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STUDY ON REDUCING THE RISK OF DAMAGE TO HYDRAULIC STRUCTURES AND INCREASING THEIR STRENGTH UNDER DEFORMATION

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Abstract: **Hydraulic structures are among the most critical infrastructure facilities, and their failure can lead to severe economic, environmental, and social consequences. This study focuses on reducing the risk of damage to hydraulic structures and increasing their structural strength under deformation through the rational selection and assessment of inert construction materials. Particular attention is paid to emergency processes occurring in coastal slopes and foundations, such as erosion, subsidence, bulging, and washout, which significantly affect the operational reliability of hydraulic facilities.**

The research is based on comprehensive laboratory investigations of sand, gravel, and crushed stone conducted at the construction materials laboratory of JSC “Hydroproject” in accordance with current national standards and regulatory documents (GOST). The granulometric composition, fineness modulus, bulk density, content of dust and clay particles, percentage of fine and needle-shaped grains, and crushability grade of aggregates were experimentally determined. Sieve analysis methods were applied to evaluate particle-size distribution, while compliance with GOST 8735-88, GOST 8736-85, GOST 10268-80, and GOST 26633-91 was systematically assessed.

The results showed that the investigated sands correspond to coarse and coarsened sand classes with fineness modulus values ranging from 2.44 to 3.15 and acceptable levels of clay and dust particles. The coarse aggregates satisfied the regulatory requirements for use in concrete and foundation strengthening, with a crushed stone strength grade of M1200. The obtained parameters confirm the suitability of the studied inert materials for reinforcing the foundations of hydraulic structures and enhancing their resistance to deformation and emergency impacts. The findings can be applied in the design, construction, and rehabilitation of hydraulic facilities to improve safety and durability under complex loading conditions.

Keywords: **Hydraulic structures; structural safety; deformation resistance; granulometric composition; sand fineness modulus; coarse aggregates; laboratory testing; GOST standards; foundation strengthening.**

Currently, among the emergencies associated with the failure of hydraulic structures, those resulting in damage occupy one of the leading positions in terms of loss. There are more than one hundred thousand hydraulic structures on the Earth's surface that pose potential hazards, and extensive scientific studies have been conducted on ensuring the safety of citizens living nearby, as well as on changes in indicators related to the reduction of useful volume. At present, one of the problems of hydraulic structures is the occurrence of various emergency situations on coastal slopes caused by impacts such as bulging, erosion, subsidence, and washing out, and preventing these situations is considered important.

As a result of the conducted research, the properties of materials obtained after sieving sand and gravel were identified for increasing the strength of the main foundations of hydraulic structures and determining the full set of parameters of inert materials to be supplied, including their granulometric composition.

These studies were carried out at the "Hydroproject" JSC construction materials laboratory based on current regulatory documents. The research was conducted in accordance with the requirements of national standards and the methods specified in regulatory and technical literature. As primary parameters, the granulometric composition of gravel, bulk density, the percentage of small and needle-shaped grains, fineness grade, granulometric composition of sand, sand bulk density, percentage of gravel in sand, sand fineness modulus, and the quantity of clay particles in sand were determined during the experiments. According to GOST 10268-80, particular attention was paid to the possibility of using sand, natural stone, gravel, and crushed gravel as fine and coarse aggregates.

The sand's fineness modulus and particle composition were determined according to the method described in Clause 3 of GOST 8735-88. GOST 10268-80 allows for the preparation of concrete according to the compressive strength class (grade) using almost any natural sand with a fineness modulus ranging from 1.0 to 3.5. Special attention was given to ensuring that other parameters (such as the content of dust, clay particles, and other inclusions) meet the required standards (GOST 8736-85).

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The particle composition and fineness modulus of the sands under study, delivered from Quarry No. 5 to the "Hydroproject" JSC construction laboratory, were determined according to Clause 3 of GOST 8735-88. Each test involved a sand sample dried to a constant weight and sieved through sieves with round holes of 10 mm and 5 mm in diameter. Table 1 shows the grain composition of sand fractions with diameters ranging from 20 to 5 mm.

