Civil and Environmental Research
ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online)
Vol.6, No.8, 2014

Settlement and Bearing Capacity of Foundations with Different Vertical Cross-sectional Shapes on Non-cohesive Soil Bases under Vertically Applied Load

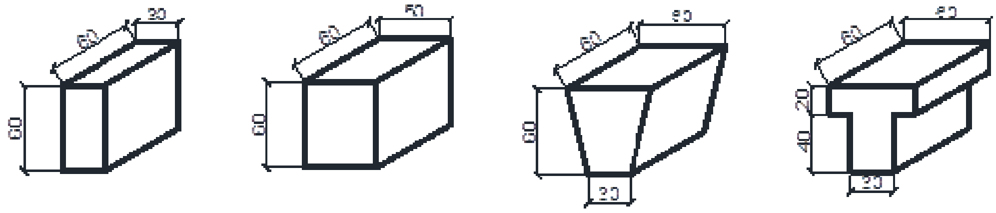
Musa Alhassan
Department of Geotechnics and Environmental Engineering, Belarusian National Technical University, Minsk, Belarus. alhassankuta@futminna.edu.ng

Abstract
Settlement and bearing capacity of foundation models with different vertical cross-sectional shapes on non-cohesive subsoil bases under the action of vertically applied load are presented. Models of foundations with rectangular, wedge and T vertical cross-sectional shapes were experimentally studied. The study generally showed foundations with rectangular vertical cross-sectional shapes having higher bearing capacity and less settlement as compared to those with wedge and T shapes, from which lower bearing capacity and higher settlement were recorded. Although, wedge and T shape foundations showed less bearing capacity, they have the potentials of actively mobilizing soil, both long their vertical trunks and beneath their bases in active resistance of structural loads.
Keywords: Bearing capacity; Foundation shape; Non-cohesive soil; Settlement; Subsoil base.

1. Introduction
Shape and dimension of foundations, their embedment depth, physico-mechanical properties of soils and load geometry, all affects settlement and bearing capacity of the soil bases. Foundations are generally classified into shallow and deep foundations. Those foundations that transmit structural loads to the soil strata at a relatively small depth are considered as shallow foundations. Terzaghi (1943) defines shallow foundation as that which is laid at a depth D_f not exceeding the width B of the foundation, that is $D_f/B \leq 1$. Subsequent studies conducted since then have shown that D_f/B can be as large as 3 to 4 for shallow foundations (Das, 1999; Das, 2010; Shakiba rad, *et al*, 2011).
Different types (shapes) of shallow foundations are known, with strip, square, rectangular and circular being the most commonly and widely used. These types of shallow foundations have different shapes that only vary from each other plan-wise or by horizontal cross-sections. Depending on their design thicknesses, the vertical cross-sectional shapes of these foundations are basically the same. This makes their mode of interaction with the soil bases trunk-wise basically the same. Load-settlement relationship is the common method, used in studying the interaction of foundations with soil bases. Many studies (Fellenius and Altaee, 1994; Briaud and Jeanjean, 1994; Montrasio and Nova, 1997; Zhu *et al*, 2001; Awad and El-Mezaini, 2001; Cerato and Lutenegger, 2007; Mahanta *et al*, 2008; Kumar, and Khatri, 2008; Jahanandish *et al*, 2010; Al-Khuzaei, 2011; Nareeman, 2012) have been conducted on the effect of foundation shape on settlement and bearing capacity of soils. These past studies mostly considered the shape of the foundations plan-wise. The interaction of these shapes of foundations with the soil bases is such that the soil above their bases contributes to the resistance of the structural loads mostly by surcharging the soil below the base of the foundation. Therefore the study of other shallow foundations' shapes, which can both partly distribute/resist structural loads vertically along their trunks and bases, is presented. V (wedge) and T shape foundations were considered along with the conventional rectangular shapes. The study presents pattern of load-settlement relationship of non-cohesive soil bases under foundations with these shapes and acted upon by vertical loads. It is commonly believed that settlement (deformation) criterion is more critical than the bearing capacity one in the designs of shallow foundations (Das, 2007), this study is therefore anchored on this fact. Generally the settlements of shallow foundations such as pad or strip footings are limited to 25 mm (Terzaghi, 1996). Recent studies on (especially small scale) shallow foundations have shown that allowable bearing capacity occur at settlement of between 5 to 10 % of foundation width. In line with the reasons advanced by Cerato and Lutenegger (2007), for this study, bearing capacity at settlement of 10 % of foundation width (i.e., s/B=0.1) was adopted as allowable.

