# Effects of the Inclination Variation of Micropile on Bearing Capacity of Sandy Soils

**Abolhassan Naeini, PhD of Geotechnical Engineering**, Naeini_h@yahoo.com
Department of Civil Engineering, Imam Khomeini International University,Qazvin,Iran

and

**Nader Fathololumi, Graduate Student of Civil Engineering**, Naderfti@yahoo.com
Department of Civil Engineering, Imam Khomeini International University,Qazvin,Iran

**Abstract**
*This paper presents the numerical analysis results of bearing capacity studies of sandy soils using ANSYS 10 finite element software. First, a sandy soil media with properly given properties is modeled and under increasing loading its bearing capacity is studied. Then micropiles with 20cm diameter and 4m length, 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 110 percent. The results of this study can provide valuable information about use of micropiles in sandy soils.*

Keywords: *Micropile, Inclination, Numerical analysis, Bearing capacity, Sandy soils.*

## 1- 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; Juran 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; Plumelle 1984; Kishishita 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 et al. 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 contains: 1) a decrease of movements and bending 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 variation on bearing capacity of sandy soils by numerical analysis. Analysis is conducted using finite-element method (FEM) with ANSYS 10 software. This software has advantages in contrast to its previous versions. 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 inclinations that 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.

## 2- Material Properties

Considering that micropiles are mostly used in loose soils to increase their bearing capacity, so we insert the couple 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 |

## 3- 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. 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 ($M_u$) equals to 0.65.

Micropiles with 20cm diameter and 4m length with inclinations of 0 to 45 degree with the vertical axes which are used in practical usages are inserted in the sandy soil. Then using ANSYS 10 software, modeling is done and increasing loading is applied to soil. Figure1 shows the finite element mesh along with boundary conditions for micropile 4m with inclination 10° with the vertical axes.

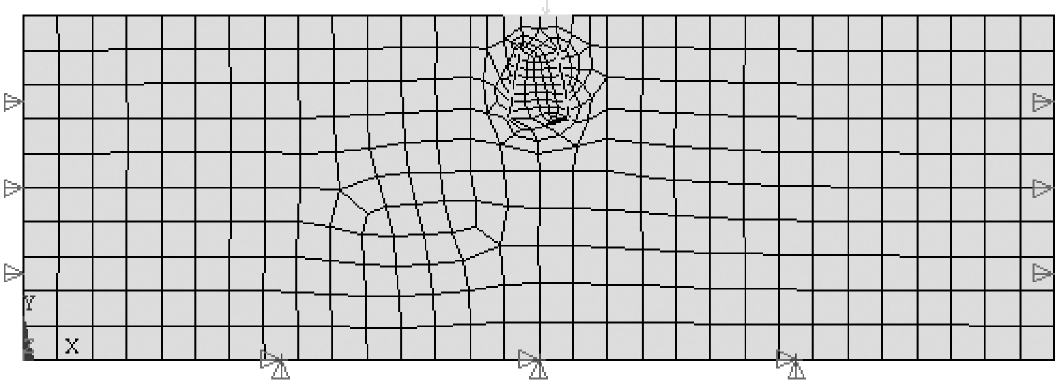


**Figure 1.** *Finite element mesh along with boundary condition for micropile 4m and inclination of 10° with the vertical axes.*

### 4- Results of Analyses

As it was mentioned previously, the results of analyses are obtained from ANSYS 10 software. Using this software, 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. Figure 2 shows the example of this state for micropile 4m 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 and it equals to 20.42cm. Figure 3 shows the settlement of soil for same previous condition and the state of loading that maximum load (350 Kpa) applied on it. As seen in this picture, the maximum settlement equals to 32.98cm. To obtain the pure settlement of soil under this load we should subtract this value from previous value. So in this condition the pure settlement of soil equals to 12.56cm (32.98 – 20.42 = 12.56cm).

