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TO THE CALCULATION OF BANK PROTECTION MEASURES FOR CHANNELS SLOPES EXPOSED TO ALONGSHORE WAVES

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Abstract

Calculation methods for strengthening and covering slopes with paving stones or tiles have been developed, and precise formulas for calculating the diameters of paving stones have been adopted. The three most characteristic locations of the triangular base of the measuring pyramid on the slope are: a) When the stones forming the nest on the slope are positioned in such a way that the measuring stone placed on the tip of the pyramid is most easily overturned in the direction of the tidal current; b) When the measuring stone can be tilted in the direction of the shoreline, towards large widths; c) When the possible direction of overturning makes a large angle of 30° with the shoreline, that is when one of the sides of the equilateral triangle of the base of the pyramid is parallel to the shoreline.

Keywords: channel, alongshore wave, coastal slope, shoreline.

Introduction

Of all the coastal protection measures, the protection of coastal slopes by stone sketch has the longest history. Currently, based on theoretical development or experimental and field observations, methods for determining diameter or weights of stones, stable waves [3, 5, 6] are created and created, but these formulas relate only to the frontal impact Waves on the shore and, therefore, their use for assessing the stability of the stone sketch of the coastal slopes of channels requires the corresponding correction. Here, first of all, we are referring to the Shaitan calculation scheme, which deals only with the frontal impact of the waves on the stone fill and in which the calculated stones are erroneously cylindrical rather than spherical (Fig. 3, a) and b)).

Conflict Setting

Below, we restrict ourselves to the consideration of the three, the most characteristic locations of the triangular base of the pyramid of stones on the slope (Fig. 3.c))

Research Results

Let us consider the stability of soil particles forming the coastal slope of the channel when alongshore periodic waves are superimposed on the surface of the water flow. Suppose that the water depth on the slope above the calculated soil particle is equal H, and the soil particle size is negligible in comparison with the length (λ) and with the amplitude (a) of the alongshore wave. Let us also assume that a crystalline soil particle has a shape close to a cube with a side d.

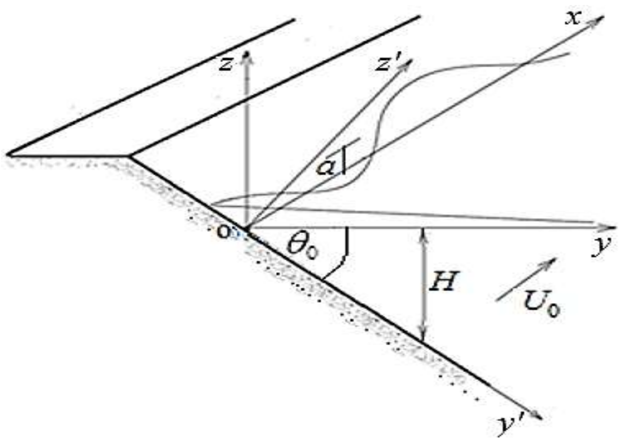

Fig. 1 Design scheme of alongshore waves in the channel

Since three-dimensional waves act on a soil particle on a slope, the particle can move in the following three directions: along the axis y', which is aligned with the coastline; along the axis , located in the plane of the slope and directed downward, towards the great depths of the water, and in the direction of the axis z', i.e., orthogonal to the plane of the coastal slope (Fig. 1.). In this case, we assume that, due to the smallness of the particle, the forces acting on it are attached at the center of gravity of the particle.

When lining the slopes of the channel with paving stones or tiles, first of all, it is necessary to determine the thickness of the lining element. Usually, each paving stone or slab is hewn in its own nest formed by neighboring stones, and therefore their movement along the slope is practically impossible. An element (stone or slab) can only be thrown out of its nest in the direction of the axis Oz' by the force of filtration backpressure (Fig.1), which manifested itself only when the wave bottom passes over the element (Fig.2) .

