Application of geogrid reinforced earth wall structure in roadway construction passing through mountainous terrain in Northern Vietnam - Experience has been successfully applied on the route connecting Bac Kan city to Ba Be lake

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ABSTRACT

The retaining wall is one of the major and breakthrough developments in the field of construction related to the construction of anti-erosion embankments, taluy roof sliding, application as a city bridgehead with a 90-degree slope roof, embankment on the riverbank, coast, upgrading and expanding the road surface towards the negative taluy roof when limited in area... Currently, the types of retaining walls with core in Vietnam are quite widely used and diverse in terms of structure. This paper focuses on the analysis of the effectiveness of using reinforced earthen walls in traffic roads in order to make full use of the excavation material and reduce the volume of excavation of the taluy yang roof. In addition, the primeval forest environment around the project can be preserved. During the construction process, technical requirements have been achieved, selected for calculation and a reference project for road structures passing through mountainous areas with large horizontal slopes.

Keywords: Reinforced Soil Slope (RSS), Geogrid, reinforced soil walls, Triple-twist hexagonal steel mesh, green structure, vegetation Slope stabilization.

1 INTRODUCTION

Rugged terrain: The Bac Kan – Ba Be area has a large slope, many cliffs and deep valleys, requiring an effective slope stabilization solution.

Weak geology: The surface soil is easily saturated with water, especially in the rainy season, leading to a high risk of landslides.

Environmental protection: Requirements to minimize the impact on the natural landscape and ecosystem around Ba Be Lake (ASEAN heritage).

When building traffic infrastructure, these areas follow the traditional plan of digging into the mountains to build roads, with this design, the roof of the taluy yang is often dug very high (20m-50m) and must be reinforced with anchors, increasing the cost and construction time. With the requirement to reduce project costs and reduce the volume of excavation affecting forest soil, the design unit has researched a solution to push out the heart of the gland to embankment on the negative taluy side, limiting the digging of the taluy yang roof combined with reinforcement with a core earthen wall.

The article introduces the application of core earthen walls to roads passing through mountainous terrain to reduce the volume of excavation, save and make full use of materials with the example of the Bac Kan City – Ba Be Road Construction Project designed by the Tong Transport and Transport Company (TEDI) below is a typical example.

2 DESIGN SOLUTIONS

2.1 Project Overview

Bac Kan City – Ba Be Lake Road Construction Project has a scale of mountainous grade III road (Bm/Bn=8/9m), design speed Vtk=40-60km/h, according to TCVN 4054:2005 standard.

The investor is the Bac Kan Department of Transport; The representative of the investor is the Bac Kan Provincial Transport Construction Investment Project Management Board and the architect is the Transport Corporation - Joint Stock Company (TEDI).

This is a project that has applied a retaining wall with reinforcement to replace the traditional concrete wall. This is the first time this technology has been deployed in Bac Kan, marking a breakthrough in the construction of transport infrastructure in mountainous areas.

2.2 Design solutions of the project

Initially, with the locations passing through the mountains, the design solution was still the option of digging the taluy roof. Due to the steep terrain, the high mountain to the height of the roof is very raking, and the volume of digging is large (figure 1). To ensure the stability of the positive roof, the solution is to use anchors combined with a concrete frame to keep it stable. This solution is very costly but still has a potential risk of slipping when there is prolonged heavy rain.

In order to solve the above difficulties, the consultant has studied the design to change from the excavated road bed to the embankment foundation by pushing the line towards the sound taluy (figure 2). When the line pushes out to the negative side, the solutions are studied and compared are gravity walls, viaducts, and earthen walls with cores. After calculating and comparing both technical and economic requirements, the project has chosen the option of making a retaining wall because:

Eco-friendly material, easy to green the surface with vegetation.

Leverage local materials: Use land on-site, reduce resource extraction and CO_2 emissions from transportation.

Integrated vegetation: The wall surface can be covered with grass or shrubs, creating a natural landscape and resisting erosion.

Anti-deformation: The tough structure helps the retaining wall withstand subsidence or vibration from earthquakes and vehicles.

