An experimental evaluation of size effect and bearing capacity of footing on non-woven geotextile-reinforced sand

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Abstract. Reinforced soil is a composite material in which elements with tensile strength were utilized for reinforcement. Geotextile is the most common material in group of geosynthetics for soil reinforcement. This paper presents the effect of a non-woven geotextile which have a higher failure strain on bearing capacity of rigid footing constructed on sand. A research has been done to investigate the bearing capacity of granular soil with plates which have standard width according to ASTM D 1194. In this study, a total number of 62 model tests were carried out in a laboratory using two square rigid steel plate with the sides of 270 mm and 350 mm. A broad series of conditions was tested by varying parameters such as the location of upper layer of geotextile, number of geotextile layers, width of reinforcement and vertical spacing between layers. In second step a series of tests were additionally carried out by varying of spaces between layers and width of geotextile layers in proportion to increase of depth. The results demonstrated that in all cases non-woven geotextile increases bearing capacity and the maximum bearing capacity was obtained in 4-layer reinforcement system. It is also shown that the optimum value of vertical spaces between layers after the upper one are respectively, 0.30 B, 0.35 B, 0.45 B. In addition, the results indicate that optimum width of the first two layers of reinforcement are 4 B and for the third and fourth one are 3 B and 2.5 B respectively.

Keywords: non-woven geotextile, bearing capacity, sand, square plate.

1. Introduction
In general definition, geosynthetics are textile or sheets made of oil and one of their main properties is incorruption against corrosive factors, hence they can be applied in many situations in soil improvement. According to standard ASTM D-4439 geosynthetic are plane products made of polymeric materials [1]. Improving soil bearing capacity by distributing the load, reducing the thickness of the embankment and preventing the mixture of high-quality materials and weak materials are of advantages of geosynthetics. [1].

The advantage of using non-woven geotextiles are in increasing the strength of soil and decreasing the reduction of resistance after maximum strength, in other words, brittleness of the sample would decrease and also, the strain values in the maximum strength would increases as compared to woven geotextiles [2-6]. Meanwhile, using strength parameters of results achieved in laboratory without consideration of displacement value are impossible. Bearing capacity of soil with square plate load test has been studied by many previous researchers. Golder [7] used square plate with sides of 80 mm and 150 mm, Meyerhof [8] used square plate with sides of 10 mm and 30 mm, Guido and Christou [9] used square plate with sides of 310 mm, and Adams [10] used square plate with sides of 100 mm and 202 mm. But according to plate load test standard ASTM D-1194 minimum and maximum allowable diameter value for plates varies in the range of 305 to 762 mm, respectively, or square steel bearing plates of equivalent area [1]. It can be seen that small number of experiments were carried out in standard sizes.

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The use of geosynthetic as appropriate and economical materials has been investigated by previous researchers in order to increase the bearing capacity of shallow foundations [11-13]. In some those cases, in evaluation the optimum width of the reinforcement some parameters remain constant. For example, Lawton and Fragaszy [14] who evaluated the optimum width of reinforcement by steel plate on sand concluded that bearing capacity increases for the width of 3B to 7B and little changes were seen for longer width. In other cases, only the number and the spacing between the layers were investigated. Yetimoglu [15] obtained optimum value of 0.3 B for single and multilayers mode. Akinbolade [16] investigated the first layer and number of reinforcement layers used strips of rope fibers for reinforcement of square foundations. Results showed that more than 3 layers did not have significant effect on bearing capacity. They also concluded that suitable depth of top layer for three reinforcement layers were less than 0.5 B and maximum bearing capacity obtained BCR = 3. Guido [17] compared geotextile and geogrid for reinforcement found that the reinforced mechanism of geotextile was different from geogrid. Reinforced mechanism of geotextile was based on friction between geotextile and soil, but, geogrid lock soil between its openings to improve the bearing capacity and the tensile strength of reinforced materials should be noticed.

As can be seen, high failure strain characteristics of the non-woven geotextiles in reinforcement were ignored. In previous research which tried to improve the bearing capacity of soil by geosynthetics, not only the vertical space between reinforcement layers was considered constant, but also the width was similar in all layers. This study investigated the changes of the optimum width and vertical spacing between non-woven geotextile layers in proportion to increase the depth of reinforcement with standard plate according to ASTM D 1194 plate load test standard.