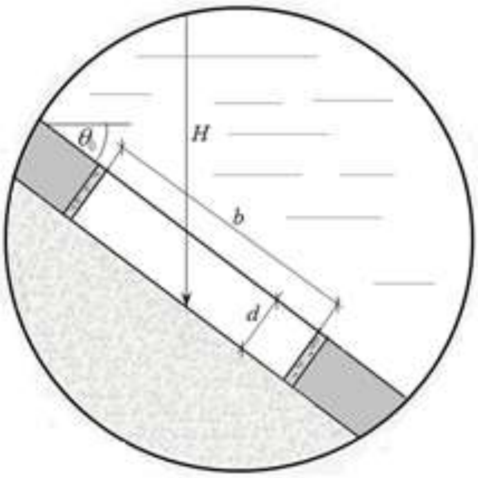

Fig.2 Scheme for calculating the thickness of the channel facing plate

In this case, we must apply the equilibrium equation,

$$\gamma_S' \cos\theta_0 d + c - \gamma A = 0. \tag{1}$$

based on which the thickness of the coating element is determined by the formula [1]

$$d_{z'} = \frac{\gamma A - c}{\gamma_S' \cos\theta_0}, \tag{2}$$

Here, the coefficient of adhesion c reflects the tensile or shear stresses resulting from the anchoring of the plates or the grouting of the gaps between the plates. In their absence $c = 0$.

In the case of short waves propagating along the channel, when calculating the parameter A, thr depth H should be substituted the difference $H - d\cos\theta_0$ (Fig. 2.), which, in the case of Stokes waves propagating over the slab gives

$$d = \frac{\gamma}{\gamma_S' \cos\theta_0} a \exp\left(-k\frac{H - d\cos\theta_0}{\sin\theta_0}\right) - \frac{c}{\gamma_S' \cos\theta_0}. \tag{3}$$

The inverse task can be made, which is to determine the depth of water in the channel, deeper which, the concrete slab by thick d will be resistant on the coastal slope of the canal. The water depth is calculated by the formula [1, 2]

$$H = d\cos\theta_0 + \frac{\sin\theta_0}{k}\ln\left(\frac{\gamma}{\gamma_S'}\cdot\frac{a}{d\cos\theta_0}\right). \qquad (4)$$

We can also use the relation (4) to estimate the stability of the coastal slope. In particular, if we compare the depth calculated by (4) with the wave amplitude of a given on the shoreline, and it turns out that $H < a,$ then we can consider that slabs with thickness d, or blocks with the same height d, are stable when streamlined by alongshore waves. Otherwise, we should either increase the thickness of the cladding element or decrease the angle of the coastal slope to the horizon.

