SLOPE STABILISATION BY GEOSYNTHETICS REINFORCED SOIL RETAINING WALLS. NUMERICAL VALIDATION OF PROPOSED USING ANALYTICAL METHODS

Lecturer PhD Eng. Cornel CIUREA[1], PhD Student Eng. Adrian GHENCEA[2], Msc Student Eng.Iuliana PAIU[3], Msc Student Eng. Aurel ISIP[4]

[1] *Civil Engineering Faculty, Ovidius University of Constanța, ciurea_68@yahoo.com, cornel.ciurea@365.univ-ovidius.ro*
[2] *Doctoral School of Applied Sciences, Ovidius University of Constanța, adrian.ghencea@allbim.net*
[3] *Master Student at Civil Engineering Faculty, Ovidius University of Constanța, iuliana.paiu@allbim.net*
[4] *Master Student at Civil Engineering Faculty, Technical University of Cluj-Napoca, aurel.isip@allbim.net*

Abstract. When it is necessary to carry out reinforcement or safety works for a slope, most often technical solutions such as reinforced concrete retaining walls, gabion walls, or various types of screens are used. All these technical solutions are widely utilized because they belong to the category of traditional solutions. However, recently, they have become uneconomical because they require a large volume of materials, labor, and result in long execution times.

In contrast to all these traditional solutions, the article aims to present the solution of reinforcement with reinforced earth retaining walls using geogrids. Beyond the functionality of reinforcement, the proposed technical solution must also offer several other important advantages, including reduced execution time, lower execution costs, compliance with environmental requirements, or meeting special aesthetic requirements (for reinforcing slopes near art works – bridges, viaducts, etc.). MSE (Mechanically Stabilized Earth) systems have a simple structure, consisting of the earth mass, geogrid reinforcement, and facades (usually made of reinforced concrete blocks or steel mesh).

To facilitate the choice of reinforced earth retaining walls as reinforcement solutions, instead of traditional technical solutions, the authors present, in the form of a case study, the steps to create an analytical model to determine the plane behavior of the MSE solution. The calculation model presented was created based on numerical methods commonly used by geotechnical design softwares.

Keywords: #retainingWall #geogrids #reinforcedEarthWithGeogrids #MSE #reinforcedEarthRetainingWall #numericalAnalysis.

1 Structure of Reinforced Earth Retaining Walls: Introduction and Technical Aspects.

A retaining wall is a complex system composed of functional subdivisions that contribute individually and collectively to the structure's performance. The components of such a retaining structure include: the fill behind the reinforced earth wall; the reinforced earth created by alternating layers of compacted soil and reinforcing elements; the natural soil surrounding the entire structure, including the foundation soil; the foundation and facade elements. The choice of the reinforcement system will consider the type of soil that needs to be improved [4].

Soil stabilization through reinforcement is often done on low cohesion fills with low plasticity (Ip<6%) or non-cohesive fills, granulometric limited to particles smaller than 250 mm, with a fine particle percentage of up to 15%. Reinforcement can also be applied to cohesive soil fills, but this requires special attention due to the chemical composition of clays, which can degrade the reinforcement. Thus, the use of these soils is conditioned by a chemical analysis of the soil and the use of an additional quantity of reinforcement to ensure satisfactory adhesion. Generally, the use of these types of fills is not recommended, especially in the case of geotechnical category 2 or 3 structures [1 ÷ 7].

The reinforcement system is established in full accordance with the soil in which it is embedded, ensuring an interaction mechanism for transmitting soil efforts to the reinforcement. For soil reinforcement, systems such as geosynthetic or even metal bands, sheets, or grids are used. Among geosynthetic elements, geogrids are most used for soil stabilization. In addition to the connection between the reinforcement and the soil layers, a connection will also be made between the reinforced system and the facade elements. The most frequently used elements in facade construction are blocks, which serve to anchor the reinforcements, ensure the spatial conformity of the slope, and have an aesthetic role.

2 Calculation and Verification Methods for the External Stability of MSE Walls

The design of MSE wall support structures considers a multitude of factors, such as location, operating conditions, geological, geographical, and geoclimatic conditions, as well as safety and stability considerations, along with economic and technological considerations. Consequently, creating such support structures requires direct adaptation based on the specific circumstances involved. This aspect significantly influences the design of reinforced earth walls, as soil behavior plays an essential role. Therefore, approaches in the specialized literature vary depending on the country of origin. As this type of mechanically stabilized wall is relatively recent in use, the formulation of clear design criteria is still under development.