2. Experimental setup
In laboratory studies despite the great deal of care in making samples, it can’t be claimed that all sample were exactly the same. In this study equal process of making samples has been done in all tests to minimize differences.

2.1. Test configuration
To do the model test a system consist of foundation, column and main beam were designed for maximum force of 30 tons in order to have enough resistance to provide reaction force on plate as shown in figure 1. The system is constructed as a reinforced concrete foundation and steel columns with a diameter of 45 mm. The main beam was designed with features of the IPB 24. The two sides of column were threaded for 350 mm in order to be adjustable between main beam and plate for different loading jack. The container used in this test was a cubic box with cross-section of 1350x1350 mm and height of 1000 mm and Plexiglas was used for sidewalls in order to ease monitoring the failure mechanism during the test. In this study, the plates were square with sides of 270 and 350 mm with thickness of 25mm according to ASTM D 1194. Reference beams were independent beam that gages and other displacement measurement connect to it. According to standard ASTM D1194 minimum allowed capacity of load jack is used (50 ton or 440 kN). Three dial gages with the accuracy of 0.01 mm and course of 30 mm were used at different points on footing surface.

2.2. Test materials
Materials used in this study can be divided in two categories of sand and reinforcement. Brief summary of these materials are shown in this section.

2.2.1. Sand. The sand used in this research is washed, dried and categorized by particle size. This sand was classified as SP in the Unified Soil Classification. The particle size distribution was characterized using the dry sieving method. The maximum and the minimum dry unit weights of the sand were found to be 17.5 and 14.6 kN/m³. The uniformity coefficient (Cu) and coefficient of curvature (Cc) for the sand were 1.40 and 1.14 respectively.
2.2.2. Reinforcement. Non-woven geotextiles tensile strength is achieved 15 kN/m with pull out test. Width of reinforcement (w); location of the top geotextile (u) and distance between the reinforcement layers (z) are used in this study.

2.2.3. The test setup and programs. The procedures for the construction of reinforced model are different from those of previous research [18-20]. Containers were poured step by step but despite the weight effects of the upper layers, bottom layers were compressed more than upper ones and had more density than the others. Because of that, layers were placed under compaction [21]. This means that bottom layers have more thickness than the upper ones. Procedures of the first phase of investigation for two square plate of 27 and 35 mm are summarized in table 1. For second and third phase of test after obtaining the optimum arrangement of geotextile, effect of changing the distance between layers proportional to increase in the depth of reinforcement and geotextile’s optimum width were changed proportionally with increasing depth of reinforcement for square plate of 270 mm was investigated, respectively (table 2 and table 3).

| u / B | z / B | w / B | N  |
|-------|-------|-------|----|
| 0.10  | -     | 5.0   | 1.0|
| 0.15  | -     | 5.0   | 1.0|
| 0.20  | -     | 5.0   | 1.0|
| 0.25  | -     | 5.0   | 1.0|
| 0.30  | -     | 5.0   | 1.0|
| 0.15  | -     | 1.0   | 1.0|
| 0.15  | -     | 2.0   | 1.0|
| 0.15  | -     | 3.0   | 1.0|
| 0.15  | -     | 4.0   | 1.0|
| 0.15  | -     | 5.0   | 1.0|
| 0.15  | 0.30  | 4.0   | 5.0|
| 0.15  | 0.35  | 4.0   | 5.0|
| 0.15  | 0.40  | 4.0   | 4.0|
| 0.15  | 0.45  | 4.0   | 4.0|
| 0.15  | 0.50  | 4.0   | 3.0|
| 0.15  | 0.60  | 4.0   | 3.0|
| 0.15  | 0.30  | 4.0   | 3.0|
| 0.15  | 0.30  | 4.0   | 4.0|
| 0.15  | 0.30  | 4.0   | 5.0|
| 0.15  | 0.30  | 4.0   | 6.0|
Table 2. Second phase testing program

| Test number | u / B | Z₁ / B | Z₂ / B | Z₃ / B |
|-------------|-------|--------|--------|--------|
| P-1         | 0.15  | 0.30   | 0.35   | 0.45   |
| P-2         | 0.15  | 0.30   | 0.35   | 0.40   |
| P-3         | 0.15  | 0.30   | 0.30   | 0.35   |
| P-4         | 0.15  | 0.30   | 0.30   | 0.45   |
| P-5         | 0.15  | 0.35   | 0.40   | 0.45   |
| P-6         | 0.15  | 0.30   | 0.30   | 0.40   |
| P-7         | 0.15  | 0.30   | 0.40   | 0.45   |
| P-8         | 0.15  | 0.40   | 0.35   | 0.30   |

