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EXPERIMENTAL EVALUATION OF ROUGHNESS COEFFICIENTS OF ANTI-EROSION GEOMATS WITH CRUSHED STONE AND VEGETATION FILLERS

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ABSTRACT

Hydraulic structures are exposed to water erosion, so the creation of protective coatings for their slopes is currently relevant. To prevent the negative effects of water erosion on soil slopes, a number of measures are taken, including strengthening the upper layer of the slope with anti-erosion clothing. Geomats are common geosynthetics, which have found their application in construction.

This article presents and discusses the results of model studies of geomats of two anti-erosion coatings used for lining watercourse beds.

The studies were carried out in the laboratory of the Department of Hydraulic Structures of Timiryazev Academy on a hydraulic installation for testing coatings.

The calculation formulas, on the basis of which the values of roughness coefficients were experimentally obtained, are analyzed.

The conducted studies, which are devoted to the assessment of the roughness coefficient for the investigated anti-erosion protective coatings, have shown the possibilities of using fasteners in practice. A model installation for finding the hydraulic characteristics of the studied coatings is described and considered.

In the future, it seems advisable to conduct additional studies with the above-considered anti-erosion coatings to determine the permissible non-washing speeds.

Keywords: Slope, Erosion, Protection, Geomat, Crushed Stone, Vegetation, Roughness Coefficient.

INTRODUCTION

Coastal protection includes a set of works to strengthen and protect the coastal line of natural and artificial reservoirs (Photo 1). Some relevant studies provide insights into groundwater characteristics in coastal aquifers, which can be pertinent to understanding coastal protection in natural reservoirs (Ngouala et al., 2016), while meaningful papers examined the water quality of a coastal basin, offering information that could be valuable for coastal protection strategies in natural reservoirs (Haddad and Ghoualem, 2014). Groundwater management (Bahir et al., 2015; Qureshi et al., 2024), reservoir operations (Mezenner et al., 2022; Trivedi and Suryanarayana, 2023; Mehta et al., 2023; Verma et al., 2023; Panchal and Suryanarayana, 2025), and the balance between groundwater and surface water use, are all essential aspects of managing coastal and near-coastal water resources (Paulo Monteiro and Costa Manuel, 2004). The impact of saltwater intrusion in coastal aquifers due to overexploitation and water desalination, is a critical issue related to coastal protection (Morsli et al., 2017; Belkacem and al., 2017; Amitouche et al., 2017; Djabri et al., 2019). The shift from groundwater to surface water sources (dam water) is a strategy that can help protect coastal aquifers from saltwater intrusion, indirectly contributing to coastal protection.

Understanding erosion processes, affecting for instance forests, watersheds, river banks, and siltation of hydraulic structures (Remini and Bensafia, 2016; Remini, 2017; Remini et al., 2019: Mfoutou and Diabangouaya, 2019), enables dynamic watersheds modelling and their management (Long et al., 2023; Kherde et al., 2024), design of effective protective structures, such as seawalls, groynes, and breakwaters, which minimize shoreline loss and safeguard coastal communities. Rockfill structures, such as gabion mattresses are widely used in hydraulic engineering applications to mitigate erosion and protect infrastructure (Chabokpour and Azamathulla, 2025). However, these structures are susceptible to erosion processes, both from upstream and downstream directions, which can compromise their integrity and effectiveness.

Currently, there are a large number of anti-erosion materials, but with the development of technology, modern geosynthetic materials have appeared, which are considered reliable and durable materials (Khomchenko, 2014; Kurbanov and al., 2020).

Common geosynthetic materials include geomats, which have found their application in construction. This anti-erosion material has a fairly extensive range of applications in hydraulic engineering. Geosynthetic construction materials provide a viable and long-term economic alternative to other types of conventional construction materials. This material is used to stabilize erosion processes of soils and grounds, making it possible to construct on weak and technogenic soils (Chernykh and Burlachenko, 2023a).

Increasing the reliability, durability, and environmental safety of constructed facilities, these materials are actively used today in the construction of hydraulic, reclamation, and environmental protection structures (Kurbanov and al., 2021; Zhukova, 2022).

