The Nucleus **57**, No. 2 (2020) 39-48

https://doi.org/10.71330/thenucleus.2020.620

www.thenucleuspak.org.pk

The Nucleus

ISSN 0029-5698 (Print)

ISSN 2306-6539 (Online)

Influence of Footing Shapes and GWT on Bearing Capacity and Settlement of Cohesive Soil Beneath Shallow Foundations

M. Khalid, A. Sardar and S.T.A. Jaffar*

School of Engineering, Department of Civil Engineering, University of Management and Technology, Lahore, Pakistan

ABSTRACT

Footing shapes and ground water table (GWT) greatly affect the bearing capacity and settlement of cohesive soil. A series of laboratory experiments and simulation techniques are performed to investigate the effect of footing shapes and GWT on bearing capacity and settlement in cohesive soils. Results showed that by increasing the depth of footing, bearing capacity of cohesive soil increases while settlement and stress influence zone decreases. In case of square footing when depth of footing is increased from 1m to 2.2m bearing capacity also increased from 26.45kPa to 27.90kPa; while settlement and stress influence zone decreased from 0.30mm to 0.20mm and 1.2m to 0.60m, respectively. In case of rectangular footing when depth of footing is increased from 1m to 2.2m bearing capacity increased from 26.25kPa to 27.60kPa; while settlement and stress influence zone decreased from 0.60mm to 0.49mm and 1.53m to 1.15m, respectively. On the basis of high stress influence zone, critical footings are further selected to study the effect of GWT. It is observed that GWT does not affect the bearing capacity when its level is below the footing bottom, while settlement keeps on decreasing with the depth. A Soil Structure Interaction (SSI) model is proposed by comparing different built-in Finite Element Method (FEM) based models in Geo-5 software. Among the studied SSI models, Modified Elastic Model and Modified Mohr Coulomb Model proved to be more realistic models in terms of settlement, shear stress and effective stress.

Keywords: *Bearing capacity, Ground water table, Cohesive soil, Foundation, Soil structure interaction model*

1. Introduction

Selection of foundation types and its design are the duties of geotechnical engineers to fulfill the criteria of safe bearing capacity and allowable settlement [1]. Bearing capacity of cohesive soils is of serious concern because cohesive soil entraps water in it due to its low hydraulic conductivity [2]. Ground water table (GWT) greatly influences the strength of the soil present beneath foundation which ultimately leads to reduction in bearing capacity of soil. The failure in bearing capacity can cause settlement in soil [3]. The bearing capacity of the soil is affected by different factors, such as eccentric loads, GWT, dimensions of footing and spacing between the footings [4, 5]. However, soil will be considered submerged if the GWT rises and approaches the foundation level [6]. Theoretically, this phenomenon is studied by Ausilio and Conte [7] and Vanapalli and Mohamed [8]. Papadopoulou and Gazetas [9] studied the shape effects on bearing capacity of footings on two layered clay using finite element analysis. According to some researchers, square and rectangular footings are opted to carry cyclic loadings [10] whereas strip footing is used for static loadings [11]. Samee [12] investigated the impact of different footing shapes on bearing capacity of layered soil subjected to vertical loading. Zhu et al. [13], studied the impact of strip footing on the bearing capacity of soil. The effect of square, rectangular and strip footing on the bearing capacity of the soil was studied by Lyamin et al. [14] and Biswas et al. [15].

After obtaining the results of soil parameters by laboratory experiments, a systematic investigation can be adopted for numerical evaluation such as the FEM [16]. Mohammed et al. [17] developed hybridized adaptive neuro fuzzy interference system model for settlement of shallow foundation. Behavior of foundations was studied by Hataf and Shafagat [18] using PLAXIS 3D.

The FEM under different soil conditions can proffer a precise simulation of soil failure pattern, but the results of soil does not creditably indicate outcomes from the field [19]. Various authors presented their studies depicting relation between footing shapes and GWT but very few are conducted to describe the correlation between stress influence zone, footing shapes and GWT. Whereas, stress influence zone plays a vital role in designing foundations and predicting safe levels of ground water.

The present study will fill this research gap by providing a mechanism to select the most efficient shape, depth and width of footing and level, where GWT does not affect the bearing capacity of cohesive soil on basis of stress influence zone. Square, rectangular and strip footings with various cross-sections are selected in this study to investigate the influence of footing shapes on bearing capacity, settlement and stress influence zone. On the basis of high stress influence zone, critical footings are further selected to investigate the effect of GWT on bearing capacity and settlement. A 2D soil structure interaction (SSI) model for settlement analysis is proposed by comparing different built-in FEM based models in Geo-5 [20, 21].

2. Methodology

2.1 Experimental Program

The disturbed soil samples were collected from the vicinity of School of Engineering Building (SEN-1), University of Management and Technology (UMT), Lahore, Pakistan. The soil testing was carried out at geotechnical engineering laboratory, UMT Lahore. Based on sieve analysis, hydrometer analysis and atterberg limits, soil was classified according to Unified Soil Classification

*Corresponding author: taseer.jaffar@umt.edu.pk

System (USCS). Classified soil was fine grained because more than 50% of soil passed through sieve #200. Further it was classified as Sandy Silt at 2.74m and Silty Clay with few percent concretion below 3m.

2.1.1 *Falling head test*

In order to determine hydraulic conductivity of soil sample, falling head test was performed as per ASTM D5084-03 specifications. The test was performed with permeability cell (model 38-T0185/1), which was connected to a manometer stand (model 38-T0185/2). Each test was performed on three samples to obtain the best suitable results. Coefficient of permeability was measured as per ASTM standard. Average hydraulic conductivity of the soil samples obtained was 6.035×10^{-8} m/sec. According to ASTM D5084-03 specifications [22], hydraulic conductivity for silty clay is between 1.0×10^{-6} m/sec to 5.0×10^{-10} m/sec which also verifies the soil classification made in the present study.

2.1.2 *Triaxial test*

Two soil samples were taken for the experiment. Triaxial test was performed as per ASTM D4767 specifications using Wykeham Farrance's electro-mechanical TRITECH 50kN under Unconsolidated Undrained (UU) conditions [23]. Normal and Shear stress were calculated as per ASTM standard. Fig. 1(a) shows the specimens were failed at deviator stress equals to 45kPa and 60kPa, respectively. Sum of deviator stress and cell pressure equals to major principal stress. Cell pressure equals to minor principal stress only. Increase in deviator stress leads to increase in major principal stress which ultimately leads to specimen failure. When the shear stress along the weakest plane exceeds its shear strength, the specimen fails. Mohr circle was plotted using major and minor principal stress. Tangent to both circles and its intercept to y-axis gives cohesion of the soil. Cohesion exists in cohesive soils only. Cohesion ($C_{u)}$ of the sample obtained was 5.9kPa. Angle of internal friction is the angle measured between normal and resultant force when failure just occurs in response to shearing stress. It is basically the measure of shear strength of soil to withstand a shear stress. Angle of internal friction (ø) obtained was 29°. Calculated shear strength of the soil was 5.9kPa. The graphical representation of applied load, strain produced and Mohr-circle of soil sample are shown in Fig. 1(b).

