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The Behavior of Polypropylene Fiber Reinforced Sand Loaded by Square Footing

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Abstract: ***This research involves the effect of both sizes of the reinforced zone and amount of polypropylene fiber reinforcement, on the structural behavior of model reinforced sand loaded by square footing. The ratio of side of the square reinforced zone to the footing width (W/B) and the ratio of the square reinforced zone depth to footing width (H/B) has been varied from one to six and from one to three respectively. The tests were carried out on a small-scale laboratory model, in which uniform graded sand was used as a fill material. It was placed in a high dense state by hitting thin wooden board placed on the sand surface with a hammer. The sand was reinforced with randomly oriented discrete fibrillated polypropylene fibers. The test results indicated a significant increase in the bearing capacity and stiffness of the sub grade and a modification of load–settlement behavior of sand to the size of the reinforced zone and amount of fiber reinforcement. On the basis of the present test results, the optimal side width and depth of the reinforced zone were 4B and 2B respectively, while the optimal percentage of fiber was 0.4%.***

Keywords: **Square footing, Polypropylene fibers, Bearing capacity, Stiffness, Load – settlement behavior, Relative density.**

SYMBOLES

B	**Width of square footing.**
H	**Height of reinforced zone.**
W	**Width of reinforced zone.**
ρ	**Fiber concentration.**
S	**Settlement of the footing.**
q	**Bearing pressure.**
BCR	**Bearing capacity ratio.**

I. INTRODUCTION

Reinforced soil is defined as, a construction material composed of cohesion less free drainage materials, which is strong in compression but weak in tension, and the reinforcing elements, with high tensile strength materials, placed in the soil fill, supplying the soil mass with the necessary tensions. The soil and reinforcing strips will interact by means of friction resistance [1], [2], and [3] and results in stable mass that behaves monolithically, and can be used as earth retention and load supporting structures.

Reinforced soil is really an attractive and economical answer to many earth retention problems associated with highway construction, such as retaining walls, bridge abutments, platform supporting structures, foundation slabs, under water quay and sea walls, dams, sedimentation basins and tunnel linings … etc.. [4], [2], and [5].

The applications of reinforced soil to soil retaining and load supporting structures have been studied on a theoretical and analytical basis. The basic assumptions and results of these studies have been checked and found to be realistic by constructing small scale models in the laboratory. Most of the studies that have been traced till now were concerning the modes of failure, seismic effect on the behavior of reinforced soil wall, suitability of materials for reinforcing strips as well as the effect of the placement condition of fill materials [6], [7], [2], and [5]. On the other hand, the works performed on a full scale structures were concentrated on the stress measurement within the soil and stress distribution along the reinforcements. The current interest in soil reinforced with synthetic materials stems largely from research by Vidal, H. [3]. In Arabian Peninsula the concept of combining straw with mud dates back several centuries. Straw is added to the clay-water mixture to minimize the loss of strength when it comes in contact with water and to prevent cracking due to hot dry weather conditions. An early investigation by Lee et. al. [2], indicated that the strength of sand reinforced with wood shavings increased by a factor of about 4 and with a dramatic increase in deformation modulus. Gray and Al-Rafeai [8] and Al-Rafeai [6] performed triaxial tests on sand reinforced with randomly oriented discrete fibers. Their test results indicated that increasing the fiber's aspect ratio increased the ultimate strength and stiffness of reinforced sand and the strength increase is proportional to amount of fiber. They also found that the failure in sand reinforced with short fibers, or tested at low confining stress, occurred by slippage of the fibers.

The main purpose of the sand reinforcement technique is to increase the bearing capacity and to reduce the settlement. The improvement in the load bearing capacity and stiffness of sand using synthetic fabric or fibers as tensile reinforcement under footing has been reported by Haliburton and Lawmaster [4] and Akinmusuru and Akinbolade [9]. Haliburton and lawmaster [4] performed model plate bearing tests on sand reinforced with four different Geotechnical fabrics. Akinmusuru and Akinbolade [9] studied the bearing capacity of square footing supported by sand which was reinforced by multilayers of oriented robe fibers.

The aim of this study is to present the fiber effects on bearing capacity and settlement through laboratory bearing capacity tests of square footing model, resting on sand reinforced with discrete randomly oriented fibers.

II. MATERIALS AND EXPERIMENTAL WORKS MATERIALS

A. Soil

The sand used in the tests in this research was obtained from Khasa river bed in Kirkuk governorate. Suitable

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amount of the sand was washed, and sieved on sieve No. 14 and 200, to have a suitable particle size, for better workability conditions. Sieve analysis was carried out on the sand to determine the grain size distribution of the sand particles, according to the British standard BS 1377, it was found that the sand was granular uniformly graded with a unified soil classification system destination SW, with a uniformity coefficient C_u=2.2, a curvature coefficient C_c=1.1 and D_{50}=0.4. The specific gravity of the sand particles was found to be 2.66. The maximum density of the sand was determined by means of compaction test, while the minimum density was found by jar test method. The upper and lower values of the density were 16.98 and 14.32 kN/m^3 respectively. The angle of internal friction between the sand grains was 35 degrees at the proposed density, which was determined using a direct shear test.