Photo 1: Damage to slopes caused by water flow on coastal slopes

Geomats are usually used to protect the soil from erosion, secure the roots of grasses, trees, or small plants on slopes, as well as in construction and hydraulic engineering (Chernykh and Burlachenko, 2023b).

The structure and main characteristics of geomats allow for soil reinforcement on the banks of rivers, lakes, ponds, as well as in other places to prevent soil erosion. A geomat is a permeable three-dimensional anti-erosion material made from polyamide fibers thermally bonded at their intersections (Photo 2).

(a)

(b)

Photo 2: Slope reinforcement using geomat, (a) for the reinforcement of road drainage channels; (b) with a biological type of reinforcement

This anti-erosion material is used to strengthen slopes that interact with water flow. The roughness coefficient of the two studied coverings was experimentally determined for conducting hydraulic calculations.

The objective of this work was to conduct hydraulic studies of the properties of geomats from two types of anti-erosion coverings used for lining riverbeds: a geomat with gravel filler and a geomat filled with gravel and sown with perennial ryegrass.

Photo 3: Options for protective coverings, (a) geomat with gravel filler; (b) geomat with vegetation. (Photo by Zhukova, 2024)

MATERIAL AND METHODS

Description of the experimental setup

The research was conducted in the laboratory of the Department of Hydraulic Structures at Timiryazev Academy on a hydraulic testing facility for coating tests. The research was conducted in the laboratory of the Department of Hydraulic Structures at Timiryazev Academy using a hydraulic installation for testing coatings.

In the experimental setup, there was the possibility to change the flow rate of the incoming water and the slope of the riverbed. The experimental hydraulic flume had a trapezoidal cross-section with a vertical slope on one side and a slope with a 1:1 inclination on the other.

The vertical slope was lined with plastic panels characterized by the following Manning roughness coefficient n = 0.009 s/m$^{1/3}$. The hydraulic installation had the capability to change the bed slope i from 0.001 to 0.03 (Photo 4).

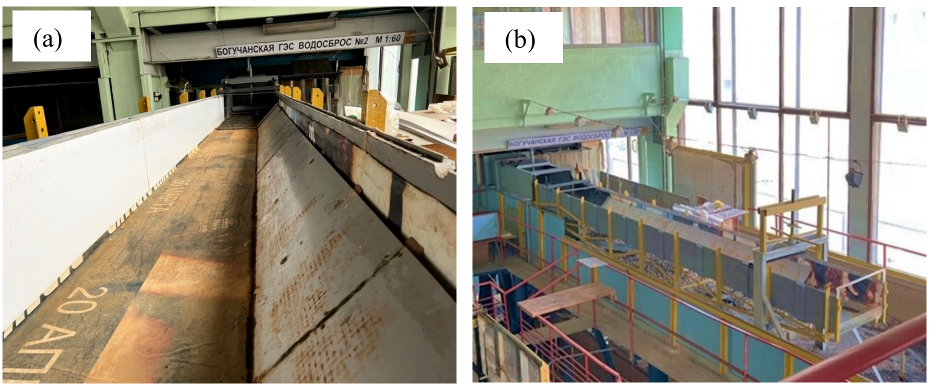

Photo 4: Experimental setup, (a) view of the work area; (b) view of the setup (Photo by Zhukova, 2024)

Hydrotechnical structures are subject to water erosion, so the creation of protective coverings for their slopes is currently relevant. To prevent the negative effects of water erosion on soil slopes (Riahi et al., 2020), a series of measures are taken, including the reinforcement of the upper layer of the slope with anti-erosion coverings. Common geosynthetic materials include geomats, which have found their application in construction. A model setup for determining the hydraulic characteristics of the studied coverings is described and examined.

During the research, the length of the working section was 4.9 m. The flow rates of the incoming water ranged from 43 to 128 l/s. The granulometric composition of the gravel was selected in such a way that the voids in the geomat structure were completely filled.

In the laboratory, the study of options for using geomats with vegetation was conducted, specifically the selection and choice of a mixture of perennial grasses, the formation of a grass stands for further evaluation of the application of such a mixed anti-erosion cover.

