Scholars Journal of Engineering and Technology (SJET) **ISSN 2321-435X**
Sch. J. Eng. Tech., 2013; 1(3):128-132

(An International Publisher for Academic and Scientific Resources)
www.saspublisher.com

Research Article

Effect of Vertical Cross-sectional Shape of Soil Reinforcing Elements on Deformation of the Soil under a Vertically Loaded Foundation

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Abstract: The paper presents results of field load-settlement tests of full-scale foundations, resting on soils reinforced with concrete piles of different vertical cross-sectional shapes.The study was carried out in construction sites in Minsk, Belarus. Deformation patterns of the foundation soils, reinforced with piles of cylindrical and conical vertical cross-sectional shapes were studied. The results of the study showssimilar variation in the patterns of vertical deformation of the soils reinforcedwith both cylindrical and conical vertical cross-sectional shaped piles. The deformation patterns of the soilsalong horizontal axis shows that, with cylindrical shaped piles as soil reinforcing elements, maximum deformation of the soil base was recorded along the edges of the foundation plate, while with conical shaped piles, maximum deformation was recorded along the center line of the foundation plate.
Keywords: Foundation;Load-settlement; Soil deformation;Soil reinforcement.

INTRODUCTION

Soil reinforcement allowed the use of sites that were initially considered to be unsuitable for civil engineering construction. This is even more pronounced with the continue decrease in the availability of good construction sites,especially in the developed and the developing cities of the world. This decrease has led to high increase in the cost of the available good construction sites. Apart from the immediate economic advantages (especially with the recent global economic meltdown), soil reinforcement also has long-term economic advantages. Introduction of reinforcing elements into soil below a footing can substantially increase the bearing capacity with decrease in settlement, and thus increasing the stability and durability of the superstructure, while obviating the necessity of a combined footing or a raft foundation[1].

While Laboratory model studies of foundations on reinforced soil provide a clear insight of the general behavioral trend of reinforced soil beds [2], to extend the results to full-scale foundations, suitable scaling laws as discussed by Butterfield [3], are used. Although, the cost and time involved in performing large scale tests are considerably high, they are more reliable, as the general mechanisms and behavior, observed in the model tests are reproduced at large scale [4].

Many studies have been conducted on foundations resting on soil reinforced with different reinforcing elements, e.g.geogrid[5-8], geotextile [9-10], geosynthetic[11-12], fiber [13-15], concrete-grid [16], etc. Cement, lime, Sandand stone columns are also reported to be very effective for reinforcing weak/soft soil deposits [17-20], while reinforced concrete columns are widely used for reinforcing loose sandy soil deposits under foundations. This paper presents load-settlement results and deformation patterns of soils, reinforced with concrete piles of cylindrical and conical vertical cross-sectional shapes under full-scale foundations. The test was carried out attwotest points located in the South-eastern part of the city of Minsk, Belarus.

SOIL CONDITION OF THE TEST POINTS

The subsoil base at the two test points generally consists of sandy soils of varying grain sizes, densitiesandlayers, reinforced with 2x2 (4 No) concrete piles of cylindrical and conical vertical cross-sectional shapes for test point 1 and 2respectively. The reinforcing piles were installed (driven) by dropping weight (Impact hammer)method. The test points were generally characterized by relatively similar soil conditions, except for the presence of a relatively thin layer of peaty soil at 1.6 m depth under the test plate at test point 1.Water table at all the test points was more than 2B (B is width of the footing) below the bottom of the foundation plates.

EXPERIMENTATION

The full-scale foundation test plates (2.236x2.236 m) were seated on layer of sand, beneath which was the reinforced soil layer. The test plates were sited at the bottom of the foundation trenches, which were 188.2 m above the Baltic Sea level. In the first test points, the reinforcing elements consisted of concrete piles of cylindrical vertical cross-sectional shape,while in the second test point, concrete piles of conical vertical cross-sectional shape, were used as reinforcing elements.

Since the sub-soil bases, on which the test plates were seated, consisted mainlyof sand of various grainsizes, in accordance with Russian Standard (ГОСТ 20276, 1999)[21] for methods of in-situ (field) determination of strength and deformation characteristics of soils, loads were applied incrementally, at successive increments of 0.05 MPa, at 1/2 h time intervals, using hydraulic jack of 2000 kN (200 tons) capacity.

Gauges of 1/100mm precision were used for measurement of settlement of both the foundation plates andthe deformation of the foundation's soil bases. For measuring settlement/deformation of the soil bases, Dynamic Cone Penetration Test (DCPT) cones, attached with steel strings, which were passed through openings, earliermade during casting of the reinforced concrete foundation test plate.The cones with attached steel strings were carefully driven using hammer blows to the required depths within the soil bases. The attached strings were then fastened to the settlement gauges as shown in fig. 1. At test point 1, gauges for the measurement of settlement/deformationof the soil bases, were through steel strings, attached to cones inserted at 0.2, 0.5, 1.0 and 1.2 m depths, while at test point 2, gauges for the measurement of settlement/deformation of the soil bases, were through steel strings, attached to cones inserted at 0.2, 0.5, 1.0 and 1.5 m depths.

