Original Scientific Paper

doi:10.5937/jaes14-9136 Paper number: 14(2016)1, 350, 28 - 35

INFLUENCE OF THE FORM AND SIZE OF THE ISOLATED FOUNDATIONS ON THE STRESS-STRAIN STATE OF THE SOIL BASE

Glushkov Alexey Vyacheslavovich
Volga State University of Technology, Russia
Bartolomey Leonid Adolfovich
Volga State University of Technology, Russia

This article reviews the investigations of the stress-strain state of the foundation bed under the variously shaped footings. The foundation basis is featured by cohesive and non-cohesive soil. Construction regulations do not allow to estimate the stress-strain state of bases with the complex shape of the bed.
The article presents qualitative and quantitative stress-strain state changes of shape modification of the drawings. Research indicates the behavior of soil under the complex form foundation, components of displacements and stress isolines are also presented. A special attention is given to the assessment of the scale factor influence on the stress-strain state in the basis of the cross-shaped foundation.
This article seems to be interesting to those who work in the field of building construc-tion and geotechnics engineering.

Key words: Foundation form, Cruciform, Cross-shaped, Three rayed, Stress-strain analysis, Scale factor

INTRODUCTION

One of the ways of decrease in a material consumption and increase of the bearing capacity of the foundation is the optimization of the form of spread foundation beds.

In the construction practice shallow foundations under the columns are carried out square and rectangular in the plan view. The improvement of the design of such foun-dations is possible by means of optimization of the form of the foundation base.

In construction regulations there is no method of calculation of the foundations with a complex form of the base in the plan view, so the problem of the estimation of the stress-strain state of effective designs of the spread foundations is actual.

LITERATURE REVIEW

Professor E. A. Sorochan [07] conducted experimental investigations of square and cross-shaped footings in a tray of 8x8x8 m in size. In the basis of the foundation sand of an medium fineness and an medium density with e=0,55-0,65 was used. The results of the tests confirm positive influence of angular cuts of foundation settlements. The replacement of square footings on cross-shaped with identical external sizes allows to reduce the consumption of metal on 26% and concrete on 15% by the identical load on the foundation.

V. P. Ermashov [01] investigated the influence of the cut forms in the reinforced con-crete foundation on the distribution pattern of normal contact stresses along the foun-dation base. As a result, V. P. Ermashov came to a conclusion, that the arrangement of angular cuts in slabs leads to the formation of local zones of a limit state in soil, con-centrating the contact stress in the central part of the foundation base. It allows to re-duce the bending moment in the critical section of the slab and to reduce the material capacity of the foundation.

Lightened bearing posts with the use of conic and pyramidal shell constructions were considered by professor A. N. Tetior [08]. From his point of view the best economy of the footing material is the calculation of durability by the limit equilibrium method with the use of the kinematic way, in the principle of which the actual schemes of the collapse of shell construction designs are laid.

THE RESULTS OF INVESTIGATIONS

Simultaneous accounting of strength and deformative properties of soil in the calcula-tions of the stress-strain state of the foundation with various forms of the foundation was carried out in

*Volga State Universtiy of Technology, 3 Lenin sq., Yoshkar-Ola, Republic of Mari El, Russian Federation, 424000; 256289@list.ru

the solution of the three-dimensional elastoplastic issue of FEM (Fi-nite Element Method) with the use of the program PLAXIS. Soil in a prelimit state rep-resents the linearly elastic continuum changing into the limit (plastic) state with the subsequent loading according to the Mohr-Coulomb yield criterion. Calculation is car-ried out with the use of the incremental load stepping.

Foundation calculations are made for two characteristic types of the basis: cohesive soil and non-cohesive soil. As cohesive soil soft clay was used (γ=18 kN/m^3, E=12,0 MPa, c=20 kPa, φ=18º); as non-cohesive soil sand of medium fineness and medium density was accepted (γ=16,5 kN/m^3, E=26,0 MPa, c=1 kPa, φ=30º). There was a re-search of the stress-strain state of the basis of the spread foundations of equal square S=4m^2=const with the various form of the foundation in the plan: square (model 1), triangular (model 2), three-rayed (model 3), cross-shaped (model 4). Settlement models of the foundations are chosen equilateral.

Researches showed that the change of the foundation form in the plan view from square (model 1) to three-rayed (model 3) and cross-shaped (model 4) influences on the stress-strain state of the soil basement.

The main results of the research connected with foundation settlements are presented in figure 2a. It is established that the foundation of cross-shaped form (model 4) with the pressure of P=400 kPa in cohesive soil is 1,27 times less than the foundation settle-ment of square form (Model 1). It can be seen from the graphs that the settlement of S triangular footing (model 2) with the pressure of P=400 kPa in cohesive soil is 1,06 times less than the foundation settlement of square form, and the settlement of the three-rayed foundation (model 3) is 1,16 times less than the foundation settlement in model 1, respectively.

The presence of ledges along the foundation base influences positively on the work of soil in the basis in comparison with the model of square form.

