Effect of Compaction on Deformation Pattern of Soil Reinforced with Vertical Piles 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 granular sub-soil base of different densities, and reinforced with concrete piles. The study was carried out in a construction site in Minsk, Belarus. Deformation patterns of the sub-soil bases under vertically loaded foundations were studied. The results of the study show similar variation in the patterns of vertical deformation of the sub-soil bases at both loose and dense state. But patterns of the deformation of the soils along horizontal axis shows loose sub-soil base, having maximum deformation along the center line of the foundation plate, while for dense sub-soil base, the deformation takes the pattern for rigid footing on a cohesive base, with maximum deformation recorded along the edges of the foundation plate.

Keywords: *Foundation; Load-settlement; Soil Compaction; Soil deformation; Soil reinforcement.*

1. Introduction

The problem of land scarcity especially in the developed and the developing cities of the world often necessitate the use of sites with soils of marginal quality. In many cases these sites can be utilized for the proposed project by using some kind of soil improvement [1]. Soil in these types of sites can be improved using compaction and reinforcement. While soil compaction is usually an economical method of mechanically improving the bearing capacity of site soils, soil reinforcement involves the introduction into the soil mass of special materials which increases the shear resistance and decreases compressibility of the soil.

Soil compaction and 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 increase in the cost of the available good construction sites. Apart from the immediate economic advantages (especially with the recent global economic meltdown), soil improvement also has long-term economic advantages. Compaction and 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 [2].

While Laboratory model studies of foundations on reinforced soil provide a clear insight of the general behavioral trend of reinforced soil beds [3], to extend the results to full-scale foundations, suitable scaling laws as discussed by Butterfield [4], 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 [5].

Many studies have been conducted on foundations resting on soil reinforced with different reinforcing elements, e.g. geogrid [6-9], geotextile [10-11], geosynthetic [12-13], fiber [14-16], concrete-grid [17], etc. Cement, lime, Sand and stone columns are also reported to be very effective for reinforcing weak/soft soil deposits [18-21], 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 foundation sub-soils of at different densities, reinforced with concrete piles under full-scale foundations. The test was carried out at a construction site located in the South-eastern part of Minsk, the capital city of Belarus.

2. Soil Condition of the Test Site

The subsoil base of the test site generally consists of sandy soils of varying grain sizes, densities and layers. The soil was reinforced with vertical concrete piles at the test points. 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 additional compaction, using vibrating roller, carried out at test point 2 before the test. The soil condition of the test site is as shown in figure 1. The variation in the density between the test points is shown in figures 2 and 3. The description and classification of the soils was done in accordance with the Russian System (Standard), as such the classification No. were so retained as shown in figure 1.

Soil Type	Depth (m)	γ, kN/m^3	c, kPa	φ, deg.	E, MPa
Sandy soil of q_c> 3,0 MPa (ИГЭ-2)	1,60	18,5	1	40	7,0
Peat and Peaty soil (ИГЭ-13)	2,00	11,5	33	11	4,2
Sandy soil of medium density (ИГЭ-6)		18,5	1	36	39

