SETTLEMENT REDUCTION UNDERNEATH SURFACE CIRCULAR FOOTING RESTING ON REINFORCED SOILS.

Hayder M. Mekkiyah
The University of Baghdad, Civil Engineering Department.

ABSTRACT

An analytical approach, adopted to find the settlement of foundations resting on reinforced soil based on the test results on a model surface circular footing resting on reinforced soil, is summarized. The soil was reinforced using biaxial geomesh. The settlement was determined by considering the compatibility of strain (settlement) between soil and reinforcement element underneath the foundation. Theoretical equations were used to estimate the settlement either from the superstructure loads or from in-situ plate load tests on the reinforced soil system. The type of geomesh used in this study has been determined based on the grain size distribution of the soil. The investigation in this study used two different types of geomesh. Uniformly graded sand was used to make it easier to control the density and fabric in different tests. It was found that initial horizontal and vertical movement of the reinforcement is needed to mobilize the reinforcing strength. Further, the initial settlement at small loads could be avoided when the reinforcement was placed closer to the base of the footing and there was an improvement in the bearing capacity value of the footing. When the reinforcement is placed away from the base of the footing(greater than B), the initial settlement decreased with a slight improvement in the bearing capacity compared with that of unreinforced soil. Non-dimensional factors were developed for settlement calculations based on the experimental test results from a series of laboratory tests on the model footing. Additional tests were performed on the model footing to evaluate the effect of the number of reinforcement layers and the depth of the top most reinforcement layer on the settlement and the improvement in the bearing capacity of the footing-reinforced soil system.

الخلاصة

اقترح في هذه الدراسة تحليل لحساب الهبوط تحت الأسس المسلحة ترابيا مبنيا على تجارب الفحوص المختبرية لهذه الأسس الجالسة على التربة المسلحة حيث أن التربة تم تسليحها بواسطة قطع (شبكة) تسليح بلاستيكية. كان مبدأ التحليل مستندا إلى التوافق في الانفعال الحاصل تحت الأسس لكل من التربة وقطع التسليح.أن المعادلات المقترحة لحساب الهبوط تحت هذا النوع من الأسس يمكن استخدامها لكل من نتائج الفحوصات الحقلية أو أية أحمال متوقعة من المنشأ يراد حساب الهبوط تحتها ،تم استخدام رمل منتظم متدرج في هذه الفحوص .لوحظ من

أجل حصول حركة (رأسية / أو أفقية) تحت الأسس المسلحة فلابد من وجود أحمال أكبر من تلك المقارنة بالأسس غير المسلحة ، وأكثر من ذلك أن هذا الهبوط الأولي تحت هذه الأسس يمكن إهماله عندما قيم الأحمال الأولية المسلطة قليلة وشرائح قطع التسليح قريبة من قاعدة الأسس كما لوحظ أيضا تحسن كبيرفي تحمل الأسس لهذه الحالة من التحميل ، في حين أن هناك تحسن أقل سعة التحمل عندما تكون هذه الشرائح بعيدة عن الأسس وفي المقابل الهبوط المتوقع يكون أكبر ،أن مثل هذا التباين في مقدار الهبوط لمثل هذه الحالات من التحميل تم أخذه بعين الاعتبار حينما تم وضع المعاملات اللابعدية من أجل حساب الهبوط المتوقع تحت الأسس في المعادلات المقترحة في هذه الدراسة.تم حساب الهبوط لحالات فحص أخرى غير تلك التي أجريت في البحث للتأكد من مقدار الهبوط المتوقع فكان مقدار هذا الهبوط يتناسب وطبيعة التربة ومقدار الأحمال المسلطة على هذه الحالة.

KEY WORDS:-Settlement, Circular, Footing, reinforced, Soil, Reduction

INTRODUCTION

Reinforced earth technique is one of the most promising materials that have emerged in the last 30 years from intensive research that has been carried out into alternative construction materials. Reinforced earth technique is not new, the earliest remaining examples of soil reinforcement are ziggurat of ancient city of Dur-Krigatzu in Iraq (6000 B.C.), and the great wall of China. It is also known that Romans have used earth reinforcement technique (Ignold 1982). Further, there are a limited number of studies in the literature on the possibility of using analytical developed equations to estimate footing settlement resting on reinforced sand. This paper reports the initial findings of such a study and attempts to provide a relatively simple approach to estimate the settlement of circular footings resting on reinforced sand. The proposed approach is based on test results of a model circular footing.

PHYSICAL MODELING

Loading tests of a model circular footing resting on the surface of a reinforced sand subgrade were performed using steel lever-arm system. The sand is placed in a square wooden box of internal dimensions of 570 mm x 570 mm x 800 mm, and 10 mm in thickness, stiffened by means of steel strips and the inside of the box was covered with two sheets of polyethylene. The model footing consists of circular aluminum metal with a diameter of 50 mm and a thickness of 50 mm. The sand flows in a flexible hose through sieve No. 4 and then to the box, where the falling height of sand was fixed at 600 mm. It was found that pouring the sand from this height in 25-mm lifts, gives a unit weight of 18.8 kN/m^3 and a relative density of 65% (medium dense sand) this lifts was kept constant for the whole layers in all tests (similar to that recommended by Bieganousky et. ,al 1976 was used).The testing were carried out at Baghdad University.

