Thessaloniki-GREECE 2007

4th International Conference on
Earthquake Geotechnical Engineering
June 25-28, 2007
Paper No. 1127

# EFFECTS OF THE INCLINATION AND LENGTH VARIATION OF MICROPILES ON BEARING CAPACITY OF SANDY SOILS

Abolhassan NAEINI [1], Nader FATHOLOLUMI[2]

## ABSTRACT

This paper presents the numerical analysis results of bearing capacity studies of sandy soils using ANSYS 10 finite element software. At first a sandy soil media with properly given properties is modeled and under increasing loading, the bearing capacity is studied. Then micropiles with 20cm diameter and with various lengths 3m to 10m and with various inclinations 0 to 45 degree with the vertical axes which are used in practical usages inserted in this sandy soil, and bearing capacity of soil is studied. Next the bearing capacity graphs for this sandy soil with and without use of micropiles with various inclinations are plotted and effects of them are studied. Finally comparisons between results obtained from these studies are done. The obtained results show that use of micropiles in sandy soils leads to increase in bearing capacity up to 100 percent. The results of this study can provide valuable information about use of micropiles in sandy soils.

Keywords: Micropile, Length, Inclination, Numerical analysis, Bearing capacity, Sandy soils

## INTRODUCTION

Today to stabilize and improve soils particularly in loose lands and to increase the bearing capacity of them, very extent and various methods are used that include the various methods of soil improvement. One of the best of these methods is the use of micropiles, the application of which is increasing for reasons such as time saving, reduction in execution costs, minor materials, choice of quick equip and transport of micropile performance facilities and settlement control.

Piles with a diameter of less than 30cm are generally referred to as micropiles (Lizzi 1980; FHWA 1997). Modern micropiles were initiated by Dr. F. Lizzi in the 1950s in Italy, where they were called pali radice (root piles) (Lizzi 1964, 1971). Micropiles are now widely used for both structural supports in foundations and in-situ earth reinforcement (Lizzi 1978; Lizzi 1980; Lizzi 1994; FHWA 1997; Tsukada & Ichimura 1997; Mitchell et al. 1999). Micropiles are considered promising foundation elements for improving the bearing capacity or preventing the settlement of existing, deteriorating foundations with minimum disturbance to structure, subsoils, and the environment (Mason 1997; Tsukada et al. 1999). As a response to the destructive Hyogoken-Nambu earthquake in 1995 in Japan, research and development regarding the applications of micropiles in strengthening foundations have been focused on in Japan (Tsukada & Ichimura 1999).

Recent studies realized about on micropiles as well as semi-static analyses conducted by Juran et al. (2001) showed that the incline of micropiles contain : 1) a decrease of movements and bending

[1] Ph.D, Department of Civil Engineering, Imam Khomeini International University, Iran, Email: Naeini_h@yahoo.com
[2] Student, Department of Civil Engineering, Imam Khomeini International University, Iran. Email : Naderfti@yahoo.com

moments in the micropiles and 2) an increase of the normal stress in the micropiles. In the literature few works were devoted to the study of the micropiles and inclined micropiles that are in static or dynamic state.

This paper attempts to analyze and study the influence of micropile inclination and length variation on bearing capacity of sandy soils by numerical analysis. Analysis is conducted using finite-element analysis (FEM) with ANSYS 10 program. This program has advantages in contrast to its previous version. The results obtained in this study provide valuable information about use of micropiles in sandy soil.

The first part of the paper presents the material properties used in this study. The second part presents analysis considerations on different conditions of micropile lengths and inclinations embedded in sandy soil. In the last part the obtained results of analyses are presented in the form of graphs and discussions about them are carried out.

## MATERIAL PROPERTIES

Considering that micropiles are mostly used in loose soils to increase their bearing capacity, so we insert the micropiles in loosely sandy soil and soil surrounding the micropiles has been denser. Since the micropiles were closely spaced and because of grouting it was assumed that densification of the soil surrounding the micropiles and corresponding group effect is significant. The properties used for the materials are shown in Table 1.