2. Experimental Methodology
Four wooden models of shallow foundations were used for the study: the first model was a rectangular shape block (marked rectangular shape-1) with dimension of *30x60x60* mm for width, length and height respectively; the second was a rectangular shape block (marked rectangular shape-2) with dimension of *50x60x60* mm for width, length and height respectively; the third models was a wedge-shape block of 60 mm height with width and length for top and lower sides as *60x60* mm and *30x60* mm respectively; while the fourth was a T-shape block of 60 mm height with width and length for top and lower parts as *60x60* mm and *30x60* mm respectively (figure 1). The dimensions of the models were chosen so as to be within $D_f/B \leq 2$ (D_f and B are depth of

foundation embedment and width respectively). Using two types of non-cohesive (sandy) soils, three non-cohesive subsoil bases were modeled in the geotechnical laboratory of the Department of Geotechnics and Environmental Engineering of Belarusian National Technical University, Minsk, Belarus. The experimental stand used for the study was a rectangular container of dimension *1100x600x250 mm* for length, height and width respectively, with a transparent front side.



a *b* *c*
d

Note: *all dimensions in mm*

Figure 1: Foundation models: a & b- rectangular shapes; c- wedge-shape; d- T-shape

Two types of non-cohesive (sandy) soils were used in modeling the subsoil bases. The first and second soils used in the study, were classified according to Russian standard (ГОСТ 25100, 2011) as coarse and medium grain sands respectively. The subsoil bases were modeled by compaction of the soils at various moisture contents to predetermined densities. Figures 2-4 show the modeled subsoil conditions.

The experimental stand was filled with the soils in layers of 25 mm, with each layer compacted to its respective unit weight (density) and at its respective moisture contents. The foundation models were placed during placement and compaction of the last three upper layers as shown in figures 2-4. Using 1:10 loading lever, loads were vertically, centrally and uniaxially applied to the foundations models in an incremental manner, recording corresponding settlement for each load increment, using dial gauges of 1/100 mm division. Subsequent load increments were made when the rate of settlement from the previous applied loads becomes less than 0.02 mm/min.

The results are presented graphically as load-settlement curves for the respective foundations models on the respective modeled subsoil conditions in figures 5-7.

Soil type	depth (mm)	γ (kN/м³)	w (%)
Coarse grain sand	60	17	8
Coarse grain sand		18	8

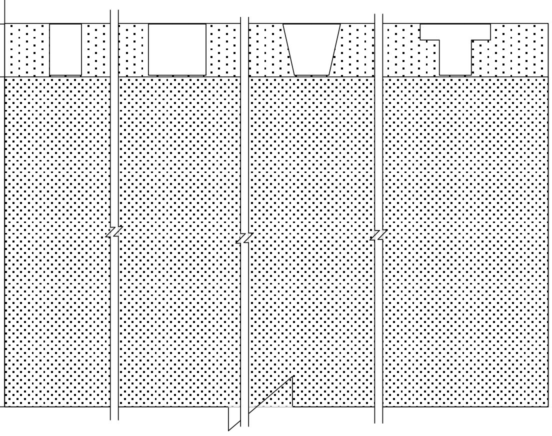


Figure 2: First modeled subsoil condition

Soil type	depth (mm)	γ (kN/м^3)	w (%)
Coarse grain sand	100	18	8
Medium grain sand	200	19	6
Coarse grain sand		18	8

