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# Effect of Partial Replacement with Crushed Concrete on Settlement and Bearing Capacity of Soft clay

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**Abstract.** This paper aims to examine the effect of partial replacement with crushed concrete as a recycled material to enhance the bearing capacity and to decrease the settlement of soft clay. To clarify the effect of scale factor, four cubic steel soil tank with four dimensions of (250 x 250 x 250) mm; (300 x 300 x 300) mm; (400 x 400 x 400) mm; and (500 x 500 x 500) mm are used to carry out the experimental works, by using a four sizes for each square and strip footings with varying the depth of replacement (0.2, 0.4 and 0.6 width of square footing) and (0.33, 0.67 and 1 width of strip footing). The effect of replacement was evaluated with regard to settlement control and bearing capacity. It is found from results of experimental works that a significant decreasing in settlement and increasing in bearing capacity of treated soil with increasing the depth of the partial replacement layer for both square and strip footing compared to untreated soil. The study also shows that the use of partial replacement layer with a depth of 0.4 B for strip footings results in reducing the settlements by an averaged percentage of 72 % and increasing the bearing capacity with an average of 96%. Also the results demonstrate that clear increasing in bearing capacity for all depth of replacement under square footing with indistinct in settlement

## 1. Introduction

These guidelines, Because of low bearing capacity and high settlement of cohesive or soft clay soils, the improving of its properties in the site is one of the main challenges faced by researchers, civil and geotechnical engineers. The need for rapid and economic improvement of the natural clay soils is widely apparent in many countries of the world, especially emerging countries with significant infrastructure development. The conventional methods of soft clay soil treatments include the following techniques: (a) Sand drain, (b) Preloading (c) Stone columns, (d) Heat treatment, (e) Chemical mixing, (f) electro-osmosis, and (f) deep dynamic compaction.

The bearing capacity of the foundations built on soft soils can be enhanced by a layer of compact sand or gravel. [1] examined the final bearing capacity of the foundations on a clay-based foundation in the two cases, in the first case of a solid layer existed on a soft layer, and the second being the presence of a soft layer covering a stiff layer. The studies were based on a model test using circular footing and a bar using a combination of layer thickness and clay strength. The results of the study were presented in the graphs that used to assess the bearing capacity of the footings constructed on the clayey soil. [2] conducted a field load test and compared these results with the corresponding numerical results using a column model more than the circular footings based on the granular soil under the soft clay and claimed that there is a good match between them. The classic method to improve soft soils is by replacing those soft soils with stronger, better soil or material to improve its properties such as a bearing capacity or reduce the anticipated settlement. The depth of the replaced sand is depended on the required bearing capacity and the allowable settlement. Sometimes the using of this method leads to great heights of soil replacement and hence the excessive cost and effort, therefore the feasible method is by substituting the