2.1 Fundamental Principles of Admissibility: Standards and International Specialized Literature

The construction of MSE walls is regulated worldwide through standardized national norms, ensuring the stability and safety of structures. Eurocode 7 (EN 1997-1/2004) is based on the analysis of limit states (SLS & ULS), applying partial safety factors for materials, loads, and resistances. AASHTO LRFD uses a semi-probabilistic approach, experimentally calibrated, to balance safety and economic efficiency, emphasizing soil-reinforcement interaction and stability checks. BS 8006-1/2010 and CSA-S6-19 adopt principles like AASHTO, with additional focus on long-term monitoring and degradation prevention. [1] ; [8 ÷ 10]

2.2 Validation Methods through National Standards and Norms: Current Status in Romania

At the national level, currently, the design of reinforced earth retaining walls is standardized by NP075 – 2:2002 which presents a sum of stabilization solutions based on MSE technology. In practice these solutions have been applied on a large scale for road and bridges infrastructure works due to their sustainability and environmental positive impact. To optimize the technical solution, their design and verification are carried out in accordance with general design norms in addition to the ones presented in the national standard. In the design commonly used is stability analyses consider soil-reinforcement interaction by applying appropriate safety factors. For technical details regarding geosynthetic materials and calculation methods, it is necessary to consult complementary standards and specific guidelines from manufacturers.

Eurocode 7, within the analysis of ultimate limit states (ULS), imposes the verification of bearing capacity and local stability, considering critical situations caused by soil collapse and reinforcement loss. In the case of serviceability limit states (SLS), the analysis of deformations and displacements is required. Verifications will be carried out using the limit equilibrium method, along with the analytical method or even the finite element method [1 ÷ 7].

3 Dimensioning and Verification of Retaining Walls (MSE) through Comprehensive Calculation Methods: Integrating Theoretical Principles and Practical Rules in Analytical Modeling

This analysis aims to provide a clear perspective on the application of theoretical concepts in current practice, emphasizing the efficiency of using analytical models in evaluating stability and bearing capacity, to obtain relevant results.

In this study, we conducted a comparative analysis of slope stabilization solutions, comparing two distinct methods: mechanically stabilized earth reinforced with geogrid and a conventional solution represented by a gabion wall. Preliminary, we decided that the functionality of the slope does not penalize these solutions from an execution conditions perspective, with both approaches being reliable from a technological standpoint.

The comparison was made through the analysis of six calculation models, three of which involve reinforcement with geogrid and blocks, while the other three address a gabion retaining wall. The iterative calculation focused on alternating the height of the support structure, highlighting the mechanical behavior and efficiency of the adopted constructive solutions for heights of 4 meters, 8 meters, and 12 meters.

The design of these retaining walls was rigorously carried out using dedicated geotechnical software. Precise modeling of the stratigraphy allowed for capturing the actual behavior of the entire assembly and highlighted the interaction between the chosen support systems and the soil layers, in compliance with the norms imposed by the current design codes.

The first stage of modeling included defining the geometry of the walls, determining the dimensions, stratifying the soil, and distributing the loads. For retaining walls with geogrid and blocks, the positioning of the geogrids was optimized for a balance between stability and material consumption. The reinforced earth was modeled based on the strength parameters of each layer, and the selection of geogrids was made according to tensile strength and adhesion reduction coefficient. The concrete blocks served as a facade, stabilizing the reinforced fill and integrating the system.

The geotechnical parameters used in this analysis were derived from a specific geotechnical study and reflect the mechanical properties of the soil. To ensure the comparability of results and an objective evaluation of the analyzed solutions, these parameters were kept constant across all studied scenarios.

The type of soil considered in this study is presented in the table below, with the parameters for each layer being established based on the results of the geotechnical investigation.

