3rd International Conference on New Developments in Soil Mechanics and Geotechnical Engineering,
28-30 June 2012, Near East University, Nicosia, North Cyprus

Experimental Investigation of Stress Behavior of Square Footings on the Sandy and Clayey Soils

Baki Bağrıaçık*
Civil Engineering Department, Cukurova University, Adana, Turkey

Ahmet Demir
Civil Engineering Department, Osmaniye Korkut Ata University, Osmaniye, Turkey

Mustafa Laman
Civil Engineering Department, Cukurova University, Adana, Turkey

KEYWORDS: Vertical stress, pressure transducers, sandy and clayey soils, square footing

ABSTRACT: In this study, the induced vertical soil stress values occuring along with horizontal surfaces at predetermined depths of the square footings on sandy and clayey soils were investigated by laboratory model tests. In the model tests pressure transducer was used to measure the stresses. It was seen that the settlement of sandy and clayey soils is directly related to the induced stress. It was determined that stress values on sandy soils decrease much more than clayey soils. The reduction in stress values when move away from the center of footing at horizontal line at the same depth are similar with sandy and clayey soil.

1 INTRODUCTION

All manmade structures are inevitably supported by the earth: let them be a skyscraper, a dam or a highway pavement, or even retaining elements for cuts, embankments and tunnels where the major load is the earth itself. The engineering concerns are the situation just and long before the act of building and the response after. Through this perspective, soil mechanics is defined by Harr (1966) as the phase of the physical sciences which deals with the state of rest or motion of soil bodies induced by forces. Two major concepts of soil mechanics are of interest for this study: stress and strain (Okumuşoğlu, 2006). Hence, It is very significant to know the real distribution of stresses and the relationship of stress–strain behaviour for solution of the problem and the design of many projects. Thus, this real distribution of stresses and relationship of stress–strain behaviour, due to the additional loads in the soils, should be found experimentally (Bağrıaçık and Laman, 2011).

2 LITERATURE REVIEW

Horizontal and vertical stresses which caused by vertical loads at sand and clay samples were measured by Terzaghi (1920). As a result of the experiments, K_0=0.42 (K_0=Coefficient of earth pressure at rest) value was obtained from Donath solution ($K_0= \sigma_v/\sigma_h$) (σ_v=Vertical stress, σ_h=Horizontal stress) for coarse sand (Donath, 1891). Effects of compaction on the values of K_0 was first investigated by Terzaghi and he reported that K_0 values are variying between 0.6–0.7 (Hanna and Ghally 1992). Additional vertical stress values by loading sand fill that occur on horizontal planes of particular specified depths, have been measured by Scheidig ve Kögler (1926).

Kjellman (1936) measured stresses in the sandy soils with a device which is similiar to triaxial compression tests and he reported that K_0 values are in between 0.5 and 1.5. Bayliss (1948) developed an instrument to measure lateral soil pressure and he indicated that K_0 value is 0.5 for sand and medium-plasticity organic clay. Hendron (1963) used an oedometer that can measure lateral pressures by strain gauge that was mounted on a metal ring that is sensitive to the lateral stresses (Keskin et al. 2004). Then, Brooker and Ireland (1965) used the data obtained from Hendron's study and they investigated the variation of earth–pressure coefficient at rest dependent on the over consolidation ratio and plasticity index (Keskin et. al. 2004). Sağlamer (1972) investigated the effect of relative density (Dr), shape of soil, particle size, stress history to K_0 in coarse-grained soils. In an odometer that was improved for this purpose, loading tests were carried out on four different air-dried sand. In his tests, three pressure transducers have been used in order to measure high stress values (Figure 1). It was found that at loading condition K_0 was mostly dependent on relative density of soil. He indicated that K_0 values in dense sand were lower than the values in loose sands.