MATERIALS USED

The sand used are passing sieve No.4 was washed with running water to remove dust as much dust as possible. The sand was then air dried before before sored in barrel,sieve analysis was carried out and a grain size distribution curves was obtained The uniformity coefficient of sand was determined as 3.2 .Laboratory tests were carried out on the sand to get some other properties and these values are listed below:

Specific gravity ……………Gs=2.63

Maximum unit weight (γd max)= 19.71 KN/m^3
Minimum unit weight (γd min)= 16.46KN/m^3
Unit weight in the Box = (γd)= 18.8 KN/m^3
Void ratios Calculated based on (γd max and γd min):
emax = 0.567 emin = 0.309

The angle of internal friction was determined as 39^o using Triaxial tests. The reinforcement used in the tests were of polymer geomeshes commercially known as Netlon geomesh (CE111 and CE121) having an aperture size of (8 mm x 6 mm) and thickness of 2.90 mm and 3.3 mm for CE111 and CE121 respectively with dimensions of 540x540 mm. The tensile strength was 2.0 and 7.68 kN/m respectively. The bearing capacity and settlement of the footing resting on sand depend on properties of sand such as the angle of internal friction ϕ and the relative density, size, shape and embedment depth of footing (Lambe and Whitman, 1979). The results obtained from small scale model tests such as the one used in this study are usually hindered by limitations associated with size and boundary effects. As a result, it is of importance to keep such limitations in mind when designing such small scale model tests and when interpreting and extrapolating results to full scale footings.

TEST RESULTS AND DISCUSSION

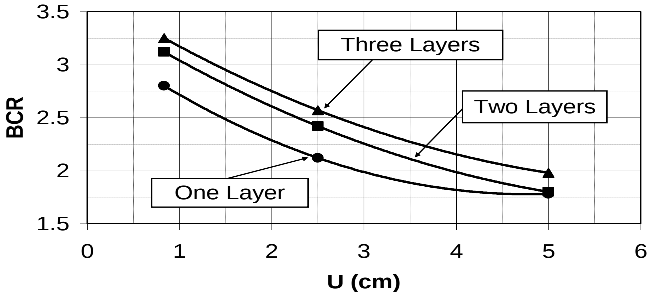
The following parameters were considered in this study:

a. Depth of top most reinforcement layer.
b. Number of reinforcement layers.
c. Improvement in the subgrade reaction value.

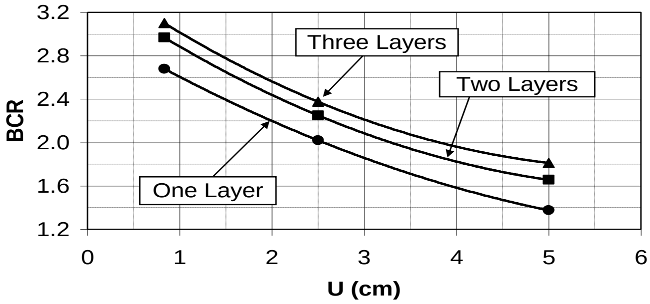
The bearing capacity of the footing-soil system with and without reinforcement, q and q_o respectively, were obtained from load-settlement relationship. The bearing capacity ratio (BCR), which is defined as (q/q_o) and represented at a settlement of 5% of footing width , most of failure cases (load -settlement curves) capacities starts within this value .

A-EFFECT OF TOP MOST REINFORCEMENT LAYER

Tests were carried out to investigate the effect of distance between the footing and the top most reinforcement layer (U), where U is used as a ratio of the diameter of the footing D. The relationship between U and bearing capacity ratio BCR is drawn for different values of U (i.e U=D/6, D/2, D &ΔHused=2cm between reinforcement layers), different types of reinforcement (Netlon CE111, and CE 121), and for different number of layers (N) as shown in Figures (1 and 2), as example of one layer layout below footing different tests were carried out at different (U) locations and similar for two and three layers of reinforcements. It is found that BCR increases as U decreases for all number of reinforcement layers. As expected and observed, the results show that the soil deformation occurs first in the upper layer of sand, just below the footing, and then propagates to deeper areas as the load is increased. This is due to the existence of the high stress zone below the footing which reflects the benefit obtained by placing the reinforcement at this zone. This observation is in agreement with that reported by Akinmusuru and Akinbolade (1981).



