Influence of cohesion strength in cohesive soils onchannel bed erosion

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Abstract. The results of experimental studies on the mechanical properties of cohesive soils associated with the use in the study of the erosion process are presented. The influence of the cohesion strength of cohesive soil on erosion is described. The relationship between the erosionflow velocities and cohesion strength has been obtained.

Keywords: soil cohesion, shear resistance, normal stress, angle of internal friction, cohesionstrength, tensile strength, erosion velocity.

1 Introduction

The erosionvelocity of the flow, which determines the erosion process, is represented by several interacting and interrelated factors [1, 5, 8, 9, 10, 11].

In this work, we do not aim to study the external, i.e., hydromechanical and other factors in depth, but we focus on the factors that are poorly covered in the literature related to this topic. Let's look at the resistance of soil to displacement, which is one of the important factors. Clarification of this factor is important in establishing effective improved methods for determining the erosion velocity of water flow.

2 Materials and methods

Maslov proposed to use the following three-term formula instead of the two-term formula to determine the shear resistance [3]:

$$\tau = \sigma tg\varphi + C_k + C_c , \qquad (1)$$

here σ - normal stress; φ - the angle of internal friction; C_k - the cohesion of the rock with the property of recovery; C_c - structural cohesion due to irreversible bonds.

This formula represents two types of cohesion, cohesion C_k in coagulation calculations and C_c the cohesionforce in solid transitions and phase bonds. Cohesive strength due to coagulant bondsduring erosion, i.e. $C \approx C_k$, is often determined in clayey soils.Therefore, the size of the cohesion depends on the density and moisture of the soil, the

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dispersion and hydrophilicity of the mineral sediments, the location of the particle in the shear plane, and other factors.

In soils dominated by phase bonds, structural cohesion is almost determined by the quantity C_c, which depends on the moisture content and composition of the soil.The structural cohesion of samples with mixed bonding is determined by both components, i.e. $C = C_k + C_c$. In normal loadings where the strength structure $\sigma < P_c$ is low C_c is more important and C_k is important when $\sigma > P_c$.From this, depending on the type of structural cohesion in clayeysediments, not only the size but also the nature of the structural cohesion changes [6].

It is possible to analyze the relationship between the angle of internal friction and the character of the structural bond. The formation of structural bonds in underwater conditions begins with the processes of coagulation and aggregation that occur during the deposition of thinly dispersed minerals. It should be noted here that close and long coagulation bonds can be formed depending on the size and shape of particles, their surface potential, relative hydrophilicity, the concentration and composition of the solution in the cavity, and their mutual identification in the dispersed medium [4].

Sections of many canals are located on bound soils, i.e. sand, loam, and silt soils. These soils are solid, plastic, and liquid depending on their moisture retention.

3 Results and Discussions

Becausecohesive soils have the characteristic of cohesion, they are resistant to shear and deformation.The ultimate resistance of soils is divided into σ_c ultimate resistance against shear and σ_p tensile ultimate resistance against stretch. σ_c ultimate resistance to shear and σ_p ultimate resistance to stretch have interrelated specifications, and soils can be determined using the same test methods.This can be determined, for instance, by the ball sampling method.

The tensile strength ofcohesive soil σ_p is much smaller than the strength to shear σ_c and, according to Ts.E. Mirtskhulava [5], it is $(0,15 \div 0,18)\sigma_c$ for soils with an aggregate structure and $(0,20 \div 0,22)\sigma_c$ for soils with an integrated structure. In this case, the dynamic strength in σ_p stretches can be taken as $\sigma_p = 0,18\sigma_c$.

Therefore, shear strength σ_c is considered the base strength characteristic ofcohesive soils. To determine the cohesion of water-saturated soils, the following relationship was obtained [1]:

$$\sigma_c = 10^7 \frac{W_p^4}{\varepsilon_n^3} \qquad (2)$$

here W_p - soil moisture at the limit of massing (the ratio of the mass of water in the sample to the dry mass of the soil); ε_n - porosity coefficient.

According to our experimental data on the soil samples, the dynamic strengths of shear σ_c and stretch σ_p were determined (Table 1).