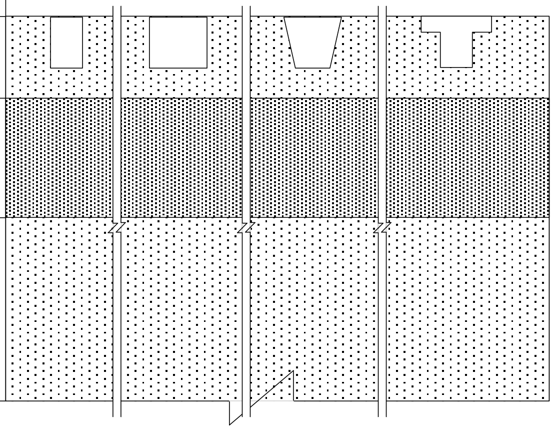


Figure 3: Second modeled subsoil condition

Soil type	depth (mm)	γ (kN/м^3)	w (%)
Medium grain sand	60	19	6
Coarse grain sand		18	8

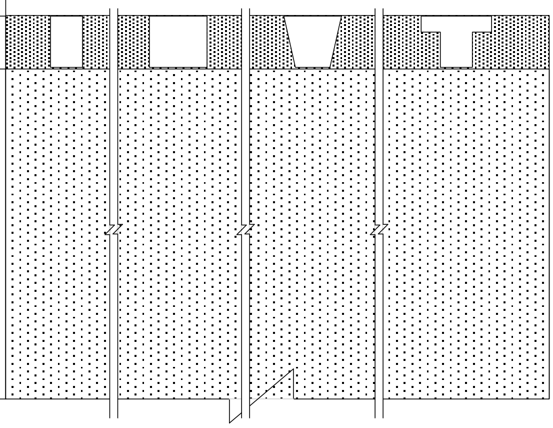


Figure 4: Third modeled subsoil condition

3. Results and Discussion

Results of the load-settlement relationship for the foundations models on the first, second and third modeled subsoil conditions are shown in figures 5, 6 and 7 respectively. From the figures, it is observed that the bearing capacities of rectangular shape foundations are generally higher than those of wedge and T shape foundations models. The highest bearing capacity was observed with rectangular shape-1. This can be attributed to its smaller width. The recorded results for rectangular shape 1 and 2 are similar to those obtained by Cerato and Lutenegger (2007), Al-Khuzaei (2011) and Nareeman (2012). The lower bearing capacity generally observed with wedge and T shape foundations can be attributed to the shape of their lower parts, which caused high settlement under the same load magnitudes, in comparison with rectangular shapes. The width of the lower parts of wedge and T shapes are smaller, compared to the width of their upper parts, resulting to more pressure on their lower parts as compared to those on the upper parts.

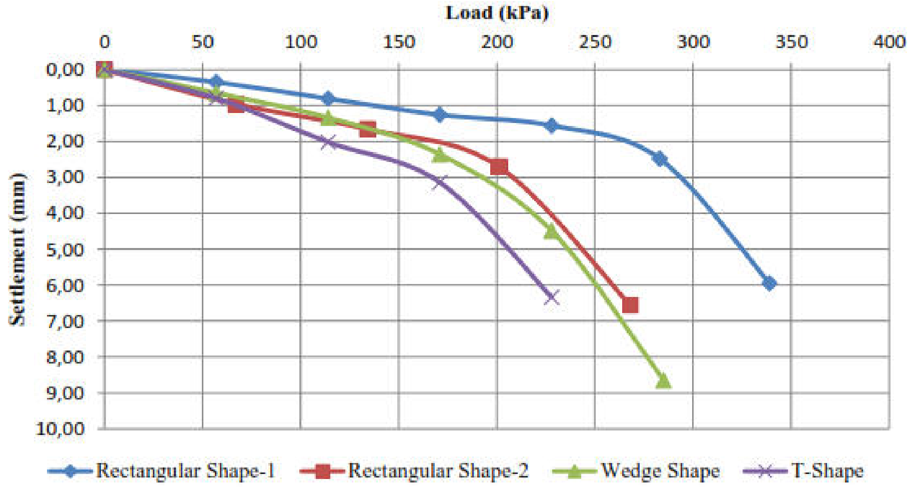


Figure 5: Load-settlement curves for foundation models on the first modeled subsoil condition

