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**-RESEARCH ARTICLE-**

## **Stress Analyses of Strip and Rectangular Footings Rested on Loose Sands**

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### **Abstract**

In this study, the stress, the bearing capacity and the settlement behavior in the loose sandy soils were investigated experimentally and theoretically. The study was performed in central loading conditions using strip and rectangular footings. The vertical stresses resulting from the external are measured for three different distances simultaneously. And also the load-settlement curves were obtained. The results showed that the bearing capacity increases when the length of the footing increases and the measured vertical stress values decrease along the depths for all the three types of the footing types. The test results were compared with theoretical results given in the literature. As seen from this comparison, the experimental results are in accordance with the theoretical results.

### **Keywords:**

Model Tests, Soil Stress, Strip Footing, Rectangular Footing.

### **Article history:**

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### **Introduction**

Their own weight and applied external loads of the soils create stresses within the soil mass. This stress varies depending on the severity of the applied load, soil properties and the size of the area the load is applied.

Due to the soils are very complex materials, make exactly stress-deformation analysis very difficult in the soil. Therefore, theory of elasticity which is an approximate solution for the soil behavior analyses is often used.

Theory of elasticity acceptances are listed as; i) soil is elastic and stress-deformation relationship is linear and ii) Soil is homogeneous. In other words, elastic constants, the elasticity

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modulus  $E$  and Poisson's ratio  $\mu$  are constant at every point. iii) Soil is isotropic, that is, features on a point are the same in every direction. iv) Soil is a semi-infinite. So, soil extends infinite distance under a plane and in any direction.

The most of researchers in the literature investigate the soil stress behavior have been used the rules of the theories of elasticity. Some of are listed below.

Terzaghi (1920) was measured with an experimental program that was created in the laboratory the horizontal ( $\sigma_h$ ) and vertical ( $\sigma_v$ ) stress resulting from vertical loads of sand and clay samples. These experimental programs are considered as one of the first experimental studies for determining the vertical and horizontal stresses. Donath (1891) defined this coefficient as the ratio of the horizontal ( $\sigma_h$ ) to the vertical ( $\sigma_v$ ) earth pressure resulting in soil due to the application of vertical load with constrained lateral deformation ( $K_o = \sigma_h/\sigma_v$ ). Terzaghi (1920) studied the effect of compaction on the value of  $K_o$  and found that the value of  $K_o$  for coarse sand was 0.42. Also, when the sand was compacted in layers with a hand compactor,  $K_o$  increased to a value between 0.6 and 0.7.

Bagriacik (2010) investigated the vertical soil stress values of the shallow foundations on sandy soils with model tests. Also, the shape effect was investigated by using foundations in different geometries. As a result, the shape effect was seen to be important in the different geometry foundations.

Yodsa-nga et al. (2012) investigated stress distribution in loess due to surcharge loading under spread footing with field testing and numerical modeling. In this study, plate bearing tests were carried out at a 3-m depth with five small pressure cells to measure the vertical stresses. The stresses were predicted using three numerical methods (Boussinesq's, Walter's and a linear finite element model). Consequently, it was suggested that numerical methods would allow realistic estimation of the contact pressure pattern for the accuracy of predictions.

Mohamed (2012) investigated the effect of a buried rock under strip footing resting on sand numerically. In this study, the effect of the buried rock on contact stresses, the effect of rock position and depth is investigated. As a result, the stresses have increased by 40%, when rock is encountered under the middle of the footing at depth  $D=0.5m$ .

Hazzard et al. (2007) were suggested a method, called the method of images, calculated. This method, allows for accurate calculation of stresses in layered materials where large stiffness contrasts exist between layers. Shortly, the tests were conducted to compare the stress results from the method of images to the results from the Boussinesq method and three-dimensional finite element models. Consequently, this method is more accurate than the Boussinesq method and much simpler than the finite element method.

Yang et al. (2012) calculated system stability indicated by the factor of safety (FS) of GRS slopes with finite element analysis. Also, stress is evaluated by using finite element analysis. They reported that the peak value was located at approximately mid-height of the reinforced slopes.

Bhaskar et al. (2015) studied the contact stress distribution experimentally and analytically without any depth of embedment. In addition, finite element software PLAXIS 3D was being carried out by placing footing at increasing depth in soil models. As a result, the contact stress distribution and settlement variation with increase of embedment varies depending soil.

Dixit and Patil (2013) investigated bearing capacity of model square footings resting on the sand soil. They evaluated the bearing capacity factor ( $N_{\square}$ ) and compared different theoretical values. Results showed that ultimate bearing capacity and settlement values are observed an increasing trend up with increase the depth of sand cushion below the footing ( $D_{sc}$ ).

Keskin and Laman (2013) investigated the potential benefits of using tire chips as lightweight material to improve the bearing capacity and the settlement behavior of sand slope experimentally. In this study, the effect of contents of the tire chips on the shear strength parameters of sand was investigated and then, laboratory model tests were performed on a model strip footing. Consequently, the settlement of strip footing on sand-tire chips mixture was about 30% less than in the case of pure sand.

Hanna and Soliman-Saad (2001) were used the stress transducers to measure horizontal and vertical stress. And also they present the results of an experimental investigation on the effect of compaction duration in a prototype model.

Uzuner et al. (2000) explained the stress distributions of the eccentrically loaded model strip foundations on sand. The stress distribution for central loading is parabola; about a curved having big values at center and small or zero values at edges. If eccentric load of the foundation increases the shape of the parabolic distribution changes and the gravity center of the parabola were seen shifted towards to the eccentricity side.

Keskin (2004) investigated vertical and horizontal stress values of the shallow (square, strip and circular) foundations on sandy soils with model tests. In addition, tests were modelled as numerical then the results were compared with theoretical and numerical results. Consequently, it is noted that when the applied load stress increases, the measured value increases and when the depth increases, the stress values decrease. It is also noted that the test results give the lower values than the theoretical results on the surface.

There are also researchers who studied the stress distributions and the bearing capacity as experimental, numerical and theoretical perspectives (Westergaard, 1938; Uzuner, 1975; Cho & Vipulanandan 1998; Jaky, 1948; Kayadelen, 2005; Saran et al. 2007; Bagriacik & Laman, 2010; Bagriacik & Laman, 2011; Ornek, 2014).

In this study, the stress, the bearing capacity and the settlement behavior in the loose sand were investigated experimentally and theoretically in central loading conditions by using strip (10cmx50cm size of strip footing) and rectangular footings (10cmx30cm and 10cmx20cm). A total of three stress transducers were used during each of the tests and the stress readings were collected simultaneously, including the vertical displacements. A total of 15 model tests were carried out in the Geotechnical Laboratory of Civil Engineering Department of Iskenderun Technical University, Iskenderun, Hatay, Turkey. The stress distribution was vertically obtained tests in central loading conditions using stress transducers. And also the load-settlement curves were obtained. The test results were compared with the theoretical results. It is expected that the information presented in this study will provide a contribution to the literature results and will be an alternative source for the design and applications for the geotechnical engineers.

## **Materials and Methods**

### ***Geometric Parameters Investigated***

The waste jute used in this study was gathered from the textile companies in Gaziantep. Different lengths (20–25 mm) of jute fibers in different percentages (0, 1, 2 and 3%) by weight of dry soil were used to reinforce the soil.

Figure 1 shows the geometry and loading system of the model strip and rectangular footings considered in this investigation. The loadings were conducted with three different shaped and sized

footings. The geometries of the footings are given in Table 1. The centric load was applied during tests. All of the model tests have been performed for the loose sand conditions.