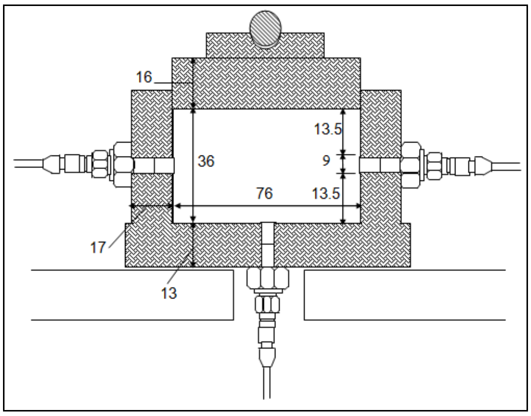

Figure 1. Sağlamer(1972) Test Equipment, (Dimensions in mm)

The test equipment that can directly measure the horizontal stresses on clay soils was used by Abdelhamid and Krizek (1976). The variations of the horizontal stress and K_0 values due to applied vertical stresses were investigated. It was concluded that the K_0 values remain stable for the vertical stresses higher than the preconsolidation pressure, but this value increased during unloading (Abdelhamid and Krizek, 1976). The induced vertical and lateral soil stress values of the square shallow footings on sandy soils were investigated by Laman and Keskin (2004). In the model tests pressure transducer was used to measure the stresses. The effect of density on the stresses was investigated. The experimental results were compared with theoretical and numerical results. Furthermore, it seemed that experimental results at three depth of soil were similiar to Boussinesq solutions. Keskin et al. (2004), investigated the effect of vertical effective stress and over-consolidation ratio to the coefficient earth pressure at rest. The vertical stress values occurred under the center line of the uniformly loaded square footings were investigated experimentally and numerically by Keskin et al. (2008). Tests were performed in a square shaped test box and pressure transducer was used to measure the stresses. The results of the study were compared with the results of Boussinesq method. In the numerical analysis, soil was modeled using finite element method with two dimensional axi-symmetric and three dimensional conditions as linear elastic and non-linear elastoplastic materials and the effect of these models on the vertical stress values was investigated. A general agreement was observed between the experimental, numerical and theoretical results for the values obtained for predetermined depths of sand and the obtained results are discussed (Keskin et al., 2008). The induced vertical soil stress values occuring along with horizontal surfaces at predetermined depths of the shallow footings on sandy soils were investigated by model tests by Bağrıaçık and Laman (2010). In the model tests pressure transducer was used to measure the stresses. Circular footings at different size were used in the model tests and the size effect were investigated. As a result of this study, the size effect at circular footings wasn't found to be an important factor on stress distribution of sandy soils (Bağrıaçık and Laman, 2010). The induced vertical soil stress values of the shallow footings in different geometries on sandy soils were investigated by laboratory model tests by Bağrıaçık and Laman (2011–a). For this purpose, induced vertical stress values, along the horizontal lanes at different depths in the soil, caused by shallow footings with three different geometries were investigated determine the effect of shape. In the tests, pressure transducers have been used in order to measure stress values. As a result of this study; the effect of shape because of shallow footing in different geometries was found to be important (Bağrıaçık and Laman, 2011–a). Additional vertical stresses, which occur in a soil as a result of uniformly loaded circular footing, resting on sandy soils unreinforced and reinforced by geogrids, have been investigated by laboratory model tests by Bağrıaçık and Laman (2011–b). Additional vertical stress values that occur on a horizontal planes of particular specified depths, have been measured. In the tests, pressure transducers have been used in order to measure stress values. Geogrid, which has double axis and placed into the depth of u=0,3D (u=depth of reinforcement, D=diameter of footing) at soil, have been used in the tests. Finally, it was concluded that additional vertical stress values, which occur in a soil as a result of uniformly loaded circular footing on a horizontal planes of particular specified depths can be decreased significantly according to the unreinforced case (Bağrıaçık and Laman, 2011–b). The depth in the ground with additional vertical and horizontal stress values caused by circular footings were investigated by model tests by Bağrıaçık et al. (2011–c). Also, the effect of K_0 which were found with the proportion of horizontal and vertical stresses, was determined by dividing horizontal stress. In addition that, the test results were compared with the results of theoratical methods (Bağrıaçık et al. 2011–c). The bearing capacity and settlement behavior of shallow footings on reinforced granular fill layer over soft clay soil were investigated using a small scale field and laboratory tests by Demir (2011). Circular footings and square footing were used in the tests. Geogrids used as reinforcement were placed in granular fill bed compacted over clay soil. The effects of parameters such as thickness of the granular fill layer, the location of the first geogrid layer, the vertical spacing of geogrid layers and the number of geogrid layers on bearing capacity and settlement were investigated in the tests by Demir (2011). After the tests, numerical analyses were carried out with finite element based two and three dimensional software PLAXIS and ABAQUS, the results obtained were compared with experimental results. Scale effect analyses with footing sizes were conducted and some statistical relations were suggested by Demir (2011).

