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ESTIMATION OF BEARING CAPACITY OF SLOPESSTRENGTHENED BY GEOTEXTILES, AND EXPERIMENTAL EXAMINATION

The authors of the article develop the calculation methods of slopes strengthened by geotextile. The received theoretical estimates of bearing capacity are compared with the experimental maximum loads obtained in tray model experiments.

K e y w o r d s: soil slopes, geotextile, bearing capacity, experimental testing.

Constructions and their natural basement must correspond to limiting state and accepted both in Russia and abroad. For instance, Eurocode 7 requires calculationin accordance with “Ultimate Limit States” (ULS) and “Serviceability Limit States” (SLS). There are no reasons to change such approach and in calculations of plastic systems “a soil file — a flexible shell” or soil files reinforced by geosynthetics.

Normative building documents confirm that calculation based on one of limiting states is neither reduced no replaced with thatbased on other limiting state.

Calculation of the soil basement reinforced by geosynthetics, based on SLS, i. e. on deformations, does not cause any difficulties [1, 2]. The elastic model of environment and a method of finite elements for calculation the stress and thedeformation of a soil file is generally used. Distinctions consist in a degree of the monitoring reinforcing layers of geosynthetics. In one case there are requirements for the increased size of the module of deformation of a soil, for example, $E = 20$ MPa. In other case environment is taken as composite, and equivalent rigidity of the reinforced is defined by elastic characteristics of geosynthetics and soil. An option of soil environment being represented byflat triangular elements, and reinforcing geosynthetics by linear elements cooperating with triangular elements is possible to imagine too.

However, calculation of bearing capacity, based on ULS, cannot be executed within elastic model since the latter is not suitable for the description ofenvironment destruction process.

Currently, the applied methods of calculation of building systems “a soil file — flexible geomaterials”, especially on bearing capacity, are represented absolutely unpersuasive. The designer cannot specify by how many percentthe bearing capacity of a structure increasesafter expensive synthetic materials being applied.

Nevertheless, poor development of calculation methods based on ULS leads to replacement of the above calculation withan indirect one, based on calculation of deformations, using some experimental data. Theoretically it means the substitution of calculation based on ULS withcalculation on SLS.

According to the marginal analysis of plastic bodies statically admissible field of stress in a slope generates the bottom estimation of limit value of external forces. For a weightless slope the bottom estimation of limit allocated load P is given in the generalized Prandtl’s solution being a combination of accurate analytical solutions: the passive elementary limit stressstate in field I, simplecentered wave in field II and the active elementarylimitstressstate in field III.

Bearing capacity of a weightless slope under strength of soil

$$\sigma_2 = -C + A\sigma_1 \quad (1)$$

is defined from the following formula

$$P = Ae^{\left(\frac{\pi}{2}-\alpha\right)\frac{A-1}{\sqrt{A}}}\left(q + \frac{C}{A-1}\right) - \frac{C}{A-1}. \quad (2)$$

If corner α is equal to zero, then the (2) allows to derivate limit intensity of strip load on natural basement.

When studyingthe bearing capacity of the composite basementmade from condensedgravel and sand mix, homogeneously interlaid with horizontal layers of geosynthetics (for example, texpall) model of a continuous rigidly-ideally-plastic body, anisotropic on aresistance toshear strength, is offered to use.

For calculation of bearing capacity of basement in questionsolution for limit strip loads on anisotropic on resistance of shear strength the soil basement is used [3—5].

Thus, the traditional concept of the strength, based on slidingplatforms is changed.