Table 1

Sieve diameter, mm	20÷10	10÷5	<5
Individual residue, %	13,2	30,18	56,62
Total residue, %	13,2	43,38	100

Note: Gravel accounts for 43.38% of the sand composition.

The residues in the sieves were weighed, and the composition of the gravel fractions in the sand with particle sizes from 5 to 10 mm—5 mm (Gr5) and 10 mm (Gr10)—was calculated by weight percentage using formulas:

$$Гр_{10} = \frac{M_{10}}{M} \cdot 100; \quad (1)$$

$$Гр_{5} = \frac{M_{5}}{M} \cdot 100, \quad (2)$$

M10 – residue in the round-hole sieve with a diameter of 10 mm, g;

M_5 – residue in the round-hole sieve with a diameter of 5 mm, g;

M – sample weight, g. Average residues in 10 mm and 5 mm sand sieves:

In the 10 mm sieve: M10 – 0.0%,In the 5 mm sieve: M5 – 11.5%.From a portion of the sand sample that passed through the 5 mm round-hole sieve, a sample weighing at least 1000 g was taken to determine the particle composition of the sand. The prepared sand sample was passed through a series of round-hole sieves with diameters of 2.5 mm, 1.25 mm, 0.63 mm, 0.315 mm, and 0.16 mm. Based on the sieve analysis results, the individual residues (α_i) in each sieve were calculated as a percentage according to the formula.

$$a_i = \frac{m_i}{m} \cdot 100, \quad (3)$$

Here, m_i -is the mass of the residue on a given sieve, g;

m -is the weight of the sample being sieved, g; the total residue on each sieve (A_i) is calculated as a percentage using the formula.

$$A_i = a_{2,5} + a_{1,25} + \dots\_ a_i, \quad (4)$$

Here, $\alpha_{2,5}$, $\alpha_{1,25}$, α_i are the individual residues on the corresponding sieves; the coarseness modulus (Mk) of sand without particles larger than 5 mm is determined using a formula.

$$M_{\square} = \frac{\square_{2,5} + \square_{1,25} + \square_{063} + \square_{0315} + \square_{016}}{100} \quad (5)$$

Here, $A_{2,5}$, $A_{1,25}$, A_{063}, A_{0315}, A_{016} represent the total residues (%) on round-holed and mesh sieves with diameters of 2.5 mm, 1.25 mm, 0.63 mm, 0.315 mm, and 0.16 mm, respectively.

$$M_{\square} = \frac{25,4 + 9,2 + 9,0 + 14,2 + 25,2 + 17,0}{100} = \frac{244,4}{100} = 2,44$$

The results of determining the particle composition of the sand are presented in Table 2. The granulometric composition of the coarse sand (fractions smaller than 5 mm)

Table 2.

Name of residue	**Residues on sieves, by weight %**					**Passed through a №0.16 (No. 014) mesh sieve, by weight %**
	2,5	1,25	0,63	0,315	0,16 (0,14)	
Separate a_i	25,4	9,2	9,0	14,2	25,2	17,0
Total A_i	25,4	34,6	43,6	57,8	83,0	100

The sand's fineness modulus (Mk) is 2.44, indicating coarse sand. The total residue on the 0.63 mm sieve (M0.63) is 43.6%, confirming that the sand is coarse. The content of dust and clay particles is 1.08% by weight. The bulk density of coarse sand particles larger than 5 mm is 1505 kg/m³.

