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The determining cross-section width of discrete restraining structures

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Currently, there is no single method for determining the width of the cross-section for the elements of anti-landslide retaining structures with a rectangular cross-section (or the diameter of the elements with a round cross-section) at a known distance between them. An algorithm for determining the diameter (in the case of a transitional view of a round shape) or the smaller side (in the case of a transverse transition of a rectangular shape) of anti-vessels supporting structures at a known distance between them is presented. In the course of the above work, obtained analytical dependencies that allow us to determine: the width of the cross-section for the elements of anti-slip retaining structures with a rectangular cross-section (or the diameter of the elements with a round cross-section) at a known distance between them, the step of arranging the elements of anticonvulsant supporting structures with a rectangular cross-sectional shape (or the diameter of the elements of a circular cross-sectional shape) at a known distance between them.

Keywords: landslide, retaining structure, diameter element, width element, step elements.

Визначення ширини поперечного перерізу дискретних утримуючих споруд

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В даний час не існує єдиної методики визначення ширини поперечного перерізу для елементів протизсувних утримуючих конструкцій з прямокутною формою поперечного перерізу (або діаметру елементів з круглою формою поперечного перерізу) при відомій відстані між ними. Було проведено теоретичні дослідження геомеханічних процесів з використанням аналітичних і чисельних математичних методів. Виконано аналіз і узагальнення результатів теоретичних досліджень. Представлено алгоритм визначення діаметру (в разі поперечного перерізу круглої форми) або меншої сторони (в разі поперечного перерізу прямокутної форми) протизсувних утримуючих конструкцій при відомій відстані між ними. В результаті отримано аналітичні залежності, що дозволяють визначити: ширину поперечного перерізу для елементів протизсувних утримуючих конструкцій з прямокутною формою поперечного перерізу (або діаметру елементів з круглою формою поперечного перерізу) при відомій відстані між ними, крок розстановки елементів протизсувних утримуючих конструкцій з прямокутною формою поперечного перерізу (або діаметру елементів з круглою формою поперечного перерізу) при відомій відстані між ними. Отримані аналітичні дані також можуть бути використані в якості попередніх даних при виконанні розрахунків з використанням сучасних програмних комплексів як по ґрунту, так і по матеріалу.

Ключові слова: зсув, утримуюча конструкція, діаметр елементу, ширина елементу крок елементів.

Introduction

Currently, in the anti-landslide restraining structures design, the following problems occur [1-3]:

1) The use of solid restraining structures (restraining walls) is a very costly and laborious process.

2) During such consumption, there appear problems with cutting the slope and, as a consequence, the stability loss, as well as the drainage of groundwater.

3) According to the spatial layout, the following restraining structures are distinguished:

– linear or extended objects, which include retaining walls, trench fences, anti-landslide structures, etc.

– point or discontinuous objects, which include fences of pits, chambers, wells, anti-landslide structures, etc.

In turn, point objects are subdivided into single-row and multi-row (from several rows of separately standing connected or unconnected retaining structures).

An alternative to solid anti-landslide structures is discrete containing structures [2, 3, 4], however, the following problems use occurs:

– the strength loss and soil stability risks, which are located between the elements of the discrete restraining structure and, as a result - soil destruction located in the zone of the restraining structure influence - and further - landslide descent.

– discrete (especially multi-row) restraining structures create a barrage effect for underground waters; the result is groundwater level rising and, as a consequence, a deterioration in the soil condition in the restraining structure influence zone - and further - its destruction.

Review of the research sources and publications

The retaining structures' design should include:

– retaining structure type selection;

– selection of a method for constructing a retaining structure;

– choice of dimensions, depth of the retaining structure, and its main geometric parameters;

– structures attach type selection;

– selection of materials for the retaining structure;

– the choice of the method of protection against groundwater;

– checking the bearing capacity of the base containing the structure according to the first and second groups of limiting states.

