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Physico-mechanical properties of the composite "Cellular system – Cell infill material"

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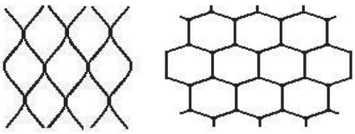
ABSTRACT: The settlement model of a layer of the ground reinforced with a cellular structure is considered. The characteristic cell has a polygonal outline form. The ground reinforced thus represents the new composite constructive-anisotropic material with controlled anisotropy which depends on properties of cell infill materials and from properties of a cellular structure. On the basis of the structural approach the influence of geometrical parameters of reinforcing structures on elastic characteristics of the composite "ground - cellular system" is investigated at the set volume of reinforcing material. It is theoretically established, that at reduction of the sizes of the cell of a cellular confinement system the effect of reinforcing grows repeatedly.

1 INTRODUCTION

Methods of calculation of pavements and the reinforced bases are developed basically by empirical way. Common fault of existing methods is traditional design procedures with continuous, homogeneous, and isotropic layers attraction for calculation of the reinforced designs being in essence constructive - anisotropic.

When wee use different forms of cellular confinement systems (Fig. 1) for soil reinforcing, wee have a problem to estimate the influence of geometric and mechanical parameters of reinforcing structure on physico-mechanical properties of the composite "soil – cellular confinement system".



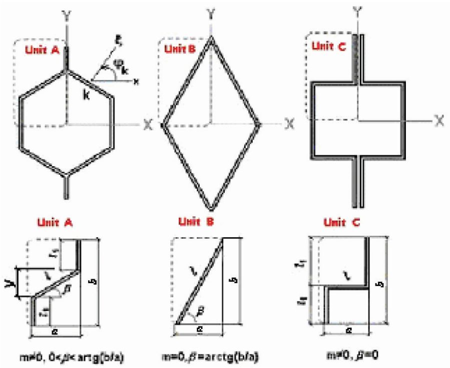
(a) (b)

Figure 1. Cellular confinement systems. (a) Geoweb, (b) Armater.

Strictly speaking, soils, synthetic materials of which reinforcing structures are made, have no properties of ideally elastic material, and their diagram of deformation – not linear. Therefore this approach to construction of mathematic model of the reinforced ground in elastic statement is considered by us as the first approximation which will be improved.

2 GEOMETRICAL PARAMETERS OF REINFORCING STRUCTURE

We research influence of geometrical parameters of reinforcing structure on elastic characteristics of a composite "soil-cellular system" at the set volume of reinforcing material. For this purpose we shall generate such structure of reinforcing which allows to model real-life designs and possesses the certain flexibility and universality. Characteristic cells of such structure are submitted on Fig. 2.



(a) (b) (c)

Figure 2. A characteristic cells of reinforcing structures. (a) polygonal; (b) rhombic; (c) rectangular.

The most universal is the polygonal cell (Fig. 2, a) which can be transformed as in rhombic (Fig. 2, b), and in rectangular (Fig. 2, c). The characteristic cell has two axes of symmetry X and Y (Fig. 2, a). For convenience wee consider one of its quarters (Unit A on Fig. 2, a). Wee have three rectilinear elements of reinforcing structure. The length of an average element wee shall letter as l (fig. 2, a, Unit A). Lengths of two others elements we shall designate as l_1 and we shall write the next equation

$$l_1 = ml/2 \quad (1)$$

where m – the set constant, as Matveev, (2002) have already mentioned.

The general length of three reinforcing elements we shall define summation

$$L = l + 2\,l_1 = l\,(1 + m) \quad (2)$$

We shall estimate the influence of reinforcing structure parameters $\frac{b}{a}$, m, L on physico-mechanical properties of a composite “soil-cellular confinement system”.

Let’s enter new parameter y (Fig. 2, unit A) which we shall define from expression

$$y = b - 2l_1. \quad (3)$$

We shall write the next equations:

$$l = Ll',\ l' = \frac{1}{1+m},\ l_1 = Ll_1',\ l_1' = \frac{m}{2(1+m)} \quad (4)$$

After transformation of expression (3) we shall receive

$$b^2 = (y + 2l_1)^2. \quad (5)$$

Let’s enter in addition a parity

$$a^2 = l^2 - y^2. \quad (6)$$

Let’s divide the left and right parts of expression (5) accordingly into the left and right parts of equality (6):

$$\frac{b^2}{a^2} = \frac{y^2 + 4yl_1 + 4l_1^2}{l^2 - y^2} \quad (7)$$

The equation (7) we shall transform as

$$A_o y^2 + B_o y + C_o = 0 \quad (8)$$

where

$$A_o = 1 + \left(\frac{b}{a}\right)^2;\ B_o = B'L;\quad C_o = C'L^2;$$

$$B' = \frac{2m}{1+m};\quad C' = \frac{1}{(1+m)^2}\left[m^2 - \left(\frac{b}{a}\right)^2\right] \quad (9)$$