3 MODEL GROUND AND TEST EQUIPMENT

Clean, uniform and fine sand supplied from the Çakıt River was used in present research. The physical properties of sand and clay are summarized in Table 1 and Table 2 .

Table 1. Properties of sand (Bağrıaçık, 2010)

Property	Unit	Sand
Coarse sand fraction	(%)	0.00
Medium sand fraction	(%)	46.40
Fine sand fraction	(%)	53.60
D_{10}	mm	0.18
D_{30}	mm	0.30
D_{60}	mm	0.50
C_U	-	2.78
C_C	-	1.00
Classification (USCS)	-	SP

Table 2. Properties of clay (Demir, 2011)

Property	Unit	Sand
Liquid limit	(%)	31.00
Plastic index	(%)	15.00
Silt content	(%)	72.00
Clay content	(%)	19.00
Maximum dry unit weight#	kN/m^3	16.70
Optimum moisture content#	(%)	18.75

#Standard Proctor test

The laboratory tests were conducted in the Geotechnical Laboratory of the Civil Engineering Department of the Cukurova University for sand and in the Geotechnical Laboratory of the Civil Engineering Department of the Louisiana State University for clay. The model tests were conducted inside a box which consists of wooden plate, glass surface and steel profile. (Figure 3) (Bağrıaçık, 2010).

Figure 3.Test Box (Bağrıaçık, 2010)

The square footing with dimension of 15 cm were used in the model tests. Test equipment used for model testing consists of a tank, loading and measurement systems. The pressure cells with dimension of 10 cm which is produced by Tokyo Sokki Kenkyujo Co., Ltd. were used in the model tests. The placing pressure cell and transportation of the samples from Louisiana State is found in Figure 4. The facility and typical model are shown in Figure 5.

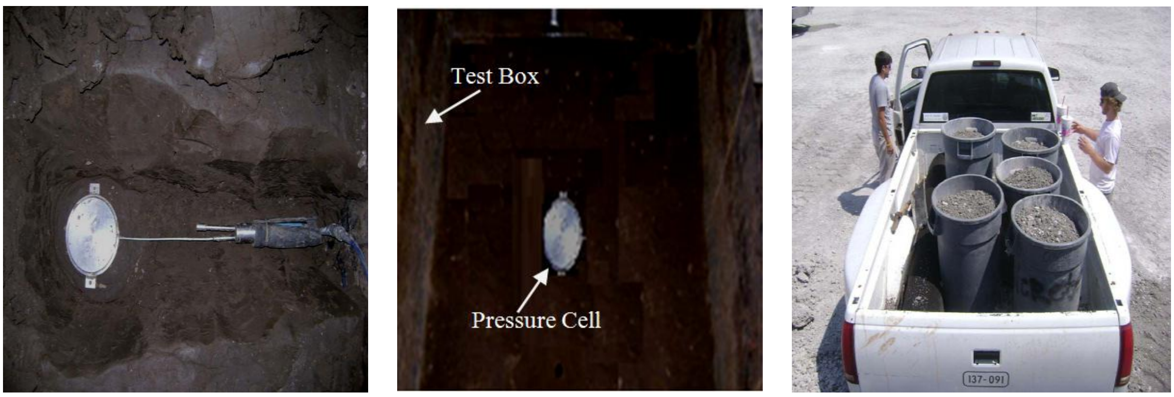

Figure 4. Placing of Pressure Cell and Transportation of Samples (Demir, 2011)