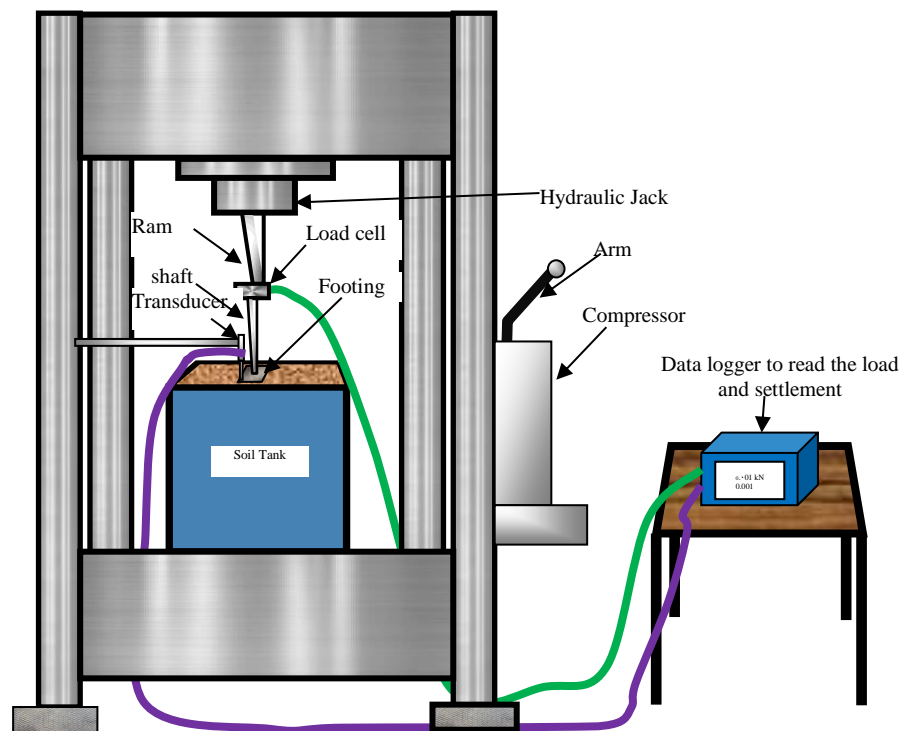


soft soil by a granular material in a specific area under the footing in similar to the trench, as many have suggested practically, theoretically and experimentally such as [3-12].

## 2. Laboratory model tests

### 2.1. Formatting Loading frame and accessories

Figure (1) shows a schematic diagram of the devices that used to conduct the model tests of this study. Four steel containers (soil tank) in the shape of a cube with four sizes as follows:(A), (250 x 250 x 250) mm; (B),(300x 300x 300) mm;(C),(400x 400x 400) mm; and (D),(500x500x500) mm, all soil tanks with thickness of 4 mm. The soil tanks are manufactured to be rigid enough to keep the plain strain as low as possible in all directions. The interior walls of the soil tank are polished smooth to minimize contact with the soil as much as possible using a coating layer. The loading system consists of a hydraulic jack operated by a hydraulic pump (compressor) to apply the load on the soil bed. The ram of hydraulic jack is attached with a load cell to identify the applied pressure with assistance of data logger to record the load. The transducer is put up on the footing model to read settlement with aid of the same data logger.



**Figure 1.** Loading frame and accessories.

### *Models of footing*

The models of footing were made of a steel plate of thickness 8 mm with a two shape and six sizes as follows:

- 1- Square footing with dimensions of 100 mm x 100 mm, tested in the soil tank (A).
- 3- Strip footing with dimensions of 30 mm x240 mm, tested in the soil tank (A)
- 1- Square footing with dimensions of 120 mm x 120mm, tested in the soil tank (B)
- 3- Strip footing with dimensions of 35 mmx280 mm, tested in the soil tank (B)
- 3- Square footing with dimensions of 130mm x 130 mm, tested in the soil tank (C)
- 4- Strip footing with dimensions of 40 mmx320mm, tested in the soil tank (C)
- 5- Square footing with dimensions of 150 x150 mm, tested in the soil tank (D)

6- Strip footing with dimensions of 50x400 mm, tested in the soil tank (D) The load is transferred to the footing through the shaft attached with load cell which was placed between the footing and the load cell.

## 2.2. Test materials

**2.2.1 Soft clay.** The natural soft clayey soil was subjected to laboratory tests to determine the physical and mechanical properties. The soft clayey soil is classified as a low plasticity clay or (CL) according to the unified classification system. The soft clay bed is prepared by placing it in layers, with a certain water content. The unconfined compression test was performed to obtain the shear strength of the soil. The soft clay bed has been mixed and placed handling in the soil tank according to the testing program. A heavy plastic hammer was used to obtain the required density of the soil bed. The characteristics of the clay bed are shown in Table 1.