Flexible design in height, slope, shape to suit technical and landscape requirements.

Adaptable to complex terrain: Can be built on weak ground, steep slopes, or areas with uneven subsidence.

Fast and easy construction.

The price is cheap, saving about 10%-30% compared to other solutions.

Materials are manufactured from synthetic polymers such as: Polyester, HDPE, Polypropylene is durable to the natural environment, high strength, low elongation, sustainable, long-lasting.

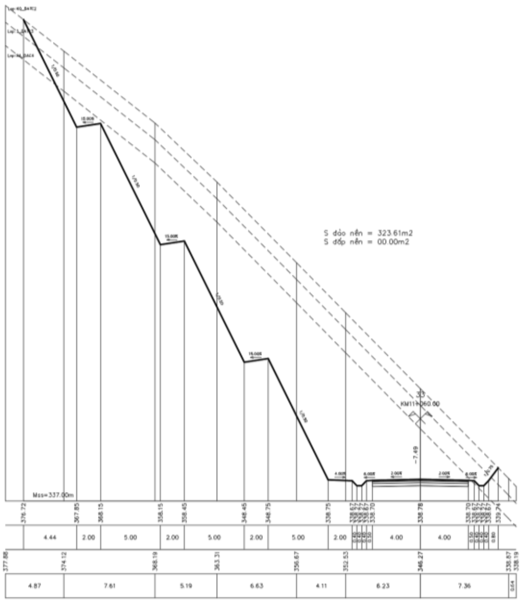


Fig. 1. The initial plan to dig the taluy roof

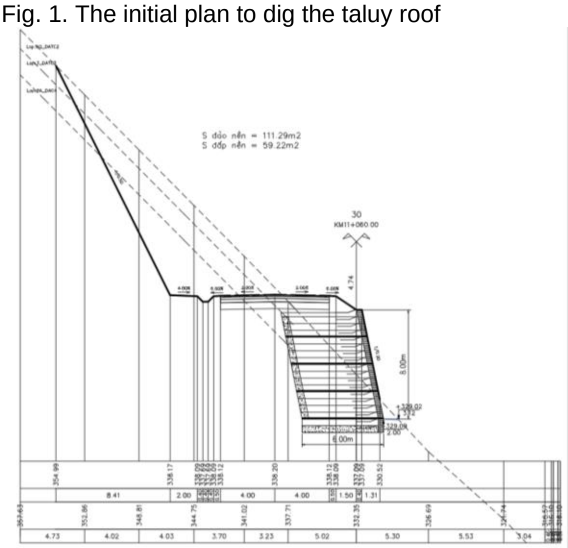


Fig. 2. Plan to propose the use of earthen walls with core

2.3 Structure of reinforced earthen walls

Face:

- The hexagonal wire mesh used for the road mold is Zn90Al10 (Gafan) aluminum-zinc coated wire mesh and PVC wrapped, fabricated by the method of weaving into a triple twist hexagonal eye to control the residual stretches that can cause deformation of the road mold and achieve the stability of the embankment material.

Wall Mold Covering:

- It is a mesh made of polypropylene multifilament high-strength fiber complex for the gauge dimension and monofilament fiber for the roll dimension, to weave into a fabric structure that retains the fiber structure and fabric holes so that plant roots can grow through the fabric hole over time. The fabric is inert to biodegradation, and is resistant to natural environments with alkaline and acidic components, as well as has a long service life in outdoor use.

Sandbags for wall molding:

- It is a bag containing rice, cement bags or bags made from geotextiles at the construction site that are filled with soil, tightly closed and sewn by a bag sewing machine.

