Hydraulic characteristics of the water flow under the conditions of stationary inward flow over pipelines with protection coating

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Abstract. While passing through waterbodies the pipeline crossings are affected by the inward flow. It might lead to soil erosion near it, and objects floating in this flow can cause damage of the pipeline, increasing risks of collapse. There are several types of protective coatings that are used on the pipelines, including the flexible protective concrete pavement (mats). Experience has shown that partial erosion of soil foundation can cause flipping of the blocks in first row of the protective coating that would result in its wrapping. This article presents the results of experimental research of hydraulic characteristics of water flow while flowing over two types of flexible concrete mats UGZBM-S and UGZBM placed crosswise the inward flow, that protect the pipeline. We’ve also determined the levels of free surface above differently buried pipeline crossings protected with two types of flexible concrete pavements under the conditions of stationary inward flow.

1. Introduction
Pipeline crossing protection while passing through waterbodies is one of fields of application for flexible protective concrete pavement [1, 2]. Pipeline crossings are classified as one of the most essential structures due to the complexity and high costs of their repairing. Therefore the quality requirements for underwater crossing constructions are very high. Engineers must consider and possibly shut out the implications caused by ice during the ice motion period, floating trees and other objects that can be found within water flows; keep the pipeline undamaged; ensure the weigh down of pipelines with positive buoyancy and shut out the soil erosion beneath the pipeline crossings.

Pipelines located under the water are affected by the river flow both during their construction and exploitation, especially during the pipeline laying on the river bedding. And the pipeline stability depends on strength of water flow implication and the negative buoyancy value.

Therefore, we suggest using universal protective concrete coatings UGZBM-S and UGZBM to protect the low buried underwater pipelines from mechanical damage, prevent soil erosion of the river bedding and damaging the river bank revetment, road slopes and bridge crossing footing [3, 4] (figure 1).
Usage of flexible protective concrete pavements has a lot of advantages:

- it allows to increase resistibility and keep the pipeline undamaged during water flow and other objects;
- protective mats reinforce the shoreline near the pipeline;
- protective mats prevent soil erosion during the pipeline exploitation;
- flexible concrete mats are easy to remove and place in case of pipeline or protective coating repairing.

Engineers consider that water flow in the acting zone of protective concrete mats is smooth with no vortex or whirlpool zones. Even more, due to their cellular structure, these mats don’t interrupt water- and shoreline plants growth, which enforces further embedment of the mat in the river bedding. Exploitation experience has shown that the mats can be damaged by the water flow due to partial erosion of soil foundation that causes flipping of the blocks in first row of the protective coating and its further wrapping [5, 6]. Though this type of mats have need widely used since 1990, the hydraulic characteristics of the flow interacting with protective mats are underexplored.

2. Methods
Since the configuration of protective coatings is complexly shaped, we’ve performed experimental research in order to determine the hydraulic characteristics of the water flow that interacts with pipelines that are protected with flexible concrete mats. The experimental research program involved determination of depth level above the mats and velocities of the flows that approaches the mat, goes above the mat, goes through the gaps between the mats and the flow that leaves the mat. The experiments were run in hydraulic channel of the Hydraulics and Hydrotechnical laboratory of the National Research University MSUCE. The key elements of this hydraulic channel are shown on figure 2 [7].
Figure 2. Laboratory hydraulic channel. 1 – work part of the channel; 2 – waterpump; 3 – pressure pipe; 4 – flow measuring device; 5 – channel control panel; 6 – channel slope control panel; 7 – piezometrical shield; 8 – electronic water-stage transmitter; 9 – millimeter grade railway for the instrumental and sonde carriage.

For this experiment we’ve made 2 working models of the pipelines with protective mats UGZBM and UGZBM-S in 1:4 scale. Experimental models of UGZBM and UGZBM-S are shown on figures 3 and 4. We’ve modeled the overflow of pipeline by fixing the mat blocks on flexible 1000 mm long plastic sheet, enveloping the pipeline d=200 mm, that was installed in the experimental channel on plexiglas foundation held fix by M8 flat head bolts. The plexiglas edge was smoothly connected with the channel with playdough. The model pipeline diameter 200 mm was chosen considered the experimental channel size and is representing a pipeline with 800 mm diameter. Protective coatings for pipelines with larger diameters have less curvature mats and therefore are less affected by the dynamic implication of the water flow. The mats were installed asymmetrically with more smooth curvature facing the inward flow. The length of the grades was taken equal to the length of a standard mat. As the flow goes down from the pipeline with protective coating, its velocity increases, and it may cause the erosion of soil foundation and mat subsidence. Therefore downstream side slope was made with more severe curvature. Considering it, we’ve laid the upstream side as 1:2.25 and the downstream side as 1:1.19.
After we’ve placed and fixed our model in the channel, we measured the vertical points of pressure selection using the electronic water-stage transmitter with measuring accuracy 0.01 mm. Then we’ve set horizontal points of pressure selection using the 1 mm scaled rule placed on the channel wall. The pressure measurement along the experimental model were made with Huba Control Type 691 pressure transmitter electronic system with 0–600mbar measuring scale. The built-in programs of HM 162.12 and HM162.13 penstocks [7] allowed us to control the experiment in real time. Water circulation in the channel was administered by centrifugal pump (#2 on fig. 2) that pumped water from four anticorrosive tanks located on the floor of the lab. The frequency of water pump’s working wheel rotation regulated the flow rate \( Q \). It was measured by EM flow measuring device (#4 on fig. 2) and was written on the control panel display (#5 on fig. 2) and computer screen.