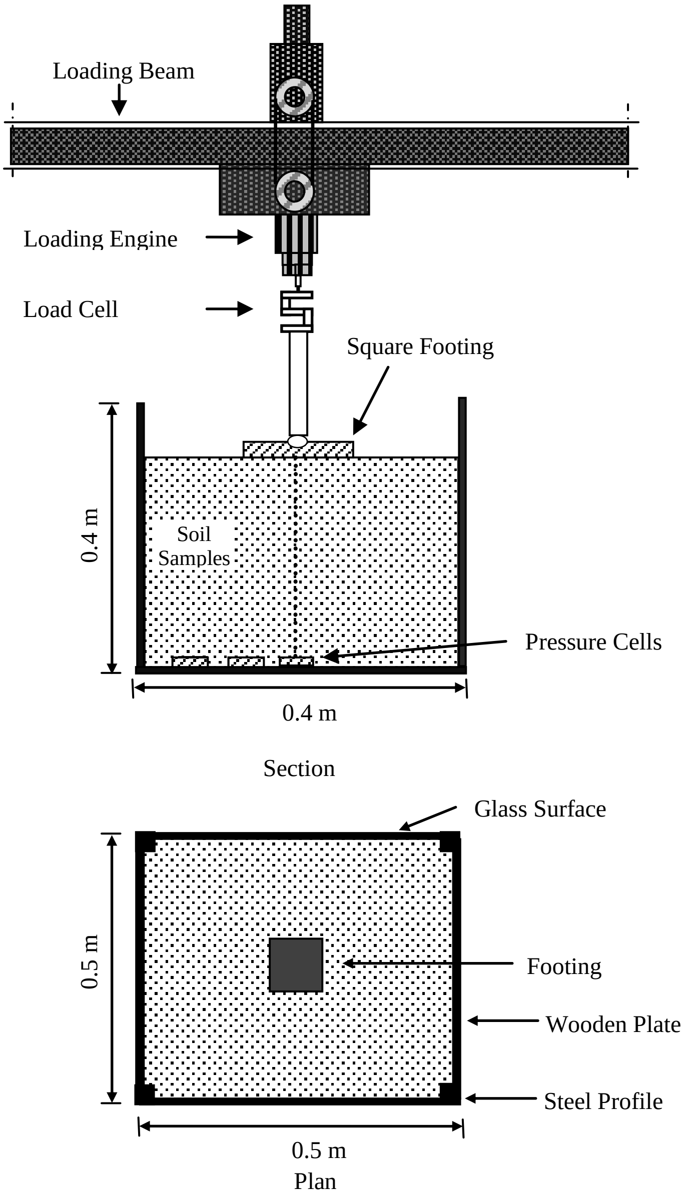

Figure 5. Test Equipment (Bağrıaçık, 2010)

4 TEST RESULTS

The purpose of this study is determined stress behaviour of square footings on the sandy and clayey soils. A series of laboratory model tests were conducted on the sandy and clayey soils. The results were presented in Figure 6, 7, 8, 9 and 10.

As seen from the Figure 6 that experimental results show a nonlinear increase in stresses on sandy and clayey soils. There was more settlement on sandy soil than clayey soil for the same loading value.

