

**HYDRAULIC MODELING OF LOCAL SCOUR IN COHESIVE SOILS
DOWNSTREAM OF HYDRAULIC STRUCTURES****Kholmamatov Islom Komil o'g'li**Associate Professor (PhD) Karshi State Technical University
E-mail: ixolmamatov93@gmail.com, +99897-585-93-27**Urishova Dilafruz Boboraimovna**Associate Professor (PhD) Karshi State Technical University
E-mail: dilafruz6595@gmail.com, +99891-456-65-95**Yuldosheva Umida Temurovna**Associate Professor (PhD) Karshi State Technical University
E-mail: yuldoshevaumida146@gmail.com, +99897-264-90-09**Raimova Nodira Jo'ra qizi**Assistant Karshi State Technical University
E-mail: raimovanodira325@gmail.com, +99895-777-96-19**Dilshodova Dilsuz Dilshod qizi**Assistant Karshi State Technical University
E-mail: dilsuzdilshodova@gmail.com, +99895-333-99-13

Abstract. This study presents an advanced hydraulic calculation method for predicting local scour in cohesive soils downstream of hydraulic structures. The approach integrates probabilistic theory, soil mechanics, and experimental hydraulics. Laboratory experiments were carried out under controlled hydraulic regimes to determine non-eroding velocities, critical flow parameters, and scour geometry. The results demonstrate that erosion resistance in cohesive soils depends on both hydraulic forces and soil physicochemical properties. A refined algorithm is proposed and validated against experimental data, showing strong agreement and practical applicability.

Keywords. Cohesive soil, local scour, hydraulic structures, erosion mechanics, critical velocity, downstream channel, sediment transport

1. Introduction

Local scour downstream of hydraulic structures is a major factor affecting structural safety and longevity. In cohesive soils, erosion mechanisms differ significantly from those in non-cohesive sediments due to inter-particle bonding, electrochemical forces, and structural heterogeneity. Traditional sediment transport theories are insufficient for cohesive soils, as they neglect cohesion, plasticity, and time-dependent degradation. Therefore, there is a need for improved predictive models that incorporate both hydraulic and geotechnical factors. This study aims to develop a comprehensive method for predicting local scour parameters in cohesive soils using experimental and analytical approaches.

2. Extended Literature Review

Numerous studies have attempted to model erosion processes in open channels. However, most classical models (e.g., Shields criterion) are applicable only to non-cohesive sediments.

Key limitations of existing studies include:

1. neglect of soil cohesion and bonding forces
2. lack of probabilistic treatment of erosion
3. insufficient experimental validation

Advanced approaches consider:

1. stochastic turbulence effects
2. aggregate-based soil models
3. time-dependent erosion

The probabilistic model of cohesive soil erosion introduces the concept of aggregate detachment under fluctuating hydraulic forces.

3. Experimental Methodology

3.1 Flume Setup

Experiments were conducted in a rectangular flume consisting of:

- energy dissipator
- stilling basin
- downstream cohesive soil section

3.2 Soil Preparation

Soil samples were prepared by drying, crushing, sieving, and mixing with water to achieve plastic consistency. Samples were compacted and saturated over 90 days.

3.3 Measurement System

1. velocity: micro current meter
2. depth: point gauge
3. scour geometry: manual profiling

4. Soil Physical and Mechanical Properties

4.1 Physical Properties

- density: 1.95 g/cm³
- porosity: 43.75%
- moisture content: 27.1%

4.2 Granulometric Composition

- clay (<0.005 mm): 15.6%
- silt (0.005–0.05 mm): 54.2%
- sand (>0.05 mm): 30.2%

4.3 Mechanical Properties

1. cohesion: 0.05–0.14 kg/cm²
2. internal friction angle: 5.7°–16.7°

These properties strongly influence erosion resistance.

5. Theoretical Framework

5.1 Force Balance Model

The proposed calculation scheme does not explicitly account for the probability of detachment, the stochastic nature of pulsating velocity distribution, the resistance of aggregates to detachment, or the duration of bed erosion.

From the standpoint of reliability and statistical stability theory, the author attempted to consider the influence of stress and resistance characteristics governing aggregate detachment over time.