**2.2.2 Crushed concrete.** Standard cubes of concrete dimensions of 150mm x 150mm x 150mm were used as replacement material underneath the footing after crushing with a special steel hammer. The crushed concrete are sieved and Table 2 shows the results of sieving analysis

**Table 1.** Properties of Soil.

Properties	Value
Liquid limit, L.L. (%)	40
Plastic limit, P.L. (%)	23
Plasticity index, P.I. (%)	17
Specific Gravity	2.65
Maximum dry unit weight (kN/m <sup>3</sup> )	18.65
Degree of Saturation	95 %
Optimum moisture content	10%
Sand content	15
Silt content	37
Clay content	48
Classification (Unified Soil Classification System)	CL

**Table 2.** Soil Used Properties.

Properties	Value
D10	2.65
D30	6.95
D60	11.15
C <sub>c</sub>	1.63
C <sub>u</sub>	4.21
Specific Gravity	2.66
Dry unit weight (kN/m <sup>3</sup> )	17.97

## 2.3. Preparation and procedure

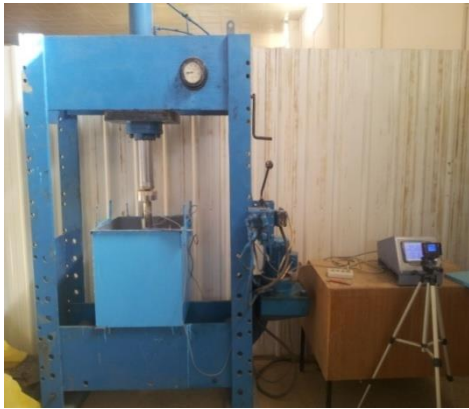
The first step of preparation of soil sample used in model tests was placing the layers of soft clay at bottom of the soil tank. Each layer has a thickness of 50 mm and it compacted with the heavy plastic hammer to reach the required density. This technique was continued to get to the final thickness of 25 cm in the soil tank (A), or 30 cm in the soil tank (B), or 40 cm in the soil tank (C), or 50 cm in the soil tank (D) according to height of the soil tank. After preparing the clay bed, the models of footing were placed in a centre position of the top surface of clay bed in the cases of untreated model tests.

In the case of treated model test with replacement of crushed concrete, the holes with the same plane area of footing was made under the model footings with the various depths as follows:

1- 0.2B, 0.4 B and 0.6 B in all models of square footing, (B= width of footing)

2- 0.33B, 0.67 B and 1 B in all models of strip footing.

The holes were then filled with crushed concrete as a replacement material as shown in Figure 2. The incremental load was applied by a hydraulic jack until reaching failure and more. The settlement of the footing was measured using displacement transducer placed on the side of the footing. Both, load and settlement were recorded with aids of digital unit or data logger.



(a): Set up of experimental work



(b): Soil tanks, A, B, C and D



(c): Partial replacement (square footing)



(d): Strip footing during the test

**Figure 2.** Experimental Works.

#### 2.4. Testing program

32 model tests were carried out to investigate the effect of scaling factor and replacement material on settlement and of square and strip footing.

### 3. Results and discussions

#### 3.1. Settlement analysis

The Figures from (3 to 10) showed the relation between the applied pressure and settlement for 32 model tests for different sizes of square and strip footings on untreated and treated of a samples of soft clay bed tested in the different steel soil tanks. The replacement technique of soft clay by using crushed concrete as alayer under footing was used to improve the settlement of soil sample.

Four sizes of square footing models with sides of (100 mm, 130mm, 140 mm and 150 mm) respectively, were tested in four cubic soil tanks with sides of (A), 250 mm; (B), 300 mm; (C), 400 mm and ; (D), 500 mm, respectively. Three depths of replacement layer of crushed concrete 0.2B, 0.4B and 0.6B were adopted in this study.

