Model and field experimental studies of reinforced clay bases

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Abstract. Using reinforced bases in clay soils is studied still insufficiently well. Therefore, in order to use the building practice of constructions of the bases on the reinforced ground it is necessary to carry out the analysis of their is stress-deformed condition to reveal a rational scope and to develop optimum constructions of the reinforced bases. For studying of work of the reinforced bases complex theoretical experimental researches have been carried out: laboratory modelling researches, natural tests, numerical modelling of work of the reinforced bases in water sated clay soils. The tests revealed that the single layer reinforcing clay base results in an increase in bearing capacity of 1.35 times the base. Effectiveness of reinforced bases increases with increasing precipitation structures. Stress-strain state reinforced base is markedly different from the stress-strain state of reinforced base. Introduction reinforcing element transforms the stress distribution in the core base. Stresses concentrate in an area of the reinforcing layer and decrease in the area below it. Redistribution of the active area in the vertical stress is reinforced based on depth amount 1.0 – 1.25 d from the base of the stamp, and in width by up to 1.0 d from the axis of the die. The test results showed high efficiency of reinforcement to increase the bearing capacity of foundations in clay soils. The carried out researches have allowed to receive a qualitative and quantitative picture of reinforced soil work of the bases and their stress-deformed condition to define a rational scope and to develop recommendations or their designing.

1. Introduction

Expenses for erection of the bases of buildings and constructions can make to 35% from a total cost of building. Reduction of the expenses on raising the bases is rather a vital problem, especially for building on the saturated clay soils. The improvement of properties of such priming coats would allow to lower cost of erection of the bases considerably.

One of ways of the improvement strength and deformative properties of the bases is applying the reinforced ground representing a combination of ground and reinforcement. The introduction of reinforcing elements allows to improve considerably strength and deformative characteristics of the soils and consequently, to lower expenses on the erection of the bases. The majority of experimental and theoretical studies of reinforced soils was carried out using sands. The conduct of reinforced bases in clay soils (CSRB) is studied not sufficiently. Therefore for introducing them in building practice of designs of the bases from a reinforced ground it was necessary to carry out the analysis of their stressed and deformed condition. Although it is long since the research in this field has been conducted by our University Bartolomey A [1], Ponomaryov A B. [1, 3], Kleveko V I [2, 4, 7, 8], Zolotozubov D G [3], Tatiannikov D A [6]. The regularity of the interaction of reinforcing layers in
clay soils are studied insufficiently, therefore it was necessary to execute complex researches of the stressed and deformed condition of an active zone of CSRB.

On the basis of these experiments the optimum range of application of CSRB in clay soils and their stressed and deformed condition is revealed.

2. Experimental researches

2.1. Model researches

Experimental researches were conducted through two stages. The first stage included carrying out small-scale modeling plate load tests of various designs of CSRB in laboratory conditions. The second stage represented plate load tests of CSRB in a natural ground conditions.

At the first stage of experimental works the trials of small-scale models of various designs of CSRB for vertical load action in loam were carried out at the liquidity index $I_L$ from 0.2 to 0.8 with triple repeatability. The researches were conducted for two sorts of reinforcing: one- and two-layer, and for two types of reinforcement, the following ones were applied: the nonwoven geotextile, having strength of 15 kN / m, the axial stiffness of 25 kN / m, and the fiber glass fabric having strength of 45 kN / m, the axial stiffness of 2100 kN / m. The choice of these types of reinforcing materials was due to different strength and deformation properties. As a base model there was used a round rigid metal stamp in diameter of 64 mm. The reinforcing material was pawned in a ground at single layer reinforcing on depth of 0.3$d$ ($d$ - diameter of a plate), and for two-layer one on depth of 0.3$d$ and 0.5$d$ and represented a circle in diameter of 3d.

The current problem of the experimental researches with CSRB models was revealing the conformity with the law of the development of the depth of immersion from loading for various designs and reinforcing materials, and also comparison of their bearing capacity with not reinforced ground. For the estimation of the bearing capacity of CSRB the factor of influence of reinforcing $K_R$, equal to the relation of the bearing capacity of CSRB to a bearing capacity not reinforced has been entered V I Kleveko [5]. For an illustration the schedule of the dependence of the factor of the influence of reinforcing $K_R$ from the liquidity index $I_L$ of ground, resulted on figure 1 has been constructed.