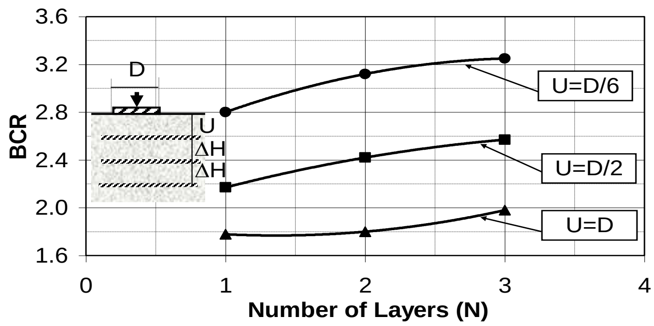
Fig(1) BCR-U Relationship for Netlon CE121.



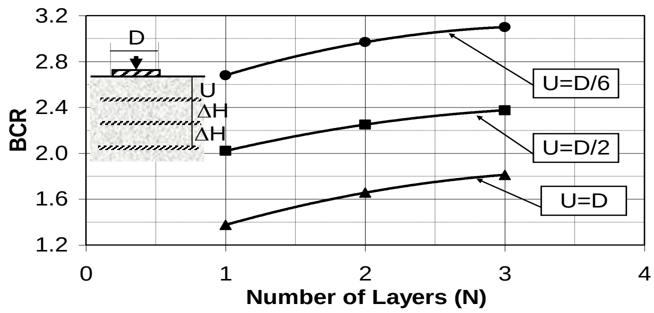
Fig(2) BCR-U Relationship for Netlon CE111.

B-EFFECT OF THE NUMBER OF REINFORCEMENT LAYERS

The effect of increasing the number of reinforcement layers (N) on the bearing capacity of footing is shown in Figures(3 and 4). The gain in the bearing capacity with the number of layers is expressed in terms of bearing capacity ratio (BCR). Figures (3 & 4) show that BCR increases with the number of reinforcement layers for both types of reinforcement(ΔH=2cm). A similar conclusion was reported by Akinmusuru and Akinbolade (1981).



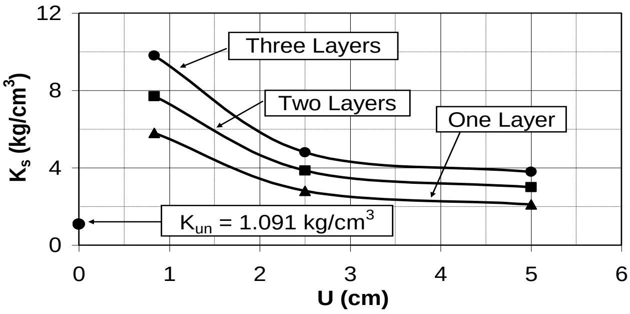
Fig(3) BCR-Number of Layer Relationship for Netlon CE121.



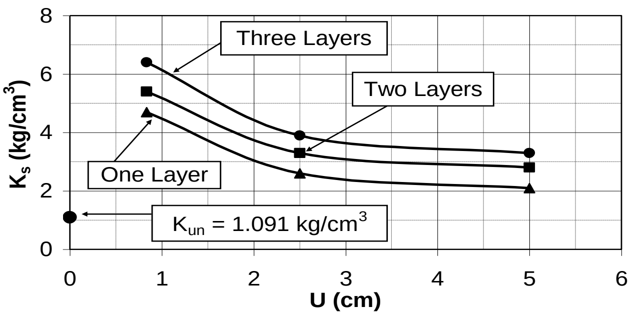
Fig(4) BCR-Number of Layer Relationship for Netlon CE111.

IMPROVEMENT IN THE SUBGRADE REACTION VALUE

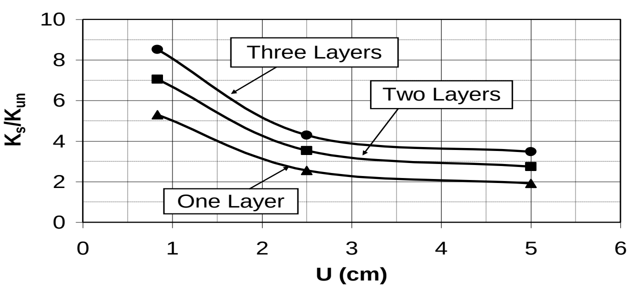
It is concluded from the tests that reinforcing the soil causes improvement in the soil subgrade reaction value (Figures 5-8) these values are calculated from ($\Delta q/\Delta H$) at a settlement of 5% of footing width. . The figures show that the modulus of subgrade increases as U decreases and as the number of layers increases. It is recommended to place the first layer of reinforcement in the zone of initial strain (i.e., close to the footing base at a depth that is less than or equal to B/6), and the second layer in the lower zone of maximum strain at a depth of 0.4B below the base of the footing. Placing the reinforcement in these levels will significantly improve the subgrade reaction value and reduced the footing settlement. The figures also show that the subgrade reaction reaches a steady value when U is larger than 80% of the diameter of the footing (D). Similar observations were also presented by Al-Dobaissi (1990). The values of subgrade reaction of the unreinforced soil (K_{un}) are also shown in the Figs. 5 and 6.