For the study, slopes and flows were also selected based on vegetation heights of 50 mm, 100 mm, and 150 mm.

The study involved examining the flow parameters and the geometric dimensions of the installation. Flow parameters were measured at five cross-sections located along the length of the control section at distances of x = 210, 307, 407, 507, and 636 cm.

In each of them, speed measurements were taken at eleven verticals, equidistant from each other and from the right wall of the trough (Guryev and al., 2015; Khanov and al., 2024).

Measurements of flow velocities were carried out across the entire section of the stream using a Pitot tube with a hole diameter of 3 mm.

Photo 5 shows the experimental setup for determining flow velocities using a Pitot tube.

Photo 5: Experimental setup for determining flow velocities using a Pitot tube, (Photo by Zhukova, 2024)

Based on the measurements data at the verticals, flow velocity profiles $V = f(z/h)$ were constructed, where (z/h) is the relative height from the bottom in the measured section, V is the flow velocity in the channel, dm/s.

RESULTS AND DISCUSSION

Flow velocity diagrams on vertical measuring lines for different slopes of the studied surfaces are shown in Fig.1 in the section 4 (the flow in this sector is more uniform compared to the other three sections studied) for two anti-erosion slopes: first (geomat with gravel filler at i = 0.017, Q = 43.7 l/s, y = 440 mm) and the second slope (geomat filled with gravel and sown with perennial ryegrass at i = 0.03, Q = 43.7 l/s , y = 440 mm).

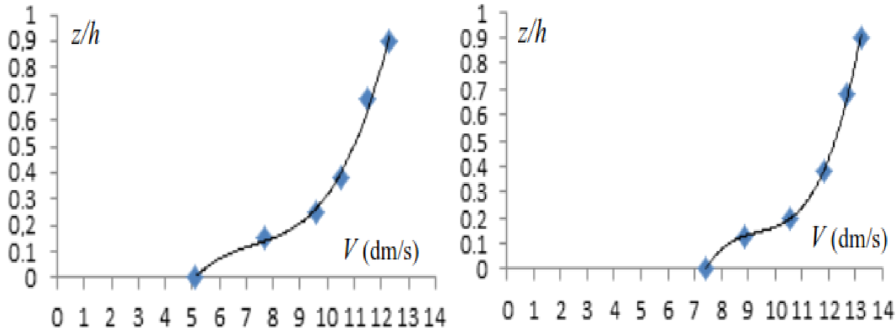

Figure 1: Diagrams of flow velocity on vertical measuring lines for different slopes of the studied surfaces. (a) geomat with crushed stone filler; (b) geomat filled with crushed stone with sowing of perennial grasses of the genus ryegrass

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.

After determining the flow velocities, the roughness coefficient n and other hydraulic characteristics of the flow were found. The roughness coefficient was determined using the dependencies presented in Table 1.

Table 1: Dependencies for determining the roughness coefficient *n*

Addiction	Dependency
Manning (1891)	$n_{man} = \dfrac{R^{2/3}\sqrt{J}}{V}$
Ganguillet and Kutter (1869)	$n_{g-k} = \dfrac{23R\sqrt{J} - V\sqrt{R}}{46V} + \sqrt{\left(\dfrac{23R\sqrt{J} - V\sqrt{R}}{46V}\right)^2 + \dfrac{R\sqrt{J}}{23V}}$
Pavlovsky (1937)	$n_{pav} = \dfrac{R^{0.37} + 2.5\sqrt{n} - 0.75\sqrt{R}(\sqrt{n} - 0.1)}{V}\sqrt{J}$

Determination of n (with different coatings in one section)	$n_n = \dfrac{n_{av} \cdot b + n_{aver}(1+\sqrt{m^2+1}) \cdot h_{ar} - n_{pl} \cdot h_{ar}}{b+\sqrt{m^2+1} \cdot h_{ar}}$

where

R (dm)	Hydraulic radius
n (s/m$^{1/3}$)	Manning roughness coefficient
V (m/s)	Average velocity, m/s
J (m/m)	Hydraulic grade line
n_{av} (s/m$^{1/3}$)	Average Manning roughness coefficient
b (dm)	Width of the tray bottom
m	Slope depth (m = 1)
h_{ar} (dm)	Average flow depth
$n_{surface}$ (s/m$^{1/3}$)	Manning roughness coefficient for surfaces covered with enamel or glaze

The calculation results for geomat with crushed stone filler and geomat filled with crushed stone with sowing of perennial grasses of the ryegrass genus are presented in Table 2.