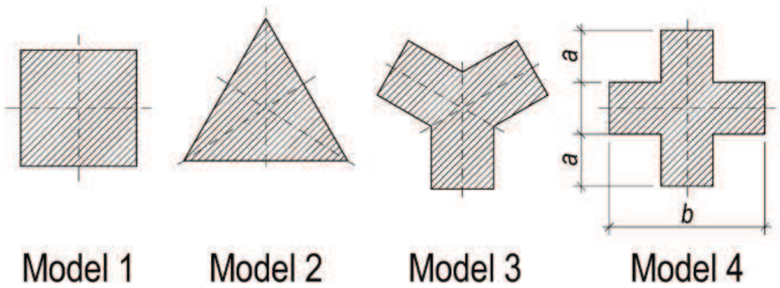

Figure 1: Settlement models of the foundations in the plan view

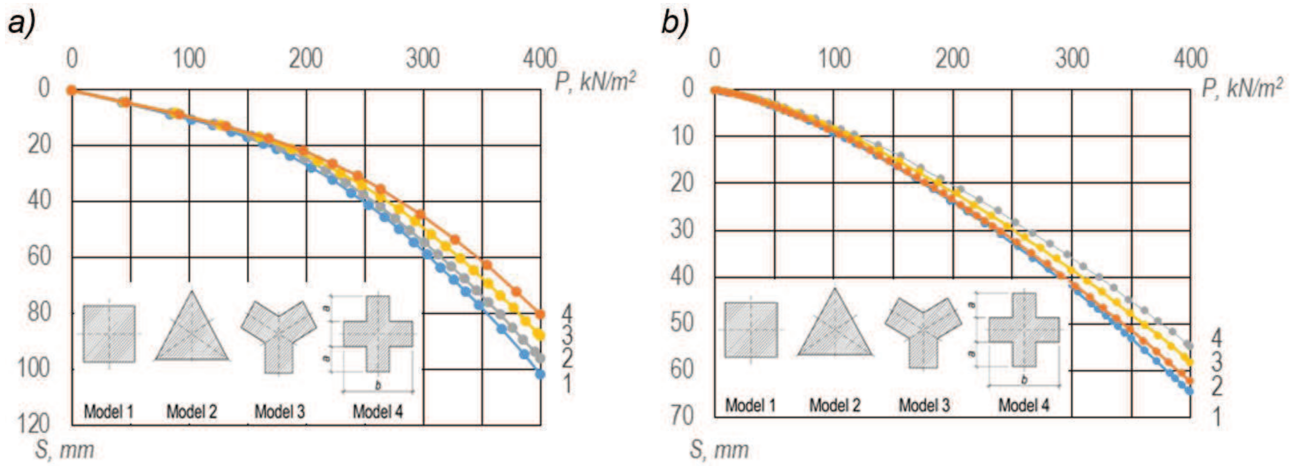

Figure 2: Settlements from vertical loading of S=f(P) for cohesive (a) and non-cohesive (b) soil with 1 – square; 2 – triangular; 3 – three rayed; 4 – cross-shaped foundations

In figure 3a isolines of vertical displacements in the basis (cohesive soil) for square (mod-el 1) and cross-shaped (model 4) foundations are given. The transition to the cross-shaped form of the foundation base leads to decrease the size of maximal vertical dis-placements at the level of the base by 1,27 times at *P*=400 kPa. The width of the de-formation zone for the cross-shaped foundation is 1,25 times more, than for the square foundation due to the activating of the more amount of soil in the active zone. At the depth of 0,5b vertical displacements of Uy make 82 mm (model 1) and 63 mm (model 4) respectively (correspondingly). The depth of the deformation zone of the square and cross-shaped foundation at *P*=400 kPa makes 1,82b and 1,76b respectively.

Isolines of horizontal displacements of U_x have a closed character. The maximum value of horizontal displacements is located at the distance of (1,10 ÷ 1,15)b from the foundation axis, at the depth of (0,35-0,40)b (figure 3b). It is established, the transition from model 1 (square) to model 4 (cross-shaped) at *P*=400 kPa leads to decrease the maxi-mum hori-zontal displacements of U_x by 1,39 times.

The analysis of distribution of vertical stresses σ_y in cohesive soil shows that there is a concentra-tion of stresses in the foundation bed, the maxi-mum values of σ_y at *P*=400 kPa for models 1 and 4 make 380,9 kPa and 386,3 kPa respectively. Observation of results (figure 4a) shows that for model 1 and model 4 various distribution pat-tern and stress decay of σ_y with the depth takes place. For the cross-shaped foundation stresses of σ_y are distributed in an active zone on the larg-er area and quicker fade with the depth. At the depth of 0,75b from the foundation σ_y value for model 1 decreases by 1,17 times, for model 4 decreases by 1,72 times respectively.

