academicJournals

Vol. 4(6), pp. 211-216, June, 2013
DOI 10.5897/JCECT2013.0277
ISSN 1996-0816©2013 Academic Journals
http://www.academicjournals.org/JCECT

Journal of Civil Engineering and Construction Technology

Full Length Research Paper

Load-settlement test of full-scale foundation on concrete-grid reinforced soil

I. L. Boiko, M. Alhassan* and T. W. Adejumo

Department of Geotechnics and Ecology in Civil Engineering, Faculty of Civil Engineering, Belarusian National Technical University, Minsk, Belarus.

Accepted 11 June 2013

Result of field test on load-settlement of full-scale foundation, resting on soil reinforced with concrete-grid is presented. The test was carried out at 3 different points within a construction site in Minsk, Belarus. The test points were characterized by different soil conditions below the reinforced base. Result of the study shows that, the use of concrete-grid as reinforcement for subsoil base under foundation, generally reduces the settlement and increases the bearing capacity of the soil, although, these were significantly affected by the type and properties of the soil below the reinforced layer.

Key words: Bearing capacity, concrete-grid, foundation, load-settlement, modulus of deformation, soil reinforcement.

INTRODUCTION

The decreasing availability of good construction sites, especially in the developed and the developing cities of the world, has led to increase in use of the marginal ones. Apart from economic advantages (especially with the recent global economic meltdown), soil reinforcement allows the use of sites that were initially considered to be unsuitable for civil engineering construction. Introduction of reinforced soil below a footing can substantially increase the bearing capacity with decrease in settlement, and thus obviating the necessity of a combined footing or a raft foundation (Saride, 2010).

While Laboratory model studies of foundations on reinforced soil provide a clear insight of the general behavioral trend of reinforced soil beds (Sitharam et al., 2005) to extend the results to full-scale foundations, suitable scaling laws as discussed by Butterfield (1999) 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 (Milligan et al., 1986).

Many studies have been conducted on foundations resting on soil reinforced with different materials e.g geogrid (Das and Shin, 2000; Liu et al., 2008; Demiröz and Tan, 2010; Ramu, 2011), geotextile (Das, 1989; Dembicki and Alenowicz, 1990), geosynthetic (Zhao, 1998; Yetimoglu, 1998; Wayne et al., 1998), fiber (Akinmusuru et al., 1982; Maheshwari et al., 2011; Maheshwari et al., 2013) etc. The use of concrete-grid as reinforcing element for soil bases under foundations have not been reported in the past studies.This paper presents load-settlement results of full-scale foundation test on soil reinforced with concrete-grid. The test was carried out in a construction site located in the South-eastern part (Shabana District) of the city of Minsk, Belarus.

Soil condition of the test site

The test site generally has a relatively complex soil conditions: the surface consists of a relatively thick layer of fill material; at various depths were layers/interlayers and lenses of peat, peaty, sandy (of varying grain sizes and densities) and soft clay soils. Tests were conducted at 3 locations within the site. The soil condition at each of the test points are as presented in Figures 1 to 3. The

*Corresponding author. E-mail: alhassankuta@futminna.edu.ng.

Type of Soil	Depth m	γ, kN/m^3	c, kPa	ϕ, deg.	E, MPa
Reinforced Soil	1.00	-	-	-	-
Fill material (ИГЭ-1)	1.70	18.9	-	-	-
Stiff silty clay soil (ИГЭ-3)	2.30	20.9	38	25	14
Sandy soil of medium grain size and density (ИГЭ-13)	2.90	17.8/10.5	2	37	25
Medium stiff silty clay soil (ИГЭ-2)	3.70	20.3	29	23	7
Peat, Peaty soil (ИГЭ-4)	5.50	12.3	25	12	2.0
Soft-Medium peaty soil (ИГЭ-5)	7.50	17.7	16	26	4.5
Peat, Heavily peaty soil (ИГЭ-4)	8.70	12.3	25	12	2.0
Soft-Medium peaty soil (ИГЭ-5)	9.70	17.7	16	26	4.5
Medium stiff silty clay soil (ИГЭ-2)	10.90	20.3	29	23	7
Medium dense sandy clay with mixture of organic matters (ИГЭ-6)	12.30	19.9	23	18	7
Medium dense coarse sand with gravel (ИГЭ-7)	14.10	15.5/9.2	-	32	10
Gravely sandy soil of medium density (q_c>5MPa) (ИГЭ-9)	15.50	17.4/10.3	-	38	26
Dense gravely sandy soil (ИГЭ-10)		18,4/10.9	-	41	35