Table 3. Third phase testing program

| Test number | W₁ / B | W₂ / B | W₃ / B | W₄ / B |
|-------------|--------|--------|--------|--------|
| P-1         | 4.0    | 4.0    | 4.0    | 4.0    |
| P-2         | 3.5    | 4.0    | 4.0    | 4.0    |
| P-3         | 3.0    | 4.0    | 4.0    | 4.0    |
| P-4         | 4.0    | 3.5    | 4.0    | 4.0    |
| P-5         | 4.0    | 3.0    | 4.0    | 4.0    |
| P-6         | 4.0    | 4.0    | 3.5    | 4.0    |
| P-7         | 4.0    | 4.0    | 3.0    | 4.0    |
| P-8         | 4.0    | 4.0    | 2.5    | 4.0    |
| P-9         | 4.0    | 4.0    | 2.0    | 4.0    |
| P-10        | 4.0    | 4.0    | 3.0    | 3.5    |
| P-11        | 4.0    | 4.0    | 3.0    | 3.0    |
| P-12        | 4.0    | 4.0    | 3.0    | 2.5    |
| P-13        | 4.0    | 4.0    | 3.0    | 2.0    |
| P-14        | 4.0    | 4.0    | 3.0    | 1.5    |

3. Results and discussion

A total number of 62 model tests were conducted on plane strain footing over sand. The bearing capacity were determined from the load-settlement curves at the 10% of the footing width, after which the footing was assumed to collapse [22]. The bearing capacity ratio of footing on the reinforced sand was represented using a non-dimensional factor, called BCR factor. This factor was defined as the ratio of the footing pressure with reinforcement (q<sub>reinforced</sub>) to the footing pressure in tests without reinforcement (q).

3.1. Optimum values of u and W (for one-layer reinforcement)

The bearing capacity of footings were determined for one-layer reinforcement and the results are shown in figure 2. Dimensions of the geotextile are 1350x1350 mm to avoid influencing the optimum width of the geotextile on result. The optimum values of u/B obtained from different distance. These results show that the maximum bearing capacity occurs at 0.15 values of u/B. Results also show that, in some cases like 0.1 B especially at initial steps of loading, bearing capacity is less than unreinforced sand. Such behavior is because of low effective stress at the interface of soil and geotextile due to lower soil layer thickness. Tensile force in the reinforcement materials was occurred by the continuity between soil and reinforcement. This stress continuity has a maximum value of friction when pressure stress is perpendicular on reinforcement layers [23]. Hence, in a single-layer system when geotextile and soil effective stress at the interface is low, reinforced soil has less bearing capacity than unreinforced one at initial steps. For further displacement due to higher stress on interface, bearing capacity was increased. In second step, optimum width of non-woven geotextiles for one-layer reinforcement were investigated. As shown in figure 3, due to limitations of box dimensions, plate load test was not performed for 35x35 cm square plate with W/B more than 4. The trend of soil bearing capacity for equivalent width of 4 and 5 times of plate sides were similar and almost have the same value. One reason for this procedure is related to the mechanism of geosynthetic. Geotextile must be fixed at specific width to reduced soil stress with its tensile performance in soil [24]. The other reason is according to soil failure behavior, thus, the maximum width of reinforcement should be
place in effective widths of failure. Reinforced element doesn’t have any significant effect if they were continued outside failure distance [25]. As the result shows, the optimum width of geotextile is $4B$.