### Test Equipment and Materials

The experimental program was carried out using the facility in the Geotechnical Laboratory of the Civil Engineering Department of the Iskenderun Technical University, Iskenderun, Hatay, Turkey. The facility and a typical model are shown in Fig. 1 and 2.

### Test Tank

The model tests were conducted in a steel tank with dimensions of 1.25m in length, 1.0m in width and 1.0m in depth. The bottom and vertical edges of the tank were stiffened using angle sections to avoid lateral yielding during soil placement and loading of the model footing. Two side walls of the tank consist of 10mm-thick glass plate and the other sides consist of 3 mm steel plate. Therefore, the inside walls of the tank were smooth enough to minimize side friction.

The boundary distances of the test tank were greater than the footing length, width, and depth during the tests. It was observed that the extent of failure zones was not more than the footing geometry, and the frictional effect was insignificant to affect the results of model tests. Static vertical loads were applied to the model footings by an electrically operated mechanical jack attached to a loading frame located above the tank. Stress, load and displacement measurements were taken using three transducers, a load cell and two LVDT's installed between the jack and the model footing. Design of apparatus of these equipment's are shown in Fig. 1.

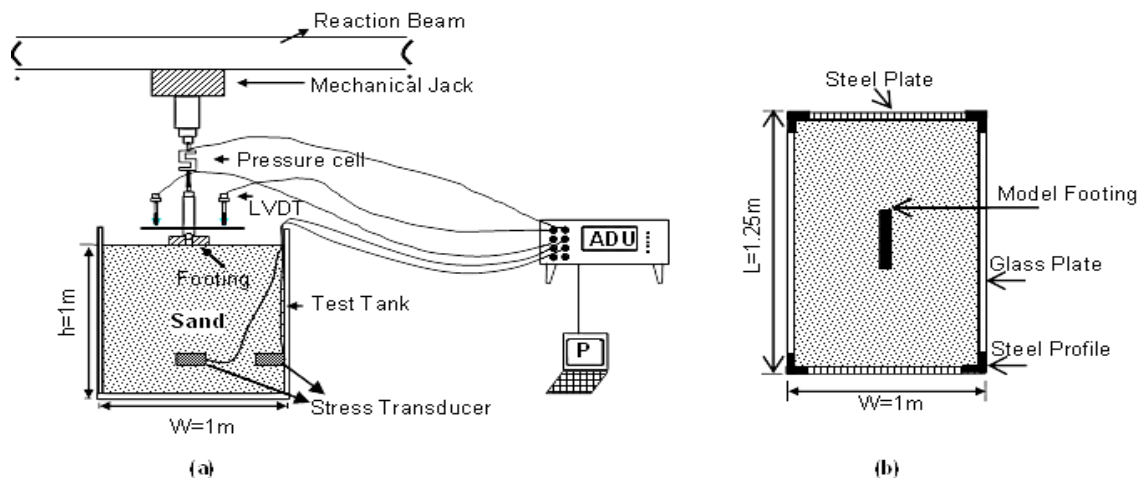


Figure 1. Design of apparatus for model test. (a) elevation, (b) plan view

### Model Footings

The loading tests were carried out on three different model rigid footings fabricated from mild steel. All models had thicknesses of 10mm and widths (B) of 10cm. Typical model geometries of the footings are shown in Fig. 2. and Table 1.

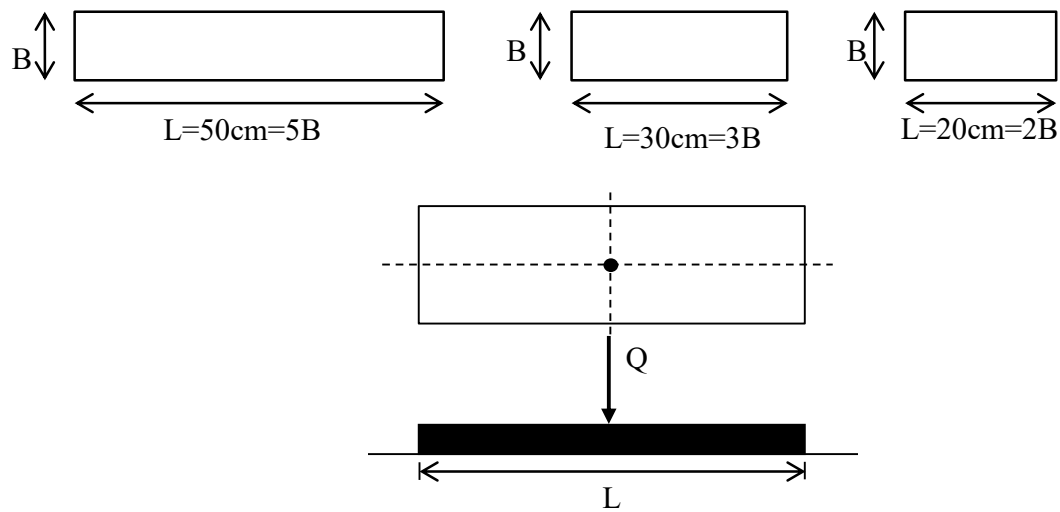


Figure 2. Strip and rectangular footings. (a) plan views, (b) elevation

Table 1. The geometries of the footings used in the tests

Footing Type	BxL [cm]	Area [cm <sup>2</sup> ]
Strip Footing (S)	10x50	500
Rectangular Footing (R1)	10x30	300
Rectangular Footing (R2)	10x20	200

### Test Medium

Uniform, clean, fine sand obtained from the Ceyhan River bed (Adana, Turkey) was used for the model tests. The laboratory tests were conducted on representative sand samples for gradation, specific gravity, maximum and minimum densities and strength parameters. These properties are summarized in Table 2. The particle size distribution of this sand is shown in Fig. 3 The model tests were conducted on loose sand condition. The angle of shearing resistances of the loose ( $D_r=25\%$ ) and dense sand ( $D_r=75\%$ ) at dry unit weights of  $15.44\text{kN/m}^3$  and  $17.11\text{kN/m}^3$  for normal pressures of 50, 100, and 200kPa were determined by the direct-shear testing. The measured average peak friction angles were  $36^\circ$  and  $42^\circ$  for loose and dense sands, respectively.

Table 2. Properties of the sand beds

Property	Value
Coarse sand fraction (%)	0.00
Medium sand fraction (%)	65.00
Fine sand fraction (%)	35.00
$D_{10}$ (mm)	0.13
$D_{30}$ (mm)	0.28
$D_{60}$ (mm)	0.58
Uniformity coefficient, $C_u$	4.46

Coefficient of curvature, $C_c$	1.04
Specific gravity	2.75
Maximum dry unit weight ( $\text{kN/m}^3$ )	17.11
Minimum dry unit weight ( $\text{kN/m}^3$ )	15.44
Dry unit weight during model tests ( $\text{kN/m}^3$ )	15.44
Cohesion, $c$ (kPa)	0.00
Classification (USCS)	SP