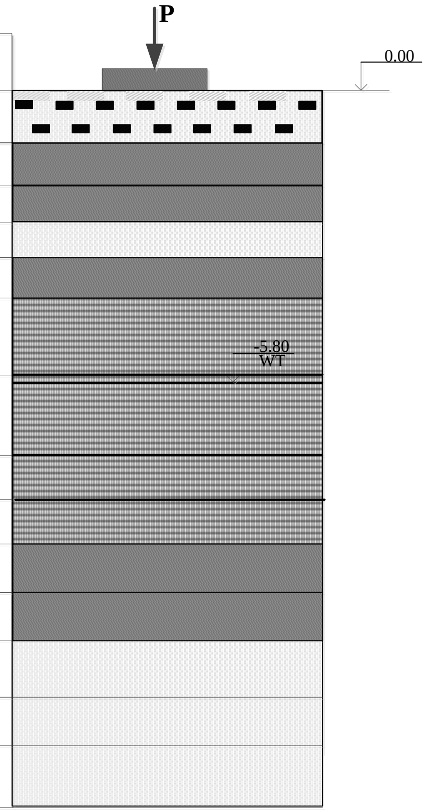

Figure 1. Soil condition at Test point 1.

Type of Soil	Depth m	γ, kN/m^3	c, kPa	ϕ, deg.	E, MPa
Reinforced Soil	1.00	-	-	-	-
Sandy soil of medium grain size and density (ИГЭ-12)	5.20	16.8/9.9	1	34	18
Gravely sandy soil of medium density (q_c <5MPa) (ИГЭ-8)	7.00	16.6/9.9	-	35	19
Medium dense coarse sand with gravel (ИГЭ-7)	10.60	15.5/9.2	-	32	10
Gravely sandy soil of medium density (q_c <5MPa) (ИГЭ-8)	11.40	16.6/9.9	-	35	19
Gravely sandy soil of medium density (q_c>5MPa) (ИГЭ-9)	12.80	17.4/10.3	-	38	26
Dense gravely sandy soil (ИГЭ-10)		18.4/10.9	1	41	35

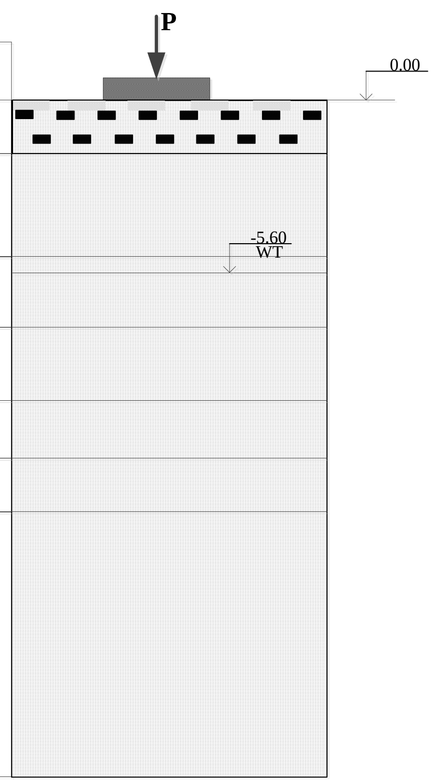

Figure 2. Soil condition at Test point 2.

