EVALUATION OF THE APPLICATION EFFECTIVENESS OF SELF-MADE GALVANIZED STEEL MESH WHEN APPLYING THE CONSTRUCTION OF RETAINING WALLS AT THE TRAN THI LY OVERPASS INTERSECTION IN DA NANG CITY

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Abstract - The article introduces self-made galvanized steel mesh (SGSM) from reinforcement type CB 300V. Numerical simulation of retaining walls at the Tran Thi Ly overpass intersection in Da Nang City when using SGSM and three other popular types of reinforcement, and calculating the construction cost of the wall when using these types of reinforcement. The results show that using SGSM is more technically and economically efficient than using other types of reinforcement currently being imported. Specifically, after wall construction and when loading 400 kN/m^2, it shows that using SGSS, the factor of safety is higher (Fs=3.85 and Fs=1.34), mobilizing more tensile force in the reinforcement (13.21% and 88.65%) and lateral displacement of the wall facing is smaller (Δ=1.961 mm and Δ=32.01 mm), the total wall construction cost are 20.24%, 5.48% and 1.76% lower than polymeric reinforcement strip, polyester geotextile mesh and galvanized flat steel strip.

Key words - Self-made galvanized steel mesh (SGSM); mechanically stabilized earth walls (MSE walls); factor of safety; tensile force in the reinforcement; lateral displacement of the wall facing; Flac 2D

1. Introduction

Currently, the construction of MSE walls requires importing reinforcement from abroad at high costs, as suppliers demand involvement in design and construction to collect royalties. Meanwhile, Central Vietnam has an abundant supply of galvanized steel reinforcement materials, offering a wide variety and meeting the mechanical specifications required for reinforcement in MSE walls. With this available reinforcement material, it will be easy to manufacture the reinforcement, easy to construct, and can use available equipment and human resources to construct the MSE walls [1]. To reduce construction investment costs, contribute to promoting the ability to be self-sufficient in construction technology, the development of domestic enterprises, and reduce the corrosion of reinforcement in the wall, the group of authors has researched and proposed to use SGSM as reinforcement for MSE walls.

There are numerous studies on MSE walls involving experimental models, real constructions, and numerical models to investigate their performance throughout the construction exploitation period. H. Vidal and F. Schlosser [2], R. T. Murray and Farrar [3], identified that the failure surface in reinforced soil blocks is characterized by a curved shape that intersects the points of maximum tensile force in the reinforcement layers. In addition, Beenish Jehan Khan [4], Le Hong Long [5], Hamzeh Ahmadi, et al. [6] developed diagrams illustrating the tensile forces and friction coefficients between the soil and the reinforcement in each layer, which allowed them to ascertain the horizontal displacement of MSE walls using a scaled-down experimental model. Yan Yu [7] utilized Flac software to demonstrate that the elastic modulus of the wall base layer and the fill material, along with the shear resistance of the fill and the shear strength of the reinforcement, all have a proportional impact on the tensile forces within the reinforcement layers. Additionally, Le Hong Long [5] and Lalinda Weerasekara, et al. [8] compared the distribution of tensile forces in the reinforcement and the displacement of the wall. Their studies, based on the Flac numerical model and miniature experimental models, revealed similarities in the results obtained.

This paper utilizes Flac software to assess the stability of MSE walls and to compare the economic efficiency of using SGSM against other types of reinforcement. The research is focused on MSE walls located at the Tran Thi Ly overpass intersection in Da Nang city.

2. Self-made galvanized steel mesh

The SGSM in this study is in the form of a mesh and arranged with ribs. The meshes are designed with dimensions as shown in Figure 1 (the mesh size is suitable for the structural requirements according to the regulations of current standards): FHWA-NHI 10-025 (2009) [9], BS 8006-1:2010 [10], TCVN 11823-11:2017 [11], AFNOR EN P94-270:2020) [12]. Using CB 300V construction steel, type Φ10 to manufacture the reinforcement mesh including longitudinal steel bars, transverse steel bars, and ribs.