From two decisions of the equation (8) it is chosen one which has positive value and it is defined under the formula

$$y = Ly',\ y' = \frac{1}{2A_o}\left(-B' + \sqrt{(B')^2 - 4A_oC'}\right) \quad (10)$$

Mattering y, width of a fragment of a cell we shall define under the formula

$$a = La',\ a' = \frac{1}{1+m}\sqrt{1 - (y')^2(1+m)^2}\,. \quad (11)$$

The area of the allocated fragment of a characteristic cell we shall express in terms of length of an average element of reinforcing structures l and a corner of an inclination of this element β

$$S = ab = l^2 f(\beta). \quad (12)$$

Where

$$a = l\cos\beta;\ b = l(m + \sin\beta);$$

$$f(\beta) = \cos\beta(m + \sin\beta). \quad (13)$$

Universality of the offered model consists that change of parameter and a corner of an inclination it is possible to change an outline of characteristic elements of reinforcing structures from rhombic (fig. 2, b) up to rectangular (Fig. 2, c).

3 MODEL OF DEFORMATION OF THE REINFORCED ELASTIC LAYER

Following Andreev & Nemirovsky, (2001), we shall consider the structural approach to definition of physico-mechanical properties of the reinforced ground as composite material.

Suppose the composite material has an elastic property. Then we shall express

$$\bar{\sigma} = A\bar{\varepsilon} \quad (14)$$

Where $\bar{\sigma}$, $\bar{\varepsilon}$ – vectors of stresses and strains; A – a matrix of elastic constants of a composite layer:

$$\bar{\sigma} = \begin{bmatrix}\sigma_x\\ \sigma_y\\ \sigma_z\\ \tau_{xy}\\ \tau_{yz}\\ \tau_{zx}\end{bmatrix};\ \bar{\varepsilon} = \begin{bmatrix}\varepsilon_x\\ \varepsilon_y\\ \varepsilon_z\\ \gamma_{xy}\\ \gamma_{yz}\\ \gamma_{zx}\end{bmatrix};$$

$$A = \begin{bmatrix} A_{11} & A_{12} & A_{13} & A_{14} & A_{15} & A_{16}\\ A_{21} & A_{22} & A_{23} & A_{24} & A_{25} & A_{26}\\ A_{31} & A_{32} & A_{33} & A_{34} & A_{35} & A_{36}\\ A_{41} & A_{42} & A_{43} & A_{44} & A_{45} & A_{46}\\ A_{51} & A_{52} & A_{53} & A_{54} & A_{55} & A_{56}\\ A_{61} & A_{62} & A_{63} & A_{64} & A_{65} & A_{66}\end{bmatrix} \quad (15)$$

The matrix A is defined from expression, obtained Nemirovsky & Matveev, (2002):

$$A = \Omega\,B_S + \Sigma\,\omega_k\,C_k^T B_k C_k \quad (16)$$

where Ω, ω_k – constants for which the following dependences are fair:

$$\omega_k = \frac{l_k \delta_k}{4ab}; \quad \Omega = 1 - \Sigma\, \omega_k, \tag{17}$$

B_s and B_k – matrixes of elastic constants of a soil and reinforcing element number k; l_k, δ_k – length and thickness of the reinforcing element number k; C_k – a matrix of transformation, obtained Lekhnitcky, (1977).

As the ground filling a cell is an isotropic material, its matrix of elastic characteristics B_s looks like

$$B_S = \begin{vmatrix} \lambda + 2G & \lambda & \lambda & 0 & 0 & 0 \\ \lambda & \lambda + 2G & \lambda & 0 & 0 & 0 \\ \lambda & \lambda & \lambda + 2G & 0 & 0 & 0 \\ 0 & 0 & 0 & G & 0 & 0 \\ 0 & 0 & 0 & 0 & G & 0 \\ 0 & 0 & 0 & 0 & 0 & G \end{vmatrix} \tag{18}$$

Where G, λ – the constants, determined from parities (Kaczkowski, 1984):

$$G = \frac{E_S}{2\,(1 + \nu_S)}; \lambda = \frac{\nu_S E_S}{(1 + \nu_S)(1 - 2\nu_S)} \tag{19}$$

where E_S, ν_S – the module of elasticity and the Poisson's factor of a soil.