Table 2: Manning and Pavlovsky roughness coefficients for the studied geomats with fillers

Coating	Parameters	n_{av}	n_{min}	n_{max}
geomat with gravel filler	n_{man}	0.0237	0.0222	0.0259
	n_{g-k}	0.0226	0.0221	0.0255
	n_{pav}	0.0229	0.0224	0.0257
geomat filled with gravel and sown with perennial ryegrass	n_{man}	0.0301	0.0289	0.0306
	n_{g-k}	0.0282	0.0279	0.0288
	n_{pav}	0.0287	0.0290	0.0298

where

n_{man} (s/m$^{1/3}$)	Manning roughness coefficient
n_{g-k}	Ganguillet – Kutter roughness coefficient
n_{pav}	Pavlovsky roughness coefficient
n_{av} (s/m$^{1/3}$)	Average value of Manning roughness coefficient
n_{min} (s/m$^{1/3}$)	Minimum value of Manning roughness coefficient
n_{max} (s/m$^{1/3}$)	Maximum value of roughness coefficient.

After comparison with known reference data for different types of channel coatings and the results of previously conducted studies of coatings with other geomats of different types of laying, as a result of recalculation of all values of roughness coefficients, real values of n were obtained for these protective coatings.

After conducting the experiments, sections of the vegetation cover were made; the sections of the cover are shown in Photo 6.

(a)

(b)

Photo 6: The state of the studied coating at the end of the experiments: (a) the supply section of the channel fragment; (b) the discharges section of the channel fragment, (Photo by Zhukova, 2024)

After a series of experiments, analysis of the sections showed that no deformations of the topsoil of the mixed fastening coating and the base underneath it was detected.

Crushed rock from geomat material Enkamat 7225 (light, voluminous, three-dimensional fiber from polymer or synthetic materials, produced by the method of thermal bonding and intertwined in a chaotic or specific order) creates greater hydraulic resistance. The roots of the grass used served as reinforcing material for the soil and prevented its erosion.

Sections of this composite coating, made after hydraulic tests, showed their excellent preservation (Zhukova and al., 2023).

RECOMMENDATIONS

It is recommended for channels operating in the studied range of fundamental parameters: flow rates, depth, bottom slopes of the tray and energy indicators, to take the value n = 0.0237 s/m$^{1/3}$, calculated using the Manning formula, when designing.

For coverings a geomat filled with crushed stone with sowing of perennial grasses of the ryegrass genus, the value n = 0.0301 s/m$^{1/3}$, calculated using the Manning formula, can be recommended (Zhukova and al., 2024).

CONCLUSION

The conducted experimental studies on the assessment of roughness coefficients for two anti-erosion coatings used for lining watercourse beds: geomat with crushed stone filler and geomat filled with crushed stone with sowing of perennial grasses of the ryegrass genus, showed the possibility of using such fastenings in practice.

After calculating the roughness coefficient, performed using three formulas: Manning, Ganguillet and Kutter, and Pavlovsky, an analysis of the obtained results was made and the average value of the roughness coefficient n was calculated.

Based on the analysis and after calculating the Manning roughness coefficients n, for the studied coatings, it is possible to recommend using: geomat with aggregate filler, coefficient value n = 0.0237 s/m$^{1/3}$, geomat with vegetation n = 0.0301 s/m$^{1/3}$, obtained using the Manning formula.

In the future, it seems advisable to conduct additional studies with the above-mentioned anti-erosion coatings to determine the permissible non-erosion velocities.

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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.