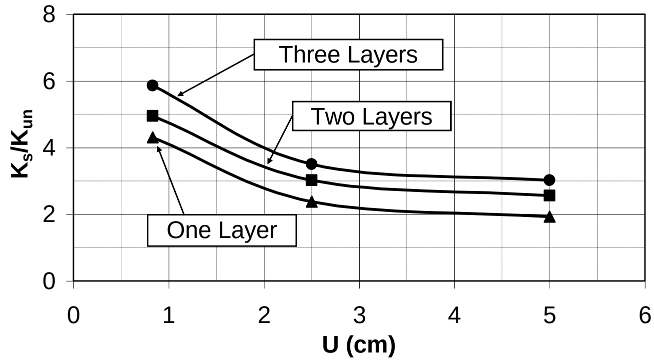
Fig(5) K_s-U Relationship for Netlon CE121.



Fig(6) K_s-U Relationship for Netlon CE111.



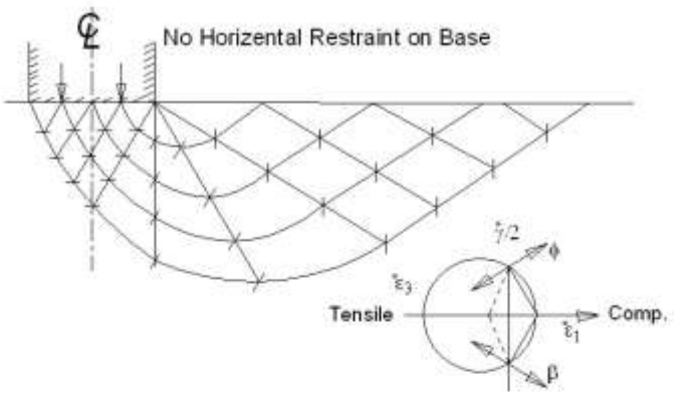
Fig(7)Stiffening Subgrade Factor (K_s/K_{un}) versus U Relationship for Netlon



Fig(8) Stiffening Subgrade Factor (K_s/K_{un}) versus U Relationship for Netlon CE111

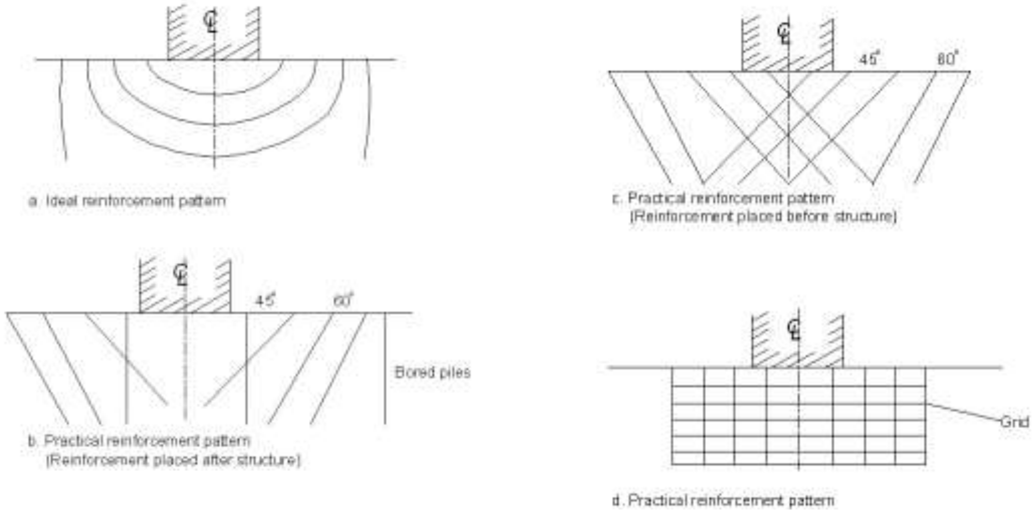
ALYTICAL AND EXPERIMENTAL APPROACH

The use of reinforcement (Geosynthetics) to improve the bearing capacity of footings and to reduce settlement has been proven to be cost-effective for foundation system. A reinforced soil-foundation system consists of one or more layers of geosynthetics and a control soil placed below a conventional spread footing. The reinforcement is usually placed horizontally. However, there are cases in which vertical or sloped reinforcement may be used below the footing. Further, the reinforcement placed within the tensile arc of strain field causes realignment of the strain field which improves the performance for the load carrying capacity (Colin JFP Jones 1985). The ideal reinforcement pattern for the direction of the principal tensile strain is shown in Figures 9 and 10. As shown in these figures, the ideal pattern has a reinforcement placed horizontally below the footing and becomes progressively more vertical further from the footing (Bassat and Last 1978) .



Zero extension characteristics for dilating soil (After Bassat and Last 1978)

Fig(9) Zero extension characteristics for dilating soil (After Bassat and Last,1978).



Fig(10) Different reinforcement orientations below the footing (After Colin JFP Jones 1985) .