Four gauges were used for measurement of the plates' settlement, and the averages were used for the load-settlement plots. For determining the deformationpatternon horizontal axisof the soil bases, three cones, each attached to gauges were installed at 0.2 m depth, with the first cone installed along the central axis, while the second and third cones were installed at the edges of the test plates and at opposite sides to the first one. The gauges attached to cones at varying depths were used for determining the vertical deformation patterns along the depth of the soil bases. The test setup is as shown in figure 2.

Fig. 1: Arrangement of the settlement gauges

Fig. 2: The test setup

RESULT AND DISCUSSION

The load-settlement results of the foundations at the two test points are shown in figures 3 and 4, while figures 5 and 6 show the vertical and horizontal settlement/deformation patternsrespectively,of the soil bases, at maximum tested loads (0.30 MPa). With the test plates at the two test points having the same geometrical parameters, and the soil conditionsrelatively similar, the main difference between the two test points was the vertical cross-sectional shapes of the reinforcing elements.

Load-settlement curves from the two test points shows that within the load intervalstested, load-settlement proportionality was not exceeded. The same patterns of load-settlement curves were relatively observed for the two test points. Observation of the results shows (figure 5) that the recorded settlement/deformation of the soil basereduces with depth. The reduction of the settlement/deformation vertically downward along the depths was more pronounce at test point 2. The relatively less reduction in the settlement/deformation along depth, recorded at test point 1 was as a result of the presence of the thin layer of peaty soil within the active (influence) zone of the test plate. From Shleicher's equation for elastic settlement of uniformly loaded footing, which was based on Boussnesq's stress distribution, it is seen that settlement within a subsoil base under uniformly loaded footing is a function of pressure i.e. $s=f(p)$, based on this, it is suffice to say that the observed trend at the two test points agrees with the existing theory for stress distribution in soil mass under a uniformly loaded footing.