The carried out analysis of τ_{xy} shearing stress dis-tribution in the basis shows that at *P*=400 kPa the greatest τ_{xy} values for models 1 and 4 have an alternating-sign charac-ter and make 64-68 kPa (figure 4b). Isolines of τ_{xy} stresses have a closed character. Maxi-ma of τ_{xy} are found at the distance of 0,55b from an axis of the foundations and are localized in the area from the depth of (0,2-0,3)b.

In figure 5 one can see distribution of zones of plastic deformations in the basis of square (model 1) and cross-shaped foundations (model 4). Zones

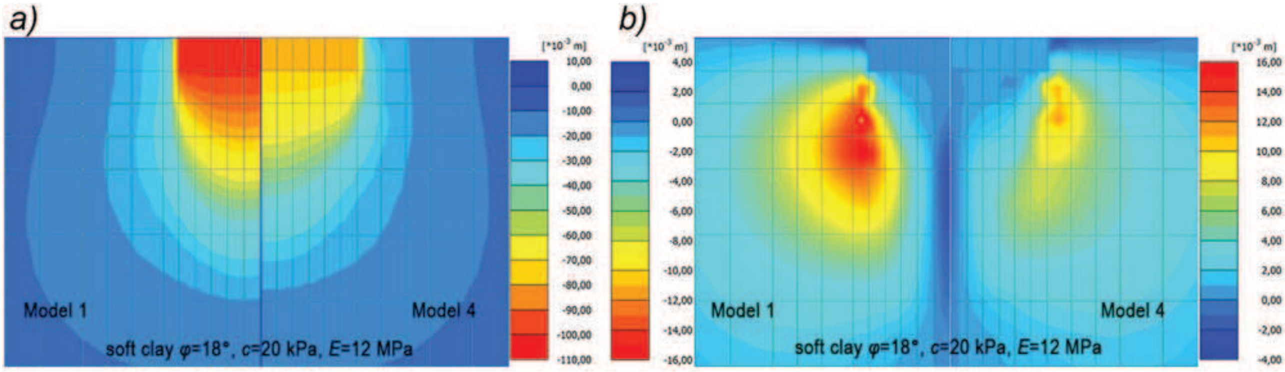

Figure 3: Isolines of vertical (a) and horizontal (b) displacements in the basis of square (model 1) and cross-shaped (model 4) foundations for cohesive soil at P=400 kPa

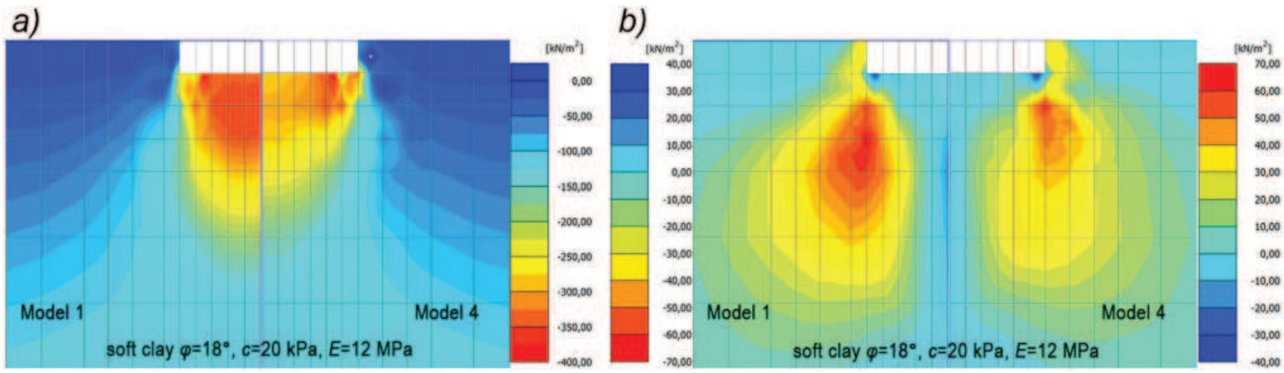

Figure 4: Isolines of vertical (a) and shearing (b) stresses in the basis of square (model 1) and cross-shaped (model 4) foundations for cohesive soil at P=400 kPa

of limit state are detected in the area of adjacent the foundation base. For the considered models 1 and 4 at *P*=400 kPa the width of the area of plastic deformations makes (2,3-2,4)b, the depth of distribu-tion of plastic zones makes 1,9b respectively.

From figure 5 it is visible that the area of distribution of limit state zones in the basis of the cross-shaped foundation is 12-15% less, than for the square form foundation.