The calculation of footing immediate settlement for different soil types is estimated on the basis of elasticity, provided that the elastic properties of the soil (modulus of elasticity E, and Poisson's ratio υ) are known. These two parameters can be evaluated in the lab from soil samples obtained during site investigation processes for cohesive soils. However, for granular soils, it is much more difficult, if not impossible in most cases. The in-situ testing on granular soils may not accurately give these soil properties which are needed for the calculation of settlement. In the case of reinforced soil systems, it seems to be difficult to use traditional investigation methods such as borings, or to use other traditional techniques such as pressuremeter tests or cone penetrometer tests. Such methods and techniques require drilling to various depths which will deform the reinforcement mesh below the footing. Plate bearing test on reinforced foundation systems resting on homogeneous sand to a sufficient depth, on the other hand, can be used as an economical alternative. The model footing can be used to estimate the overall modulus of the soil which provides a representative parameter for use in conventional settlement estimation.

From Figures. 5 and 6, it was concluded that the improvement in the modulus of subgrade reaction as a result of reinforcement is in the range of 2 to 10 times that of unreinforced soils. It was assumed that the modulus of elasticity of reinforced soil (E_R) will be increased by the same ratio (i.e., E_R=2-10E_S), where E_S is modulus of elasticity for unreinforced soil and E_R can be estimated from equation (1)

$E_R = (FI) * Ksun * B\,(1-\upsilon^2)$ -------------------(1)

Where:
E_R: Modulus of elasticity for reinforced soil.
FI: Improvement factor (FI = 2 and 10 for 1 and 3 reinforcement layers respectively)
Ks_{UN}: The subgrade reaction value of unreinforced soil.
B: Footing width (for an equivalent square).
υ: Poisson's ratio (recommended ranges are between 0.28 and 0.34 for 3 and 1 reinforcement layers respectively).

While the settlement below a reinforced soil system can be estimated from equation (2) which should be used with the following limitations in mind

- Best estimation for base contact pressure (q) should be used.
- For the circular footing it is better to convert the footing width to equivalent square.
- The sands layer depth can cause settlement to a depth of Z= 1.5 to 2 times B or to a depth where a hard stratum is encountered below the base.

$$\delta_{FlP} = 0.8\frac{q \times B}{E_R} \quad \text{----------------------------} \ (2)$$

Where:

δ_{FlP} : Footing and/or plate settlement.

q: Load on footing and/or plate.

B: Footing width (an equivalent square).

When the previous limitations are considered, the settlement estimated from the above equation gives good correlation with the test results.

Another method of analysis was proposed for settlement estimation by adopting a non-dimensional factor for any size of footing or plate size. The value of α factor that will provide a settlement of 25 mm is used in equation (3).

$$\delta_F = \frac{2\delta_P}{\left(B_P / B_F\right)^{\alpha}} \quad \text{----------------------} \ (3)$$

Where:

δ_F : Footing settlement (mm).

δ_P : settlement from a plate test of model footing and/or plate bearing test.

α: **non dimensional factor as shown and proposed in Figures** (14-21).

B_P: plate size (m).

B_F: footing size (m).

By using the plate load-settlement curve for δ_F of 25mm, the value of the corresponding bearing pressure can be found from the curve of the computed value of δ_P from equation (3). This bearing pressure is the safe pressure for a given permissible settlement (δ_F), or one can run a reverse calculation to find out the safe pressure for the settlement criterion. If the footing is allowed to settle for (50 mm) then the value of (α) obtained from Figs. 14-21 should be increased by 20-25%.

