# Improvement of Soil by Using Polymer Fiber Materials Underneath Square Footing

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## ABSTRACT

The change in project cost, or cost growth, occurs from many factors, some of which are related to soil problem conditions that may occurs during construction and/or during site investigation period. This paper described a new soil improvement method with a minimum cost solution by using polymer fiber materials having a length of (3 cm) in both directions and (2.5 mm) in thickness, distributed in uniform medium dense sandy soil at different depths (B, 1.5B and 2B) below the footings. Three square footings has been used (5 ,7.5 and 10 cm) to carry the above investigation by using lever arm loading system design for such purposes. These fibers were distributed from depth of (0.1B) below the footing base down to the investigated depth. It was found that the initial vertical settlement of footing was highly affected in the early stage of loading due to complex Soil-Fiber Mixture (**SFM**) below the footing. The failure load value for proposed model in any case of loading increased compared with the un-reinforced soil by increasing the depth of improving below the footing. The Bearing Capacity Ratio (**BCR**) for soil-fiber mixture has been increased by ratio of (1.4 to 2.5), (1.7 to 4.9), and (1.8 to 8) for footings (5, 7.5, and 10 cm) respectively. The yield load-settlement for soil-fiber mixture system started at settlement of about 1.1% B while the yield load in un-reinforced soil started at smaller percentage which reflects the benefits of using such fiber materialfor improving soil behavior. Comparison between experimental and predicted (calculated) settlement below the footings showed the difference in ranges were within accepted limits for foundation settlements design.

**Keywords**: **polymer fibe**r, **sand**, **reinforced soil**, **square footing**, **bearing capacity ratio**

# تحسين سلوك التربة بأستخدام الالياف البوليميرية تحت الاسس المربعة

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**مدرس**

**الخلاصة**

أن التغير في كلف المشروع أو تنامي كلفه تحدث بسبب عوامل عديدة بعضا منها يعود لمشاكل التربة خلال فترة الانشاء أوفي مرحلة تحريات الموقع. الدراسة تقدم طريقة جديدة لتحسين تصرف التربة بأقل كلفة ممكنة بأستخدام الالياف البوليميرية (ذات الابعاد 3x3 cm وبسمك 2.5 mm) والالياف موزعة تحت اسس مربعة جالسة على رمل جاف متوسط الكثافة اختبرت لاعماق (B, 1.5B, 2B) . أن الاسس المربعة المستخدمة لاجراء هذه الدراسة كانت بابعاد(5, 7,10 cm) وباستخدام صندوق زجاج مقوى ونظام لذراع تحميل صمم لهذا الغرض . الالياف تم نشرها تحت الاسس بعمق يبدأ من ( 0.1B) تحت قاعدة الاساس ليصل الى العمق المطلوب للدراسة . نتائج الفحوص أظهرت بأن الهبوطات العمودية تحت هذه الاسس تأثرت في مراحل التحميل الاولية بسبب استخدام خليط التربة والالياف (**SFM**). تحسن قيم حمل الفشل لخليط التربة والالياف في الموديل ولاي حالة تحميل مقارنة مع التربة غير المسلحة. سعة التحمل لهذه الاسس(**BCR**) قد ازدادت بقيم (1.4-2.5)و (1.7-4.9) و (1.8-8) لاسس (5, 7,10cm) على الترتيب. حمل الخضوع لخليط (**SFM**)يبدأ عند هبوط (1.1% B) في حين حمل الخضوع للتربة غير المسلحة يبدأ عند نسبا أقل وهذا يعكس الفائدة من استخدام هذه الالياف. أجريت مقارنة بين الهبوطات العملية وتلك المحسوبة وقد أظهرت النتائج تقاربا كبيرا بين القيم المقارنة.

**الكلمات الرئيسيه : ألياف بوليميرية، تربة رملية، تربة مسلحة، اسس مربعة ، نسبة سعة التحمل**

## 1-INTRODUCTION

The decision of ground improvement is taken for a site area when it needs such treatment methods and alsobased on the project design performance requirements that will dictate some of design parameters, including the required stability and the allowable deformation (settlements) of related soil under static or dynamic loading. Different types of structures will have different settlement requirement. The well-designed foundations induce stress-strain states in the soil that are neither in the linear elastic range nor in the range usually associated with perfect plasticity. Thus, in order to predict the settlement accurately underneath the foundation rest on sandy soil, analysis that are more realistic than simple elastic analysis are required and a comparison can be made between the settlement for reinforced and unreinforced soil conditions.

