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2D ANALYSES OF GLOBAL STABILITY OF A GEOSYNTHETIC-REINFORCED MECHANICALLY STABILIZED EARTH RETAINING WALL WITH DIFFERENT SOIL CONDITIONS

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ABSTRACT: The technology of reinforcing slopes with geosynthetics retaining walls has been widely applied in highways, infrastructure, hydraulics, seaports and civil works. The stability of geosynthetic-reinforced retaining walls is the major interest. The limit equilibrium method (LEM) is regularly known as the primary method for stability analysis of unreinforced and reinforced slopes due to its economy, effectiveness and simplicity. The paper presents several limit-equilibrium methods for slope stability analysis. A case study is taken from the section from Km0+360 to Km0+440, which belongs to the Huong Son-Kep town highway project, with an embankment height of 9 meters. The soil foundation profile consists of an organic soil layer with a thickness of 0.3 to 0.5 m, followed by a layer of clayey soil in semi-hard to hard state. The soil parameters are taken from the in situ and laboratory tests. The stability of a 9-height geosynthetic MSE wall is analyzed by employing various LEMs embedded in Geostudio software version 2018 R2. The paper then evaluates the influence of different soil conditions, including the internal friction angle, cohesion, unit weight and surcharge on the stability of the wall. The numerical outcomes indicate that the Janbu method gives a factor of safety that is 8% smaller than that of Bishop, Spencer and Sarma. The Bishop method is then suggested for the following studies. Additionally, the results indicate that the parameters of the foundation soil truly impact the stability of the geosynthetic-reinforced retaining wall structure.

Keywords: Two-dimensional, Geosynthetic, MSE wall, Limit equilibrium method, Factor of Safety

1. INTRODUCTION

The technique of geosynthetic-reinforced retaining walls has been widely employed in practice as an alternative to regular retaining walls. This is because the technique offers several advantages, including cost-effectiveness, aesthetics, reduced construction time, and smaller construction area [1]. In addition, thanks to simple construction technology, with only precast wall panels, combined with geosynthetic layers, it is possible to build retaining walls up to several tens of meters high.

In terms of the working principle of a geosynthetic-reinforced retaining wall, the embankment is reinforced by the geosynthetic layers. It works based on the geosynthetic-soil interaction mechanism. In such a manner, the reinforced soil works as a cohesive unified mass, bearing its self-weight and the external loads while designing retaining wall structures [2].

The major task of the geosynthetic layers within the soil is to enhance the tensile capacity of the soil mass by creating a friction effect along the reinforcement surface and passive support in the transversal direction to the movement. Whereas the shear stress acting on the soil decreased, the normal stress on the failure surface increased. Although the geosynthetic-reinforced retaining wall has been constructed for about four decades, the failure behavior of that wall is still not fully understood [3].

The stability of geosynthetic-reinforced retaining walls is the major interest. The limit equilibrium method (LEM) has been known as the familiar method for stability analysis of unreinforced and reinforced slopes thanks to its economy, effectiveness and simplicity. It consists of analyzing the forces applied to the failurable mass and calculating the factor of safety (FS), which is the ratio of the force resisting the movement of the slope (shear strength) to the force causing the slope to fail (shear stress) [4]. In the method, the complex behavior of a soil is simplified by assuming that the soil is in the limit equilibrium state (it is at the failure threshold). FS is considered an important indicator to evaluate the stability of a slope. It quantifies the stability of a slope against potential failure. The slope is stable as FS is greater than 1. Conversely, it is unstable and disposed to fail as FS is less than 1. To simplify the real problems, a 3D natural slope is usually converted to a 2D slope in planar geometry. Based on differences in assumptions and simplifications, the different equilibrium equations are established. Hence, the different equations of FS are determined.

To audit the stability of reinforced earth structures, the analytical methods, laboratory and site tests, and numerical models have been established. However, almost all conventional designs for geosynthetic-reinforced earth walls were constructed based on the limit equilibrium method. In the present approaches, the failure planes are determined according to conventional retaining wall forms, then adjusted for metallic and geosynthetic materials reinforced retaining walls. Mandal and Jambale (1992) analyzed the behavior of geosynthetic-reinforced soil walls using the limit equilibrium method. In the research, the influences of the length, width, geosynthetic spacing, unit weight of soil, surcharge load, soil-geosynthetic friction coefficient, and yield strength thickness of reinforcement on the failure plane were taken into account. The results showed that an increase in the length of reinforcement did not increase the failure height of the wall. Increasing the strength of reinforcement did not illustrate an insignificant increase in the critical height if the slipping phenomenon occurs [5]. Han and Leshchinsky (2006) presented recent studies using the limit equilibrium and the finite difference software in analyzing the stability of geosynthetic-reinforced earth structures. The findings showed that there were almost similar results of FS between the limit equilibrium method and the finite difference method for the geosynthetic-reinforced earth walls [6].