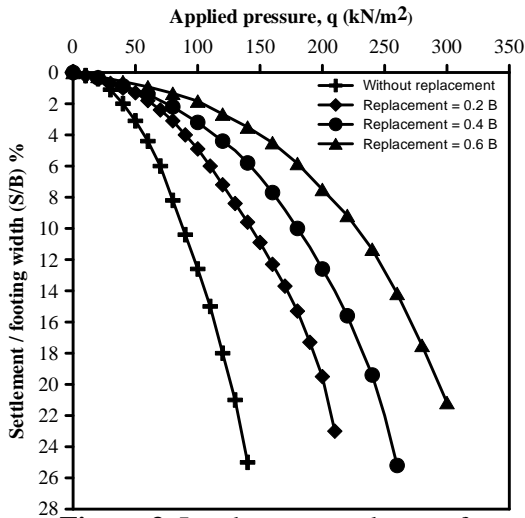


Figure 3. Load versus settlement for square footing in soil tank A

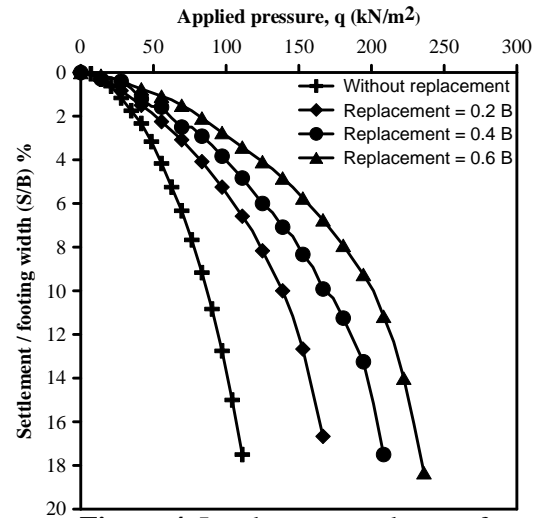


Figure 4. Load versus settlement for square footing in soil tank B

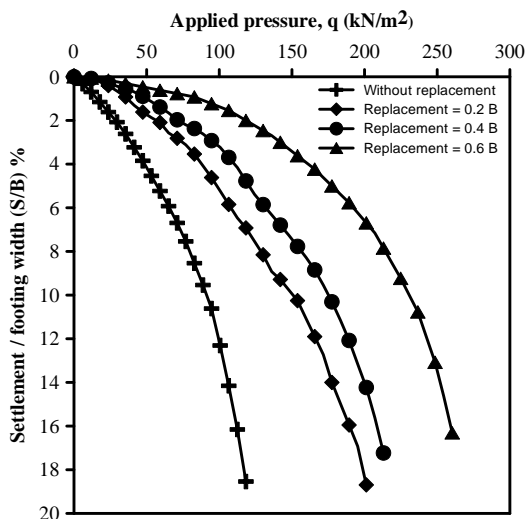


Figure 5. Load versus settlement for square footing in soil tank C

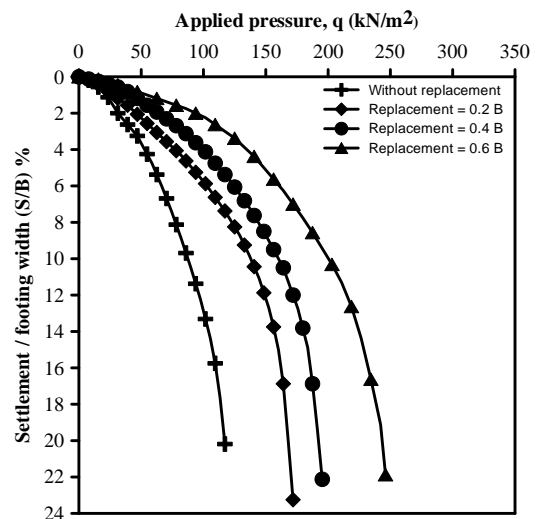


Figure 6. Load versus settlement for square footing in soil tank D

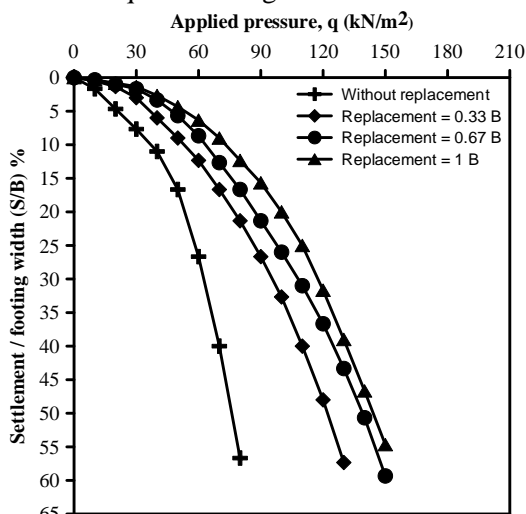


Figure 7. Load versus settlement for

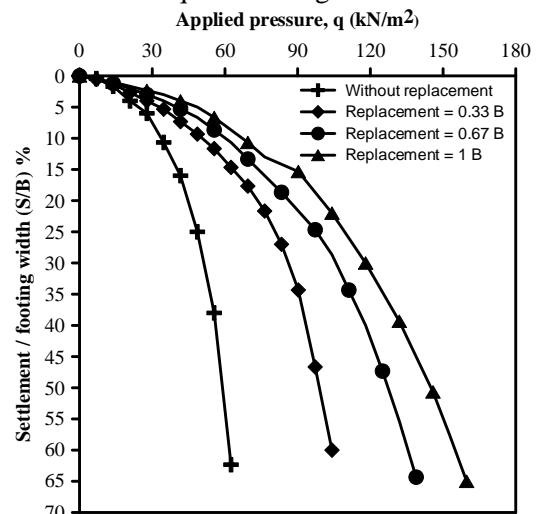
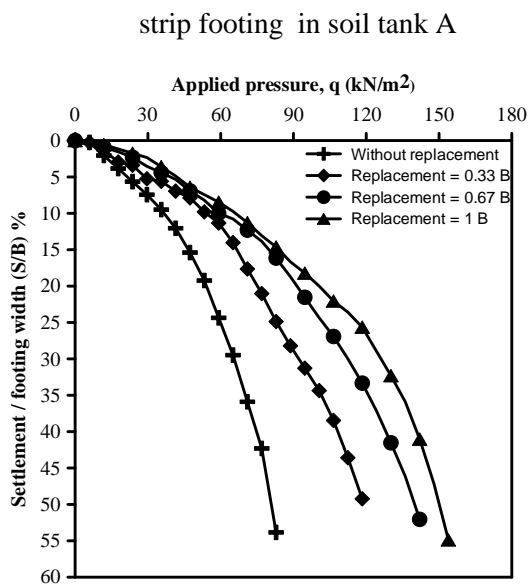