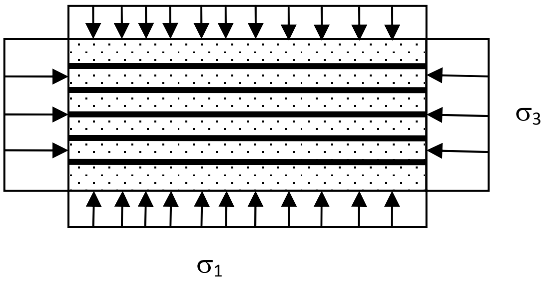
Let us consider any representative volume of the composite basement (fig. 1), being in limit stress stateof soil. If this volume is located in zone withactive limit stress of soil III (fig. 1, *a*), thenthe presence of geosyntheticslayers perpendicular to the first mainstream, will not lead to any noticeable hardening of this volume of soil. If this volume is located in zone with passive limit stress of soil I (fig. 1, *b*), then the presence of geosyntheticslayers parallel to the first mainstream, will considerably strengthen this volume of soil depending on rupture strengthvalue of geosynthetics.

Have any representation volume of the basement, the sides of which coincide with the main platforms, placed in the field of the centered wave II. The corner between the first mainstream and geosyntheticslayers will be equal to $\pi/2$ — θ and change from $\pi / 2$ up to 0 on area II. The issue of increasing the strength of the soil environment volume reinforced with inclined layers of geosynthetics can be investigated experimentally.

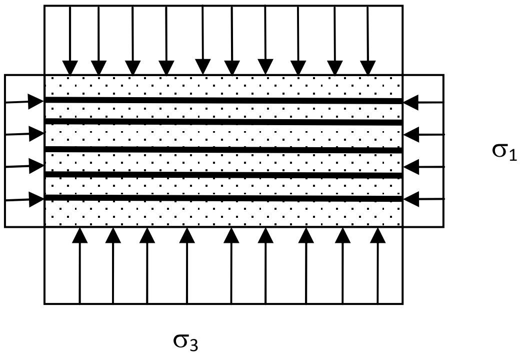
Let ussuggesta hypothesis about linear dependence of strength characteristics *A* and *C* from corner θ. Meanwhile, strength characteristics in the field III are accepted as forsoil without geosynthetics. In field I to the soil intercept cohesion the “equivalent” cohesion calculated as the ratio of geosynthetics rapture force tothe corresponding area, is to be added.

Take, for example, a basementmade fromgravel and sand mix, having nocohesion, horizontal layers of the stabitex being interlaidthrough each meter. The rapture limit ofa meter stabitexstrip is 80 kN. Hence, in this case in field I there will appear “equivalent” cohesion $c = 80$ kN/m^2.

Have the slope strengthened by periodic horizontal geosyntheticslayers. In the same way like transition from generalized Prandtl’s solution for isotropic under resistance to shift of soil half-space to the solution for anisotropic soil half-space is made, we shall make transformation for slope too. Instead of the (2) for bearing capacity of weightless isotropic slope we shall receive algorithm for calculation of bearing capacity of the reinforced slope (fig. 2).



a



b

Fig. 1. To the concept of durability of the composite environment

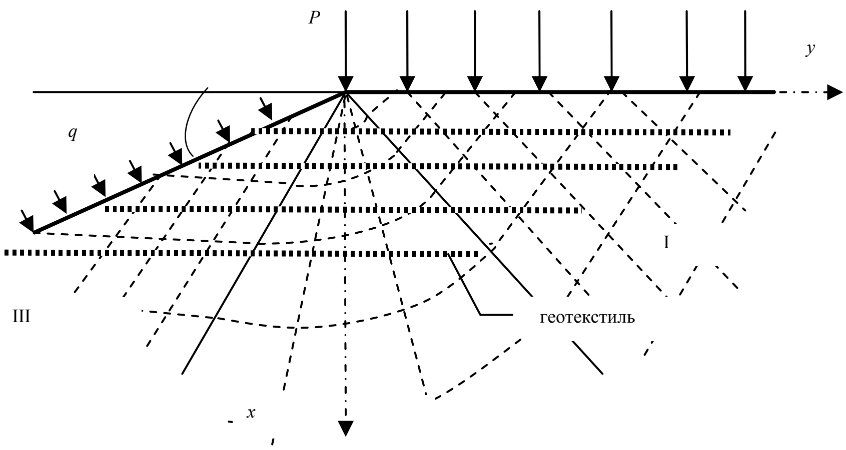


Fig. 2. A limit stress of the weightless slope strengthened by geosynthetics

In case of slope in field III, corner of the first mainstream with axis *OX* $\theta = \alpha$. Strength characteristics are constant through this area and equal $A(\alpha)$ and $C(\alpha)$.