Sandy soil sample 6 does not have the dynamic strengthto shear σ_c and stretch σ_p due to a large amount of fine sand.

At the beginning of the formation of cohesive soils at the channel bed, the sediment cracks are filled by coagulation, and then sedimentation and continuous consolidation of the sediments occur, and this process leads to the formation of the fissured cell structure of the soils.In such soils, the particle size $d < 10^{-5}$ m is very small, their porosity coefficient $\varepsilon_n > 1 \div 1.5$ and moisture content are 80-85%, and they are called clays.

Table 1. Dynamic strengths in σ_c shear and σ_p stretch

№	Soil sample	C, kg/sm^2	υ_e, m/s	υ_c, m/s	d	i	U_*	$\sigma_c = 10^7 \frac{W_p^4}{E_n^3}$	$\sigma_p = 0{,}18 \cdot \sigma_c$
1	2	3	4	5	6	7	8	9	10
1	Soil-1	0,094	0,67	0,48	0,004	0,003	0,0108	0,004*10^7	0,00072*10^7
2	Soil-2	0,088	0,51	0,36			0,0108	0,001*10^7	0,00018*10^7
3	Soil-3	0,084	0,67	0,48			0,0108	0,0007*10^7	0,000126*10^7
4	Soil-4	0,068	0,5	0,36			0,0108	0,0005*10^7	0,00009*10^7
5	Soil-5	0,043	0,45	0,32			0,0108	0,0006*10^7	0,000108*10^7
6	Soil-6	0	0,47	0,34			0,0108	-	-

We know that highly water-saturated clays produce a fluid viscous-plastic environment that does not obey Newton's law:

$$\tau = \tau_b + \mu_{ef} \frac{d\overline{u}}{dz}, \qquad (3)$$

where τ - tension between moving layers; τ_b -initial stress in shear; $\mu_{эф}$ - effective viscosity.

The effective viscosity can be determined by the following formula:

$$\mu_{ef} = \mu\left(1 - ac^n\right)^n, \qquad (4)$$

Here, α and n are parameters.

According to experimental experiments [1] $a = 1{,}58$ and $n = 0{,}175$ can be accepted. According to Mirtskhulava's experiments, it is equal to $a = 1{,}3$.

We now consider the effect of the cohesionforces in cohesivesoil against erosion. Cohesion forces in cohesivematerials have a very complex nature and are determined by the following internal cohesions: intermolecular-contact; colloidal structural; with cementation [3, 4, 5, 6, 7].

If the cohesive soils are saturated with water, then the cohesive forces increase their resistance to being washed away by the flow, and these forces determine their degree of consistency.

We conducted experiments in the laboratory of "UzGAShKLITI" LLC (State Project-Research Institute of Construction, Geoinformatics and Urban Development Cadastre) to determine the cohesive strength of soil samples prepared for the study of the washing of cohesive soils under the influence of currents.

Based on the experimental data, we will consider the impact of the cohesive soil on the shear resistance (Table 2).

According to Table 2, we construct a graph of the relationship between shear strength τ and normal stress (Fig. 1) and analyze it according to the relationship.

From Table 2, with the increase of the friction force C, the value of the shear strength τ also increases.[20, 21, 22]

Since the experiments were carried out under slow consolidation shear conditions, the relationship $\varphi = f(\sigma)$ takes a straight line, while the value of the coefficient φ increases. The following reasons can be given for the increase in φ coefficient: [19]

- reduction of the hydrated film layer in coagulating contacts and increased molecular interaction between particles when squeezing water from the system;
- an increase in the amount of contacts.