Kalatehjari and Ali (2013) reviewed the 3D analyses of slope stability using LEM. The study indicated the limitations of 2D methods in determining the direction of sliding (DOS) and the advantages and disadvantages of each 3D analysis method [7]. Liu et al. (2015) compared the obtained results from LEMs and two finite element methods (enhanced limit strength method, ELSM, and strength reduction method, SRM) in terms of factor of safety and critical slip surface. Their outcomes showed that there was a rather good agreement for the critical slip surfaces between LEM and the two finite element methods. The factor of safety calculated from the limit equilibrium method is marginally less than that from the finite element methods [4].

Wang et al. (2015) developed a simple and practical approach using deformation analysis to look for the critical slip surface using the 2D slope stability analysis. The method has been verified by the two presented examples and the real project [8]. Firincioglu and Ercanoglu (2021) used both 2D and 3D analyses to gain a deep understanding and viewpoints for the limit equilibrium method. The authors concluded that Morgenstern and Price's and Spencer's methods could be used to solve 2D solutions with high reliability in most cases, with different slip surface curves, water conditions, geological features, and external influences. Meanwhile, Bishop's method has a similar recommendation, but is limited to circular slip surfaces. The study also figured out that there was a lower factor of safety in 3D analyses as compared to 2D analyses [9]. Rahmaninezhad et al. (2021) indicated that the FS of modular block facing walls was higher than that of wrap-around facing walls. The geosynthetic-reinforced earth walls with lower FS had greater lateral facing deflections than those with higher FS. The exponential relationship between the Bishop's factor of safety and the maximum lateral facing deflection was figured out [10]. Wang et al. (2023) concluded that the limit equilibrium method, with its clear mechanical fundamentals, produced reliable results. It was suitable for slope stability analysis and theoretical research [11]. A high degree of satisfaction in the FS between the FEM and LEM was indicated, with an R^2 correlation of approximately 1 [12].

Related to soils, the embankment fill is commonly assumed to be a completely granular soil; the cohesion is not considered. Geosynthetic reinforcement could enhance the soil strength; from a durability viewpoint, the use of purely granular soil is not essential. Especially in areas where it is difficult to find completely granular soils, the use of non-completely granular soils is highly cost-effective for the construction of reinforced retaining walls. Additionally, when well-drained soils were unavailable for backfill, the solution for poorly drained soils has been profitable. To be sure of the usage capacity of poorly-graded soils, some laboratory experiments have been conducted to clarify the behavior of geosynthetic-reinforced earth walls where the embankment was filled with marginal and cohesive soils [13]. The authors concluded that it is possible to use those soils, but the necessary forethought is considerable. Therefore, studying the influence of the soil parameters for the embankment on the performance of the retaining wall brings great efficiency both technically and economically.

Besides, in current design codes, the geosynthetic-reinforced earth wall is generally constructed on good soil, and the behavior of the soil foundation is likely an elastic material. The deformation of the soil foundation is rarely considered. Nonetheless, many studied cases have figured out that when the yielding of the ground below the retaining wall is extreme, which leads to the large lateral displacement, the tilting of the wall, and the excessive settlement. When the stress-strain behavior of the soil is improperly estimated during the design phase, unforeseen ground yielding situations can arise. Although the suitability of a given soil condition is implicitly checked in terms of internal and external stability and the load-bearing capacity, the impact of a geosynthetic-reinforced MSE wall on soil deformation is not explicitly addressed in current design methods [14].

Based on a review of previous studies, it can be seen that former authors have indicated that the limit equilibrium method is reliable in analyzing the stability of unreinforced and reinforced slopes. However, the comparison of the stability of the different LEMs has not been performed. The stability analysis of geosynthetic-reinforced earth walls for different soil conditions was not given much consideration. Therefore, the paper builds 2D numerical models to analyze the stability of geosynthetic-reinforced earth walls using different LEMs. In addition, the influence of soil parameters on the stability of earth structure is evaluated.

2. RESEARCH SIGNIFICANCE

The paper clarifies the content and formula for the factor of safety of slope using different limit equilibrium methods. The 2D models are constructed to calculate FS according to the above methods and check the consistency of the results between the methods. In addition, the paper makes clear the influence of some geotechnical parameters of the reinforced soil, the retained soil and the foundation soil, such as the internal friction angle, cohesion, unit weight, and surcharge load on the overall stability of the geosynthetic-reinforced retaining wall.