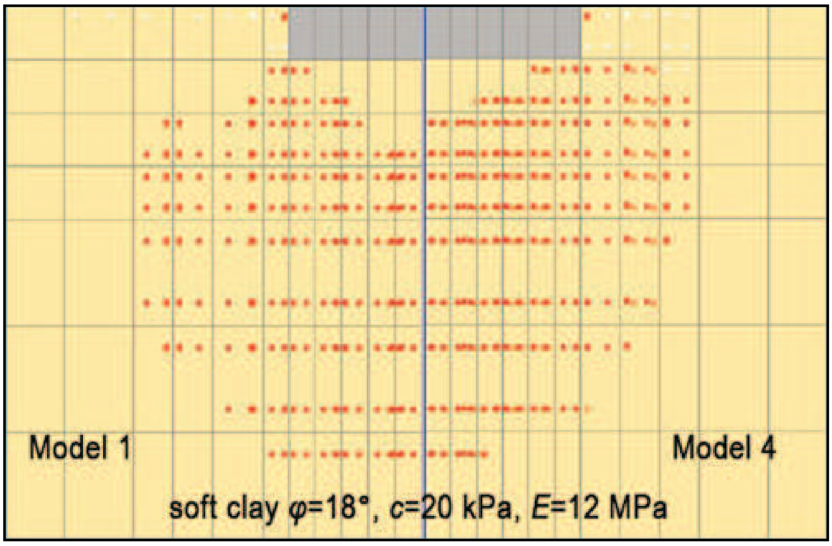

Figure 5: Zones of plastic deformations in the basis of square (model 1) and cross-shaped (model 4) foundations for cohersive soil at P=400 kPa

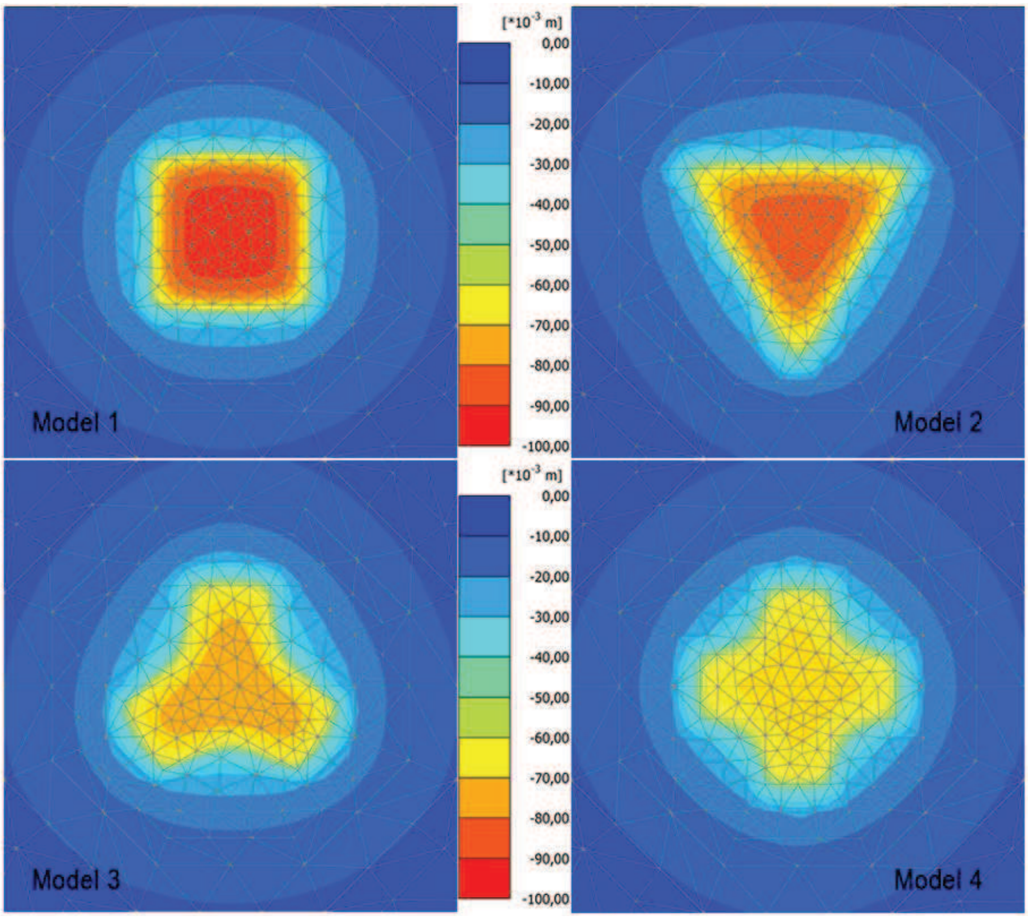

Figure 6: Isolines of vertical displacements at the depth of 0,25b in the basis of calculation models of the foundations for cohesive soil at P=400 kPa