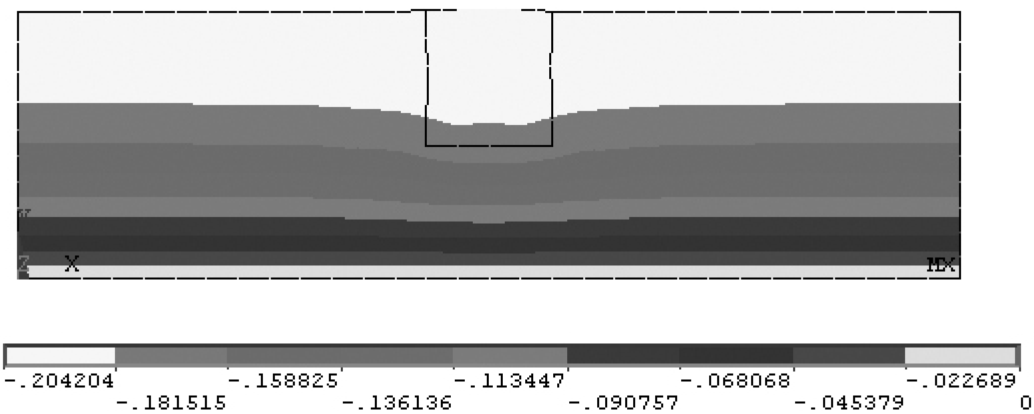


**Figure 2.** *Soil settlement for state that soil is loaded under only its gravity load.*

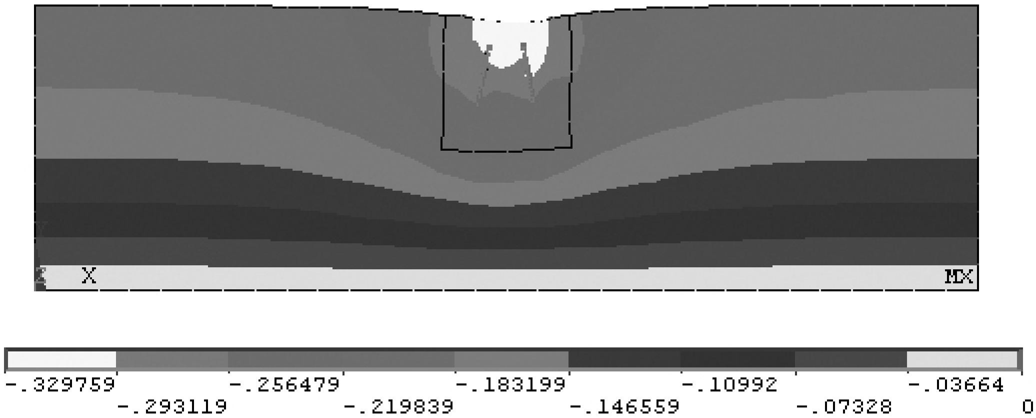


**Figure 3.** *Soil settlement for state that soil is loaded under maximum load (350 Kpa).*

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 load – displacement curves that are mentioned as bearing capacity curves, without and with use of micropiles are plotted. Figures 4 to 9 show the bearing capacity graphs for sandy soil, without and with use of 4m micropiles with inclinations of 0°, 10°, 20°, 30°, 40° and 45° respectively.

To plot the load – displacement curve, the soil is loaded increasingly and for each load respective settlement is obtained and this process continues until the results of analyses are not converged and the solution is not done. Of coarse, the form of curve is important and end point of curve (which soil is collapsed) only as a part of curve is valuable.

As seen in these graphs, in each of them, the load – displacement curves for state that soil is loaded with and without use of 4m micropiles by mentioned inclinations, is plotted. Under these conditions, the influence of use of micropiles on increasing the bearing capacity of sandy soils is studied. Also comparing these graphs together, show the influence of enhancement of micropile inclination on bearing capacity of sandy soils.

Of coarse, in next part these results are presented extensively and with plotting these curves along with in one graph, influence of enhancement of micropile inclination on bearing capacity of sandy soils is specified.

