Justification of the Application of Engineering Protection Methods for Territories Subject to Erosion Processes

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Abstract. The urgency of the problem of the development of erosion processes is substantiated. Existing methods of engineering protection of territories from the development of erosion are considered. Indicated areas of the urban environment, most prone to the development of erosion processes. The practical significance of the research was determined. The mathematical model of the development of erosion processes on slopes is given, which makes it possible to carry out a preliminary assessment of the erosion resistance of soils and on the basis of this assessment determine the need for additional measures for their consolidation. Based on the mathematical model, the criteria for assessing the risk of erosion processes are defined. On the basis of the selected criteria, the main conditions that modern methods of protecting territories from erosion processes should meet. Innovative methods of protecting slopes from the development of erosion processes are presented. Systematization of existing and innovative methods of engineering protection of territories from erosion processes is carried out. Geosynthetic materials are considered that are an integral part of geocomposition systems, allowing to protect slopes from erosion processes. The main criteria to be met by geocomposition systems are determined. The practical application of geocomposition systems in various areas of construction is considered: civil, transport, hydraulic engineering, special. The directions of further research are determined. Conclusions are drawn on the results of practical application of geocomposition systems to protect slopes from erosion processes. The article contains mathematical model of the development of erosion processes on slopes of roads allowing a preliminary assessment of erosion control soil stability and on the basis of this assessment to determine the need for additional measures for their fastening.

1. Introduction

Human life and its economic activities are largely connected with water objects. However, rivers, ponds, streams, being sources of life and objects of economic activity of people, at the same time have adverse effects on adjacent territories, engineering structures and settlements. This may be due to both the natural development of water bodies and anthropogenic impact, necessitating protection from the destruction of settlements, engineering structures and communications. Any development of coastal areas, construction on the banks, construction of water intakes are associated with the risk of destruction due to the erosion of the banks and the bottom of the riverbed. This is facilitated, firstly, by the almost complete absence of observations of the deformations of the channels, because of which the created threat of destruction or withdrawal from the operational state is almost always considered an elemental destructive phenomenon. Secondly, communal, communication, industrial, town-
planning development of territories adjacent to water bodies is carried out, or with complete disregard for natural processes occurring at water bodies, or channel processes are estimated and predicted for a short period of time, not sufficient for their comprehensive study.

2. Relevance

Watercourses and water bodies, like other components of the natural environment, are affected by urbanization and industrial development of the territory, covering their watersheds, valleys, floodplains and riverbeds of watercourses. Water bodies, the whole basin of which is within the urban agglomeration, completely degrade, and those rivers that flow through the city in transit retain their appearance, but the processes occurring in them, irreversibly change, and can cause irreparable damage to the objects of the city. Among the natural processes and phenomena that cause the destruction of engineering structures, communications, residential buildings, agricultural lands that make it difficult or impossible to operate economic objects that threaten their withdrawal from the operational state, that is, ultimately endangering people's lives, a prominent place belongs to erosion-channel processes developing in erosion-channel systems. Erosion-and-channel systems include slopes on which processes of flushing the soil by non-river flows develop, gully formation processes occurring under the influence of time flows, channel processes developing under the influence of constantly operating water currents. Natural and anthropogenic-induced erosion-channel processes occurring in urban areas acquire a qualitatively new character. Anthropogenic activities on the speed and mass impact on the riverbeds of watercourses and reservoirs exceed the influence of natural factors on them [1].

3. Scientific significance of the issue

In view of the fact that the objects in question are located in urbanized areas, the damage caused by the uncontrolled development of erosion-channel processes can be expressed not only as an economic, but also as human victims. To prevent the above-mentioned consequences, it is necessary to carry out an assessment of the danger of the development of erosion-channel processes. According to the data of studies [1], the risk assessment of channel processes can be compared with the stability indicators of the channel: the less stability of the channel, the greater the danger. Such indicators are the number of Lohtin (characterizing the mobility of the channel):

\[ L = \frac{d}{I} \]

and the stability factor of N.I. Makkaveeva

\[ K_s = \frac{d}{b \times I} \]

\( d \) – coarse particle size, mm;
\( I \) – surface slope, %
\( b \) – channel width, m.