Binquet and Lee (1975a, 1975b) investigated the use of strip footings rest on sandy soil reinforced by wide strips of aluminum foil, along with a method for estimating the carrying capacity of soil based on tests results.

Fragaszy and Lawton (1984) used the aluminum reinforcing strips below a model strip foundations to study the effect of sand density and length of reinforcing strips on bearing capacity of the improved soil.Comparison was made between the reinforced and unreinforced soil test results.Several authors also studied strip foundation butwith different materials such as steel bars(Milovic 1977, Bassat and Last, 1978), geotextiles (Das, 1988) and geogrid (Milligan and Love, 1984).

Khan (2005) examined stabilizing the soil by using Bamboo industry waste, the study shows that using such material can improve the CBR value with increasing fiber content percentage, Figure (1) shows the variation in CBR and swelling of the soil with varying percentage of Bamboo fibers. Figure (2a) shows the shape of Bamboo fibers. Figure (2b) shows soil mixed with different percentage of Bamboo waste.

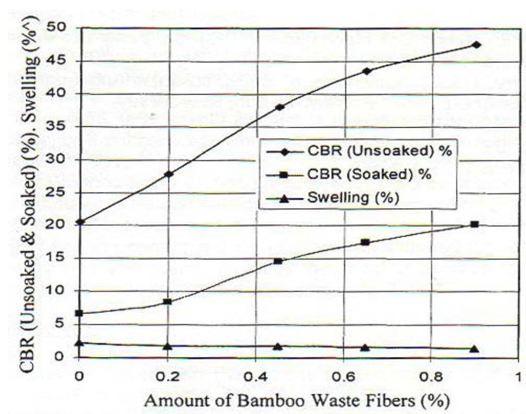
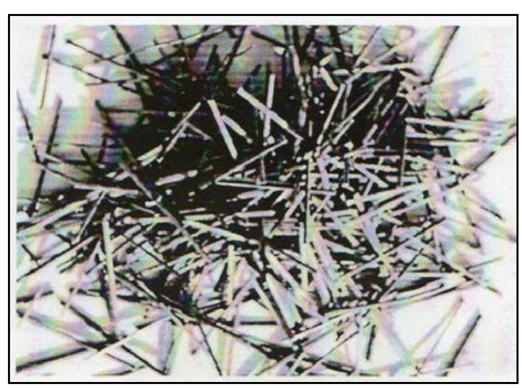
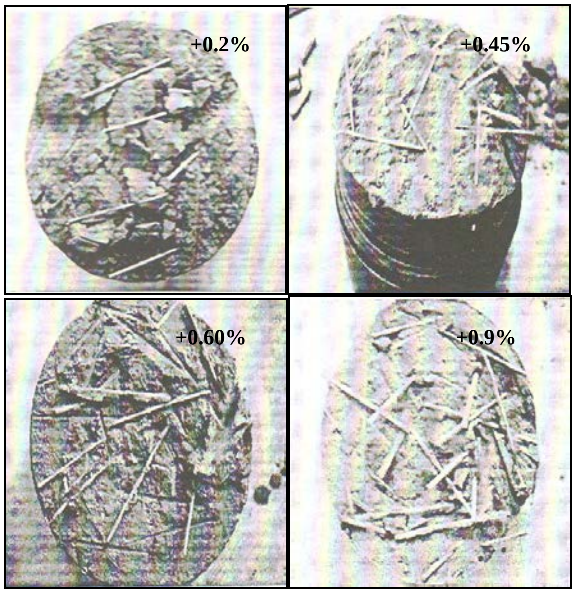



**Figure (1) Variation in CBR and Swelling of Soil with Varying Percentage of Bamboo Fibers (Khan, 2005)**



**(a) Bamboo Waste**




**(b) Soil Stabilized by Different Bamboo Waste Percentages**

**Figure (2) Improving Soil by Bamboo Waste (Khan, 2005)**

Osman (2005) presents the results of a preliminary laboratory investigation on soft clay strengthened by fibers. The system consists of fiber-reinforced sand (the sand mixed with randomly oriented fiber and compacted in layers) between two geo-textiles sheets over fiber-reinforced sand columns inside the soft clay. The results have indicated that the settlement decreases and the bearing capacity increases by using the new system. It shows an effective solution to solve the problem of large settlement of footings over problematic soils such as soft clay. Figure (3) shows the system setup used in the study. Figure (4) shows the load settlement relationship for different arrangements and the new system shows improvement in the carrying load capacity of footing compared with other arrangement but without controlling the initial settlement under initial loading which is required to mobilize the reinforcement strength..