2.2 *Data Analysis*

2.2.1 *Simulation using Geo-5*

Data analysis was performed using Geo-5 software [20, 21]. It allows its user to select different types of shallow and deep foundations for analysis. Geo-5 enables its user to study the effect of GWT on the bearing capacity and settlement of particular shallow or deep foundation.

Following are the models that can be opted in Geo-5 software for investigation purposes:

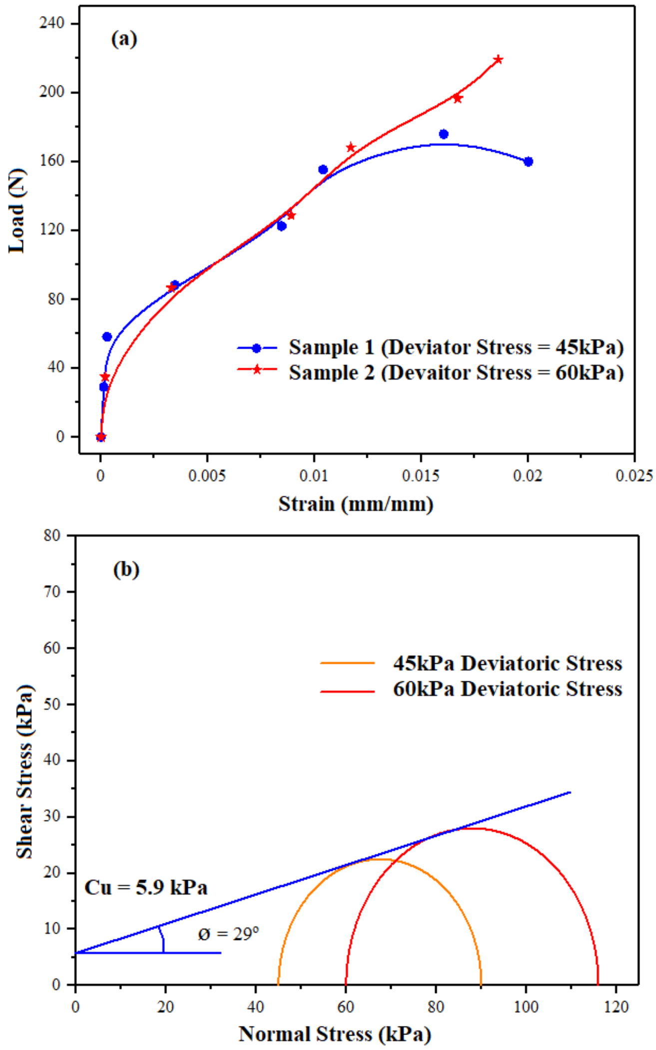

Fig. 1: Triaxial test results (a) Load vs Strain behavior of the collected samples (b) Mohr-circle for cohesion and angle of internal friction of collected samples.

1. Linear Models: It is very quick but least accurate method of investigation of true material response. It does not provide possible mechanisms and location of failure. The linear models include:

a. Elastic Model (EM): This model is based on Hooke's law which provides a linear variation of displacements as a function of applied loads.

b. Modified Elastic Model (MEM): Linear behavior of soil is acceptable only for low magnitude of loads applied. It may be noted when the soil is unloaded it only experiences small amount of elastic deformation rather than overall deformation. To accommodate this phenomenon modified elastic model considers different modulus of loading and unloading.

2. Non-Linear Models: Application of non-linear models allows to investigate the specific non-linear response of soils.

a. Mohr-Coulomb Model (MCM): This model has many drawbacks because it is based on traditional soil and rock mechanics.

b. Modified Mohr Coulomb Model (MMCM): A slightly stiffer response of the material can be expected with the MMCM when compared to MCM and DPM models. This model requires inputting the following parameters: modulus of elasticity, poisons ratio, angle of internal friction and cohesion.

c. Drucker Prager Model (DPM): DPM is also known as Von-Mises model. It modifies the MMCM yield functions to avoid stiffer response. DPM yield surface is smooth and it plots as a cylindrical cone in the principal stress space.

d. Hypoplastic Model: This model investigates the non-linear response of soil both in loading and unloading. As compared to other models, it only allows to calculate the total strains. Hence, it shows no distinction between elastic and plastic strains.

2.2.2 Dimensions and parameters of modelling

All the imported parameters of soil were obtained from the experimental results. Same field conditions were applied in the software to study the simulated results. To make the calculations more precise, model dimensions were selected at 16m depth and 30m width [5]. Undrained condition was used because cohesive soil was under analysis. After creation of the model, 2 soil layers were specified and each layer was given its own properties [Unit weight (γ), Poisson's ratio (v), Porosity (n), Elastic modulus (E_s), Deformation modulus (E_{def}), Cohesion (C_u), Angle of internal friction (ø), Saturated unit weight (γ_{sat})] determined through experimentation and theoretical equations. 1st layer was sandy silt having 2m depth and the 2nd layer was silty clay of 14m depth. Layout of model is shown in Fig. 2.

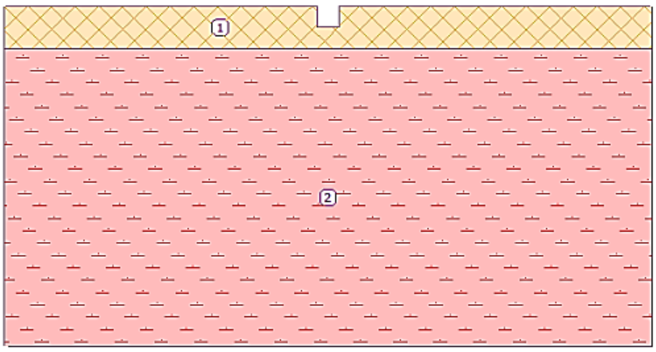

Fig. 2: Soil model layers made in Geo-5 software.

3. Methodology of Analysis

100kN/m^2 of Load was applied to maintain symmetry of analysis. American Concrete Institute (ACI 318-89 Method) design manual was used for footing concrete mix. Elastic modulus used for concrete was 23GPa and concrete strength at 28 days was 25MPa (M25 concrete mix having proportions of aggregates as 1:1:2). In modeling of aforementioned footing shapes, depths of footing (d_f) were selected as 1m, 1.60m, 2.20m and widths of footing (b_f) were selected as 1m, 1.60m, 2.2m respectively. When GWT is considered, safe bearing capacity of foundation is reduced [25]. Analysis was performed in three phases. To improve the research outputs, effect of GWT was not considered in the 1st phase of analysis. The analysis was performed by keeping the footing depth fixed while width of the footing was kept varying. Afterwards, the same analysis was performed by keeping the width of footing fixed while depth was varying.

In the 2nd phase, critical footings were selected on the basis of high stress influence zone and the effect of GWT was investigated. GWT was fluctuated between different depths to analyze its effect on the bearing capacity and settlement. For GWT levels, equation (1) was used [7].

$$d_w / b = 0.5 \tag{1}$$

where, d_w is the level of water table below the footing and b is the width of footing.

