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Deformation Pattern of Non-cohesive Soil Bases under Foundations with Different Vertical Cross-sectional Shapes

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ABSTRACT: *Pattern of vertical deformations of soil bases, under shallow foundation modelsof different vertical cross-sectional shapes were experimentally studied on three different modeled non-cohesive subsoilconditions. Foundations models with rectangular, wedge and T shape vertical cross-sections were studied. Result of the study showed that, under the action of vertical load, bulk of the vertical deformation of subsoil bases at the instance of foundations with rectangular vertical cross-sectional shapes, is mostly associated with the soil beneath the foundation, while at the instances of those with wedge and T vertical cross-sectional shapes, deformation of the soil occurs both under the foundations' bases and along their vertical stems. This indicates that, although less loads were generally resisted by the wedge and T shape foundations, using then can help in mobilizing substantial mass of soil above the foundation bases, to function not only as surcharge to the soil below the base, but also in resisting structural loads.*

KEYWORDS*:* *Deformation pattern; Foundation shape; Non-cohesive soil; Soil base; Vertical load.*

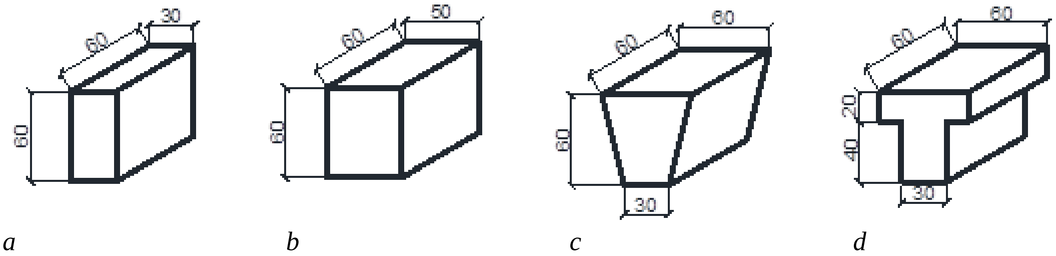
I. INTRODUCTION

The earth provides the ultimate support for most civil engineering structures including, bridges, earth fills, earth and concrete damsetc., as such the behavior of the supporting ground, under these structures, directly affects their stability. Soil (since sound rocky stratum is often rare to come by) is usually the supporting ground. Since soilis weaker than most other construction materials like wood, concrete, steel or masonry, hence, compared to structural members made out of these materials, a larger area or mass of soil will necessarily be requiredto carry the same load. Foundations are the structural elements that transmit the structural loads to the ground in a way that the supporting soil is not overstressed and do not undergo deformation that would cause excessive settlement of the structure [1]. 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 that transmit structural loads to the soil strata at a relatively small depth. Terzaghi [2] 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, subsequent studies have shown that, for shallow foundations, D_f/B can be as large as 3 to 4 [3-5].

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 shape foundation were considered along with the conventional rectangular shaped foundation.The study presents pattern of vertical deformation (settlement) of non-cohesive soil bases under foundations of these shapes. This study wasbased 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 [6]. Settlement of 25 mm is usuallytaken as the allowable in the design of shallow foundations such as pad or strip [7].

II. EXPERIMENTAL METHODOLOGY

Fourwooden models of shallow foundations were used for the study. The first model (labeled as rectangular shape-1) was a rectangular shape block with dimension of *30x60x60*mm for width, length and height respectively, the second model (labeled as rectangular shape-2) was a rectangular shape block with dimension of *50x60x60* mm for width, length and height respectively, the third was a wedgeshape block of 60 mm height with width and length for top and lower sides as *60x60* mm and *30x60* mm respectively, while the fourthwas a T-shape 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 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).Three subsoil conditions of non-cohesive soil 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 containerwithdimension*1100x600x250 mm*forlength, height and width respectively, with a transparent front side (fig. 2).