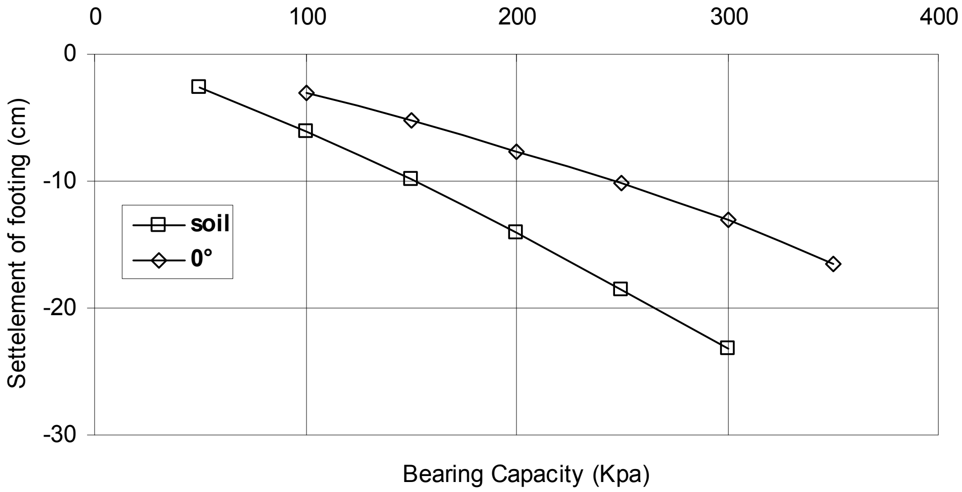


**Figure 4.** *Bearing capacity graph with and without use of 4m micropile with inclination 0°*

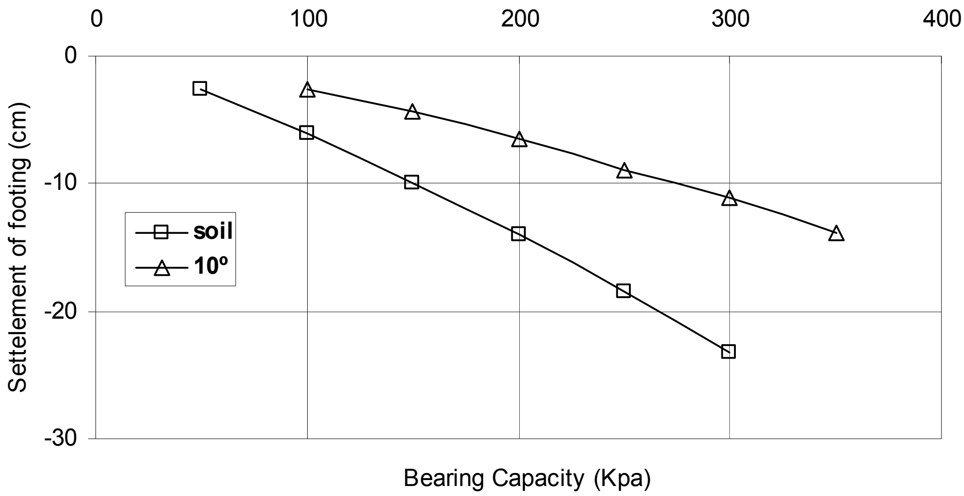


**Figure 5.** *Bearing capacity graph with and without use of 4m micropile with inclination 10°*

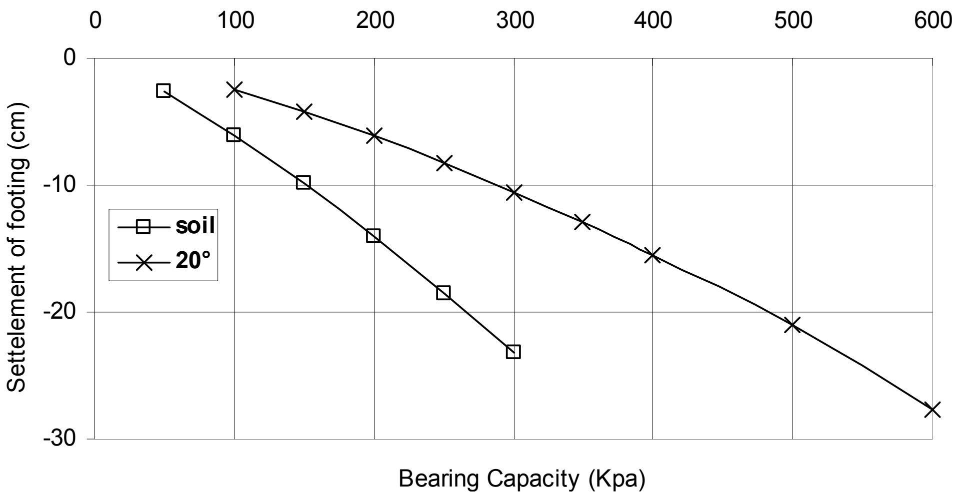


**Figure 6.** *Bearing capacity graph with and without use of 4m micropile with inclination 20°*

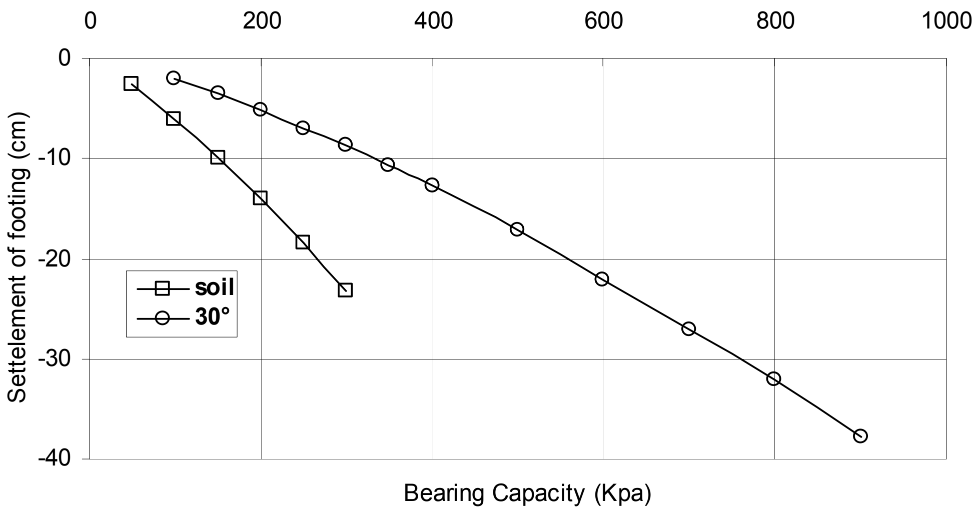


**Figure 7.** *Bearing capacity graph with and without use of 4m micropile with inclination 30°*

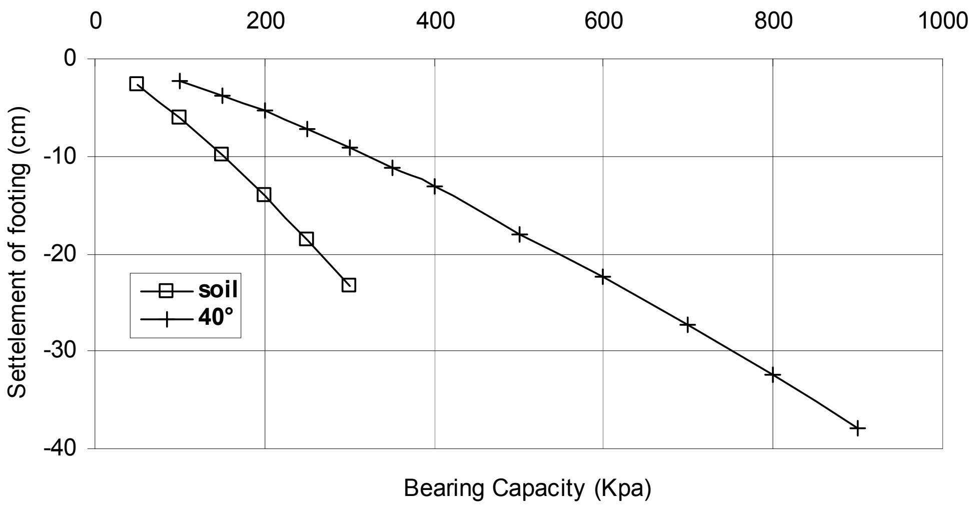


**Figure 8.** *Bearing capacity graph with and without use of 4m micropile with inclination 40°*

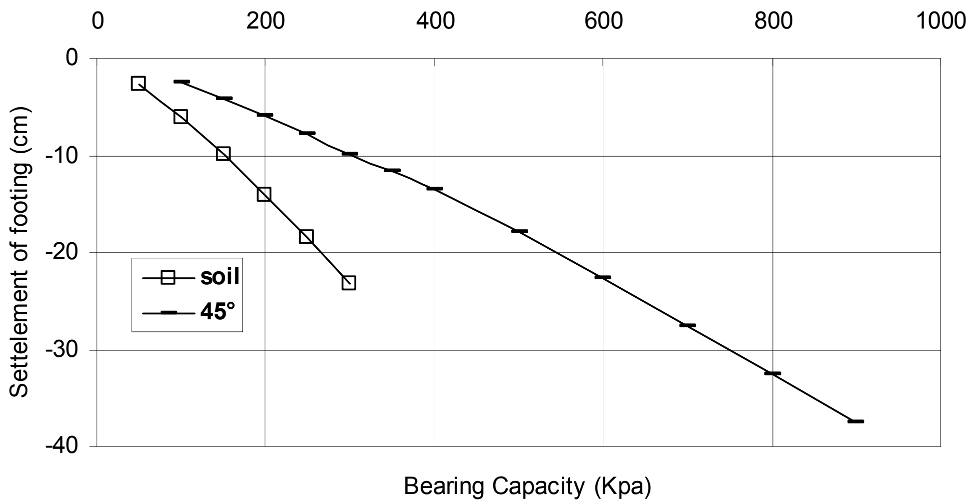


**Figure 9.** *Bearing capacity graph with and without use of 4m micropile with inclination 45°*

## 4- Discussion

Considering the results of analyses plotted in the graph forms, we can induct very important contents about use of micropiles in sandy soil. As seen in Figures 4 to 9, there are basic differences between 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 importance of micropile using in increasing the bearing capacity of soils. For example as seen in Figure 4, when the soil is loaded without use of micropiles the bearing capacity for 10cm settlement, equals to 150 Kpa while, when the micropiles of 4m lengths are inserted at 