The strength parameters of the steel bars provided by the manufacturer include: tensile strength is 490 ÷ 608 N/mm^2 (satisfying greater than 450 N/mm^2 according to TCVN 1651-2:2018 [6]); yield strength is 375 N/mm^2 (> 300 N/mm^2 [13]); tensile failure strain is 19%. The length of the reinforcement bars was L = 3.8 m. The vertical spacing between the reinforcement layers was S_v = 0.8 m (5 reinforcement layers along the height of the wall H = 4 m). In each layer, 4 longitudinal steel reinforcement bars were installed with a space of 0.375 m (S_h = 0.375 m). In addition, the horizontal spacing between the reinforcement bars (the transverse direction) was 0.5 m. (> 0.15 m, so the anchorage force of the reinforcement consists of the friction force on the longitudinal bars and the passive resistance of the soil on the side of the transverse bars [14]). The 3 cm high ribs were bonded at the reinforcement mesh to enhance soil-reinforcement interaction, as shown in Figure 1.

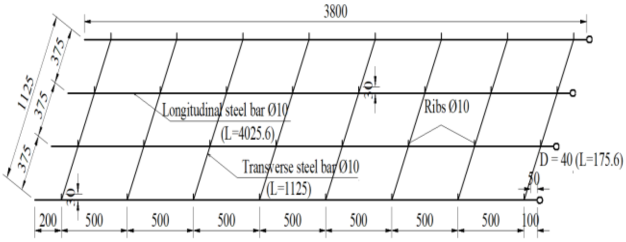


Figure 1. *Design of the self-made galvanized steel mesh*

Furthermore, to enhance corrosion resistance for the reinforcement, the steel bars were galvanized by a zinc layer of 70 µm thickness [1]. The SGSM was rigidly connected to the facing panels. SGSM has been experimented on full-scale models and ensures load capacity and corrosion resistance during service life [15].

3. Evaluation of the application effectiveness of SGSM when applying the construction of retaining walls at the Tran Thi Ly overpass intersection in Da Nang City

To see the effectiveness of using SGSM, this study conducted numerical simulations and determined the factor of safety, tensile force in the reinforcement and lateral displacement of the wall facing at the Tran Thi Ly overpass intersection in Da Nang city in 4 cases using 4 different types of reinforcements. In addition, this study calculated the cost of wall construction when using these 4 types of reinforcement to have a basis for comparison and evaluation. Case 1: using polymeric reinforcement strip (used for design and construction) [16]; Case 2: using polyester geogrid mesh (reinforcement type is widely used); Case 3: using galvanized flat steel strip (reinforcement type is widely used); Case 4: using self-made galvanized steel mesh - SGSM (research by the author group).

3.1. Introduce the MSE wall section in the study

MSE walls at the Tran Thi Ly overpass intersection in Da Nang City have been designed, constructed, and put into use. According to the technical design documents approved by the Department of Transport of Da Nang City, the MSE wall is built on the road leading to the bridge, from the first abutment (KM0+363.03 to KM0+427.84) to the second abutment (KM0+619.25 to KM0+683.06). The length of the wall at each bridge abutment is 63.81 m, height H = (2.3 ÷ 5.2) m. The reinforcement used to build the wall is polymeric reinforcement strips [16]. In this paper, the wall section to be simulated in Flac 2D software is taken from KM0+424.93 to KM0+426.43 (right side of the bridge abutment) from Rong bridge to Tien Son bridge, the wall height is H = 4 m and the vertical surface is arranged with reinforcement as shown in Figure 2.

3.2. Numerical simulation to calculate the factor of safety, tensile force in the reinforcement, and lateral displacement of the wall facing

The paper uses Flac 2D software to calculate the factor of safety, tensile force in the reinforcement, and lateral displacement of the wall facing in 4 cases using the various reinforcements mentioned above. Flac 2D (or 3D) software is based on the Finite Difference Method theory applied to continuous environments to simulate planar problems (or spatial problems) in the field of geotechnical engineering (soil/rock environment). Flac is a software with the advantage of quickly and accurately solving large deformation problems and nonlinear behavior [17, 18]. This is open software, integrating 12 material behavior models and structural elements of beams, anchors, and shells,... Flac users can integrate additional material models and other structural elements. Flac analyzes and simulates static and dynamic problems, and thermal and magnetic problems [17]. Therefore, Flac 2D software is chosen to simulate the MSE wall in this study.

