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ASSESSMENT OF CHANNEL EROSION BASED ON THE PHYSICAL PROPERTIES OF COHESIVE SOILS

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Abstract

On the basis of laboratory studies, the physical properties of the studied soils for erosion were established. The resistance of these soil properties is shown with the eroding ability of the water flow. A relationship has been established between the eroding flow rates and the intensity of erosion of cohesive soils.

Key words

soil erosion, erosion velocity, erosion intensity, clay deposits, cohesive soil, granulometric composition.

Only a limited number of researchers have studied the problems related to the erosion process based on the physical and mechanical properties of cohesive soils [1, 2, 3, 5]. The influence of the physical and mechanical properties of cohesive soils on erosion has been thoroughly investigated by Academician T. E. Mirtskhulava [2].

In this study, the main objective was to determine the physical and mechanical properties of collected cohesive soil samples in order to assess their erosion rate, and to utilize these properties in subsequent analyses.

To assess the erosion of cohesive soils under flow conditions in a channel model, disturbed cohesive soil samples were prepared in laboratory conditions using metal containers. The samples were categorized as follows: 1 – light loam taken from a natural channel; 2 – medium loam soil; 3 – light coarse sandy loam; 4 – light sandy loam; 5 – light sandy loam;

6 – heavy silty sandy loam. Additionally, a sample of light loam was collected from the "Dustlik" canal in the Kashkadarya region during field experiments. In

the subsequent sections, these soils will be briefly referred to as Soil 1, Soil 2, and so on.

To evaluate the erosion of cohesive soils under the influence of flow in a channel model, disturbed cohesive soil samples were prepared in metal containers under laboratory conditions. These soils were classified as follows:

1 – light loam from a natural channel;
2 – medium loam soil;
3 – light coarse sandy loam;
4 – light sandy loam;
5 – light sandy loam;
6 – heavy silty sandy loam.

In addition, a light loam (легкий суглинок) soil sample was taken from the "Dustlik" canal in the Kashkadarya region, where field experiments were conducted. In the following sections, these soils will be briefly referred to as Soil 1, Soil 2, and so on.

After conducting experiments on the erosion rate of soils under flowing water, samples were taken from each soil type, and tests were carried out to determine their physical properties.

To study the erosion of cohesive soils under channel flow conditions, experiments were conducted at the laboratory of "UzGASHKLITI" LLC (State Design and Research Institute for Construction, Geoinformatics and Urban Planning Cadastre) to determine the physical properties of the prepared cohesive soil samples.

The physical and mechanical characteristics of the cohesive soil samples used in the experiments are presented in Table 1. Биз бу ишимизда канал ювилиш жараёнига бевосита таъсир этадиган боғланган грунтларнинг лаборатория тажрибаларида ўрнатилган физик хоссаларини қараб чиқамиз.

The analysis of the established physical properties of the soils used in the experiment indicates that, to date, the physical characteristics of cohesive soils are considered among the key factors in erosion processes occurring in cohesive channels. However, general patterns that link these properties to flow parameters have not yet been identified. In this study, the determined properties of the cohesive soils correspond to the scope of the experiments conducted to investigate erosion processes in channels.

Table 1

Physical and Mechanical Properties of Cohesive Soils

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Soil	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5	Soil 6
W, 0%	14,2	33,6	27,4	24,4	21,8	21,9
$V_{гр}$,	1,58	1,66	1,73	1,77	1,83	1,82
$V_{ск}$,	1,38	1,24	1,36	1,42	1,50	1,49
ρ , г/см³	2,69	2,70	2,68	2,67	2,66	2,65
n, %	48,7	54,1	49,3	46,8	43,6	43,8
ε	0,949	1,177	0,971	0,880	0,773	0,779
I_w	0,40	0,77	0,76	0,74	0,75	0,75
W_{max}, %	35,5	43,6	36,05	32,97	29.06	29.2
W_T,%	32,8	28,1	22,3	19,5	16,1	-
W_P,%	24.4	20,0	16,0	13,6	13,5	-
I_P	8.4	8,1	6,3	5,9	2,9	-
I_L		1,68	1,81	1,83	2,86	-
vp	1,52	1.44	1,41	1,.28	0,9	0,7

The analysis of the established physical properties of the soils used in the experiment reveals that, to date, physical characteristics of cohesive soils are considered key factors in the erosion processes occurring in cohesive channels. However, no general laws linking these properties to flow parameters have been identified.