The degree of danger of channel processes caused by horizontal deformations of channels depends on the morphodynamic type of bed. The direction of vertical deformations of channels in natural conditions, as a rule, are of low intensity, but noticeably activated under the influence of anthropogenic factors. A wide variety of research methods are used in the study and assessment of the hazard [2], including: field observations (exploration of the territory, experimental field work, etc.), analytical (experimental and mathematical modeling), and instrumental methods. Based on the risk assessment, the risk is calculated from the development of erosion-channel processes. Risk reduction is achieved through the implementation of activities aimed at regulating the dangers and vulnerabilities of social and material spheres [4]. The study of the nature and factors of the development of erosion-channel processes is the fundamental basis for managing them and preventing the danger posed by their development. However, even with good knowledge of all the patterns of erosion and channel processes, their management is extremely difficult. Designed measures of engineering protection should provide: prevention; elimination or reduction to the permissible level of the negative impact of erosion-channel processes in the protected area; the production of works in ways that do not lead to the emergence of new and intensification of existing erosion-channel
processes; preservation of existing landscapes; The use of biological methods for engineering protection of territories subject to erosion-channel processes.

4. **Formulation of the problem**

The most acceptable, relatively cheap, biologically pure, aesthetically favorable and at the same time effective method of combating erosion in urbanized areas is the natural strengthening of slopes and slopes by plant communities. However, the use of natural strengthening of slopes and slopes for a number of reasons is not always possible and even its presence is not always sufficient to prevent the development of erosion processes. Therefore, the question arises of applying engineering methods of protecting the territory, which include: - the organization and diversion of surface runoff; - smoothing of the slopes; - application of gabion constructions; - the use of reinforced concrete structures - the construction of a stone outline, etc. The application of these methods of protection against soil erosion is based, as a rule, on experience and does not provide for additional preliminary study and calculation of decisions.

5. **Theoretical part**

Thus, there is a need to consider the process of erosion from the point of view of the mathematical description and justification of the interrelation of the decisions taken with the use of additional measures to protect slopes from erosion.

1. Theoretical foundations describing flow velocities are expressed in the following dependences [2,5]:

\[ V_c = \log \frac{8.8H}{d} \omega = 1.41 \cdot V_n, \]  

\( V_c \) – breaking speed 
\( V_n \) – non-moving speed;
\( H \) – flow depth;
\( d \) – grain diameter;
\( \omega \) – hydraulic grain size at standard (turbulent) wrapping flow regime.

An important parameter in determining the erosion resistance of soils is the runoff coefficient or surface absorption coefficient. Based on the experiments carried out in 1932-34, under the leadership of N.N. Belov and in 1939-40, and in 1946, L.T. Abramov, it was found that the coefficient of runoff depends on the intensity \( q \) (l / s ha) and the duration of the rain \( t \), min, and this relationship is presented in the form

\[ \psi = z \cdot q^{0.2} \cdot t^{0.1} , \]  

\( z \) – coefficient, depending on the genus of the surface.

Another characteristic of the eroded surface, which affects the erosion processes, is the surface roughness \( (n) \), which is defined as follows:

\[ n = \frac{\Lambda^6}{22.2}, \]  

\( \Lambda \) - effective height of the roughness protrusions will be:

\[ \Lambda = 0.7k_5, \]  

\( k_5 \) – diameter of the largest grains, the proportion of which in the mixture is 5%.

One of the main indicators characterizing the behavior of particles in the water flow is hydraulic size. By hydraulic size \( \omega \) we mean the speed of a uniform unrestricted incidence of a particle in a fluid at rest. To determine the value of the hydraulic size [5]:
\[ \omega = \sqrt[4]{\frac{2gd \gamma_g - \gamma_v + 1,25 C_{rs} + \sigma_{scs}}{1,75 \gamma_v k}}, \]  

(7)

g - acceleration of free fall, m/s²;
\gamma_g - specific gravity of soil, kN/m²;
\gamma_v - specific weight of water, kN/m²;
d - diameter of grains, m;
C_{rs} - the estimated least possible resistance of the cohesive soil to the break, Pa;
k - overload factor;
\sigma_{scs} - stress caused by swelling.