The geometric dimensions of the wall, the backfill soil properties, and the aggregate density in the four cases are declared and simulated the same as the technical design drawings that have been built [16]. Simulate a wall height H = 4 m (equivalent to the height of 3 wall panels: 2 panels x 1.6 m + 1 panel x 0.8 m), and arrange 5 layers of reinforcement in the wall, each layer is 0.8 m apart. The length of the reinforcement layers varies from the foot of the wall to the top of the wall as shown in Figure 2. Below the retaining wall foundation is a 5 m thick layer of soil. The parameters of the backfill soil, reinforcement, and wall panels declared in the Flac numerical model are presented in Tables 1 to 2.

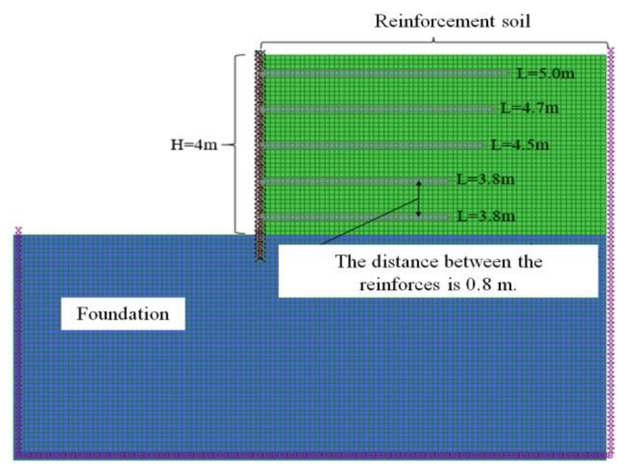


Figure 2. *Geometry simulation of 4 m high MSE wall*

- Wall panels: T-shaped wall panels are 160 mm thick and have 20 mm architectural edges, total wall thickness is 180 mm, made of concrete compacted by vibrating method, produced in a concrete mixing plant [16].

- Backfill soil is in the form of well-graded granules, does not contain organic matter, and meets the regulations for use as reinforced backfill soil according to current standards. The soil under the wall foundation is compacted with K98 [16].

- Reinforcement: Use 4 types of reinforcement as mentioned above.

- The apparent friction coefficients for the steel reinforcement and backfill interfaces were calculated based on the suggestion of current standards [9, 10, 12, 19]. For Polymeric reinforcement strip and polyester geotextile mesh, the value of f* is as per the technical design description. For metal reinforcement, f* is determined as per the formula (1) ÷ (3) [9, 10, 12, 19].

$$\text{If } z > z_0 = 6 \text{ m}; \quad f^* = \tan\varphi \qquad (1)$$

$$\text{If } z \leq z_0 = 6 \text{ m}; \quad f^* = f_o^*(1 - z/z_o) + (z/z_o)\tan\varphi \qquad (2)$$

$$f_o^* = 1.2 + \log_{10}(C_u) \qquad (3)$$

Where: f* and fo* are the apparent friction coefficients for the steel reinforcement and backfill interfaces; C_u is the coefficient of uniformity of the backfill soil; z is the depth of the reinforcement layers from the top of the wall, z_0 = 6 m; φ is the friction angle of the backfill soil. Table 1 and Table 2 illustrates the properties of backfill-reinforcement interactions and facing panel-backfill interactions.

- The interface between the backfill soil and concrete facing panel was modeled using the values suggested by Huang, et al. [20] and Huang, et al. [21]. In detail, the friction angle between the soil and concrete panel was 260; the interface normal stiffness was 2.4 MPa/m and the shear stiffness was 2.4 MPa/m.