Note: USCS = Unified Soil Classification System

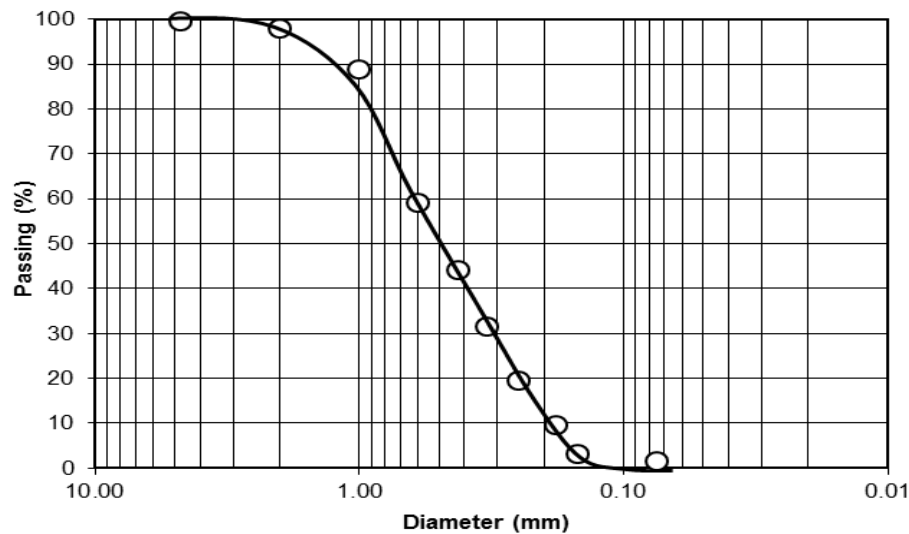


Figure 3. Particle size distribution of the test sand

### Preparation of the Sand Bed

The sand bed was prepared up to the base level of the model footings in layers of 50mm thick. After bed preparation, the sand was carefully levelled in the areas directly beneath the footing. This was performed to ensure that the model footing had full contact with the sand and that the load applied to the footing was vertical (normal).

The model footing tests were performed with the sand at unit weight of  $15.44\text{kN/m}^3$ , i.e. the loose sand soil condition. In all tests, the minimum depth of the sand below the base of the model was 0.95m.

### Preparation of the Sand Bed

The model footing was placed on the surface of the sand bed at predetermined locations in the test tank. Vertical compressive load was gradually applied to the model footing by means of a mechanical jack supported against a reaction beam. Then, the load was measured using a calibrated stress transducer. A ball bearing was positioned between the load cell and the footing model to ensure that no extraneous moment was applied to the footing. Constant load increment was maintained until the footing settlement had stabilized. Stress distributions and settlements of the footing were measured respectively using calibrated stress transducer (HTD 20419) and two LVDT's (Novotechnik TYP TR 50) placed on either side of the footing as shown in Fig. 4. For each test, load-settlement and stress distribution readings were recorded by a sixteen-channel data

logger unit (MM700 Series Autonomous Data Acquisition Unit) and converted to produce values of settlement at ground level and load using Geotechnical Software-DS7 on a PC. The tests were continued until the applied vertical load clearly reduced or a considerable settlement of the footing resulted from a relatively small increase in vertical load. At the end of each test, the sand was carefully excavated.

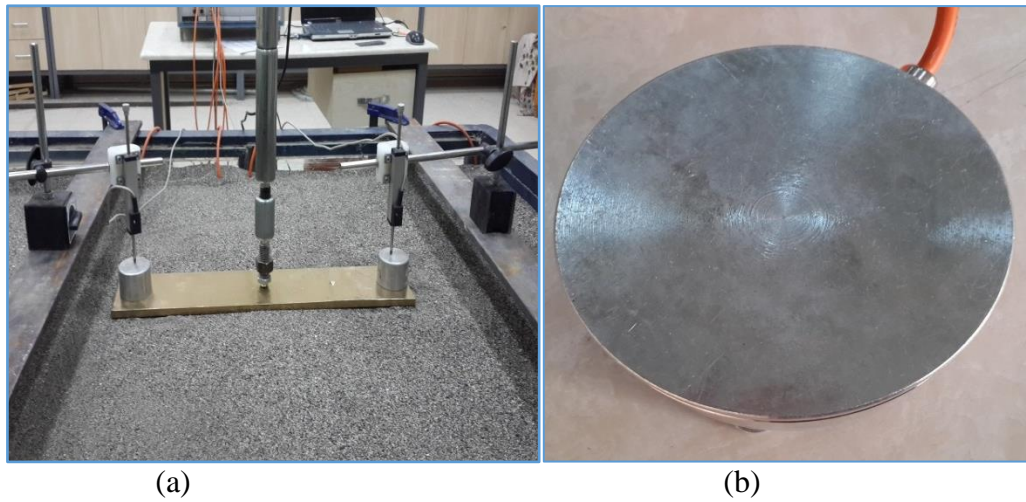


Figure 4. Test setup (a) overview, (b) stress transducer

## Results and Discussion

### *Interpretation of Test Results*

In the laboratory tests, additional vertical stress values with load-settlement relationship were investigated at the five different depths inside the sandy soil. The test results were compared with the theoretical results.

There are several different theoretical practice techniques to compute the stress in engineering. For the soil media, commonly used techniques are the Boussinesq method, the Westergaard method and the 2:1 method. Of these, the Boussinesq method is probably the most popular (Hazzard et al., 2007).

### *Boussinesq Method*

The method uses the theory of elasticity to calculate the stress under a point load in a homogeneous semi-infinite half space (Bowles, 1996). Stress increase in the soils due to external load is considered as an estimated Boussinesq problem. The expression obtained by Boussinesq for computing vertical stress  $\Delta\sigma_z$ , at point P due to a point load Q is

$$\Delta\sigma_z = \frac{Q}{z^2} \left\{ \frac{3}{2\pi} \frac{1}{\left[ \left( \frac{r}{z} + 1 \right) \right]^{5/2}} \right\} \quad (1)$$

where,  $r$  is the horizontal distance between an arbitrary point  $P$  below the surface and the vertical axis through the point load  $Q$ .  $z$  is the vertical depth of the point  $P$  from the surface (Figure 5).

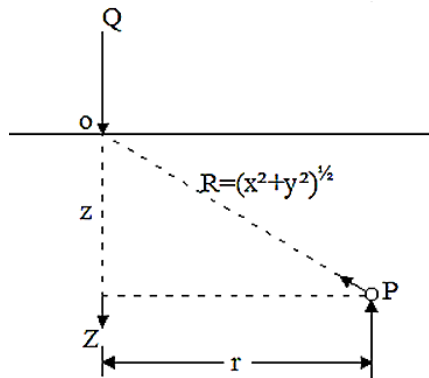


Figure 5. Vertical pressure within an earth mass

### ***Boussinesq Method***

Westergaard (1938) proposed a formula for the computation of the vertical stress  $\sigma_z$  by a point load,  $Q$ , at a point in  $z$  depth;

$$\Delta\sigma_z = \frac{Q}{z^2\pi} \left\{ \frac{1}{\left[1 + 2\left(\frac{r}{z}\right)^2\right]^{3/2}} \right\} \quad (2)$$

where the explanation of the parameters  $r$ ,  $z$  and  $Q$  are given in Fig. 5.

### ***2:1 Method***

In preliminary analyses, the vertical stress increase under the center of rectangular loads, geotechnical engineers often use an approximate method (sometimes called the 2:1 method). The approximate method is reasonably accurate (compared with Boussinesq's elastic solution) when  $z > B$  (Fig. 6). The vertical loading stress at some depth is then calculated by:

$$\Delta\sigma_z = \frac{qBL}{(B+z)(L+z)} \quad (3)$$

where  $B$  and  $L$  are the geometry of the loaded area and  $z$  is the depth for the stress calculation.