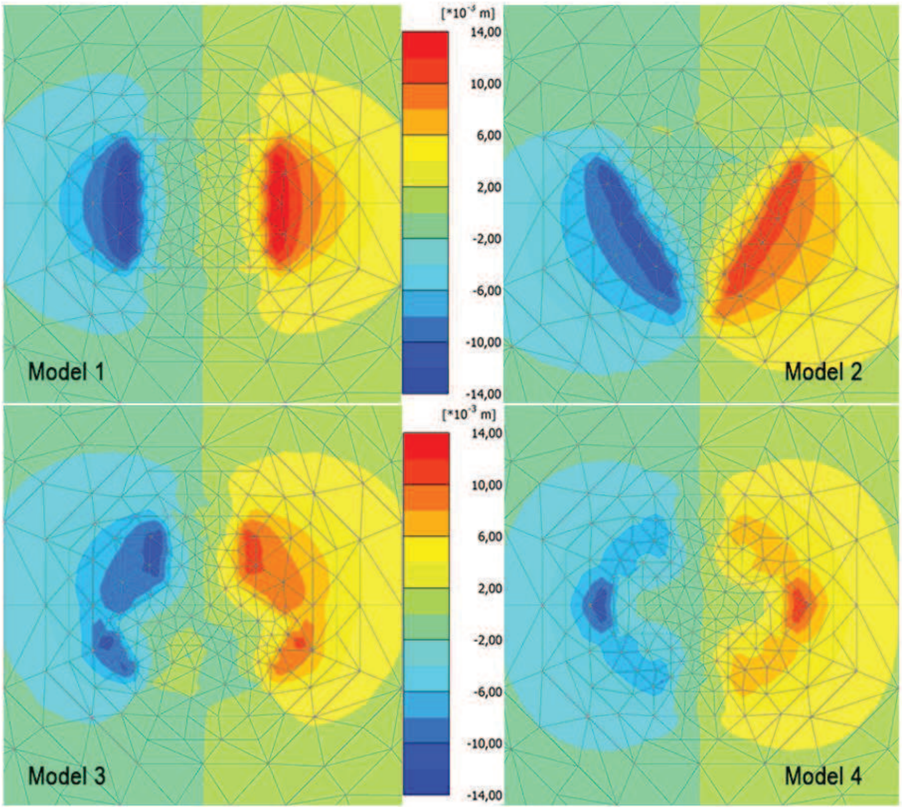

Figure 7: Isolines of horizontal displacements at the depth of 0,25b in the basis of calculation models of the foundations for cohesive soil at P=400 kPa

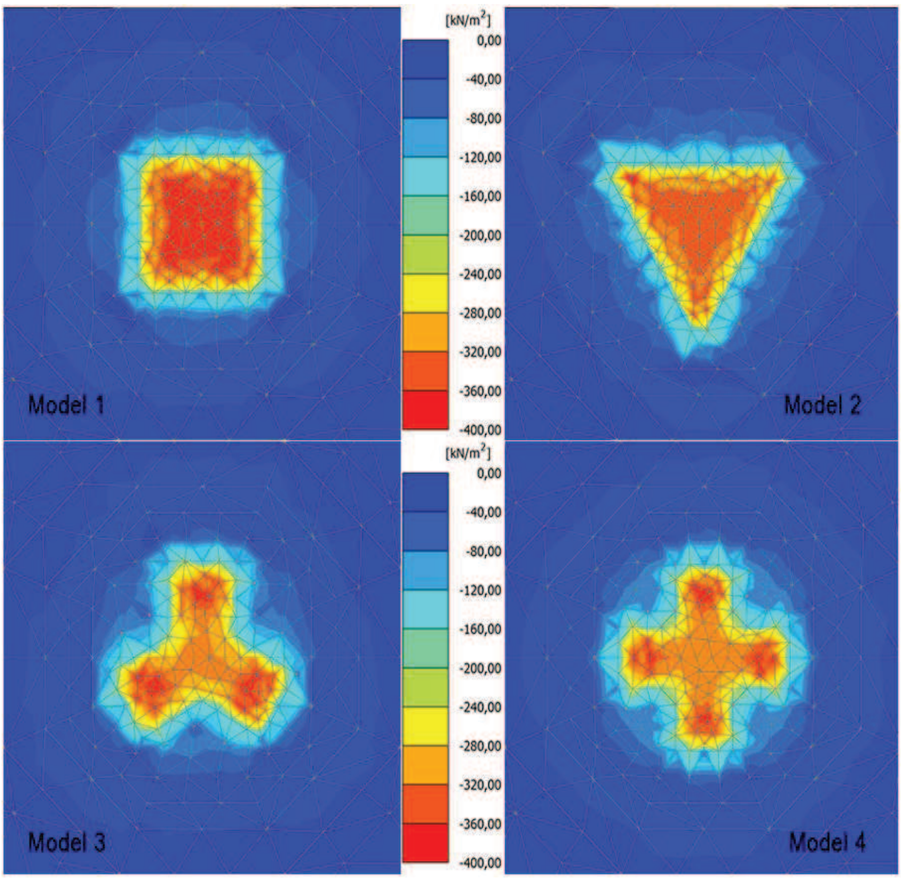

Figure 8: Isolines of vertical stress at the depth of 0,25b in the basis of calculation models of the foundations for cohesive soil at P=400 kPa