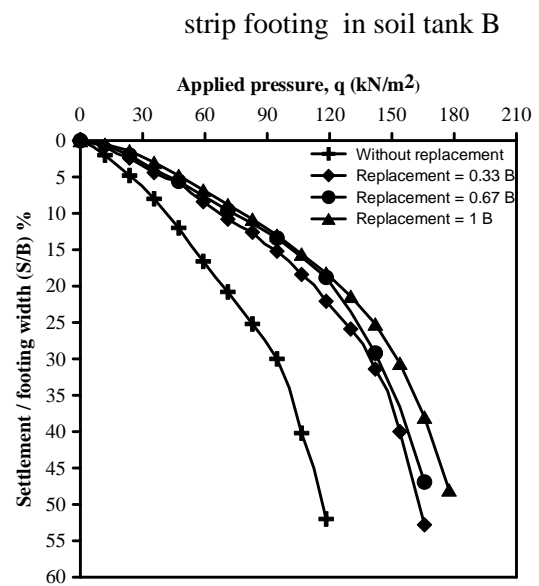


Figure 8. Load versus settlement for



**Figure 9.** Load versus settlement for strip footing in soil tank C



**Figure 10.** Load versus settlement for strip footing in soil tank D

To demonstrate the effect of the replacement layer of crushed concrete, on the settlement of the treated soils, the ratio called is  $S_r$  or settlement ratio which is defined as follows:

$$S_r = \frac{S_{treated}}{S_{untreated}} \quad (1)$$

where  $S_{treated}$  = Settlement of treated soil with crushed concrete corresponding to the same applied the load at failure of untreated soil.