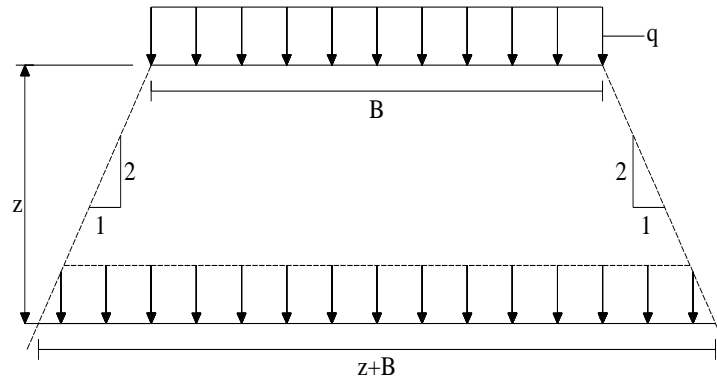


Figure 6. Simplified approach to vertical stress increases

**Test Series 1: Load-Settlement Relations**

Load-settlement and vertical stress relations were investigated in this series. Load-settlement curve is given in Fig. 7 for S, R1 and R2 footings.

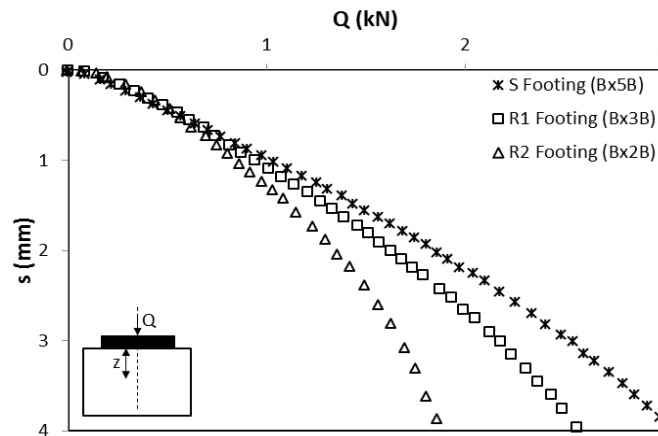


Figure 7. Load-settlement curve

As shown in the Fig. 7, the bearing capacity increases when the length of the footing increases. For example, for 4mm settlement, the Q values are approximately 1.86kN, 2.57kN and 3.00kN for S, R1 and R2 footings, respectively. While the length of the footing increases from 2B to 5B, the loading capacity increases by about 38%.

**Test Series 2: The Vertical Stress Changes along the Depth**

In this section, the measured stress values due to the applied stresses are presented in Figure 8, 9 and 10 for the five different depths as 1.0B, 2.0B, 3.0B, 4.0B and 5.0B. The measured stress changes are drawn for 10kPa, 20kPa, 30kPa and 40kPa stress levels for all the types of footings S, R1 and R2, respectively.

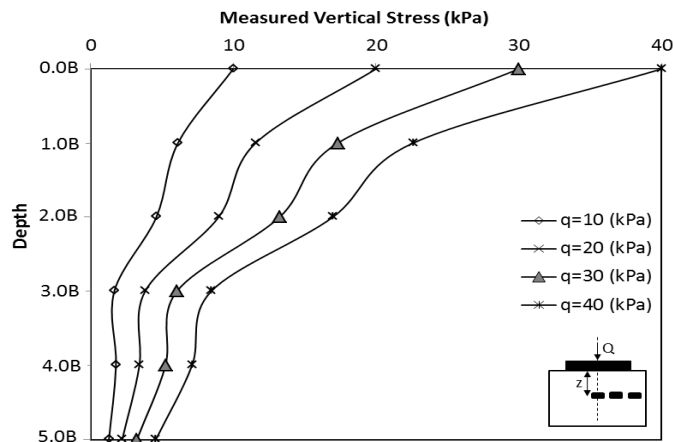


Figure 8. Vertical stress distribution along the depth at the different loading levels for S footing

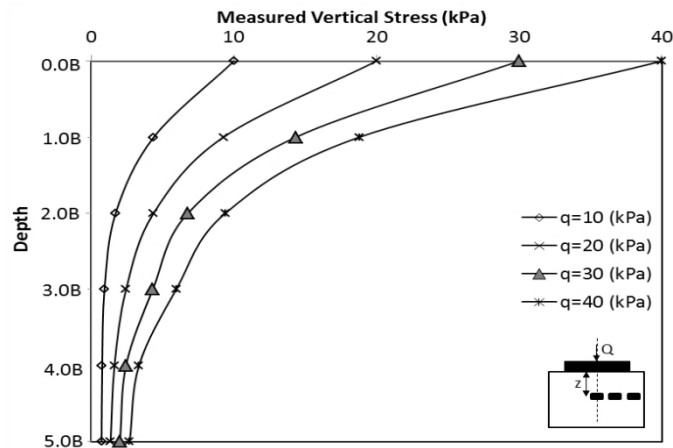


Figure 9. Vertical stress distribution along the depth at the different loading levels for R1 footing

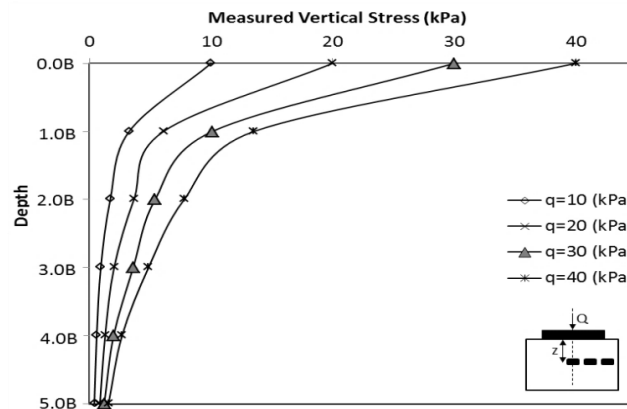


Figure 10. Vertical stress distribution along the depth at the different loading levels for R2 footing

For all these footing models, it is seen that the measured stress values have decreased along the depths for all the loading levels. For example, the measured stresses have decreased 43%, 53%

and 70% in 1B depths and 89%, 94% and 97% in the 5B depths compared with the applied stresses for S, R1 and R2 footings, respectively. It can be said that the effect of the external loads is lose at about 5B, for the strip and rectangular model footings used in this study.

**Test Series 3: Comparison between Test and Literature Results**

In this series for the 30kPa applied stresses, the test results are compared with Boussinesq method, Westergaard method and 2:1 method (Fig. 11, 12 and 13). The comparison was performed for S, R1 and R2 type footings. The measured stress values for Boussinesq, Westergaard and 2:1 method were calculated using the Equations 1, 2 and 3.

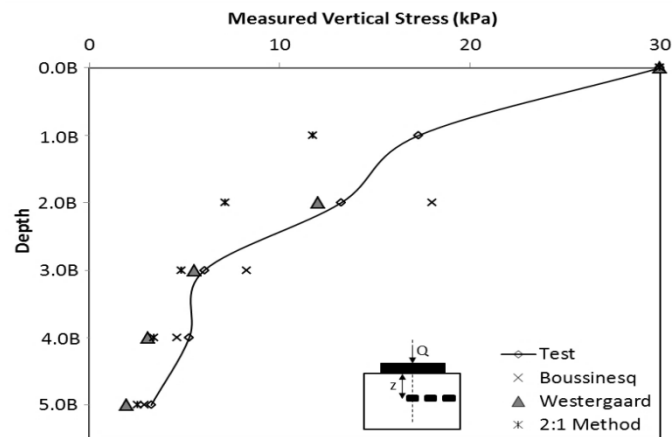


Figure 11. Comparison between test and the literature results along the depth for S footing