3. LIMIT EQUILIBRIUM METHODS FOR SLOPE STABILITY ANALYSIS

According to the current calculation viewpoint, the slip surface in slope stability analysis is often assumed to have a circular or cylindrical shape. The sliding mass is formed by the limitation of the slope plane (or the slope crest plane) and the circular sliding surface. To analyze the slope stability, the sliding mass is normally discretized into vertical slices. Each part is considered a free sliding mass (Fig. 1). This technique is known as the method of slices. The considered equilibrium states include internal forces and moments.

The factor of safety is defined as in Equation 1.

$$FS = \frac{\sum_{1}^{n}\left(c_i l_i + N_i \tan\phi_i\right)}{\sum_{1}^{n}\left(\mathrm{W}_i \sin\phi_i\right)} \qquad (1)$$

Where c_i is the cohesion at the i slice base, l_i is the i slice base length, N_i is the base normal of the i slice ($W_i \cos\alpha_i$), ϕ_i is the friction angle, W_i is the weight of the i slice, and α_i is the base inclination of the i slice.

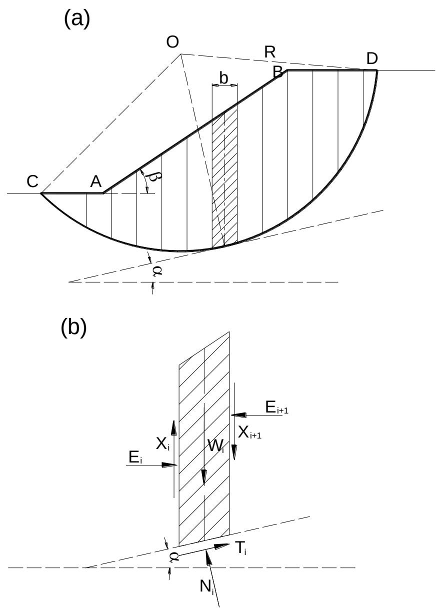

Fig. 1. Method of slices: (a) discretized into vertical slices; (b) each vertical slice equilibrium

Based on the vertical slices technique, the concepts of LEM and the simplified boundary conditions, many 2D analytical methods were proposed, which were the methods of Fellenius (1939), Janbu (1954), Bishop (1955), Morgenstern-Price (1965), Spencer (1967), and Sarma (1973).

The ordinary method is known as the Swedish Circle or Fellenius method [15]. It is the simplest slice method for global stability analysis. In the method, the interslice forces were not taken into account, where $X_i = X_{i+1} = 0$ and $E_i = E_{i+1} = 0$ (Fig. 1). The factor of safety was then shortened as in Equation 2.

$$FS = \frac{\sum_{1}^{n}\left(c_i l_i + \left(\mathrm{W}_i \cos\alpha_i - u_i l_i\right)\tan\phi_i\right)}{\sum_{1}^{n}\left(\mathrm{W}_i \sin\phi_i\right)} \qquad (2)$$

When considering the effects of surcharge and geosynthetic tension, the factor of safety was calculated as in Equation 3.

$$FS = \frac{\sum_{1}^{n}\left(c_i l_i + \left(\left(\mathrm{W}_i + \Delta_{\sigma_i}\right)\cos\alpha_i - u_i l_i\right)\tan\phi_i\right)}{\sum_{1}^{n}\left(\mathrm{W}_i \sin\phi_i + E_i\right)} \qquad (3)$$

Herein, $\Delta_{\sigma i}$ is the surcharge on the slope, and E_i is the tension of the geosynthetic.

Due to its simplicity, the factor of safety of the ordinary method is easy to calculate by hand. However, in practice, this method has the limitation of use due to its unrealistic factor of safety.

Bishop (1955) proposed the circle slip theory in analyzing the slope stability, *known as the Bishop method*. The slide mass was divided into smaller vertical slices. In each vertical slice, the difference between interslice normal forces was taken into