Al Mosawe et al., (2010) investigated the effect of geogrid reinforcement installed below square footing rest on sandy soil and subjected to eccentric loading. The results show improvement in the bearing capacity ratio by (22% to 48%) for one and two number of layers respectively without control on the initial settlement that is required for mobilizing reinforcement strength during loading.

Al Mosawe et al., (2011) present the results of improving soft clay soil (i.e. Kaolin) by compacted fly ash. The results show that there is a noticeable improving in the behavior of square footing settlement and bearing capacity ratio (**BCR)** of (1.3) in average but also without controlling the initial settlement.

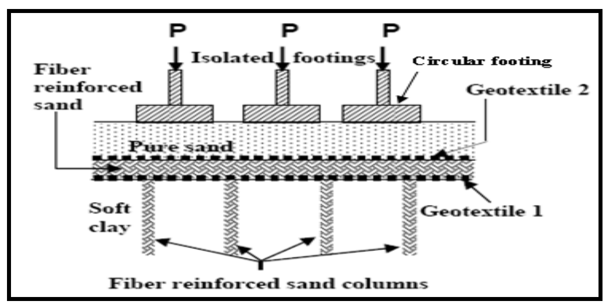



**Figure (3) The New System (Osman, 2005)**

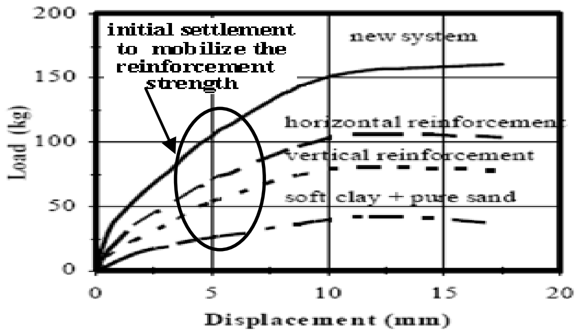



**Figure (4) Load–Displacement Characteristics (Osman, 2005)**

It can be concluded from the above studies that reinforcement can increase the bearing capacity and reduce the corresponding settlement of the foundations compared with unreinforced soil. However, it was also found that an initial vertical movement of the reinforcement is still needed to mobilize the reinforcement strength which reflects such matter of the foundation settlements. In the previousstudies the initial settlement at small loads still could not be avoided; such requirements is a very important design step that is usually controlled by limiting the expected settlement of footing rest on sandy soil.

The study shows new step method to improve soil strength and behavior not only by increasing the bearing capacity and reduce the settlement but also control the initial settlement at initial loads due to the complex interaction of such fiber materials with the sandy soil through the investigated depths (B, 1.5B and 2B).

## 2-PHYSICAL MODELING AND MATERIALS

Tests were performed on sandy soil with geotechnical sand properties listed in Table (1) [more than 95 passing No.4 mm sieve and less than 2 % passing No.200 sieve]. The poorly graded sand (**SP**) was used to facilitate and control sand density during raining process inside the glass box. Static loading tests for surface square concrete footings (5, 7.5 and 10 cm) were achieved by using steel lever-arm system. The sand is poured in square glass box with dimensions of (72 x 72 x 80 cm). The glass thickness was (6 mm) stiffened by means of steel sections as shown in Figure (5).

Table (1) Geotechnical Sand Properties

| | |
|---|---|
| Specific Gravity $G_s$ | **2.63** |
| Relative Density Dr (%) | **65** |
| Maximum Unit Weight (Dry) $kN/m^3$ | **19.73** |
| Minimum Unit Weight (Dry) $kN/m^3$ | **15.5** |
| Unit Weight tested soil (Dry) $kN/m^3$ | **18.0** |
| Void Ratio **e** | $e_{max}$=0.696<br>$e_{min}$= 0.333<br>$e_{test}$=0.46 |

The sand-fiber material flows in a flexible hose through sieve No.4 to the box where the falling height of sand from hopper was fixed at 45 cm as shown in Figure (5). It was found that pouring Sand-Fiber Mixture (**SFM**) from such height with a (25 mm) soil lifts (1% of fiber by weight mixed with each soil lift), gives a unit weight of 18.0 $kN/m^3$ (i.e. Dr=65%); similar to the procedure recommended by Bieganousky and Marcuson (1976). The angle of internal friction for sand was determined as ($\phi$=33°) from triaxial consolidated undrained test. The fiber materials used in the tests having a size of (3 cm) in both perpendicular directions and thickness of (2.5 mm) as shown in Figure (6).