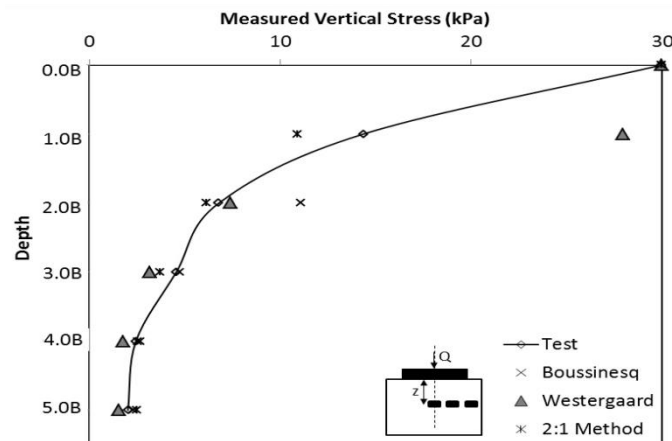


Figure 12. Comparison between test and the literature results along the depth for R1 footing

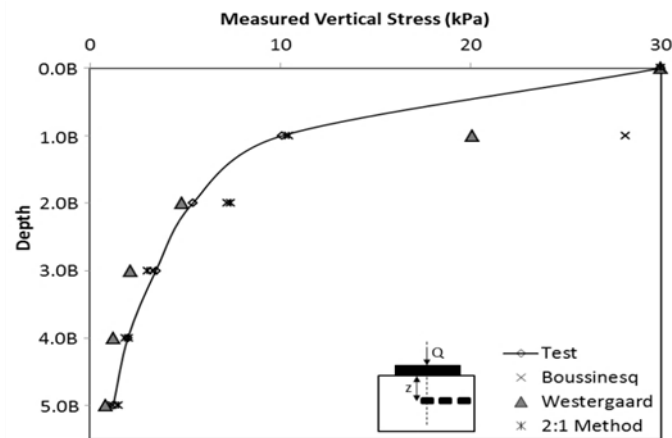


Figure 13. Comparison between test and the literature results along the depth for R2 footing

As seen from the figures that the measured stresses calculated using Boussinesq and Westergaard methods are very high at the near-surface depths and also quite different when compared with the experimental results. But, the measured stress values are closer to each other with increasing depth for all the methods. For example, the measured stress values obtained in the test, Boussinesq, Westergaard and 2:1 method for R1 footing are 10.095kPa, 28.127kPa, 20.084kPa and 10.461kPa at the 1B depth, respectively. These values are 3.451kPa, 3.323kPa, 4.800kPa and 3.021kPa, for the 3B depth (0.3m). Whereas, 2:1 method results are quite close to the test results for all the depths and footings types.

**Test Series 4: Vertical Stress Distributions along The Horizontal Distance**

In this Series of the test, the measured stress distribution along the horizontal distance for different depths are examined. Figure 14 shows the distribution for 1.0B, 2.0B, 3.0B, 4.0B and 5.0B depths for three types of footings. The horizontal range is 2.4B from each side of the footing center. The numerical values of the measured stresses are given in Table 3. In the table, x represents the horizontal distance from the center of footing and z represents the depth from the footing base. The applied load of 30kPa was used in this Series of the study.

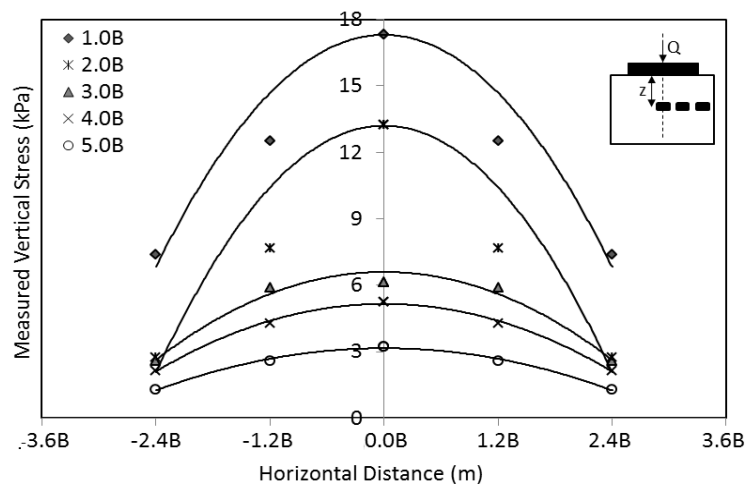


Figure 14. The stress distribution curves along the horizontal distance (S Footing)

Table 3. The numerical values of the stress distribution along the horizontal distance (S Footing)

Measured Vertical Stress (kPa)					
x→	-2.4B	-1.2B	0.0B	1.2B	2.4B
z↓					
0.00	30.00	30.00	30.00	30.00	30.00
1.0B	7.38	12.51	17.32	12.51	7.38
2.0B	2.76	7.68	13.24	7.68	2.76
3.0B	2.56	5.88	6.15	5.88	2.56
4.0B	2.14	4.27	5.25	4.27	2.14
5.0B	1.28	2.56	3.25	2.56	1.28

Similar to the S-Footing, the stress distribution curves and numerical values for R1 and R2 footing are presented in Fig. 15-16 and Tables 4-5.

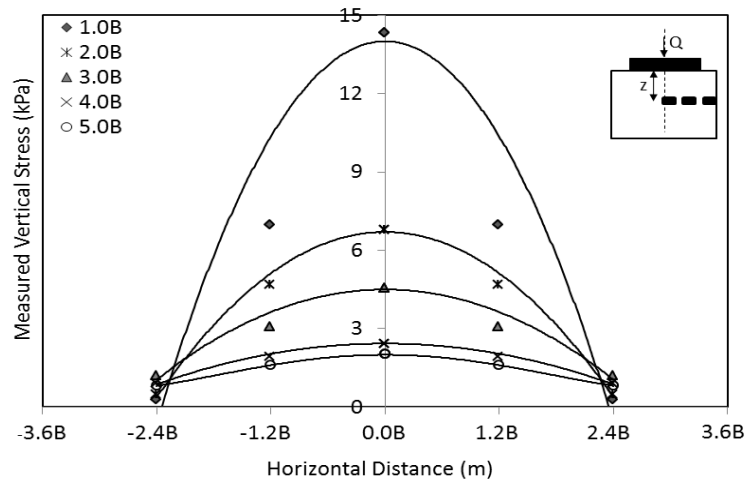


Figure 15. The stress distribution curves along the horizontal distance (R1 Footing)

Table 4. The numerical values of the stress distribution along the horizontal distance (R1 Footing)

Measured Vertical Stress (kPa)					
x→	-2.4B	-1.2B	0.0B	1.2B	2.4B
z↓					
0.00	30.00	30.00	30.00	30.00	30.00
1.0B	0.28	6.98	14.35	6.98	0.28
2.0B	0.49	4.70	6.78	4.70	0.49
3.0B	1.20	3.07	4.55	3.07	1.20
4.0B	0.90	1.92	2.44	1.92	0.90
5.0B	0.82	1.60	2.02	1.60	0.82