The matrix of elastic characteristics B_k of the reinforcing element number k, working in a flat intense condition:

$$B_k = \begin{vmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & B_{22} & B_{23} & 0 & 0 & 0 \\ 0 & B_{32} & B_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & B_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{vmatrix} \tag{20}$$

Where

$$B_{22} = B_{33} = \frac{E_a}{1 - \nu_a^2}; B_{23} = B_{32} = \frac{\nu_a E_a}{1 - \nu_a^2};$$

$$B_{55} = G_a = \frac{E_a}{2(1 - \nu_a)}; \tag{21}$$

E_a, ν_a – the module of elasticity and the Poisson's factor of the reinforcing structure material.

The equation (16) establishes communication between elastic constants of a constructive-anisotropic material (elements of a matrix A), characteristics of the initial environment (elements of matrix B_S), characteristics of the reinforcing structure material (elements of matrix B_k) and its geometrical parameters (elements of matrix C_k and constants Ω, ω_k).

4 ANALYSIS OF RESULTS OF THE NUMERICAL DECISION

Schemes of reinforcing structures for which calculations were carried out, are shown in Figure 3.

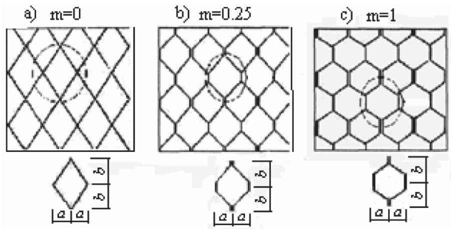


Figure 3. The types of reinforcing structures with relative sizes of cell b/a = 1: (a) m = 0; (b) m = 0,25; (c) m = 1.

The initial data:

- Geometrical parameters of a cellular system: $1 \le \frac{b}{a} \le 2$; $0 \le m \le 1$; $0.1 \le L \le 1$; δ = 1.27 mm; h = 200 mm.
- Characteristics of a soil: E_S = 40 MPa; ν_S = 0.35.
- Characteristics of a cellular system: E_a = 392 MPa; ν_a = 0.4.

For an estimation of influence of reinforcing on elastic characteristics of a soil we shall calculate in percentage terms change of modules of elasticity of the receiving composite material in comparison with corresponding elastic characteristics of a soil under the formula

$$K_{ij} = \frac{A_{ij} - B_{ij}}{B_{ij}} \times 100\% \tag{22}$$

Parameter K_{ij} we shall name effect of reinforcing for the component A_{ij} matrixes A.

Results of calculations are submitted on Fig. 4, where six diagrams are represented. Each diagram shows the change of the effect of reinforcing K_{ii} (i = 1, 6) in dependence on parameter m.

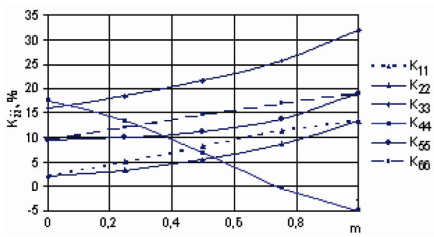


Figure 4. The change of the effect of reinforcing K_{ii} (i = 1,6) in dependence on parameter m for relative sizes of cell b/a = 1, L = 0,1 m.

- The effect of reinforcing K_{11} for the module of elasticity in a direction of an axis X grows with increase in parameter m, reaching the maximal value 13.4% (Fig. 4) for the structure of reinforcing submitted on Fig. 3, c ($b/a = 1$, m = 1, $L = 100$ mm).
- The effect of reinforcing K_{22} for the module of elasticity in a direction of axis Y also grows in an interval from 2% up to 13.4% at increase in parameter m from 0 up to 1.
- The effect of reinforcing K_{33} for the module of elasticity in a direction of axis Z grows with increase in parameter m, reaching maximal value 31.8% (Fig. 4) for the structure of reinforcing, submitted on Fig. 3, c ($b/a = 1$, $m = 1$, $L = 100$ mm).
- The effect of reinforcing K_{44} for the shear module in horizontal plane XY is decreases with increase in parameter m. For a cell with the relative sizes $b/a = 1$ max $K_{44} = 17.5\%$ at $m = 0$, $L = 100$ mm.
- Effects of reinforcing K_{55} and K_{66} for shear modules in vertical planes YZ and ZX grow from 9.5% up to 18.9% with increase in parameter m.

As a result of calculations appeared, that thickness of the elastic reinforced layer h, conterminous with height of a cellular system, does not render any influence on elastic constants-components of a matrix of A. During the calculations, which are carried out at various values of parameter h (from 100 up to 500 mm), numerical values of constants in a matrix A remained without change.

The received theoretical results are comparable to results of experimental researches (Shuvaev et al., 2003) concerning effect of reinforcing K_{33}. More detailed comparisons unfortunately are impossible in view of absence in quoted work of data on modules of elasticity of cell infill materials.

5 CONCLUSIONS

Summarizing stated, we shall emphasize, that the offered mathematical model allows to determine physico-mechanical properties of an elastic layer reinforced by cellular confinement system theoretically.

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