![Figure 1. The dependence of the factor $K_R$ on the liquidity index $I_L$.](image)

The analysis of the results received after the conducted researches, allows to draw the following conclusions:

1. Reinforcing the base depending on a consistence leads to bearing capacity increase in 2 times and more in comparison with the bearing capacity of not reinforced base in similar conditions.
2. The most effective application of reinforcing is reached in soils liquidity index $I_l$ from 0.4 to 0.6.
3. In the investigated range of the liquidity index $I_l$ of ground it is more an effective using of reinforcing materials with high strength and deformative characteristics.

2.2. Field test

For checking the results of modelling researches and defining of the stressed and deformed condition of CSRB in situ plate load researches have been conducted. While carrying out the trials the round rigid plate in diameter of 600 mm was used. As a reinforcing material fiber glass fabric by the size of 3d, settling down on the depth of 0.25d ($d$ - diameter of a round plate) was applied. The trials were conducted for the reinforced and unreinforced base in clay with following parameters: the liquidity index $I_l = 0.4$, cohesion $c = 13$ kPa, angle of internal friction $\phi = 10^\circ$, water content $w = 28\%$, unit weight $\gamma = 18.8$ kN/m$^3$, $E = 7.5$ MPa. In total, three tests were carried out for the reinforced and unreinforced bases.

For studying the stressed and deformed condition of an active zone of CSRB normal pressure by means of pressure sensors and vertical deformations of soil by means of soil gauge were measured. On figure 2 the scheme of the installation of the pressure sensors and the soil gauges is presented.

Small-diameter holes were drilled to install pressure sensors and soil gauges below the reinforcing layer. They were filled with soil that was recovered during drilling after the sensors were installed. The ground surface was carefully leveled and sensors were installed on it. Then the reinforcing layer was laid. On top of it, filling and compaction of a layer of soil 15 cm thick was carried out. Compaction of the soil was carried out with a hand roller to a compaction coefficient equal to 0.95. After the installation of all the equipment, an exposure was made for two weeks to relax the stresses in the soil.

On the test results schedules of the dependence of the depth of immersion of the plate from loading and value of vertical pressure and deformations are received. Figures 3 and 4 show photographs of field tests of the reinforced base.

On figure 5 the schedules of dependence of settlements of the plate from loading for the reinforced and not reinforced bases are resulted. From schedules it is visible, that divergences in experimental and theoretical settlements for both sorts of the bases are insignificant.

**Figure 2.** The scheme of the installation of the pressure sensors and the soil gauges.
Figure 3. Preparation for field testing of reinforced bases - laying of reinforcement.

Figure 4. Process of conducting field testing of reinforced bases.
Figure 5. The comparison of the results of the in situ plate load tests and numerical experiments.

On figures 6 to 8 the results of the measurements of vertical pressure are presented. On figures 9 to 11 the results of the measurements of the vertical deformations are presented.

Figure 6. The comparison of the values of vertical pressure for load 125 kPa on the depth 0,25d.
Figure 7. The comparison of the values of vertical pressure for load 125 kPa on the depth 0.75d.

Figure 8. The comparison of the values of vertical pressure for load 125 kPa on the depth 1.25d.

Figure 9. The comparison of the values of the vertical deformations for load 125 kPa on the depth 0.25d.
The analysis of the results in situ plate load researches in clay soils allows to draw the following conclusions:

1. Reinforced bases in soils lead increasing their bearing capacity minimum 1.2 times and decreasing their settlements to 1.6 times.

2. The stressed and deformed condition of CSRB considerably differs from the stressed and deformed condition of unreinforced bases. The introduction of a reinforcing element transforms the stress distribution in the upper part of an active zone of the base on the depth to 1.25d. The vertical pressure under the reinforcing layer decreases on average to 38-39%.