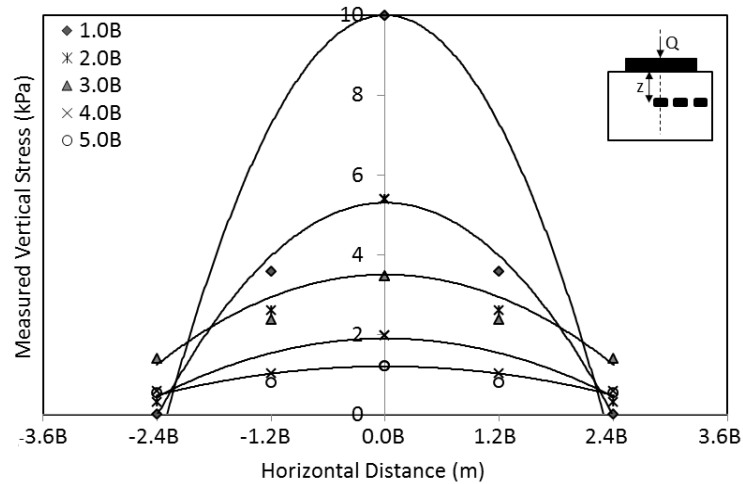


Figure 16. The stress distribution curves along the horizontal distance (R2 Footing)

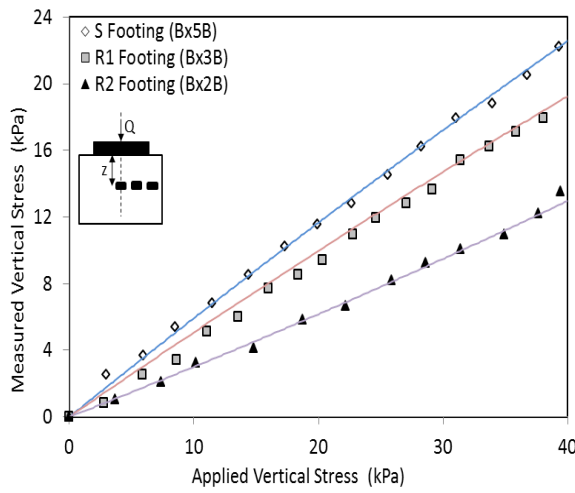
Table 5. The numerical values of the stress distribution along the horizontal distance (R2 Footing)

Measured Vertical Stress (kPa)						
x→	-2.4B	-1.2B	0.0B	1.2B	2.4B	
z↓						
0.00	30.00	30.00	30.00	30.00	30.00	30.00
1.0B	0.00	3.57	10.00	3.57	0.00	
2.0B	0.31	2.61	5.39	2.61	0.31	
3.0B	1.39	2.38	3.45	2.38	1.39	
4.0B	0.57	1.03	1.98	1.03	0.57	
5.0B	0.54	0.78	1.21	0.78	0.54	

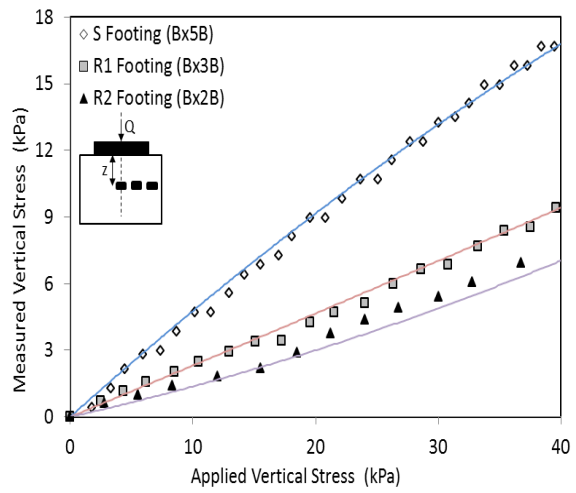
As seen from figures and tables in Series 4 that the measured stress values reach their maximum levels along the central axis of the footing for every depth (1.0B, 2.0B, 3.0B, 4.0B and 5.0B). The measured stresses have decreased farther away from the center of footing. For example measured vertical stresses at 3.0B ( $z=0.3\text{m}$ ) depth and 2.4B ( $x=0.24\text{m}$ ) horizontal distance for strip footing are less than 0.0B (footing center) and 1.2B just about 59%, 56%, respectively.

**Investigation of Scale Effect**

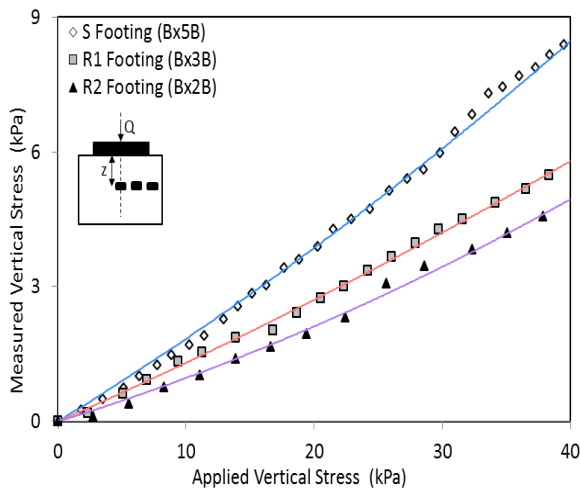
In this section of the study, the effect of the footing size on the measured vertical stress was considered. Measured vertical stress distributions formed under the model footings in three different lengths (5B, 3B and 2B) for the same depths are drawn in Fig. 17 Additionally, the measured vertical stress values are given in Table 6, for 40kPa of applied vertical stress. In the Table 6, the measured vertical stress values are presented along the center of the footings.



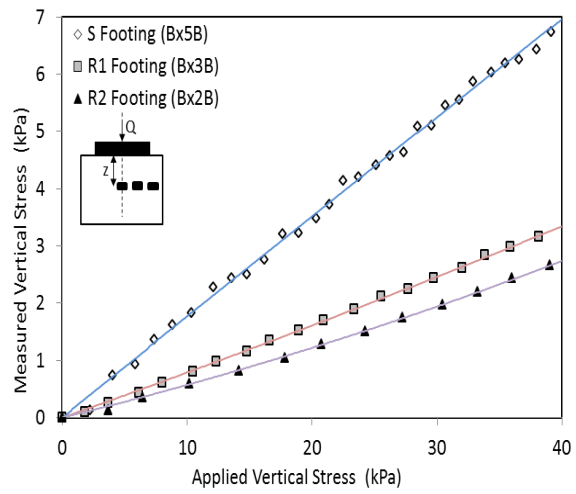
(a) 1.0B Depth



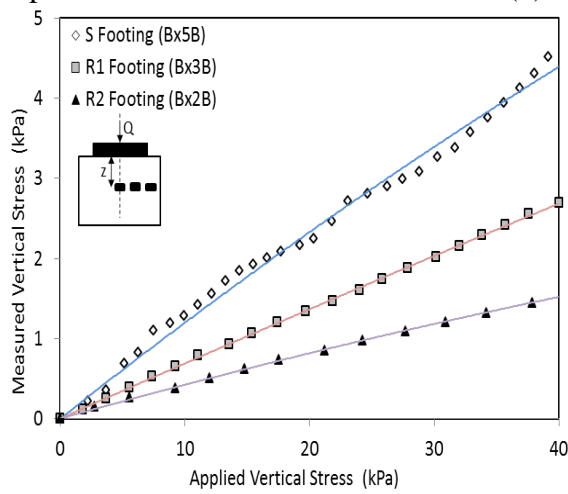
(b) 2.0B Depth



(c) 3.0B Depth



(d) 4.0B Depth



(e) 5.0B Depth

Figure 17. Investigation of scale effect for different depths

Table 6. Investigation of scale effect

Footing Type	Depths (m)	Applied Vertical Stress (kPa)	Measured Vertical Stress (kPa)
S Footing (Bx5B) (0.1mx0.5m)	1.0B	40	22.720
	2.0B	40	16.900
	3.0B	40	8.423
	4.0B	40	7.214
	5.0B	40	4.533
R1 Footing (Bx3B) (0.1mx0.3m)	1.0B	40	18.802
	2.0B	40	9.402
	3.0B	40	5.902
	4.0B	40	3.342
	5.0B	40	2.682
R2 Footing (Bx2B) (0.1mx0.2m)	1.0B	40	13.514
	2.0B	40	7.768
	3.0B	40	4.932
	4.0B	40	2.902
	5.0B	40	1.374

As seen from the Figure 16 and Table 6 that the measured stress values increase with increase in widths for a constant depth. And the measured stress values get smaller with increase in depth for every footing type. For example, the applied stress values for 40kPa at the 3B depths are 8.423kPa, 5.902kPa and 4.932kPa, for S, R1 and R2 type footings, respectively. The percentages of the decrease are 30% for the R1-footing and 42% for the R2 footing.