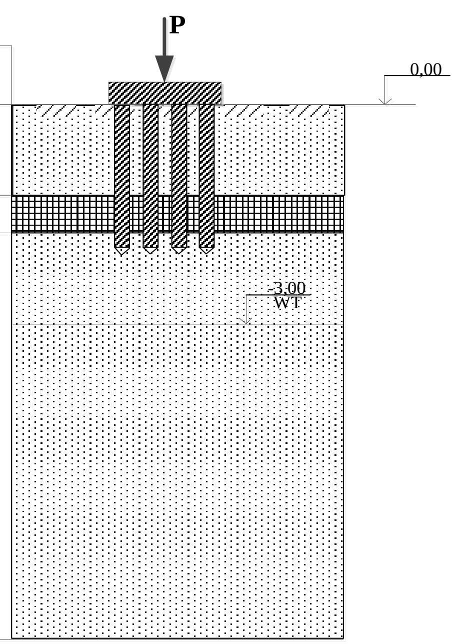

Fig. 1: Soil condition of test point 1

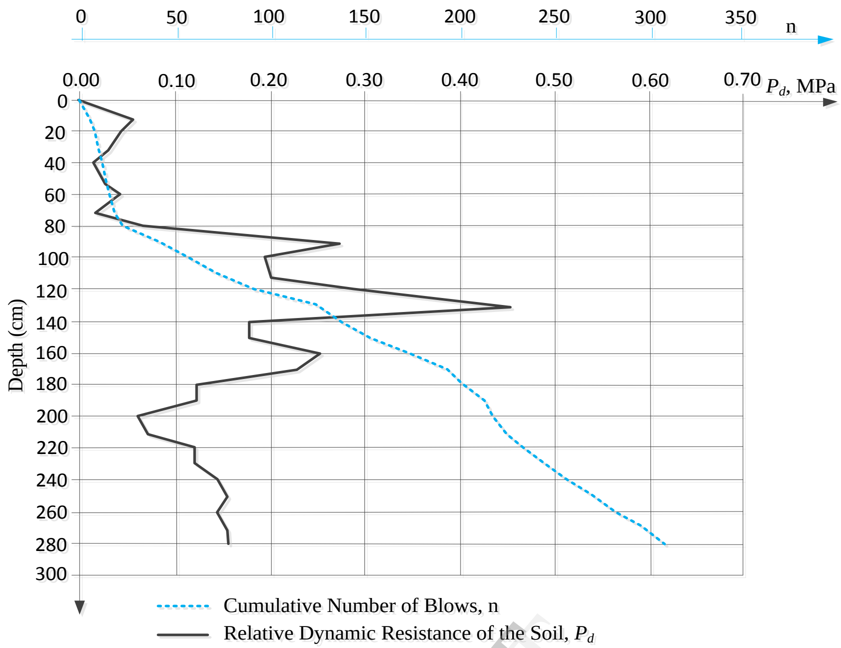

Fig. 2: DCPT result for test point 1

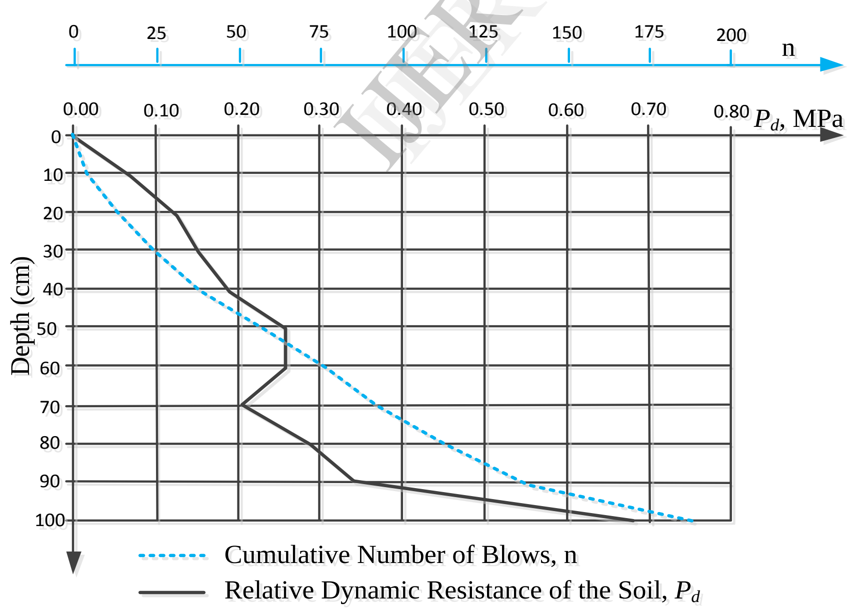

Fig. 3: DCPT result for test point 2

3. 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 test was carried out on a relatively less compacted (loose) soil, while in the second test point additional compaction was carried out before the test. In the test points Dynamic Cone Penetration Test (DCPT) was carried to determine the state of densification of the soil (figures 2 and 3). The dynamic resistance of the soil P_d shown in the figures was calculated in accordance with Russian Standard (ГОСТ 19912-2012) [22].

Since the sub-soil bases, on which the test plates were seated, consisted mainly of sand of various grain sizes, in accordance with Russian Standard (ГОСТ 20276, 1999) [23] 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 and the deformation of the foundation's soil bases. For measuring settlement/deformation of the soil bases, DCPT cones, attached with steel strings, which were passed through openings, earlier made 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/deformation gauges as shown in fig. 4. At test point 1, gauges for the measurement of settlement/deformation of the soil bases, were through steel strings, attached to cones inserted at 0.2, 0.6, 1.0 and 1.5 m depths, while at test point 2, gauges were through steel strings, attached to cones inserted at 0.2, 0.5, 1.0 and 1.2 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 deformation pattern on horizontal axis of 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 5.