Type of Soil	Depth m	γ, kN/m^3	c, kPa	ϕ, deg.	E, MPa
Reinforced Soil	1.00	-	-	-	-
Sandy soil of medium grain size and density (ИГЭ-13)	1.40	17.8 / 10.5	2	37	25
Sandy soil of medium density (ИГЭ-14)	2.10	18.5 / 10.9	2	38	33
Sandy soil of medium grain size and density (ИГЭ-13)	3.40	17.8 / 10.5	2	37	25
Sandy soil of medium density (ИГЭ-14)		18.5 / 10.9	2	38	33

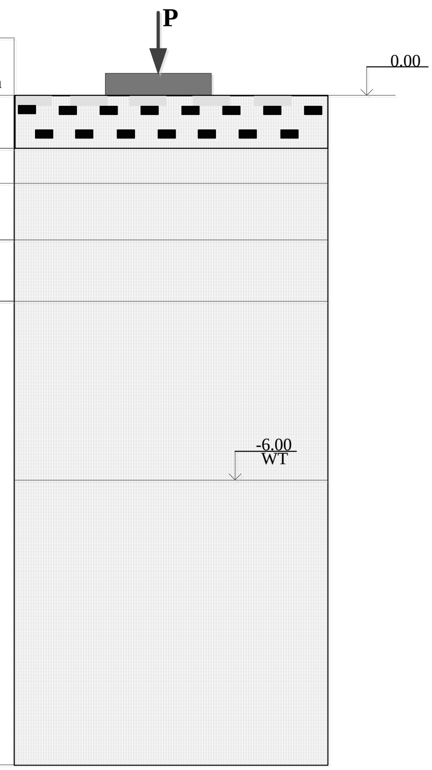

Figure 3. Soil condition at Test point 3.

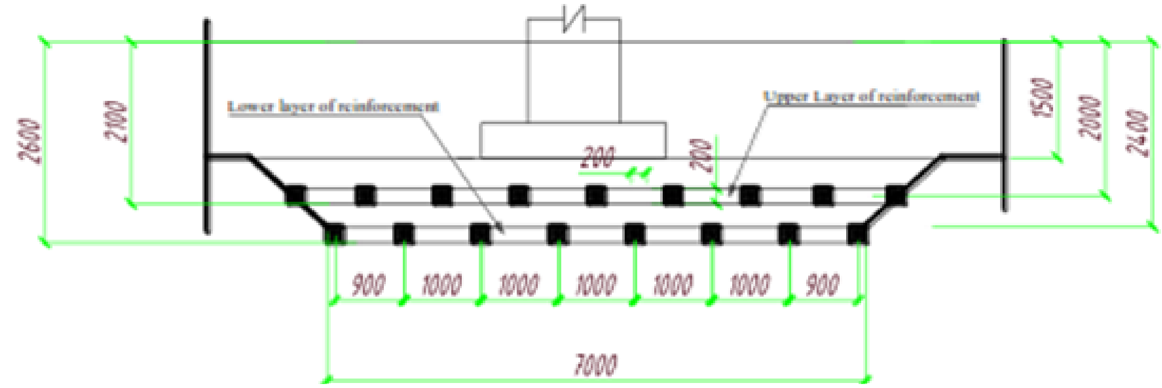

Figure 4. Cross-sectional sketch showing arrangement of the reienforcement.

description and classification of the soils was done in accordance with the Russian System (Standard), as such the classification Number were so retained as shown in Figures 1 to 3. The tests were conducted at thebottom of the foundation trench, which was approximately 1, 20 m below the natural ground level. In-situ plate load test, conducted during soil investigation of the site, showed that, the modulus of deformation of the soil at this depth ranges between 9 and 10 MPa.

The reinforced layer consisted of medium sized grain sand with two layers of concrete-grid as reinforcement. Water table at all the test points was more than 2B (B is width of footing) below the bottom of the test foundation.

EXPERIMENTATION

The full-scale foundation text plate (2.236 × 2.236 m) was seated on 1 m thick reinforced soil layer of medium sized grain sand at the bottom of the foundation trench, which was 188 m above the Baltic sea level. The reinforcement consisted of two layers of 1 × 1 m concrete grid at 0.3 m apart and M15 concrete grade was used. A vertical cross-sectional sketch, showing the reinforcement dimensions and arrangement is shown in Figure 4. Since the reinforced layers, on which the test plates were seated, consisted of sand of medium sized grains, in accordance with Russian Standard

Figure 5. Arrangement of settlement gauges.

