Experimental Study of the Effect of Foundation Shape on the Deformation of Soils

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Abstract

Vertical deformations of soil under three prototypesof shallow foundations with different vertical cross-sectional shapes were studied on three different modeled subsoilconditions. Prototypesof shallow foundations with rectangular, wedge and T-shape vertical cross-sections were studied. The study generally showed that bulk of the vertical deformation of subsoil bases at the instance of shallow foundations with rectangular shape vertical cross-sections is mostly associated with the soil beneath the foundation, while at the instances of those with wedge and T-shape vertical cross-sections, deformation of soil occurs both under the foundations' bases and along theirvertical stems. This indicates that using foundations with wedge and T-shape vertical cross-section can help in mobilizing substantial mass of soil above the foundation base, to function not only as surcharge to the soil below the foundation base, but also in resisting loads, and therefore assisting in the distribution of structural load to less dipper soil strata, especially when stronger soil layers is underlain by weaker ones.

Keywords: Foundation shape; Soil base; Deformation

1. Introduction

For most structures including, bridges, earth fills, earth and concrete dams, it is the earth that provides the ultimate support. The behavior of the supporting ground must, therefore, affect the stability of the structure. The supporting ground is usually a soil (since sound rocky stratum is often rare to come by) which is weaker than any construction material like wood, concrete, steel or masonry. Hence, compared to structural members made out of these materials, a larger area or mass of soil is necessarily involved in carrying the same load. Structural foundations are the substructure elements which transmit the structural load to the earth in such a way that the supporting soil is not overstressed and do not undergo deformation that would cause excessive settlement of the structure (Ranjan and Rao, 2000). This is achieved through choice of foundation type and its geometry (shape).

Foundations are generally classified into shallow foundations and deep foundations.Shallow foundations are considered those types of foundations that transmit structural loads to the soil strata at a relatively small depth. 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 $D_f/B \leq 1$. However, research studies conducted since then have shown that, for shallow foundations, D_f/B can be as large as 3 to 4 (Das, 1999; 2010; Shakiba rad *et al*, 2011). EAG (2012) states that, foundation elements are considered to be shallow when the depth to breadth ratio is less than 5 ($D_f/B<5$). A study conducted by Gourvenec (2008), using small-displacement finite element analyses, shows a quadratic relationship between depth factor for shallow foundation and embedment ratio(D_f/B),with the quadratic function reachingits maximum at an embedment ratio of 2.5.

Various types (shapes) of shallow foundations are known, with strip, square, rectangular and circular being the most widely used.These typesof shallow foundations have different shapes which only vary from each otherplan-wise or by horizontal cross-section. Depending on the design thicknesses, the shapes of theirvertical cross-sections arebasically the same. This makes the mode of their interaction with the soil basestrunk-wise (vertically) basically the same.

Their interaction 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 shapes of shallow foundations that can both partly distribute structural loads vertically along their trunks and bases is presented. V and T-shaped foundation were considered along with the conventional rectangular shaped foundation.The study presents pattern of vertical deformation (settlement) of soil under foundations of these shapes. This study is anchored on the fact that, in the design of shallow foundations,it is commonly believed that settlement (deformation) criterion is more critical than that of the bearing capacity (Das and Sivakugan, 2007). Generally the settlement of shallow foundations such as pad or strip footings is limited to 25 mm (Terzaghi et al. 1996).

2. Experimental Methodology

Three wooden prototypes of shallow foundations were used for the study: the first prototype was a rectangular shapedblock with dimension of *50x60x60*mm for width, length and height respectively, the second prototype was a wedge-shaped block of 60 mm height with width and length for top and lower sides as *60x60* mm and *30x60* mm respectively, while the third prototype was a T-shaped block of 60 mm height with width and length for top and lower parts as *60x60*mm and *30x60*mm respectively (fig. 1). The dimensions of the prototypes were chosen so as to be within $D_f/B\leq 2$($D_f$and$B$ are depth of foundation embedment and width respectively). In accordance with the physico-mechanical properties of Nigerian soils (Boiko *et al*, 2012) and the classification of Nigerian subsoil bases by Alhassan *et al*(2012), three subsoil conditions were modeled in the geotechnical laboratory of the Department of Geotechnics and Ecology in Civil Engineering of Belorussian National Technical University, Minsk, Belarus. The experimental stand used for the study was a rectangular containerof dimension*1100x600x250*forlength, height and width respectively, with a transparent front side(fig. 2).

