquefied Ground Motion”, 12th World Conference On Earthquake Engineering 2000, p.p 1-8

[12] W. D. Liam Finn, “A Study of Piles during Earthquakes: Issues of Design and Analysis”, Bulletin of Earthquake Engineering, Springer 2005 ,Vol 3, p.p141–234