Figure 6. The test set up.

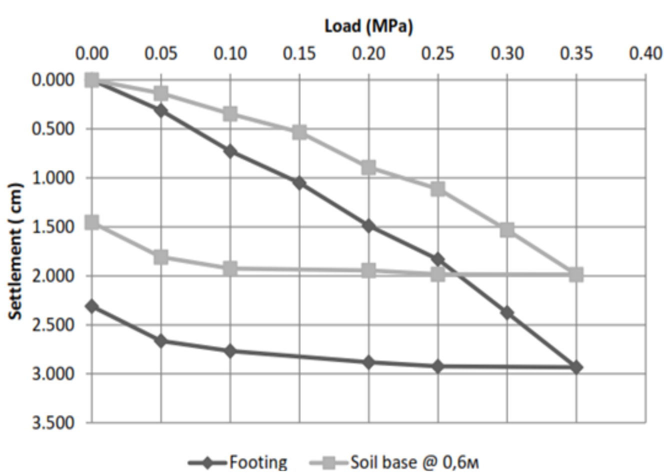

Figure 7. Load-settlement curves of Test point 1.

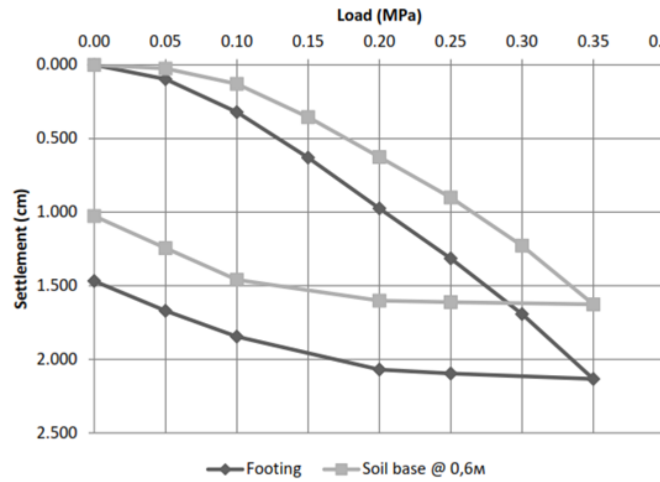

Figure 8. Load-settlement curves of Test point 2.

(ГОСТ 20276, 1999) 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 ½ h time intervals, using hydraulic jack of 2000 kN (200 tons) capacity. Gauges of 1/100 mm precision were used for measurement of settlement of both the foundation plate and the foundation soil base.

For measuring settlement of the soil base, Dynamic Cone Penetration Test (DCPT) cones, on which steel strings were attached, were passed through openings on the foundation test plate and driven to the required depths within the soil base. The attached strings were then fastened to the settlement gauges as shown in Figure. 5. On Test point 1 and 2, gauges for the measurement of settlement within the soil bases, were inserted at depths of 0.6 m, while for Test point 3, gauges were inserted at 0.6, 0.7, 0.8, and 2.4 m depths.

Four gauges were used for measurement of the plate settlement, and the averages were used for the load-settlement plots. For measurement of settlement of the subsoil base at Test points 1 and 2, three gauges each were installed at 0.6 m, with the first gauges installed along the central axis, while the second and third were installed at horizontal equal distance and at opposite sides of the first one. At Test point 3, four gauges were installed; with each gauge at the depthsindicated above.The test setup is as shown in Figure 6.

RESULT AND DISCUSSION

The load-settlement results of the foundation at the 3 Test points are shown in Figures 7 to 9, while Figures 10 and 11 showed the horizontal and vertical variation of settlement within the soil bases, at maximum tested load. Although, the test plates at the 3 Test points have the same geometrical parameters and the reinforced soil layer similar at all the test points, the main difference within the 3 Test points was the soil condition.