Based on the results of the conducted research, the author derived the following relationships for the permissible average and near-bed velocities that determine the erosion of cohesive soils:

$$V_{H.dop} = (l_g \frac{8.8h}{d}) \sqrt{\frac{2gm}{2.6\rho n} [(\rho_n - \rho)d + 1.25C_y^H K]} ; \quad (1)$$

$$V_{\Delta H / dop} = 1.25 \sqrt{\frac{2gm}{2.6\rho n} [(\rho_n - \rho)d + 1.25C_y^H K]} , \quad (2)$$

Here: m — operating condition coefficient; n — stress coefficient; ρ_n — soil density; ρ — water density; d — average diameter of the aggregate; h — flow depth; C_y^H — normative tensile strength at break; K — coefficient of uniformity of cohesive soils.

The proposed calculation scheme describes the process of the beginning of erosion and shows satisfactory agreement with our experimental data. However, the deformation properties of cohesive soils are determined not only by shear stresses and shear strength properties, but also

by complete information on the physical, mechanical, and chemical properties of the soil. In this case, it is necessary to take into account the type and quantity of clay minerals, the microscopic and macroscopic porosity of the cohesive soil, its moisture content, pore water, the structure of the cohesive soil and its acidity (pH), as well as a number of other properties.

When the flow affects the cohesive soil in the lower pool, a number of specific features appear in the washout mechanism. A distinctive feature, unlike the initial erosion, is that after the fine clay particles are washed out by the flow, the aggregate breaks off. In the washout funnel, this process occurs only at the initial moments of time; then the diameter of the breaking aggregates increases, and when the washout funnel appears, the sizes of the breaking aggregates decrease significantly. The diameter of the breaking aggregates, of course, depends to a large extent on the texture and structure of the cohesive soil, but mainly it is more dependent on the scale of flow turbulence in the washout funnel.

5.2 Non-Eroding Velocity

The critical (non-eroding) velocity is determined as a function of:

- flow depth (h)
- soil density (ρ_n)
- water density (ρ)
- aggregate diameter (d)
- cohesion strength (C)

According to many authors, in channels with a high slope having a water circulation zone, certain energy losses occur, and in the section from the fixed part to the washout focus, the flow movement obeys the regularities characteristic of free submerged jets with certain restrictions (in this case, the flow axis is taken as the free surface line) (Figure 1).

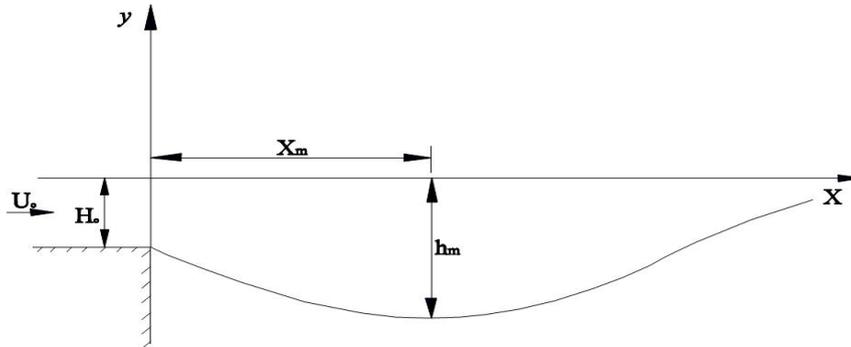


Figure 1. Scheme of the submerged jet spreading process in the washout funnel.

Based on these considerations, we assume that at the end of the fixed section, i.e., at the initial cross-section, the velocity is uniformly distributed, and we take the flow depth and the specific discharge as .

The length after the boundary of the initial section is determined as follows:

$$x_n = 1,03 \frac{H_0}{a} , \quad (2)$$

where is a - an experimental parameter equal to 0.23 for a submerged jet.

In the flow, a velocity distribution close to the Gaussian curve and expressed by the Reichardt formula is formed:

$$\frac{u}{u_m} = e^{-\frac{1}{2} \frac{y^2}{ax}} , \quad (3)$$

where is the u_m -velocity on the jet axis (on the flow surface for the case under consideration); is the local velocity.