It is shown [6], which calculation of bearing capacity of the reinforced weightless slope comes to solution of the nonlinear differential equation of the first order.

Remark. Applying famous approached method by Sokolovsky, influence of soil weight on bearing capacity value is possible to consider. Fig. 3 illustrates the above method. With corners α, being smaller then internal frictioncorner, to allocated load *P* certaintriangular pressure diagramwill be added, and with biggercorners α — subtracted. We shall notice that total load will be also the bottom estimation of unknown bearing capacity of slope.

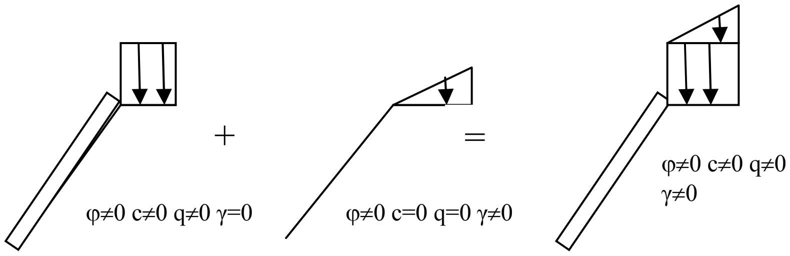


Fig. 3. Sokolovsky's method

To check the operation of the developed estimations of limit load slope modelingtray tests have been carried out.

To study sand basementsunder flat deformation a testerwas designed. Subsequently, to study the operation of foundations models on slope, the tester has been modified. The tester (fig. 4) consists of tray, made of organic glass with 30 mm thickness. A working part of the tray has the sizes 800 × 105 × 600 mm ($L \times B \times H$). The loading device is equipped with two hinges to eliminate kinematic moving restrictions of the foundation model. Load on the foundation model was "dead" and was created by metal disks in weight of three kg each. The sand of average coarse in dense dry air condition (density ρ = 1,75 g/sm^3, factor of porosity e = 0,53) was used for modeling the soil basement.

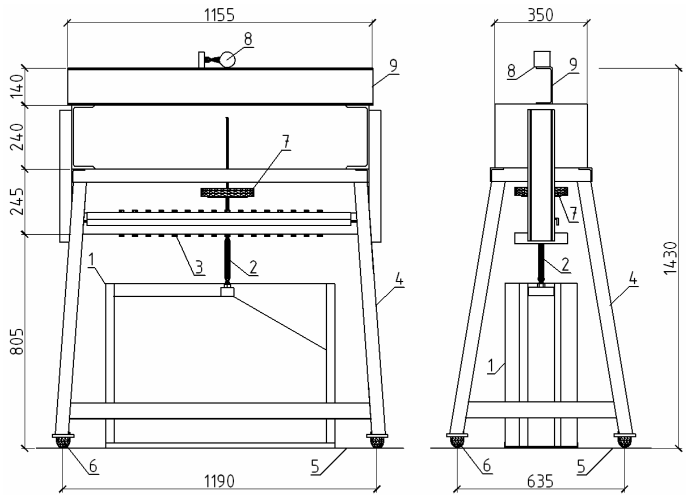


Fig. 4. Plan of the testerfor flat deformation: *1* — tray; *2* — the loading device; *3* — frame plug; *4* — frame; *5* — table of the basement; *6* — adjusting screws; *7* — flat weights; *8* — deflectometer; *9* — cross bar

The experiments on loading the strengthened slopes in the given tray were carried out by author of the article under supervision of S. A. Pavlyushchik and N. M. Bondarenko, a student of Master course.