REFERENCES

AMITOUCHE M., LEFKIR A., REMINI B., MERADJI H., MOKHTARI O. (2017). Chemical discharge on the marine environment from desalination plants in Algeria, Larhyss Journal, No 32, pp. 199-211. (In French)

BAHIR M., EL MOUKHAYAR R., CARREIRA P. SOUHEL A. (2015). Isotopic tools for groundwater management in semi-arid area: case of the wadi Ouazzi basin (Morocco), Larhyss Journal, No 23, pp. 23-39.

BELKACEM Y., BENFARES R., ADEM A., HOUMA BACHARI F. (2017). Evaluation of the impact of the desalination plant on the marine environment: case study in Algeria, Larhyss Journal, No 30, pp. 317-331.

CHABOKPOUR J., AZAMATHULLA H.M.D. (2025). Multi-scale CFD analysis of erosion dynamics in heterogeneous rockfill structures implications for sustainable hydraulic engineering design, Larhyss Journal, No 61, pp. 217-239.

CHERNYKH O.N., BURLACHENKO A.V. (2023a). Assessment of the main parameters of wave action on gentle slopes of the banks of large water bodies, Journal of Structural mechanics of engineering structures and structures, Vol. 19, No 1, pp.110-116.

CHERNYKH O. N., BURLACHENKO A.V. (2023b). Features of the use of landscape hydraulic engineering methods in river restoration, Collection of articles of the V International Scientific and Practical, 9 January, Conference – Petrozavodsk, International Center for Scientific Partnership, New Science, pp. 327-333.

MFOUTOU W., DIABANGOUAYA D.B. (2019). Bank erosion on the Mfilou river on Brazzaville, Larhyss Journal, No 39, pp. 299-311. (In French)

GANGUILLET E., KUTTER W.R. (1869). Research into the establishment of a new general formula for the uniform flow of water in canals and rivers, Zeitschrift des Oesterreichischen Ingenieur und Architekten-Vereines (Journal of the Austrian Association of Engineers and Architects), Vol. 21, Issue 1, pp. 6-25.

GURYEV A.P., KOZLOV D.V., KHANOV N.V., FARTUKOV V.A., NOVICHENKO A.I. (2015). Hydraulic studies of an anti-erosion coating - geomat grade Enkamat A 20, International scientific conference Scientific personnel support for food security in Russia, 2-4 December, Moscow, Reports of the Timiryazev Agricultural Academy, Publisher, Green Era, Issue 287, Vol. 2, pp. 358-363.

HADDAD H., GHOUALEM H. (2014). Physicochemical characterization of the waters of the Algiers coastal hydrographic basin, Larhyss Journal, No 18, pp. 155-167. (In French).

KHANOV N.V., ZHUKOVA T.Y., ALEKSEEV D.A. (2024). Laboratory studies of a coating made of composite geomat filled with crushed stone and reinforced with ryegrass, Journal of Land Reclamation and Hydraulic Engineering, Vol.14, No.4, pp. 403–417.

KHOMCHENKO Y.V. (2014). Stability of slopes and embankments reinforced with geotextile materials, Bulletin of Polotsk State University, No 16, pp. 54–59.

KURBANOV S.O., SOZAEV A.A., BALKIZOV A.V. (2020). Effective technical solutions for channel regulation small rivers and construction of reclamation water intakes, Science Education Practice proceedings of the International University Science Forum, September 30, Infinity Publishing Toronto, Canada, pp. 117–130.

KURBANOV S., SOZAEVA., SHOGENOV A., KARSHIEV A. (2021). Bioengineering systems for protection and improvement of urbanized areas of coastal and recreational zones, in the collection, In the collection, Innovative Technologies in Environmental Engineering and Agroecosystems, March 18-19, Nalchik, Russian Federation, E3S Web of Conferences 1st International Scientific and Practical Conference, pp. 30-35.

LONG A., MOKHTAR M., HALIM S., AHMED F. (2023). Fostering inclusive watershed management through Multihelix engagement model on micro hydropower electrification in Sabah, Malaysia, Larhyss Journal, No 56, pp. 7-24.

MANNING R. (1891). On the flow of water in open channels and pipes, Proceeding of Institution of Civil Engineers of Ireland, Vol. 20, pp. 161-206.