Table 2. Shear resistance of cohesive soils

№	Soil sample	σ	$tg\varphi$	C	$\tau = \sigma tg\varphi + C$
1	2	3	4	5	6
1	Soilsample - 1	1,194	27	0,094	0,703
2	Soilsample - 2	1,113	27	0,088	0,656
3	Soilsample - 3	1,063	26	0,084	0,579
4	Soilsample - 4	1,025	25	0,068	0,545
5	Soilsample - 5	0,956	25	0,043	0,488
6	Soilsample - 6	0,191	10		0,034

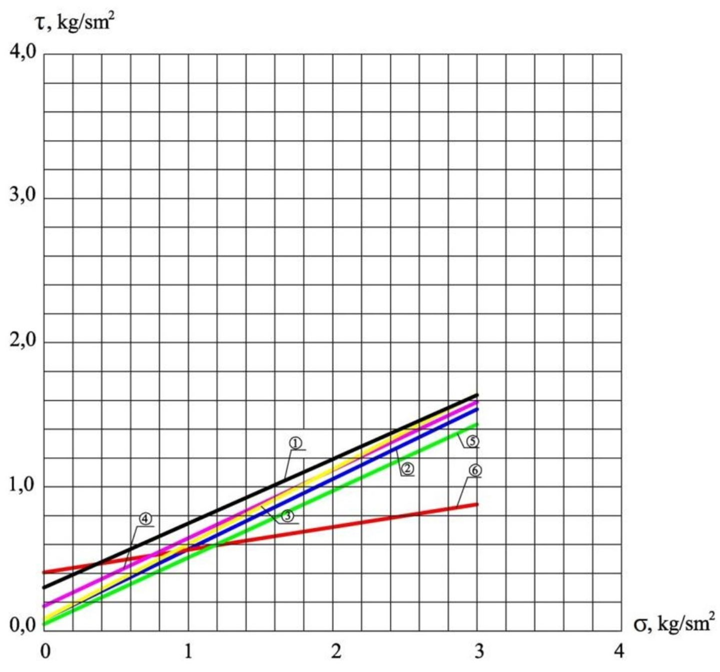

Fig. 1. $\tau = f(\sigma)$ connection graph: 1- soil sample – 1, 2- soil sample – 2, 3- soil sample – 4, 4- soil sample – 4, 5- soil sample – 5, 6- soil sample

Therefore, in clayey rocks with strong phase contact, $\tau = f(\sigma)$ graph has a straight-line appearance, and its angle of inclination relative to the abscissa axis does not depend on the experimental conditions. Because of these clayey rocks have a high degree of strength, their φ angle is much higher.

The erosionrate of cohesive soils by the flow depends mainly on their cohesion strength.The cohesion strengthof soils when fully saturated with water often determines the degree of cohesion strength and stands out by priority over other physical-mechanical properties of cohesive soils that resist erosion. [11, 12, 13]

To show the priority of this factor, we analyze the laboratory data (Table 1) on the determination of the cohesion strength of cohesive soil samples. [14, 15, 16, 17]

In cohesive (sand, loam) soils with an aggregate structure, erosion occurs as a result of the disruption of the interconnection between the aggregates. It should be noted that the size of the released aggregate particles is determined by the structure and intensity of water flow turbulence.Disruption of aggregates in almost flat channel beds occurs only under the influence of pressure pulsation force, and it can be determined as follows [2]:

$$p' = 3,5\rho u_*^2 \tag{5}$$

In there u_* - the dynamic velocity of the flow.

The variable dynamic pressure, which depends on the effect of pulsating pressure, leads to a violation of the bonding properties between aggregates. As a result, it always creates conditions for the occurrence of micro-cracks. At this time, aggregates can stay in place only under the influence of their own gravity. The resulting pressure pulsations cover a much larger part of the surface of the bottom of the well. It is in this case that the value of the standard pulsation of the pressure on the surface of the soil aggregate is so small that it can be neglected. If the negative pulsating pressure force on the surface of the aggregate is equal to the force of gravity acting on the aggregate, erosion of the cohesive soil occurs. We express this mentioned condition in the following form: [18, 19]

$$p' \cdot d_a^2 = (\rho_s - \rho) g d_a \cdot d_a^2, \tag{6}$$

There d_a - is the aggregate size.

taking into account the parameter (5), we write equation (6) in the following form:

$$3,5\rho u_*^2 d_a^2 = (\rho_s - \rho) g d_a^3 \tag{7}$$

ρ_s - soil density.