This research work [7] presents the results of numerous experiments on loading unreinforced slopes of various inclinations, includingthe ones of experiments with 30° sandy slopes.

The results of the experimentson loading 30° sandy slopes reinforced in 20 mm intervalsby polythene horizontal layers (in double) are presented in the paper. Geometrical and physical conditions of modeling were met.

The loading was carried out graduallyby 6 kg. On each step certaintime was given for consolidation of the basement, and then yielding of foundation model were being fixed. The reinforced slope was brought todestruction, and limit load was defined.

Fig. 5 shows diagramof relation of yielding of foundation model on reinforced 30° slope to load in experiment № 7. For comparison in the same figure the corresponding diagram for unreinforced slope [7] is presented. The destructive load (fig. 6) on the reinforced slope in 204 kg has exceeded that on unreinforced slope as many as four times.

First, results ofthe experiments carried out will allow designers to make economically reasonable decisions, for example, in road construction.

Secondly, to apply correctly force in geosyntheticsin calculating estimations of bearing capacity [6].

Strictly speaking, theoretically the lower bound estimations inthe work [6] are derived for the continuous weightless environment, anisotropic on resistance toa shear. Such continuous environment was modeling the composit environment: dense sand interlaid with geosynthetics. This or that purpose of cohesion of the anisotropic continuous environment function on size of the limit forcefor short-term break of geosynthetics can deprive estimation of bearing capacity adjective “bottom”.

It is necessary to say, that European practice recommends that when applying work load on geosynthetics the test rapture force for geosynthetics should be divided into a number of rates, each of which is more than one.

Dense sand dilatesat shear deformation, and its resistance reaches maximum at certain shear deformation, followed by reducing the resistance. At such deformations in geosyntheticsitsstressesare unlikely to reach the limit values. It is clear, that cohesion for the modeling anisotropic environment should be appointed on the reduced short-term experimental rapture loads on geosynthetics.

Standard tests on stretching 2,5 sm width polythene strips have shown the rapture load of 0,9 kg. The double strip has limit rapture effort in 1,8 kg. Hence, the composite environment (2 sm thickness layer sof condensed sand interlaid with double polythene layers) having horizontal direction will show cohesion. Its size on each rectangular 2,5 sm × 2 sm = 5 sm^2 is equal to 1,8 kg. Consiquently, equivalent cohesion in a horizontal direction c = 0,36 kg/sm = 36 kPa. For the above reasons to calculate the estimation of bearingability usingtechnique [6], specific cohesion in 70 % from short-term rapture load, i. e. c = 25,2 kPa be taken.

