



EXPERIMENTAL DETERMINATION OF MANNING'S ROUGHNESS COEFFICIENT FOR A CRUSHED-STONE-FILLED GEOMAT

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ABSTRACT

Water erosion poses a serious threat to hydraulic structures, gradually destroying them. Therefore, the development and application of effective protective coatings for watercourses and bank slopes is particularly relevant today. The aim of this study is to determine the roughness coefficient of a protective coating for a watercourse and bank slope, consisting of geotextiles with crushed stone as a filler. This article examines the features of a model setup for determining the hydraulic characteristics of an anti-erosion coating and describes the methodology for their determination. The calculation formulas used to empirically obtain roughness coefficient values are analyzed. The results of experimental studies aimed at determining the roughness coefficient of a protective coating for various flow rates and channel bottom slopes are presented. The obtained results are analyzed, and the average roughness coefficient value is derived. Laboratory studies evaluating the roughness coefficient of an anti-erosion protective coating made from geotextiles with added crushed stone demonstrated the practical potential of this innovative fastening material. Recommendations for the use of this protective anti-erosion coating are provided.

Keywords: Erosion, Channel, Bank protection, Anti-erosion coating, Geomat, Crushed stone.

INTRODUCTION

Slope stabilization is especially important during the construction and renovation of drainage channels, riverbeds, banks, reservoirs, dams, and embankments (Riahi et al., 2020; Hariri Asli and Nazari, 2021). Uncontrolled water flow can have a destructive impact on banks and channel beds, contributing to landslides, washouts, erosion, and other negative consequences (Benfetta et al., 2016; Benfetta et al., 2017a; 2017b; Riahi et al., 2020; Long Ye et al., 2023; Mehta et al., 2023; Qureshi et al., 2024).

It is possible to prevent the negative impact of water on the integrity of the banks and channels of water bodies by using engineering solutions with the use of geosynthetic materials (Kana Collins, 2017; Remini, 2017; M’Foutou and Diabangouaya, 2019; Chabokpour and azamathulla, 2025). Among these materials, the most widely used in modern hydraulic engineering is geomat (Enkamat), a lightweight, three-dimensional fiber made of polymer or synthetic materials. These meshes are thermally bonded and interwoven in a random or patterned manner (Mfoutou et Diabangouala, 2025; Haddad et Ghoulam, 2014; Ngouala and al., 2016; Amitouche et al., 2017). This coating made of Enkamat grade 7225, which is a stable three-dimensional fibrous structure with a backing of polyamide monofilaments, under certain conditions effectively strengthens the slopes of canals, small rivers and reservoirs.



Figure 1: Strengthening the slopes of water bodies with geomat (Chernykh 2023). in river renaturation in combination with rock fill and biological strengthening (grass sowing).

Because geomat is made of a polymer material, its service life is sufficient to provide long-term protective performance (Chernykh et Burlachenko, 2023; Guryev et al., 2015; Khanov et al., 2024). However, hydraulic studies must be conducted considering the composition of not only the Enkamat 7225 anti-erosion coating itself, but also, in particular, its hard and fine-grained aggregate, in this laboratory study, the aggregate used for its structural design.

Therefore, the objective of the study was to determine the roughness coefficient (Achour and Amara, 2020a; 2020b) of a protective watercourse coating consisting of Enkamat 7225 geomat with aggregate filler.

MATERIAL AND METHODS

The experimental setup was made in the form of a tray with a trapezoidal cross-section with a vertical right ($m = 0$), inclined left ($m = 1$) slope and a variable bottom slope $i = 0.001 \dots 0.017$, with a total length of the section with coverage of 8 m (Fig. 2).