Nowadays, L. K. Ginzburg (1), N. N. Maslov (2) and (3), R. Hill (4), S. I. Make (5), G. E. Hennessy (6) [3-7] formulas are most often used to determine the spacing size for the anti-landslide discrete restraining structures placement.

$$b=\frac{6\cdot\xi^2\cdot H\cdot c\cdot\cos(\alpha)-E_{op}\cdot\left[2\cdot -tg(\varphi)\right]}{0.2\cdot E_{op}\cdot\xi^2\cdot\cos(\alpha)};\quad \xi=\frac{E_{op}\cdot\sqrt{E_{op}^2-2\cdot E_{op}\cdot H\cdot c\cdot tg(\varphi)}}{4\cdot H\cdot c} \tag{1}$$

$$b=\frac{\pi\cdot\gamma\cdot H\cdot D\cdot\left(D\cdot tg(\varphi)+\frac{H}{2}+\frac{c}{\gamma\cdot tg(\varphi)}\right)}{E_{op}\cdot\left(ctg(\varphi)+\varphi-\frac{\pi}{2}\right)} \tag{2}$$

$$b=\frac{c\cdot\pi\cdot\gamma\cdot H\cdot D}{E_{op}} \tag{3}$$

$$b=\frac{2\cdot H_c\cdot c_c\cdot\pi\cdot D\cdot\left(1+\frac{\pi}{2}\right)}{E_{op}} \tag{4}$$

$$b=1.52\cdot D\cdot\ln\left(\frac{7\cdot H\cdot c-E_{op}}{9\cdot H\cdot c}\right) \tag{5}$$

$$b=2\cdot\frac{c}{E}\cdot D\cdot h\ . \tag{6}$$

where b is the distance between the containing elements in the axes;

D is the diameter of the circular shape containing element section or the smaller side of the rectangular element;

E_{op} is shearing pressure;

H is the soil thickness at the location of the restraining structure;

c and φ are soil strength characteristics [8];

γ is soil specific gravity;

α is the inclination angle to the horizon of the sliding soil massif.

Each of the above formulas only partially takes into account the strength characteristics of the soil and restraining structures.

Definition of unsolved aspects of the problem

Nowadays, there is no single method for determining the width of the cross-section for elements of anti-landslide retaining structures with a rectangular cross-sectional shape (or the diameter of elements with a circular cross-sectional shape) with a known distance between them.

Problem statement

The main goal of the presented article was to find analytical dependencies that allow determining the following design parameters of discrete anti-landslide structures:

– the width of the cross-section for the elements of anti-landslide restraining structures with a rectangular cross-sectional shape (or the diameter of elements with a circular cross-sectional shape) at a known distance between them.

– the spacing of the anti-landslide restraining structures elements with a rectangular cross-sectional shape (or the diameter of elements with a circular cross-sectional shape) at a known distance between them.

Basic material and results

Equalities (1) - (6) analyzing.

From equality (1) it follows that the distance between the restraining elements is measured in unit fractions, which is not correct. In addition, there is not presented the intersection parameters of the restraining structure in this formula. Therefore, this dependence will not be considered in the future.

From equality (2) it follows that when the specific cohesion is equal to zero (i.e. for absolutely loose soil), the distance between the elements of the containing structure can be nonzero. This contradicts experimental data and modern concepts of the behavior under a load of ideally loose soils. Therefore, this dependence will not be considered in further research.