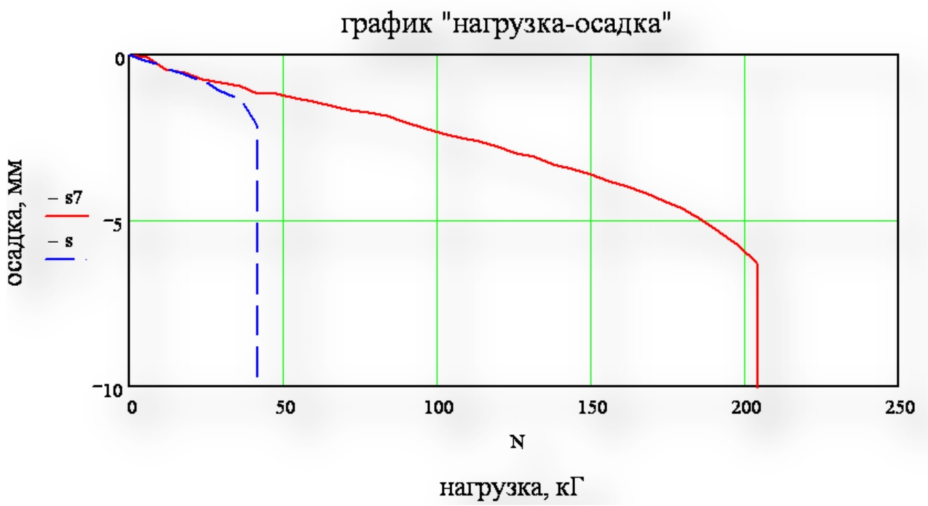


Fig. 5. Results of experiments on loading reinforced (a continuous line) and unreinforced (a dashed line) slopes

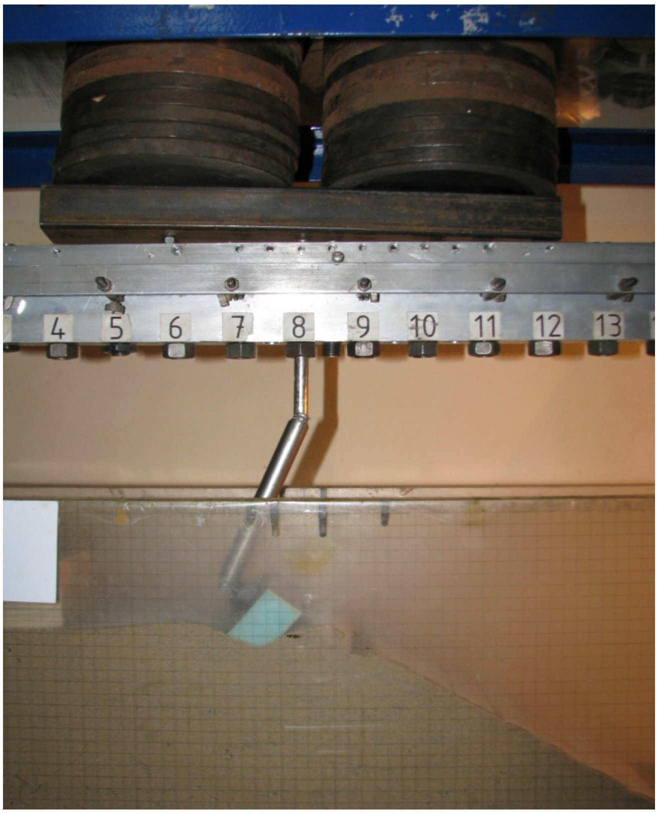


Fig. 6. Destruction of reinforced slope

Further, we shall study theoretical calculation of bearing capacity for model tests conditions. The algorithm of calculation is presented here, too.

ESTIMATIONS OF TESTLIMIT LOADS

Characteristics of the modeling anisotropic environment:

$\varphi := \frac{\pi \cdot 40}{180}$ - - angle of internal friction

$c := 0.025$ 2 МПа - - specific cohesion

$C1 := \frac{2 \cdot c \cdot \cos(\varphi)}{1 - \sin(\varphi)}$

$A1 = 4.599$ $A0 := A1$ $C0 := 0$ МПа $C1 := 0.108$ МПа

$A(\theta) := 2 \cdot \frac{\theta \cdot (A1 - A0)}{\pi} + A0$ $C(\theta) := 2 \cdot \frac{\theta \cdot (C1 - C0)}{\pi} + C0$

A add load $q := 0$ МПа

$$\mathbf{m}(\theta, g) := \sqrt{\left[\left[(A1 - A0) \cdot \frac{2 \cdot q}{\pi}\right] - \left[(C1 - C0) \cdot \frac{2}{\pi}\right]\right]^2 + 4 \cdot A(\theta) \cdot [(A(\theta) - 1) \cdot g - C(\theta)]^2}$$

$$\mathbf{f}(\theta, g) := \frac{(C1 - C0) \cdot \frac{2}{\pi} - (A1 - A0) \cdot \frac{2 \cdot q}{\pi} - m(\theta, g)}{2 \cdot A(\theta)}$$