In this study, the determined properties of cohesive soils align with the scope of the experiments conducted to investigate erosion processes in channels.

Table 2
Granulometric Composition of Cohesive Soil Samples

№	Soil example	Granulometric Composition of the Soil,%								Sum of tions %
		>1,0mm	1,0-0,5mm	0,5-0,25 mm	0,25-0,10 mm	0,10-0,05 mm	0,05-0,01 mm	0,01-0,005 mm	<0,005 mm	
1	Soil 1	59,54	8,43	20,37	7,38	2,78	0,94	0,33	0,22	100,0
2	Soil 2	73,12	4,58	18,15	2,79	0,87	0,31	0,13	0,05	100,0
3	Soil 3	32,17	18,22	30,78	10,29	5,14	2,03	1,03	0,33	100,0
4	Soil 4	56,48	10,46	22,32	6,53	3,18	0,76	0,21	0,05	100,0
5	Soil 5	41,90	14,42	25,69	9,51	4,37	2,41	1,26	0,44	100,0

It is well known that the granulometric composition of soils determines their strength characteristics. To date, no clear functional relationship has been established between the flow velocity and the granulometric composition of the soil.

The average specific gravity of the cohesive soils was found to be between 2.65 and 2.75 g/cm³. The bulk density of the soil skeleton is one of the main characteristics of the soil, which changes in response to the expansion or contraction of cohesive soils, but it shows minimal change relative to the bulk density (Table 1).

When the porous structure of cohesive soils is fully saturated with water, friction between soil particles is significantly reduced, and their volume also increases. In this case, the water films between the particles smooth out the roughness of individual aggregate particles due to molecular attraction forces. For this reason, friction is very low in saturated clayey soils.

In clayey deposits, new precipitates exhibit high porosity (45...90%). The porosity of plastic clays varies from 3% to 6%.

In the experiments, no clear relationship was observed between the values of the porosity coefficient and the flow erosion rate for cohesive soil samples. However, experiments on the flow erosion rate revealed that with the decrease in the porosity of cohesive soils, their resistance to erosion increased. Since no distinct functional relationship was found between these factors, this parameter was not considered when evaluating the flow erosion rate.

Additionally, we examine the plasticity characteristics of the soil samples in relation to their erosion resistance. The moisture between the upper and lower limits of plasticity is closely related to the free water bound in the soil. Cohesive soils exhibit plasticity at a specific thickness of the free water layer.

Most researchers believe that the plasticity characteristics of cohesive soils are manifested only when water films (layers) of a certain thickness surround the particles. In this case, when clay particles are saturated with water, the loosening of the inter-particle bonds and the intense development of diffusion films on the surface of the particles lead to the expansion of cohesive soils and the manifestation of particle displacement. Under such conditions, the ease of sliding between particles is ensured by external influences.

The degree to which the plasticity characteristics of cohesive soils are displayed depends on their unique properties, such as composition (granulometric, mineral, and exchangeable base composition), shape, and the specific properties of the vapor solution interacting with them, including chemical composition and concentration.

The upper limit of soil plasticity is one of the indicators of cohesive soils, which provides a general understanding of the composition of the clay particles in cracks and the hydrophilic degree of the minerals forming them.

The amount and hydrophilicity of the clay particles determine the bonding forces in the soil, which subsequently affect the erosion process.

Experiments did not establish a functional relationship between the flow erosion rate and the upper limit of soil plasticity.

From Table 1, it can be observed that as the plasticity of cohesive soils increases, their resistance to erosion also increases.