Determining the diameter of the circular cross-section or the width of the rectangular element cross-section of the restraining structure, the equalities (3) - (6) concerning the parameter "D" were solved. In this case, the following is presented:

– for the N.N. Maslov solution (original formula (3)):

$$D = \frac{b \cdot E_{op}}{c \cdot \pi \cdot H}; \quad (7)$$

– for the R. Hill solution (original formula (4)):

$$D = \frac{b \cdot E_{op}}{c \cdot (2+\pi) \cdot H}; \quad (8)$$

– for the S.I. Matsiy solution (original formula (5)):

$$D = \frac{0.658 \cdot b}{\ln\left(\frac{7 \cdot c \cdot H - E_{op}}{9 \cdot c \cdot H}\right)}; \quad (9)$$

- for the R. E. Hennes solution (original formula (6)):

$$D = \frac{b \cdot E_{op}}{2 \cdot c \cdot \pi \cdot H}; \quad (10)$$

Analysis of formulas (3) - (10), which have a physical meaning, allowed us to conclude that they do not include such an important characteristic as the angle of internal friction.

The following research materials are aimed at solving this contradiction.

The research task was the basis for its solution, the assumptions were formulated as follows:

– upon the destruction of the soil massif interacting with the discrete retaining structure, an arch of a fall of unit thickness is formed, directed by its convex part towards the shear displacement vector. For the sake of simplicity, take it as a pointed arch (see. design scheme in Fig. 1);

– a uniformly distributed load q is applied to the arch, which is numerically equal to the ratio of the landslide pressure E_{op} to the thickness of the soil layer H (ie $q = \frac{E_{op}}{H}$; see Fig. 1);

It was assumed that the destruction of the soil between the elements of the discrete restraining structure (in the diagram, this soil is indicated in yellow) occurs in the center of the arch span.

– the arches support rest on adjacent elements of the discrete restraining structure. In this case, horizontal R_h and vertical R_v reactions occur;

– the rock destruction mechanism is displacement. Therefore, its fracture behavior obeys the Coulomb-Mohr strength condition [8, 9]:

$$\left.\begin{aligned} \frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3 + 2 \cdot c \cdot ctg(\varphi)} = \sin(\varphi) \\ \sigma_1 > \sigma_2 > \sigma_3 \end{aligned}\right\} \quad (11)$$

where σ_1, σ_2, σ_3 are principal normal stresses;
φ is an angle of internal friction;
c is a specific cohesion.

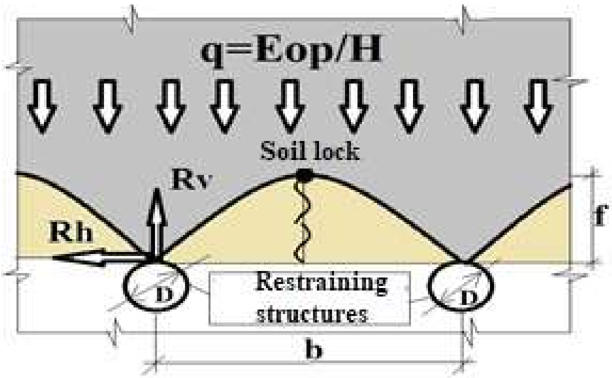

Figure 1 – Scheme for calculating the diameters of discrete restraining structures elements and the distances between them

– strength characteristics of the soil are known (its specific cohesion c and the angle of internal friction φ).

– known as either the element spacing of the anti-landslide restraining structure or the cross-section diameter of the element restraining structure of a circle shape or the smaller side of the rectangular cross-section shape.

– when the soil is destroyed between the restraining structure elements, a fallen arch with a lifting arrow f is formed.

Within the framework of the Coulomb-Mohr strength criterion, it is necessary to determine:

– the section diameter D, to a known element spacing of the anti-landslide restraining structure b.

– the element spacing of the anti-landslide restraining structure b, to a known cross-section diameter of the restraining structure element D.