Mesh as reinforcement:

- The geogrid used as reinforcement for reinforced soil is Flexi geogrid based on Poly-Ethylene Terephalathe polymer, which is produced by weaving or knitting technology, with working stress tension and PVC coating to protect the quality of the fiber.
- The geogrid needs to meet the long-term design life (LTDS) values of 120 years located in the soil (calculated according to the values declared by the manufacturer with an independent testing system for quality control and reliable documents on the reduction factor).
- Realizing that there are a lot of raw aggregates D > 63mm used on site, in order to ensure the minimization of the damage coefficient due to construction to the reinforced retaining wall and increase the resistance to drag and slip (According to the self-inserting mechanism of interlocking), the size of the mesh cell is opened about D ≥ 45mm;

Drainage system behind the wall:

- Behind the wall is a layer of 1x2 crushed stone covered with geotext. This layer of crushed stone is connected to a perforated ribbed HDPE pipe wrapped in geotextile to direct the water behind the back of the wall (if any) out.

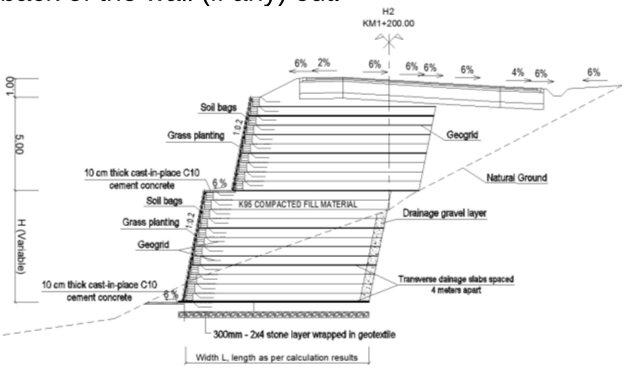


Fig. 3. Typical cross-sectional calculation at the location utilizing mechanically stabilized earth walls

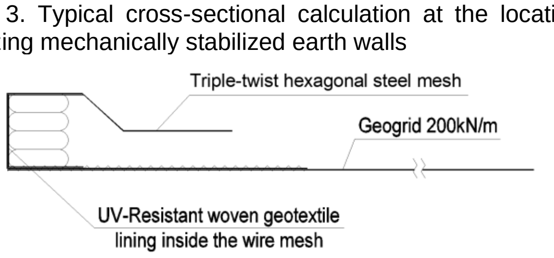


Fig. 4. Detail of a 0.5m thick layer of bent wire mesh reinforcement per layer

2.4 Calculation model

Calculation cross-section: Height of embankment 8m, width of roadbed 9m, roof coefficient m=0.2.

Geological cross-section: Above is layer 3 Clay with little plasticity, less flexible dust (CL, ML), mixed with sand chips, hard to hard plastic, the thickness drilled into the layer is 17.40m. Below the 3rd grade is grade 8a Crystalline sand, strong to medium weathering, especially strong cracking. The characteristics of the land plot are as shown in Table 1.

Table 1. Parameters of geological background and soil layer used in calculation

	γ	c	φ
backfill	18.3	23	16.4
Layer 3	18.5	18.9	16.22
Layer 3bh	18.9	14.7	11.45
Layer 8a	24	90	36.8
Layer 8abh	24	80	33

Reinforcement characteristics: Using Hock Technology's 200/100 kN/m strength geogrid. The core step is taken by multiples of the thickness of the embankment layer, typically 0.5m.

The stability coefficient of the slope is determined as:

Fs = Total Limit Contact Stress / Total Net Stress at the Sliding Block

When applying the Bishop method for stability audit, the smallest stability number Fs = 1.40 (TCCS 41) design consultant increases Fs ≥ 1.7 due to dependence on construction level, quality management, large height and residential houses at the foot of the building, so the stability coefficient should be increased to ensure stability in the long term.

Audit by ReSSA+ software and standard reference BS_8006-1-2010

With the final critical state, the base strength (TB) is TCB, the breaking strength at the appropriate time: TB = TCB = Tchar / RFCB

In which:

Tchar: is a short-term force;

RFCB: is the creep reduction factor;

fm = RFID x RFW x RFCH x fs’

In which:

RFID: is the reduction factor of installation damage;

RFW: is the weather-induced reduction factor;

RFCH: is the coefficient of reduction due to chemicals/environment;

fs' is the safety factor that allows data to be extrapolated.