In the 3rd phase, linear model (MEM) and non-linear models (MMCM and DPM) were compared and analyzed to identify the most suitable models in terms of stiffness as settlement and shear stress. Considering linear behavior of soil, MEM was used which is acceptable only for low magnitudes of loads. In linear behavior of soil, it experiences small amount of elastic deformation rather than overall deformation. While, considering non-linear models it allows us to investigate non-linear response of soils. Both the linear and non-linear models were used under same loading conditions to study the simulated results. These results were derived in terms of FEM models. The denser region in FEM models represents high settlement, shear stress and effective stress regions or total stress. Selection of boundary conditions, mesh size and refinement affect the FEM solutions [25, 26]. Therefore, fixed boundary conditions were assigned at bottom of soil model, vertical boundaries were restrained from horizontal movement and only vertical directions were set free [27, 28]. Medium size mesh was used for FEM solution [29].

4. Results and Discussion

4.1 Influence of Footing Shapes on Bearing Capacity, Settlement and Stress Influence Zone

Analysis of square footing having depth fixed while varying width is shown in Fig. 3. Fig. 3(a) shows the footing depth was kept 1 m while various footing widths were taken for the analysis. The highest bearing capacity obtained using simulation was 26.45kPa and minimum settlement and stress influence zone obtained was 0.3mm and 1.2m at footing width equals to 2.6m. Fig. 3(b) shows the footing depth equals to 1.6m. The highest bearing capacity obtained using simulation was 27.35kPa and minimum settlement and stress influence zone obtained was 0.29mm and 0.9m at footing width equals to 2.6m. Fig. 3(c) shows the footing depth equals to 2.2m. The highest bearing capacity obtained using simulation was 27.90kPa and minimum settlement and stress influence zone obtained was 0.20mm and 0.60m at footing width equals to 2.6m.

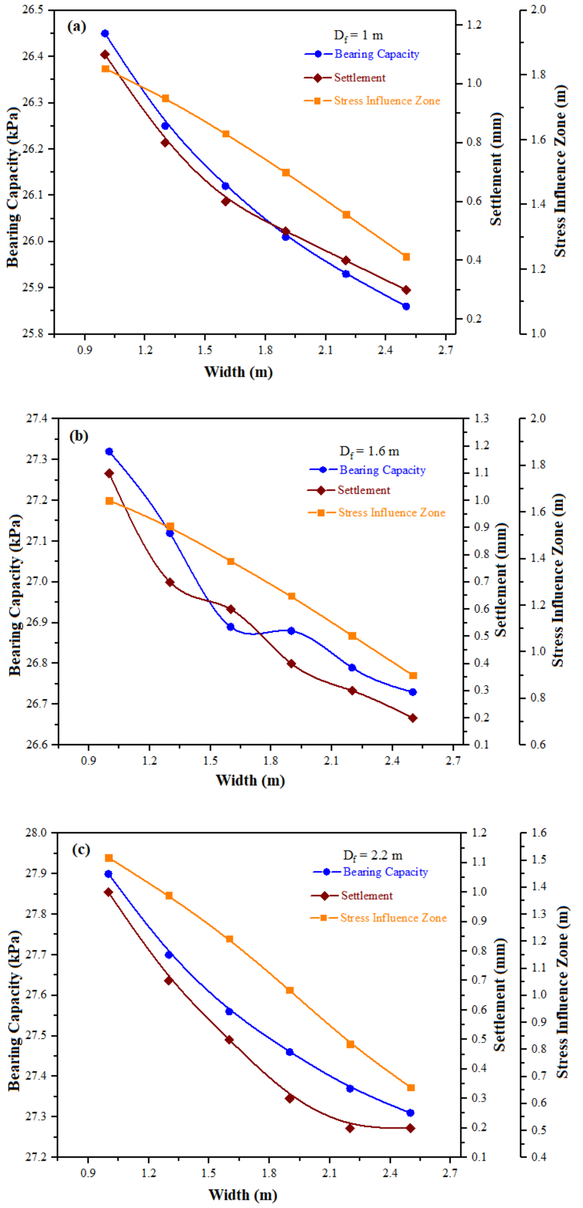

Fig. 3: Effect of square footing on bearing capacity, settlement and stress influence zone keeping depth fixed and varying width (a) d_f = 1m (b) d_f = 1.6m (c) d_f = 2.2m.

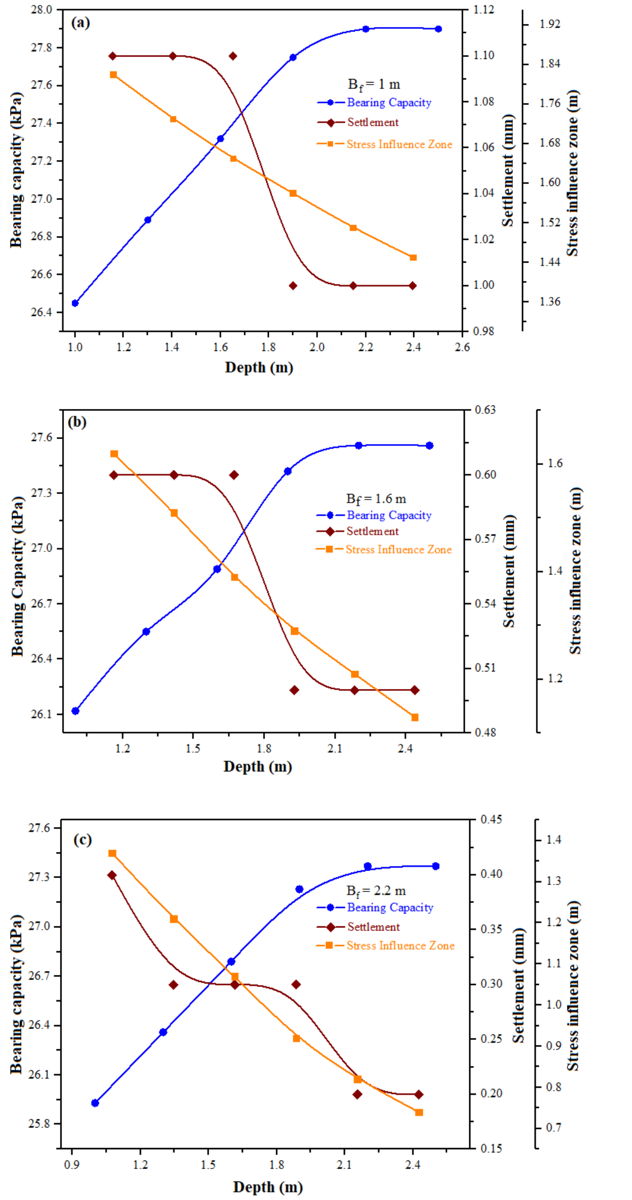

Fig. 4: Effect of square footing on bearing capacity, settlement and stress influence zone keeping width fixed and varying depth (a) b_f = 1m (b) b_f = 1.6m (c) b_f = 2.2m.

Analysis of square footing having width fixed and varying depth is shown in Fig. 4. Fig. 4(a) shows the footing width was kept 1m while various footing depths were taken for the analysis. The highest bearing capacity obtained using simulation was 27.8kPa and minimum settlement and stress influence zone obtained was 1mm and 1.44m at footing depth equals to 2.6m. Fig. 4(b) shows the footing width equals to 1.6m. The highest bearing capacity obtained using simulation was 27.60kPa and minimum settlement and stress influence zone obtained was 0.50mm and 1.1m at footing depth equals to 2.6m. Fig. 4(c) shows the footing width equals to 2.2m. The highest bearing capacity obtained using simulation was 27.30kPa and minimum settlement and stress influence zone obtained was 0.20mm and 0.70m at footing depth equals to 2.6m.