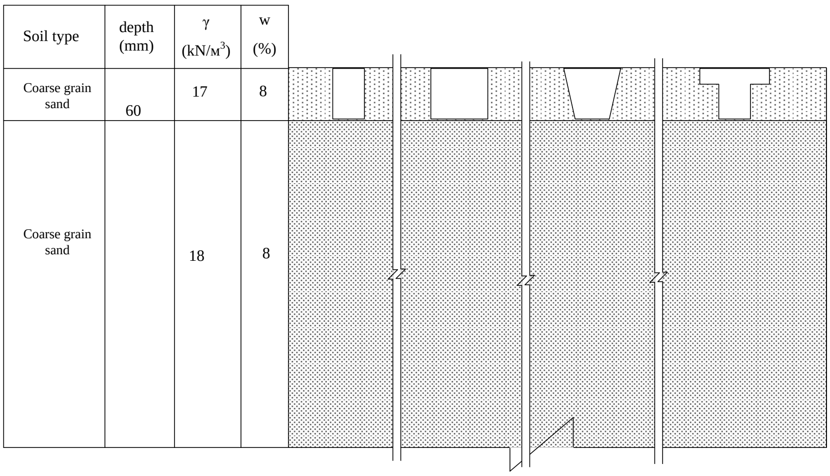
a *b* *c* *d*

Note: *all dimensions in mm*

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

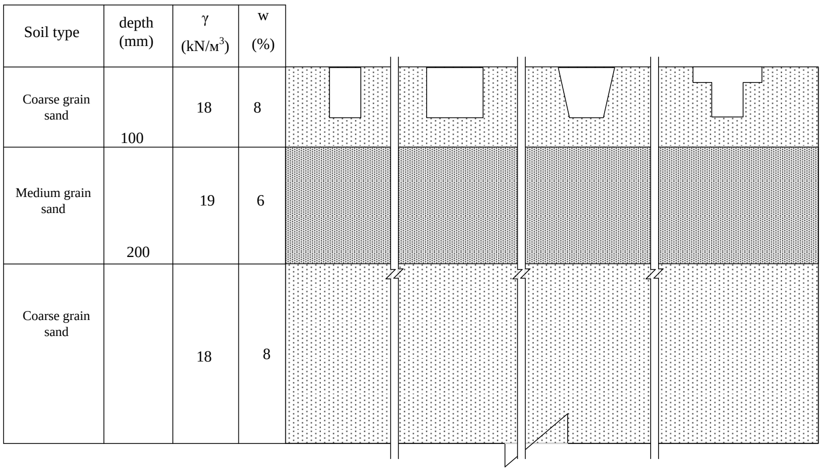
Fig. 2: Experimental stand

Two types of non-cohesive (sandy) soils were used in modeling the subsoil bases. The first soilwas classified according to Russian standard [8] as coarse grain sand, while the second soil was classified as medium grain sand. The subsoil bases were modeled by compaction of the soils at various moisture contents and densities.Figs. 3-5 show the modeled subsoil conditions.The experimental stand was filled with the soils in layers of 50 and 25 mm, with each layer compacted to the respective unit weight (density) and at respective moisture contents. 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, and using gauges, the vertical deformations (displacements) of the soil layers at the instance of each of the foundation models were measured. The markings also make visual observations of the deformation process possible. The foundation models were placed during placement and compaction of the last two upper layers as shown in figs. 3-5. Using 1:10 loading lever, loads were statically, vertically, centrally and uniaxially applied to the foundation models.