$S_{untreated}$  = Settlement of untreated soil with crushed concrete that equal to 10% of the width of footing according to criteria of Terzaghi to define the load failure.

The results of settlement reduction ratio ( $S_r$ ) of 16 model tests of square footings are summarized in Table 3. It can be noticed from data of Table 3 that the  $S_r$  for replacement layer depth of 0.2 B is ranged from 0.48 to 0.51 for 4 sizes of square footing (100, 120, 130 and 150) mm, i.e. the settlement of treated soil is decreased to approximately 50% percent or equal to half of the untreated soil. Also, the  $S_r$  for soil treated with the crushed concrete depth of 0.4 B were (0.28, 0.39, 0.41 and 0.36) for the same previous of footing sizes, respectively with an average equal to 0.36. i.e. the settlement was decreasing by percentage of 64%. While the average the settlement of soil treated with 0.6 B depth of crushed concrete is reduced with the averaged percentage of 71%. These results showed that no clear difference between settlement reduction of soil treated with 0.4B and 0.6B because the stress bulb is decreased with depth. Four sizes of strip footing models with sizes of (30 x 240) mm<sup>2</sup>, (35 x 280) mm<sup>2</sup>, (40 x 320) mm<sup>2</sup> and (45 x 360) mm<sup>2</sup> are tested in the four same previous soil tanks: (A), 250 mm; (B), 300 mm; (C), 350 mm and ; (D), 500 mm, respectively. Three depths of replacement layer of crushed concrete were 0.33B, 0.67B and 1B are adopted in present work. Figures from (7 to 10) demonstrate the relationship between the applied pressure and deformation ratio (Settlement/footing width) for four sizes of strip footing. Table 4 presents a summary of the results of the values of the settlement reduction ratio ( $S_r$ ) due to the use of the crushed concrete layer under the strip footing in three different depths, (0.33B, 0.67B and 1B). The following points can be drawn about  $S_r$  from tabulated data of partial replacement of strip footings with three depths of partial replacement layers.

1. The relation between the settlement ratio ( $S_r$ ) and size of strip footing is not obvious.
2. The averaged value of ( $S_r$ ) for soil treated with crushed concrete for four sizes of the strip footing at a depth of a replacement layer of 0.33B was 0.42. The minimum value of  $S_r$  was in strip footing of (50 x 400) mm and the maximum value was in strip footing of (30 x 240) mm.

4. The values of  $S_r$  obtained from models of soil treated with replacement layer of 0.67B in the four sizes of the strip footing were (0.26), (0.31), (0.27) and (0.32) respectively.

5. The  $S_r$  was ranged from (0.11) to (0.23) with an average value of (0.17) for replacement layer depth of 1B.

6. The settlement reduction is more visible in strip footing than square footing at three depths of replacement layer.

**Table 3.** Settlement reduction ratio ( $S_r$ ) of square footing models

Soil tank size	Size of square footing	Depth of replacement layer		
		0.2 B	0.4B	0.6B
(250 x 250 x 250) mm	(100 x 100) mm	0.51	0.28	0.23
(300 x 300 x 300) mm	(120 x 120) mm	0.52	0.39	0.29
(400 x 400 x 400) mm	(130 x 130) mm	0.59	0.41	0.33
(500 x 500 x 500) mm	(150 x 150) mm	0.48	0.36	0.32
Average		0.52	0.36	0.29

**Table 4.** Settlement ratio ( $S_r$ ) of strip footing models

Soil tank size	Size of strip footing	Depth of replacement layer		
		0.33B	0.67B	1B
(250 x 250 x 250) mm	(30 x 240) mm	0.38	0.26	0.18
(300 x 300 x 300) mm	(35 x 280) mm	0.44	0.31	0.23
(400 x 400 x 400) mm	(40 x 320) mm	0.43	0.27	0.11
(500 x 500 x 500) mm	(50 x 400) mm	0.47	0.32	0.18
Average		0.42	0.28	0.17