Analysis of rectangular footing having depth fixed while varying width is shown in Fig. 5. Fig. 5(a) shows the footing depth was kept 1m while various footing widths were taken for the analysis. The highest bearing capacity obtained using simulation was 26.25kPa and minimum settlement and stress influence zone obtained was 0.60mm and 1.53m at footing width equals to 2.6m. Fig. 5(b) shows the footing depth equals to 1.6m. The highest bearing capacity obtained using simulation was 27.20kPa and minimum settlement and stress influence zone obtained was 0.50mm and 1.30m at footing width equals to 2.6m. Fig. 5(c) shows the footing depth equals to 2.2m. The highest bearing capacity obtained using simulation was 27.60kPa and minimum settlement and stress influence zone obtained was 0.49mm and 1.15m at footing width equals to 2.6m.

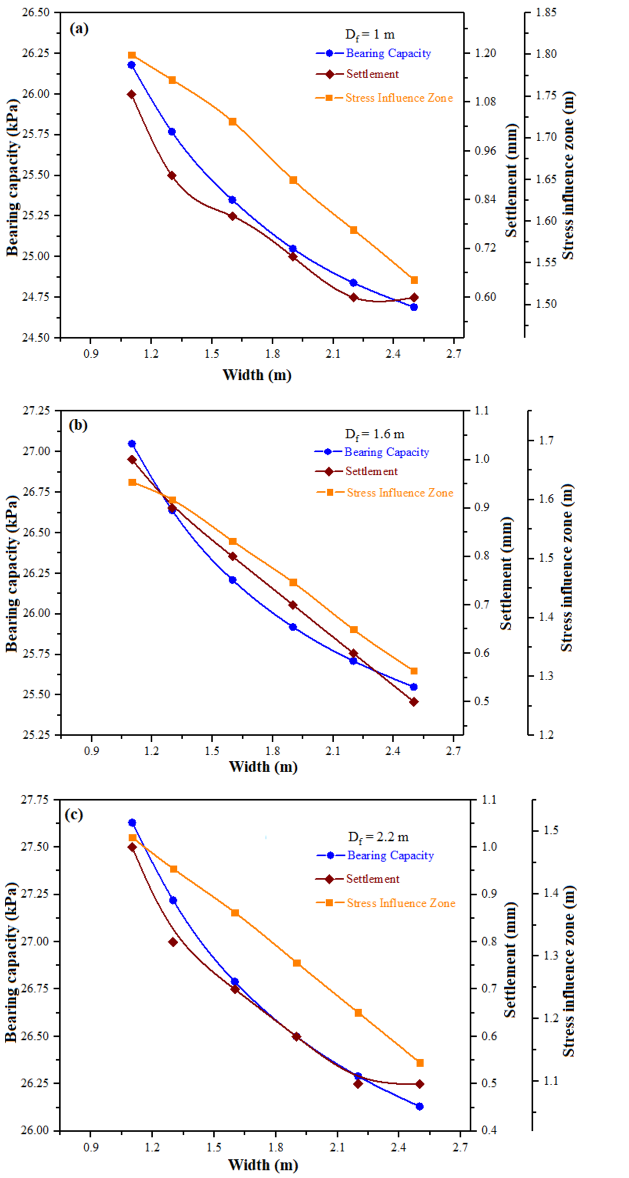

Fig. 5: Effect of rectangular footing on bearing capacity, settlement and stress influence zone keeping depth fixed and varying width (a) d_f = 1m (b) d_f = 1.6m (c) d_f = 2.2m.

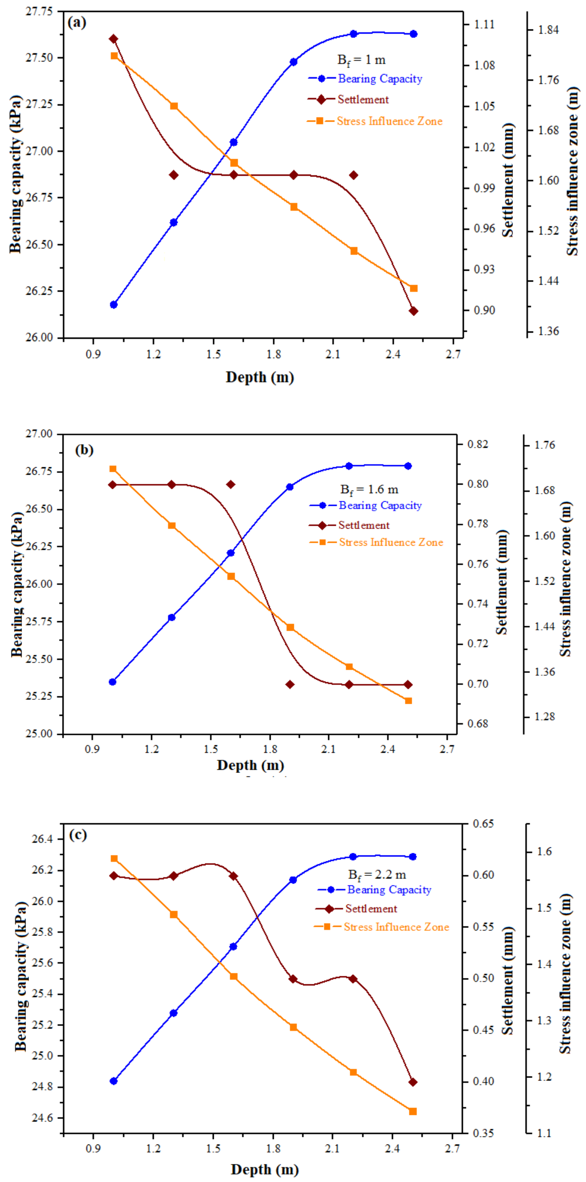

Fig. 6: Effect of rectangular footing on bearing capacity, settlement and stress influence zone keeping width fixed and varying depth (a) b_f = 1m (b) b_f = 1.6m (c) b_f = 2.2m.

Analysis of rectangular footing having width fixed and varying depth is shown in Fig. 6. Fig. 6(a) shows the footing width was kept 1m while various footing depths were taken for the analysis. The highest bearing capacity obtained using simulation was 27.70kPa and minimum settlement and stress influence zone obtained was 0.90mm and 1.44m at footing depth equals to 2.6m. Fig. 6(b) shows the footing width equals to 1.6m. The highest bearing capacity obtained using simulation was 26.75kPa and minimum settlement and stress influence zone obtained was 0.70mm and 1.32m at footing depth equals to 2.6m. Fig. 6(c) shows the footing width equals to 2.2m. The highest bearing capacity obtained using simulation was 26.30kPa and minimum settlement and stress influence zone obtained was 0.40mm and 1.15m at footing depth equals to 2.6m.