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m^3]	γ_{su} [kN/m^3]	δ [°]
1	Umplutura din spatele zidului de sprijin		30.00	80.00	20.44	12.00	3.00
2	Umplutura antropică neomogena		10.00	10.00	17.00	9.00	3.00
3	AP loessoidă galben-cafenie cu intercalații galben roșcate		30.87	73.25	18.60	9.90	10.00
4	A cafeniu roșcată		23.60	124.75	20.22	10.60	8.00
5	A cafeniu deschis		26.58	89.54	19.67	10.60	9.00
6	A cafeniu roșcată glomerulară		26.16	66.80	20.72	10.90	9.00
7	A galben-verzuie glomerulară		23.77	136.56	21.06	11.30	8.00
8	A-AN galben roșcată		30.00	59.25	20.65	11.00	10.00
9	Nisip calcaros alb-gălbui în masă de calcar degradat		34.00	0.00	21.00	12.00	11.00
10	Calcar lumaşelic alb-gălbui, masiv, relativ dur, compact, dar cu goluri neuniform distribuite umplute cu Argilă cafeniu-roşcată – roşcată saturată		45.00	0.00	22.00	13.00	0.00
11	Bolovăniş calcaros lumaşelic alb-gălbui, de la îndesat la foarte îndesat, cu interspațiile umplute cu Nisip şi Pietriş calcaros lumaşelic alb-gălbui în masă de calcar lumaşelic degradat şi Argilă cenuşiu-verzuie saturată		45.00	0.00	22.00	13.00	0.00

Fig. 1. Basic soil parameters

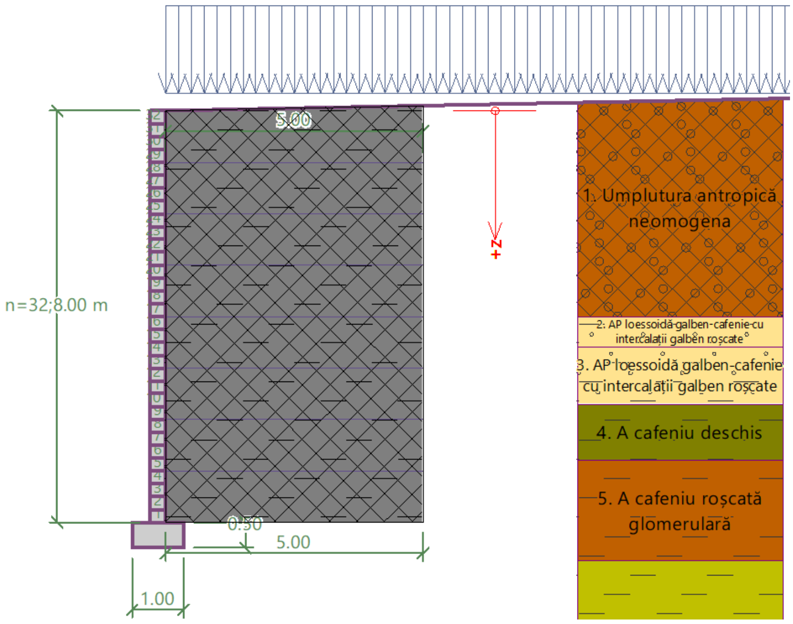


Fig. 2. Soil Stratification and Structure Conformation of the Retaining Wall as MSE Wall

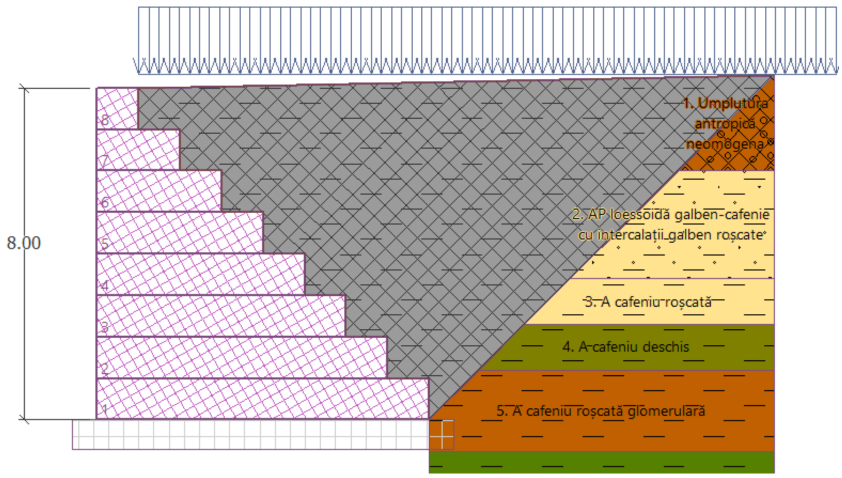
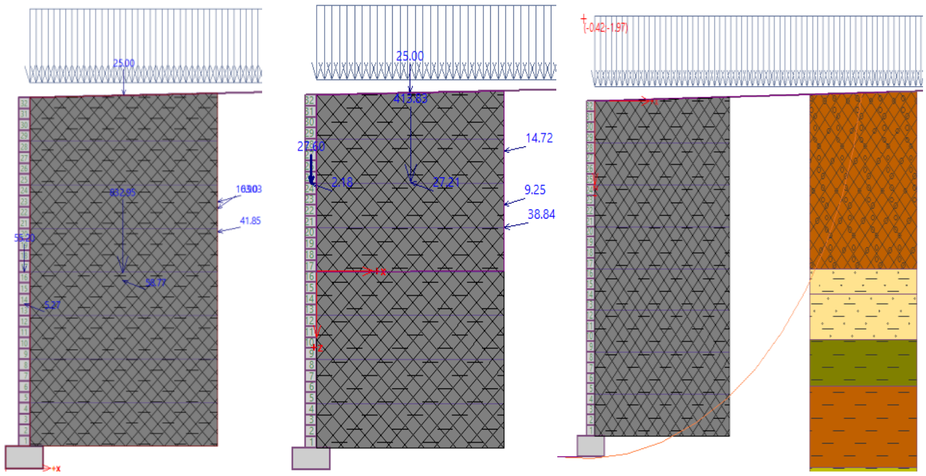