Table 1. *The MSE model parameters in FLAC*

Parameter	Unit	Value
Concrete panel		
Width	m	0.18
Height	m	1.6
Length	m	1.5
Young's modulus	Pa	$2x10^{11}$
Compressive strength of concrete	MPa	35
Foundation soil		
Unit weight, γ_{Found}	kg/m^3	2100
Friction angle, φ_{Found}	degrees	24.5
Cohesion, c_{Found}	Pa	45000
Bulk modulus	Pa	$4.39x10^{10}$
Shear modulus	Pa	$3.02x10^{10}$
Backfill soil		
Unit weight, γ_{soil}	kg/m^3	2100
Friction angle, φ_{soil}	degrees	34
Cohesion, c_{soil}	Pa	2000
Bulk modulus	Pa	10^7
Shear modulus	Pa	$6x10^6$

Table 2. *Technical parameters of reinforcement in 4 calculation cases and interface properties*

Parameter	Unit	Polymeric reinforcement strip	Polyester geotextile mesh	Galvanized flat steel strip	Self-made galvanized steel mesh
Geometrically					
Length	m	3.8; 3.8; 4.5; 4.7; 5			
Steel bar thickness	m	0.0017	0.0015	0.004	0.010
Calculation width	m	1.5	1.5	1.5	1.5
Number of longitudinal bars per calculation width	strip	4	4 (1 mesh)	4	4 (1 mesh)
Mechanically					
Young's modulus	Pa	$9x10^{10}$	$9x10^{10}$	$2.1x10^{10}$	$2x10^{11}$
Tensile strength	N/m	40000	42000	50000	49000
Tensile failure strain	%	0.218	0.216	0.191	0.189
Shear stiffness	N/m^2	$4x10^5$	$4x10^5$	$7x10^6$	$2x10^7$
Backfill soil - Concrete panel					
Normal stiffness	Pa/m	$2.4x10^6$			
Shear stiffness	Pa/m	$2.4x10^6$			
Friction angle	degrees	26			
Backfill soil- Steel reinforcements					
Shear stiffness	N/m^2	$4x10^5$	$4x10^5$	$7x10^6$	$2x10^7$
Cohesion	N/m	$7x10^4$	$7x10^4$	$8x10^5$	$1x10^5$
Initial apparent friction coef (f)*					
Layer 5		0.675	0.675	2.031	2.031
Layer 4		0.675	0.675	1.660	1.660
Layer 3		0.54	0.54	1.381	1.381
Layer 2		0.54	0.54	1.098	1.098
Layer 1		0.54	0.54	0.816	0.816

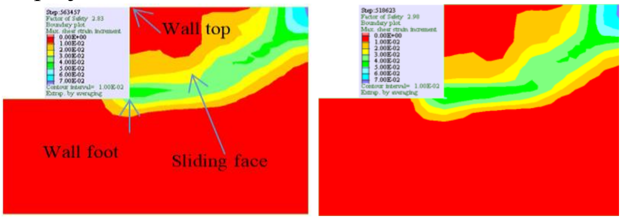
3.3. The results of numerical simulation

Numerical simulation results calculate the factor of safety, tensile force in the reinforcement, and lateral displacement of the wall facing in 4 cases. The results and graphs are similar to the research results of R. T. Murray and Farrar [3], Beenish Jehan Khan [4], Le Hong Long [5], Hamzeh Ahmadi [6], Lalinda Weerasekara [8].

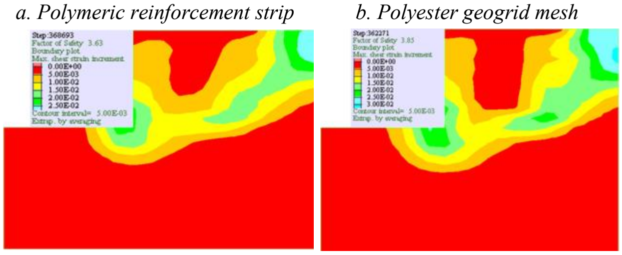
From Figure 3 ÷ 8 and Table 3, after construction and at a load level of 400 kN/m^2, using SGSM gives a higher factor of safety (F_s = 3.85 and F_s = 1.34), mobilizes more tensile force in the reinforcement (13.21% and 88.65%) and smaller lateral displacement of the wall facing (Δ = 1.961 mm and Δ = 32.01 mm) compared to the other three cases.