**Table 1. Properties of materials used in modeling**

| Material | model | C (Kpa) | φ (°) | ψ (°) | E (Mpa) | υ | γ (KN/m$^3$) |
|---|---|---|---|---|---|---|---|
| Loose sand | Druger Prager | 1 | 25 | 6 | 13 | 0.3 | 18 |
| Dense sand | Druger Prager | 1 | 35 | 8 | 30 | 0.3 | 20 |
| Micropile | Elastic | - | - | - | $2.1\times10^5$ | 0.25 | 78.5 |
| Footing | Elastic | - | - | - | $2.3\times10^4$ | 0.28 | 24 |

## ANALYSIS CONSIDERATIONS

In the analysis, the concrete footing is taken as beam element and assumed to behave as flexible and full footing of width 4.0m is analyzed as plane strain problem. Standard boundary conditions (viz. imposing horizontal as well as vertical fixity to all nodes at both sides of mesh) are applied and when the length of micropiles increases, the depth and width of soil consequently increase so that the standard boundary conditions are considered. The soil was modeled as Druger-Pruger material and the micropile is modeled as elastic material while the footing is taken as beam element with elastic behavior. The space between micropile and soil (dense sand) was modeled with contact element (node to node) with friction coefficient (Mu) equal to 0.65.

Micropiles with 20cm diameter and length of 3m and with inclinations 0 to 45 degree with the vertical axes which are used in practical usages are inserted in the sandy soil and using ANSYS 10 program the modeling is done and increasing loading is applied to soil. After above operations, this process for lengths of 4m, 5m, 7m and 10m is repeated and result of these studies are obtained.

Fig 1 shows the finite element mesh along with boundary conditions for micropile 7m with inclination 10° with the vertical axes.

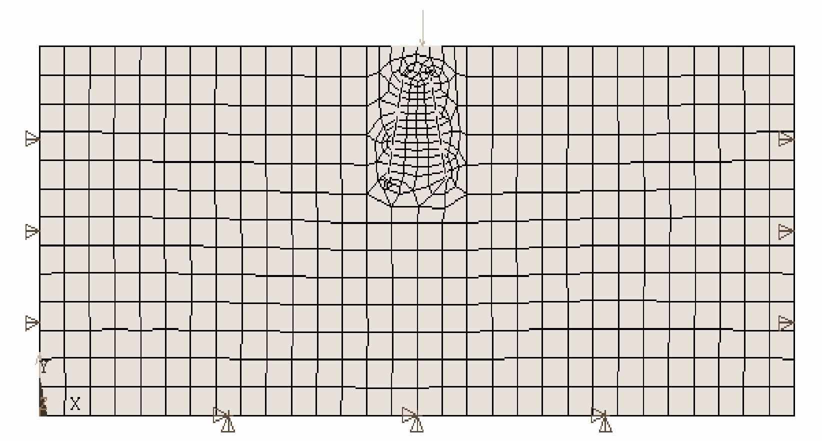


**Figure 1. finite element mesh along with boundary condition for micropile 7m and 10° with the vertical axes.**

## RESULTS OF ANALYSES

As it was mentioned previously, the results of analyses are obtained from ANSYS 10 program. Using this program we are modeling and analyze the different conditions of micropiles establishment in soil and for each other conditions the maximum settlement under applied load is obtained. Fig 2 shows the example of this state for micropile 10m and 10° inclination with the vertical axes. In this figure, the settlement is in such a state that the soil is loaded under only its gravity load.

Fig 3 shows the settlement of soil for same previous condition and the state of loading that maximum load (900 Kpa) applied on soil and in this condition the settlement equal to 46.19cm (101.40 – 55.21 = 46.19cm).