Two types of clay soils were used in modeling the subsoil bases. The first was a stiff clay soil having *relative consistency* of 2.33 and *liquidity index*of less than 0,unit weight and moisture contents of the soil were 18 kN/m^{3}and 10 % respectively.The second was soft claysoil having *relative consistency* of 0.67 and *liquidity index* of 0.33, unit weight and moisture content of the soil were 17 kN/m^3 and 20 % asrespectively. The first modeled subsoil condition was a homogeneous stiff clay soil (fig. 3),the second was soft clay overlaying stiff clay (fig. 4), whilethe third modeled condition was soft clay in between layers of stiff clay at top and below (fig. 5).

The experimentalstand was filled with the soils in layers of 25 mm, with each layer compacted to unit weight of 18 kN/m^3 and 17 kN/m^3 at moisture contents of 10 % and 20 % for stiff and soft soil respectively. The top of each layer was marked from the inside side of the transparent side of the box with thin layer of powdered chalk, while thin marker was used to trace the marks on the outside surface. With these, using gauges,the vertical deformations (displacements) of the soil layers at the instance of each of the foundation prototypes were measured. The markings also makevisual observations of the deformation process possible. The foundation prototypes were placed during placement and compaction of the last two upper layers as shown in fig. 3-5. Using 1:10 loading lever, loads were vertically,centrally and uniaxially applied to the foundations.

On the first modeled subsoil condition, maximum loads of 1000, 830 and 913 kN/m^{2}was applied to rectangular, wedge and T-shaped foundation prototype respectively. On the second subsoil condition, maximum load of 1000kN/m^2 was applied to rectangular shape foundation prototype and 830 kN/m^{2}was applied to bothwedge and T-shapedprototype foundation.On the third modeled condition, 203, 280 and 336 kN/m^2 loads was applied respectively to rectangular, wedgeand T-shape foundation prototype respectively.At these respective loads, the patterns of vertical deformation of the subsoil bases at the instance of these prototype foundations were studied.

3. Results and Discussion

The results are presented according to the modeled subsoil conditions.

3.1 First modeled subsoil condition

Investigation on the first modeled subsoil condition showed that on loading rectangular shaped foundation prototype,soil under its baseto a depth of *b* (*b* - width of the foundation)deformed, the maximum deformation occurs in the soil directly below the foundation, and decrease with depth, the soil along the trunk of the foundation shows no significant deformation, also nosignificant heaving and bulging of the soil surface were observed. This observation is similar to those reported by ALChamaa*et al*(2005).

Two deformation zones were observed in the case of wedge-shaped foundation prototype on the first subsoil condition. The first deformation zone occurs from *0.5h* depth along the trunk of the foundation to the depth *h* (*h* - the depth of the foundation), minimum deformation in this zone occurs with the soil at *0.5h*depth, and increases to its maximum with the soil at the depth *h*. The second deformation zone occurs under the foundation to a depth of *b′* (*b′*– width of the lower part of the foundation). Maximum deformation was observed with soil directly under the foundation. Heaving and bulging of the soil surface were not observed.

On loading the T-shaped foundation prototype, two deformation zones in the subsoil were also observed. The first deformation zone occurs from the ground surface of the soil along the vertical sidesof the foundation to the depth *h*. Maximum deformation in this zone occurs at depth *h*. The second deformation zone occurs under the foundation to a depth of *b′*, with the maximum observed with the soil directly beneath the base of the foundation, and decreases with depth. Heaving and bulging of the soil surface were not observed.

Fig. 6 shows the vertical deformation of the soil base under the respective maximum loads for the foundation prototypes on the first modeled subsoil condition.From the figure (fig. 6), it can be observed that, more soil mass is involved in the deformation process around wedge and T-shaped foundations than around the rectangular shaped.

3.2 Second modeled subsoil condition

Study of the foundation prototypes on the second modeled subsoil condition showed that on loading rectangular shaped foundation prototype, soil under the foundation deformed to a depth of *b*. No deformation was observed with the soil along the vertical sides of the foundation. Maximum deformation occurs with the soil immediately beneath the foundation base, and reduces with depth. Significant uplift and bulging of the soil surface were not observed.