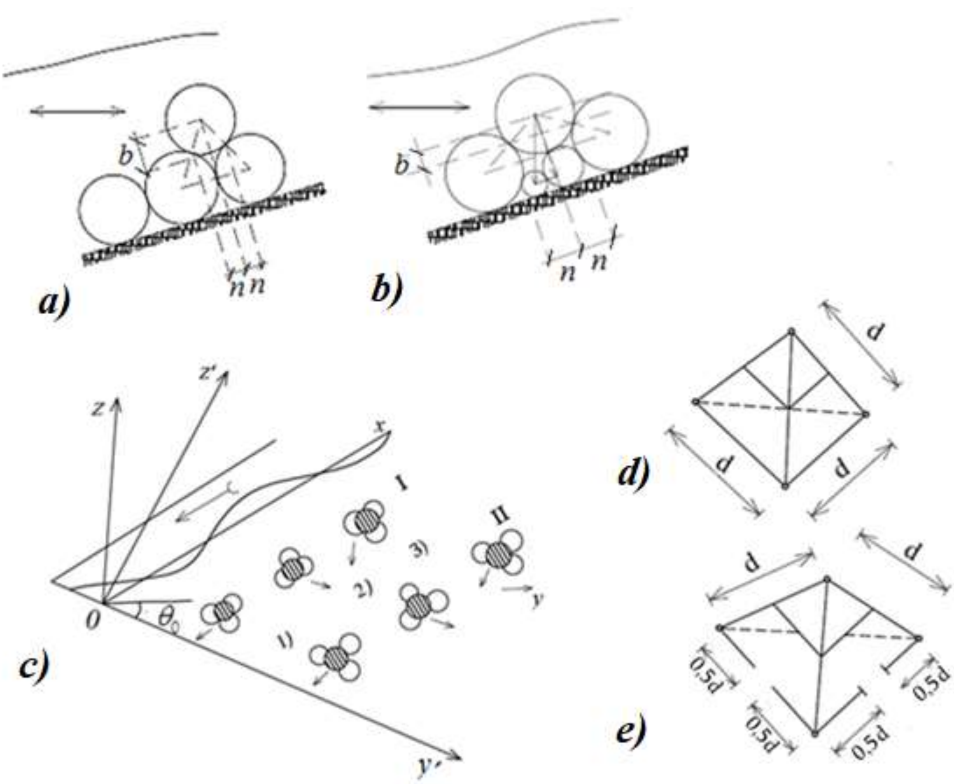

Fig. 3 Calculation schemes for assessing the stability of the protective stones sketch from the effects of waves $a)$ and b) - with frontal Impact of waves [6]; $c),d)$ and e) - when the Impact of an alongshore wave ([1])

On our proposed schemes (Fig. 3 $c),d)$ and e)), the surface stone having a size small compared to the wave parameters is placed in the nest formed from three identical surfaces in the form and size of stones. Such pyramidal schemes of the location of the stones are suitable for estimating the stability of the stone sketch, both when exposed to front and three-dimensional alongshore waves.

Below, we restrict ourselves to the consideration of the three, the most characteristic locations of the triangular base of the pyramid of stones on the slope (Fig. 3.*c*))

These cases:

1. When the base stones on the slope are located, so that the stone on the top of the pyramid is most easily turned over in the direction of the waves, that is, in the direction of the coastline (Fig. 3 *c*), position 1);
2. When the settlement stone can roll down the slope, perpendicular to the coastline (Fig. 3 *c*), position 2);
3. When the stone at the top of the pyramid is turned over by waves at an angle of 30° relatives to the shoreline, that is when a single edge of the base of the pyramid of stones is parallel to the shoreline, and the top of this base triangle is directed toward greater depths (Fig. 3. *c*), position 3).

In the first case, the equation of moments of forces applied in the center of gravity of the stone with diameter , relative to the instantaneous axis of rotation (it is shown in Fig. 3.d) with a bold line) will be written in the following form:

$$G'\cos\theta_0 \cdot n - 0{,}5\tilde{c}\rho\omega\,|\vec{V}|^2 \cdot b = 0\,, \tag{5}$$

where G' denotes the weight of a spherical stone under water

$$G' = 0{,}523\gamma_S' d^3; \tag{6}$$

ω - the midship area of the of the stone perpendicular to the axis Ox

$$\omega = 0{,}648\, d^2; \tag{7}$$

n and b - shoulders of forces of weight and the component along the axis Ox of the force of the frontal flow around the stone, respectively

$$n = 0{,}145d\,,\quad b = 0{,}41d\,. \tag{8}$$

If we assume that the center of gravity of the reference stone is submerged in water to a depth of H , we can calculate the velocity modulus $|\vec{V}|$. Then the solution of equation (5) with respect to diameter d gives us that limiting value of stone diameter that ensures the stability of homogeneous stone sketch in the direction of wave propagation. This diameter is calculated by formula

$$d_1 = 1{,}75\frac{\tilde{c}\gamma}{g\gamma_s'\cos\theta_0}(U_0 + AG)^2\,. \tag{9}$$

In the relation (9) it is taken into account that maximum wave impact in the axis Ox direction is observed when the wave crest passes over the calculated stone, i.e. when $\sin(\sigma t - kx) = 1$.

In the second limiting case, when the calculated stone may fall out of the socket and roll down the slope of the canal, the equation of limiting equilibrium (moments) takes the form:

$$G'\cos\theta_0 \cdot n - G'\sin\theta_0 b - 0{,}5\tilde{c}\rho\omega\,|\vec{V}|\vec{V}_{Oy'}b = 0\,. \tag{10}$$

If we put the values of forces and arms into equation (5) and take into account that the velocity component along the axis Oy' is

$$\vec{V}_{Oy'} = AG\cos(\sigma t - kx) \tag{11}$$

from equation (11) we obtain the diameter of the stone at the limit equilibrium in the direction of the axis Oy':

$$d_2 = 0{,}133\frac{\tilde{c}\gamma}{g\gamma'_s}\cdot\frac{AC\cos\beta\left[U_0^2 + 2U_0 AG\sin\beta + A^2G^2\right]^{1/2}}{0{,}076\cos\theta_0 - 0{,}214\sin\theta_0}\,. \tag{12}$$