Analysis of strip footing having depth fixed while varying width is shown in Fig. 7. Fig. 7(a) shows the footing depth was kept 1m while various footing widths were taken for the analysis. The highest bearing capacity obtained using simulation was 23.65kPa and minimum settlement and stress influence zone obtained was 1.69mm and 3.66m at footing width equals to 2.6m. Fig. 7(b) shows the footing depth equals to 1.6m. The highest bearing capacity obtained using simulation was 24.52kPa and minimum settlement and stress influence zone obtained was 1.59mm and 3.30m at footing width equals to 2.6m. Fig. 7(c) shows the footing depth equals to 2.2m. The highest bearing capacity obtained using simulation was 25.10kPa and minimum settlement and stress influence zone obtained was 1.35mm and 2.97m at footing width equals to 2.6m.

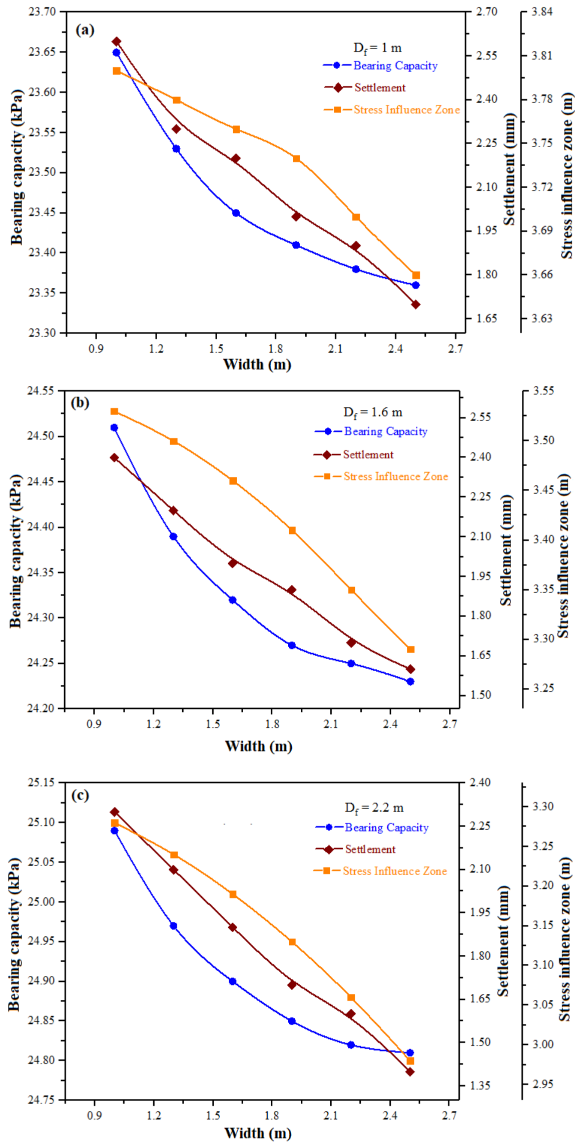

Fig. 7: Effect of strip footing on bearing capacity, settlement and stress influence zone keeping depth fixed and varying width (a) d_f = 1m (b) d_f = 1.6m (c) d_f = 2.2m

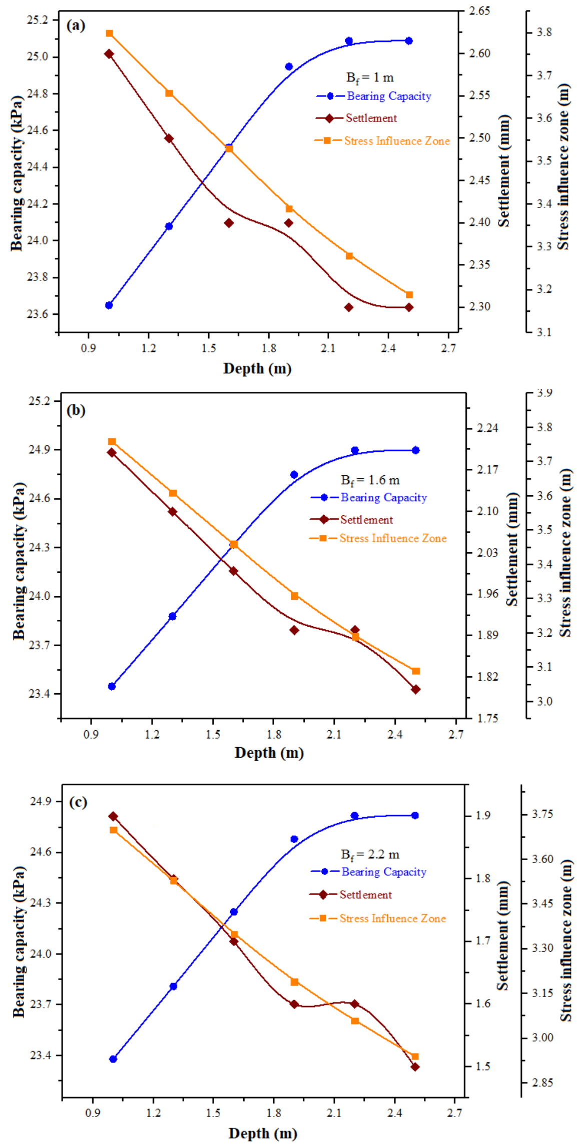

Fig. 8: Effect of strip footing on bearing capacity, settlement and stress influence zone keeping width fixed and varying depth (a) b_f = 1m (b) b_f = 1.6m (c) b_f = 2.2m.

Analysis of strip footing having width fixed and varying depth is shown in Fig. 8. Fig. 8(a) shows the footing width was kept 1m while various footing depths were taken for the analysis. The highest bearing capacity obtained using simulation was 25.1kPa and minimum settlement and stress influence zone obtained was 2.30mm and 3.15m at footing depth equals to 2.6m. Fig. 8(b) shows the footing width equals to 1.6m. The highest bearing capacity obtained using simulation was 24.9kPa and minimum settlement and stress influence zone obtained was 1.78mm and 3.09m at footing depth equals to 2.6m. Fig. 8(c) shows the footing width equals to 2.2m. The highest bearing capacity obtained using simulation was 24.7kPa and minimum settlement and stress influence zone obtained was 1.50mm and 2.90m at footing depth equals to 2.6m.

4.2 *Influence of GWT on Bearing Capacity of Cohesive Soil Beneath Shallow Foundation*

Analysis of GWT on bearing capacity and settlement in case of square, rectangular and strip footing is shown in Fig. 9. Fig. 9(a) shows the effect of GWT on square footing. When GWT is at level 0m i.e. exactly below the footing bottom, the bearing capacity and settlement obtained was 22.25kPa and 1.2mm while bearing capacity increases to 26.5kPa and settlement decreases to 0.7mm when GWT lowered from 0m to 3m. Fig. 9(b) shows the effect of GWT on rectangular footing. When GWT is at level 0m i.e. exactly below the footing bottom, the bearing capacity and settlement obtained was 21kPa and 1.5mm while bearing capacity increases to 26kPa and settlement decreases to 0.45mm when GWT lowered from 0m to 3m. Fig. 9(c) shows the effect of GWT on strip footing. When GWT is at level 0m i.e. exactly below the footing bottom, the bearing