![Figure 2. Variation of BCR with (u/B) for (one-layer reinforcement) on sand.](image)

![Figure 3. Variation of BCR with width of reinforcement (W/B) for (one-layer reinforcement) on sand.](image)

### 3.2. Optimum values of $z$

In this step, the optimum distance of first layer and optimum width of geotextile given from previous tests were used. As it is shown in figure 4, distance between layers equivalent $0.3B$ has maximum bearing capacity and after that $0.35$, $0.40$ and $0.45$ have maximum bearing capacities respectively. As shown in figure 5 curves does not have maximum value. In other words, geotextile did not reach to its maximum tensile strength. Thus, geotextile tensile strength is not the effective factor in failure. The results also show that, there was no significant difference in first steps and in some cases curves were overlapped, for this reason differences between reinforcement elements will be determined at high displacement. Non-woven geotextiles used in the test have high failure strain, hence, occurrence of failures in the sample due to rupture of geotextile is impossible and geotextile inspection after tests confirmed it. In maximum resistance when failure was occurred in reinforce element large drawdown in the stress-strain curve is observed. This behavior usually occurs in geogrid and woven geotextiles because of low failure strain [23, 26]. Non-woven geotextile with greater flexibility due to the high failure strain was expressed as the appropriate solution for this problem. Results shows that non-woven geotextile improve soil bearing capacity. Also, the maximum bearing capacity occurs at different values of ($x$) depending on the number of reinforcement layers. Thus, it can be concluded that reporting a single value of ($x$) for optimum bearing capacity is not a correct procedure as reported by some researchers [15, 27]. Reinforced elements at specified depth has a greater effect on the bearing capacity as is shown in figure 6 and increasing bearing capacity after 4 layers were negligible, therefore 4 reinforcement layers are optimum number of geotextile layers. As shown in all cases, the BCR values using smaller plates are more than BCR values using larger plates.
Research with triaxial test on reinforced sand has shown that mechanism of increasing sand resistance was due to increase of confining pressure in sample. Also, the increase of these equivalent confining pressure were significant on low confining pressure [4, 28, 29]. The reason for higher BCR values and decreasing of it with increasing size of plate are related to smaller spacing between geotextile layers (smaller plates have smaller spacing between geotextile layers) and considerable effect of confining pressure. After obtaining the optimum spacing between layers when the distance between layers were constant, combination modes of optimum distance as shown in table 3 were studied. As results show, reinforced elements near ground surface (low confining pressure) have
greater effect in increasing capacity. As shown in figure 7 modes 1, 6 and 2 which have closer layers near ground surface have the highest BCR and in modes 7 and 8 due to higher distance between layers near ground surface have the lowest BCR. However, it can’t be concluded that decreasing the distance between layers (x) leads to the increasing the bearing capacity in all cases. As result shown that although mode 3 has smaller distance between layers than modes 1, 2, 4 and 5 but because of low effective stress on interface have lower BCR.

![Figure 7. Variation of BCR with test number (for different distance between reinforcement layers).](image)

3.3. Optimum values of W (for multi-layer reinforced)
After the optimum arrangement of the geotextile were gave, in this phase optimum width of reinforcement were investigated as shown in table 3. For one-layer reinforcement optimum width of geotextile was gave 4 B. Another mechanisms of geotextile to increase the bearing capacity of the soil is stress diffusion and its efficiency decreases with increasing depth of reinforcement [30-33]. Therefore, it can be concluded that first layer reinforcement must have a longer width than the others. As shown in figure 8 mode 6, 7, 10, 11 and 12 have maximum BCR respectively. But due to economic limitations the best mode is selected as the 12th mode.

![Figure 8. Variation of BCR with test number (for different width).](image)

4. Conclusions
Improving soil flexibility is one of the most important advantages of using non-woven geotextiles. Non-Woven geotextile like woven geotextile and geogrid improves soil bearing capacity on particular displacement in all cases. Maximum BCR obtained with this type of non-woven geotextile were almost 1.6. For one-layer reinforcement first distance of 0.15 B and width of 4 B were obtained for optimum value for two square plate. As results indicates, reinforced elements near ground surface (low confining pressure) have greater effect in increasing soil bearing capacity. Therefore, reinforcement with closer layers' distance near ground surface have the highest BCR. However, it cannot be
concluded that decreasing the distance between layers leads to increase the bearing capacity in all cases. Maximum bearing capacity ratio were obtained for optimum numbers of 4-layer geotextile while distance between layers are 0.3, 0.35 and 0.45, respectively. Optimum width of geotextile for 4 cases. Maximum bearing capacity ratio we concluded that decreasing the distance between layers leads to increase the bearing capacity in all cases. Maximum bearing capacity ratio were obtained for optimum numbers of 4-layer geotextile while distance between layers are 0.3, 0.35 and 0.45, respectively. Optimum width of geotextile for 4-layers system from first layer are, 4 B, 4 B, 3 B and 2.5 B, respectively.

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