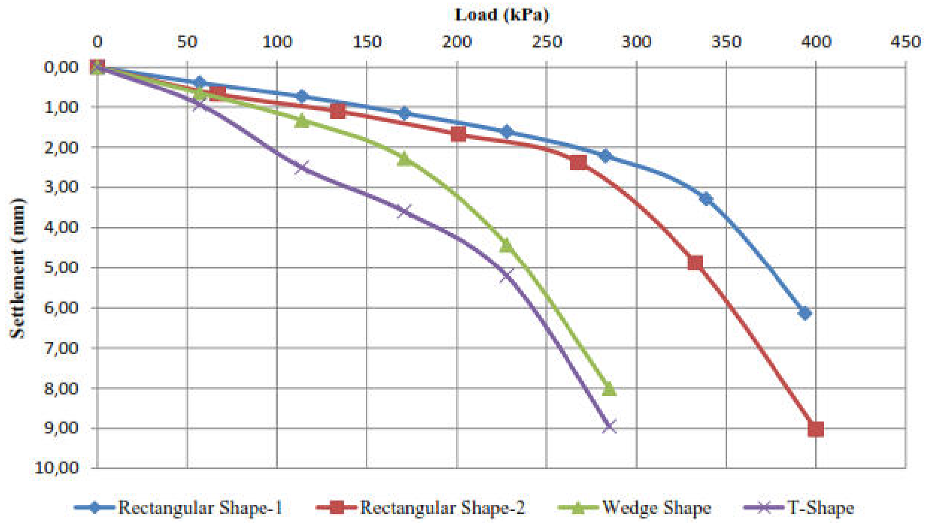


Figure 6: Load-settlement curves for foundation models on the second modeled subsoil condition

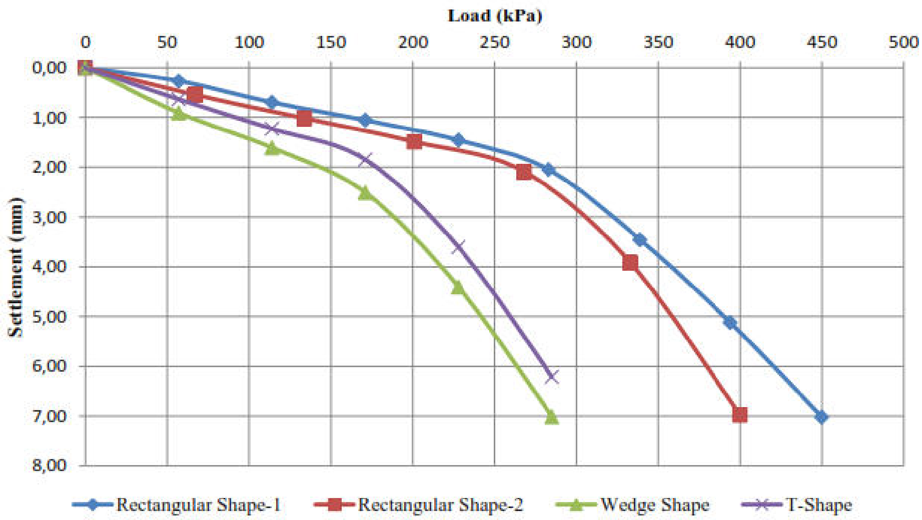


Figure 7: Load-settlement curves for foundation models on the third modeled subsoil condition