During the research of overflow of mats protecting pipeline we’ve held the slope at 0.001. The model flow rate was 60 m\(^3\)/h, equivalent to 1920 m\(^3\)/h per mat.

3. Results and discussions
The main goal of the research was to determine the exploitation characteristics of UGZBM and UGZBM-S as protective coatings of variously buried pipelines.

During the exploitation of UGZBM and UGZBM-S as protective coatings of pipelines there forms a repelled jump behind the mats (figures 5 and 6).
The dynamic implication of the water flow over the undersoil intensifies in the repelled jump zone, which can cause local soil erosion in the areas where the flow leaves protective mat [8–12]. And this is the reason why we’ve researched both types of hydraulic jumps created by the flow: placed closer to the protected pipeline and further behind it.

Levels of the free surface of the flow overflowing the pipelines protected by UGZBM and UGZBM-S mats were measured with electronic water-stage transmitter. The results of the experiment allowed us to compare the levels of the free surface above two different types of mats, protecting the pipeline crossings with the same slope (0.001) and flow rate (60 m$^3$/h). The curvatures of free surface
above the UGZBM and UGZBM-S protective mats of non-buried pipeline crossings are shown on figure 7.

![Image](image1.png)

**Figure 7.** Comparison of levels of free surface above the UGZBM and UGZBM-S protective mats of non-buried pipelines.

The comparison of levels of free surface above the UGZBM and UGZBM-S protective mats of pipeline crossings, buried by 1/2 and 1/4 of the pipeline diameter, are shown on figures 8 and 9.

![Image](image2.png)

**Figure 8.** Comparison of the levels of free surface above the UGZBM and UGZBM-S protective mats of the pipeline, buried by 1/4 of its diameter.

![Image](image3.png)

**Figure 9.** Comparison of the levels of free surface above the UGZBM and UGZBM-S protective mats of the pipeline, buried by 1/2 of its diameter.
The curvatures of free surface above the UGZBM and UGZBM-S protective mats under the condition of drowned hydraulic jump are shown on figures 10 and 12.

**Figure 10.** Comparison of levels of free surface above the UGZBM and UGZBM-S protective mats of non-buried pipelines under the condition of drowned hydraulic jump

**Figure 11.** Comparison of the levels of free surface above the UGZBM and UGZBM-S protective mats of the pipeline, buried by 1/4 of its diameter, under the condition of drowned hydraulic jump

**Figure 12.** Comparison of the levels of free surface above the UGZBM and UGZBM-S protective mats of the pipeline, buried by 1/2 of its diameter, under the condition of drowned hydraulic jump

The comparison of curvatures of free surface above the UGZBM and UGZBM-S protective mats with the same flow rate (figures 7–12) shows that characteristics of the flow both with hydraulic jumps placed closer to the protected pipeline and further behind it are practically identical.
With the hydraulic jumps placed further behind the protected pipeline, the depth of the flow, overflowing the pipeline, decreases and its velocity increases. This being said, the depth of the flow is only slightly above the compressed depth \( h_{\text{compr}} \), and the velocity in the hydraulic jump zone of this model only reached 1.75 m/s. Higher velocity that accumulates beyond mats are considered dangerous as they tend to cause erosion on the river bedding, and therefore such behavior is unwanted. Because of this, we’ve also run experiments with the hydraulic jumps placed closer to the protected pipeline.

The comparison of calculated values of researched flow types separate depth (conjugated with compressed depth) with normal depth while overflowing the pipelines with UGZBM and UGZBM-S protective mats are shown in table 1.

### Table 1. The comparison of calculated values while overflowing the pipelines protected by UGZBM and UGZBM-S protective mats

|       | \( Q \) (m³/s) | \( q \) (m²/s) | \( h_{\text{compr}} \) (m) | \( h_{\text{compr}} \) (m) | \( h_{\text{sep}} \) (m) | \( h_{\text{normal}} \) (m) |
|-------|----------------|---------------|-----------------|-----------------|----------------|-----------------|
| UGZBM | 1.143          | 0.285         | 0.286           | 0.593           | 0.286         | 0.593           |
| UGZBM-S| 1.143          | 0.285         | 0.067           | 0.796           | 0.067         | 0.796           |

4. Conclusions
The comparison shows that for every type of flow the pipelines with protective mats were overflown under conditions of hydraulic jump placed closer to the protected pipeline with \( h_{\text{sep}} < h_{\text{normal}} \).

Thus the usage of protective mats is advisable under the conditions of hydraulic jump placed closer to the protected pipeline with depths of the tail-water equal to \((1,1÷1,15)\cdot h_{\text{sep}}\). This should be taken into consideration while designing the protection for the pipelines that are crossing water objects.

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