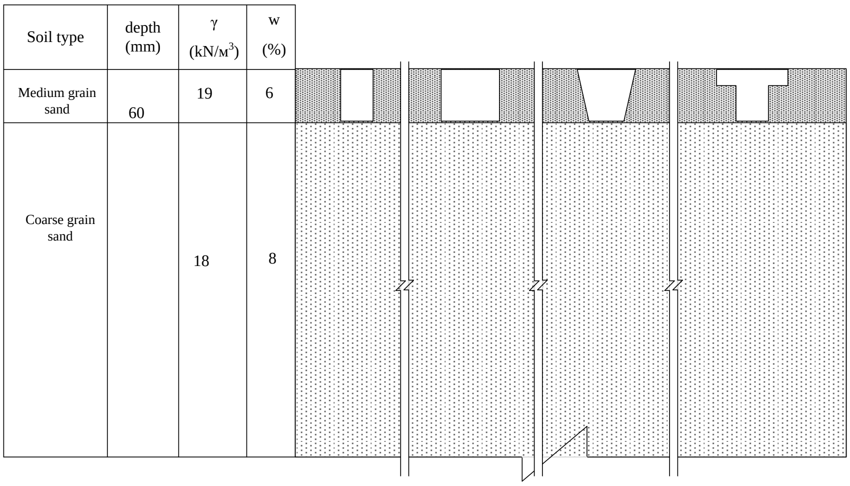
Soil type	depth (mm)	γ (kN/м^3)	w (%)
Coarse grain sand	60	17	8
Coarse grain sand		18	8

Fig. 3: 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

Fig. 4: Second modeled subsoil condition



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

Fig. 5: Third modeled subsoil condition

On the first modeled subsoil condition, maximum loads of 339, 267, 228 and 285kPa were applied to rectangular-1, rectangular-2, wedge and T shape foundation models respectively. Maximum loads of 394, 400, 228 and 285kParespectively,were applied to rectangular-1, rectangular-2, wedge and T shape foundation models, on the second subsoil condition. On the third modeled condition, 450, 400, 285 and 285kPaloads were applied respectively to rectangular-1, rectangular-2, wedge and T shape foundation models respectively. At these respective loads, the patterns of vertical deformation of the subsoil bases at the instance of these models foundations were studied.

III. RESULTS AND DISCUSSION

Investigation on the first modeled subsoil condition showed that on loadingthe rectangular shape foundation models,heaving and bulging of the ground surface to 0,1b and 0,04b (*b* – width of the foundation models) respectively for rectangular-1 and 2, occurred. Soil under their basesto a depth of *b* deformed, the maximum deformation occurs in the soil directly below the foundation, and decrease with depth. This observation is similar to those reported by ALChamaa*et al* [9].On loading wedge shapefoundation models, two deformation zones were observed –along its vertical trunk and below the base. Minimum deformation of the soil base was observed at the ground surface and increases to the maximum at the base of the foundation model. Heaving and bulging of the ground surface was not observed in this case.On loading the T-shape foundation model, 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'*(*b'* – width of the stem part of the foundation model), 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 was not observed.

Fig. 6 shows the vertical deformation of the soil bases under the respective maximum loads for the foundationmodels on the first modeled subsoil condition.