### 3.2. Bearing capacity analysis

The bearing capacity ratio (BCR) was used in the present work to demonstrate the effectiveness of using the crushed concrete under footings in both types of square and strip footing. The BCR was defined as the ratio between the bearing capacity of treated soil with crushed concrete (B.C treated) and bearing capacity of untreated soil (B.C untreated) at the settlement level equal to 0.1 widths of footing (0.1 B).

$$BCR = \frac{B.C_{treated}}{B.C_{untreated}} \quad (2)$$

It can see clearly from Figs. from 3 to 10 that the use of the partial replacement technique is affected the bearing capacity. To make the comparison between untreated and treated soil with crushed concrete, the values of (BCR) are collected in Tables 5 and 6.

The following main points can be inferred from the data in Tables 5 and 6 when using the partial replacement method for both the square and strip footings and the three replacement depths for the bearing capacity ratio BCR:

1. The maximum value of BCR was in a model of square footing with side 100 mm for all depths of partial replacement layer (0.2B, 0.4B and 0.67).
2. No clear differences between the BCR values in the model footing of sizes (120 x 120) mm<sup>2</sup> and (130 x 130) mm<sup>2</sup>.
3. The bearing capacity ratio increases significantly when the replacement layer depth is increased for both the types of footing.
4. In general, the effect of using a layer of crushed concrete under the square footing region was more effective than strip footing especially in the depth of 0.6B.
5. The BCR for treating soil when using square footing of side 130 mm are (1.62, 1.92 and 2.33) for three depths of replacement layer (0.2B, 0.4B and 0.6B) respectively. These values of BCR were closed to average values for all treatment.



6. The average value of BCR in treating soil with partial replacement layer of depths (0.33B, 0.67B, and 1B) were 1.48, 1.69 and 1.88 respectively on a strip footing.

**Table 5.** Bearing capacity ratio (BCR) of square footing models

Soil tank size	Size of square footing	Depth of replacement layer		
		0.2 B	0.4B	0.6B
(250 x 250 x 250) mm	(100 x 100) mm	1.85	2.16	2.39
(300 x 300 x 300) mm	(120 x 120) mm	1.60	1.93	2.31
(400 x 400 x 400) mm	(130 x 130) mm	1.62	1.92	2.33
(500 x 500 x 500) mm	(150 x 150) mm	1.58	1.83	2.29
Average		1.66	1.96	2.33

**Table 6.** Bearing capacity ratio (BCR) of strip footing models

Soil tank size	Size of strip footing	Depth of replacement layer		
		0.33B	0.67B	1B
(250 x 250 x 250) mm	(30 x 240) mm	1.43	1.70	1.97
(300 x 300 x 300) mm	(35 x 280) mm	1.47	1.71	1.88
(400 x 400 x 400) mm	(40 x 320) mm	1.45	1.61	1.77
(500 x 500 x 500) mm	(50 x 400) mm	1.59	1.73	1.88
Average		1.48	1.69	1.88

#### 4. Conclusions

The following main points can be drawn from the results of present work

##### 4.1. Settlement ratio SR

1. The relation between the settlement ratio (Sr) and size of strip footing is not obvious.
2. The settlement ratio (Sr) is increased clearly with increasing the depth of partial replacement.
3. The settlement reduction is more visible in strip footing than square footing at any depths of partial replacement layer.

##### 4.2. Bearing capacity ratio BCR

1. The maximum value of BCR was in a model of square footing of less dimensions.
2. The bearing capacity ratio increases significantly when the partial replacement layer depth is increased for both the types of footing (square and strip).
3. In general, the effect of using a layer of crushed concrete under the square footing region was more effective than strip footing.

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