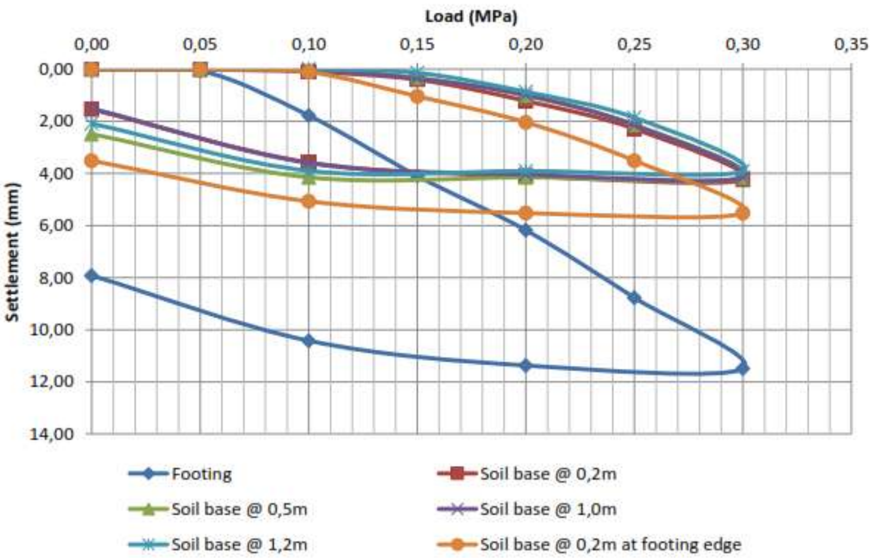

Fig. 3: Load-settlement curves of test point 1

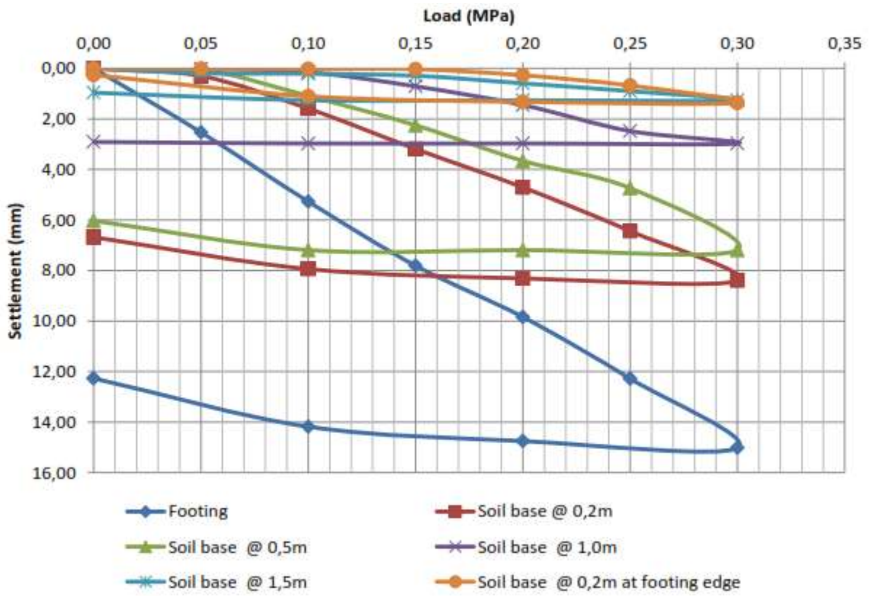

Fig. 4: Load-settlement curves of test point 2

From figure 6, the horizontal variation (pattern) of the soil deformation (settlement) at a given depth (0.2m) shows maximum value within the soil base under test point 2,along the center line of the foundation plate, while for test point 1, maximum values were observed at the edges of the foundation plate. Apart from the stress distribution theory, the trend in the horizontal variation of the deformation observed at test point 2 is also attributed to the vertical cross-sectional shape of the reinforcing piles. With the cross-sectional area (volume) of the piles increasing upward, on loading the foundation plate, downward movement of the piles causes both vertical and lateral (horizontal) movement (displacement) of the soil. The lateral (horizontal) displacement of the soil by the piles increases the density of the surrounding soil. With group effect in play, the soil surrounding the pile group becomes more compacted, and hence less settlement. The larger settlement (deformation) observed at the edges of the foundation at test point 1 is attributed to the lack of confinement in the soil [22, 23].

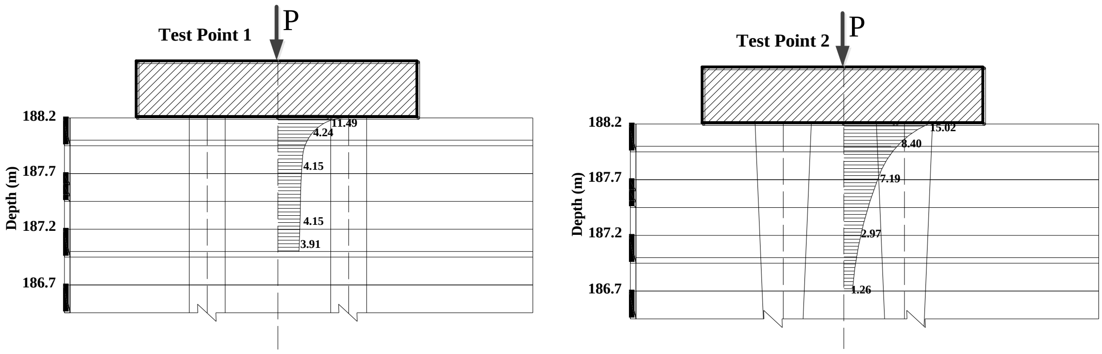

Fig. 5: Vertical variation of deformation of soil bases.

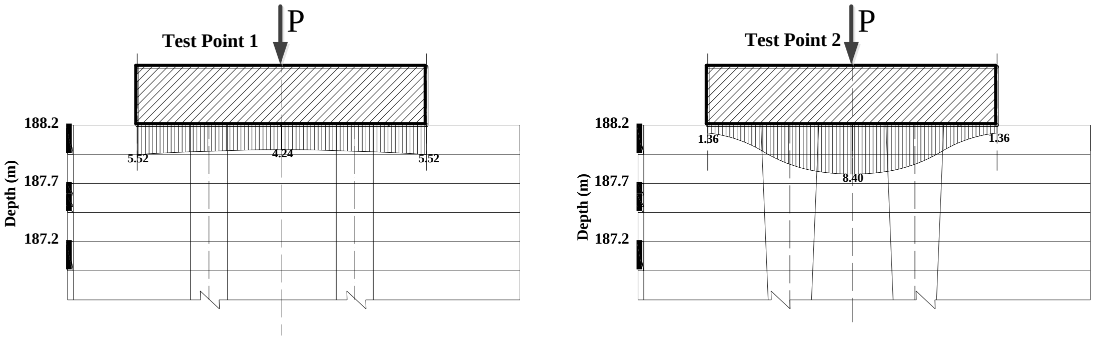

Fig. 6: Horizontal variation of soil deformation at 0.2 m depth.

CONCLUSION

Load-settlement relationship and soil deformation patterns of foundation resting on soil reinforced with pile of cylindrical and conical vertical cross-sectional shapes were investigated.The load-settlement curves and vertical variation of deformation of the soil was found to be similar for both the soil bases reinforced with cylindrical and conical shapes. Deformation patterns along horizontal axisshow that, for soil reinforced with cylindrical shaped piles, maximum deformation occurs beneath theedges of the foundation, while for soil reinforced with conical shaped piles, maximum deformation occurs beneath the center line of the foundation.

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