0° inclination in soil, this value reaches to 250 Kpa that shows increasing of 67 percent in bearing capacity of sandy soil. As seen in figures 5 to 9, these values reach to 275 , 290 , 320 , 310 and 300 Kpa respectively. As seen, in inclination of 308, the bearing capacity equals to 320 Kpa that shows increasing up to 110 percent in bearing capacity while in higher inclinations (i.e. 408 and 458) this value decrease to 310 and 300 Kpa respectively that indicates inclination of 308 have better operation and suggested as optimum inclination of 4m micropile in sandy soil. To compare these curves together, whole of them are plotted in one graph that shows in figure 10.

As seen in figure 10, increasing the micropile inclination leads to sustain higher loads and better operation of micropile, but this increasing of inclination continues until a special value (308) and after this value of inclination, the bearing capacity curves some deal has been invariable. Also as seen in figure 10, we can say this inclination almost equals to 30° and 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.

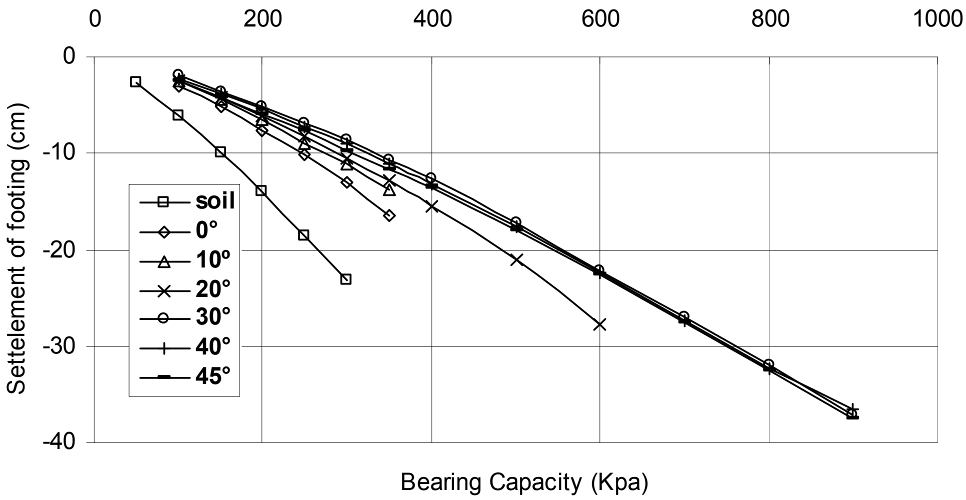


**Figure 10.** *Bearing capacity graph for sandy soil with 4m micropile with various inclinations.*

## 5- Conclusion

In this study, micropiles with 20cm diameter and 4m length with various inclinations are inserted in sandy soil media and the effects of micropile inclination variation on bearing capacity of sandy soil studied. The summery of the results of analyses are as follows:

1. The use of micropiles leads to increase in bearing capacity of loose sandy soils.

2. Increasing the micropile inclination leads to sustain higher load and better operation of micropile. But this increasing continues up to 308 of inclination and after

this value, the bearing capacity decrease. So, the optimum inclination of 308 which resulted in more than 110 percent increase in bearing capacity is suggested.

**6- References**

[1] 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.

[2] 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.

[3] 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.

[4] 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.

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

[6] 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.

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

[8] 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.)

[9] 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.

[10] 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.

[11] 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.

[12] 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.

[13] 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.

[14] 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.