Classification of the Granular Composition of Sands

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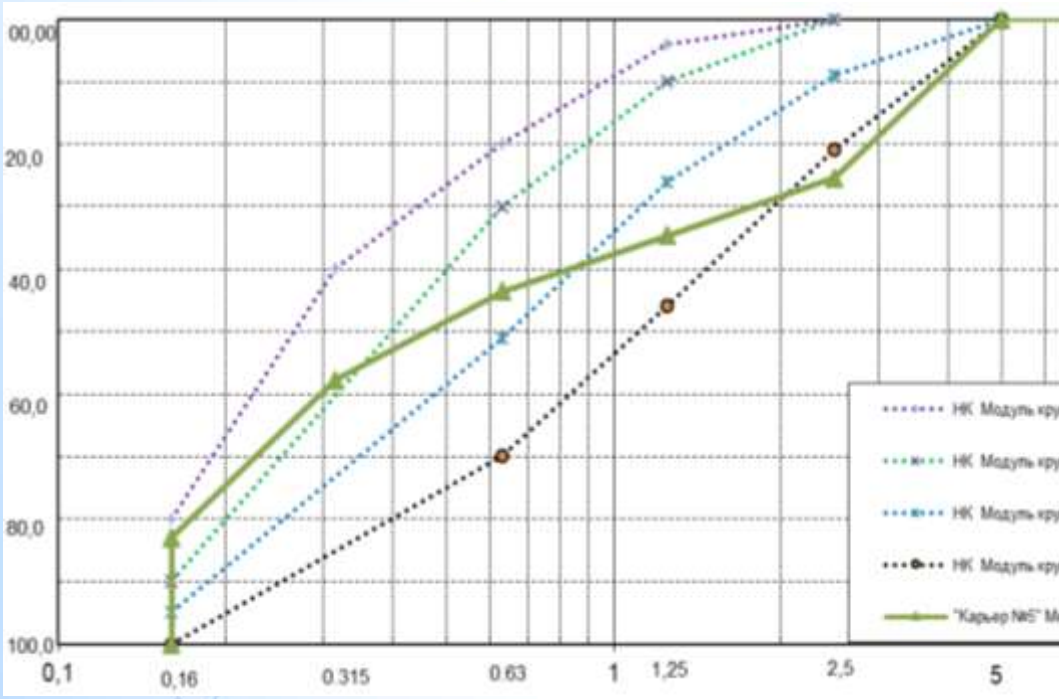

Composition %

Particle Size, mm

According to GOST 10268-80, sand, natural stone, gravel, and crushed gravel can be used as fine and coarse aggregates. The particle size distribution and the sand's fineness modulus were determined using the method specified in clause 3 of GOST 8735-88. GOST 10268-80 allows concrete preparation according to the compression strength class (grade) using almost any natural sand with a fineness modulus from 1.0 to 3.5, and other indicators such as the content of dust and clay particles comply with the requirements of this standard (GOST 8736-85)

The construction laboratory of the "Hydroproekt" quarry No. 17 was carried out in accordance with GOST 8735-88 in accordance with GOST 8735-88. Each sample of sand grains, constantly dry, with a diameter of 10 and 5 mm, was analyzed with a diameter of 10 and 5 mm. In the 3rd layer, the fraction with a diameter of 20.5 ÷mm was determined to contain the composition of the grainy sand.

Table 3.

Sieve diameter, мм	20÷10	10÷5	<5
Individual residues, в %	1,69	30,47	67,84
Total residues, %	1,69	32,16	100

Note: Crushed stone constitutes 32.16% of the sand composition.

The residues on the sieves were weighed, and the particle sizes in the sand from 5 to 10 mm (Gr5) and 10 mm (Gr10) gravel fractions were calculated as a percentage by weight using formulas

$$Гр_{10} = \frac{M_{10}}{M} \cdot 100; \quad (1)$$

$$Гр_5 = \frac{M_5}{M} \cdot 100, \quad (2)$$

M10 – residue on the round-holed 10 mm sieve, g.;

M5 – residue on the round-holed 5 mm sieve, g;

M – sample weight in grams; average residues on 10 mm and 5 mm sand sieves:

On the sieve with 10 mm openings, M10 – 0.0%. On the sieve with 5 mm openings, M5 – 11.5%.