The moisture content or the degree of saturation coefficient, which shows the relative amount of gas phase in the soil pores, is an important characteristic.

The composition of clay minerals has the most significant effect on the maximum molecular moisture capacity. For montmorillonitic clays, it is equal to 50-100%; for hydrosmectitic, kaolinitic, and polymineral clays, it is equal to 12-40%. Organic substances increase the maximum molecular moisture capacity.

Due to the relationship between the maximum molecular moisture capacity and the surface area of the microstructural elements, an approximate estimation can be made regarding the size of the soil's microaggregate composition. The maximum molecular moisture capacity (in %) for clays is greater than 24%; for heavy clayey soils, it is 24-16%; for medium soils, 16-12%; for light soils, 12-8%; for heavy sandy soils, 8-5%; and for light sandy soils and sand, it is less than 5%.

Another characteristic of soil is its shrinkage. Shrinkage refers to the reduction in the volume of soil during the drying process. In the plastic state of cohesive soils, the water-colloid films are quite strong, and the particles can move (shift) easily relative to one another. During shrinkage, the evaporation of moisture, an increase in surface tension forces, and the noticeable manifestation of intermolecular forces cause the particles to come closer together. Shrinkage occurs as the soil transitions from a two-phase system to a three-phase system, continuing until the upper layer reaches a state of hygroscopic moisture and dries out.

Shrinkage phenomena often occur with the formation of cracks (fissures), which reduce the cohesion of the soil mass. Montmorillonitic clays exhibit maximum shrinkage, while hydrosmectitic, polymineral, and kaolinitic clays shrink to a significantly lesser extent. The fewer clay-colloid particles there are, the greater the shrinkage will be.

The intensity of erosion in channels was observed to be higher in periodically operating channels compared to continuously operating channels. The primary

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reason for this is related to the moisture content of cohesive soils. In continuously operating channels, the moisture remains high, while in periodically operating channels, the moisture almost disappears during non-operation, and cracks develop in the channel bed. Due to the lack of moisture in the cracks when water interacts with the soil, the cohesive forces are diminished, leading to soil erosion. This situation was observed in the periodically operating "Dostlik" channel. By the end of the irrigation season, the channel eroded so much that it significantly reduced the ability to supply water to the irrigated fields.

Experiments were conducted to study the specific effect of moisture on channel erosion, both in the field and laboratory conditions. The research was carried out in the "Dostlik" channel located in the Kashkadarya region. The physical properties of the soil samples taken from the laboratory and the channel are listed in Table 1.

To study the relationship between the erosion rate and soil moisture, the first sample of both channel cohesive soil and laboratory soil was used. The soil taken from the channel was placed in the channel model at moisture levels of 5-10%, 16-20%, 28-35%, and 39-50%, while the laboratory soils were placed at moisture levels of 7-10%, 13-22%, 28-35%, and 41-53%. The erosion rates were then measured, and the research data is presented in Table 3.

Table 3

Dependence of Soil Moisture on Flow Washout Rate

Cohesive Soil	Experiment №	Moisture, W, %	t, *мин*	υ_p, $м/с$	$\upsilon_н$, $м/с$	h_p, *мм*	Erosion intensity, V mm/min
Loam (nature)	1	5-10	60	0,21	0,15	8	0,13
	2	16-20	60	0,32	0,23	6	0,10
	3	28-35	60	0,53	0,38	5	0,08
	4	39-50	60	0,72	0,51	2	0,03
Loam (laboratory)	5	7-10	60	0,28	0,20	7	0,12
	6	13-22	60	0,40	0,29	5	0,08
	7	28-35	60	0,64	0,46	4	0,07
	8	41-53	60	0,80	0,57	2	0,03

Experiments determined the washing time. In addition, the concept of washing intensity was introduced to express the nature of washing. This washing intensity shows the ratio of the washed depth to the specified time, i.e., $V = h_p / t,\ мм/мин$.

Deformation velocities were determined for cohesive soils with different moisture contents. The experimental results are included in Table 3, and based on these, the cohesive graph $\upsilon_p = f(\upsilon_H)$ was constructed (Figure 1).