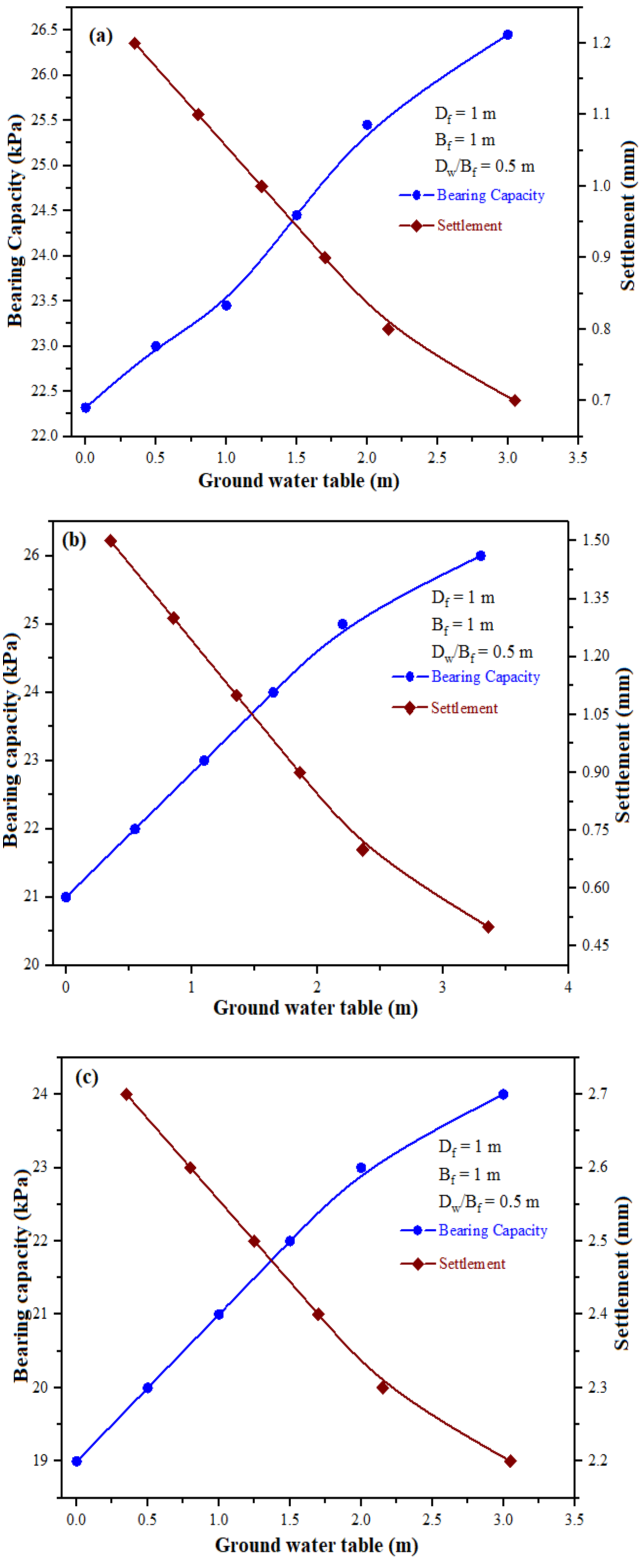

Fig. 9: Effect of GWT on bearing capacity and settlement (a) Square footing (b) Rectangular footing (c) Strip footing.

capacity and settlement obtained was 19kPa and 2.7mm while bearing capacity increases to 24kPa and settlement decreases to 2.2mm when GWT fluctuates from 0m to 3m.

4.3 FEM Models for Settlement, Shear Stress and Effective Stress (with GWT) and Total Stress (without GWT) Beneath Shallow Foundations

This phase of analysis was further divided into two phases. In the 1st phase of analysis considering the effect of GWT**,** it was observed that DPM slightly overestimated the settlement as compared to MEM and MMCM. While, MMCM overestimated the shear stress as compared to MEM and DPM. Whereas, all of the three models showed almost the same results for effective stress. The maximum settlement, shear stress and effective stress obtained using MEM was 6.4mm, 14.36kPa and 229.52kPa beneath the footing. The effect of the applied loading or stress influence zone reached the depth of 12m from the ground surface. The maximum settlement, shear stress and effective stress obtained using DPM was 13mm, 15.26kPa and 228.98kPa beneath the footing. The effect of the applied loading or stress influence zone reached the depth of 10m from the ground surface. The maximum settlement, shear stress and effective stress obtained using MMCM was 9.5mm, 14.71kPa and 229.36kPa beneath the footing. The effect of the applied loading or stress influence zone reached the depth of 11.5m from the ground surface. Fig. 10 shows the FEM models studied in Geo-5. Fig. 10(a) shows the settlement model, Fig. 10(b) shows the shear stress model and Fig. 10(c) shows the effective stress model.

In the 2nd phase of analysis i.e. without considering the effect of GWT it was again observed that DPM slightly overestimated the settlement as compared to MEM and MMCM. While, MMCM overestimated the shear stress as compared to MEM and DPM. Whereas, all of the three models showed almost the same results for total stress.

It is evident from the results that increase in footing depth results in increase of bearing capacity, decrease of settlement and stress influence zone. The hard-underlying strata at greater depth is the major factor for high bearing capacity [24]. With the increasing depth, soil particles become highly densified which makes the soil less porous [30]. Decrease in porosity also decreased the settlement which consequently decreased the stress influence zone.

The highest stress influence factor represented the lowest bearing capacity in square, rectangular and strip footing [5]. Similarly increase in footing width also increased the bearing capacity of cohesive soil but it was less as compared to bearing capacity achieved at higher depth. When footing width was increased, it distributed the load over the larger area beneath foundation but it does not transmit the load to the hard-underlying strata. Increased distributed load beneath foundation resulted in low settlement because a large number of soil particles took the load. Stress influence zone also decreased by increasing the width of footing which was in accordance with Moravej et al. [5] and Taiebat and Carter [31]. Simultaneous increase in footing depth and width resulted in the increased bearing capacity, decreased settlement and stress influence zone. In this case footing

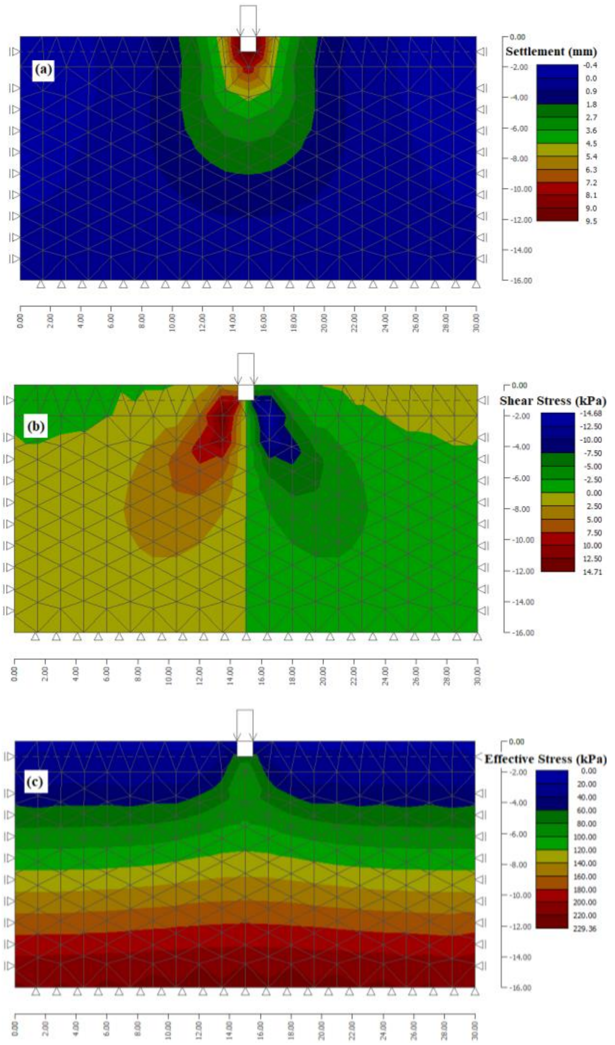

Fig. 10: FEM based models with GWT effect (a) Settlement model (b) Shear stress model (c) Effective stress model.