The algorithm for determining the diameter (in the case of a circular cross-section) or the smaller side (in the case of a rectangular cross-section) of anti-landslide restraining structures with a known distance between them is shown below:

Vertical R_v and horizontal R_h reactions in the arch abutment are equal:

$$R_v = \frac{q \cdot b}{2} \;;$$
$$R_h = \frac{q \cdot b^2}{8 \cdot f} \;; \qquad (12)$$
$$q = \frac{E_{op}}{H} \;.$$

The following stresses effect the contact between the displacement and the restraining structure surface:

– directed against the shear, is numerically equal to:

$$\sigma_{R_v} = \frac{R_v}{D} = \frac{q \cdot b}{2 \cdot D} \;; \qquad (13)$$

– directed parallel to the line along which the restraining structures are placed, is numerically equal to:

$$\sigma_{R_h} = \frac{R_h}{D} = \frac{q \cdot b^2}{8 \cdot f \cdot D} \;; \qquad (14)$$

– vertical, numerically equal to:

$$\sigma_v = \gamma \cdot z \;; \qquad (15)$$

Of the stresses considered, the largest is the stress due to the vertical reaction R_v at the arch abutment, and the smallest stress is zero. This is due to the fact that horizontal reactions in adjacent arch abutments cancel each other out. In connection with the above, we have:

$$\sigma_1 = \sigma_{R_v} = \frac{R_v}{D} = \frac{q \cdot b}{2 \cdot D} \;; \qquad (16)$$
$$\sigma_2 = 0$$

After, substituting the principal stresses (16) into the Coulomb-Mohr strength criterion (11) and solving the equality obtained in this way concerning the diameter of the restraining structure element D:

$$D = \frac{q \cdot b}{4 \cdot c} \cdot \frac{1 - \sin(\varphi)}{\cos(\varphi)} \;. \qquad (17)$$

The equality (17) allows you to determine the safe distance between the restraining elements. It is equal to:

$$b = \frac{4 \cdot c \cdot D}{q} \cdot \frac{\cos(\varphi)}{1 - \sin(\varphi)} \;. \qquad (18)$$

Equalities (17) and (18) make it possible to determine the diameters of the anti-landslide discrete restraining structure elements for a soil layer of unit thickness. Taking into account the entire thickness of the sliding soil massif, use in (17) and (18) is $q = \frac{E_{op}}{H}$:

$$D = \frac{E_{op} \cdot b}{4 \cdot c \cdot H} \cdot \frac{1 - \sin(\varphi)}{\cos(\varphi)} \;;$$
$$b = \frac{4 \cdot c \cdot D \cdot H}{E_{op}} \cdot \frac{\cos(\varphi)}{1 - \sin(\varphi)} \qquad (19)$$

The formulas' (19) disadvantage is that they can only be applied to homogeneous bases. To eliminate this drawback, replace their strength characteristics with the weighted average values $\overline{c}$ and $\overline{\varphi}$. In this case, equalities (19) take the form:

$$\left.\begin{aligned} D &= \frac{E_{op} \cdot b}{4 \cdot c \cdot H} \cdot \frac{1 - \sin(\varphi)}{\cos(\varphi)} \\ b &= \frac{4 \cdot c \cdot D \cdot H}{E_{op}} \cdot \frac{\cos(\varphi)}{1 - \sin(\varphi)} \\ \overline{c} &= \frac{\sum_{i=1}^{m} c_i \cdot h_i}{h}; \overline{\varphi} = \frac{\sum_{i=1}^{m} \varphi_i \cdot h_i}{h} \end{aligned}\right\} \qquad (20)$$

where c_i , φ_i – strength characteristics i-th soil layer with a thickness h_i and soil layers number m.

In general, it was concluded that the obtained formulas allow to determine the diameter and elements' spacing of anti-landslide restraining discrete structures.

In this case, the obtained dependences are free from internal contradictions given in formulas (1) - (10).

These data are very important in the calculation and design of discrete restraining structures.

Conclusions

In the course of this article, analytical dependencies were obtained that allow calculating the step of placing discrete anti-landslide restraining structures with a known diameter and contrariwise, the diameter (or the cross-section width) of discrete anti-landslide restraining structures with a known step of their placement.

The obtained simple analytical data can also be used as preliminary data for performing calculations using modern software systems for soil and material equally.

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