Two deformation zones were observed withthe soil beneath the wedge-shaped prototypefoundation when loaded on the second subsoilcondition. The first deformation zone was observed along the vertical sidesof the foundation to a depth of *h*, while the second deformation zone occurs under the foundation to the depth *b*. Deformation of the first zone increases to depth *h*, whereas that of the second zone decreases with depth. Heaving and bulging of the soil surface to a height of *0,05b* was observed.

On loading T-shaped prototype foundation on the second subsoilcondition, two zones of deformation of foundation subsoil were also observed. The first zone occurs from the surface of the soil along the trunk of the foundation to depth *h*, and the second deformation zone occurs under the foundation to the depth *b*. The deformation of the first zone increases to the depth h, whereas that of the second zone attenuated with depth. The surface of the soil bulges to a height of *0.03b*.

Fig. 7 shows the vertical deformation of the soil base under the respective maximum loads for the foundation prototypes on the second modeled subsoil condition.From the figure (fig. 7), it is observed that, although, more settlement is recorded, even with comparatively lesser loads, more soil mass is involved in the deformation process with wedge and T-shaped foundations than with rectangular shaped foundations.

3.3 Third modeled subsoil condition

Studyof the foundation prototypeson thethird modeled subsoil condition,showed that the soil under the rectangular shapedfoundation prototype deformed to a depth of *1.5b*, soil along the vertical surfaces of the foundation from the ground surface to a depth of *0.6h*heaves, and settles from *0,6h* to a depth *h*. That is heavingof the soil was observed from*0.6h*depth to the ground surface of the soil.The ground surface bulges to a height of *0,06b*.

Two zones of deformation were observed in the subsoil base under wedge-shaped foundation prototype when loaded on the third modeled ground condition. The first zone of deformation occurs along the stem of the foundation to a depth of *h*, and the second zone of deformation occurs under the foundation to a depth of *1.25b*. Heaving of the soil was observed from *0.33h*depth to the ground surface of the soil.The ground surface bulges to a height of *0.05b*.

On loading T-shapedfoundation prototype on the third condition, two deformationzones were observed in the subsoil. The first zone of deformation occurs from the surface of the soil along the trunk of the foundation to a depth *h*, while the second zone occurs under the foundation to a depth *b*.Heaving of the soil occurs from*0.05h*depth to the ground surface,while bulging of the soil surface to a height of *0.02b*was observed.

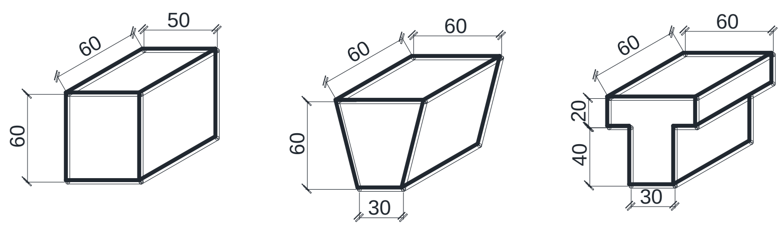
Fig. 8 shows the vertical deformation of the soil base under the respective maximum loads for the foundation prototypes on the third modeled subsoil condition.

3.4 General observations

The results generally showed that bulk of vertical deformation of soil bases under rectangular shaped foundations is mostly associated with the soil below the base of the foundations, while in the case of wedge and T-shaped foundations, both soil along the trunks and bases of the foundation vertically deformed, meaning that more soil mass is involved in the deformation process. These can be generally summarized diagrammatically as shown in fig 9, with stressed soil zones (pressure bulbs) around each of the studied foundations.

4. Conclusion

The results generally showed that bulk of the vertical deformation of soil bases under shallow foundations with rectangular shape vertical cross-section is mostly associated with the soil below the base of the foundations, while in the case of foundationswith wedge and T-shape vertical cross-section, both soil along the trunks and bases of the foundation vertically deformed. This indicates that using foundationswith wedge and T-shape vertical cross-sectioncan help in mobilizing substantial mass of soil above the foundation base, to function not only as surcharge to the soil below the foundation base, but also in resisting loads, and therefore assisting in the distribution of structural load to less dipper soil strata, especially when stronger soil layers is underlain by weaker ones.



a *b* *c*

Note: *all dimensions in mm*

Fig. 1: Foundation prototypes: a- rectangular shaped, b- wedge-shaped, c- T-shaped.