The strength indicators of the Geogrid are obtained according to the following table (Refer to and supported by Hock Technology):

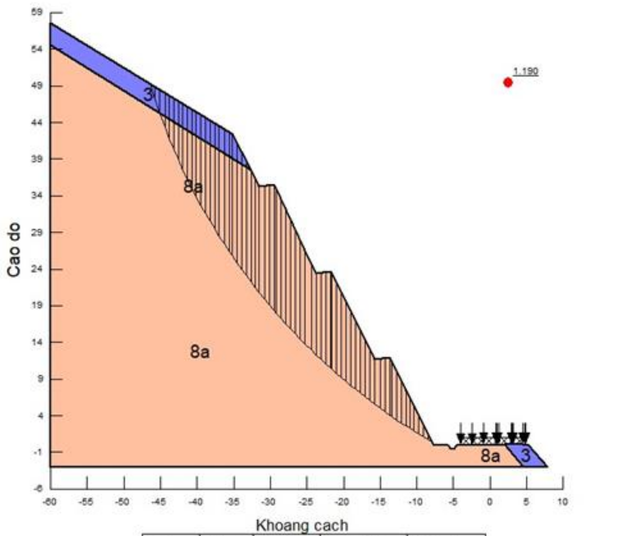
Table 2.

T_{ult}	RF_{ID}	RF_{W}	RF_{CH}	RF_{a}
200	1.1	1.43	1.17	1

Overall stability audit software with Geostudio software, core earth wall design calculation with ReSSA+ software, control calculation with Plaxis software.

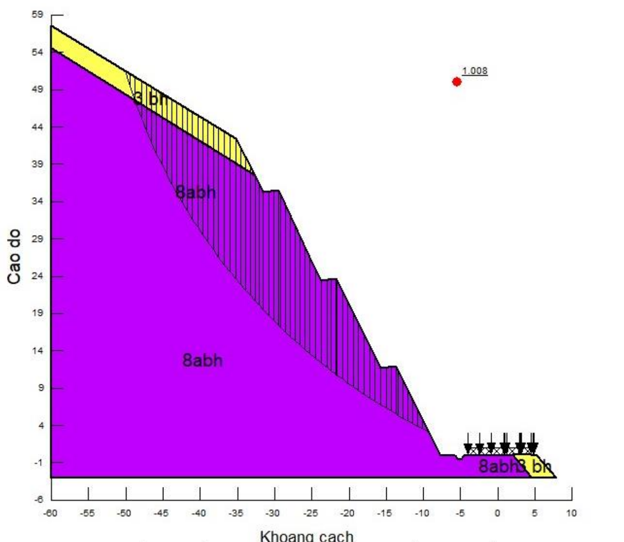
2.5 Calculation results

Calculation results according to the ward of the peach system:



Color	Name	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)
	3	18.5	18.9	16.22
	8a	24	90	36.8

Fig.5. Stable audit results with Geostudio under natural humidity conditions



Color	Name	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)
	3 bh	18.9	14.7	11.45
	8abh	24	80	33