The bearing capacity and settlement of the footing resting on sand depend on properties of sand such as the angle of internal friction $\phi$ 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/or extrapolating results to full scale footings.


**Figure (5) Frame System along with Glass Box Filled with Dry Sand during Testing**

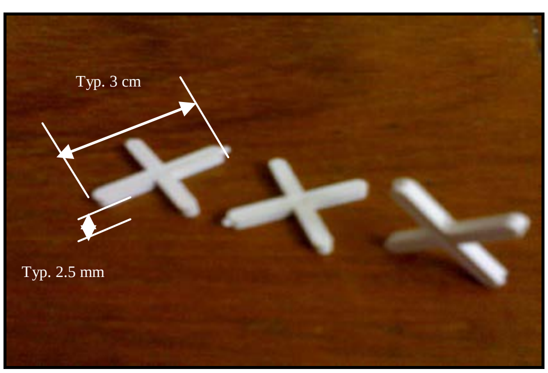



**Figure (6) Polymer Fiber Reinforcement Material used in Testing**

## 3-TEST RESULTS AND DISCUSSION

The following parameters were considered in this study:

a. Improvement for the bearing capacity of soil related to footing size.
b. Improvement for the subgrade reaction value of (**SFM)** system.
c. Experimental and calculated settlement comparison.

The bearing capacity of soil was improved by using polymer fiber material (i.e. $q_f$); while thebearing capacity of soil without fibers is $q_{un}$. The load-settlement relationships are shown in Figures (7) to (9). The bearing capacity ratio (**BCR**), which is defined as ($q_f/q_{un}$) represented at a settlement of about 1.1% from footing width. It was found that the **(BCR)** increased by ratios of (1.4 to 2.5), (1.7 to 4.9), and (1.8 to 8) for footing (5 cm and 7.5, and 10 cm) respectively as shown in Figure (10). The subgrade reaction value ($q/\Delta H$) calculated as yield bearing load of such case divided by corresponding yield settlement value which is mostly started at about 1.1% B for the reinforced case. It was found that the ratio of ($K_s/K_{sun}$) increased by (1.4 to 3) for footings (5 and 7.5 cm) and (1.8 to 4.5) for footing (10 cm) as shown in Figure (11).The improvement in footings performance for the new geotechnical polymer soil-fiber mixture (**SFM**) system was due to the lateral and vertical restraint that comes from random fibers distribution in the surrounding sandy soil below the footing. The fiber material also preventing the failure lines below the footing to propagate in flow offailure direction towards tensile arc strain locations as shown in Figure (12).