Also, the measured stresses occur along the horizontal distance at the each depth (1.0B, 2.0B, 3.0B, 4.0B and 5.0B) under the 30kPa of applied vertical stress are given in Fig. 18-22 and Tables 7-11 (they are given for all the footings).

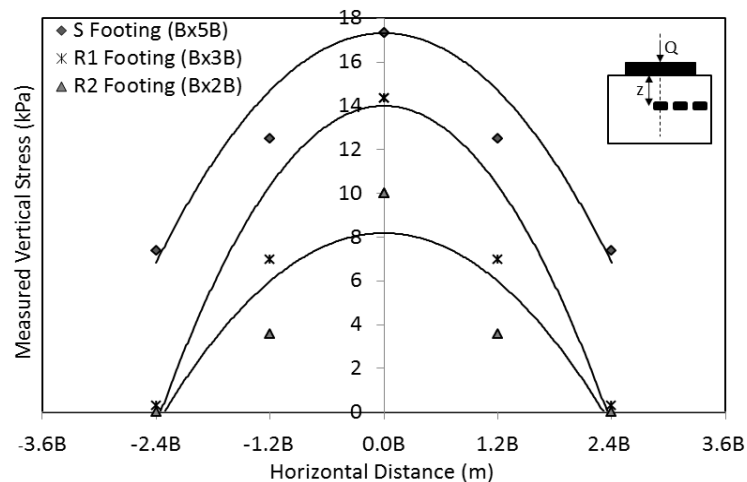


Figure 18. Measured vertical stress distribution (z=1.0B depth)



Table 7. Measured vertical stress values (1.0B depth)

1B (0.1m) Depth and 30kPa Applied Vertical Stress					
x→ Footing Types ↓	-2.4B	-1.2B	0.0B	1.2B	2.4B
S Footing (Bx5B)	7.38	12.51	17.32	12.51	7.38
R1 Footing (Bx3B)	0.28	6.98	14.35	6.98	0.28
R2 Footing (Bx2B)	0.00	3.57	10.00	3.57	0.00

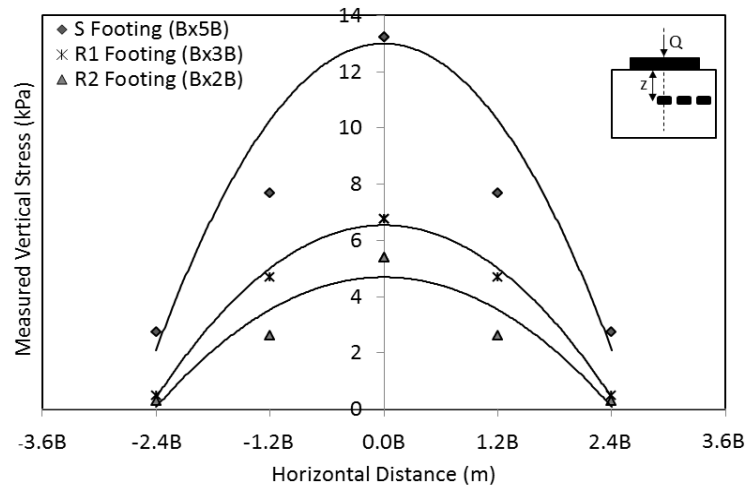


Figure 19. Measured vertical stress distribution ( $z=2.0B$  depth)

Table 8. Measured vertical stress values (2.0B depth)

2B (0.2m) Depth and 30kPa Applied Vertical Stress					
x→ Footing Types ↓	-2.4B	-1.2B	0.0B	1.2B	2.4B
S Footing (Bx5B)	2.76	7.68	13.24	7.68	2.76
R1 Footing (Bx3B)	0.49	4.70	6.78	4.70	0.49
R2 Footing (Bx2B)	0.31	2.61	5.39	2.61	0.31

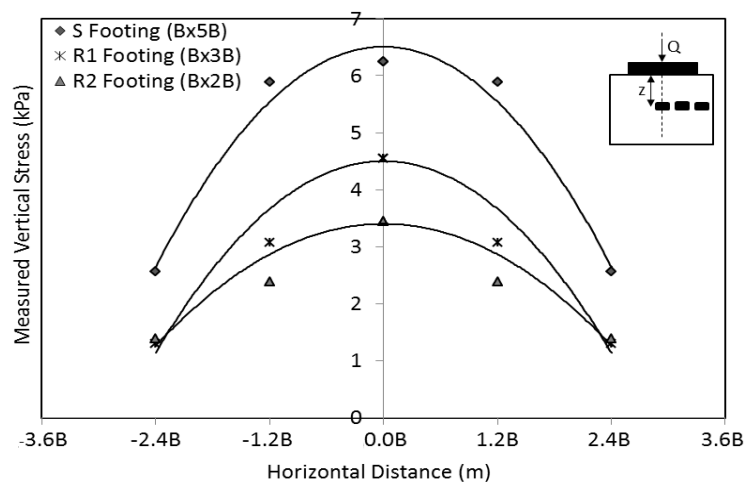


Figure 20. Measured vertical stress distribution ( $z=3.0B$  depth)

Table 9. Measured vertical stress values (3.0B depth)

3B (0.3m) Depth and 30kPa Applied Vertical Stress					
x→	-2.4B	-1.2B	0.0B	1.2B	2.4B
Footing Types ↓					
S Footing (Bx5B)	2.76	7.68	13.24	7.68	2.76
R1 Footing (Bx3B)	0.49	4.70	6.78	4.70	0.49
R2 Footing (Bx2B)	0.31	2.61	5.39	2.61	0.31

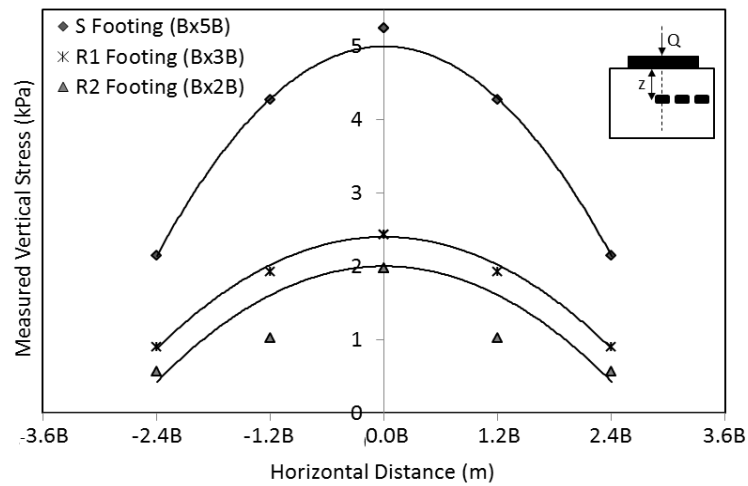


Figure 21. Measured vertical stress distribution ( $z=4.0B$  depth)