From the graphs (figures 5-7), it is possible to evaluate the effect of the shapes of the foundations models on the settlement and bearing capacity of the soils. Studies have shown that for shallow foundations on soils, the maximum settlement at which the bearing capacity is considered allowable can be taken as 10 % of foundation width (Briaud and Jeanjean, 1994; Cerato and Lutenegger, 2007; Jahanandish *et al*, 2010; Al-Mosawe *et al*, 2009; Budhu, 2012). Thus, the maximum permissible settlement of the studied foundation models was taken as 10 % of the width of the models, i.e. 3 mm, 5 mm, 6 mm, and 6 mm respectively for rectangular shape-1, rectangular shape-2, wedge shape and T-shape models. Therefore, from the graphs (figures 5, 6, 7), the allowable bearing capacity of each foundation models at the given settlements is presented in table 1.

Table 1: Allowable Bearing capacity of foundation models

Foundation type	Bearing capacity (kPa)		
	First modeled soil condition	Second modeled soil condition	Third modeled soil condition
Rectangular shape -1	295	330	323
Rectangular shape -2	260	351	386
Wedge-shape	250	255	265
T-shape	243	242	270

From table 1, it can be observed that on all the modeled subsoil conditions, the highest allowable bearing capacities were recorded with rectangular shape foundation models. The lowest allowable bearing capacity on the first and second soil conditions was recorded with T-shape foundation, while on the third modeled soil condition, the lowest allowable bearing capacity was recorded from wedge shape foundation model. The observed trend in the bearing capacity of T-shape foundation on third soil conditions can be attributed to location of the top part (flanges) of the foundation in a relatively denser soil as compare to the first and second soil conditions.

4. Conclusion

Settlement and bearing capacity of foundation models with different vertical cross-sectional shapes on non-cohesive subsoil bases under the action of vertically applied loads was studied. The study generally showed foundations with rectangular vertical cross-sectional shapes having higher bearing capacity and less settlement as compared to those with wedge and T vertical cross-sectional shapes, from which lower bearing capacity and higher settlement were recorded. Although, wedge and T-shape foundations showed lower bearing capacity, they have the potentials of actively mobilizing both soil long their vertical stems (trunks) and beneath their bases in the resistance of structural loads.

References

Al-Khuzaei, H. M. (2011), “Verification of Scale Effect of Shallow Foundation in Determination of Bearing Capacity of Sand”, *Al-Rafidain Engineering* **2**(2), 1-11.

Al-Mosawe, M. J. A., Albusoda, B. S. and Yaseen, A. S. (2009), “Bearing Capacity of Shallow Footing on Soft Clay Improved by Compacted Cement Dust”, Journal *of Engineering* **15**(4), 4417-4428.

Awad, M. A. and El-Mezaini, N. S. (2001), “Effect of Footings Interaction on Bearing Capacity and Settlement of Sandy Soil”, *Journal of the Islamic University of Gaza* **9**(1), pp. 43 - 55.

Briaud, J. L. and Jeanjean, P. (1994), “Load settlement Curve Method for Spread Footings on Sand”, *Journal of Geotechnical and Geoenvironmental Engineering, ASCE* **133**(8), 905-920.

Budhu, M. (2012), “Design of Shallow on Heavily Overconsolidated Clays”, *Canadian Geotechnical Journal-NRC Research Press* 184–196.

Cerato, A. B. and Lutenegger, A. J. (2007), “Scale Effects of Shallow Foundation Bearing Capacity on Granular Material”, *Journal of Geotechnical and Geoenvironmental Engineering, ASCE* **133**(10), 1192-1202.

Das, B. M. (1999). Shallow Foundations - Bearing Capacity and Settlement. *CRC Press LLC*, USA, 354 p.

Das, B. M. (2010). Principles of Foundation Engineering. 7th edition. *CL Engineering*, -816 p.