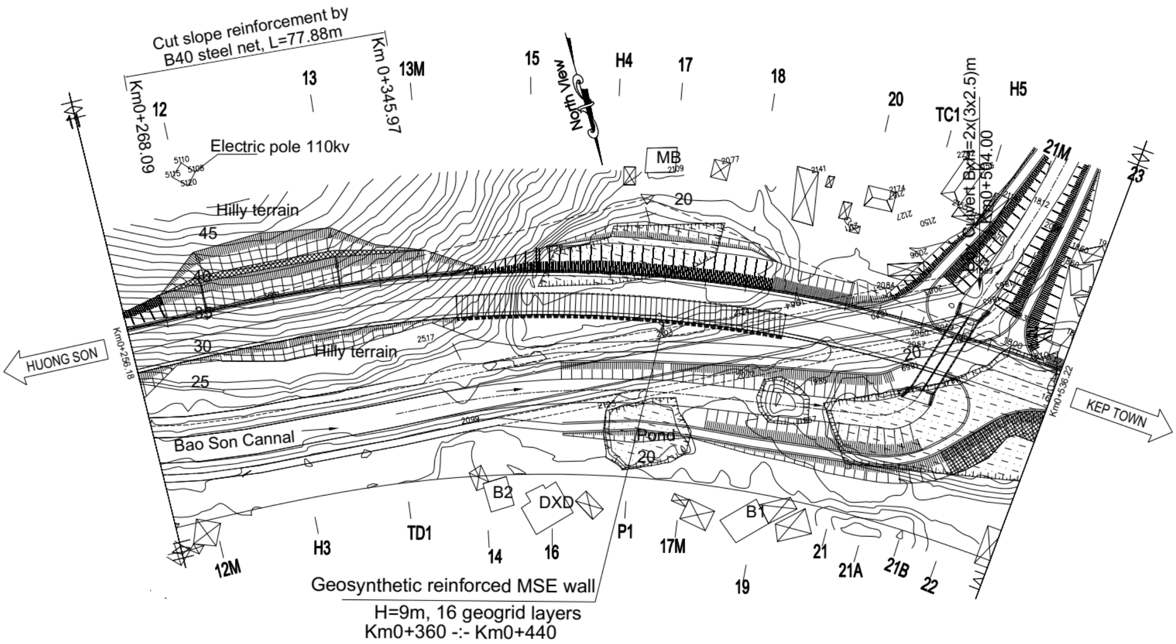

Fig. 3. Plan view of the road alignment [20]

account, and the interslice shear forces were taken to be equal. The equilibrium condition of moment was satisfied. The horizontal force equilibrium was not considered. The factor of safety was determined as in Equation 4 [16]. It can be seen that FS appears on both sides of the equation. The problem is repeatedly solved until a consistent value of FS is obtained. Hence, it is difficult to calculate by hand from the Bishop method. The computer algorithms must be required.

$$FS = \frac{\sum_{1}^{n}\left(c_i l_i + \left(W_i - u_i l_i\right)\tan\phi_i\right)}{\sum_{1}^{n}\left(W_i \sin\alpha_i\right)\left[\cos\alpha_i + \frac{\sin\alpha_i \tan\varphi_i}{FS}\right]} \qquad (4)$$

Janbu (1954) developed the ordinary method for free-forming the vertical slides. The features in the Janbu method were similar to the Bishop method regarding the normal inter-slice forces. However, the Janbu equation was based on the horizontal force equilibrium. In addition, the Janbu method was possibly used for both non-circular and circular failure slip surfaces [17].

In the Spencer method, both inter-slide normal and shear forces were taken into account, and the two factors of safety were calculated, including the factor of safety for moment equilibrium and another for horizontal force equilibrium [18]. However, a constant relationship between the inter-block shear and normal forces was adopted. The iterative procedure for the shear force to normal force ratio was performed until the two factors of safety were similar. The ratio of shear force to normal force that made the similarity of two factors of safety meant that both force and moment equilibrium conditions were satisfied.

Sarma (1973) presented the analysis method for slope stability for non-perpendicular slices or for regular blocks, as in Fig. 2 [19]. In general, the Sarma method not only deals with both interslice shear and normal forces, the force and moment equilibrium, but it also relates the interslice shear and normal forces by a quasi-equation of shear strength.

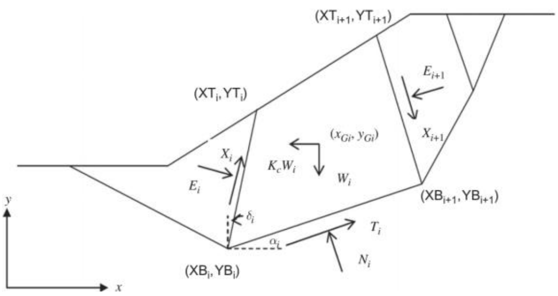

Fig. 2. Inter-slice forces acting on individual blocks in Sarma's method

4. NUMERICAL MODELING

4.1. A Case Study

The Huong Son - Kep town highway project has a length of 2.626 kilometers. The road alignment passes through Huong Son commune and Kep town, Lang Giang district, Bac Giang province. A case study is taken from the section from Km0+360 to Km0+440 with an embankment height of 9 meters

(Fig. 3). The typical cross-section shows a height of 9m at the shoulder. The grade of the embankment slope is 1:1.5.