Fig.6. Geostudio stability test results under natural humidity conditions

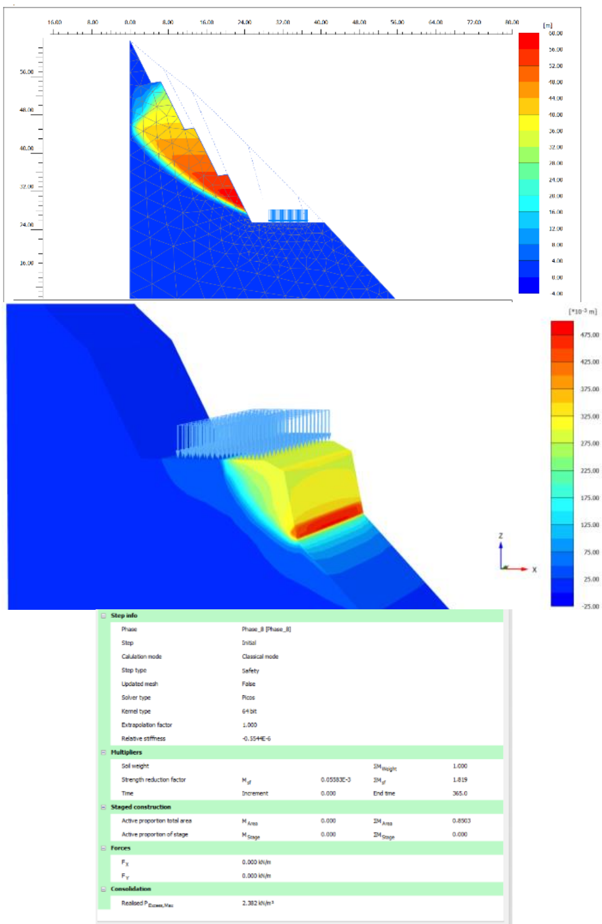
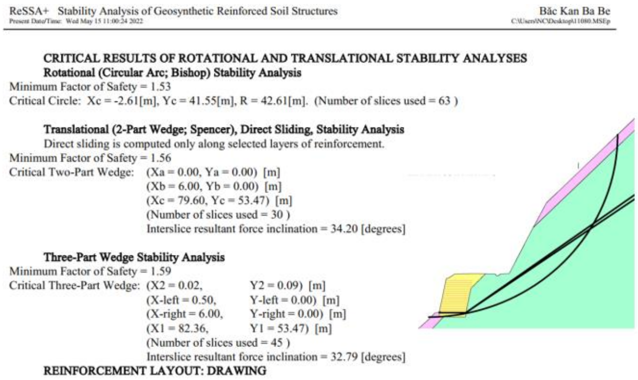


Fig.7. Kết quả tính toán bằng phần mềm Plaxis

From the results of the audit by Geostudio under the saturated condition Fs = 1.008 and according to Plaxis Fs = 1.019, the roof is not stable (Fs >1.25), it is necessary to reinforce the roof with anchors combined with a concrete frame. This reinforcement solution is very expensive.

The results of the calculation of the design plan are changed from the excavated road bed to the embankment foundation by pushing the line towards the reinforcing taluy with a core earthen wall.


ReSSA+ Stability Analysis of Geosynthetic Reinforced Soil Structures — Băc Kan Ba Be
Present Date/Time: Wed May 15 11:00:24 2022 — C:\Users\NC\Desktop\11080.MSEp

CRITICAL RESULTS OF ROTATIONAL AND TRANSLATIONAL STABILITY ANALYSES
Rotational (Circular Arc; Bishop) Stability Analysis
Minimum Factor of Safety = 1.53
Critical Circle: Xc = -2.61[m], Yc = 41.55[m], R = 42.61[m]. (Number of slices used = 63)

Translational (2-Part Wedge; Spencer), Direct Sliding, Stability Analysis
Direct sliding is computed only along selected layers of reinforcement.
Minimum Factor of Safety = 1.56
Critical Two-Part Wedge: (Xa = 0.00, Ya = 0.00) [m]
(Xb = 6.00, Yb = 0.00) [m]
(Xc = 79.60, Yc = 53.47) [m]
(Number of slices used = 30)
Interslice resultant force inclination = 34.20 [degrees]

Three-Part Wedge Stability Analysis
Minimum Factor of Safety = 1.59
Critical Three-Part Wedge: (X2 = 0.02, Y2 = 0.09) [m]
(X-left = 0.50, Y-left = 0.00) [m]
(X-right = 6.00, Y-right = 0.00) [m]
(X1 = 82.36, Y1 = 53.47) [m]
(Number of slices used = 45)
Interslice resultant force inclination = 32.79 [degrees]
REINFORCEMENT LAYOUT: DRAWING

Fig.7. Results calculated by software ReSSA+

Phase	Phase_26 [Phase_26]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	1.000			
Relative stiffness	1.163E-3			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	5.986E-3	ΣM_{sf}	1.508
Time	Increment	0.000	End time	85.00
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9344
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	108.2 kN/m²			