B. Reinforcement

The reinforcement used in the model in this research was 50 mm long fibrillated polypropylene fiber. Properties of the fiber as supplied by the manufacturer (Synthetic Industries) are listed in Table (I) below.

Table (I) Fiber Properties

Specific gravity G_s	**0.90**
Single fiber tensile strength (N/cm^2)	**36**
Young's modulus (N/cm^2)	**350**
Elongation at break (%)	**17 ± 5**
Equivalent diameter (mm)	**0.40**

III. EXPEREMENTAL WORK

A. Testing apparatus

The plan and the appropriate section of the testing apparatus of this research are shown in Fig. (1) and Fig. (2) respectively. The testing apparatus consists of:

- A well stiffened box of 500 x 500 x 420 mm internal dimensions, with 10 mm side thickness and 20 mm thickness base. The sides were made of Perspex plates in order to minimize friction between soil and box walls and provide direct observation during compaction and testing. The base was made of wooden plate.
- A rigid steel frame, one meter high to support the box and prevent lateral displacement.
- The square footing model was 50 mm side length, 20 mm thick and made of aluminum, with sand glued to its base to simulate a rough base condition [1].
- Two dial gauges were placed on the two outside sections of the footing to measure its settlement.

B. Testing program

The main parameters concerned in this research were:

- Effect of ratio of width of the reinforced zone to the footing width (W/B).
- Effect of ratio of depth of the reinforced zone to the footing width (H/B).
- Effect of percentage of fiber concentration (ρ).

For this purpose the testing program is divided into two groups, as follows:

1. Group I

One test was done on non-reinforced sand.

2. Group II

Seventeen tests were done on reinforced sand, as follows:

a. Twelve tests to show the effect of the ratio of the width of the reinforced zone to the footing width (W/B = 1, 2, 4 and 6) using fiber concentration (ρ = 0.4%) for different ratios of depth of the reinforced zone to the footing width (H/B=1, 2 and 3).

b. Five tests to show the effect of fiber concentration (ρ=0.1%, 0.2%, 0.3%, 0.4% and 0.5% by weight), using the ratio of depth of the reinforced zone to the footing width (H/B=2) and the ratio of the width of the reinforced zone to the footing width (W/B=4).

While other parameters such as width of the strip footing (B), relative density of the sand and type of reinforcement (50 mm long fibrillated polypropylene fiber) was kept constant.

C. Testing procedure

For non-reinforced sand test, the dry sand was mixed with sufficient amount of water (5% by weight). A predetermined weight of moist sand needed to produce a dry density of 17.7 % kN/m^3 (relative density D_r=70%) was compacted in 50 mm thick layers (equal to fiber length). Compaction was accomplished by placing a wooden board on the sand surface and hitting the board with a hammer [11]. When the depth of the sand in the box reaches 400 mm, the model footing was centrally placed on the top of the non-reinforced sand, then the two dial gauges were placed on the outside sections of the footing to measure its settlement, and then it was loaded at a constant axial displacement rate of 0.15 mm/min to failure.

In the case of tests on reinforced sand, the moist sand was mixed with a desired percentage of fiber (ρ) by hand to ensure a uniform mixture. Reinforced sand was deposited in the form of square trench below the footing (according to testing program). For making the square trench, different wooden plates were used to create square trenches with width / footing width (W/B) ratios of 1, 2, 4 and 6, and height / footing width (H/B) ratios of 1, 2 and 3. When the desired height of non-reinforced sand layer was reached, the wooden mold was centrally fixed in the test box on the compacted non-reinforced sand. The non-reinforced sand portion was then compacted in 50 mm thick layers, and then the inserted wooden mold was removed, leaving a square trench. A predetermined weight of fiber reinforced sand mixture was then deposited into the trench and compacted

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in 50 mm thick layers using a wooden board of the same size as the trench. This process is repeated until the desired trench is created. Fiber reinforced sand was compacted to the same dry density as the non-reinforced sand (i.e. D_r=70%), then the model footing was centrally placed on the top of the reinforced sand in the trench, and the two dial gauges were placed on the outside sections of the footing to measure its settlement, and then it was loaded at a constant axial displacement rate of 0.15 mm/min to failure.

IV. RESULTS AND DISCUSSION

A. MODEL TEST ON NON-REINFORCED SAND

Fig. (3) shows a typical plot of bearing pressure (q_0) on the square footing model and the corresponding settlement ratio (S/B) for test on non-reinforced sand. The observed load settlement curve exhibits the typical general shear failure, with an ultimate bearing capacity of 128 kPa occurred at a settlement of about 8% of the width of the footing. The used moisture content had no significant effect on the stiffness and stress-deformation properties of the sand.