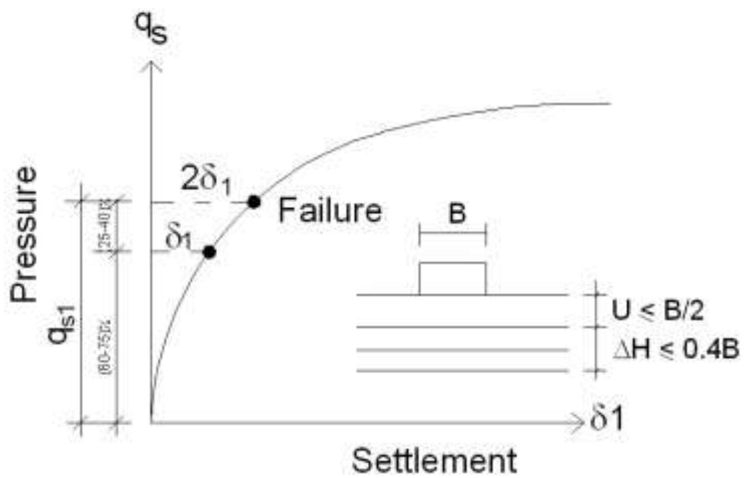
YIELD CRITERION IN REINFORCED FOUNDATION SYSTEMS

The yield stress is defined when permanent deformation initiates. The yield stress which is a boundary to separate the elastic and plastic deformation for soils is usually not clearly defined and is not a constant value. The locus of the stress at which a soil yields is called yield surface. The stresses smaller than yield stresses cause the soil to respond elastically, and stresses larger than yield stresses cause the soil to respond in an elastoplatic way. The yield stress for soil continuously increases or decreases as the soil hardens or softens. The load settlement curves for reinforced foundation systems was found to be elastic when the reinforcement is placed close to the base of the footing (i.e., U ≤ B/2). A number of tests were performed to verify this behavior, and higher yield stresses were obtained at failure due to reinforcement location in this zone (when U is smaller than or equal to B) and due to the inclusion of additional confining stresses in the soil. The additional confining stresses are the result of the placement of the reinforcement in the soil. The proposed failure criterion in the medium dense reinforced sand have been proposed and defined as the bearing capacity at which the settlement is twice the settlement at 60-75% of the safe bearing pressure for the case of U ≤ B/2 (Fig. 19), Further, the proposed failure criterion in the medium dense reinforced sand has been defined as the bearing capacity at which the settlement is twice the settlement at 80-90% of the safe bearing pressure for the case of U ≥ B (Fig. 20).

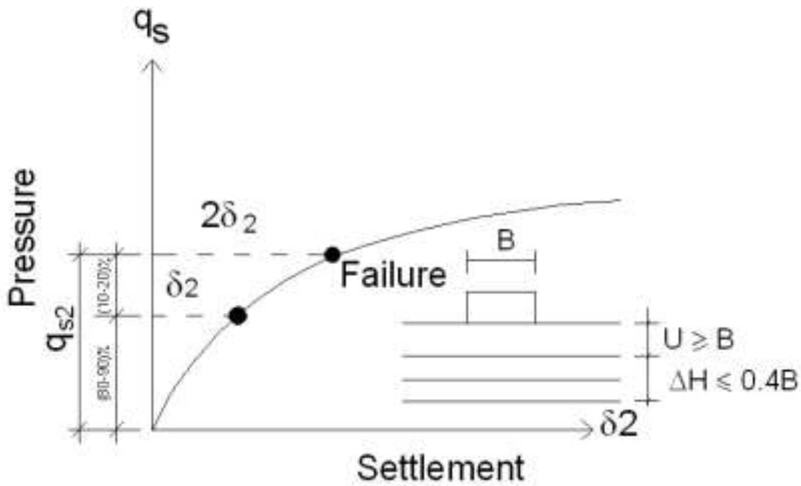
From the tests results it was found that δ_1 is clearly smaller than δ_2, which clearly shows the benefit of reinforcement inclusion in the zone of tension arc, where the zone of high tensile stresses exists. Figure 21 shows the general load settlement trends for both cases.

Additionally, the footing on a reinforced foundation system is more likely to experience a gradual failure curve than a plunging failure. This clearly shows that the settlement is highly reduced when reinforcement is placed closer to the base of footing, while it is improved in a lesser degree when reinforcement is placed further from the footing (Figures 19 and 20).

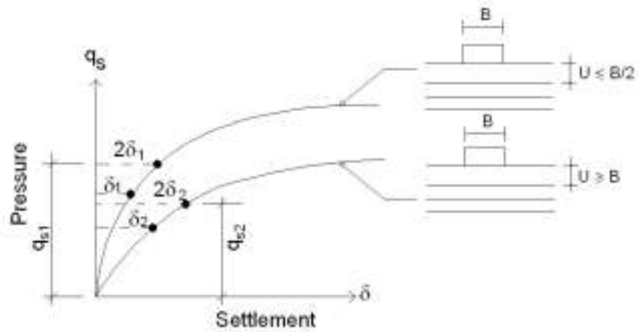
The value of δ_p obtained from equation (3) represents the value $2\delta_1$ and /or $2\delta_2$ in figures 11 and 12 in order to verify the proposed safe bearing pressure in the proposed yield failure criterion for reinforced footing systems. The plate load tests should not be used to determine the ultimate bearing pressure of footings resting on sandy soils because scale effects in such a case give misleading results .



Fig(11) proposed Safe bearing capacity (q_s) for the settlement criterion of circular footing resting on reinforced subgrads (U ≤ B/2).



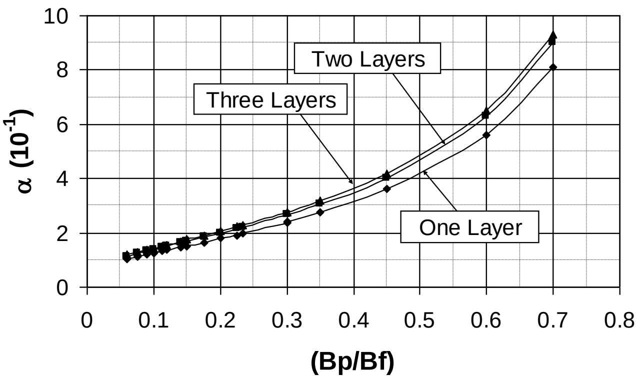
Fig(12) Proposed Safe pressure (qs) for the settlement criterion of circular footing resting on reinforced subgrads (U$\geq$ B).