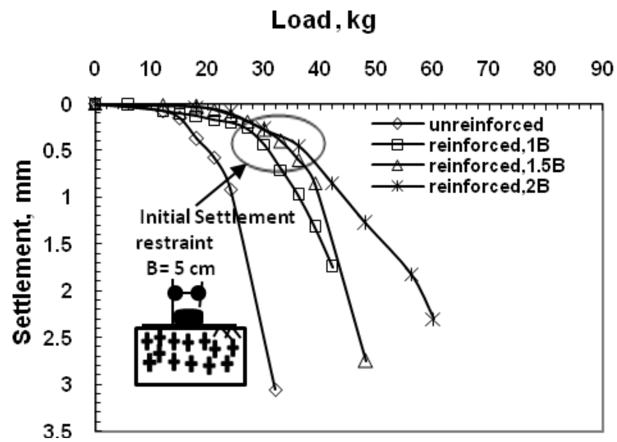



Figure (7) Load vs Settlement for Footing (5 cm) Width

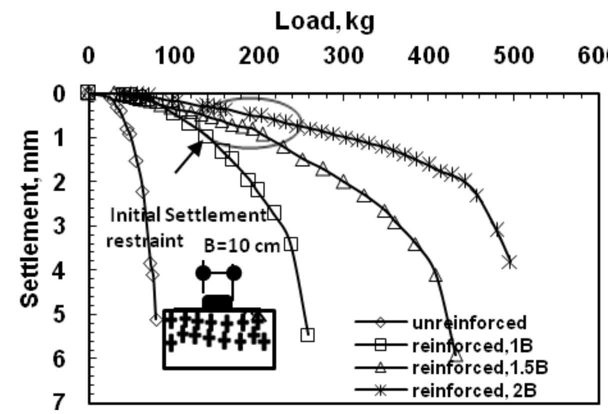



Figure (9) Load vs Settlement for Footing (10 cm) Width

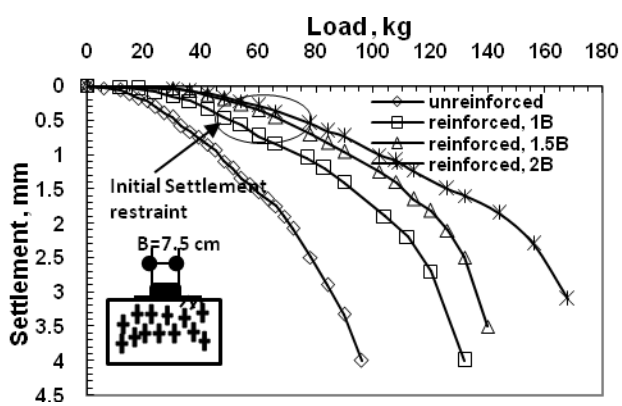



Figure (8) Load vs Settlement for Footing (7.5 cm) Width

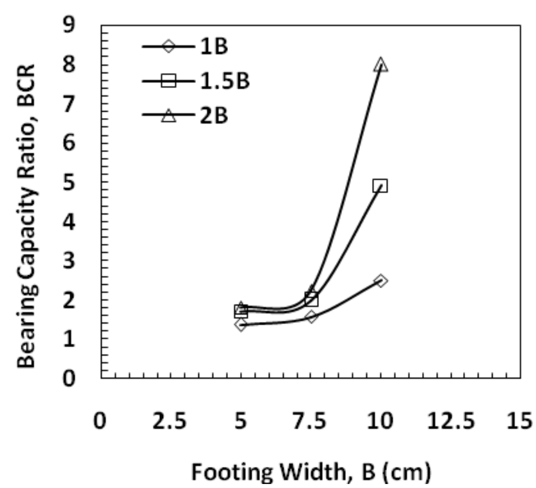



Figure (10) BCR vs Footing Width

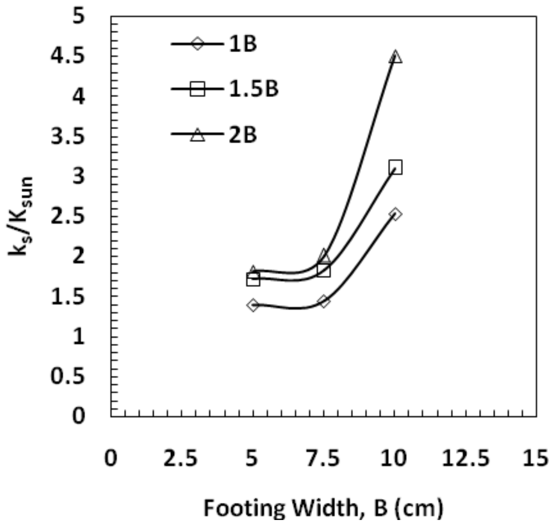



**Figure (11) $K_s/K_{sun}$vs Footing Width**

## 4-SETTLEMENT CRITERIA

The use of reinforcement materials to improve the bearing capacity of soil and to reduce settlement has been proven to be cost-effective solution for foundation design. The reinforcement materials are usually placed horizontally. However, there are cases in which vertical or sloped reinforcement may be used below the footing. Furthermore, using such random fiber orientation inside the soil placed within the tensile arc of strain field causes realignment of the strain field which improves the performance for the load carrying capacity of the footing (Jones, 1985). The ideal reinforcement patterns for the direction of the principal tensile strains areshown in Figures (12) and (13). From 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).