B. MODEL TESTS ON REINFORCED SAND

Load settlement behavior

Prior to testing; two series of tests were conducted to examine how the load-settlement relation is influenced by varying the depth (H) and width (W) of the reinforced zone below the footing base. It was necessary to select a suitable fiber concentration to be used in the model tests. Trial sand-fiber mixes with different concentrations were used to build sand reinforced trench (W/B=H/B=2). It was necessary to increase the compaction effort to maintain the desired relative density with increasing fiber concentration. Sand reinforced with a fiber concentration of ρ=0.4% were selected because it was easily and efficiently compacted, with minimum disturbance to the surrounding compacted non-reinforced sand layers.

It appears that the reinforced zones resist the lateral displacement of soil underneath the footing and create a sand confinement situation. Furthermore, the fibers modify the uniform pattern of strain which usually develop in non-reinforced sand, to a more complex deformation mechanism and hence increase the bearing capacity.

Fig. (4) shows the load-settlement curves for model footing resting on the shallow reinforced zone (H/B=1) with W/B ratio varied from 1 to 6. The nature of the load - settlement obtained is primarily by general shear failure. The reason for this is probably that the failure surface starting from the footing edges extend and pass through a great depth of non-reinforced sand. In the case of deep reinforced zone (H/B=2 and H/B=3) the general shear failure mode is completely eliminated, in contrast with non-reinforced case in which a well-defined general shear failure plane was visible. Degree of curvature of the load-settlement curves decreased with increasing W/B ratio, as shown in Fig. (5) and Fig. (6). It is interesting to note that, in none of the reinforced tests a reduction in stiffness did occur. In their work, Andrawes et. al. [12] have found that for the strip foundation of geotextile reinforced sand, the presence of geotextile had little effect on the load-settlement behavior of The footing until the settlement reached approximately 8% of the footing width.

C. Effect of reinforced zone depth H/B

For convenience in expressing and comparing test data a dimensionless bearing capacity ratio, which has been introduced by Binquet and Lee [13], is used in this study. The bearing capacity ratio was defined as BCR=q/q_0, where q and q_0 are the bearing pressure for reinforced and non-reinforced sand respectively, both measured at the same vertical settlement. As a majority of the load-settlement curves obtained did not show a well-defined failure point, and because fiber reinforcement continued to influence the ultimate bearing capacity at relatively large settlements, the BCR values corresponding to S/B=8% were adopted as representative values for comparison.

Fig. (7) Shows the effect of reinforced zone depth H/B on the bearing capacity ratio BCR. It is clear that the BCR increases rapidly with increasing H/B ratios up to a maximum value, after which it remains practically constant. There is no significant difference in the BCR between the reinforced zones with H/B equal to 2 and 3. This suggests that the optimal value of reinforced zone parameter H/B exists between 1 and 2. Reinforcing to a depth greater than 2B has no effect on the bearing capacity of the footing because the zone of active and radial shear deformation beneath the footing extends no deeper than twice the footing width. Haliburton and Lawmaster [4] observed similar results in their model footing tests on sands reinforced with geotextiles.

D. Effect of reinforced zone width W/B

Fig. (8) Shows the variety of BCR versus the reinforced zone with ratio W/B for H/B of 1 to 3. The magnitude of BCR ***Increases*** with W/B and reaches a maximum value at about W/B between 2 and 4. From Fig. (8) It can be realized that for W/B>4, the magnitude of BCR remains constant. Akinmusuru and Akinbolade [9] observed similar results for model footing tests on sand reinforced with oriented fibers.

E. Settlement of footings S/B

The objective of using fiber reinforcement is not only to maximize the strength of reinforced sand at the expense of the stiffness, but rather to improve the global properties of the reinforced composite body, i.e. to maximize its strength and / or minimize boundary deformation [14]. The BCR variation with settlements of footings on the reinforced zone with different values of H/B and W/B ratios is shown in Fig. (9).It is found that the contribution of fiber reinforced zone to the bearing capacity increases are high as the settlement of footing increases. The most effective width and depth of reinforced layer obtained from Fig. (9) are W=4B and H=2B respectively.

F. Effect of fiber concentration ρ

A number of tests were performed with H/B and W/B ratios of 3 and 2 respectively to investigate fiber concentration effect on the bearing capacity and settlement of surface faulting. The soil dry density was kept constant

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(D_r=70%) for this series of tests. The observed relationships between the load and settlement are given in Fig. (10). The plots demonstrate a significant increase in the stiffness and the bearing capacity was gained by increasing the fiber concentration. There seems to be no significant difference in the effect of improvements for fiber concentration ρ>0.4%. The response to the applied load of footings on sand reinforced with low fiber concentration (0.1% - 0.2%) is of a general shear failure mode, while for those of sand reinforced with high fiber concentration ρ>0.3% is of a progressive failure type. In Fig. (11), the effect of fiber reinforcement is plotted as the BCR values calculated at S/B=8%. The BCR increases with the fiber concentration almost linearly up to a maximum value of ρ=0.4% and remains particularly constant thereafter.

