Use of program ANSYS in the analysis of interaction between a rigid foundation and reinforced soil

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Abstract. Work is devoted to model and process the results of interaction between a rigid metal plate and a reinforced sand base using the software "ANSYS". One of the effective ways to increase the strength is the inclusion of various materials (reinforcement) in the soil below the structure. It increases the resistance of the soil to stress and shear, limits lateral deformation. Organic, synthetic, metal and stone materials are used as reinforcing elements. The studies showed that the effectiveness of the reinforcement and the bearing capacity of the reinforced ground depend on the position, length, roughness and fixity condition of the reinforcement [27].

1. Introduction

In the laboratory of "soil Mechanics" TSTU more than 20 years, conducted testing of reinforced bases. This article presents the results of the tank tests of a two-layers base, the upper layer of which (in the first series of the experiments was 30cm, in the second 10cm) was represented by distribution cushion of fine homogeneous sand, the lower (in the first series was 30cm, in the second 50cm) imitated a weak base. Sawdust was used for the lower layer. In order to strengthen the base, smooth and corrugated steel rods were used, which were placed both under the sole of the model and outside the sole. Cement-sand injections with different angles of inclination and volumes were also used. Rods and injections were supposed to limit lateral deformations and change the stress state in the soil [1-5, 8, 10], adding reinforcing fibers basically can increase soil tensile strength [26]. Reinforcing also increases bearing capacity of soil [14-22] and reducing settlement [23-25]. During experimental tests, were determined the current displacement (s), where s – is the displacement of the center of the model, and displacement prior to ultimateload (sₙ). Deformations were measured by indicators of the hour type ICH-10, fixed on the reference frame. The repeatability of the experiments was 2..3 times [6, 7, 9].

To assess the effect of reinforcing soil on the development of deformation in the base, a numerical solution by FEM for the scheme "Foundation – base" was performed. The results were processed using finite element method by ANSYS / Multiphysics [11-13].

To simulate soil-matrices, a three-dimensional model / Drucker-Prager with dimensions of 550 mm x 650 mm x 750 mm was studied, which consisted of 6256 elements, each of which had a length of 40 mm, a width of 40 mm and a depth of 40 mm as in Fig.1.

Injections were considered as a rod diameter = 6 mm with modulus of elasticity E = 6000 MPa, density ρ = 1800 kg/m³ and Poisson's ratio ν = 0.17. InjectionwassimulatedusingelementLink180.
The development of displacement was limited in the x and y directions, i.e. the displacements could develop only in the vertical direction z. The plate was modeled using a linear isotropic model by Solid 45 element type, the model consisted of 32 elements. An element is defined by eight nodes that have three degrees of freedom at each node.

Plate diameter 100 mm, modulus of elasticity \(E = 203940\) MPa, Poisson's ratio \(\nu = 0.3\); density \(\rho = 7700\) kg/m\(^3\).

![Model by ANSYS (a) and Stress-strain state of unreinforced sand.](image1)

Injections of cement mortar into a well with a diameter of 6mm to a depth of \(\frac{1}{4}D\) and \(\frac{1}{2}D\) (D-diameter of the Foundation model) on two or three sides were carried out. With angle of injection 30°, 45° and 60°. At the end of the hardening of the mortar, the vertical load on the base was transferred by means of a lever through a plate D=100mm. The volume of cement mortar, angle of inclination and depth of injections were changed. The projection scheme is shown in Fig.2.

![Scheme for the arrangement of injections.](image2)

Characteristics of the layer of fine sand - General modulus of deformation \(E = 48000\) kPa, Poisson's ratio \(\nu = 0.3\); density \(\rho = 1510\) kg/m\(^3\), cohesion \(c = 6\) kPa, angle of internal friction \(\phi = 38°\). For sawdust layer - \(\rho = 0.5\) g/sm\(^3\), \(\omega = 50\%\), modulus of deformation \(E = 220\) kPa, cohesion \(c = 2\) kPa; the angle of internal friction \(\phi = 30°\), Poisson's ratio \(\nu = 0.016\).

The effectiveness of reinforcement was evaluated by values:

a) coefficient of relative strain at a fixed load,

\[ k_s = \frac{s}{s_0} \]  

(where \(s\) is the settlement-in case of reinforced, \(s_0\) is settlement, for unreinforced base at same load);

b) the reinforcement ratio,

\[ k_\mu = \frac{F_{us}}{\mu s} \]  

(1)

(2)
(where $\mu_0$ is the percentage of reinforcement of base, $\mu_0 = V_g / V$, is the volume of reinforcement, $V$ is the volume of the base used in the work, conventionally defined as $V = B \cdot L \cdot H$, $L$ is the length, $B$ is width, and $H$ is the height; all of the base); c) coefficient of relative bearing capacity of the base,

$$k_r = \frac{F_{us}}{F_u}$$

(3). (where $F_{us}$ - bearing capacity of reinforced base - ultimate load), $F_u$ - the same but for non-reinforced.

The results of comparison of numerical simulations and experimental values of settlement for the angle of inclination of 45° injections, are shown in Fig.3 (a-e). The development of the main stresses under the foundation in the software package "ANSYS" is shown in Figure 3 (a,b).