A sample of sand that passed through a 5 mm sieve was taken with a weight of at least 1000 g to determine the particle composition of the sand. The prepared sand sample was passed through a series of round-hole sieves with diameters of 2.5 mm, 1.25 mm, 0.63 mm, 0.315 mm, and 0.16 mm. Based on the results of the sieving, the following were calculated. According to the formula below, the individual residue (αi) on each sieve is expressed as a percentage:

$$a_i = \frac{m_i}{m} \cdot 100, \quad (3)$$

Here, m_i is the mass of the residue on the given sieve, g;

m – the weight of the sample passing through the sieve, g; the total residue on each sieve (A_i) as a percentage according to the formula

$$A_i = a_{2,5} + a_{1,25} + \ldots\_ a_i, \quad (4)$$

Here, $\alpha_{2,5}$, $\alpha_{1,25}$, α_i represent the individual residues on the corresponding sieves;the fineness modulus ($M_к$) of coarse, grainless sand larger than 5 mm was determined using a formula:

$$M_□ = \frac{□_{2,5} + □_{1,25} + □_{063} + □_{0315} + □_{016}}{100} \quad (5)$$

Here, $A_{2,5}$, $A_{1,25}$, A_{063}, A_{0315}, A_{016} represent the total residues on sieves with round holes of diameters 2.5 mm and on mesh sieves numbered 1.25, 0.63, 0.315, 0.16, expressed as a percentage (%).

$$M_□ = \frac{32,8 + 14,4 + 15,4 + 17,0 + 13,0 + 7,4}{100} = \frac{314,8}{100} = 3,15$$

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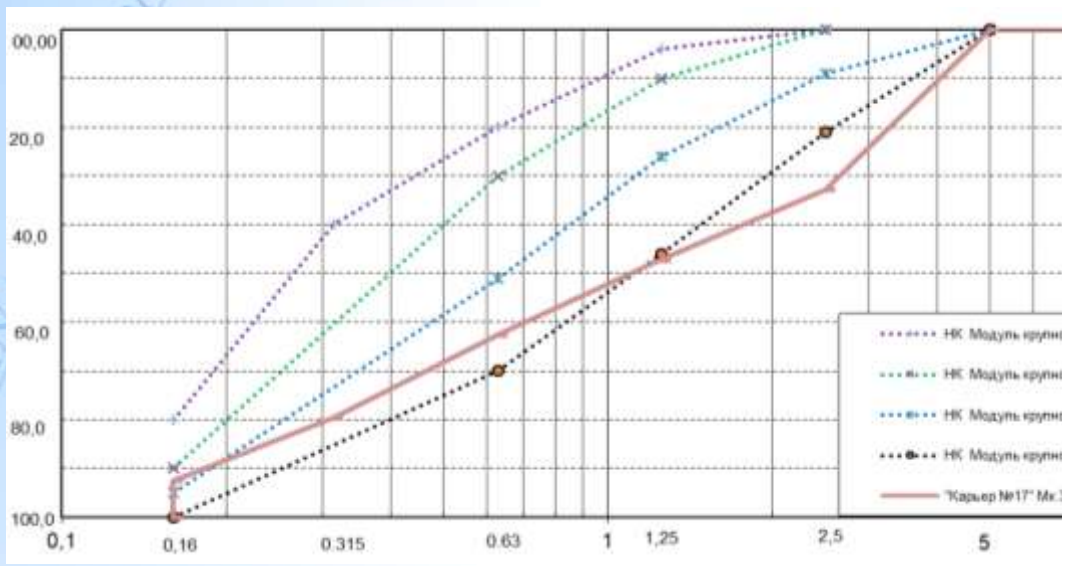
The results of determining the particle size distribution of the sand are presented in Table 4. The granulometric composition of coarse sand (fractions less than 5 mm) is shown.

Table 4.