V. CONCLUSION

Laboratory model test results for bearing capacity of square surface foundation resting on fiber reinforced sand have been presented. Based on experimental investigation, the following conclusions have been drawn:

- Inclusion of discrete, randomly oriented fibers below a foundation in sand increases the load carrying capacity and stiffness.
- The bearing capacity and stiffness increase as the depth and width of the reinforced zone are increased.
- The optimal depth and width of the reinforced zone for increasing the bearing capacity and stiffness are 2B an4B respectively. Greater Depths and widths of reinforcement are ineffective in increasing bearing capacity.
- Foundations on fiber reinforced zone with suitable dimensions can tolerate larger settlement before failure.
- Increasing the fiber concentration increases the bearing capacity and considerably increases the footing settlement at failure up to some limiting concentration. Thereafter, the bearing capacity and stiffness approach an upper limit.
- Large scale field tests are necessary to verify the present findings.

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APPENDIX

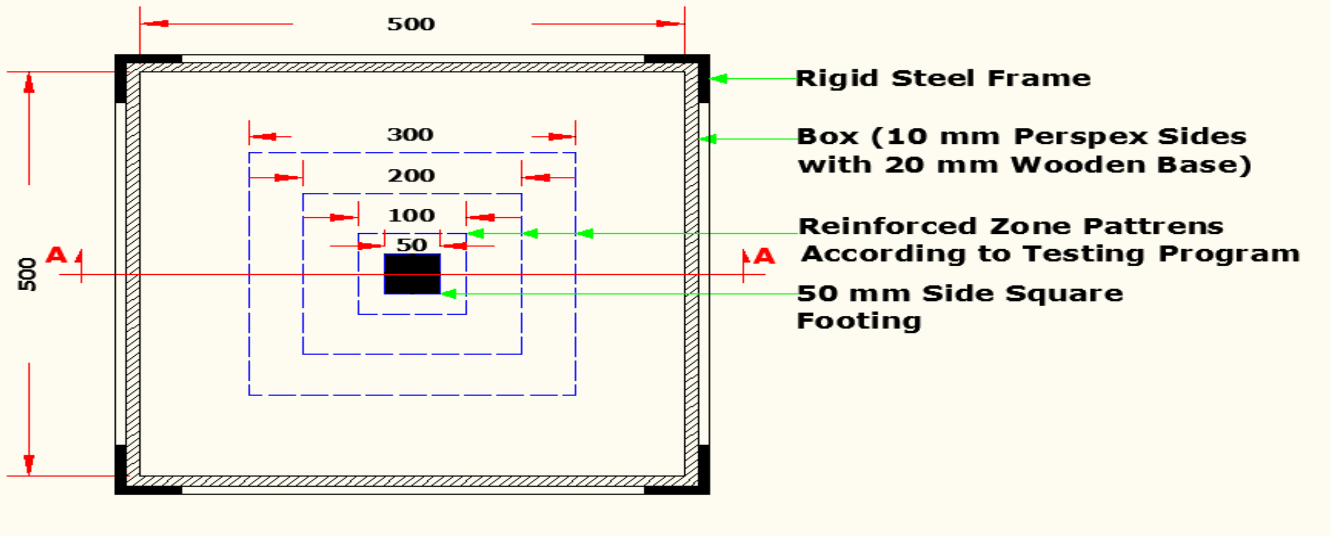

Fig. (1) Model Test Plan

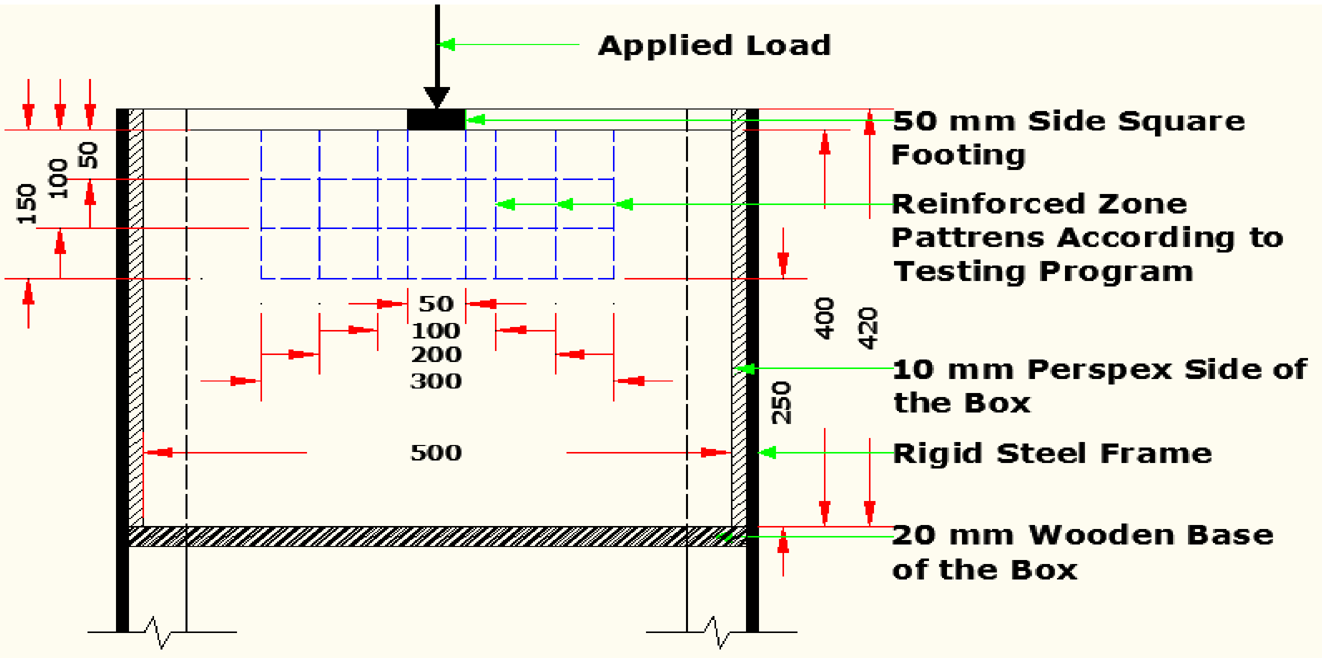

Fig. (2) section A-A

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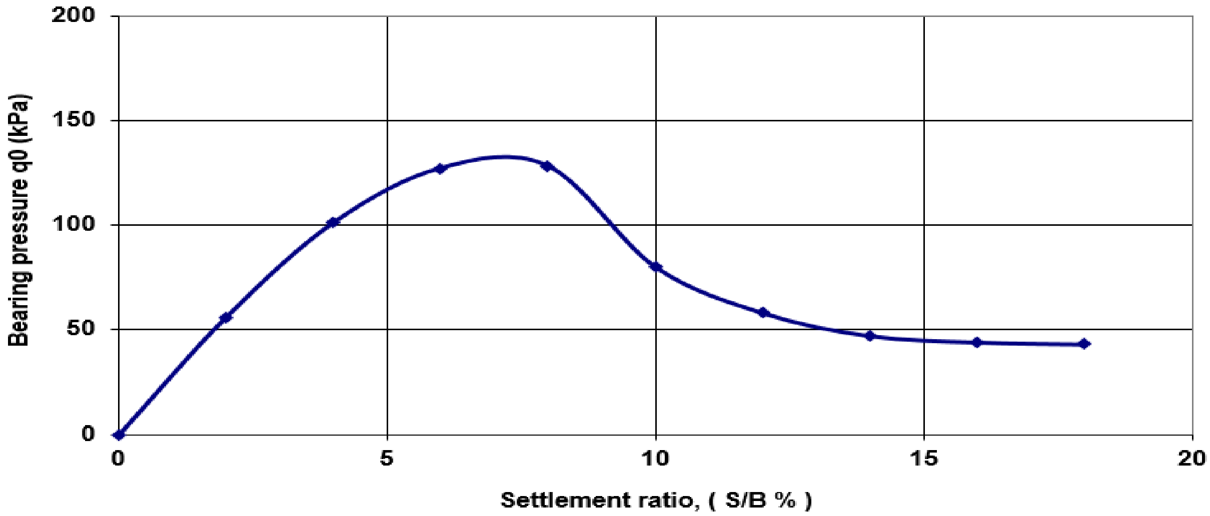

Fig. (3) Pressure - settlement relationship for non-reinforced

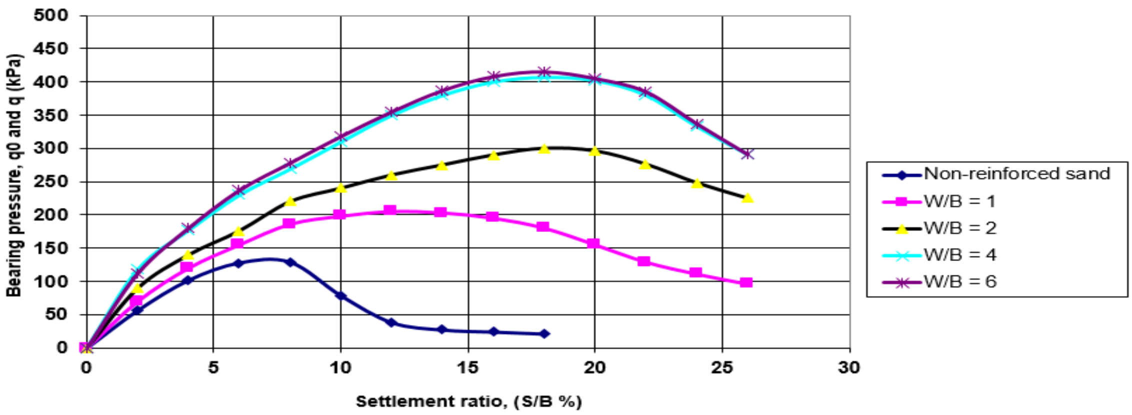

Fig. (4) Pressure-settlement relationship (H/B = 1)