Fig. 2: Experimental stand

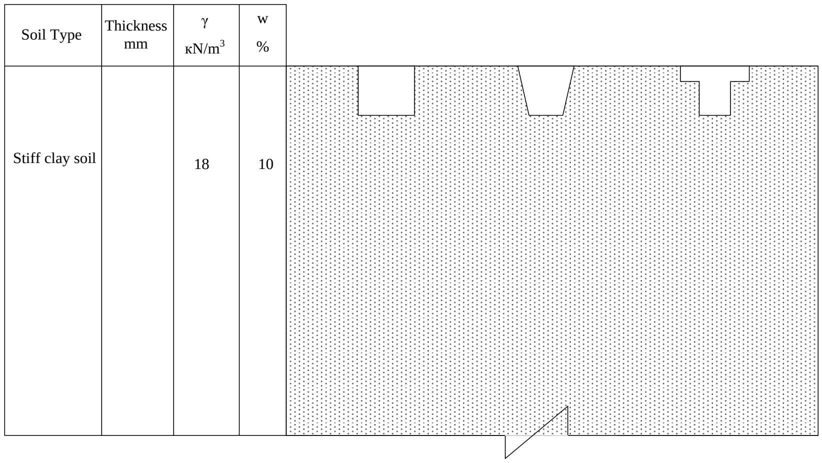


Fig. 3: First modeled subsoil condition

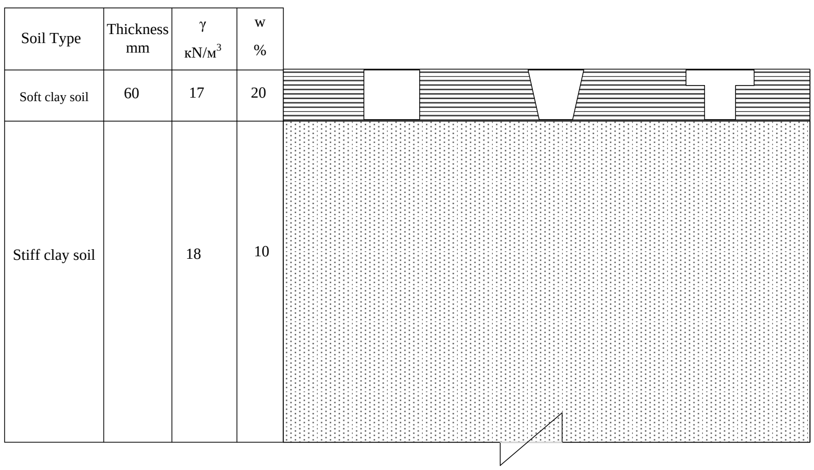


Fig. 4: Second modeled subsoil condition

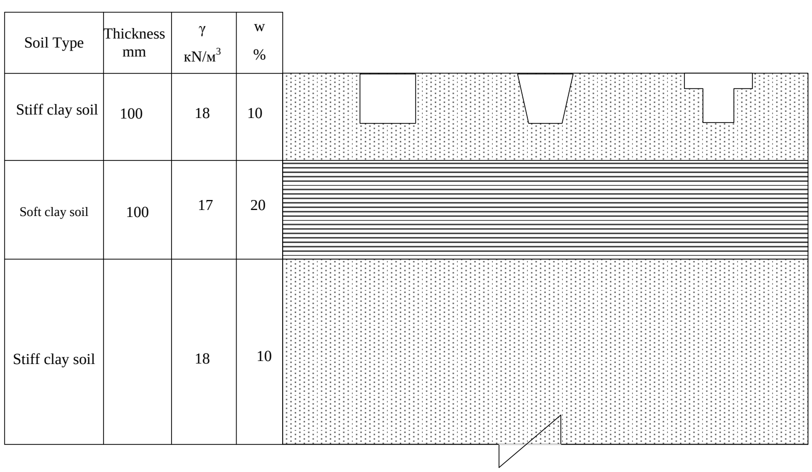
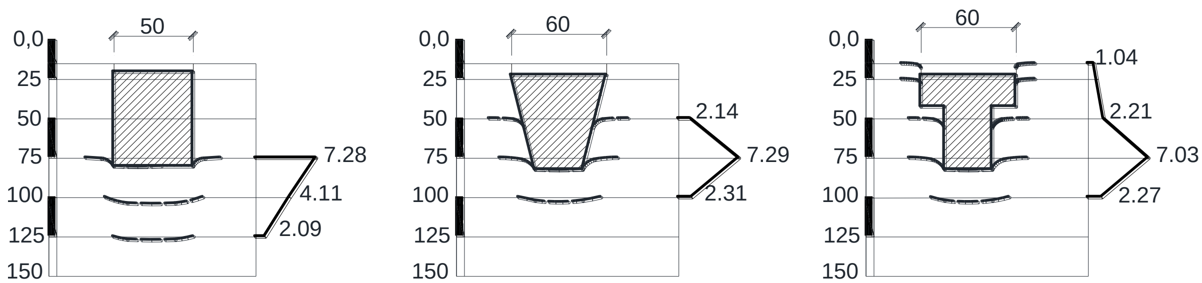
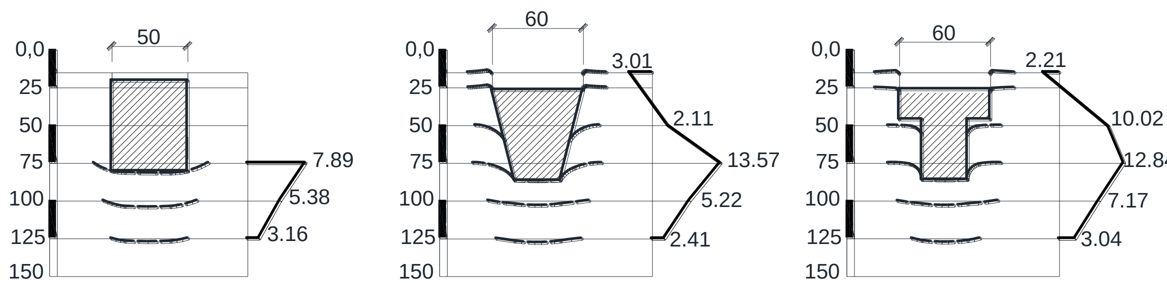


Fig. 5: Third modeled subsoil condition



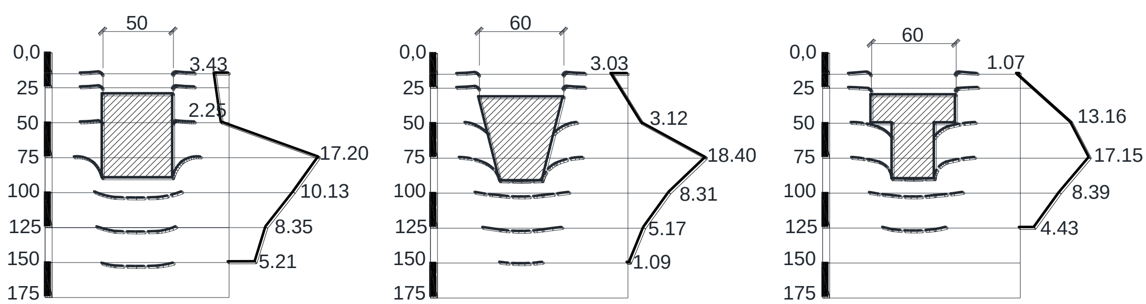
Note: *all dimensions and deformation in mm*

Fig. 6: Deformation of soil under foundations prototypes on the first modeled subsoil condition



Note: *all dimensions and deformation in mm*

Fig. 7: Deformation of soil under foundations prototypes on the second modeled subsoil condition



Note: *all dimensions and deformation in mm*

Fig. 8: Deformation of soil under foundations prototypes on the third modeled subsoilcondition

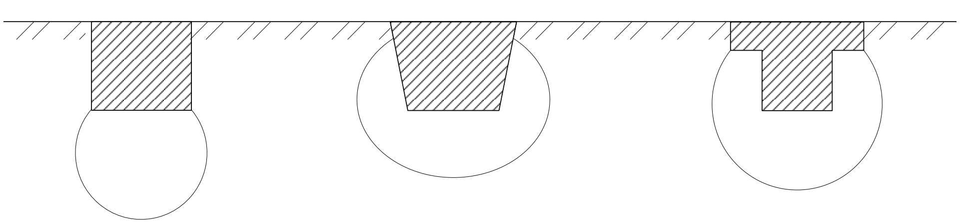


Fig. 9: Sketch of the development of pressure bulbs under basesof foundations of different shapes

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