Economic substantiation of construction of narrow profile hydraulic-fill structures

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Abstract: Hydraulic-fill structures with free flow of pulp have a flattened transverse profile, especially in cases of hydraulic fill of the structure into water. The flattened profile of the structure demands significant financial and labor costs for its construction, reducing the efficiency of the hydraulic-fill structure. This paper deals with the existing methods for the construction of narrow profile hydraulic-fill structures, their economic indicators; the designs of hydraulic-fill structures using geosynthetic materials developed by the authors, which make it possible to increase their efficiency in comparison with previously known methods, especially when the structures are hydraulically filled into water.

1. Introduction
The construction of hydraulic structures using hydromechanization methods is one of the most highly productive and efficient methods of earth works [1, 2, 3]. During hydraulic fill of the structure the development, transportation and laying of soil are combined into a single technological process. Hydraulic deposite of soil allows providing the required soil density in the road fill body, often without additional costs for mechanical compaction.

In hydraulic engineering hydraulic-fill structures have become widely used for the construction of dams, canals, coast protection and for the creation of artificial territories in water reservoirs and water ducts. The use of hydromechanization facilities in Russia started developing rapidly in the mid-30s - 40s of the XX century, during the construction of the Moscow and the Volgo-Donskoy named after Lenin canals. Later it was used at large hydroelectric power plants in many regions of the country (Gorkovskaya, Saratovskaya, Ivankovskaya, Uglichskaya, Rybinskaya, Tsimlyanskaya, Nizhneamskaya hydroelectric power stations, etc.) [3]. Currently hydromechanization is still widely used in hydraulic engineering, however due to the fact that there’s hardly any large-scale dam construction, its main areas of application are clearing riverbeds, coast protection and creation of artificial territories (figure 1, 2, 3, 4).

When creating hydraulic-fill soil structures, it is customary to distinguish between hydraulic filling into ground and into water, with freely and forcedly formed slopes. In the case of free flow of pulp hydraulic-fill structures have a flattened transverse profile, especially in cases of hydraulic fill of the structure into water.

The flattened profile of the structure leads to significant financial and labor costs for its construction, reducing the efficiency of the hydraulic-fill structure. There are various ways to increase the efficiency of hydraulic-fill structures. However they usually have got typical disadvantages: they are not applicable when the structure is hydraulically filled into water; they are labor consuming, material-intensive and expensive.
In this regard the search and development of technical solutions to improve the efficiency of the hydraulic-fill structure is a vital task.

![Figure 1. Exit of pulp from hydraulic fill pipeline.](image1)

![Figure 2. Hydraulic fill of dam.](image2)

![Figure 3. Hydraulic fill of territories.](image3)

![Figure 4. Hydraulic fill of coast protection (beach).](image4)

2. **Materials and methods**

In process of hydraulic fill of soil structures into ground forced formation of slopes is usually the most economical solution (see figure 1). Compression of profile is carried out by filling an earth banking, which is formed before the filling starts (primary banking) and limits the flow of pulp, as well as during the construction of the structure (accompanying earth banking). The steepness of the forcibly formed slopes of such structures ranges from 1: 2 to 1: 4, but in the case of free flow of pulp the steepness of their slopes can reach 1:50 [7]. The construction of hydraulic-fill structures with banking (compressed profile) into water is associated with a number of difficulties, i.e. when forming primary banking, which is built up as a rule using end-dumping method, it becomes necessary to fill the bank to a level exceeding the builder level of water by at least 35 cm [6], with slopes from 1: 1.5 (when using stone) to 1: 4 (when using sandy soils), which often leads to a significant decrease in the efficiency of hydromechanized work, especially if there are no reserves of stone in the area where the construction takes place. The hydraulic fill of the soil structure into water with freely formed slopes leads to the appearance of a flattened profile with the slopes laid at up to 1:10 (see figure 5). Thus, e.g. during the construction of coast protecting structures in narrow roadbeds, the use of hydraulic...
filling method becomes technologically and economically inefficient, even if there are reserves of soil suitable for hydraulic fill at the construction site.

![Figure 5](image_url)

**Figure 5.** The methods of forming hydraulic filled slope into water: 1 - primary banking; 2 - slope with stone filling; 3 - slope with sand filling; 4 - slope with sand filled into water; 5 – accompanying earth banking; I, II – the stages of sand filling behind dams.

The authors faced this problem during the development of design documentation for the project "Coast protection of the Usta River near the village of Kirillovo, Krasnobakovsky District of Nizhny Novgorod Region". The purpose of the project was to protect the right-bank coastline, buildings, infrastructure and lands of Kirillovo village from destruction by the waters of the river Usta. The river bed is composed mainly of fine sands with interlayers of loamy soils on the right bank. Based on the topographic, geological and hydrological conditions of the area, as the first option for the construction of the coast protection structure a construction method was developed using rock placement into water at the foot of the slope, with the formation of a toe, the crest of which was located above the builder level of water in the river Usta. However stone quarries with required quality indicators were found only at a significant distance from the construction site, which led to high transport costs for its delivery and exceeding the permissible cost of construction of coast protection structures.