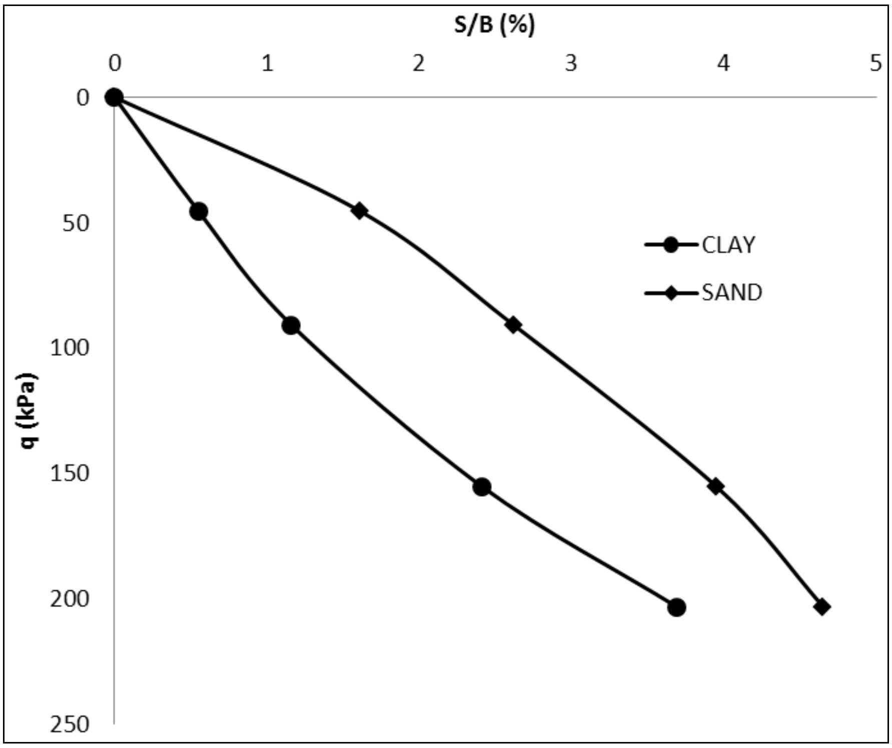

Figure 6. Comparison Between Results of Footing Pressure on Sandy and Clayey Soils
(S:Settlement, B:Dimension of Footings)

It is found from Figure 7 and Figure 8 that additional vertical stress values on sandy soil are bigger than on clayey soil for the same settlement values (S/B=%3 and S/B=%5) up to z=1.30B(z:Depth of the Soil). Under z=1.30B, vertical stres values on sandy soil are smaller than the other soil.

The reduction in stress values when moves away from the center of footing at horizontal line at the same depth are similar with sandy and clayey soil. But the reduction stress values at %5 settlement rate are bigger than %3 settlement rate on two soils (This reduction is 8 kPa for sand and 15 kPa for clay at the center of footing) (Figure 9). Furthermore, it was seen that the settlement of sandy and clayey soils is directly related to the induced vertical stress.

At the same settlement rate (S/B=%3 and S/B=%5), stress values on clayey soil are bigger than the sandy soil. The reduction stress values between sandy and clayey soils for S/B=%3 are smaller than S/B=%5 (This reduction is 5 kPa for S/B=%3 and 27 kPa for S/B=%5 at the center of footing) (Figure 10).

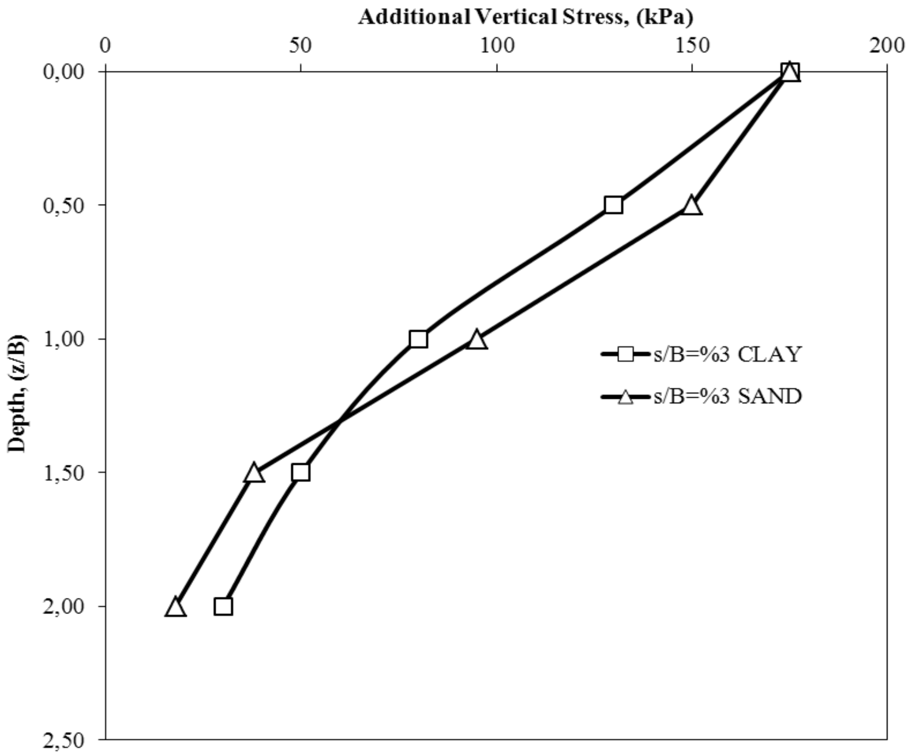

Figure 7. Comparison Between Results of the Additional Vertical Stress Values at different Depths on Sandy and Clayey Soils (S/B=%3) (z: Depth of Soils)