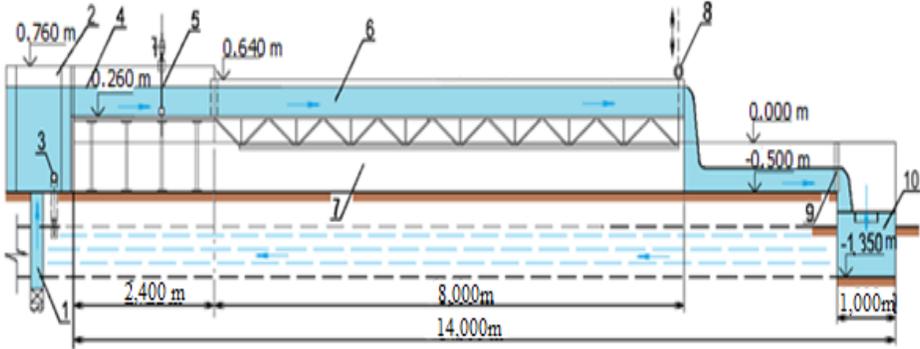


Figure 2: Structural section of the experimental setup. 1. Feed pipe; 2. Receiving tank; 3. Drain pipe; 4. Inlet chute; 5. Flow regulator; 6. Model working chute; 7. Common drain chute; 8. Working chute lifting system; 9. Louvered valve; 10. Discharge chute

The experimental setup simulated water flow in a channel of constant width, with flow parameters consistent with actual flow conditions. Smooth plastic sheets were attached to the vertical edge to reduce friction and eliminate the influence of edge unevenness on the flow pattern (Khomchenko, 2014; Kurbanov, 2014). To improve adhesion to the geomat under study, the bottom and left edge of the trough were covered with a reinforcing mesh of 1 mm diameter wire with 1 x 1 cm mesh, followed by Enkamat 7225 geomat with crushed rock filler (6 to 10 mm in size) (figure 3). The granulometric composition of the crushed rock was pre-selected for the study based on the conditions for filling the voids of the Enkamat 7225 geomat.

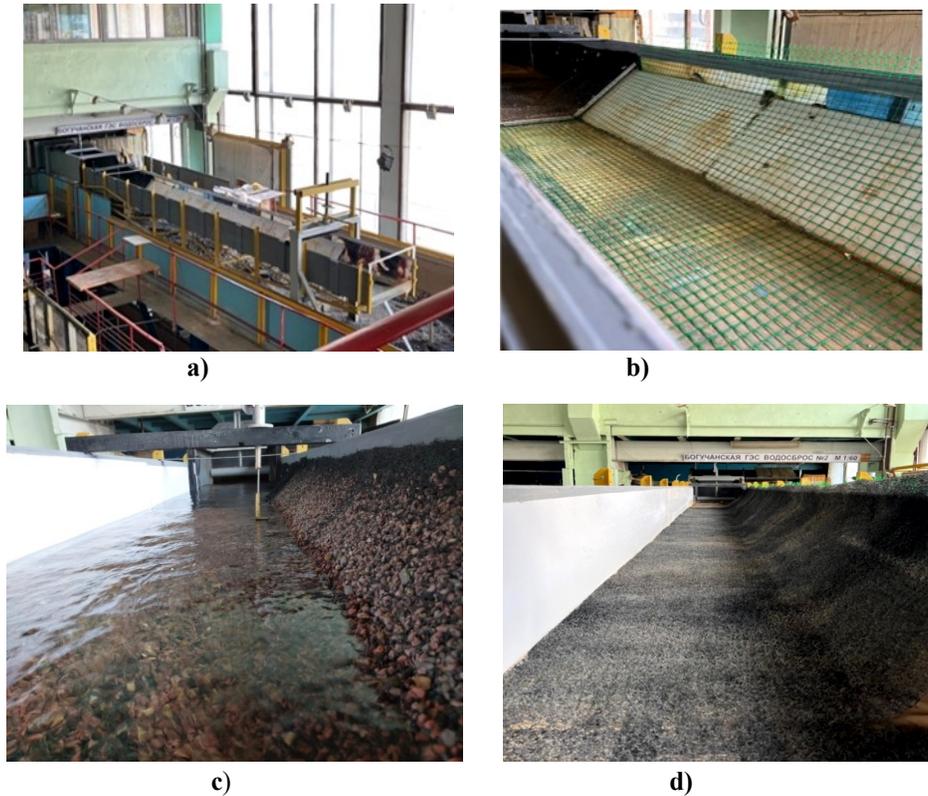


Figure 3: General view of a fragment of the experimental setup. (a) general view of the tray; (b) installation covered with reinforcing mesh; (c) fragment of the tray covered with geomat; (d) during installation, geomat with crushed stone, (photo by Zhukova, 2024)