The results of the study through numerical simulation show that: After construction, the bottom reinforcement layer has the largest tensile force in the reinforcement, at a load level of 400 kN/m^2 (15 ÷ 20 times the design load), the top reinforcement layer has the largest tensile force in the reinforcement. Figures 5 and 6 show the distribution of tensile force in the bottom reinforcement layer and the top reinforcement layer when using the above 4 types of reinforcement.

The article calculates a load level of 400 kN/m^2. At this load level, using SGSM results in a safety factor (Fs) of 1.34. Additionally, the lateral displacement of the wall facing is 32.01 mm, which is less than the allowable limit of 40 mm. Meanwhile, using polymeric reinforcement strip gives a safety factor (Fs) of 1.14 and a horizontal displacement of 205.3 mm, which is more than the allowable limit of 40 mm. If the applied load exceeds 400 kN/m², utilizing SGSM will result in the MSE wall losing stability in this study. In fact, the project is being utilized with the load within the design load range, ensuring that the project remains safe and stable.

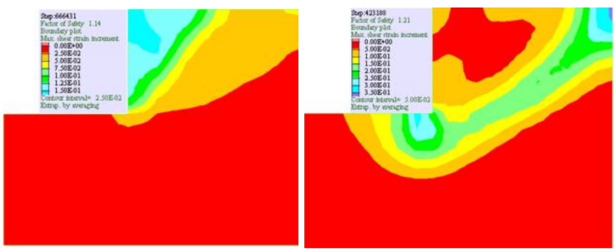


a. Polymeric reinforcement strip b. Polyester geogrid mesh

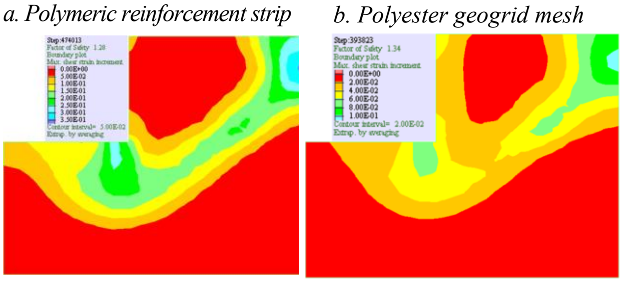


c. Galvanized flat steel strip d. Self-made galvanized steel mesh

Figure 3. *The factor of safety of the wall after construction from numerical simulation*

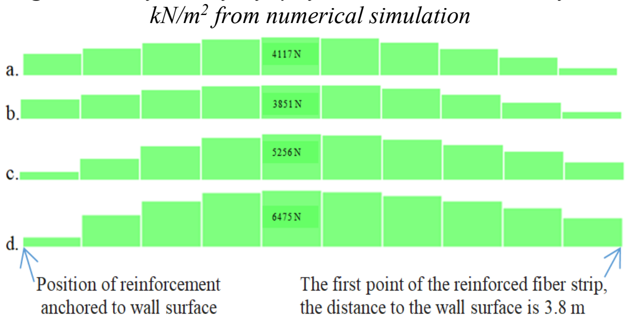


a. Polymeric reinforcement strip b. Polyester geogrid mesh



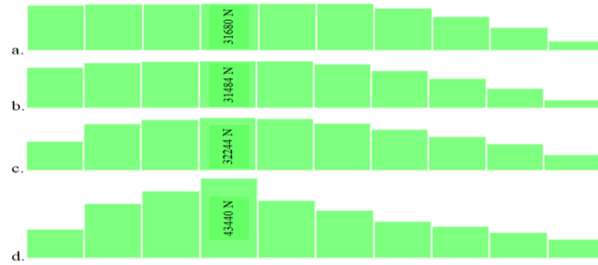
c. Galvanized flat steel strip d. Self-made galvanized steel mesh

Figure 4. *The factor of safety of the wall at a load level of 400 kN/m² from numerical simulation*