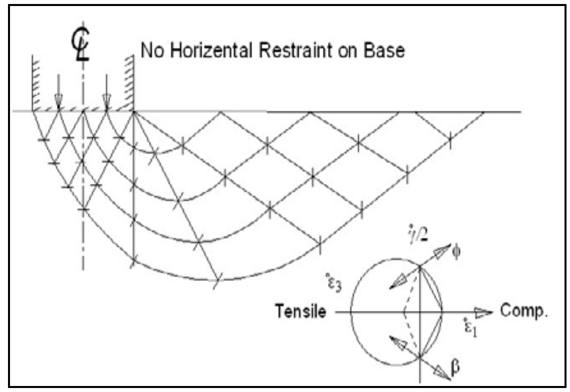



**Figure (12) Zero Extension Characteristics for Dilating Soil (Bassat and Last, 1978)**

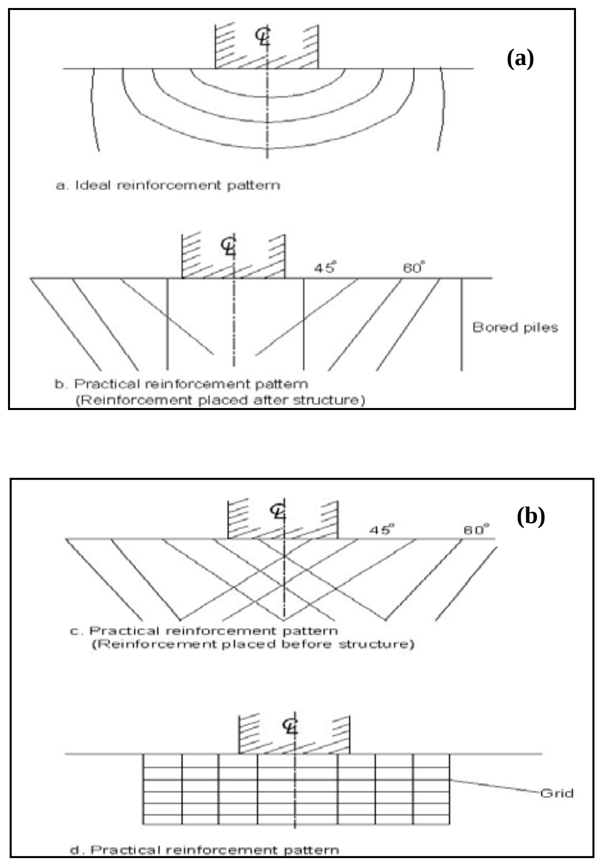



**Figure (13) Different Reinforcement Orientations below the Footing (a &b) (Jones, 1985)**

The calculation of immediate settlement of footings 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 laboratory 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 for granular soils may not accurately give these soil properties which are needed for the calculation of settlement. In the case of soil-fiber mixture (**SFM**) 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 to estimate the footing settlement. The model footing can be used to estimate the overall modulus of the soil which provides a representative parameter in conventional settlement estimation. Mekkiyah and Alansari (2004) proposed empirical equations to estimate the settlement and modulus of elasticity of reinforced soil underneath surface circular footing rest on sandy soil by using Equations (1) and (2). The modulus of elasticity for soil-fiber mixture system improved compared with unreinforced soil calculated from Equations below, while test results are shown in Figure (14).

$$\delta_f = 0.8 * \frac{q * B}{ER} \qquad (1)$$

where:

$\delta_f$ = Footing settlement.

q= Load carrying capacity of footing.

B= Footing width.

ER= Modulus of elasticity for reinforced soil.

$$ER = (FI) * K_{sun} * B * (1 - \upsilon^2) \qquad (2)$$

where:

FI= Improving factor for the case of footing [FI = (1.5 to 2.5) for 1B, (2 to 3) for 1.5B, and (2.5 to 4) for 2B]

$K_{sun}$=Subgrade reaction value for unreinforced soil.

υ= Poisson’s ratio (recommended value of 0.3).

From Figures (15 and 16) comparison between experimental and calculated settlement showed that the difference in settlement calculation increased with increasing improving depth below the footing and as follows [i.e. based on Line of Perfect Agreement (**LPA**)]; within an average of 10%, 15%, 20%, and 25% for unreinforced, 1B, 1.5B, and 2B cases respectively.