The current status of the area on both sides of the research road shows that there are residents living on both sides of the road, and the land on both sides is rural residential land, perennial crop land, and rice growth land. Therefore, it is necessary to consider solutions to minimize the land occupation area on both sides. In addition, because the road is expanded with two more lanes in Phase 2 on the left side of the road, the proposed right slope will be reinforced with a geotechnical retaining wall; the height of the wall is selected to be 9 meters.

The geological conditions of the study area include an organic soil layer with an average thickness of 0.3 to 0.5 m, followed by a layer of clayey soil with gravel in gray-brown, gray-yellow color in semi-hard to hard state, and this is considered a good soil layer capable of directly placing the foundation of the project without reinforcing or improving. Next is the moderate to strong weathering siltstone, 5 to 7 m thick. The groundwater level is located at a depth greater than -10m below the natural ground surface [21]. The influence of the drainage and groundwater has not been considered in the analyses.

From the analysis of the above design solution factors, the geosynthetic-reinforced retaining wall method is recommended to replace the traditional slope embankment method. For some reason, using a geosynthetic-reinforced retaining wall significantly reduces the backfill volume, decreases the area of land clearance, ensures long-term stability, and increases the aesthetics, especially for projects located in urban areas.

4.2. Geometry of Model and Parameters

The 9-meter height of the geosynthetic MSE wall was founded on the 15-meter soil foundation. There were 16 geogrid layers arranged at corresponding distances from the top of the wall, as presented in Fig. 4. In the geometry detail, the model was divided into three parts which were the reinforced soil, retained soil, and foundation soil. The geosynthetics used in the analyses were Tensar RE560 series geogrids. The spacing between geogrid layers, S_v, ranged from 0.4 to 0.6 meters, as shown in Table 1. The length of geogrids, L, was selected as 7 meters.

The reinforced soil and retained soil use clayey soil as the standard soil for embankment, with a relative humidity of 0.6. Their parameters were assumed. The parameters of the soil foundation were taken from the soil investigation at the site. The soil types and their parameter used for numerical analyses are shown in Table 2. The geosynthetic material used in the analyses is the geogrid of Tensar manufacture. The allowable strength of the geogrid is calculated by Equation 5. In the analyses, the types of Tensar geogrids from UX1100MSE to UX1700MSE are used (https://www.tensarcorp.com); the allowable strength of these geogrids is presented in Table 3.

Table 1. Geosynthetic arrangement from the top of the embankment

Layer	Distance to top level (m)	Layer	Distance to top level (m)
1	0.30	9	5.10
2	0.90	10	5.70
3	1.50	11	6.30
4	2.10	12	6.85
5	2.70	13	7.35
6	3.30	14	7.85
7	3.90	15	8.30
8	4.50	16	8.70

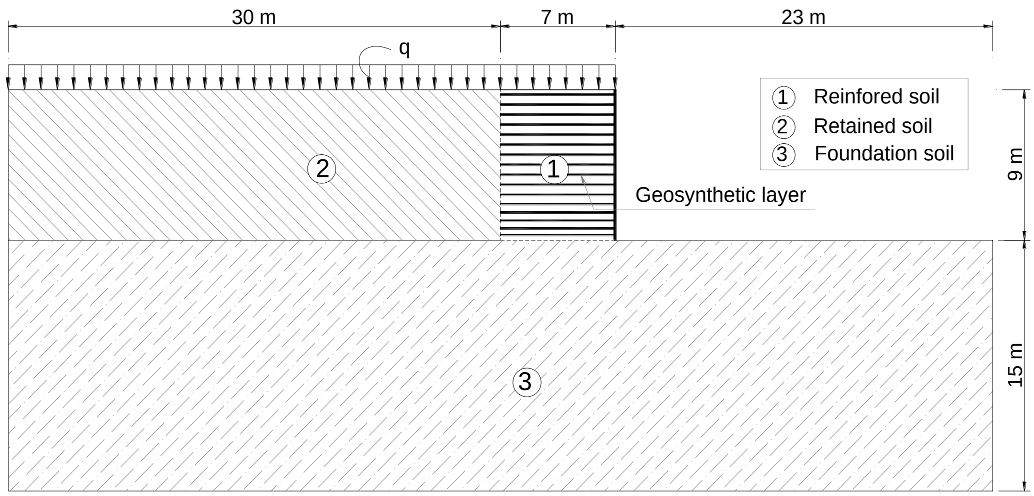

Fig. 4. Geometry of numerical model

Table 2. Soil parameters for numerical analyses in the reference case

Soil parameters	Soil types		
	Reinforced soil	Retained soil	Foundation
Unit weight, kN/m^3	18.5	18.5	18.5
Friction angle, ^{o}	28	24	24
Cohesion, kPa	32	32	32