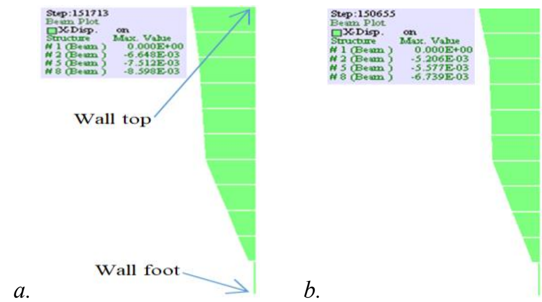
a. Polymeric reinforcement strip; b. Polyester geogrid mesh; c. Galvanized flat steel strip; d. Self-made galvanized steel mesh

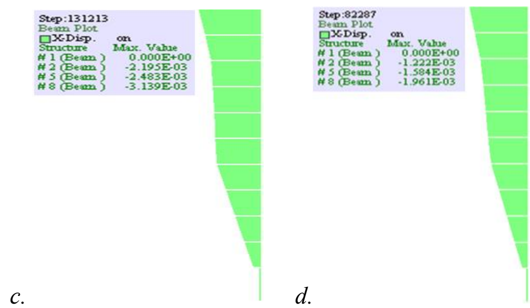
Figure 5. *Graph of tensile force distribution in the bottom reinforcement layer (after construction)*



a. Polymeric reinforcement strip; b. Polyester geogrid mesh; c. Galvanized flat steel strip; d. Self-made galvanized steel mesh

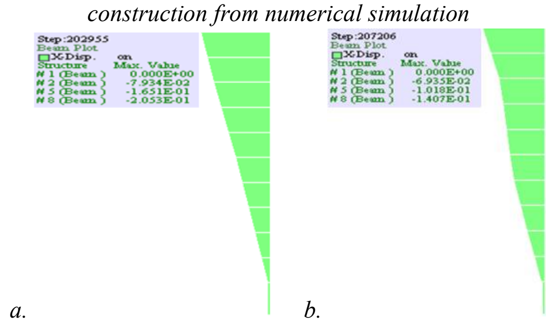
Figure 6. *Graph of tensile force distribution in the top reinforcement layer (at a load level of 400 kN/m²)*

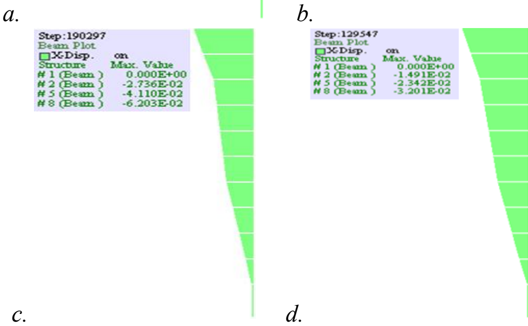




a. Polymeric reinforcement strip; b. Polyester geogrid mesh; c. Galvanized flat steel strip; d. Self-made galvanized steel mesh.

Figure 7. *Lateral displacement of the wall facing after construction from numerical simulation*





a. Polymeric reinforcement strip; b. Polyester geogrid mesh; c. Galvanized flat steel strip; d. Self-made galvanized steel mesh

Figure 8. *Lateral displacement of the wall facing at a load level of 400 kN/m² from numerical simulation*

Table 3. *Summary the factor of safety, tensile force in the reinforcement, and lateral displacement of the wall facing in 4 cases*

	Polymeric reinforcement strip	Polyester geotextile mesh	Galvanized flat steel strip	Self-made galvanized steel mesh
The factor of safety Fs				
After construction	2.83	2.98	3.63	3.85
Loading 400 kN/m^2	1.14	1.21	1.28	1.34
Maximum tensile force in the reinforcement (N)				
Before construction	40 000	42 000	50 000	49 000
After construction	4117	3851	5256	6475
Loading 400 kN/m^2	31680	31484	32244	43440
Lateral displacement of the wall facing (mm)				
Permissible value	40 mm			
After construction	8.598	6.739	3.139	1.961
Loading 400 kN/m^2	205.3	140.7	62.03	32.01

3.4. Calculate the cost of wall construction

The cost of wall construction is calculated based on the approved unit price and calculation table provided by the technical design and construction unit. [16]. Tables 4 ÷ 5 are unit prices, summarizing the results of calculating the cost and the difference in construction costs of MSE walls for bridge abutment 1 and bridge abutment 2 when using the 4 types of reinforcement above. From Table 5, the total cost of MSE wall construction when using SGSM is lower than those using polymeric reinforcement strip, polyester geogrid mesh, and galvanized flat steel strip by 20.24%, 5.48%, and 1.76% respectively.