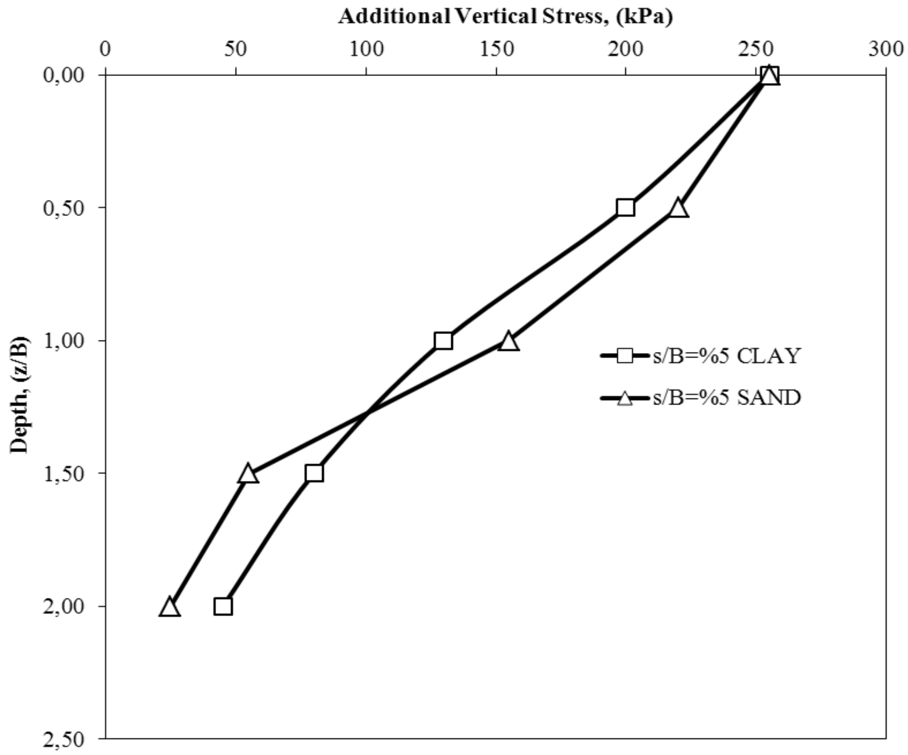

Figure 8. Comparison Between Results of the Additional Vertical Stress Values at different Depths on Sandy and Clayey Soils (S/B=%5)