$$T_{all} = (ULS * R_c) / (RF_{un} * RF_{ID} * RF_D * RF_{CR}) \qquad (5)$$

In which, T_{all} is the allowable strength; ULS is the ultimate tensile strength; R_c is the coverage ratio of geogrid (R_c = 1.0); RF_{un} is the reduction factor for uncertainties (RF_{un} =1.50); RF_{ID} is the reduction factor for installation damage (RF_{ID} = 1.15); RF_{CR} is the reduction factor for creep (RF_{CR} = 3.10); RF_D is the reduction factor for drainage capacity (RF_D = 1.10).

Table 3. Allowable strength of Tensar geogrids

Layer number	Geogrid type	ULS	T_{all}
1, 2,3	UX1100MSE	58	9.86
4,5,6	UX1500MSE	114	19.38
7,8,9	UX1600MSE	144	24.48
10,11,12,13,14,15,16	UX1700MSE	175	29.75

4.3. Numerical Procedure

Using Geostudio software version 2018 R2 with the SLOPE/W module to build the geosynthetic-reinforced retaining wall structure. The wall height is 9 meters. The spacing of the layers is presented in Table 1. First, the reference case is analyzed. The soils and geosynthetic properties are taken as in Tables 2 and 3. The surcharge load, q, is taken by 30 kPa. Then, the parameter studies are conducted, which are:

- The influence of different LEMs;
- The effect of soil parameters which are friction angle, cohesion and unit weight;
- The influence of surcharge load.

In the analyses, the factor of safety is figured out and compared.

5. NUMERICAL RESULTS

5.1. Global Sliding Stability Analysis

Fig. 5 shows the numerical result for a geosynthetic-reinforced retaining wall using Bishop's method. The most dangerous sliding curve is not within the reinforced soil part, but rather in the retained one behind the wall, which extends down to the natural foundation. The potential sliding arc passes through the lowest point of the reinforced soil mass. The calculated minimum factor of safety is 1.567. This factor of safety is greater than the allowable value, [FS], which is set at 1.3. Therefore, the geosynthetic retaining wall ensures the overall stability. The factor of safety ranges from 1.87 to 2.47 as the sliding curve is through the reinforced soil area. It is significantly greater than that in the retained and foundation soils. It means that the possibility of failure within the geosynthetic-reinforced mass does not appear.