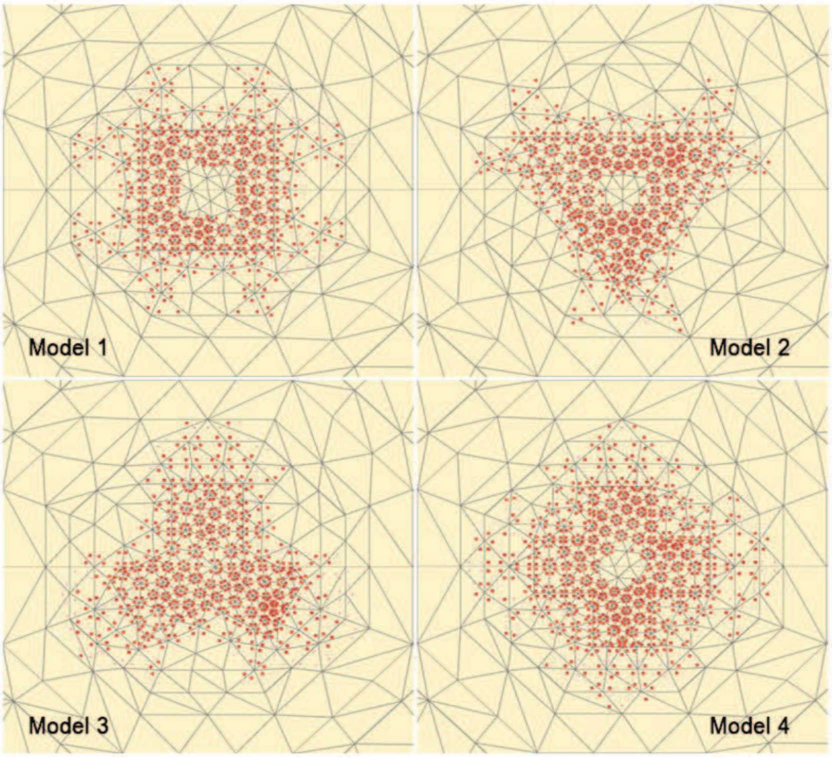

Figure 9: Zones of plastic deformations at the depth of 0,25b in the basis of calculation models of the foundations for cohesive soil at P=400 kPa

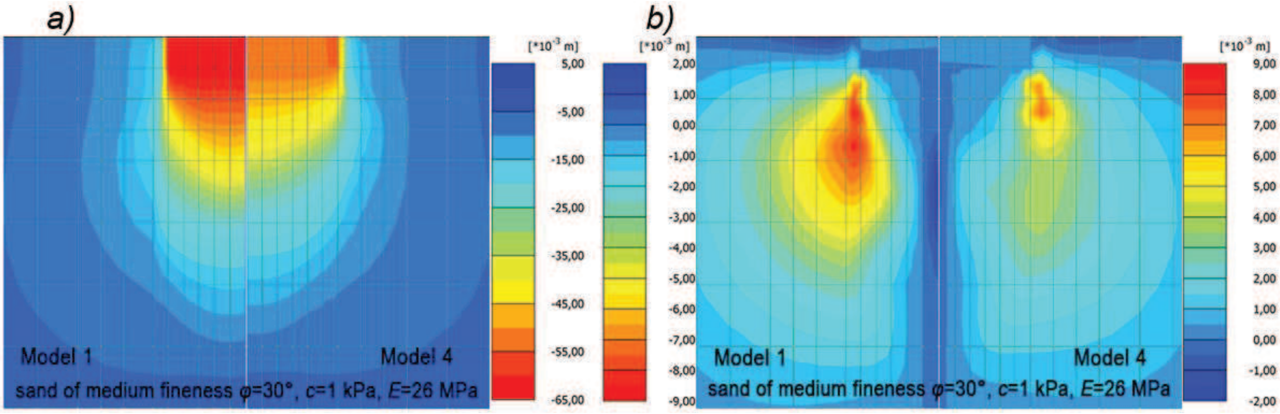

Figure 10: Isolines of vertical (a) and horizontal (b) displacements in the basis of square (model 1) and cross-shaped foundations (model 4) at P=400 kPa (non-cohesive soil)