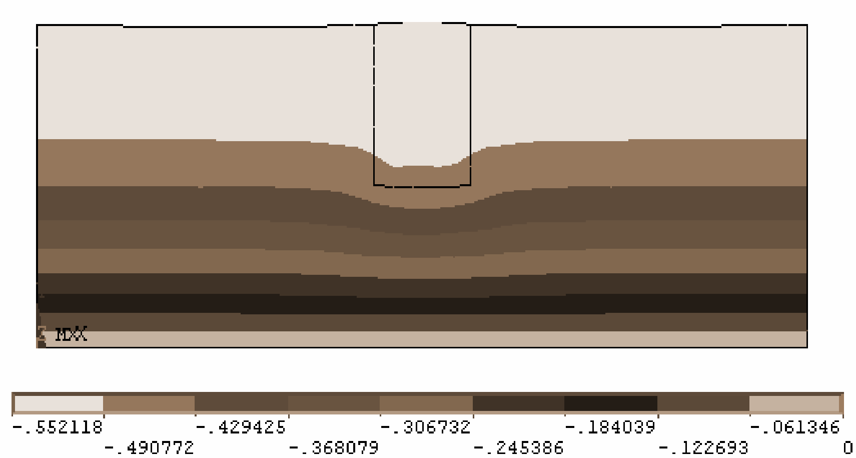


**Figure 2. Settlement of soil for state that soil is loaded under only its gravity load.**

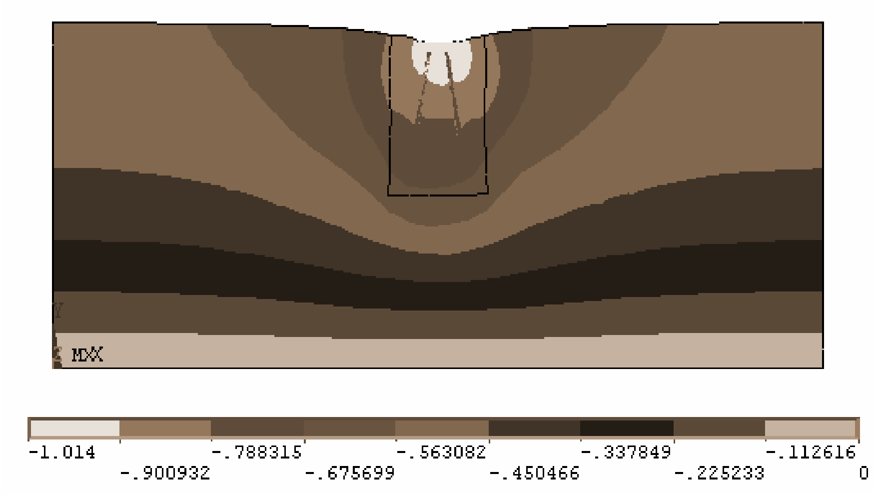


**Figure 3. Settlement of soil for state that soil is loaded under maximum load (900 Kpa).**

Similar to this state for other conditions also loading is done and maximum settlement is obtained. After the maximum settlement for all state of micropiles establishment in soil are obtained, the bearing capacity curves are plotted. Figures 4 to 8 show the bearing capacity graphs for micropiles 3m, 4m, 5m, 7m and 10m respectively.

Considering that the most of bearing capacity graphs for micropiles with various lengths in literature are in such a state that in which for a particular length of micropile while the inclination is varied the curves are plotted, so as a new study, for state that the inclination of micropile is fixed and its length is varied the bearing capacity curves are plotted. Figures 9 to 14 show these bearing capacity graphs for inclinations 0°, 10°, 20°, 30°, 40° and 45° respectively.

## DISCUSSION

Considering that the results of analyses are plotted in the graph forms, so we can induct very important contents about use of micropiles in sandy soil.

As seen in figures 4 to 8, in all of micropiles 3m to 10m there is basic difference in bearing capacity curves when soil is loaded without use of micropiles that specified by “soil“ title in graphs, and when micropiles with various inclinations are inserted in it. This indicates micropile using importance in increasing the bearing capacity of soils. For example as seen in Fig 4, when the soil is loaded without use of micropiles the bearing capacity for 10cm settlement, equals to 150 Kpa while, when the microiles of 3m lengths are inserted in soil this value equals to 300 Kpa and more, that shows increasing of 100 percent in bearing capacity of sandy soils.

As an other result, as seen in figures 4 to 8, in all micropiles, increasing the micropile inclination leads to sustain higher loads and better operation of micropile, but this increasing of inclination continues until a special value and after this value of inclination, the bearing capacity curves some deal has been invariable. Also as seen in figures 4 to 8, we can say that this inclination almost equal to 30° and in some lengths (4m, 7m and 10m) this inclination is the optimum and best micropile inclination. Of course, there are some interfaces in curves that this is duo to micropile operation in respective condition. But as a basic result it can be resulted, the operation of micropile in each length and inclination is unique.

In general, In comparison with existent experimental data in this case, the obtained results from this study have well coincident with them, and whereas the results of experimental data and this study, the enhancement of micropile length and inclination leads to increase in bearing capacity of soil.