A study of the effect of Enkammat 7225 geomat filled with crushed stone on the roughness coefficient n was conducted over a 4.9 m test section (Zhukova, 2022; Zhukova et al., 2023). For the experiments, slopes and flow rates were selected during the preliminary research phase based on an analysis of the conditions for crushed stone particle movement along the bottom. Laboratory studies were conducted with flow rates varying from $Q = 43$ to 128 l/s.

RESULTS AND DISCUSSION

At each station, velocity measurements were taken at 11 verticals. At each vertical, velocity measurements were made using a 2 mm diameter Pitot tube at six vertical points (Fig. 4).

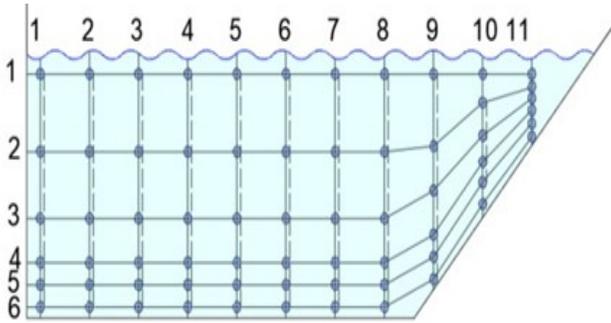
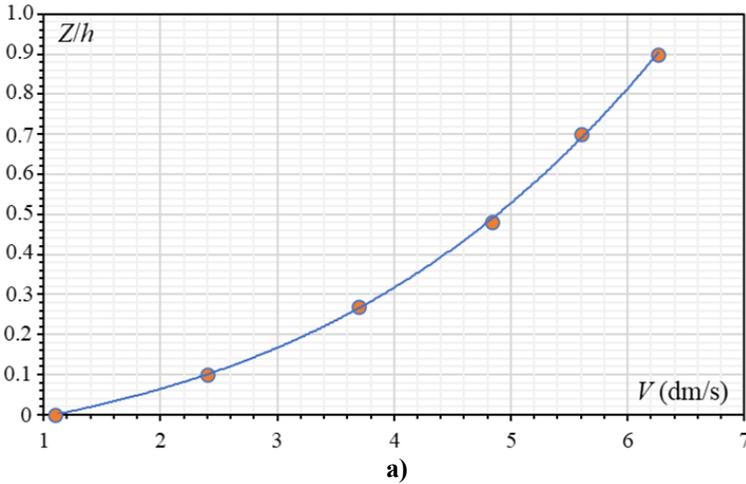


Figure 4: Layout of verticals and points for determining flow velocities in a channel model

Based on the vertical measurement data, flow velocity diagrams $V = f(z/h)$ were constructed, where (z/h) is the relative height from the bottom in the measured cross-section. Flow velocity diagrams on vertical measurement lines for a geomat-with-gravel covering are shown in Fig. 5 for different slopes i and flow rates Q : a) $i = 0.001$, $Q = 43.7$ l/s, $y =$ section 4; b) $i = 0.017$, $Q = 43.7$ l/s, $y =$ section 4.

In section 4, the flow in this sector is more uniform compared to the other three sections studied.