![Figure 3](image)

**Figure 3.** Load-settlement curve in case, angle of inclination equals 45° for: a- unreinforced base-30 cm sand, b- reinforced by 2 injections- 30 cm sand, c- reinforced by 3 injections- 30 cm sand, d- reinforced by 2 injections- 10 cm sand, e- reinforced by 3 injections- 10 cm sand.
The results of laboratory experiments are shown in table 1 (settlement values were determined at $P=190$ kPa during two injections at $\frac{1}{2} D$, the angle of injection $45^\circ$, and a layer of sand 30 cm).

The main stresses $\sigma_1 (a)$ and $\sigma_2 (b)$ in the base of the model at a pressure under the sole $P=190$ kPa during two injections at $\frac{1}{2} D$, the angle of injection $45^\circ$, and a layer of sand 30 cm.

Table 1. Experimental results of the base, reinforced by cement-sand injection

| $n_p$ | $l$ | $\beta^\circ$ | $F_{ls}[kN]$ | $S[mm]$ | $\mu,\%$ | $k_\mu$ | $k_f$ | $k_\mu$ |
|-------|-----|---------------|---------------|---------|---------|---------|-------|---------|
|       |     |               |               |         |         |         |       |         |
|       | 0.25 | 30 | 1.65 | 2.47 | 0.90 | 0.49 | 1.22 | 1.83 |
|       |      | 45 | 1.50 | 2.79 | 1.12 | 0.55 | 1.11 | 1.35 |
|       |      | 60 | 1.50 | 3.46 | 1.57 | 0.68 | 1.11 | 0.95 |
|       | 0.5  | 30 | 1.80 | 2.69 | 1.36 | 0.53 | 1.33 | 1.32 |
|       |      | 45 | 1.65 | 3.58 | 1.66 | 0.71 | 1.22 | 0.99 |
|       |      | 60 | 1.50 | 3.52 | 2.35 | 0.70 | 1.11 | 0.64 |
|       | 0.25 | 30 | 1.50 | 4.01 | 1.36 | 0.79 | 1.11 | 1.10 |
|       |      | 45 | 1.35 | 4.43 | 1.65 | 0.85 | 1.00 | 0.82 |
|       |      | 60 | 1.35 | 4.60 | 2.35 | 0.91 | 1.00 | 0.57 |
|       | 0.5  | 30 | 1.80 | 2.05 | 2.04 | 0.40 | 1.33 | 0.88 |
|       |      | 45 | 1.50 | 2.23 | 2.50 | 0.44 | 1.11 | 0.60 |
|       |      | 60 | 1.65 | 2.38 | 3.53 | 0.47 | 1.22 | 0.47 |
|       | 0.25 | 30 | 0.75 | 5.29 | 0.90 | 0.89 | 1.11 | 1.10 |
|       |      | 45 | 0.75 | 5.08 | 1.12 | 0.85 | 1.11 | 0.82 |
|       |      | 60 | 0.75 | 4.42 | 1.57 | 0.74 | 1.11 | 0.57 |
|       | 0.5  | 30 | 1   | 2.77 | 1.36 | 0.46 | 1.48 | 0.88 |
|       |      | 45 | 1   | 2.46 | 1.66 | 0.41 | 1.48 | 0.60 |
|       |      | 60 | 0.85 | 3.71 | 2.35 | 0.62 | 1.26 | 0.47 |

Table 1. Experimental results of the base, reinforced by cement-sand injection

| $n_p$ | $l$ | $\beta^\circ$ | $F_{ls}[kN]$ | $S[mm]$ | $\mu,\%$ | $k_\mu$ | $k_f$ | $k_\mu$ |
|-------|-----|---------------|---------------|---------|---------|---------|-------|---------|
|       |     |               |               |         |         |         |       |         |
|       | 0.25 | 30 | 0.75 | 3.75 | 1.36 | 0.63 | 1.11 | 0.55 |
|       |      | 45 | 0.82 | 2.34 | 1.65 | 0.39 | 1.22 | 0.50 |
|       |      | 60 | 0.75 | 4.01 | 2.35 | 0.67 | 1.11 | 0.32 |
|       | 0.5  | 30 | 1.27 | 2.59 | 2.04 | 0.43 | 1.89 | 0.62 |
|       |      | 45 | 1.12 | 2.48 | 2.50 | 0.41 | 1.67 | 0.45 |
|       |      | 60 | 1.05 | 3.01 | 3.53 | 0.50 | 1.56 | 0.30 |
2. Summary
The settlement of the reinforced base is less than the unreinforced, and the carrying capacity is higher. A significant influence on the development of deformation, having the angle of injection (the values of $K_s$ when injection angle $30^\circ, 45^\circ$ and $60^\circ$ to a depth of $1/4D$, respectively, was equal to $k_s=0.49; 0.55; 0.68$ by $p= 0.17$ MPa, $\mu=0.903, 1.07, 1.57$), and the volume of cement mortar($0.53/0.41; 0.71/0.45; 0.45/0.70.47$).

It is shown that increasing the depth of the reinforcement zone from $1/4$ D to $1/2$D reduces the rate of settlement developed by 2 times regardless of the thickness of the weak layer. Deformation at a lower thickness of the weak layer is lower, since in this case the weak layer is not within the compressible zone.

The bearing capacity of the reinforced base was increased up to 1.5 times depending on the angle of inclination and volume of the injected mortar.

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