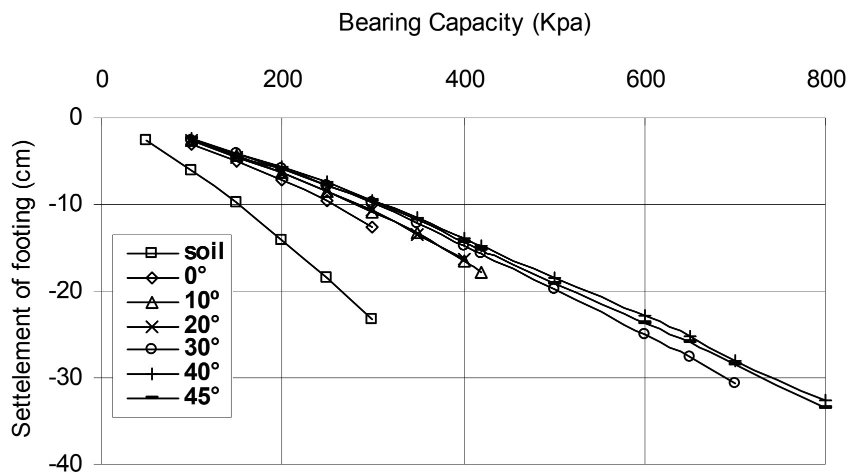


**Figure 4. Bearing capacity graph for micropile 3m length with various inclinations.**

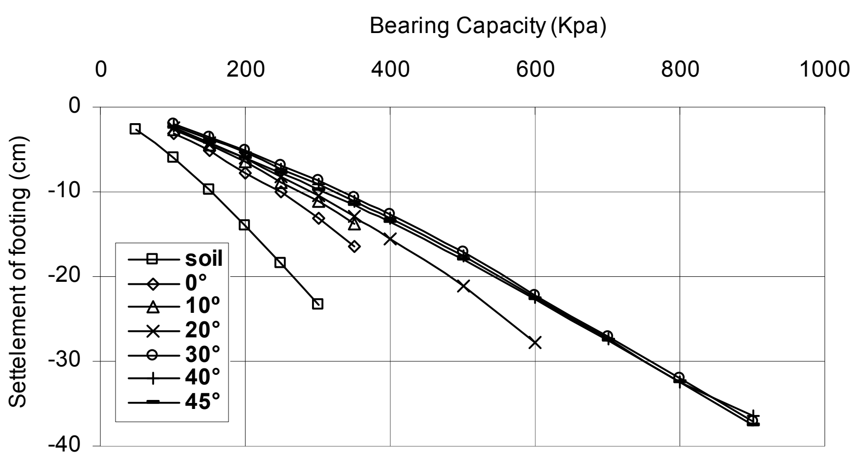


**Figure 5. Bearing capacity graph for micropile 4m length with various inclinations.**

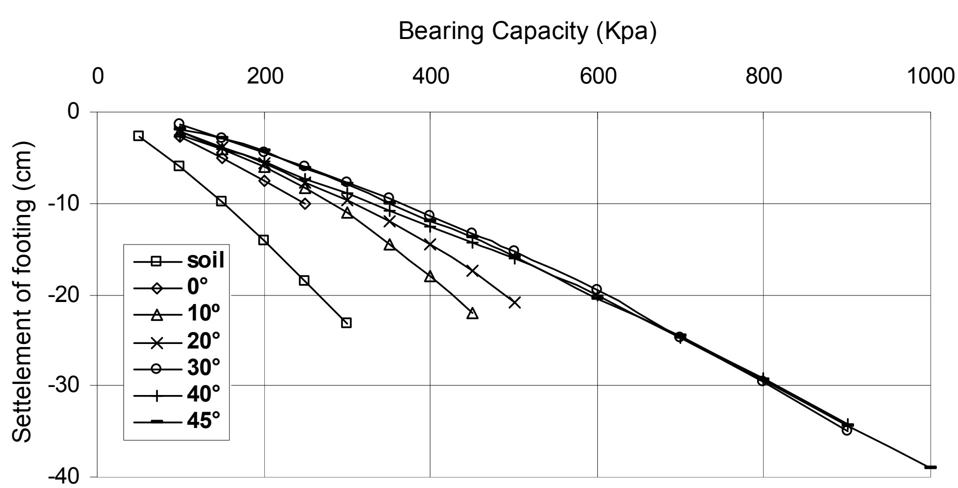


**Figure 6. Bearing capacity graph for micropile 5m length with various inclinations.**

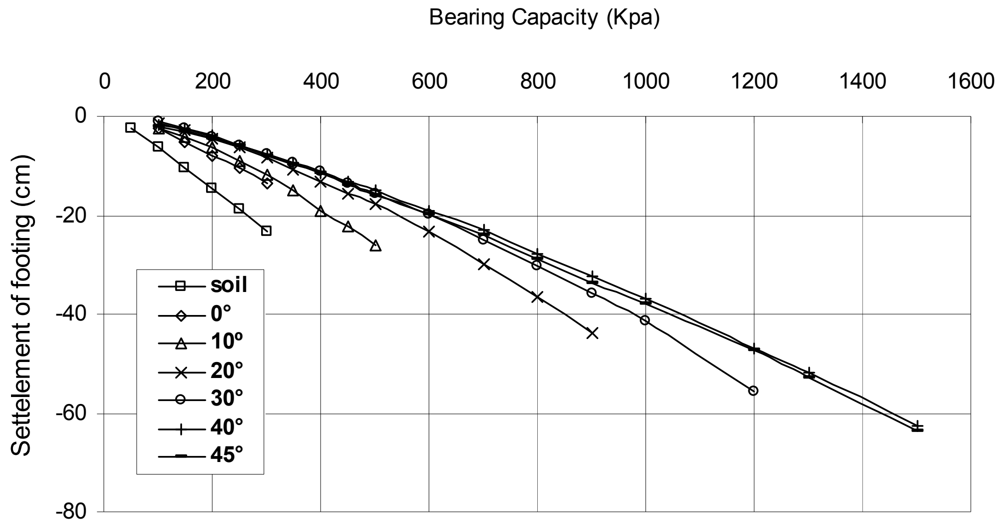


**Figure 7. Bearing capacity graph for micropile 7m length with various inclinations.**

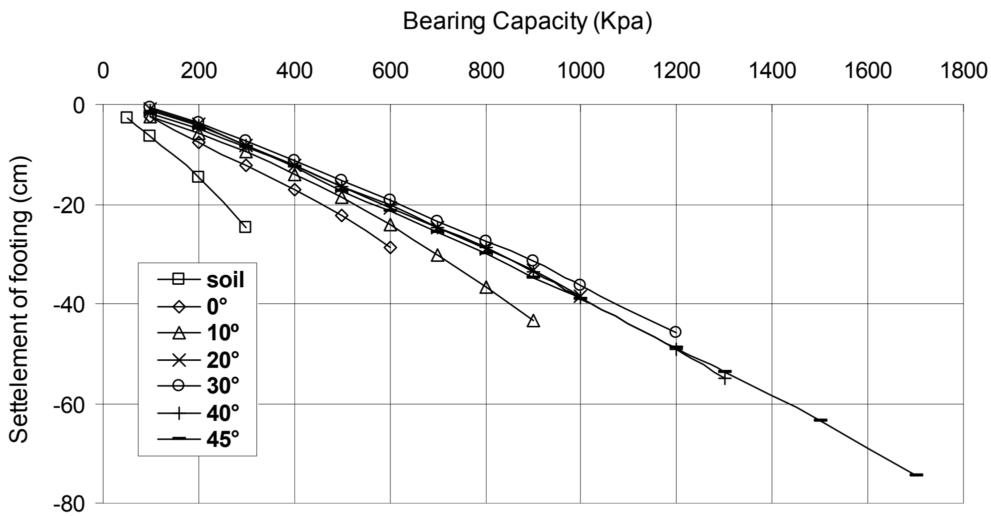


**Figure 8. Bearing capacity graph for micropile 10m length with various inclinations.**

In figures 9 to 14 the inclination of micropiles are fixed while their lengths are varied. In this case, as expected we can see that the enhancement of micropile's length leads to better operation of micropiles and sustain higher loads by soil. Of coarse, there are some interfaces in curves, for example as seen in figures 13 and 14 (that are relevant to inclinations of 40° and 45° respectively), the lengths of 7m and 10m have interfaces together that is due to same reasons that mentioned previously.