It is possible to find the sizes of aggregates breaking from equation(7), i.e

$$d_a = \frac{3,5u_*^2}{g\left(\frac{\rho_s}{\rho} - 1\right)} \tag{8}$$

According to laboratory experiments, the size of aggregates breaking off at velocities $u_* = 10 \div 15\ sm/s$ is about $d_a = 3 \div 4\ mm$.From this we can see that the process of failure of cohesive soil associated with turbulent flow is always dependent on factors other than the cohesionstrength. [23]

Now, on the basis of the experimental data, we will establish a connection between the cohesion strengthof thecohesive soil, which is connected with the erosion velocity of the flow (Fig. 2). [3, 4, 5]

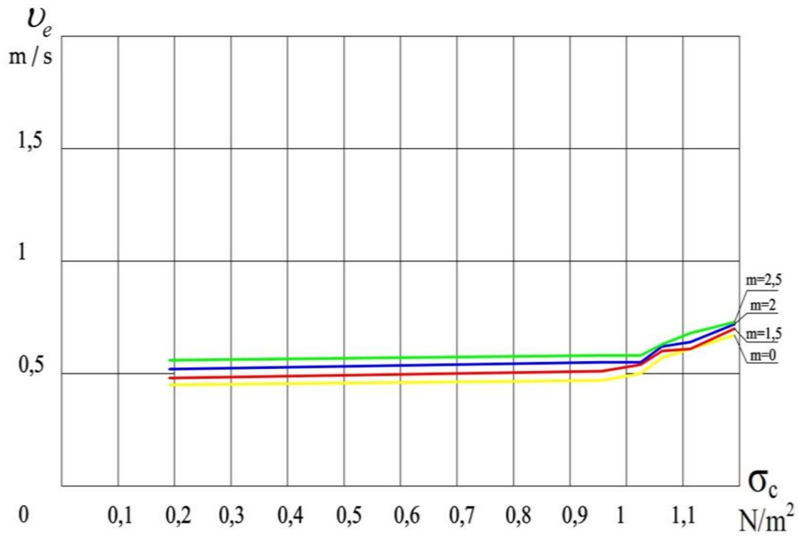

Fig. 2.Graph $\upsilon_e = f(\sigma_c)$

The $\upsilon_e = f(\sigma_c)$ graph shows the condition for determining theerosion velocity of flow concerning the parameter of dynamic shear strength.[6, 7, 8]

We also plot $\upsilon_e = f(C_b)$ the relationship between υ_e the erosion velocityof the flow and C_b the cohesive strength of the cohesive soil according to the experimental data. [8, 9, 10]

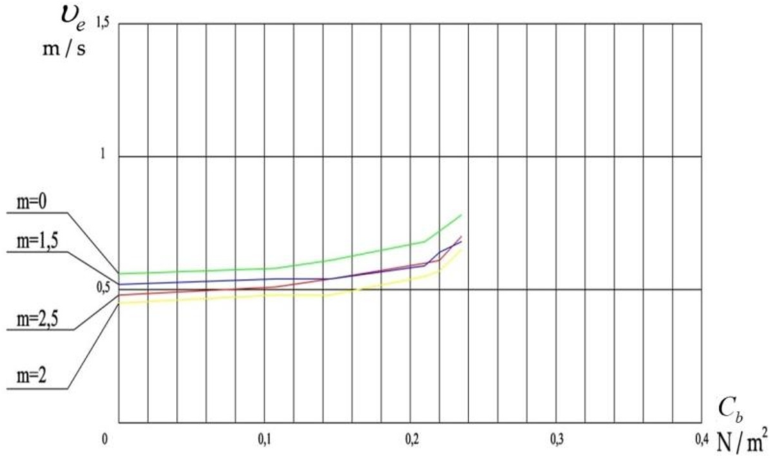

Fig. 3. Graph $\upsilon_e = f(C_b)$

4 Conclusions

In laboratory and field conditions, it was observed that the erosion resistance of cohesive soilsincreased with increasing cohesionstrength.Evidence of this can also be seen in the $\upsilon_e = f(C_b)$ connection graph shown in Figure 3.

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