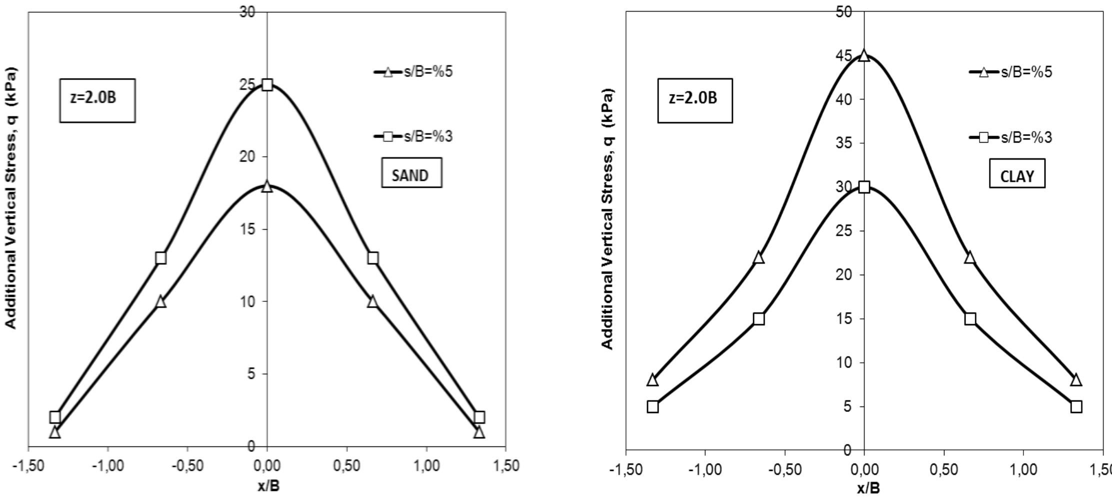

Figure 9. Comparison Between Results of the Additional Vertical Stress Values at different settlements on Sandy and Clayey Soils (S/B=%3 and S/B=%5) (x:Horizontal Distance)

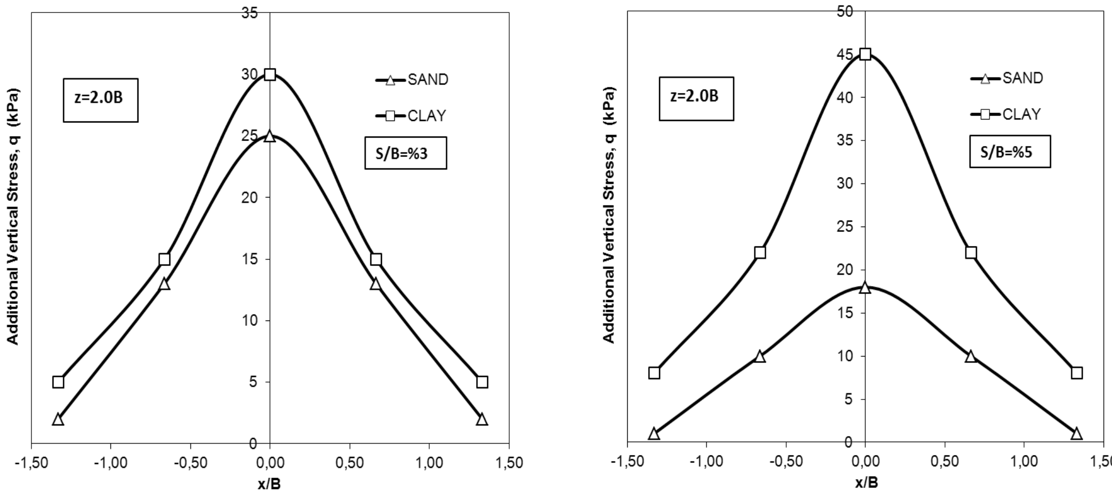

Figure 10. Comparison Between Results of the Additional Vertical Stress Values at the Depth of 2B on Sandy and Clayey Soils (S/B=%3 and S/B=%5)

5 CONCLUSIONS

Experimental results show a nonlinear increase in stresses on sandy and clayey soils.
It was occurred more settlement on sandy soil than clayey soil for the same loading value.

Additional vertical stress values on sandy soil are bigger than on clayey soil for the same settlement values (S/B=%3 and S/B=%5) up to z=1.30B. Under z=1.30B, vertical stres values on sandy soil are smaller than the other soil.

The reduction in stress values when moves away from the center of footing at horizontal line at the same depth are similar with sandy and clayey soil. But the reduction stress values at %5 settlement rate are bigger than %3 settlement rate on two soils.
It was seen that the settlement of sandy and clayey soils is directly related to the induced vertical stress.

At the same settlement rate (S/B=%3 and S/B=%5), stress values on clayey soil are bigger than the sandy soil. The reduction stress values between sandy and clayey soils for S/B=%3 are smaller than S/B=%5.

ACKNOWLEDGEMENTS

First author's special thanks to TUBITAK (The Scientific and Technological Research Council of Turkey) for scholarships financial support.

REFERENCES

Abdelhamid, M.S. and Krizek, R.J., (1976) At Rest Lateral Earth Pressure of a Consolidation Clay, Journal of Geotechinal Engineering, Vol.102, No.GT7, 721-738.

Bağrıaçık, B., (2010). Zeminlerdeki Gerilme Durumlarının Deneysel ve Teorik Olarak İncelenmesi, Yüksek Lisans Tezi, Çukurova Üniversitesi, Adana(In Turkish).