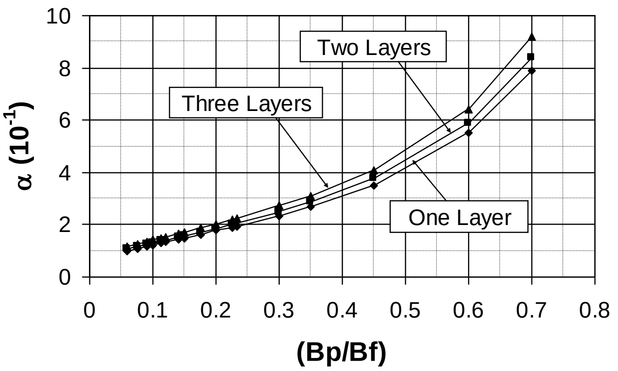
Fig(13) Proposed Safe bearing capacity (q_s) for the settlement criterion for RFS(U$\leq$B/2 and U$\geq$B) rest on sandy soils.

It was also noted that, when the reinforcement was placed in the zone of maximum soil shear, it acted to significantly inhibit the development of a classical bearing failure .

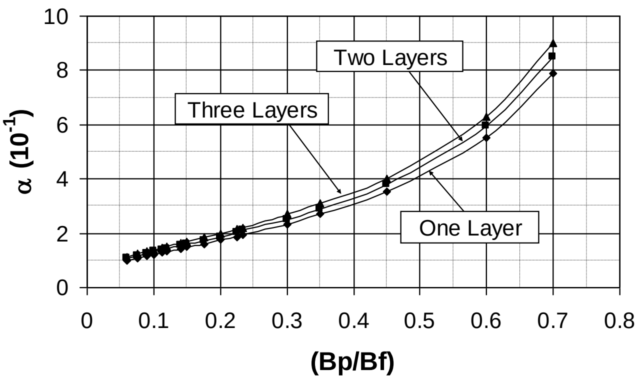
The results in the next figures clearly demonstrate that reinforcement below the shallow footing on sand can reduce the amount of the of settlement, especially differential settlement under the four corners of footings. Footings resting on unreinforced sandy soil settled unevenly, while footings on reinforced soil settled evenly with no tipping of any corners during the observation for the settlement values at the corners after ending the test.



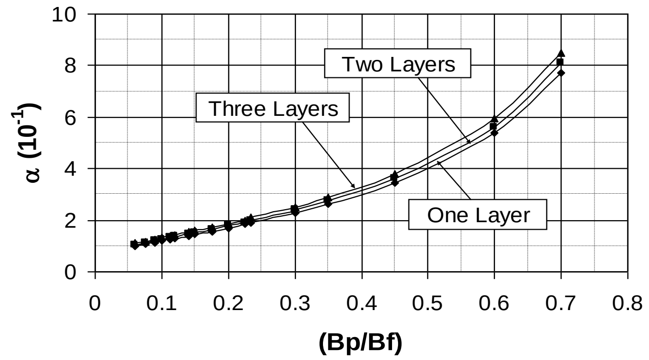
Fig(14) α - (Bp/Bf) relationships for (U=B/6) CE111.



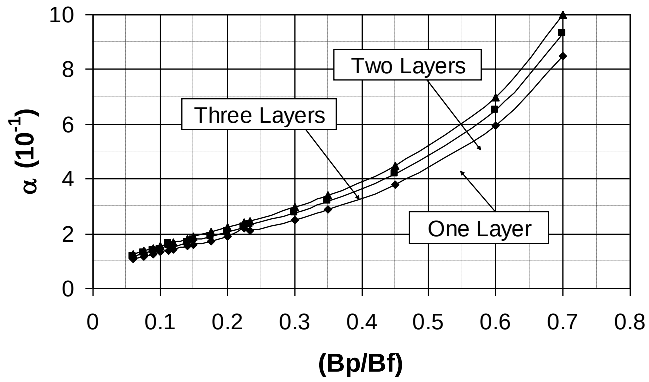
Fig(15) α - (Bp/Bf) relationships for (U=B/3) CE111.



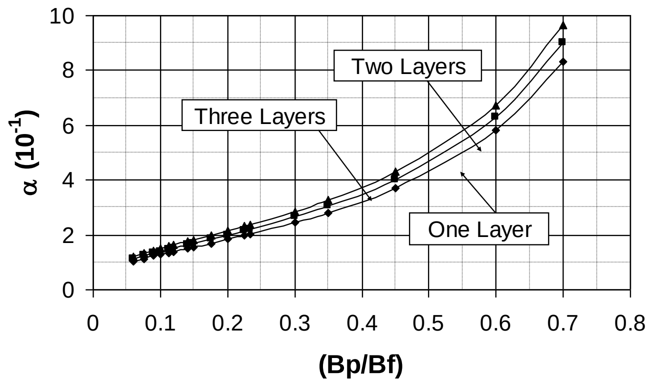
Fig(16) α - (Bp/Bf) relationships for (U=B/2) CE111.