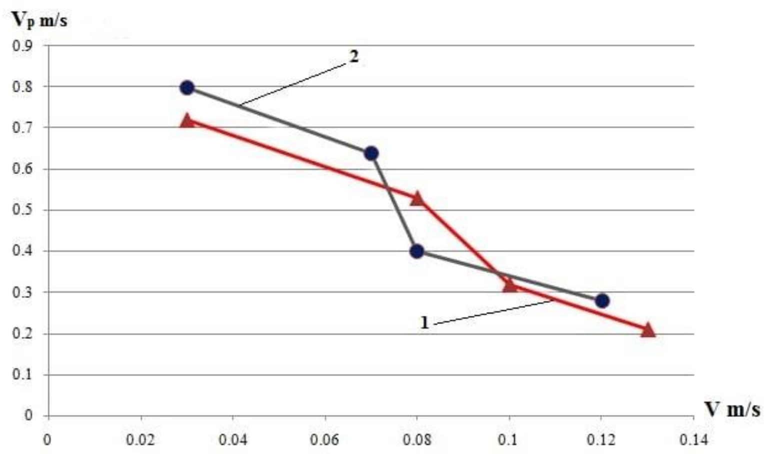

Fig. 1. The dependence of soil erosion intensity on the erosion rate, graph $\upsilon_p = f(V)$. 1 – soil; 2 – soil.

In dry air conditions (5-10%) for the cohesive soil in the canal, the average critical erosion velocity is 0.13 m/s, for soil with natural moisture (16-20%) it is 0.23 m/s, for soil with natural moisture (28-35%) it is 0.38 m/s, and for soil with moisture (39-50%) it is 0.51 m/s.
From the comparison of the obtained results, it can be observed that the soils with higher natural moisture values can withstand higher erosion velocities compared to the dry air condition soils (Figure 2).

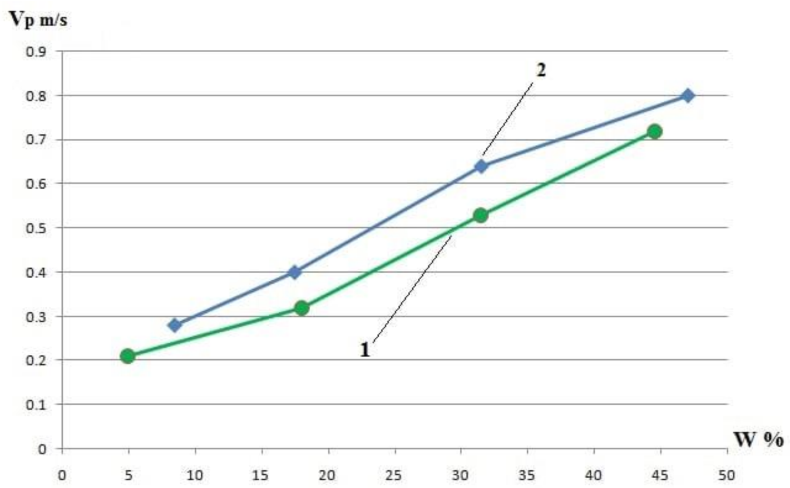

Fig. 2. The relationship between the erosion washing velocity and soil moisture $\upsilon_p = f(W)$.

As a result of the impact of dry air on the soil, the porous medium layer is quickly occupied, and the internal bonds between the particles are weakened. Additionally, the compressed air bubbles cause a mechanical failure process that weakens the inter-particle cohesion. When water affects moist soils with maximum molecular water retention capacity, the swelling occurs very slowly, so the soil is protected from various types of damage. This can also be explained differently. If the soil moisture is greater than the maximum molecular water retention capacity, a certain amount of capillaries (pores) are filled with water, and water only enters the unfilled capillaries, which results in a reduced chance of soil failure.

Thus, the high moisture content in the soil significantly increases the erosion resistance rate.

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