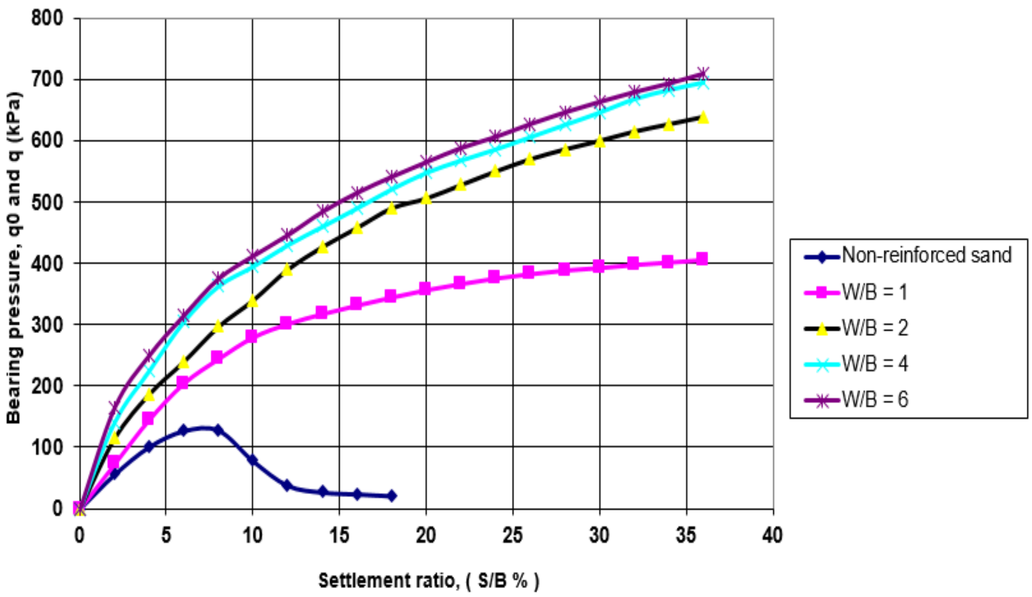

Fig. (5) Pressure-settlement relationships (H/B = 2)

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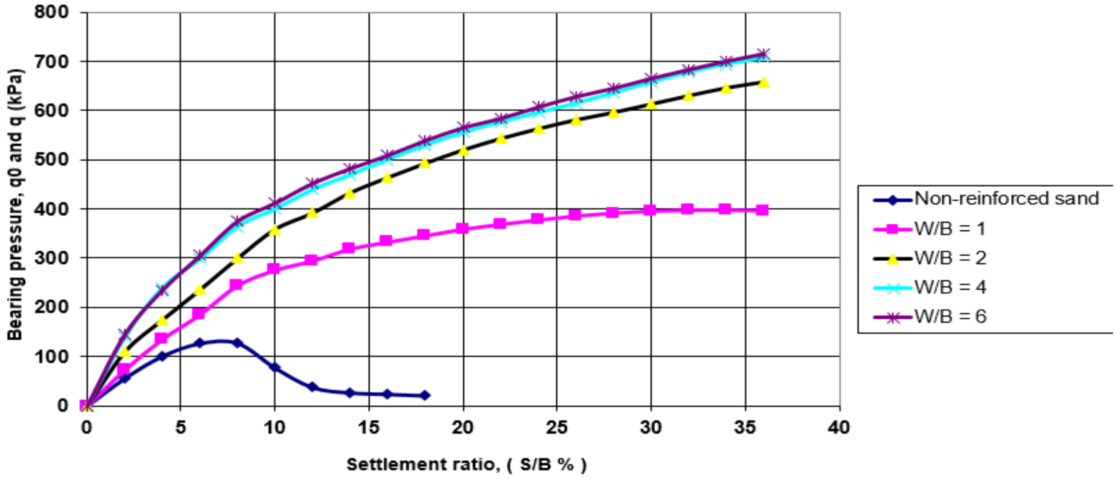

Fig. (6) Pressure-settlement relationships (H/B= 3)