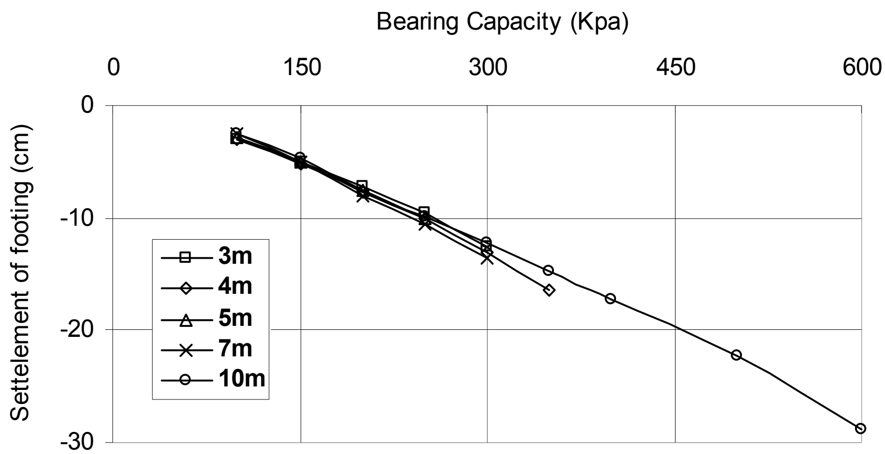


**Figure 9. Bearing capacity graph for micropiles with various lengths and angle of 0° with the vertical axes.**

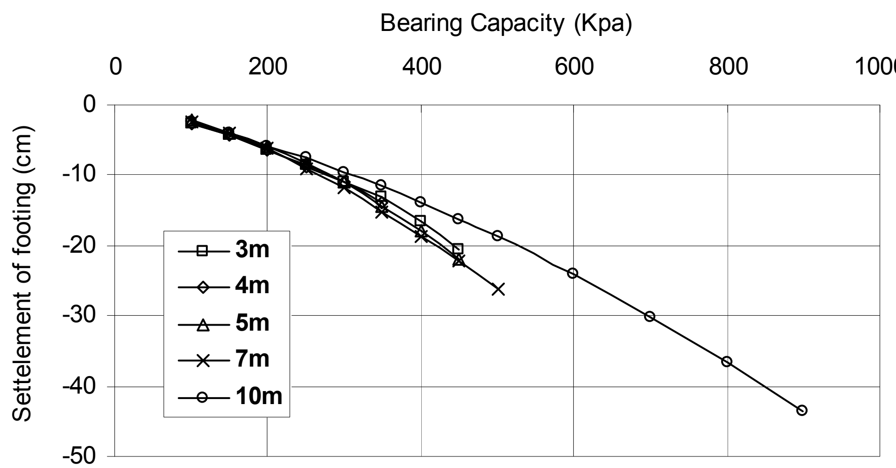


**Figure 10. Bearing capacity graph for micropiles with various lengths and angle of 10° with the vertical axes.**

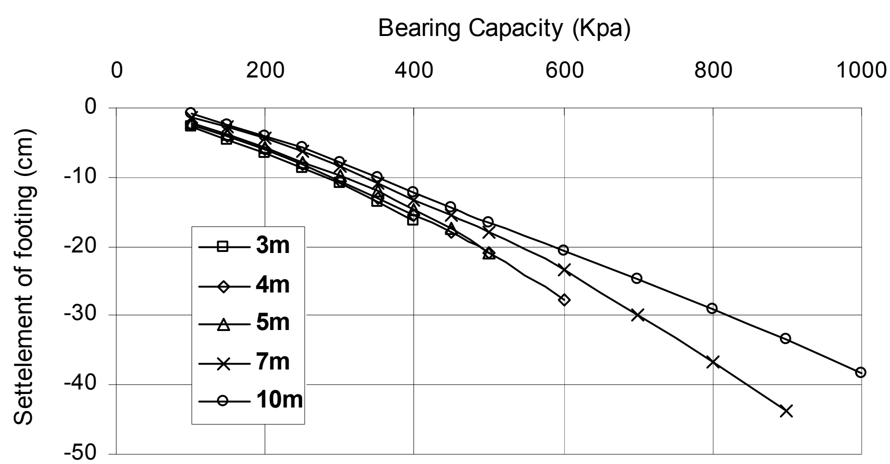


**Figure 11. Bearing capacity graph for micropiles with various lengths and angle of 20° with the vertical axes.**

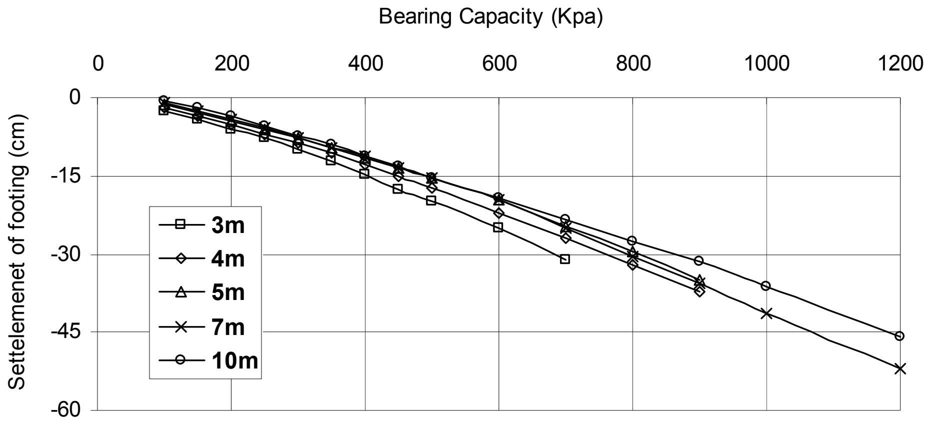


**Figure 12. Bearing capacity graph for micropiles with various lengths and angle of 30° with the vertical axes.**

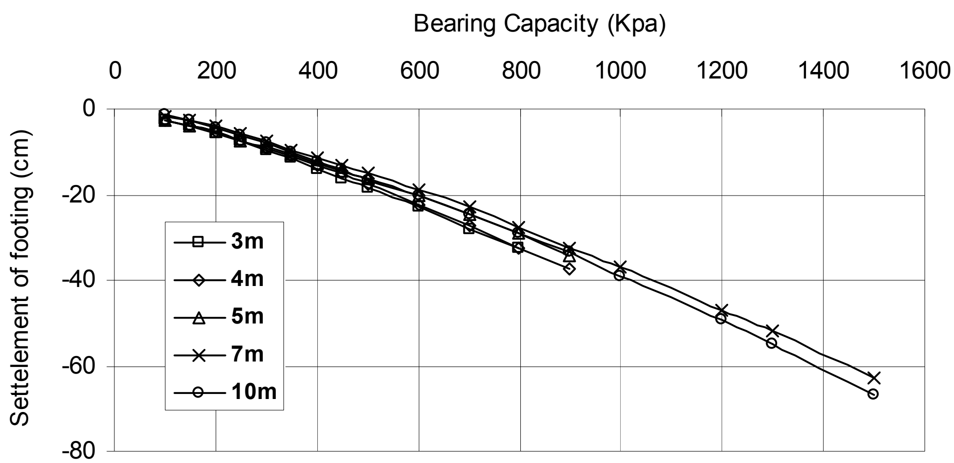