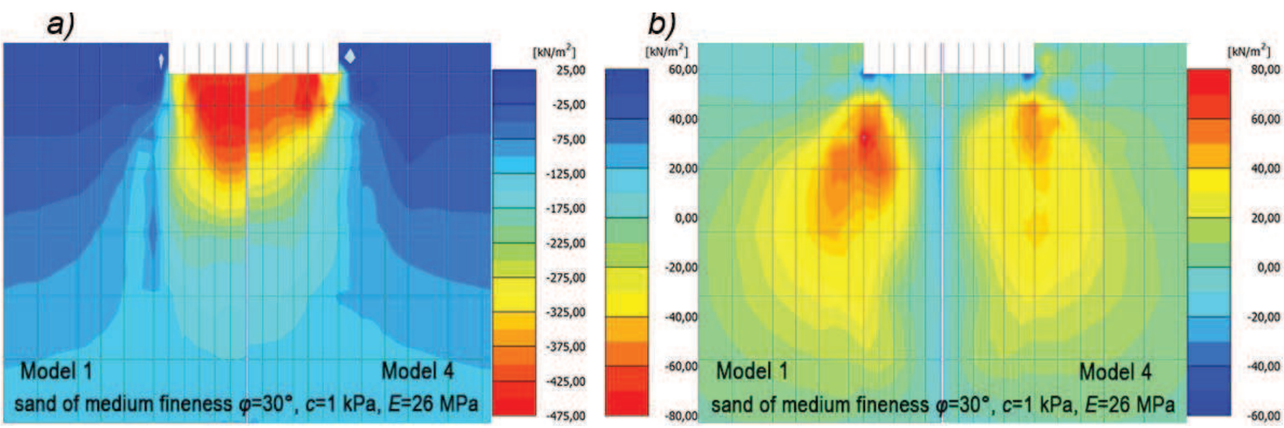

Figure 11: Isolines of vertical (a) and shearing (b) stresses in the basis of square (model 1) and cross-shaped foundations (model 4) at P=400 kPa (non-cohesive soil)

The assessment of influence of the scale factor on the stress-strain state in the basis of the cross-shaped foundation is carried out. As a scale factor to overall dimensions of the foundation b index K was used. At *K*=1,0 the size value of the area of the founda-tion makes K^2*x A*=4,0 m2.

Loading settlement distribution *S*=f(P) of spread cross-shaped foundations at various values of scale factors of K=0,5 (*A*=1 m2), *K*=1,0 (*A*=4 m2), K=2,0 (A=16 m^2), to *K*=5,0 (A=100 m^2) for cohesive and non-cohesive type of soil in the basis are given in figure 13. The increase in the area of the cross-shaped foundation leads the settlement S to the essential increase. At the increase of the area A of cross-shaped foundation by 25 times (*K*=5,0) in the cohesive soil at *P*=400 kPa the settlement increases by 3,37 times (figure 13a), and in the non-cohesive basis by 3,14 times (figure 13b) respectively.

In the analysis of vertical displacements of Uy it can be seen that the increase in the area of the cross-shaped foundation leads to the proportional reduction of the depth of the deformation zone. At the increase in the area *A* by 25 times (*K*=5,0) the deformation zone in cohesive soil decreases from 1,11b to 1,01b at *P*=400 kPa, in non-cohesive soil from 1,29b to 1,13b respectively.

It is established by researches that at the increase in overall dimensions of the cross-shaped foundation there is a proportional growth of the maximum horizontal displace-ments of Ux for cohesive soil. So, at *P*=400 kPa in the cohesive basis the value of Ux max makes 11,6 mm (*K*=1,0); 22,8 mm (*K* =2,0); 49,1 mm (*K*=5,0) respectively. In non-cohesive soil at *P*=400 kPa there is no such a proportion at the change of the scale factor: $U_x max$=6,9 mm (*K*=1,0); $U_x max$=9,1 mm (*K*=2,0); $U_x max$=15,6 mm (*K*=5,0).

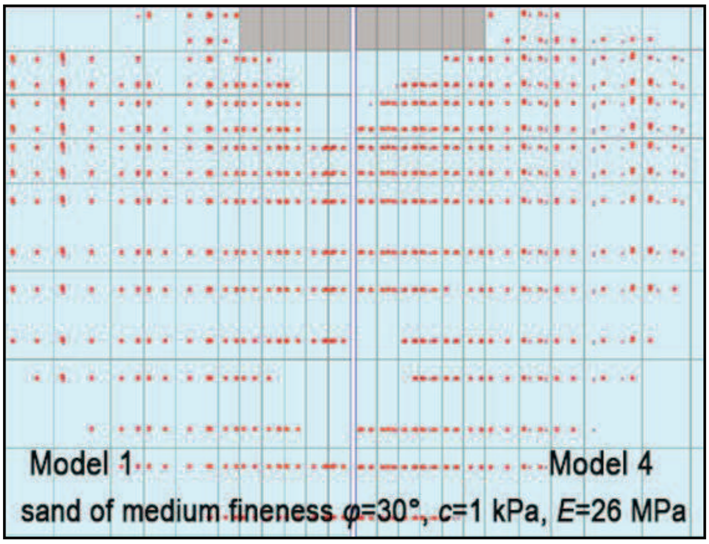

Figure 12: Zones of plastic deformations in the basis of square (model 1) and cross-shaped foundations (model 4) at P=400 kPa (non-cohesive soil)