Load-settlement curves from all the Test points showed that, within the test load interval, load-settlement proportionality was not exceeded. At Test point 1, below the layer of reinforced soil, was a layer of fill material (ИГЭ-1), peat and heavily peaty soil (ИГЭ -4) at a depth of 3.7 to 8.7 m with a modulus of deformation E = 2 MPa.

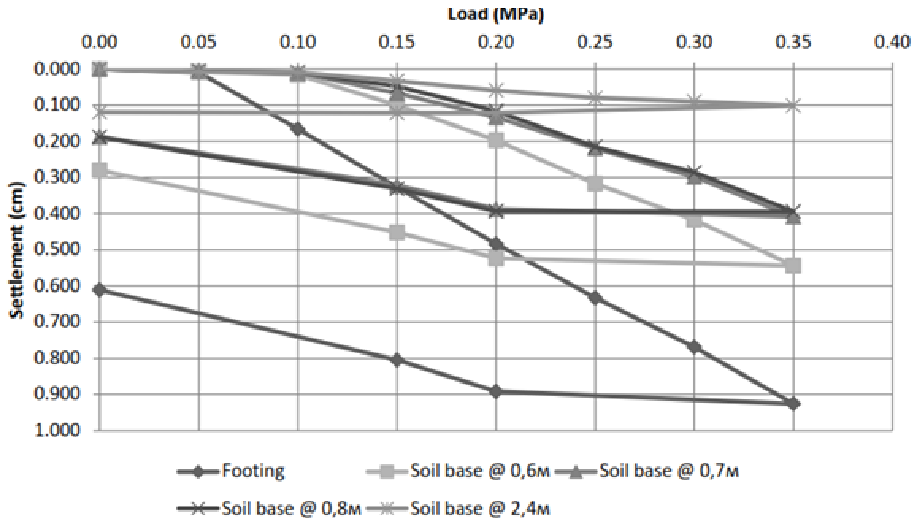

Figure 9. Load-settlement curves of Test point 3.