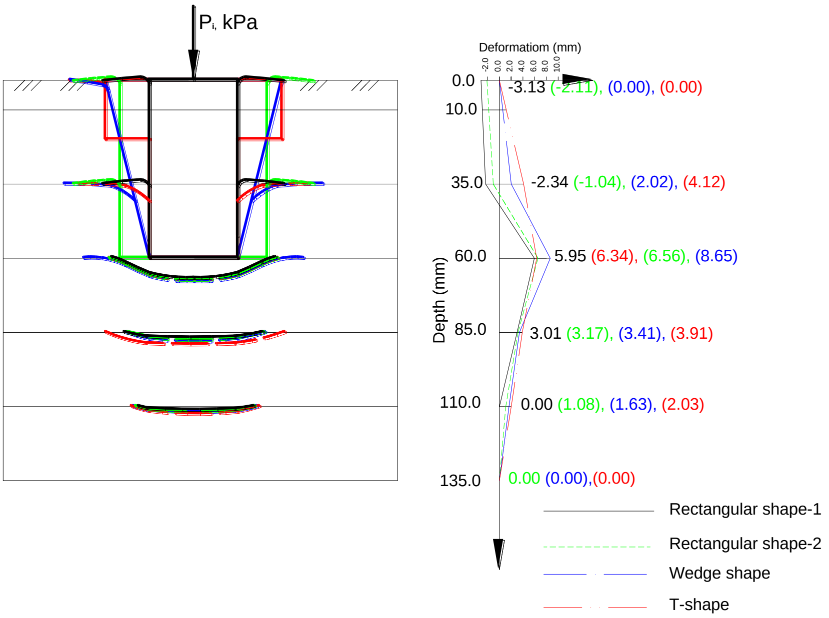


Fig. 6: Deformation of soil under foundation models on the first modeled subsoil condition

Study of the deformation patterns of the soil on the second modeled subsoil condition showed two types of deformation on loading rectangular and wedge shape foundationmodels. First type of deformation is heaving of the soil along the vertical trunks of the foundation,from *0,6h*(*h*– thickness of the foundation) to the ground surface, while the second type of deformation was settlement of the soil from *0,6h*to the depth of *1b* below the foundation bases. Maximum deformation (settlement) occurred at depth *1h* and decreases to *1b*below the foundation bases. Heaving and bulging of the soil surface was not observed with rectangular-1 and wedge shape models, but in the case of rectangular-2 heaving and bulging of the soil surface to *0,06b*height was observed.On loading the T-shape foundation model on the second modeled subsoil condition, both soil along the vertical trunk and beneath the foundation base settles (deformed). Minimum deformation was observed at the ground surface and increases to its maximum value at the base of the foundation i.e. at the depth *1h*. Heaving and bulging of the soil surface was not observed with in this case. Fig. 7 shows the vertical deformation of the soil bases under the respective maximum loads for the foundation models on the second modeled subsoil condition.

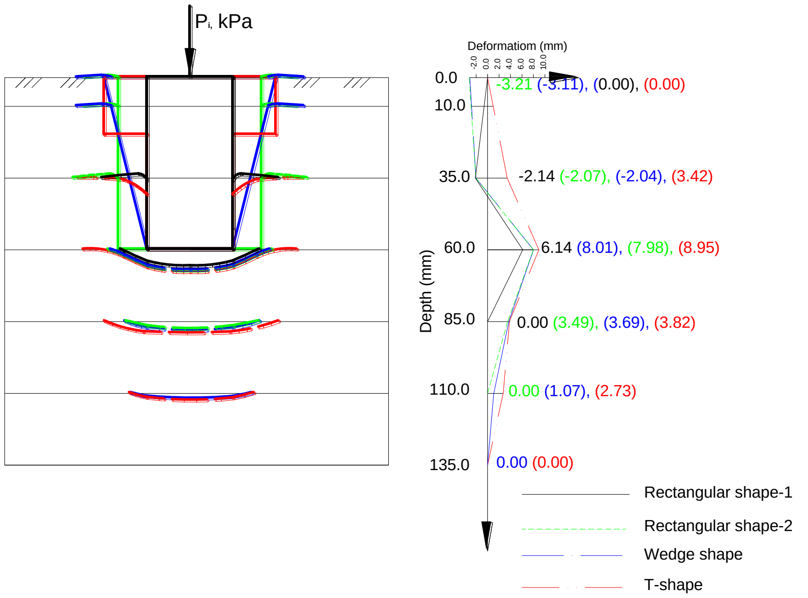


Fig. 7: Deformation of soil under foundation models on the second modeled subsoil condition