The geological conditions of the Usta riverbed prompted the development of technical solutions using local sand. The solution using hydromechanization seemed to be especially effective. Thus the installation of a dredger near the left bank made it possible to solve two problems at once - widening the riverbed and simultaneous formation of a stable slope near the right bank. However in the case of using the technology of soil hydraulic fill with a freely formed slope, with the construction depth of water at 4.8 m and laying the filled slope at 1:10, the slope with a length of 48 m was formed, practically covering the entire riverbed. For the above reasons the use of stone for the formation of the primary banking was not economically efficient. When searching for possible solutions geosynthetic materials were looked at. The first developed solution - using geosynthetic shells - has already been tested many times in various projects of coast protection structures and in the hydraulic fill of territories [4, 5]. In this case along the coast geosynthetic shells are stacked on top of each other and form a stable slope. The space inside and behind them is filled with alluvial sand (figure 6). This solution has made it possible to compress the profile of the hydraulic-filled structure significantly and to form a stable slope, while minimizing the amount of materials transported from offsite.
Figure 6. Narrow-profile hydraulic-fill coast protection structure with geosynthetic shells 1 - designed stable slope; 2 - geosynthetic shells; 3 - slope with free flow of the pulp into water; I-V - stages of hydraulic fill of the structure.

Figure 7. Narrow-profile hydraulic-fill coast protection structure with woven geotextile 1 - designed stable slope; 2 - joints for attaching geotextile to the guide; 3 - slope with free flow of pulp into water; 4 - guides; 5 - woven geotextile; I - stages of hydraulic fill of the structure.
As the second option for building a narrow-profile hydraulic-fill structure, a construction technology using woven geotextile has been developed, which has got no analogues at the moment. Woven geotextile is a water-permeable material made from durable synthetic threads by interweaving them at an angle of 90 degrees. Geotextiles must have the following characteristics: tensile strength at break of 100/100 kN/m, elongation at break of not more than 20%, open pore size of Oo = 100 microns, water permeability of at least 3 l/(m²s). The essence of the invention is as follows. With the help of an excavator or a dredger, the bottom of the river at the foot of the slope is leveled, then metal guides (pipe, channel, etc.) are immersed at the foot of the existing and designed slopes. Rolls of woven geotextile of required length are cut and sewn together (taking into account the location of the guide, the formation of the necessary slope and the selected length of the grip). Either metal rings or woven loops are sewn on along the edges of the fabric and in the place of its bend. After the immersion of the guides, the rings (loops) fastened to the woven fabric are fixed on it, then the filling of the space between the coast and the woven fabric with sand pulp begins (figure 7). At the same time it is necessary to control the volume and location of pulp flow, in order to prevent the upfloat of the woven fabric, as well as to record the intensity of water drainage from the pulp through the fabric and the geometry of the formed slope. During the construction of such an alluvial structure, local sand is used, which, when reclaimed, turns into a slurry of 10% concentration. The slurry consumption during reclamation depends on the accepted brand of the dredger and ranges from 400 to 2000 m³/h.

The described construction technology with the use of woven geotextile can also be applied for hydraulic fill of a structure into ground, eliminating the need to form the earth banking.

3. Results
The results of economic comparison of the existing and developed options for constructing the narrow-profile hydraulic-fill structure are presented in table 1.

Table 1. The economic comparison of the existing and developed options for constructing the narrow-profile hydraulic-fill structure

| №  | Construction method   | Place of hydraulic fill | Construction cost², Euro |
|----|-----------------------|-------------------------|--------------------------|
| 1  | Banking               | Ground                  | 310,0                    |
| 2  | Geosynthetic shells   | Ground                  | 590,0                    |
| 3  | Woven textile         | Ground                  | 470,0                    |
| 4  | Banking               | Water                   | 1400,0                   |
| 5  | Geosynthetic shells   | Water                   | 750,0                    |
| 6  | Woven textile         | Water                   | 590,0                    |

²The construction cost is given per one linear meter, the height being 5 meters, excluding the cost for hydraulic fill of the soil structure’s body.

4. Conclusion
1 Hydromechanization techniques are still widely used in hydraulic engineering. The main areas of their application are associated with clearing water bodies and water drainage, as well as with creating artificial hydraulic fill territories.

2 The known technologies of soil hydraulic fill into water are not always effective, due to the need to create a flattened profile of the structure, especially when filling coast protection structures in not very wide roadbeds.

3 The technology developed by the authors for the hydraulic fill of the narrow-profile structure into water allows the creation of a hydraulic-fill soil structure of a given geometric shape. It is characterized by high productivity of work and low construction costs.

4 The economic comparison of the options has shown the efficiency of using geosynthetic materials when a narrow-profile structure is filled into water. The technology developed by the authors for creating the narrow-profile hydraulic-fill structure with use of woven geotextiles is 50% more economically
efficient than the technology of banking into water and 21% more economically efficient than technology with use of geosynthetic shells.

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