Fig. 4: Arrangement of the settlement gauges

Fig. 5: The test setup

4. Result and Discussion

The load-settlement results of the foundations at the two test points are shown in figures 6 and 7, while figures 8 and 9 show the vertical and horizontal settlement/deformation patterns respectively, of the soil bases, at maximum tested loads of 0.20 and 0.30 MPa for test point 1 and 2 respectively. With the test plates at the two test points having the same geometrical

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 10, October - 2013

parameters, the same reinforcing elements, the main difference between the two test points was the density of the sub-soil bases.

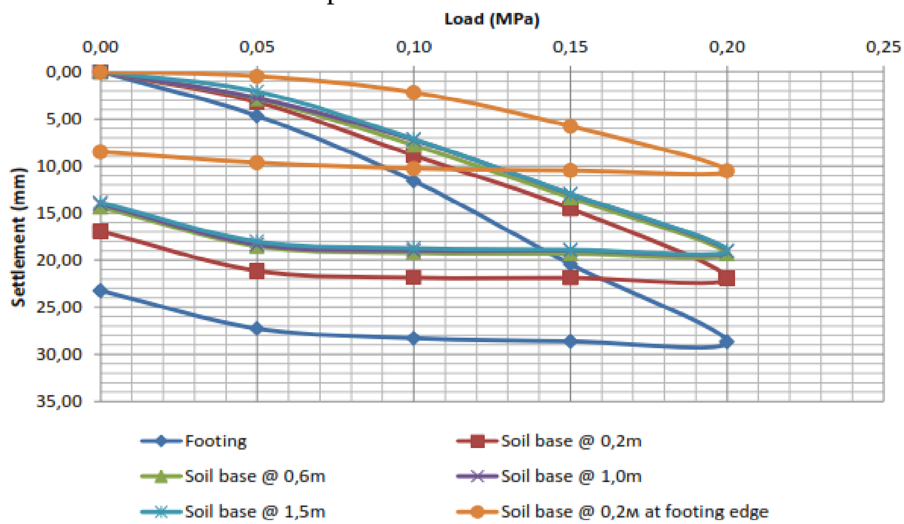

Fig. 6: Load-settlement curves of test point 1

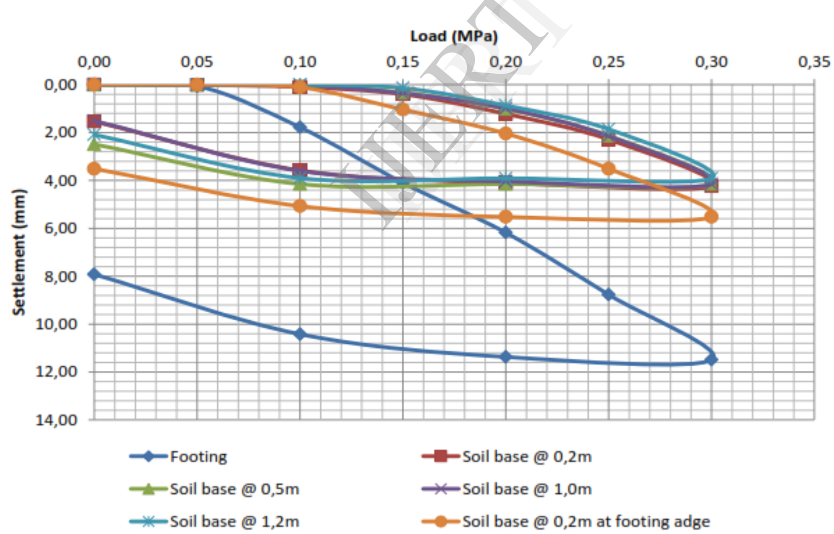

Fig. 7: Load-settlement curves of test point 2

Load-settlement curves from the two test points shows that within the load intervals tested, load-settlement proportionality was not exceeded. Although, more settlement/deformation at corresponding loads was generally recorded at test point 1, the same patterns of load-settlement curves were relatively observed for the two test points. The curves for the sub-soil base at test point 2 are more cluster together than at test point 1. Observation of the results shows (figure 5) that the recorded settlement/deformation of the soil base reduces with depth. The relatively less reduction in the settlement/deformation along depth, recorded at the two test points was as a result of the presence of the thin layer of peaty soil within the active (influence) zone of the test plate. The presence of the peaty soil makes the soil layers above, act relatively as single unit settling under load.

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.