Das, B. M. and Sivakugan, N. (2007), “Settlements of Shallow Foundations on Granular Soil: An Overview”, *International Journal of Geotechnical Engineering*, J. Ross Publishing, Inc. **1**(1), 19–29.

Fellenius, B. H. and Altaee, A. (1994), “Stress and Settlement of Footings in Sand”, *Proceedings of the American Society of Civil Engineers, ASCE, Conference on Vertical and Horizontal Deformations for Foundations and Embankments, Geotechnical Special Publication, GSP, No. 40, College Station, TX, June 16 - 18*, vol. **2**, 1760 - 1773.

Jahanandish, M., Veiskarami, M. and Ghahramani, A. (2010), “Effect of Stress Level on the Bearing Capacity Factor, N_γ, by the ZEL Method”, *KSCE Journal of Civil Engineering* **14**(5), 709-723.

Kumar, J. and Khatri, V. N. (2008), “Effect of Footing Width on Bearing Capacity Factor, N_γ”, *Journal of Geotechnical and Environmental Engineering, ASCE* **134**(9), 1299-1310.

Mahanta. R., Prakasha, K. S., Deshpande, A. R. and Dholey, H. S. (2008), "Assessment of Bearing Capacity and Settlement of Irregular-Shaped Mat Supported Oil Drilling Rigs Using Finite Element Analysis", *Proceedings of the 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG),* Goa, India, 3127-3132.

Montrasio, L. and Nova, R. (1997), "Settlement of Shallow Foundation on Sand", *Geotechnique* 47(1), 49-60.

Nareeman, B. J. (2012), "A Study on the Scale Effect on Bearing Capacity and Settlement of Shallow Foundations", *International Journal of Engineering and Technology* **2**(3), 480-488.

Shakiba rad, S., Heshmati, A. A. and Salehzadeh, H. (2011), "Application of Adaptive Neuro-Fuzzy Inference System (ANFIS) to Predict the Ultimate Bearing Capacity of Shallow Foundation on Cohesionless Soil", *Electronic Journal of Geotechnical Engineering (EJGE)* **16** (Bund S), 1459-1469.

Terzaghi, K. (1943). Theoretical Soil Mechanics. *John Wiley & Sons*, New York, -510 p.

Terzaghi, K., Peck, R. B. and Mesri, G. (1996). Soil Mechanics in Engineering Practice. 3rd Edition, *John Wiley & Sons*, New York, 729 p.

Zhu, F., Clark, J. I. and Phillips, R. (2001), "Scale Effect of Strip and Circular Footings Resting on Dense Sand', *Journal of Geotechnical and Geoenvironmental Engineering, ASCE* **127**(7), 613-621.

ГОСТ 25100 (2011). Soil Classification. Interstate Scientific-Engineering Council on Standardization, Engineering Norms and Certification in Civil Engineering.

The IISTE is a pioneer in the Open-Access hosting service and academic event management. The aim of the firm is Accelerating Global Knowledge Sharing.

More information about the firm can be found on the homepage:
http://www.iiste.org

CALL FOR JOURNAL PAPERS

There are more than 30 peer-reviewed academic journals hosted under the hosting platform.

Prospective authors of journals can find the submission instruction on the following page: http://www.iiste.org/journals/ All the journals articles are available online to the readers all over the world without financial, legal, or technical barriers other than those inseparable from gaining access to the internet itself. Paper version of the journals is also available upon request of readers and authors.

MORE RESOURCES

Book publication information: http://www.iiste.org/book/

IISTE Knowledge Sharing Partners

EBSCO, Index Copernicus, Ulrich's Periodicals Directory, JournalTOCS, PKP Open Archives Harvester, Bielefeld Academic Search Engine, Elektronische Zeitschriftenbibliothek EZB, Open J-Gate, OCLC WorldCat, Universe Digtial Library , NewJour, Google Scholar