When calculating by formula (12), instead of $\beta = (\sigma t - kx)$, the extreme value of the phase $\beta = \beta'$ should be substituted for $\beta = (\sigma t - kx)$. In the case $U_0 = 0$, i.e. on the surface of standing water $\beta' = 0$, which corresponds to passing over the stone of the nodal line of the wave back, and when $U_0 \neq 0$ the extreme value of the wave phase is calculated by the dependence

$$\beta' \approx \arcsin\left\{-\frac{U_0^2 + A^2G^2}{6U_0AG} \pm \left[\left(\frac{U_0^2 + A^2G^2}{6U_0AG}\right)^2 + 1\right]^{1/2}\right\}. \tag{13}$$

In the third case, when the possible tipping direction of the stone is at an angle of 30° with the shoreline, the equation of moments takes the form

$$G'\cos\theta_0 \cdot n - G'\sin\theta_0\cos 60^\circ - 0{,}5\tilde{c}\rho\omega\,|\vec{V}\,|\vec{V}_{30^\circ}\cdot b = 0\,, \tag{14}$$

Where the projection of velocity vector in the direction of rock shift is defined by formula

. $$\vec{V}_{30^\circ} = \frac{\sqrt{3}}{2}\left[U_0 + AG\sin\beta\right] + 0{,}5AG\cos\beta\,. \tag{15}$$

If we determine the limit value of rock diameter from equation (14), we get

$$d_3 = 0{,}115\frac{\tilde{c}\gamma}{g\gamma'_s}\cdot\frac{\left[U_0 + AG(\sin\beta + 0{,}585\cos\beta)\right]}{0{,}076\cos\theta_0 - 0{,}107\sin\theta_0}\times\left[U_0^2 + 2U_0AG\sin\beta + A^2G^2\right]^{1/2} \tag{16}$$

Based on (16), the analytical determination of the extreme value of the wave phase involves long calculations. In this case, without much loss of accuracy, we may limit ourselves to determining the limiting value of the wave phase β, which corresponds to zero velocity of the main water flow in the channel ($U_0 = 0$), and is equal to $\frac{\pi}{3}$. Then dependence (16) will take a simpler form:

. $$d_3 = 0{,}115\frac{\tilde{c}\gamma}{g\gamma'_s}\cdot\frac{\left(U_0 + 1{,}16AG\right)\left(U_0^2 + 1{,}73U_0AG + A^2G^2\right)^{1/2}}{0{,}076\cos\theta_0 - 0{,}107\sin\theta_0}\,. \tag{17}$$

In the case of a device of a homogeneous stone sketch, the above formulas give excessive stone diameters, as they correspond to the most marginal state of the stones on the coastal slope. Most often the outcrops consist of stones of various shapes and merits, which can be arranged on the coastal slope arbitrarily. One of such probable forms, suitable for real quantitative estimation of stability of a rock outline is a case when the surface stones (having a spherical form) only half of their diameter protrudes from the sockets formed by the underlying three stones of the same diameter (Fig. 3.*e*). In this case the shoulders of tilting of the stone n and b the cross-sectional area ω of the midsection take the following values:

$$n = 0{,}217d\,;\;\; b = 0{,}25d\,;\;\; \omega = 0{,}785d^2\,. \tag{18}$$

Only the values of coefficients $\tilde{c}$ of frontal streamline forces on the stone can be considered unchanged.

Taking into account the values of these parameters, the minimum diameter d^* of the design stone of heterogeneous embankment in the direction of waves and water flow in the channel, i.e. in the direction of the axis Ox, is calculated by the formula

$$d_1^* = 0{,}86\frac{\tilde{c}}{g}\cdot\frac{\gamma(U_0 + AG)^2}{\gamma_s'\cos\theta_0}\,. \tag{19}$$