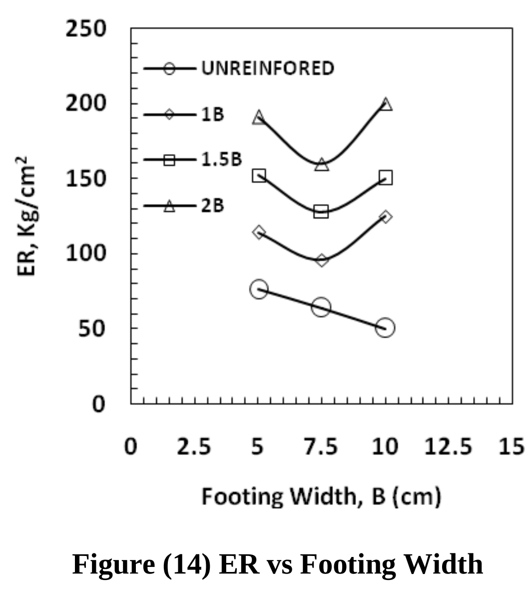



**Figure (14) ER vs Footing Width**

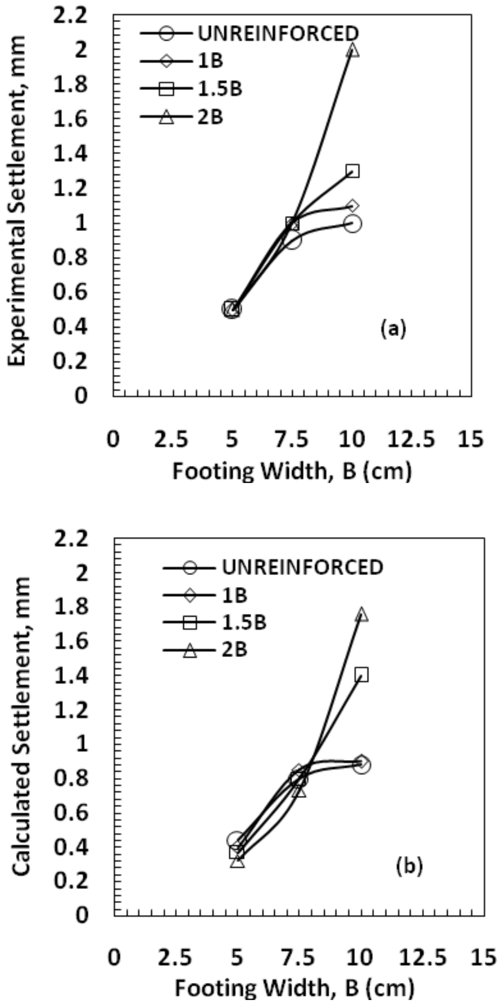



**Figure (15) Settlement vs Footing Width: (a) Experimental, (b) Calculated**

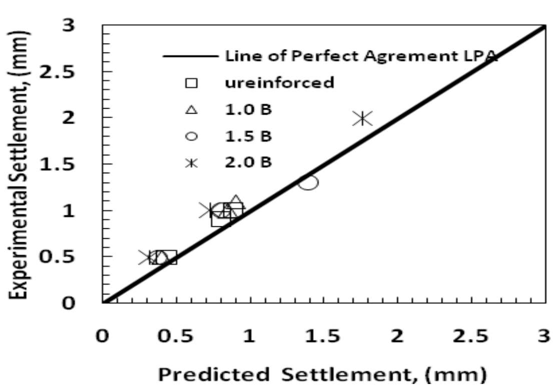



**Figure (16) Settlement Comparison**

## 5-CONCLUSION

The following conclusions are drawn from this study:

- The bearing capacity ratio (**BCR**) increased with a ratios of (1.4 to 2.5), (1.7 to 4.9), and (1.8 to 8) for footings (5, 7.5, and 10 cm) respectively; which reflect the benefit of using such polymer fiber material underneath footing as minimum cost solution for increasing the bearing capacity and reduce soil settlement.

- The subgrade reaction values for the reinforced soil-fiber mixture (**SFM**) increased by ratios of (1.4 to 3) for footings (5, 7.5 cm) and (1.8 to 4.5) for footing (10 cm).

- Settlement analysis were achieved for both experimental and predicted settlement, the results showed that the difference in analysis still in accepted limits in the view of geotechnical foundation settlement design. The lateral and vertical restraint in the values of initial settlement at small loads can be avoided from the random fiber distribution in the sandy soil below the footing. The fiber materials also preventing the failure lines in soil below the footing to propagate in flow direction of failure towards the tensile arc strain locations and thusimprove in soil behavior in terms of bearing capacity, settlement reduction and restrain the initial vertical settlement of footing during early stage of loading.

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