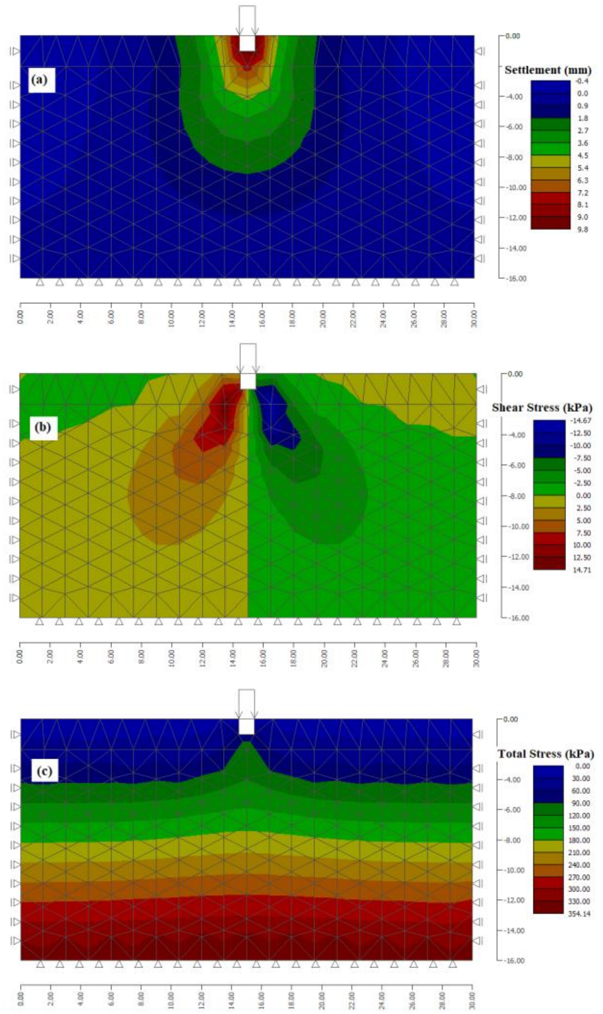

Fig. 11: FEM based models without GWT effect (a) Settlement model (b) Shear stress model (c) Total stress model.

transferred its load both to the hard-underlying strata and over the large area beneath foundation. Moreover, results also showed that bearing capacity of square footing was high with low settlement and stress influence zone as compared to strip and rectangular footings. This phenomenon can be attributed towards the load transfer mechanism of square footing in which load spreads over the larger area which resulted in low settlement.

GWT significantly reduced the bearing capacity and increased the settlement of shallow foundation. Under the application of load, pore water pressure of saturated soil decreases. This phenomenon led to increased settlement which resulted in high stress influence zone. Consequently, high stress influence zone led to low bearing capacity [5]. However, when GWT was present above the footing base, it significantly reduced the bearing capacity of shallow foundation. Whereas, it did not cause any significant change in the bearing capacity of shallow foundation when GWT was at higher depth below the footing base. GWT reduces the saturated unit weight term in Terzaghi equation, i.e., γ_{sat} which reduced the bearing capacity of soil [7]. Maximum bearing capacity of square footing, rectangular footing, strip footing was 26.45kPa, 26.25kPa and 24kPa respectively and bearing capacity showed increasing trend which indicated that GWT did not reduce the bearing capacity when it reached the depth greater than foundation width. While settlement decreased for all three footings when GWT is lowered.

Considering FEM models, it is worth discussing that soil present below the footing was in direct contact with the load which resulted in high settlement in this region while settlement decreased downwards. The negative shear stress indicated the soil was in tension while positive shear stress indicated the soil was in compression. Considering the effect of GWT, highest tensile stress in the soil indicated high effective stress and settlement. DPM slightly over-estimated the shear stress as compared to MEM and MMCM. It is because that DPM yield surface is smooth but it plots as a cylindrical cone in the principle stress region. Without considering GWT, it was evident that increase in shear stress also increased the total stress and vice versa. Increased shear stress indicated the increased settlement. Specifically, in MEM it was observed that with the little increase in shear stress, settlement increased significantly because it only considers the linear behavior of soil.

5. Conclusions

A parametric assessment was performed to study the effect of footing shape and GWT on the bearing capacity of shallow foundation and different built-in SSI models were compared to identify the most efficient model in terms of settlement. Following are the main conclusions of this study:

1. In all the cases investigated in this study, bearing capacity of square footing is higher as compared to rectangular and strip footing. The bearing capacity of square footing is 26.45kPa at d_f = 1m, 27.35kPa at d_f = 1.6m and 27.90kPa at d_f = 2.2m. In case of rectangular footing bearing capacity is 26.25kPa at d_f = 1m, 27.20kPa at d_f = 1.6m and 27.60kPa at d_f = 2.2m. In case of strip footing bearing capacity is 23.65kPa at d_f = 1m, 24.52kPa at d_f = 1.6m and 25.10kPa at d_f = 2.2m.
2. Stress influence zone decreased by increasing the depth of footing. When depth of square, rectangular and strip footing increased from 1m to 2.2m respectively, stress influence zone decreased from 1.2m to 0.60m, 1.53m to 1.15m and 3.66m to 2.90m.
3. When GWT is above the footing bottom, it significantly affects the bearing capacity and settlement of cohesive soil. When GWT is below the footing bottom, it does not affect bearing capacity while settlement keeps on decreasing. Considering the effect of GWT on square footing, bearing capacity and settlement increased from 22.25kPa and 1.2mm to 26.25kPa and 0.7mm when GWT lowered from 0m to 3m below the footing. In case of rectangular footing bearing capacity and settlement increased from 21kPa and 1.50mm to 26kPa and 0.45mm. While in strip footing bearing capacity and settlement increased from 19kPa and 2.7mm to 24kPa and 2.2mm.
4. Strip footing is more vulnerable to GWT whereas square and rectangular footings are least affected by GWT. This can be attributed towards stress distribution phenomena of strip footing. Strip footing has larger stress distribution coefficient. The value of stress distribution factor for strip footing is 0.35 at the edge and 0.50 at center while square and rectangular footing has 0.22 and 0.27 at edge and 0.33 and 0.40 at center.
5. Among the studied soil structure interaction (SSI) models, Modified Elastic Model (MEM) and Modified Mohr Coulomb Model (MMCM) proved to be more realistic than Drucker Prager Model (DPM) in terms of settlement only. DPM slightly over estimated the settlement as compared to MEM and MMCM. The settlement obtained exactly beneath the footing using MEM, MMCM and DPM are 6.4mm, 9.5mm and 13mm. While considering the shear stress and effective stress, all of the models gives almost same results. The shear and effective stress exactly beneath the footing using MEM, MMCM and DPM are 14.36kPa, 14.71kPa and 15.26kPa and 229.52kPa, 229.36kPa and 228.98kPa.