The value of is determined from the following formula:

$$u_m = \frac{1,2u_0}{\sqrt{\frac{ax}{H_0} + 0,41}} \quad (4)$$

To determine the coordinates of the washout focus, in equations (4.4) and (4.5) we replace with the abscissa of the washout focus and with the maximum depth of the washout.

5.3 Probabilistic Consideration

The erosion process is treated as stochastic due to turbulence-induced velocity fluctuations.

6. Results and Analysis

6.1 Erosion Stages

1. detachment of fine particles
2. weakening of structure
3. aggregate separation
4. scour hole formation

6.2 Critical Velocity Comparison

| Method | Velocity (m/s) |
|--------------|----------------|
| Calculated | 0.35–0.48 |
| Experimental | 0.39–0.46 |

Good agreement confirms model validity.

6.3 Velocity Distribution

Velocity follows Gaussian distribution:

$$u = u_{\max} \exp(-y^2/2\sigma^2)$$

6.4 Scour Geometry

- steep upstream slope
- gentle downstream slope
- maximum depth at jet impact zone

7. Advanced Calculation Algorithm

Step-by-step procedure:

1. determine soil cohesion (C)
2. calculate fatigue strength
3. define uniformity coefficient (c)
4. compute critical velocity (V_{cr})
5. determine bottom velocity (d)
6. calculate scour depth (h_s)
7. estimate scour length (L_s)

8. Engineering Applications

The proposed model can be applied in:

- dam design
- spillway protection
- channel stabilization
- erosion risk assessment

9. Discussion

The results highlight that cohesive soil erosion is governed by both hydraulic forces and soil structure. Unlike non-cohesive sediments, erosion occurs through aggregate detachment rather than individual particle motion.

The probabilistic approach improves prediction accuracy by accounting for turbulence effects.

Conclusion

- A refined hydraulic model for cohesive soil erosion is developed
- Experimental validation confirms reliability
- Soil properties significantly influence erosion resistance
- The model is suitable for engineering applications

References

1. Попова К.С. Местный размыв мелкозернистых грунтов за рисбермами плотин. Изв. ВНИИГ им. Б.Е.Веденеева, т.109, – Д.: 1975,с. 266-276.
2. Попова К.С. К расчету местных размывов неоднородных несвязных грунтов. Изв. ВНИИГ им. Б.Е.Веденеева, т.138, 1980, с. 63-69.
3. Попова К.С. Исследование кинематической структуры потока на рисберме и з яме размыва за водосливными плотинами на несвязных грунтах. Изв. ВНИИГ им. Б.Е.Веденеева, т.94, 1970, с. 96-104.
4. Кумин Д.И. Гашение энергии и турбулентность водных потоков в нижнем бьефе водосбросов: Автореферат диссертации на соискание ученой степени доктора техн.наук ЛПИ им. М.И.Калинина. – Л.: 1956 – 22 с.
5. Кумин Д.И. Гидравлический расчет крепления з нижнем бьефе водосбросов – Л.: Госэнергоиздат, 1955, – 56 с.
6. Кумин Д.И. Пульсации давления при сопряжении бьефов и связь ее с пульсацией скорости, Изв. ВНИИГ им. Б.Е.Веденеева, 1059, Т.62, с. 57-73.
7. Eshev, S. S., Gayimnazarov, I. X., Latipov, S. A., Rahmatov, M. I., & Kholmammatov, I. K. (2023, March). Calculation of parameters of subsurface ridges in a steady flow of groundwater channels. In AIP Conference Proceedings (Vol. 2612, No. 1, p. 050033). AIP Publishing LLC.
8. Bazarov, O., Babazhanova, I., Babazhanov, Y., Eshev, S., Kholmammatov, I., & Ruzieva, G. (2023). Calculation of bank deformation in the confluence of two streams. In E3S Web of Conferences (Vol. 410, p. 05021). EDP Sciences.
9. Latipov, S., Sagdiyev, J., Eshev, S., Xolmamatov, I., & Rayimova, I. (2021). Qumli kanallarda suv oqimining maqbul tezligi. E3S Web of Conferences (274-jild, 03002-bet). EDP fanlari.