In the axis Oy' direction, i.e. down the slope, perpendicular to the shoreline

$$d_2^* = 0{,}057\frac{\tilde{c}\gamma}{g\gamma_s'}\cdot\frac{m_0 - 2{,}82}{m_0 - 1{,}15}\cdot\frac{AG\cos\beta'\cdot\left[U_0^2 + 2U_0AG\sin\beta' + A^2G^2\right]^{1/2}}{0{,}076\cos\theta_0 - 0{,}214\sin\theta_0}\,, \tag{20}$$

and, down the slope, at an angle of 30° to the shoreline

$$d_3^* = 0{,}05\frac{\tilde{c}y}{g\gamma_s'}\cdot\frac{m_0 - 1{,}41}{m_0 - 0{,}58}\cdot\frac{(U_0 + 1{,}16AG)\left(U_0^2 + 1{,}73U_0AG + A^2G^2\right)^{1/2}}{0{,}076\cos\theta_0 - 0{,}107\sin\theta_0}\,. \tag{21}$$

In dependencies (19) ÷ (21) m_0 means the slope coefficient of the bank slope of the canal, $m_0 = \cot\theta_0$; In the absence of stationary flow of water in the channel, in these dependencies must be substituted $U_0 = 0$; The coefficient $\tilde{c}$ of the frontal streamline flow in accordance with Mescheli's recommendations [4], according to which $\tilde{c} \approx 1{,}05$; Wave phases β' are determined by dependence (13) or approximately it is possible to assume that $\beta' = \pi/3$.

After determining the limiting diameters of the stones using dependencies (19) ÷ (21), the maximum of them should be chosen as the calculation one.

Conclusion

As the water depth on the slope increases, the values of diameters calculated by the above dependencies decrease. Therefore, initially the calculations should correspond to the shoreline, where the water depth is $H = 0$.

In addition, note that the opposite direction of alongshore waves in the channel relative to the uniform flow does not affect the size of the stones, because, in this case, in the above formulas simultaneously change both signs of the front U_0 and signs of extreme values of the wave phase β', and therefore the formulas for calculating the diameter of the stone remain unchanged.

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ԱՓԱՄԵՐՁ ԱԼԻՔՆԵՐԻ ԱԶԴԵՑՈՒԹՅԱՆԸ ԵՆԹԱՐԿՎՈՂ ՋՐԱՆՑՔՆԵՐԻ ԱՓԱՊԱՇՏՊԱՆ ՄԻՋՈՑԱՌՈՒՄՆԵՐԻ ՀԱՇՎԱՐԿԻ ՎԵՐԱԲԵՐՅԱԼ

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Մշակվել են ափամերձ ալիքների ազդեցության ենթարկվող եռանկյունաձև և սեղանաձև ջրանցքների լանջերի ամրացման հաշվարկային մեթոդներ:

Լանջերը բետոնե սալերով ամրացնելու դեպքում տրվում են հաշվարկային գործակիցներ՝ կախված դրա խորությունից՝ դրա հաստությունը որոշելու համար: Դիտարկվել է ջրանցքի ափամերձ լանջին բուրգի եռանկյունաձև հիմքի տեղակայման երեք առավել բնորոշ դեպքերը:

Բանալի բառեր. ջրանցք, ափամերձ ալիք, ափամերձ լանջ, առափնյա գիծ

К РАСЧЕТУ БЕРЕГОЗАЩИТНЫХ МЕРОПРИЯТИЙ КАНАЛОВ, ПОДВЕРЖЕННЫХ ВОЗДЕЙСТВИЮ ВДОЛЬБЕРЕГОВЫХ ВОЛН

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Разработаны методы расчета укрепления откосов каналов треугольного и трапецеидального сечений бетонными плитами и каменной наброской подверженных воздействию вдольбереговых волн.

В случае укрепление откосов бетонными плитами приведены расчетные соотношения для определения толщины плиты в зависимости от её заглубления.

При укреплении откосов каменной наброской, рассматриваются три наиболее характерных случаев расположения треугольного основания пирамиды созданной наброской на береговом склоне канала, в частности:

а) Когда камни, образующие гнездо на склоне, расположены таким образом, что расчётный камень, помещенный на вершину пирамиды, опрокидывается по направлению течения волнового потока; б) Когда расчётный камень может быть опрокинут перпендикулярно береговой линии, в сторону больших глубин; в) Когда возможное направление опрокидывания камня составляет угол 30° с береговой линией, то есть когда одна из сторон равностороннего треугольника основания пирамиды параллельна береговой линии.

Ключевые слова: канал, вдольбереговая волна, береговой откос, береговая линия, размеры элементов покрытия.

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