Name of residue	**Residues on sieves, by weight** %					**Passed through a №0.16 (No. 014) mesh sieve, by weight** %
	2,5	1,25	0,63	0,315	0,16 (0,14)	
Separate $a_и$	32,8	14,4	15,4	17,0	13,0	7,4
Total $A_и$	32,8	47,2	62,6	79,6	92,6	100

The sand fineness modulus $M_к$ is 3.15, corresponding to coarse sand. The total residue on sieve No. 0.63 ($M_{0,63}$) is 62.6%, indicating coarse sand. The content of dust and clay particles by weight is 2.7%. The bulk density of coarse sand particles larger than 5 mm is 1545 kg/m³.

Classification of the Granular Composition of Sands



Particle Size, mm

According to the method of Clause 4.3 of GOST 8269.0-97, the gravel was tested to determine its particle-size composition. The particle-size composition of the gravel was determined by passing the sample through a standard set of sieves. According to Table 5, the average individual residues of gravel with a 5–20 mm fraction on the sieves are expressed as a percentage (%):

Table 5.

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Sieve opening diameter (мм)	40-20	20-10	10-5	<5
Individual residue on sieves, by weight %	2,6	89,4	7,0	1
Total residue on sieves %	2,6	92,0	99,0	100

The coarse aggregate fractions in the concrete mix delivered to the laboratory for testing met the requirements of Clause 3.5.2.4 of GOST 26633-91, meaning that fractions of 20–10 mm must account for at least 65% of the total composition. Using the visual dismantling method (according to Clause 4.7 of GOST 8269.0), the composition of layers (fragmented) in the gravel was determined. The number of fine grains in the fragmented aggregate fractions accounted for 19.9% of the total mass of the coarse aggregate. According to Clause 3.5.2.6 of GOST 26633, the composition of layers (fragmented) and needle-shaped grains in the coarse aggregate should not exceed 35% of the mass. The bulk density of the gravel was measured using a 10-liter metal cylinder in accordance with Clause 4.17 of GOST 8269.0-97. The average bulk density of gravel in the 5–20 mm fraction was 1420 kg/m³. The crushing of the gravel was determined according to GOST 8269-97 by the degree of grain destruction during compression (crushing) in the cylinder.

When testing crushed stone composed of mixed fractions, fineness was determined according to Clause 4.1.7 of GOST 8269.0-97. After crushing the gravel fractions and passing them through a 2.5 mm sieve, 7.15% of the mass passed, and the grade of the crushed stone was determined as M1200. Based on the results, the work carried out on the topic and the laboratory testing of inert materials for the facility “Angren-Pop Electrified Tunnel Construction” allowed the following observations regarding the main foundation of the facility:

Sand with a particle diameter of 0.14–5 mm, with a fineness modulus of Mk = 2.44 – coarse sand. The total residue on a 0.63 mm sieve (M0.63) was 43.6%. The bulk density of sand particles larger than 5 mm was 1505 kg/m³. The composition of dust and clay particles by weight was 1.08%. For sand with a particle diameter of 0.14–5 mm and a fineness modulus Mk = 3.15 – coarsened sand, the total residue on the 0.63 mm sieve (M0.63) was 62.6%, the bulk density of sand with particles larger than 5 mm was 1545 kg/m³, and the dust and clay content by weight was 2.7%.

The coarse aggregate fractions delivered to the laboratory met the requirements of GOST 26633-91. The bulk density of crushed stone was measured according to Clause 4.17 of GOST 8269.0-97 and was 1420 kg/m³. The number of fine grains in the coarse aggregate fractions

accounted for 19.9% of the total mass. After crushing the gravel fractions and passing them through a 2.5 mm sieve, 7.15% of the mass passed, and the grade of the crushed gravel was determined as M1200.

In our country, measures to strengthen hydraulic structures, ensure the safety of settlements in areas with high flood risk, and protect the population and economic sectors from flood losses, as well as to reduce economic and environmental damage, and improve the efficiency of emergency response and other urgent operations, are important. In these works, key parameters include: determining the granulometric composition of gravel, bulk density, percentage of fine and needle-shaped grains, grade of crushability, granulometric composition of sand, bulk density of sand, percentage of gravel in sand, sand fineness modulus, and amount of clay particles in the sand.

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