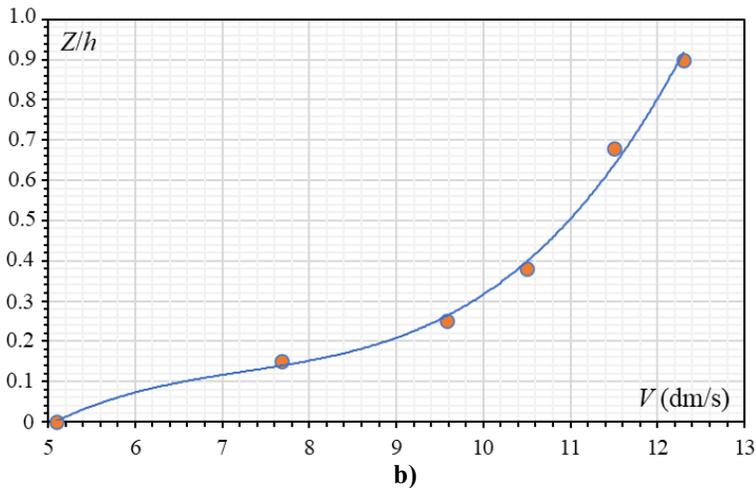


Figure 5: Examples of flow velocity diagrams $V = f(z/h)$ on vertical lines for a geomat with-gravel: a) $i = 0.001$, $Q = 43.7$ l/s; b) $i = 0.017$, $Q = 43.7$ l/s.

Comparison of flow velocity diagrams for different slopes of the studied surfaces showed that with an increase in the slope of the watercourse bottom, the flow velocity in the channel increases.

When assessing the distribution of average depths h_{av} , cross-sectional energy e and total specific energy E of the flow, well-known formulas were used (Zhukova et al., 2023):

$$h_{av} = \frac{\int_0^h h db}{b} \tag{1}$$

$$e = h + \frac{u^2}{2g} \tag{2}$$

$$E_x = (x_0 - x)i + h + \alpha \frac{V^2}{2g} \tag{3}$$

where:

- h_{av} (dm) Average flow depth
- h (dm) Flow depth
- d Differential, Variable
- u (dm/s) Local velocity
- b (dm) Width of the tray bottom
- g (dm/s²) Acceleration due to gravity

x_0 (dm)	distance from the origin of the x -axis to the cross-section through which the comparison plane passes
x (dm)	distance to the section under consideration
i	Channel bed slop
α	Coriolis coefficient
V (dm/s)	Average velocity

The most typical examples of the distribution of average flow depths h_{av} , section energy e and total specific energy E of the flow along the length of the flume when passing through it a flow rate of $Q = 43.7$ l/s for $i = 0.001$ and $i = 0.017$, section 4 are shown in Fig. 6.

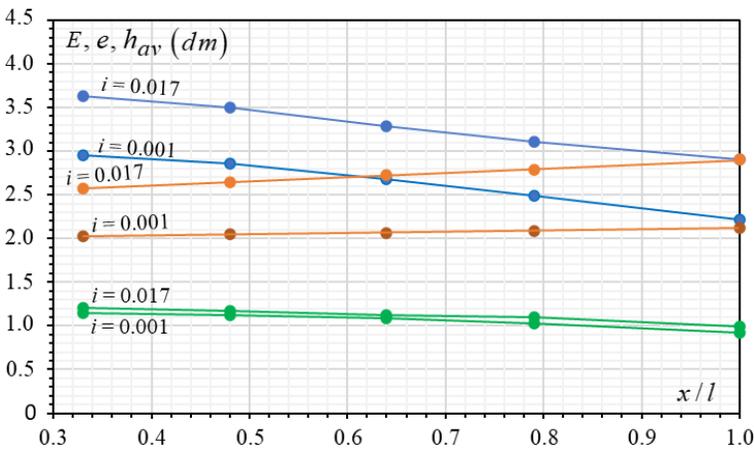


Figure 6: Dependencies reflecting the distribution of average depths h_{av} , cross-sectional energy e , and total specific energy E of the flow along the length of the channel at a flow rate of $Q = 43.7$ l/s; x = distance to the section under consideration; l = length; —●— = Full energy E ; —●— = Specific energy e ; —●— = depth h_{av}

A comparison of the change in the average flow depth h_{av} , the total specific energy E of the flow, and the energy in the cross-section (e) at $Q = 43.7$ l/s and an increase in the slope of the watercourse bottom i from $i = 0.001$ to $i = 0.017$ showed that with an increase in the slope of the watercourse bottom, the total specific energy and the energy of the cross-section increase.