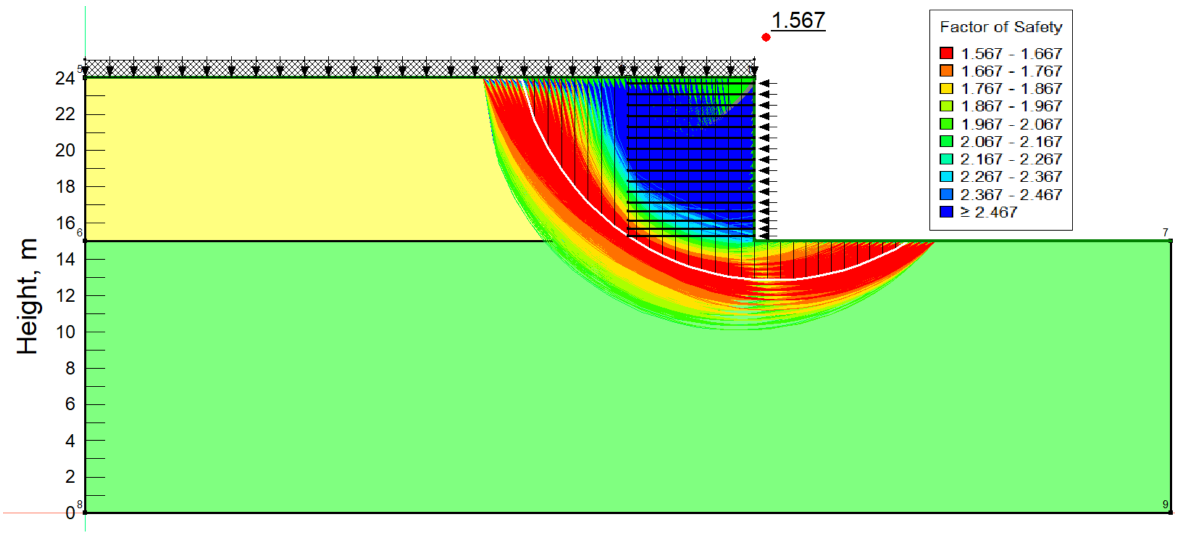

Fig. 5. Overall sliding stability analysis results by Bishop's method

To clarify the difference in LEMs, the 2D analyses with different LEMs were performed. The factor of safety for the four methods is expressed in Fig. 6. It can be seen that FS is rather homologous according to the methods of Bishop, Spencer and Sarma. It is approximately 1.57. It is significantly larger than the value of the Janbu method, with a difference of 8%. The result is in agreement with the findings from Firincioglu and Ercanoglu (2021) [9]. It is due to the fact that in the Janbu method, both the horizontal and vertical force components are taken into account, which results in a smaller anti-slip moment component and less factor of safety. Thanks to a similarity in results between the methods of Bishop, Spencer and Sarma. The method of Bishop is going to be recommended for the following 2D numerical analyses.

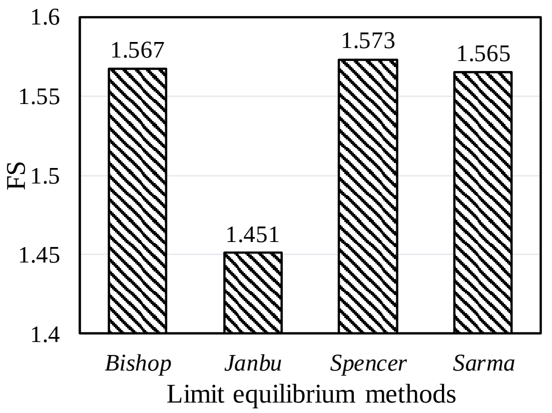

Fig. 6. Effect of the different limit equilibrium methods on factor of safety

5.2. Effect of Internal Friction Angle of Soils

The study analyzes the influence of the internal friction angle of soils on the overall stability of the geosynthetic-backfill-soil retaining wall system. The studied friction angles range from 10˚ to 40˚. The numerical analysis results are shown in Fig. 7. In general, as the internal friction angle increases, the stability coefficient of the retaining wall increases. This may be because an increase in the friction angle of the soil increases the soil shear resistance, that is, it increases the resistance of the sliding arc, and increases the FS value. However, the influence of the friction angle of each part on FS is not similar. The internal friction angle of the soil foundation has a great influence on FS, which ranges from 1.0 to 2.22. Meanwhile, the friction angle of the retained soil significantly affects the slope stability. When the internal friction angle rises from 10° to 40°, FS increases from 1.45 to 1.60. In the case of the reinforced soil, the friction angle has less of a clear influence on FS. The factor of safety increases insignificantly from 1.58 to 1.63 when the internal friction angle increases from 10° to 40°. This is explained because the sliding arc does not pass through the range of the reinforced earth retaining wall, and the backfill soil parameters have a negligible influence on the factor of safety. Therefore, from the perspective of overall stability, increasing the internal friction angle of the soil foundation will be highly effective in improving the overall stability of the wall.

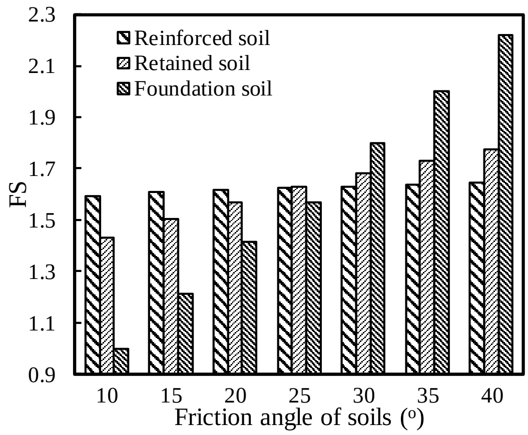

Fig. 7. Effect of internal friction angle of soils on factor of safety

5.3. Effect of Cohesion of Soils

To consider the influence of the soil cohesion on FS. The cohesions of foundation, reinforced and retained soils are changed from 1 kPa to 40 kPa. Fig. 8 describes the effect of cohesion of soils on the overall sliding stability. Similar to the effect of the internal friction angle, the cohesion of foundation and retained soils has a notable influence on FS. FS increases as the cohesion increases. FS rises from 1.37 to 2.03 in the case of foundation soil and increases from 1.30 to 1.62 in the case of retained soil, when the cohesion grows from 1 kPa to 40 kPa. On the contrary, the cohesion of the reinforced soil has an insignificant impact on FS. The factor of safety increases slightly from 1.59 to 1.61 when the cohesion increases from 1 kPa to 40 kPa.