3. Numerical model

On the basis of numerical researches by the program "PLAXIS" the analysis of the stressed and deformed condition of reinforced earth foundations in clay soils is given. The comparison of the numerical analysis and experimental results of researches has been executed.

For the research of the stressed and deformed condition of CSRB and its comparison with unreinforced base vertical pressure and settlements in the active zone of the base by means of the program "PLAXIS" have been defined. The axisymmetrycal problem was resolved in elastoplastic statement. The "advanced" Mohr-Coulomb model of ground was applied to calculations. The comparisons of the results of the calculation on numerical analysis and in situ results are resulted on figures 5 to 8 and 12 to 14. The analysis of these schedules shows, that for CSRB the average error makes 12.7 %, and for unreinforced base of 11.4 %. The comparison of the results of values of vertical
deformations has shown, that the average error for CSRB has made 4.4 %, and for not reinforced base – 8.2%. The carried out analysis shows, that the program "PLAXIS" allows to count CSRB with sufficient accuracy.

Figure 12. The comparison of values of the vertical deformations of soil for numerical analysis and in situ plate load tests for load 125 kPa on the depth 0.25d.

Figure 13. The comparison of values of the vertical deformations of soil for numerical analysis and in situ plate load tests for load 125 kPa on the depth 0.75d.

Figure 14. The comparison of values of the vertical deformations of soil for numerical analysis and in situ plate load tests for load 125 kPa on the depth 1.25d.
4. Conclusions

1. For low loaded bases it is optimal to use single layer reinforcing by horizontal layers with their placing on the depth of 0.2–0.25d from the bottom of the foundation. A rational range of application of reinforcing in clay soils has the following date – IL from 0.4 to 0.6.

2. Earth bases reinforced by horizontal layers allows to raise the bearing capacity of clay ground to 1.2 times and to lower deposits of the bases on CSRB to 1.6 times.

3. The executed researches of the stressed and deformed condition of CSRB has revealed, that the introduction of the reinforcing element transforms the stress distribution within the upper part of the active zone of the base on the depth to 1.25d. The vertical pressure under the reinforcing layer decrease on the average up to 38–39%.

4. According to the foregoing researches a special method of the foundation settlement estimate was created V I Kleveko [5].

References

[1] Bartolomey A, Ponomaryov A, Kleveko V and Ofrikhter V 1996 Use of geosynthetic materials for increasing bearing capacity of clayish beddings Geosynthetics: Applications, Design and Construction; Proc. of the first European Geosynthetics conf. EUROGEO 1 (Maastricht, 30 September - 2 October 1996) (Rotterdam: Balkema) pp 459–61

[2] Kleveko V I 2012 Estimate of the settlement of the foundation on clay grounds reinforced with horizontal layers PNRPU Bulletin. Environmental protection, transport, security of life 1 89–98

[3] Ponomaryov A B, Kleveko V I and Zolotozubov D G 2010 Experience of geosynthetic material application for karst danger Geosynthetics: Advanced Solutions for a Challenging World, Proc. 9th Int. Conf. on Geosynthetics (Guarujá, Brazil, 23-27 May 2010) pp 2005–08

[4] Kleveko V I 2014 Experimental studies of the stress-strain state of reinforced soil foundations in clayey soils News Kazan State University of Architecture and Civil Engineering 4 188–97

[5] Kleveko V I 2014 Research of the work of reinforced clay bases PNRPU Bulletin. Construction and Architecture 4 101–10

[6] Tatiannikov D A and Kleveko V I 2015 Investigation of the interaction of geosynthetics with ground on the example of shear test and pull-out test Geotechnical Engineering for Infrastructure and Development. Proc. of the XVI European Conf. on Soil Mechanics and Geotechnical Engineering, ECSMGE 2015. Geotechnical Engineering for Infrastructure and Development 6 pp 3389–94

[7] Semyonov D A and Kleveko V I 2018 Use of geosynthetic shells in construction PNRPU Bulletin. Construction and Architecture 2 78–87

[8] Gorbunova M A and Kleveko V I 2020 Analysis of methods for strengthening the subgrade with vertical and horizontal reinforcement Master's Journal 1 149–55