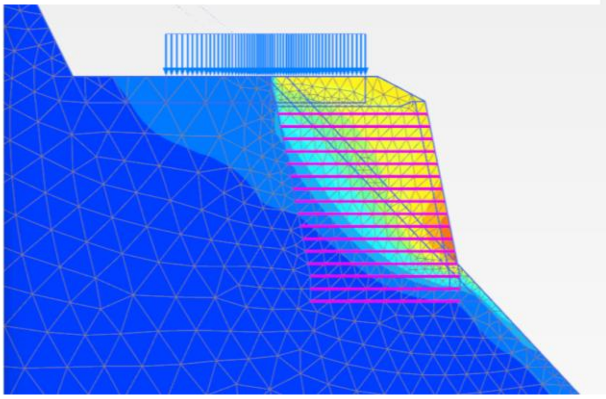


Fig.8. Calculation results by Plaxis software

Evaluation of calculation results

With the plan to use the soil wall with a core, the audit results according to ReSSA+ Fs = 1.53 and Plaxis Fs = 1.508 ensure stability, the apricot part is low, so it also ensures stability without reinforcement.

2.6 Construction Process

Currently, the Bac Kan – Ba Be project is in the final stage of the construction process. The locations are designed with solid earthen walls that have been almost completed.

When the construction of the retaining wall was started, the contractors who had no construction experience encountered many problems, many contractors also proposed to change the design solution. But after being guided by the material supplier (Hock Technology Group and Phu Thanh Phat Import-Export Co., Ltd.), the contractors were able to understand the order and method of construction, the construction was very fast. Below are some pictures of the actual construction at the Bac Kan – Ba Be project.

Fig.9. Images of the Mechanically Stabilized Earth project during construction

2.7 Result

The implementation time from 2022 to now the project has been completed. The reinforced earthen wall with a wall height design from 6m - 24m ensures all the requirements of the design to help speed up the project progress.

Taking advantage of excavation materials as embankment materials for the core soil to balance the excavation volume and embankment volume to reduce costs for the project.

Typhoon No. 3 (Yagi) in 2024 has greatly affected the investment project to build the Bac Kan city - Ba Be lake route. After the rain and storm on the route, there are currently 35 locations of landslides on the roof. However, thanks to the main design solutions made of earthen walls with cores, sustainable materials, the building still ensures stability and safety. These experiences are the basis for other mountainous projects in Vietnam to optimize their design and effectively respond to climate change and natural disasters.

Fig. 10. Typical Cross-Section at Location Utilizing Mechanically Stabilized Earth Walls

3 CONCLUSION

Retaining walls are the optimal solution for projects that require economy, flexibility and environmental friendliness. Thanks to its outstanding advantages in cost, durability, and applicability, it is gradually replacing traditional methods in modern construction. However, in order to be effective, it is necessary to accurately design and select core materials that are suitable for geological conditions.

The Ba Be - Bac Kan project is a typical project that goes through many complex terrains, the use of earthen walls with the core is appropriate, reducing the digging of the roof, ensuring stability in the long term. is a typical demonstration of the application of soil technology in the construction of mountainous roads. With valuable lessons learned, the project not only brings economic benefits but also contributes to environmental protection and sustainable development for the region:

- Improve traffic connections: The route helps shorten the travel time between Bac Kan City and Ba Be Lake, promoting trade and tourism.

- Local economic development: The project creates many new jobs, promoting service industries such as hotels, restaurants and ecotourism.

- Natural landscape conservation: Soil technology has a core to help minimize the impact on the environment, protect the natural beauty of Ba Be Lake

On the basis of the success of the project, this solution should be applied to similar projects passing through hilly areas and traffic works in the Northern region and throughout Vietnam;

With the technical capabilities in Vietnam, we can completely build larger walls with more complex conditions than current projects;

With the characteristics of our country's gas being tropical monsoon, the climate has obvious seasonal differentiation. With such natural conditions, the exterior wall formwork using geogrid as the face plate will have a lower service life. In order to increase the life of the project, it is proposed to use a metal site (wire mesh).

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