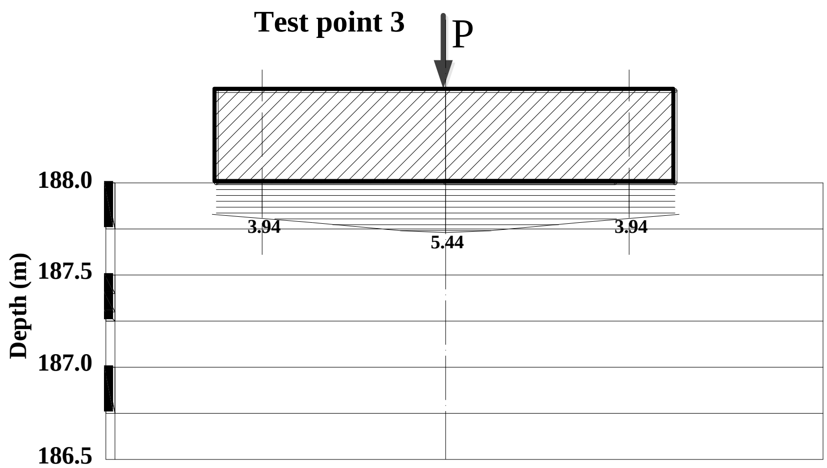

Figure 10. Horizontal variation of settlement at 0.6 m depth for Test point 3

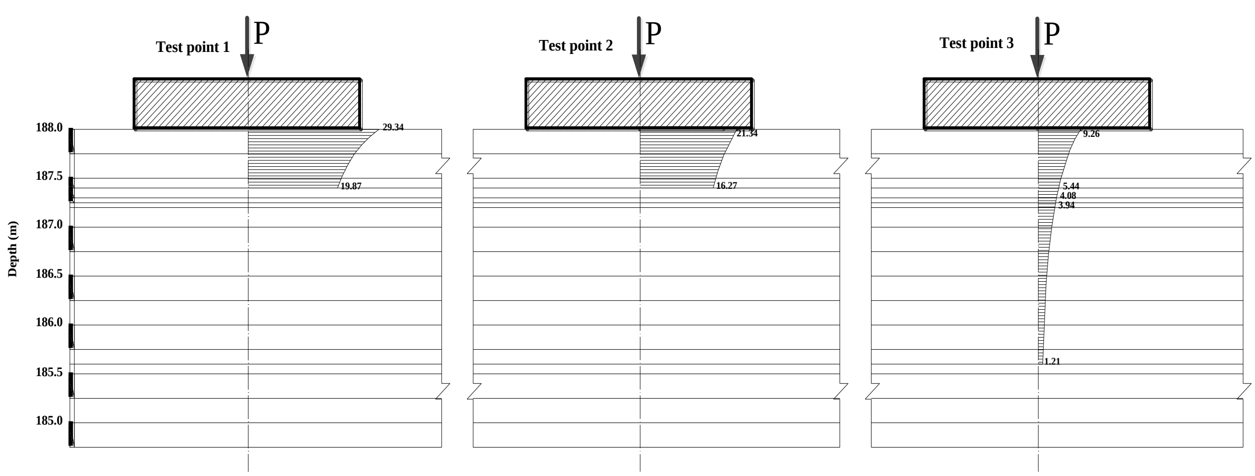

Figure 11. Vertical variation of settlement at test points.

With this soil condition under the layer of the reinforced soil, and in comparison with the other test points, maximum settlement of 29.34 mm was recorded for the footing at maximum load of 0.35MPa, while from the results of the load test of Test point 1, modulus of deformation of the soil base was determined as 19.25 MPa.

The Modulus of deformation of the soil base was determined in accordance with Russian standard (ГОСТ 20276-85, 1985) by the expression:

$$E = (1 - \nu^2) K_p K_1 \; B \;\; \Delta P / \Delta S \qquad (1)$$

Where, ν - Poisson's ratio taken as 0.30 - for sand and sandy soil; K_p–constant that depends on the ratio d/B; d-the depth of the test plate relative to the ground surface, in cm; B–width of the test plate, in cm; K_1- constant taken as 0.78 for square test plate;$\triangle$P - increase in pressure on the test plate, in MPa, equal to P_n-P_0;ΔS-increase in settlement corresponding to $\triangle$P, in cm, determined on linear portion of thegraph. The constant K_p is taken as 1 when the test is conducted in foundation pits/trench.

Below the layer of reinforced soil, at Test point 2, lies medium size grain sand of medium density (ИГЭ-12) with modulus of deformation E = 18 MPa, and below were layers of sand with varying grain sizes and densities. With this soil condition under the layer of the reinforced soil, maximum settlement of 21.34 mm was recorded for the footing at maximum load of 0.35 MPa. Modulus of deformation of the soil base at this test point was determined to be 22.31 MPa.

Below reinforced layer at Test point 3, lies sand of medium density (ИГЭ-13) with a modulus of deformation E = 25 MPa. In this case, maximum settlement of 9.26 mm was recorded for the footing at maximum load of 0.35 MPa.Modulus of deformation of the soil base at this test point was determined to be 50.76 MPa.

From Figure 10, the horizontal distribution of settlement at a given depth shows maximum value within the soil base along the center line of the footing. Observation of Figure 11 shows that, the recorded settlement reduces with depth. 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 that is, *s = f(p)*, based on this, it is suffice to say that the observed trend agrees with the existing theory for stress distribution in soil mass under a uniformly loaded footing.

Observation of the results from the 3 Test points showed that, the concrete-grid reinforcement generally increased the modulus of deformation of the soil bases, when compared with the initial values from the field exploration test. Although, the observed values were significantly affected by the type and properties of the soil below the reinforced layer, lower values were recorded with the presence of soft or weak soil(s) below the reinforced layer and vice versa.

Conclusion

The result of the study shows that, using concrete-grid for reinforcement of subsoil base under foundation, generally reduces the settlement and increases the bearing capacity of the soil, although, these are significantly affected by the type and properties of the soil below the reinforced layer. The presence of stiff or densesoil below the reinforced layer, gives lower settlement and higher bearing capacity values for the reinforced base as a whole,and vice versa.

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