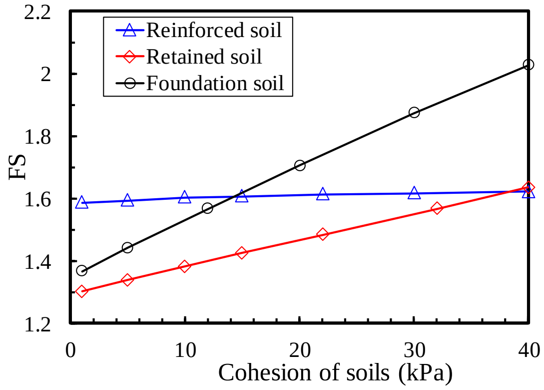

Fig. 8. Effect of cohesion of soils on factor of safety

5.4. Effect of Unit Weight of Soils

The unit weight of soils influencing overall sliding stability is presented in Fig. 9. In general, the influence of unit weight of soils on the factor of safety is not so obvious, and there are two contrary tendencies in increasing the unit weight of soil parts. The greater the unit weight of foundation soil is, the greater the factor of safety of the soil is. The more the unit weight of retained soil and reinforced soil is, the less the soil factor of safety is. However, the effect of the unit weight of the retained soil component on the overall safety factor is larger than that of the reinforced one. This can be explained by the fact that increasing the unit weight of the foundation soil leads to an increase in the bearing capacity of the foundation soil, thereby increasing the stability factor of the retaining wall system placed on weak soil. By contrast, increasing the unit weight of the reinforced soil and the retained soil results in an increase in the applied load on the foundation soil, which reduces the overall safety factor of the retaining wall.

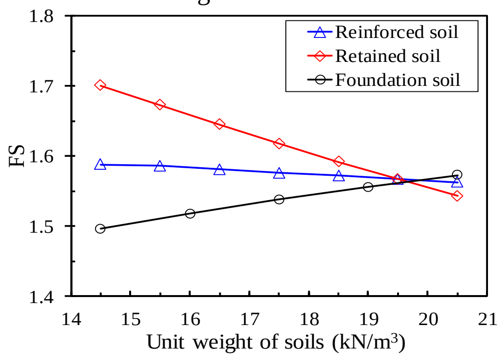

Fig. 9. Effect of unit weight of soils on factor of safety

5.5. Effect of Surcharge

Fig. 10 shows the influence of the surcharge load on the factor of safety. It can be seen that when the surcharge load increases, the sliding stability factor decreases. When the external load is small, the factor of safety is 1.78. When the external loads are equal to 30 kPa, 70 kPa and 100 kPa, the calculated factors of safety are 1.61, 1.45 and 1.35, respectively.

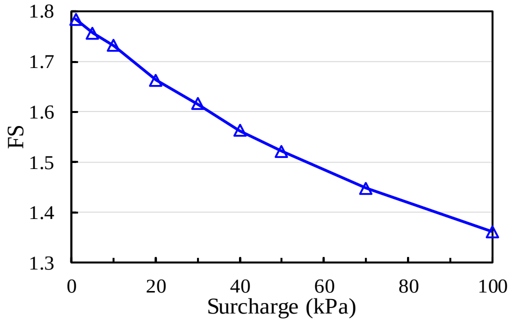

Fig. 10. Effect of surcharge on factor of safety

6. CONCLUSIONS

Studying the influence of different soil conditions on the global stability of geosynthetic-reinforced MSE walls brings the following conclusions:

1. There is a similarity in the results between the methods of Bishop, Spencer and Sarma, while the Janbu method gives slightly smaller results. Bishop's method is proposed to be used for the following studies.

2. As the friction angle and cohesion of soils increase, the stability of the retaining wall increases. The friction angle and cohesion of the foundation soil have more influence on FS than the amount of retained soil does. The friction angle and cohesion of reinforced soil have an insignificant effect on the global stability of the geosynthetic-reinforced MSE wall. There are two opposite tendencies in increasing unit weight corresponding to the different soil parts. The factor of safety decreases as the unit weight of reinforced and retained soils increases. Meanwhile, it slightly increases as the unit weight of foundation soil increases.

3. The surcharge load has the significant effect on slope stability. A rise in surcharge results in a reduction in the factor of safety.

In the paper, the influence of rainfall and groundwater on overall sliding stability has not been considered. The factors are only considered through the cohesion, the friction angle and the unit weight. In practical design calculations, it is necessary to assess the influence of rainfall and groundwater on the reduction of these mechanical parameters on the stability of the retaining wall.

7. ACKNOWLEDGMENTS

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