Acknowledgement

The authors are thankful to University of Management and Technology for allowing to carry the experimental work in geotechnical engineering laboratory.

References

[1] B.M. Das and K. Sobhan, ‘‘Principles of geotechnical engineering’’, Cengage Learning, Stamford, USA, pp. 448, 2013.

[2] B.M. Das, ‘‘Principles of geotechnical engineering’’, Cengage Learning, Stamford, USA, pp. 704, 2010.

[3] H. Shahir and A. Pak, ‘‘Estimating liquefaction-induced settlement of shallow foundations by numerical approach’’, Comput. Geotech, vol. 37, no.1, pp. 267-279, 2010.

[4] A. Asakereh and A. Akbari, ‘‘Effect of groundwater and various parameters on bearing capacity of shallow foundations using finite element method’’, IRJET, vol. 2, no. 5, pp. 39-43, 2015.

[5] S. Moravej, H. Khabbaz and A. Shafaghat, ‘‘Effect of footing shape on bearing capacity and settlement of closely spaced footings on sandy soil’’ IJGGE, vol. 12, no.11, pp. 661-665, 2018.

[6] P.B. Pande, S.P. Bajad and S.R. Khandeshwar, ‘‘The effect of degree of saturation on the bearing capacity of shallow foundation’’, IJIRSET, vol. 3, no.7, pp. 14569-14577, 2014.

[7] E. Ausilio and E. Conte, ‘‘Influence of groundwater on the bearing capacity of shallow foundations’’, CGJ, vol. 42, no.2, pp. 663-672, 2005.

[8] S.K. Vanapalli and F.M.O. Mohamed, ‘‘Bearing capacity and settlement of footings in unsaturated sands’’, Int. J. Geomate, vol. 5, no.1, pp. 595-604, 2013.

[9] K. Papadopoulou and G. Gazetas, “Shape Effects on Bearing Capacity on Two Layered Clay”, Geotech. Geol. Eng., vol. 38, pp. 1347-1370, 2020.

[10] U.B. Choubey, D. Goswami and A. Karma, ‘‘Experimental study of various shaped isolated footings under monotonic and incremental cyclic loading on sandy soil’’, IJIRSET, vol. 1, no. 7, pp. 229-235, 2014.

[11] E. Allen and W. Zalewski, ‘‘Form and forces: Designing efficient, expressive structures’’, John wiley and sons, New Jersey, USA, 2009.

[12] A.E. Samme, ‘‘Effect of footings shape on bearing capacity factors for cohesion-less soil’’, AJBAS, vol. 9, no.7, pp. 764-772, 2015.

[13] F. Zhu, J.I. Clark and R. Phillips, ‘‘Scale effect of strip and circular footings resting on dense sand’’, JGGE, vol. 127, no. 7, pp. 613-621, 2001.

[14] A.V. Lyamin, R. Salgado, S.W. Sloan and M. Preezi, ‘‘Two and three-dimensional bearing capacity of footings in sand’’, Geotechnique, vol. 57, no. 8, pp. 647-662, 2007.

[15] A. Biswas, A.M. Karishna and S.K. Dash, ‘‘Influence of subgrade strength on the performance of geocell-reinforced foundation systems’’, Geosynth. Int., vol. 20, no. 6, pp. 376-388, 2013.

[16] H. Yongqing, ‘‘Settlement of shallow foundation on cohesionless soil considering modulus of degradation of soil’’, PhD thesis, School of Civil and Environmental Engineering, Nanyang Technological University, 2011.

[17] M. Mohammed, A. Sharafati, N. Al Ansari and Z.M. Yaseen, “Shallow foundation settlement quantification: Application of hybridized adaptive neuro fuzzy interference system model”, Adv. Civ. Eng., vol. 2020, pp. 14, 2020.

[18] N. Hataf and A. Shafaghat, ‘‘Numerical comparison of bearing capacity of tapered pile groups using 3D FEM’’, Geomech. Geoengin., vol. 9, no. 5, pp. 547-567, 2015.

[19] A. Parvizi and K. Abrinia, ‘‘A two-dimensional upper bound analysis of the ring rolling process with experimental and FEM verification’’, Int. J. Mech. Sci., vol. 79, no. 1, pp. 176-181, 2014.

[20] J. Pruska, "Comparison of geotechnic software-Geo FEM, Plaxis, Z-soil", CTU in Prague Department of Geotechnics, vol. 2, pp. 819-824, 2009.

[21] M.M. Sazzad, R. Faysal and M.A.A. Mamun, "Effects of water level variation on the stability of slope by LEM and FEM", Proc. of the 3rd Int. Conf. on Civil Engineering for Sustainable Development, February 12-14, 2016, Khulna, Bangladesh, pp. 953-959, 2016.

[22] American Society for Testing and Materials, ASTM: D5084-03, "Standard test methods for measurements of hydraulic conductivity of saturated porous materials using flexible wall permeameter", West Conshohocken, P.A., USA, 2003.

[23] American Society for Testing and Materials, ASTM: D4767-04, "Standard test method for consolidated undrained triaxial compression test for cohesive soils", West Conshohocken, P.A., USA, 2011.

[24] A. Namdar and X. Feng, ''Evaluation of safe bearing capacity of soil foundation by using numerical analysis method'', Frat. Ed Integrita Strutt., vol. 8, no. 30, pp. 138-144, 2014.

[25] C. Cox and P. Mayne, ''Soil stiffness constitutive model parameters for geotechnical problems, a dilatometer testing approach", Proc. 3rd Int. Conf. on Flat Dilatometer, pp. 393-400, 2015.

[26] P.M. Bandini and S.M. Pham, ''Bearing capacity of embedded strip footings in two-layered clay soil'', Proc. of the Geo-Frontiers, March 13-16, 2011, Dallas, Texas, American Society of Civil Engineers, USA, pp. 332-341, 2011.

[27] J. Han and G. Jiang, ''Influence of inclined bedrock on undrained bearing capacity of shallow strip foundations'', Geo-Frontiers: Advances in Geotechnical Engineering, pp. 322-331, 2011.

[28] M. Zhu, ''Bearing capacity of strip footings on two-layer clay soil by finite element method'', Proc. of ABAQUS User's Conference, vol. 777, pp. 787, 2004.

[29] A.A. Tagar, J. Changying, J. Adamowski, J. Malard, D. Qishuo and N.A. Abbasi, ''Finite element simulation of soil failure patterns under soil bin and field-testing conditions'', Soil Tillage Res., vol. 145, no. 1, pp. 157-170, 2015.

[30] O. Anvari and Y.M.A. Lotfollahi, ''A study on the scale effect of footing settlement in clay using Plaxis'', Proc. of 2nd Int. Conf. on Environ. Engg., Istanbul, Turkey, 2016.

[31] H.A. Taiebat and J.P. Carter, ''Numerical studies of the bearing capacity of shallow foundations on cohesive soil subjected to combined Loading'', Geotechnique, vol. 50, no. 4,pp. 409-418, 2000.