Study of the deformation patterns on the third subsoil conditions showed two zones of deformation on loading rectangular shape foundation models. The first zone of deformation was heaving of the soil along the vertical trunk of the foundation to *0,6h* depth, while the second zone was settlement of the soil, which occurs from *0,6h* depth to *1b* below the base of the foundations. Maximum deformation occurs with the soil directly at the foundation bases, and decreases with depth. Heaving and bulging of ground surface was observed. Heaving of the soil occurred from *0,6h* depthto the ground surface. The ground surface rose to a height of *0,07b* and *0,05b*respectively for rectangular shapes 1 and 2.On loading wedge and T shape foundation models on third subsoil condition, two deformation zones were also observed. The first zone of deformation (heavingof the soil) occurs from the ground surface along their trunks to a depth of *0,25h*, while the second zone of deformation (settlement) occurs from *0,25h* depth to the bases of the foundations. Heaving of the soil occurred from*0,25h* to the ground surface.The ground surface heaved to a height of *0,04b* and *0,04b* for wedge and T shapemodels respectively, bulging was observed at the surface. In all the models, maximum deformation of soil base occurred with the soil directly under the base of the foundations, and decreases with increasing depth. Fig. 8 shows the vertical deformation of the soil bases under the respective maximum loads for the foundation models on the second modeled subsoil condition.

It was observed that more soil mass is involved in the deformation process around wedge and T shape foundation models than around the rectangular shapes.The result of the study of the deformationpatterns of the soil bases at the instances of foundations with these shapes can be summarized as shown in fig. 9.

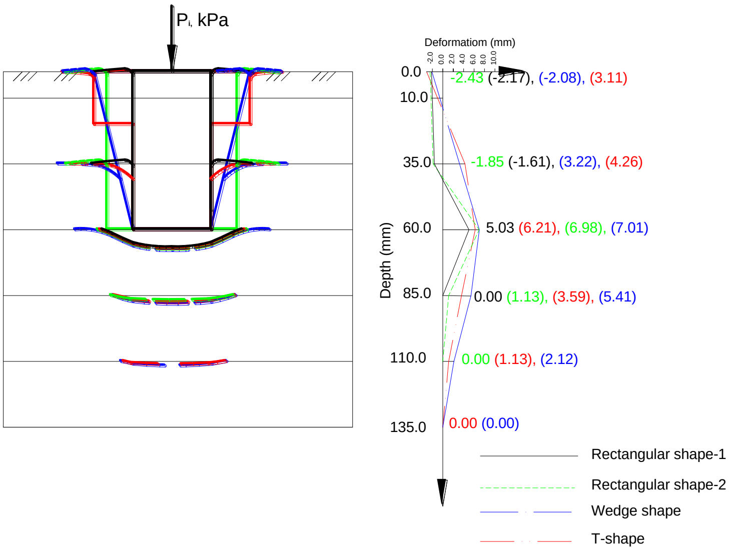


Fig. 8: Deformation of soil under foundation models on the second modeled subsoil condition

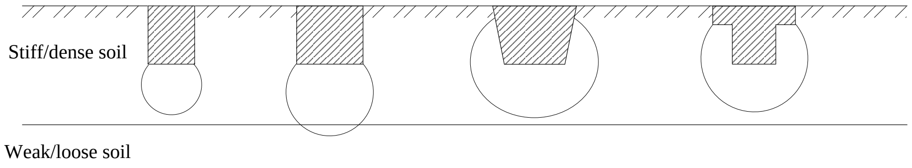


Fig. 9: Summarized patterns of deformation of the soil bases under the studied foundations shapes

IV. CONCLUSION

Deformation patterns of foundation models with different vertical cross-sectional shapes on non-cohesive subsoil bases under vertically applied load were studied.The results generally showed that bulk of the vertical deformation of the soil bases under shallow foundations with rectangular vertical cross-sectionalshapesis mostly associated with the soil below the base of the foundations, while those with wedge and T vertical cross-sectional shapes, both soil along the trunks and below their bases, vertically deformed. This showsthat although, less loads were resisted by these (wedge and T) shapes,using them can help in mobilizing substantial mass of soil above the foundation bases, to function not only as surcharge to the soil below the bases, but also in resisting structural loads.This potential can especially be usedwhen stronger soil layers are underlain by weaker ones.

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