Fig. 3. Soil Stratification and Structure Conformation of the Retaining Wall as Gabion Wall

The verifications included the analysis of overturning and sliding stability, as well as internal stability by evaluating the interaction between soil and geogrid. Additionally, the sliding stability on the contact surface between the geogrid and soil was assessed, considering the interaction between the reinforcement and the compacted fill.

The bearing capacity of the foundation was evaluated by analyzing the contact pressure at the base of the wall and the eccentricity of the applied loads. [16 ÷ 17]

Parallel to the modeling of retaining walls with geogrid and blocks, three calculation models were developed for gabion retaining walls, with the same heights of 4 meters, 8 meters, and 12 meters. The purpose of this analysis was to compare the structural and economic performance of the two constructive solutions. The geometry definition for the gabion walls was based on structures composed of superimposed modular elements, with a stepped design. [14 ÷ 15]



a b c

Fig. 4. Verification of: a- overturning; b- slip on georeinforcement; c- global slope stability analysis for a reinforced earth retaining wall.

Tabel 1. Summary Table of Stabilizing and Destabilizing Efforts for MSE Walls

MSE Walls						
Type of check	**Destabilizing Effort**			**Stabilizing Effort**		
	4m	8m	12m	4m	8m	12m
Overturning stability [kNm/m]	35.21	506.40	1541.49	189.75	2796.57	5391.74
Slip [kN/m]	87.46	103.52	217.35	106.15	548.92	1112.93
Bearing capacity [kPa]	42.31	79.76	138.45	360.00	360.00	360.00
Slip along geo-reinforcement [kN/m]	32.31	63.54	126.57	71.09	412.28	719.83
Tensile strength	4.99	11.17	17.35	21.50	21.50	21.50

[kN/m]						
Pull out resistance [kN/m]	4.99	11.17	17.35	22.21	22.21	22.21
Slope stability (Bishop)	FS = 1.71 > 1.00	FS = 3.17 > 1.00	FS = 2.24 > 1.00	FS = 1.71 > 1.00	FS = 3.17 > 1.00	FS = 2.24 > 1.00