MEHTA D., ACHOUR B., PASTAGIA J., AZAMATHULLA H., VERMA S. (2023). Review of reservoir operation, Larhyss Journal, No 56, pp. 193-214.

MEZENNER N., BENKACI T., BERMAD A., DECHEMI N. (2022). Dam reservoir operation optimization using genetic algorithm and principal component analysis simulation model - case of dam Ghrib, Larhyss Journal, No 51, pp. 145-160.

MORSLI B., HABI M., BOUCHEKARA B. (2017). Study of marine intrusion in coastal aquifers and its repercussions on the land degradation by the use of a multidisciplinary approach, Larhyss Journal, No 30, pp. 225-237. (In French)

NGOUALA M.M., MBILOU U.G., TCHOUMOU M., SAMBA-KIMBATA M.J. (2016). Characterization surface water - groundwater aquifer in coastal watershed of the republic of Congo Loémé, Larhyss Journal, No 28, pp. 237-256. (In French)

PANCHAL S.L., SURYANARAYANA T.M.V. (2025). Optimized operation of a multipurpose reservoir by evolutionary algorithm for Panam reservoir project in eastern Gujarat, India, Larhyss Journal, No 61, pp. 31-52.

PAULO MONTEIRO J., COSTA MANUEL S. (2004). Dams' groundwater modelling and water management at the regional scale in a coastal mediterranean area (the southern Portugal region – Algarve), Larhyss Journal, No 3, pp. 157-169.

PAVLOVSKY N.N. (1937). Hydraulic Handbook, United Scientific and Technical Publishing House, Main editorial board of energy literature, Leningrad, p. 910.

QURESHI H.U., ABBAS I., SHAH S.M.H., TEO F.Y. (2024). Hydrologic evaluation of monthly and annual groundwater recharge dynamics for a sustainable groundwater resources management in Quetta city, Pakistan, Larhyss Journal, No 60, pp. 27-53.

REMINI B., BENSAFIA D. (2016). Siltation of dams in arid regions - Algerian examples, Larhyss Journal, No 27, pp. 63-90. (In French)

REMINI B. (2017). When two opposing ecosystem wet and dry bind by erosion phenomenon? case of the Sahara Desert and the amazon forest, Larhyss Journal, No 31, pp. 249-285. (In French)

REMINI B., BOUABIBSA R., MOUDJED K. (2019). Beni Haroun and Koudiat Acerdoune (Algeria): two large dams threatened by the phenomenon of siltation, Larhyss Journal, No 38, pp. 131-151. (In French)

RIAHI R., BELAID H., HATIRA A., BACCOUCHE S. (2020). Contribution to the study of runoff and erosion of low slope homogeneous hydrological units of a watershed of the middle valley of Medjerda Tunisia, Larhyss Journal, No 43, pp. 119-137.

TRIVEDI M., SURYANARAYANA T.M.V. (2023). An assessment of optimal operation policies for a reservoir using particle swarm optimization, Larhyss Journal, No 56, pp. 107-121.

VERMA S., SAHU R.T., PRASAD A.D., VERMA M.K. (2023). Reservoir operation optimization using ant colony optimization a case study of Mahanadi reservoir project complex Chhattisgarh – India, Larhyss Journal, No 53, pp. 73-93.

ZHUKOVA T.Y. (2022). Use of geosynthetic materials and geotextiles in construction, Journal Innovations, Science, Education, No 52, pp. 393-397.

ZHUKOVA T.Y., EREMEEV A.V., KHANOV N.V., SHODIEV B. (2023). Study of the possibility of application of anti-erosion coating - geomate with ground and sowing of permanent grasses, E3S Web Conferences, Open access proceeding in environment, energy, and earth sciences, Vol. 365.

ZHUKOVA T.Y., KHANOV N.V., CHERNYKH O.N., REDNIKOV S.N. (2024). Experimental studies of the roughness coefficient of a coating made of composite geomat filled with crushed stone, Journal Land Reclamation and Hydraulic Engineering, Vol. 14, No 2, pp. 260-274.