To determine the roughness coefficient, the following well-known dependencies were used: (Manning, 1890), (Ganguille-Kutter, 1869) and (Pavlovsky, 1925), (Manning, 1891; Ganguillet et Catter, 1869; Pavlovsky, 1937):

$$n_{man} = \frac{R^{2/3} \sqrt{J}}{V} \quad (4)$$

$$n_{g-k} = \frac{23R\sqrt{J} - V\sqrt{R}}{46V} + \sqrt{\left(\frac{23R\sqrt{J} - V\sqrt{R}}{46V}\right)^2 + \frac{R\sqrt{J}}{23V}} \quad (5)$$

$$n_{pav} = \frac{R^{0.37} + 2.5\sqrt{n} - 0.75\sqrt{R}(\sqrt{n} - 0.1)}{V}\sqrt{J} \quad (6)$$

where:

- n (s/m^{1/3}) Manning roughness coefficient
- R (dm) Hydraulic radius
- V (m/s) Average velocity
- J Energy slope

Since the experimental setup had a right vertical wall covered with a glossy coating in the experiments to determine the roughness coefficient for this anti-erosion coating, the roughness coefficient for it was taken to be $n_{pl} = 0.009$, as for surfaces coated with enamel or glaze. Therefore, for the studied section of the channel, to take into account the coating with different roughness, the average roughness coefficient was determined using the transformed formula (Zhukova et al., 2024; Zhukova et al., 2025):

$$n_n = \frac{n_{av}b + n_{av}\left(1 + h_{ar}\sqrt{m^2 + 1}\right) - n_{pl}h_{ar}}{b + h_{ar}\sqrt{m^2 + 1}} \quad (7)$$

where:

- n_{av} Manning roughness coefficient
- b (dm) Width of the tray bottom
- h_{ar} (dm) Average flow depth
- n_{pl} (s/m) Manning roughness coefficient for surfaces covered with enamel or glaze

To determine the true value of the roughness coefficient, these values were recalculated using Eq. (7). The results of the calculation of n are presented in Table 1.

Table 1: Results of calculation of roughness coefficient n of anti-erosion coating

Parameter designation	n_{av} (s/m ^{1/3})	n_{min} (s/m ^{1/3})	n_{max} (s/m ^{1/3})
n_{man} (s/m ^{1/3})	0.0237	0.0222	0.0259
n_{g-k} (s/m ^{1/3})	0.0226	0.0221	0.0255
n_{pav} (s/m ^{1/3})	0.0229	0.0224	0.0257

where:

n_{man} (s/m ^{1/3})	Manning roughness coefficient
n_{g-k} (s/m ^{1/3})	Ganguiller - Kutter roughness coefficient
n_{pav} (s/m ^{1/3})	Pavlovsky roughness coefficient
n_{av} (s/m ^{1/3})	Average roughness coefficient value
n_{min} (s/m ^{1/3})	Roughness coefficient minimum value
n_{max} (s/m ^{1/3})	Roughness coefficient maximum value

After comparing with known reference data for various types of canal linings and the results of previous studies of linings with various geomat types, all roughness coefficient values were recalculated to obtain the actual n values for a protective lining consisting of Enkamat 7225 geomat filled with crushed stone.

Based on the above, it is recommended that for canals operating in the studied range for this design of erosion control lining, $n = 0.0237$ s/m^{1/3}, calculated using Manning's formula, be used in the design.

CONCLUSION

Laboratory studies evaluating the roughness coefficient for an erosion-control protective coating consisting of Enkamat grade 7225 geomat with crushed stone filler demonstrated the potential for using this type of support in reclamation practices.

After calculating the roughness coefficient using three formulas: Manning, Ganguillier-Kutter, and Pavlovsky, the results were analyzed and the average roughness coefficient n was calculated. Based on the results of these experiments studying the coefficient n for hydraulic calculations of canals with crushed stone filler, it is recommended to use Enkamat 7225 geomat, using a roughness coefficient of $n = 0.0237$ s/m^{1/3} calculated using Manning's formula.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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