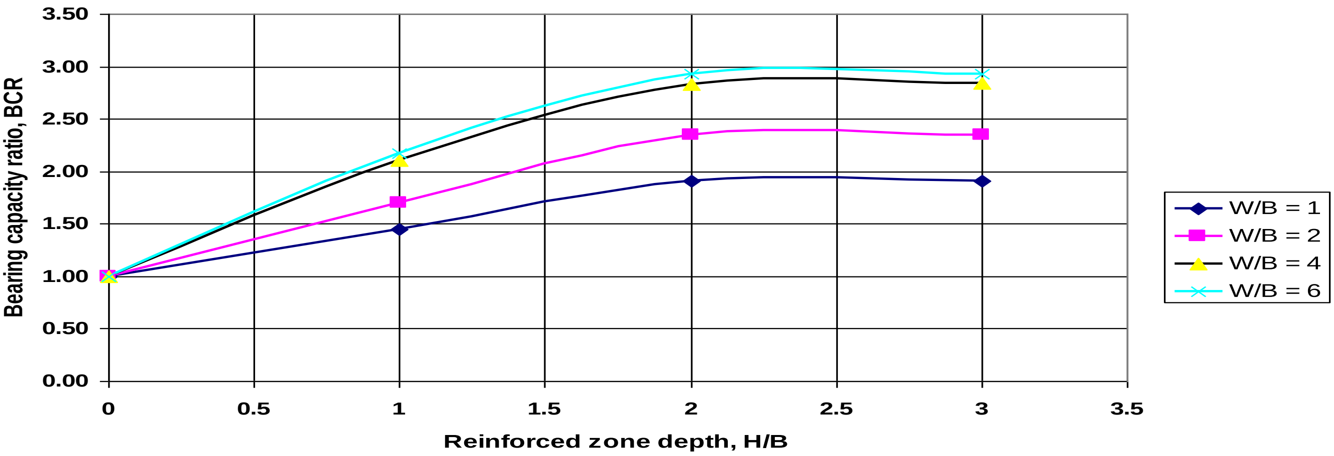

Fig. (7) Effect of reinforced zone depth H/B on bearing capacity ratio BCR

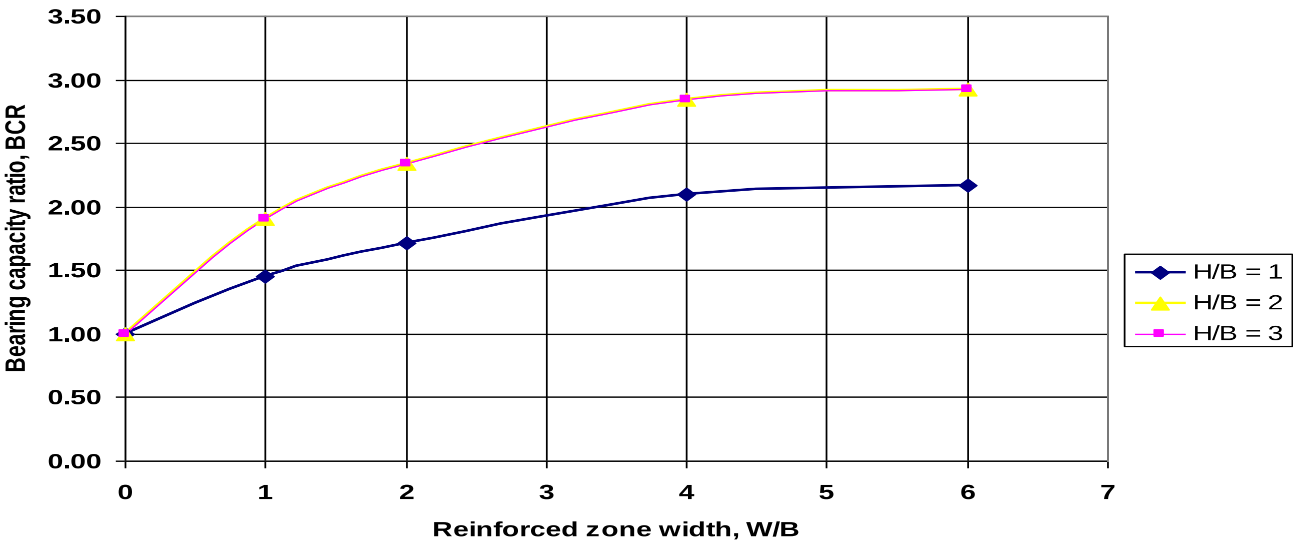

Fig. (8) Effect of reinforced zone width (W/B) on bearing capacity ratio BCR

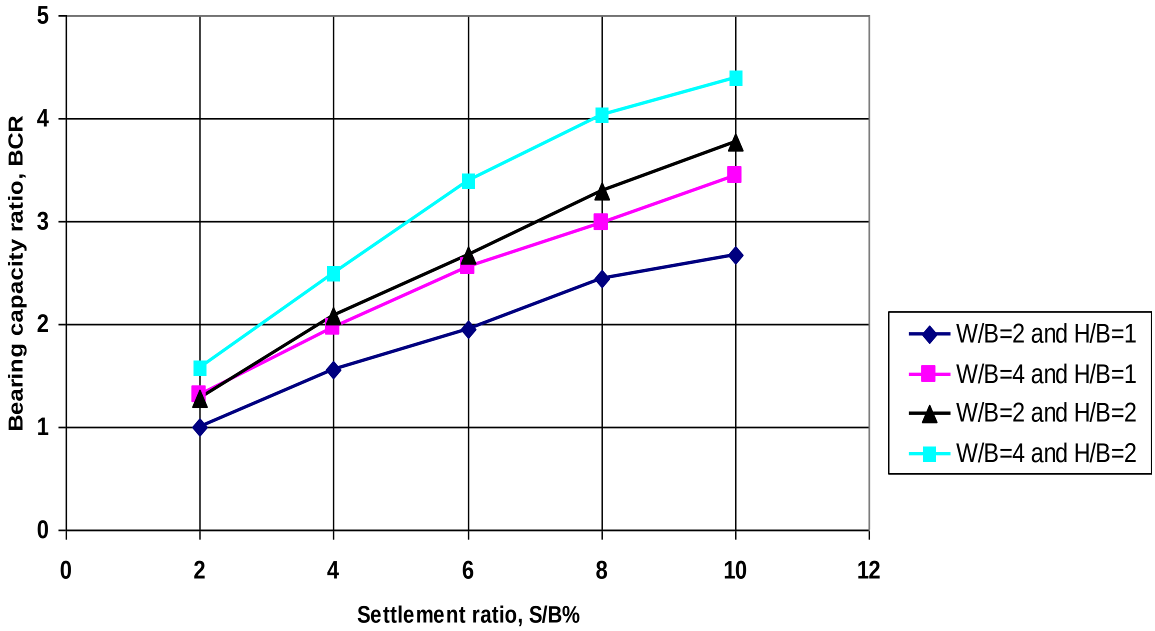