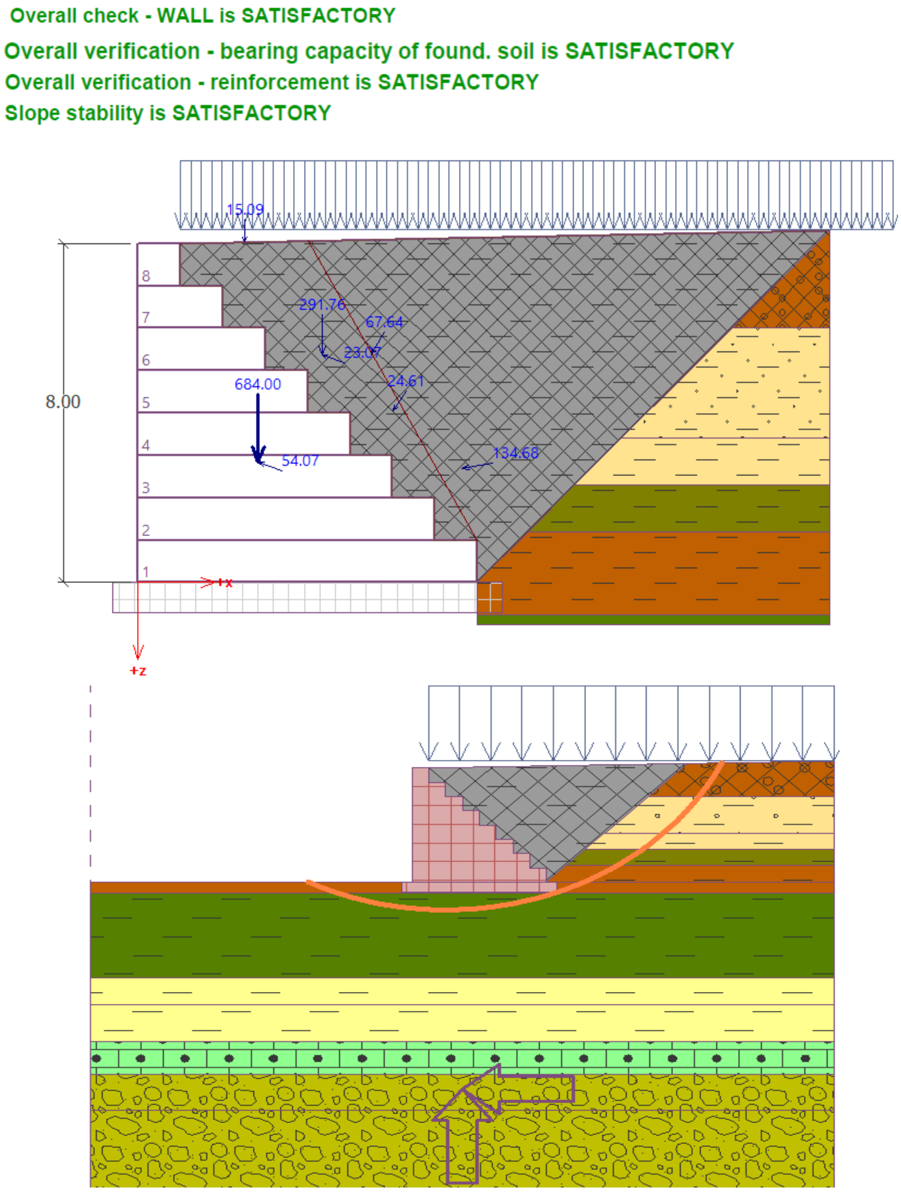


Fig. 5. Verification of: a- overturning and sliding; b- global slope stability analysis for a gabion retaining wall.

Tabel 2. Summary Table of Stabilizing and Destabilizing Efforts for Gabion Walls

Gabion Walls						
Type of check	**Destabilizing Effort**			**Stabilizing Effort**		
	4m	8m	12m	4m	8m	12m
Overturning stability [kNm/m]	117.38	861.70	2819.82	523.11	3773.99	13740.58
Slip [kN/m]	68.20	254.42	558.26	198.58	747.12	1738.41
Bearing capacity [kPa]	91.78	183.32	272.00	360.00	360.00	360.00
Bearing capacity against transverse pressure [kPa]	5.43	28.41	42.02	45.00	45.00	45.00
Slip for joint [kN/m]	5.60	196.83	471.28	14.56	637.63	1615.47
Overturning stability for joint [kNm/m]	2.54	584.76	2184.39	9.37	2508.52	10385.85
Joint btw. blocks [kN/m]	5.43	28.41	42.02	95.00	95.00	95.00
Slope stability (Bishop)	Factor of safety = 4.16 > 1.00	Factor of safety = 4.33 > 1.00	Factor of safety = 3.35 > 1.00	Factor of safety = 4.16 > 1.00	Factor of safety = 4.33 > 1.00	Factor of safety = 3.35 > 1.00

Overall check - WALL is SATISFACTORY
Bearing capacity of foundation is SATISFACTORY
Joint for overturning stability is SATISFACTORY
Joint for slip is SATISFACTORY
Transverse pressure check is SATISFACTORY
Joint between blocks is SATISFACTORY

The summary tables are intended to provide an overview of both the applied design forces and the corresponding resistant forces, serving as a basis for validating the dimensions determined for the structural elements analyzed.