**Figure 13. Bearing capacity graph for micropiles with various lengths and angle of 40° with the vertical axes.**

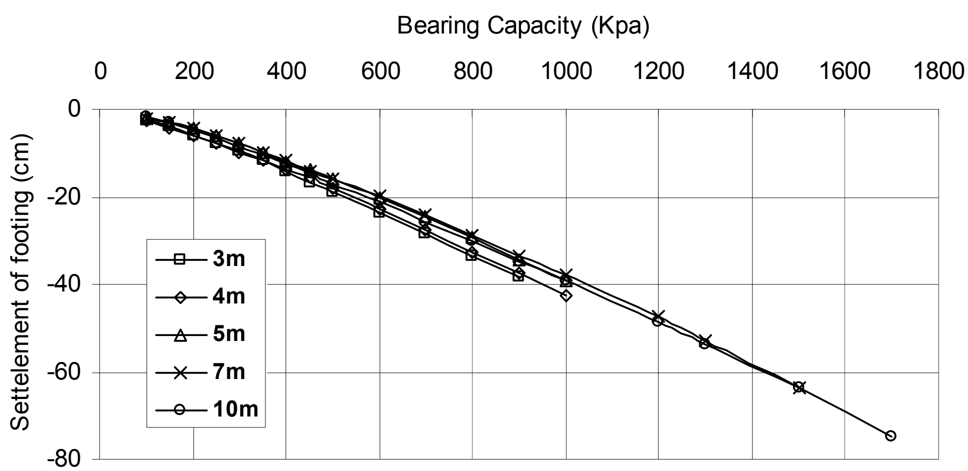


**Figure 14. Bearing capacity graph for micropiles with various lengths and angle of 45° with the vertical axes.**

## CONCLUSION

This paper presents numerical analysis results about the effects of micropiles with various lengths and inclinations on bearing capacity of sandy soils. The summery of the results of analyses are as follows :

1. The use of micropiles leads to increase in bearing capacity of loosely sandy soils up to 100 percent as seen in respective graphs.