Fig. (9) BCR variation with settlement of footing for various H/B and W/B ratios

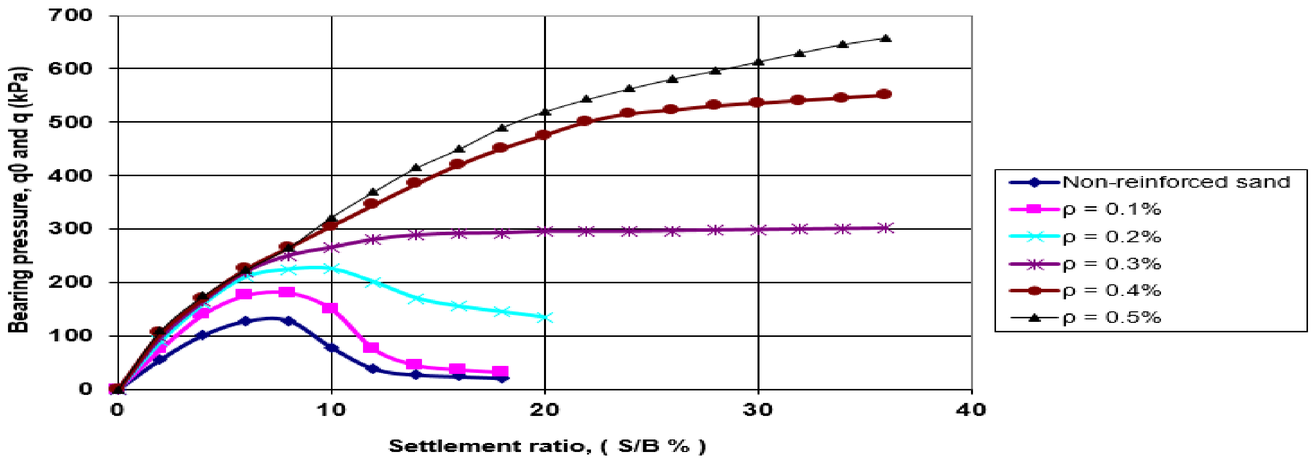

Fig. (10) Pressure-settlement relationships for different fiber concentration with (H/B= 3 and W/B = 2)

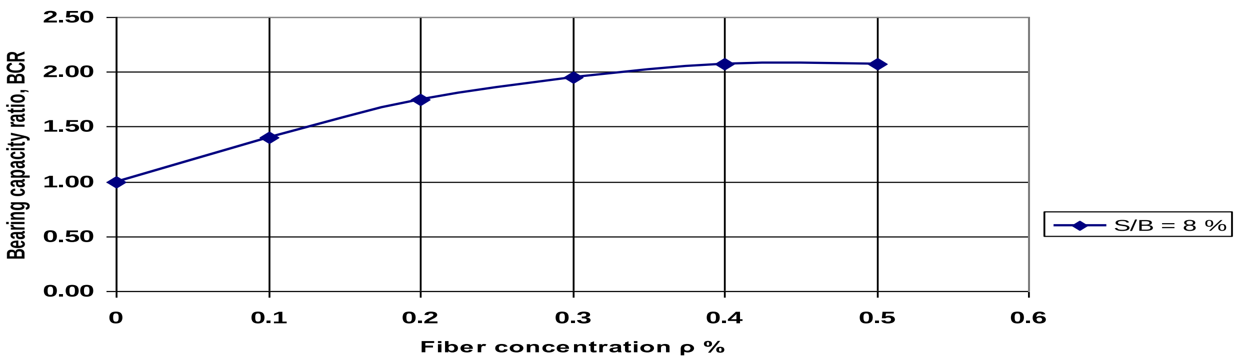

Fig. (11) Effect of fiber concentration ρ % on bearing capacity ratio BCR