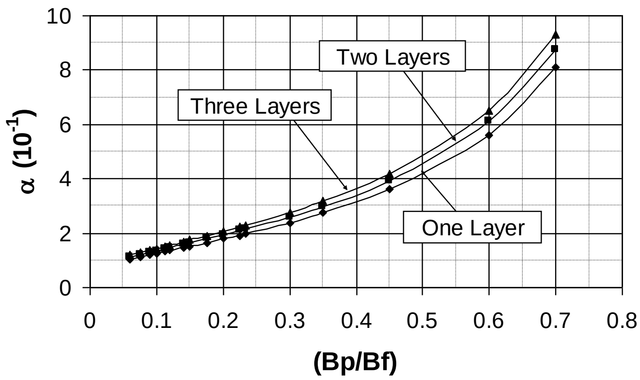
Fig(17) α - (Bp/Bf) relationships for (U=B) CE111.



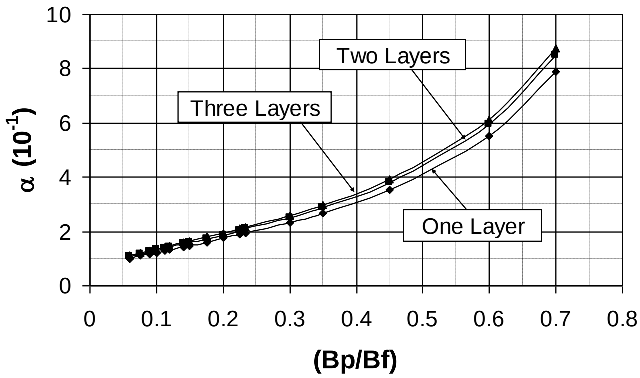
Fig(18) α - (Bp/Bf) relationships for (U=B/6) CE121.



Fig(19) α - (Bp/Bf) relationships for (U=B/3) CE121.



Fig(20) α - (B_p/B_f) relationships for (U=B/2) CE121.



Fig(21) α - (Bp/Bf) relationships for (U=B) CE121.

CONCLUSIONS

The following main conclusions are drawn from this study:

- The depth of top most reinforcement layer is found to be more effective when it is located near the base of the footing (tension arc zone) and the BCR increased up to 3 rapidly when the value of U is close to footing base and the number of layers of reinforcement is three, while a little improvement was achieved beyond that number of layers.
- The settlement value is smaller when a stiff geogrid (CE121) is used below the footing compared with another geogrid (CE111). This was the result of the fact that the value of modulus of the reinforced soil K_s was larger when Netlon CE121 was used compared with Netlon CE111.
- The subgrade reaction values for reinforced soil were found to improve by 2 to 5, 3 to 7 , and 4 to 9 times for one layer, two layers, and three layers of reinforcement respectively when compared with those of unreinforced soils. The lower limit reflects the effect of top most reinforcement layer (U is greater than or equal to D), and the upper limit reflects the effect of the case when U is equal D/6. The value of subgrade reaction became steady when U was larger than 0.8D. However, the steady value of subgrade reaction is still larger than that of unreinforced soil.
- The failure criterion in the medium dense reinforced sand has been defined as safe bearing capacity at which settlement is twice the settlement at 60%-75%

of q_s for the case of (U≤B/2), while the reinforced layer at depth of (U≥B), the failure criterion can be defined also near to that of unreinforced and medium sand at 80%-90% percentage of q_s. This amount of reduction in settlement are shown from that the value of $\delta 1 << \delta 2$.

- The safe bearing pressure for footing resting on reinforced soil can be estimated with (Fs=3) from equation (2) after getting (δp) from equation (3); in condition that a plate load test should be achieved.

REFERENCES

Akinmusuru, J.o., and Akinbolade, J. A. (1981). "*Stability of Loaded footing of Reinforced soil*", ASCE Journal of geotechnical engineering, vol. 107, No. GT6, PP. 819-829.

Al-Dobaissi, H. H. (1990). "*Footings on Reinforced Earth Subjected to Impact Loading"*, Master Thesis, University of Baghdad, Iraq.

Ingold, T. S. (1982). "*Reinforce Earth*"; published by Thomas Telford ltd, London, England.

Bassat, R.H. and Last, N.C. (1978). *"Reinforced Earth Below Footing and Embankments"*, ASCE Proc. Conf. Pittsburgh.

Colin JFP Jones (1985). *"Earth Reinforcement and Soil Structures"*. Butterworth and Co. (Publishers)Ltd.

Lambe, T. W., and Whitman, R. U. (1979). "*Soil Mechanics*"; Published by John Wiley and Sons. Inc.

Bieganousky et. ,al 1976;" Uniform placement of Sand",J.of Geo.Eng.Div.,ASCE,Vol.(102),Gt.PP(229-235).