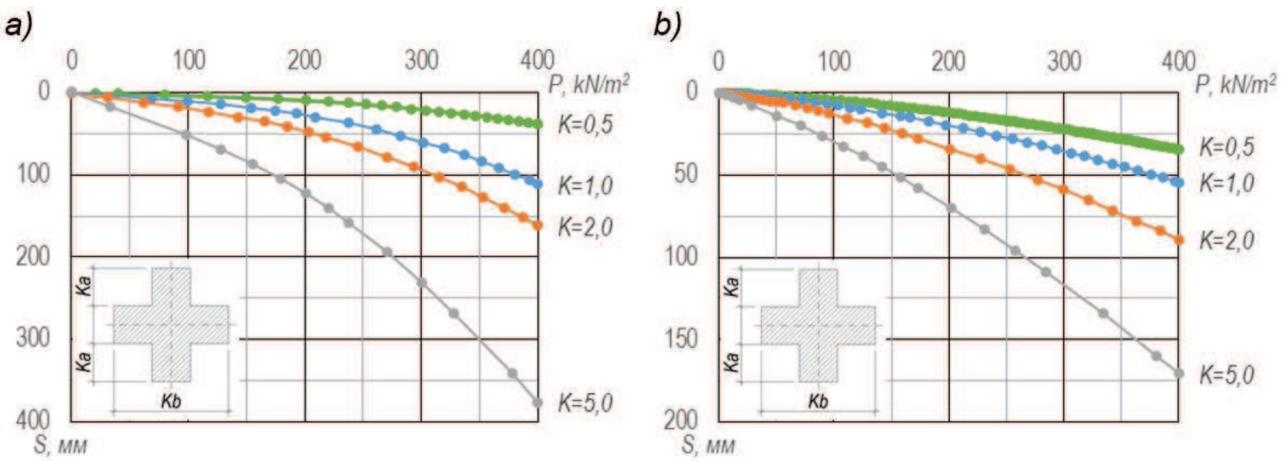

Figure 13: Dependences of the settlement from vertical loading of S=f (P) for cohesive (a) and non-cohesive (b) soil at various values of the scale index K

The analysis of distribution of plastic deformation zones at *P*=400 kPa shows that the greatest width of the distribution area makes (1,7-1,9)b at the depth of (0,30-0,40)b for cohesive and non-cohesive type of the foundations. The change of the scale index K from 1,0 to 5,0 at *P*=400 kPa leads to the reduction of the depth of distribution zones of limit balance from 1,40b to 1,14b (cohesive soil); and from 1,77b to 1,15b (non-cohesive soil) respectively.

With the loading growth the elastic core having a triangle form under the foundation detects. The height of the elastic core which moves soil apart depends on the value of the scale index *K*. For non-cohesive soil at *P*=400 kPa the height of the elastic core makes: *h*=0,24b (*K*=1,0); *h*=0,36b (*K*=2,0); *h*=0,53b (*K*=5,0) respectively. In the cohesive basis the values of h make: h=0,22b (*K*=1,0); *h*=0,22b (*K*=2,0); *h*=0,28b (*K*=5,0).

RESULTS

For the wide use in practice design of nonlinear solutions of soil mechanics it is obvi-ously possible to reveal the influence of factors (φ; c; E; *v*; p; H/b; K) on the deposit of S cross-shaped foundations. As the mathematical model, connecting the size of the cross-shaped foundation settlement with initial parameters, multifactor power dependence is accepted.

$$S = \frac{0,12 \cdot p^{1,90} \cdot (H / b)^{0,37} \cdot K^{1,05}}{E^{0,89} \cdot c^{0,66} \cdot \varphi^{1,49} \cdot^{0,71}} \qquad (1)$$

(cohesive soil)

$$S = \frac{2441,06 \cdot p^{1,60} \cdot (H / b)^{0,49} \cdot K^{0,82}}{E^{1,55} \cdot \varphi^{3,31}} \qquad (2)$$

(non-cohesive soil)

Comparison of the received nonlinear decisions to data of static tests of the founda-tions with various forms of the foundation base [5] indicates their good compliance and possibility of the design of effective foundations with the complex form of the founda-tion base, proceeding from the condition of the maximum allowable settlement.

REFERENCES

1) Ermashov, V.P. (1985) Influence of the foundation form on the distribution of normal contact stresses, Basements, foundations and soil mechanics Vol. 2, p.p. 16-17, Moscow: Stroyizdat
2) Glushkov, A.V., Bartolomey, L.A., Glushkov, V. E. Patent for the invention No. 2529977 (2013) of the Russian Federation "The foundation with ledges on the foundation base", Moscow: Rospatent.
3) Glushkov, A.V., Bartolomey, L.A., Glushkov, V.E. (2013) Stress-strain analysis of the odd-shaped footings, Materials of the international conference "Innovative constructions and materials in foundation engineering and geotechnics", Lipetsk: Paleotip, p.p. 146-151.
4) Glushkov, A.V., Glushkov, V. E. Useful model patent No. 108053 (2011) "The cross-shaped foundation with the ledge on the foundation base", Moscow: Rospatent.
5) Glushkov, A.V., Glushkov, V.E. (2014) Stress-strain analysis of the odd-shaped footing soil basement, Modern problems of science and education Vol. 3, http://www.science-education.ru/117-13192
6) Glushkov, V.E, Glushkov, A.V. (2010) Optimization of the foundation base form, Materials of the 5th international conference "City Agglomerations in Landslide Territories", Volgograd: VOLGGASU, p.p. 49-52.
7) Sorochan, E.A. (1986) Foundations of industrial buildings, Moscow: Stroyizdat.
8) Tetior, A.N. (2010) Foundations, Moscow: Academy.

Paper sent to revision: 28.09.2015.

Paper ready for publication: 13.01.2016.