Bağrıaçık, B., ve Laman M., (2010). Yüzeysel Temel Geometrisinin Zeminlerde Oluşan Gerilmelere Etkisinin Araştırılması. Çukurova Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, pp. 155-166, No 1-2, Cilt 25, Haziran-Aralık 2010(In Turkish).

Bağrıaçık, B., ve Laman M., (2011–a). Investigation of the Shape Effect at Different Geometries on Stress Distribution of Sandy Soils pp. 78, International Balkans Conference on Challenges of Civil Engineering, BCCCE, 19-21 May 2011, EPOKA University, Tirana, ALBANIA.

Bağrıaçık, B., ve Laman M., (2011–b). Donatısız ve Donatılı Kumlu Zeminlere Oturan Dairesel Temeller Altında Gerilmelerin Değişimi. Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, Ankara, Vol:26, No:4, 787-800, 2011-(SCI, in Turkish)

Bağrıaçık, B., Laman M. and Demir A., (2011–c). Kum Zeminlerde Sükunetteki Toprak Basıncı Katsayısının Deneysel Olarak Belirlenmesi, 4. Geoteknik Sempozyumu, Çukurova Üniversitesi, Adana(In Turkish).

Bayliss, J., (1948). Desing, Calibration and Use of The Lateral Earth Pressuremeter. MS Thesis, Princeton University.

Demir, A., (2011). Yumuşak Kil Zemin Üzerinde Güçlendirilmiş Stabilize Dolguya Oturan Yüzeysel Temellerin Analizi, Doktora Tezi, Çukurova Üniversitesi, Adana(In Turkish).

Donath, A.D., (1891) Untersuchungen Veber den Erddruck auf Stuetzwaende. Zeitschrift Fuer Bauwesen.

Brooker, E.W. and Ireland, H.O., (1965) Earth Pressures at Rest Related to the Stress History. Canadian Geotechnical Journal, Vol.2, 1-15.

Hanna, A., and Ghaly, A., (1992). Effects of K_0 and Overconsolidation on Uplift Capacity. Journal of Geotechnical Engineering, 118 (9), 1449-1469.

Harr, M.E., (1966). Foundation of Theoretical Soil Mechanics. McGraw-Hill. New York.

Hendron, A.J., (1963) The Behaviour of Sand in One Dimensional Compression, Ph.D.Thesis, University of Illinois.

Keskin, S.N., Tekinsoy, M.A. and Uzundurukan S., (2004) The Effects of over Consolidation Ratio and Effective Stresses to The Earth Pressure at Rest at Clay Soils, Digest 2004 947-961.

Keskin, M.S., Laman, M. and Baran T., (2008). Kuma Oturan Kare Temeller Altında Oluşan Düşey Gerilmelerin Deneysel Tespiti ve Sayısal Analizi İMO Teknik Dergi, pp. 4521-4538, No 299 (In Turkish).

Kjellman, W., (1936). Report on an Apparatus for the Determination of the Coefficient of Lateral Earth Pressure at Rest. Proc. 1st Int. Conf. on Soil Mech. And Fnd. Engrg., Harvard Printing Office, Cambridge, Mass., 2, 16-20.

Laman, M. and Keskin, M.S., (2004). Kumlu Zeminlerde Oturan Kare Temeller Altında Düşey Gerilme Analizi. Türkiye Mühendislik Haberleri, Sayı 431-2004/3, 53-57 (In Turkish).

Okumuşoğlu, B., (2006) Stress Distribution And Elasto Plastic Settlements Under Shallow Foundations, Master Thesis, Istanbul Technical University.

Sağlamer, A., (1972) Kohezyonsuz Zeminlerde Sükunetteki Toprak Basıncı Katsayısının Zemin Parametreleri Cinsinden İfadesi, İTÜ, Doktora Tezi, İstanbul, (In Turkish).

Scheidig and Kogler, (1926). Die Verteilung Senkrechter Drücke in Schüttungen, Dissertation, Freiberg.

Terzaghi, K., (1920). Old Earth Pressure Theories and New Test Results, Engrg. News-Rec., 85 (14), 632-637.