Choosing SGMS will be cheaper than galvanized flat steel strip by 1.76% of the total wall construction cost (including material and labor costs). If galvanized flat steel strip is chosen, the reinforcement will need to be imported from abroad, and the supplier will require involvement in the design and construction processes to collect copyright fees. This means that Vietnamese investors will be reliant on the reinforcement suppliers, and the construction costs will likely rise even more, not just by 1.76% due to the additional copyright fees.

Table 4. *Unit price of 4 types of reinforcement*

Case	Types of reinforcement	Unit	Unit price (VNĐ)	Note
1	Polymeric reinforcement strip	m	180,000	
2	Polyester geogrid mesh	m^2	190,000	The technical design unit has provided [16]
3	Galvanized flat steel strip	m	210,000	
4	SGSM	m	12,600	According to the price list of Vietnam-Japan steel in Da Nang

Table 5. *Compare the cost of constructing MSE walls when using different types of reinforcement*

Types of reinforcement	Total cost of wall construction (VNĐ)	Cost of materials used for reinforcement (VNĐ)	Unit price for 1m^2 of reinforcement (VNĐ)	Unit price of reinforcement for 1m^2 of construction when the project is completed (VNĐ)
MSE wall construction costs for bridge abutment 1 and bridge abutment 2				
Polymeric reinforcement strip	6,577,279,345	1,836,982,800	2,161,035	424,764
Polyester geogrid mesh	5,550,220,229	821,695,470	947,239	190,000
Galvanized flat steel strip	5,340,067,192	614,334,000	302,490	142,052
SGSM	5,246,304,672	464,010,976	1,827,785	107,293
The cost difference between types of reinforcement compared to Self-made galvanized steel mesh				
Polymeric reinforcement strip	1,330,974,673 *(20.24%)*	1,372,971,824 *(74.74%)*	333,250 *(15.42%)*	317,471 *(74.74%)*
Polyester geogrid mesh	303,915,557 *(5.48%)*	357,684,494 *(43.53%)*	-880,546 *(-92.96%)*	82,707 *(43.53%)*
Galvanized flat steel strip	93,762,520 *(1.76%)*	150,323,024 *(24.47%)*	-1,525,295 *(-504.25%)*	34,759 *(24.47%)*

4. Conclusion

Compared with two cases of using soft reinforcement (polymeric reinforcement strips, polyester geogrid mesh), using SGSM brings outstanding results both technically and economically. Besides, the construction cost difference between using galvanized flat steel strips and SGSM is not much, but using SGSM is still more technically effective (higher factor of safety, mobilizing more tensile force in the reinforcement, lateral displacement of the wall facing is smaller), and promote self-reliance in production technology, construction techniques and the development of domestic enterprises.

SGSM can be applied to MSE walls in the construction of bridges, roads, railways, coastal works (seaports, dams), civil works, airports or to prevent landslides on high slopes... However, for each type of construction when using MSE walls, it is necessary to experiment, calculate, and evaluate the ability to exploit SGSM to choose the diameter, and steel strength, and arrange the reinforcement mesh with different sizes and distances (ensuring the structural requirements according to the prescribed standards).

In addition, the supply of construction reinforcement materials in Vietnam is very diverse, fulfilling the mechanical specifications required for rigid reinforcement used in MSE walls. Utilizing SGSM facilitates the manufacturing of reinforcement mesh, simplifies construction, and allows for the use of readily available equipment and manpower, ensuring the effective building of MSE walls from both technical and economic perspectives.

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