The analysis of the proposed cases confirms that, as the height of the slope increases, the structure's geometry changes. For gabion walls, this modification results in an exponential increase in the need for materials, labor, and workmanship, which significantly impacts the costs and complexity of execution.

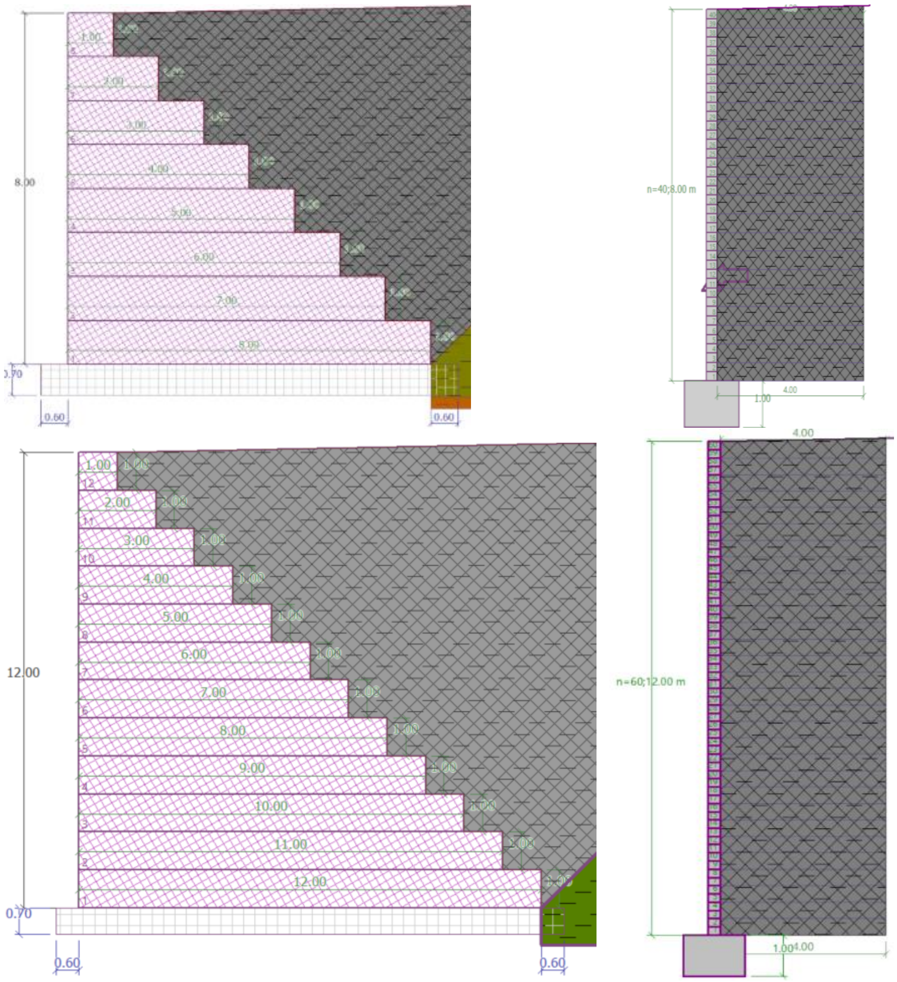


Fig. 6. The Evolution of Cross-sectional Dimensions with Increasing Slope Height for: a- Gabion Walls; b- MSE Walls

4 Conclusions

Determining the optimal solution involves a comparative evaluation of the available options. Choosing a specific system requires a careful analysis of the determining factors to ensure a balance between performance and efficiency. The analysis of the studied cases highlights the essential differences between the two proposed solutions. Their configuration shows that, from the concept stage, the constructive approaches are fundamentally different. The dimensions of Mechanically Stabilized Earth (MSE) extend over a wider width due to the need for soil reinforcement, while the Gabion Wall (GW) develops predominantly vertically, with a support base that increases with height.

Excavations are a crucial comparison criterion. For MSE walls, the volume of excavation is significant but increases linearly. For gabion walls (GW), it increases exponentially with height due to the increasingly larger dimensions of the elements.