Table 10. Measured vertical stress values (4.0B depth)

4B (0.4m) Depth and 30kPa Applied Vertical Stress					
x→	-2.4B	-1.2B	0.0B	1.2B	2.4B
Footing Types ↓					
S Footing (Bx5B)	2.14	4.27	5.25	4.27	2.14
R1 Footing (Bx3B)	0.90	1.92	2.44	1.92	0.90
R2 Footing (Bx2B)	0.57	1.03	1.98	1.03	0.57

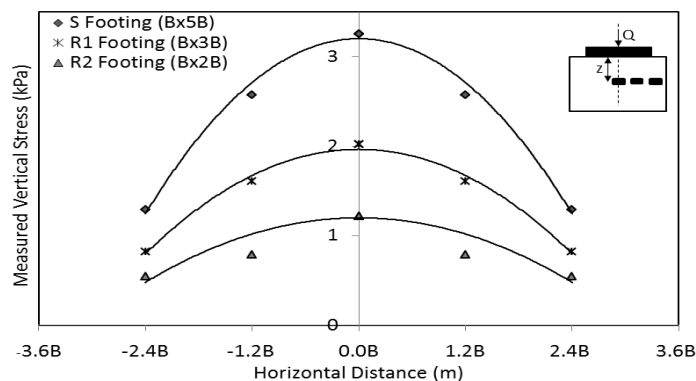


Figure 22. Measured vertical stress distribution ( $z=5.0B$  depth)

Table 11. Measured vertical stress values (5.0B depth)

5B (0.5m) Depth and 30kPa Applied Vertical Stress					
x→ Footing Types ↓	-2.4B	-1.2B	0.0B	1.2B	2.4B
S Footing (Bx5B)	1.28	2.56	3.25	2.56	1.28
R1 Footing (Bx3B)	0.82	1.60	2.02	1.60	0.82
R2 Footing (Bx2B)	0.54	0.78	1.21	0.78	0.54

As seen from these figures and tables that there is a size effect in the measured vertical stresses for a constant applied stress. When the footing size increases, the measured stress values increases at the same ratio. Also, the measured stress values obtained all horizontal distances decreases in three footing types when the depth increases.

### Conclusions

In this study, the stress, the bearing capacity and the settlement behavior in the loose sand were investigated experimentally and theoretically with three types (10cmx50cm size of strip footing, 10cmx30cm and 10cmx20cm sizes of rectangular footings) of model footings. A total of 15 model tests were carried out in the Geotechnical Laboratory of Civil Engineering Department of Iskenderun Technical University, Iskenderun, Hatay, Turkey. The measured stress distribution was vertically obtained in the tests in central loading conditions using three stress transducers. And also the load-settlement curves were obtained. Then the test results were compared with theoretical results. Based on the results from this investigation, the following main conclusions can be drawn:

- The bearing capacity increases when the length of the footing increases. While the length of the footing increases from 2B to 5B, the loading capacity increases by about 38%.
- There is a size effect in measured vertical stresses for a constant applied stress. The measured stress values are sorted as  $\sigma_{5B} > \sigma_{3B} > \sigma_{2B}$  (L=5B, 3B and 2B).
- The measured vertical stress values decrease along the depths for all the three types of the footing. The reduction in the measured stress values reaches approximately up to 97%.
- The literature results are close to the experimental test solutions all of the depths and types of the footings.
- The measured stresses reach their maximum values in central axis of the footings and minimize getting far away from the center of footing for each depth.

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### References

- Bagriacik, B., (2010). Experimental and theoretical analyses of the stress conditions of soils. *MSc Thesis*, Cukurova University, Adana.
- Bagriacik, B. & Laman M. (2010). Investigation of the effect of shallow foundation geometry on soil stress distribution. *Cukurova University, Journal of the Faculty of Engineering and Architecture*, 25(1-2), 155-166.

- Bagriacik, B. & Laman M. (2011). Distribution Of Stresses In Unreinforced And Reinforced Soils Induced By A Circular Foundation. *Cukurova University, Journal of the Faculty of Engineering and Architecture*, 26(4), 787-800.
- Bhaskar D.R.C., Shukla S.J. and Dinesh S. (2015). A numerical study of foundation depth on contact stresses and settlements for various sub soils. *50th Indian Geotechnical Conference 17th – 19th December 2015*, Pune, Maharashtra, India.
- Bowles, J.E. (1996). Foundation analysis and design. 5th ed., McGraw Hill, Ney York, NY, USA.
- Cho, S., & Vipulanandan, C. (1998). Verification of stress distribution in a soil box. *CIGMAT-Department of Civil and Environmental Engineering University of Houston, Texas*, 77204-4003.
- Donath, A.D. (1891). Untersuchungen ueber den erddruck auf stuetzwaende. *Zeitschrift für Bauwesen*, Berlin, Germany.
- Dixit M. S. & Patila K. A. (2013). Experimental estimate of  $N_{\gamma}$  values and corresponding settlements for square footings on finite layer of sand. *Geomechanics and Engineering*, 5 (4), 363-377.
- Hanna, A.M., & Soliman-Saad, N. (2001). Effect of compaction duration on the induced stress levels in a laboratory prepared sand bed. *Geotechnical Testing Journal*, 24(4), 430-438.
- Hazzard, J. F., Yacoub T. E., Vijayakumar S. & Curran J. H. (2007). Stresses under footings in multilayered soils: a comparative study. *Bearing Ground in the Nation's Capital*, Ottawa.
- Jaky, J. (1948). Pressure in soils. *Proc. 2nd Conf. on Soil Mechanics and Foundation Engineering*. A. A. Balkema, Rotterdam, the Netherlands, 1, 103-107
- Kayadelen, C., (2005). Investigation of lateral earth pressures in  $K_0$  condition for unsaturated fine grained soils", *PhD Thesis*, Cukurova University, Adana.
- Keskin, M.S. (2004). Stress analysis of soils with various methods. *MSc Thesis*, Cukurova University, Adana.
- Keskin, M.S. & Laman M. (2014). Experimental study of bearing capacity of strip footing on sand slope reinforced with tire chips", *Geomechanics and Engineering*, 6(3), 249-262.
- Mohamed A. K. (2012). Numerical study for the behavior of strip footing on sand in the existence of a buried rock. *Journal of Engineering Sciences, Assiut University*, 40(6), 1611-1624 .
- Ornek, M. (2014). Estimation of ultimate loads of eccentric-inclined loaded strip footings rested on sandy soils. *Neural Computing and Applications*, 25, 39-54.
- Saran, S., Kumar, S., Garg, K.G. & Kumar, A. (2007). Analysis of square and rectangular footings subjected to eccentric-inclined load resting on reinforced sand. *Journal of Geotechnical and Geoenvironmental Engineering*, 25, 123-137.
- Terzaghi, K. (1920). Old earth pressure theories and new test results. *Engrg. News-Rec.*, 85(14), 632-637.
- Uzuner, B.A. (1975). Centrally and eccentrically loaded strip foundations on sand. *PhD Thesis*, University of Strathclyde, Glasgow, UK.
- Yang K.H., Zornberg J. G., Liu C.N., & Lin H.D. (2012). Stress distribution and development within geosynthetic-reinforced soil slopes. *Geosynthetics International*, 19(1), 62-78.
- Yodsa-nga P., Gasaluck W. & Punrattanasin P. (2012). Stress distribution in khon kaen loess under spread footing. *The Electronic Journal of Geotechnical Engineering*, 17, 3753-3769.