$\theta 0 := 0$ $\theta 1 := \frac{\pi}{2}$ $g0 := -q$

Corner of slope: : $\alpha := \frac{\pi \cdot 30}{180}$ $\alpha = 0.524$

$$\mathbf{m}(t, y) := \left[\left[(A1 - A0) \cdot \frac{2 \cdot y}{\pi}\right] - \left[(C1 - C0) \cdot \frac{2}{\pi}\right]\right]^2 + 4 \cdot A(t) \cdot [(A(t) - 1) \cdot y - C(t)]^2$$

This QuickSheet can be used to solve an ordinary differential equation of the form:

$$\frac{d}{dt} y(t) = f(t, y) \qquad Y(t0) = y0$$

Enter the initial value problem specifics:

$t0 := \alpha$ $y0 := -q$

Enter the desired solution parameters:

$$f(t, y) := \frac{(C1 - C0) \cdot \frac{2}{\pi} - (A1 - A0) \cdot \frac{2 \cdot y}{\pi} - \sqrt{m(t, y)}}{2 \cdot A(t)}$$

Endpoint of solution interval $t1 := \frac{\pi}{2}$

Number of solution values on [t0,t1] N := 1000

Given

$y'(t) = f(t, y(t))$ $y(t0) = y0$

$y := \text{Odesolve}(t, t1)$

$y\left(\frac{\pi}{2}\right) = -0.064$

Limit pressure upon the anisotropic basement

$p := C\left(\frac{\pi}{2}\right) - y\left(\frac{\pi}{2}\right) \cdot A\left(\frac{\pi}{2}\right)$ $p = 0.400$ МПа

Limit pressure byPrandtlon the isotropic basement

$p0 := A0 \cdot e^{\frac{\left(\frac{\pi}{2} - \alpha\right) \cdot (A0 - 1)}{\sqrt{A0}}} \cdot \left(q + \frac{C0}{A0 - 1}\right) - \frac{C0}{A0 - 1}$ $p0 = 0$ МПа

$p1 := A1 \cdot e^{\frac{\left(\frac{\pi}{2} - \alpha\right) \cdot (A1 - 1)}{\sqrt{A1}}} \cdot \left(q + \frac{C1}{A1 - 1}\right) - \frac{C1}{A1 - 1}$ $p1 = 0.771$ МПа

$s := 50$ см² $N := 10 \cdot p \cdot s$ кГ

Limit force on foundation model: N = 200.093 кГ

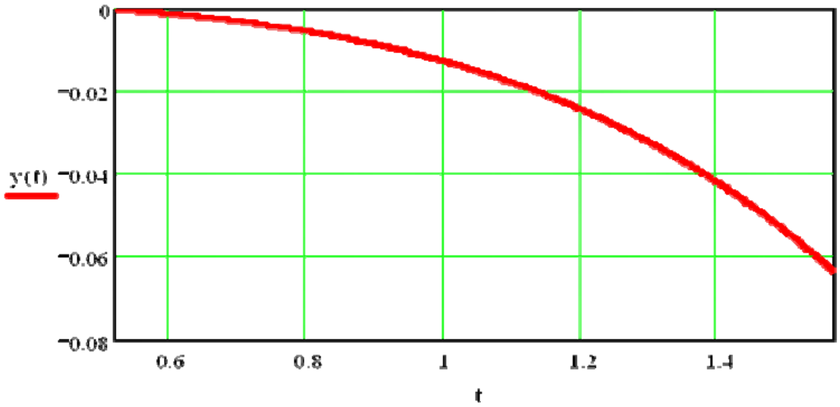


Fig. 7. The diagram of solution for Koshi's problem

Calculations have show, that theoretical 200,1 kg limit load gives good conformitywithtest limit load of 204 kg.

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