The quantity and diversity of materials influence the decision on the constructive solution. MSE uses geogrid, blocks, anchors, and a compact concrete foundation, while GW consists of metal gabions with aggregates, anchors, and a significantly larger reinforced concrete foundation. The increase in height affects costs and execution differently: linearly for MSE and exponentially for GW.

Another criterion strongly influenced by the dimensions of the structure is the technological one. The transportation of gabions requires heavy machinery, welding equipment, and the making of connections, as well as a large workforce consisting of qualified personnel for these works. In contrast, the materials used in the MSE solution are lightweight and do not require special transportation. Applying geogrids is an iterative and lengthy process but does not require many skilled workers or an extensive workforce.

Finally, sustainability criteria play an important role in choosing the optimal solution. Building a gabion retaining wall requires the use of aggregates enclosed in metal cages. If these materials are not locally or nearby available, their transportation can generate significant additional costs, especially due to their large size and weight. In contrast, the geogrids used in the MSE solution are easier to transport and have high market availability. Obtaining raw materials for this solution is easier, involving lower logistical costs compared to gabion walls.

Comparing the solutions, the reinforced earth wall, although seemingly more technologically complex, maintains its geometry relatively constant regardless of slope changes. In contrast, gabion walls require significant adjustments in dimensions as the slope increases, which involves additional stabilization efforts, including extending the structure.

Therefore, we can conclude that the use of reinforced earth retaining walls with geogrids is not the most efficient solution for relatively small structures (< 4m) due to the execution technology, which can generate high costs. However, for medium and large support structures (> 8m), this solution becomes extremely advantageous, offering considerable savings in time and materials due to a linear increase in costs compared to the exponential growth of material volume, execution time, and labor required for constructing a gabion structure.

References

1. European Committee for Standardization: *Eurocode 7: Geotechnical Design – Part 1: General Rules*. EN 1997-1:2004. Brussels (2004).
2. European Committee for Standardization: *Eurocode 7: Geotechnical Design – Part 2: Ground Investigation and Testing*. EN 1997-2:2007. Brussels (2007).
3. Ministerul Lucrărilor Publice, Transporturilor și Locuinței: *Normativ pentru utilizarea materialelor geosintetice la lucrările de construcții*. Indicativ NP 075-02. București (2002).
4. Ministerul Transporturilor, Construcțiilor și Turismului: *Ghid privind proiectarea structurilor de pământ armat cu materiale geosintetice și metalice*. Indicativ GP 093-06. București (2006).
5. Ministerul Dezvoltării Regionale și Administrației Publice: *Normativ privind proiectarea și execuția lucrărilor de terasamente pentru drumuri, aerodromuri și platforme industriale*. Indicativ NP 120:2014. București (2014).
6. Ministerul Transporturilor: *Normativ privind utilizarea geosinteticelor la ranforsarea structurilor rutiere cu straturi asfaltice*. Indicativ AND 592/2014. București (2014).
7. Ministerul Dezvoltării Regionale și Turismului. *NP 124:2010 - Normativ privind proiectarea geotehnică a lucrărilor de susținere*. București: MDLPA, 2010.
8. American Association of State Highway and Transportation Officials (AASHTO): *LRFD Bridge Design Specifications*. 9th Edition, Washington, D.C. (2020).
9. British Standards Institution (BSI): *BS 8006-1:2010 - Code of practice for strengthened/reinforced soils and other fills*. London, UK (2010).
10. Canadian Standards Association (CSA): *CSA S6:19 - Canadian Highway Bridge Design Code*. Toronto, Canada (2019).
11. Barros, P.L.A.: *Gawac 3.0 – Gabion Wall Design, Reference Manual*. V.1, Jun.2019.
12. Santos Junior, P., Mazzon, N., Mahajan, R.R., Di Pietro, P.: *GAWAC 3.0 – Gabion Wall Design, GSC Manual*. Version 1.0, April 2019.
13. Elis Pavaje: *Keystone Block Retaining Walls*. Technical Brochure. Petrești, Romania (2024).
14. GEO5 – „*Help - Gabion*”, https://www.finesoftware.eu/help/geo5/en/backfill-05/
15. GEO5 – „*Help - Gabion*”, https://www.finesoftware.eu/help/geo5/en/stability-05/
16. GEO5 – „*Help - MSE Wall*”, https://www.finesoftware.eu/help/geo5/en/reinforcement-02/
17. GEO5 – „*Help - MSE Wall*”, https://www.finesoftware.eu/help/geo5/en/stability-10/