To take into account the inhomogeneity of the C_{p,c} can be represented as the product of the normative (average) resistance C_{p,c} on the coefficient of homogeneity K, characterizing the variability of the strength index of the soil.

\[ C_{nm} = K C_{nm}^n, \]  

(8)

Due to the dynamic effect of the turbulent flow on the unit for the standard resistance, the tensile strength at the dynamic load of the Sleep should be taken. This index can approximately be determined from the dependence on the static strength of cohesion of the soil, determined by indenting a spherical stamp [5]:

\[ C_{nm}^n = 0,035 C, \]  

(9)

If there are no experimental measurements of the static strength of the soil, it can be calculated as a function of the average particle diameter:

\[ C = \frac{3,3}{d^{0,65}} \]  

(10)

This expression is obtained by mathematical calculations, based on the assumption that each type of soil corresponds to its grain size. At the moment, the dependence is valid for soils with a coefficient of porosity e = 0.65, given in SNiP 2.02.01-83 * "Foundations of buildings and structures." Taking into account the foregoing, the dependence for calculating the hydraulic size takes the following form:

\[ \omega = \sqrt[4]{\frac{2gd \gamma_g - \gamma_v + 0,12/d^{0,65} K}{1,75 \gamma_v k}}, \]  

(11)

In order to take into account that the weighting action of water on soil particles is not always the same, Alekseev AA [1] suggested to determine the weighting effect of water on partially submerged grains. For this it is necessary to assume that the grains have the shape of a sphere. This means that you can use the dimensionless coefficients of the ratio of the volumes of the underwater \((k_{nv})\) and above-water \((k_{nv})\) parts of the grain. From the equations of the volume of the sphere and the volume of the spherical segment, these coefficients will be equal to [1]:

\[ k_{nv} = \frac{4\pi \left( \frac{d}{2} \right)^3 - \pi \frac{d - R}{d} \left( \frac{d}{2} - \frac{d - R}{3} \right)}{4\pi \left( \frac{d}{2} \right)^3}, \]  

(12)
However, in the case where \( R \leq \frac{d}{2} \), i.e. the particle is immersed in water by less than half (typical for small rains, when the infiltration value approaches zero and the surface runoff begins to form), the value of the coefficients varies [6]:

\[
kV_n = \frac{\pi d - R^2 \left( \frac{d - R}{2} \right)}{4\pi \left( \frac{d}{2} \right)^3}.
\]

(13)

(14)

(15)

The introduction of these coefficients in (9) allows us to more accurately determine the critical undistorted flow velocity at which the erosion of the underlying soil, including the strengthened one, has not yet begun.

The necessity of additional anti-erosion measures on the slopes can theoretically be determined from the following condition:

\[
V \geq V_n,
\]

(16)

\( V \) – the actual average flow velocity, which can be calculated from the formulas of Pavlovsky and Chezy [3,5]:

\[
V = \sqrt{\frac{g\alpha R 1.5\sqrt{n+0.5}}{N}}.
\]

(17)

When comparing the values of the critical velocities to the actual average velocities, it is possible to estimate the erosion stability of the slopes and to identify the need for their additional strengthening, or for carrying out other engineering measures. The analysis of the developed mathematical model presented above, as well as the results of the field experiment, allow us to draw the following conclusions:

- the depth of the flow has a great influence on the erosion resistance of the soils;
- for soils with a particle size of less than 1 mm, their static strength renders the erosion resistance of the soils. And the smaller the particle size of the soil, the greater the strength and the greater the erosion resistance of soils;
- the least anti-erosion resistance is possessed by soils with a particle size of 0.1 to 1 mm (silt and fine sands). This is due to the small weight of the particles and the low static strength of the soil massif;
- this mathematical model allows an initial assessment of the erosion resistance of soils without resorting to instrumental methods for assessing and controlling erosion hazard, i.e. if the values of the actual flow rate are at the top of the graph, additional measures should be applied to protect slopes from erosion, and if in the lower, then this need is absent and the soils are resistant to erosion.
- the results of the completed full-scale experiment are completely consistent with the developed mathematical model, which confirms its probation.

6. Practical significance, proposals and results of implementation, the results of experimental studies
The performed research has shown a high degree of urgency of the considered problem, connected with maintenance of ecological safety of the territories prone to erosive processes. The obtained dependences can be used as justifying the use of anti-erosion protection. The specified mathematical model allows us to justify the use of technical methods for strengthening slopes, slopes and banks of water bodies and streams at the design stage. The results of the experiment confirming the correctness of the developed mathematical model make it possible to extend the main research data to analog objects.

7. The conclusion
The necessity of mathematical modeling of erosion processes is caused by the complexity of the problem being solved, as well as by the availability in a modern practice of a number of methods of protection with different cost. The use of grounded innovative methods of protecting territories from erosion processes (geocomposite systems based on geosynthetic materials) can significantly reduce the material consumption and labor intensity of engineering protection, while ensuring the environmental safety of the protected areas.

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