2. The enhancement of micropiles inclination leads to increase in bearing capacities but this increasing continues until a special value and after that, the increasing in bearing capacity is neglect able. Of coarse, there are some interfaces in bearing capacity curves due to micropiles operation in respective conditions. In many lengths such as of 4m, 7m and 10m this optimum inclination equals to 30°.

3. The increasing of micropile length leads to increase the bearing capacity in sandy soils. In this case, also, the behavior is not exactly predictable and there are some interfaces in bearing capacity curves that this due to unique operation of micropiles in respective lengths and inclinations.

## REFERENES


FHWA (Federal Highway Administration, US Department of Transportation), (1997) *Drilled and Grouted Micropiles: State-of -Practice Review,* Volume I, II, III and IV, Publication No. FHWA-RD-96-018.

Jahed, H. ; Noban, M.R. & Eshragi, M.A. 2004. *ANSYS finite element.* Tehran: University of Tehran Press.

Juran I., Benslimane A., & Hanna S. 2001 Engineering Analysis of dynamic behavior of micropile systems, Transportation Research Record No. 1772., *Soil Mechanics* 2001, pp.91-106.

Juran, I., Bruce, D.A., Dimillio, A., & Benslimane, A. (1999). "Micropiles: the state of practice. Part II: design of single micropiles and groups and networks of micropiles". *Ground Improvement,* 3, 89-110.

Kishishita, T., SAITO, E. & Miura, F., (1999). Dynamic response characteristics of structures with micropile foundation system. *Proceedings of the 2nd International Workshop on Micropiles.* Ube city, Japan: 161-168.

Lizzi, F. (Soc. An. Fondedile, Naples), (1964). Root-pattern piles underpinning. *Proceeding of Symposium on Bearing Capacity of Piles.* Roorkee, India: 305-320.

Lizzi, F. (1971). Special patented systems of underpinning and more generally, subsoil strengthening by means of Pali Radice (Root Piles) with special reference to problems arising from the construction of subways in built-up area. *Special Lecture* given at university of Illinois at Urbana-Champaign, etc.

Lizzi, F., (1978). Reticulated root piles to correct landslides. *A Preprint of ASCE Convention,* Chicago, Ill., October: 1-25.

Lizzi, F., (1980). The use of 'Pali Radice' (root pattern piles) in the underpinning of monuments and old buildings and in the consolidation of historic centers. Naples (Italy): *Fondedile S.P.A.*: 25pp. (An English imprint of an article published in Italian Technical Magazine, L'INDUSTRIA DELLE COSTRUZIONI, No.110, Dec. 1980 of A. N. C. E.)

Lizzi, F., (1994). The 'reinforced soil' in the future of geotechnics. In Balasubramniam et al. (Editor), *Proceedings of Symposium on Development in Geotechnical Engineering,* Balkema, Netherland: 553-563.

Moaveni, S. 2002. *ANSYS finite element analysis.* Tehran. Nagus publications.

Mason, J. A., (1997). Seismic design concepts and issues for reticulated micropile foundation systems. *Proceedings of the 1st International Workshop on Micropiles,* September, Seattle, Washington, USA: 202- 227.

Mitchell C. L B, Perkins W. J. & Okumatsu T., (1999) Micropile project in US: a bridge seismic retrofit in Seattle, *Proceedings of the 2nd International Workshop on Micropiles,* Ube city, Japan: 175-176.

Plumelle, C. (1984). "Improvement of the bearing capacity of the soil by inserts of group and reticulated micropiles". *International symposium on in-situ reinforcement of soils and rocks,* Paris, 83-89.

Sridharan, A., & Murthy, B.R.S. (1993). "Remedial measures to building settlement problem". *Proceedings of Third International conference on case histories in Geotechnical Engineering,* St. Louis, Missouri, 221-224.

Tan, S.A., Luo, S.Q., & Yong, K.Y. (2000). "Simplified models for soil-nail lateral interaction". *Ground Improvement,* Vol. 4, No. 4, 141-152.

Tsukada, Y. & Ichimura, Y., (1997). Micropiles in Japan: present status and future prospects. *Proceedings of the 1st International Workshop on Micropiles,* September, Seattle, Washington, USA: 266-278.

Tsukada, Y.; Miura, K.; Tsubokawa, Y.; Ishito, M.; Nishimura, N.; Otani, Y. & You, G. L., (1999). Experimental investigation on the improvement of bearing capacity of surface footing with micropiles. *Proceedings of the 2nd International workshop on Micropiles,* September, Ube city, Japan: 139-148.