From figure 6, the horizontal variation (pattern) of the soil deformation (settlement) at a given depth (0.2m) shows more deformation generally recorded at test point 1 even at less load, than at test point 2. Maximum deformation (settlement) of the soil base along the horizontal variation axis at test point 1 was recorded along the center line of the foundation plate, while for test point 2, maximum values were observed at the edges of the foundation plate. The pattern of deformation along horizontal axis, observed at test point 1 is in agreement with explanations advanced by Das [24] and Murthy [25] for a rigid footing on a cohesionless soil.

The pattern of deformation along horizontal axis, observed at test point 2 is similar to the deformation pattern for a rigid footing on a cohesive soil. With the soil between the reinforcing elements at this point been more dense/compacted, the sub-soil base as a whole behaves more like a cohesive medium, and hence the observed pattern [24, 25]. In addition, the trend in the horizontal variation of the deformation observed at this test point can also be attributed to the group effect of the reinforcing pile. That is in dense state, the soil within the pile group and the piles act as a single dense unit, and hence less settlement.

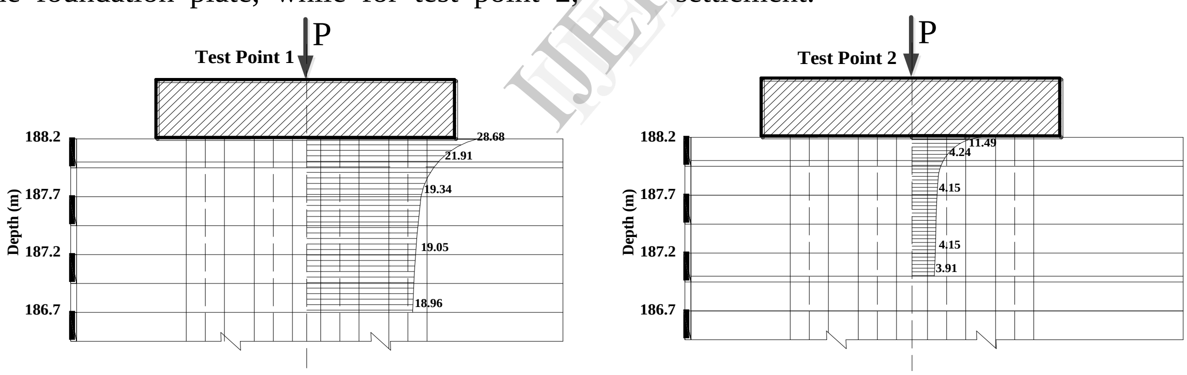

Fig. 8: Variation of deformation of soil bases along vertical axis.

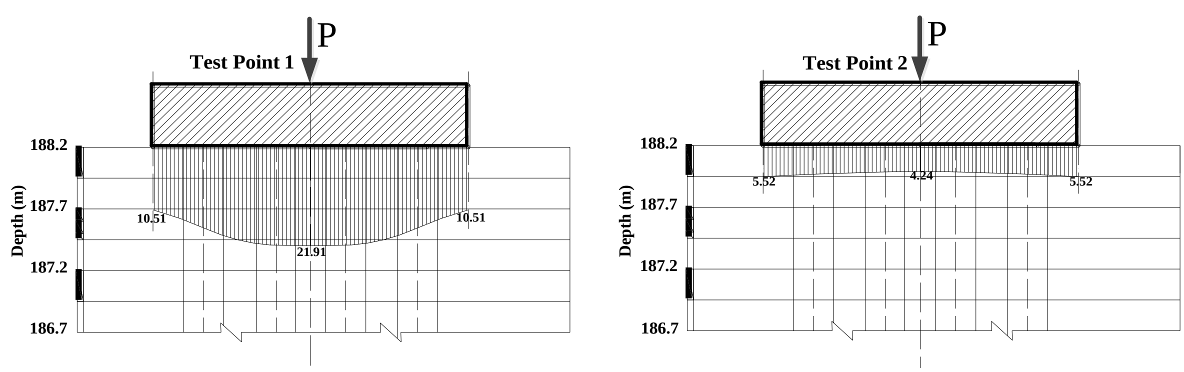

Fig. 9: Horizontal variation of soil deformation at 0.2 m depth.

5. Conclusion

Load-settlement relationship and soil deformation patterns of foundations resting on soil at different densities and reinforced with vertical piles were investigated. The results of the study show similar variation along vertical axis, in the patterns of deformation of the sub-soil bases at both loose and dense state. But patterns of the deformation of the soils along horizontal axis shows loose sub-soil base, having maximum deformation along the center line of the foundation plate, while for dense sub-soil base, the deformation takes the pattern for rigid footing on a cohesive base, with maximum deformation recorded along the edges of the foundation plate.

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