ARPN Journal of Engineering and Applied Sciences

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INFLUENCE OF THE USE OF SINGLE-TWIST MESH ON REINFORCED SLOPES WITH ANCHORS SUPPORTED ON INDIVIDUAL CONCRETE BLOCKS

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ABSTRACT

During the last few years, slope stabilization by means of anchors supported on concrete blocks has increased substantially in Colombia. The implementation of these systems has generated doubts regarding the erosion problems presented in the areas not covered by the support surfaces. To counteract this problem, some designers have proposed the use of single torsional meshes supported by anchors, with the purpose of guaranteeing that the uncovered zones remain confined during the life of the structure, thus avoiding local slope failures. For this research, we evaluated, by means of finite element modeling, the influence of the use of single torsional mesh on the factor of safety and the distribution of forces on the face of the slope when having different dimensions of support surfaces. It was found that the use of the single torsional mesh does not influence the factor of safety, and that its use does not guarantee the confinement of the soil in the areas not covered by the bearing surfaces.

Keywords: slope stability, finite element method (FEM), anchor heads, numerical modeling.

1. INTRODUCTION

To carry out the stabilization of a slope by means of anchored systems, it is necessary to implement a support surface that transmits the tension load imparted by the retained soil, to the soil behind the potential failure surface; such surface can vary depending on the designer or site conditions. In the country you can find anchors supported on continuous slabs, individual concrete blocks, or beam-type elements. The choice of the type of support depends largely on the parameters and geometry of the profile; however, the criteria of each professional varies according to their experience and the availability of project resources.

In the department of Antioquia (Colombia), the use of individual concrete blocks as a support surface in prestressed anchorage systems has increased (see Figure-1a); however, one of the recurrent criticisms of these systems is the erosion problems that occur in the uncovered areas (see Figure-1b). To respond to this problem, some designers have proposed the use of single torsional meshes in order to confine the soil between the supports and control its susceptibility to erosion (see Figure-1c, 1d)[1].

Regarding the use of single torsion mesh, it is common among builders and consultants to hear divided opinions about the influence of mesh on the reinforcement system. There are those who say that the use of the mesh with individual concrete blocks does not generate a confinement effort on the face of the slope, and that therefore its use represents an unnecessary extra cost in the projects; and other designers who affirm that the use of the mesh shored with the concrete blocks, allows to generate a distributed load on the face of the slope, therefore, they consider that this type of systems generate great benefits in terms of stability.

Given these concerns, it is evident that there is still no clarity about the influence of the simple torsion mesh on the behavior of slopes reinforced with anchors, which are supported on individual concrete blocks; therefore, this research sought to determine the benefits of the implementation of the simple torsion mesh in terms of increasing the safety factor of a reinforced slope and the erosion problems that occur in the uncovered areas of the slope.

a) Support surfaces with individual concrete blocks.

b) Erosion problems in areas not covered by individual concrete blocks.

c) Individual concrete blocks with single twist mesh.

d) Individual concrete blocks with single twist mesh

Figure-1. Anchors supported on individual concrete blocks (author's source).

2. MATERIALS AND METHODS

To carry out the evaluation of the influence of the use of the single torsion mesh on slopes reinforced with active anchors supported on individual concrete blocks, two types of reinforcement were considered: *Type A Reinforcement System:* active anchors supported on isolated bearing surfaces (see Figure 1a); and *Type B Reinforcement System:* single torsion mesh supported by active anchors supported on concrete blocks (see Figure 1c).

In order to perform the numerical modeling to define the slope behavior, a two-dimensional analysis was performed in the Plaxis v8.6 software. This software is commonly used for the modeling of geotechnical structures, since it allows the use of different constitutive models to predict the behavior of geomaterials according to the input parameters of the problem, and the results obtained in terms of stress-strain analysis are satisfactory [2].

2.1 Definition of the Analysis Profile

The slope under study is constituted of a homogeneous soil, whose geotechnical properties are shown in Table 1 and its geometry in Figure-2. The analysis proposed for the slope consists of a variation of parameters in terms of height (h), slope (H:V) and dimensions of the support surface [3].

Table-1. Effective input parameters for the hardening soil model.

Unit weight	**γ_h=17,99 [kN/m^3]**
Cohesion	C_{ref}=23,3 [kN/m^2]
Angle of friction	$\emptyset$=30^o
Dilatancy angle	ψ=0^o
Reference secant stiffness from drained triaxial test	E_{50}^{ref}=14100 [kN/m^2]
Reference tangent stiffness for oedometer primary loading	E_{oed}^{ref}=14100 [kN/m^2]
Exponential power	Power(m)=0,55
Reference unloading/reloading stiffness	E_{ur}^{ref}=42300 [kN/m^2]
Unloading/reloading Poisson's ration	ν_{ur}=0,25
Reference pressure	p^{ref}=100 [kN/m^2]
Coefficient of Earth pressure at rest	K_o^{nc}=0,5
Failure ratio	R_f=0,82

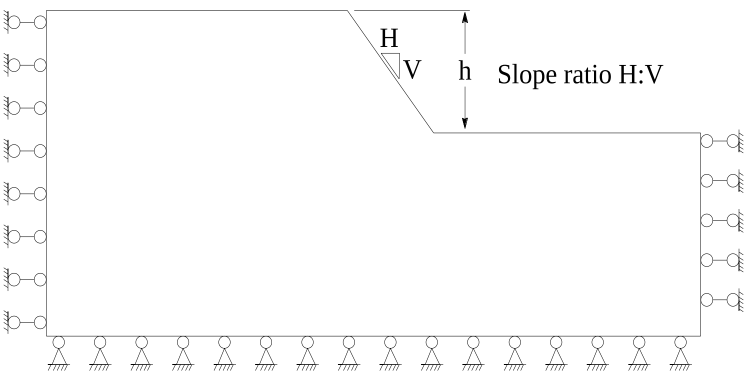

Figure-2. Geometry of analysis with the different support systems.

2.2 Mechanical Properties of the Reinforcement System

To define the geometric and mechanical properties of the reinforcement system, the materials typically used in slope stability projects were considered. For the *Type A Reinforcement System*, concrete blocks with a thickness of 30 cm were used; and for the *Type B Reinforcement System*, the protection of the slope surface with a simple torsional mesh type TECCO-G65 with an axial stiffness EA=1800kN/m, was proposed [4]. As for the support surfaces, a concrete elasticity modulus of 21000 MPa, Poisson ratio 0.2, thermal expansion coefficient of $1.1x10-5$ per °C and density of 2400 kg/m^3 were considered. The anchors used in the two reinforcement systems were each stressed with a load of 250kN and the inclination of the anchors with respect to the horizontal was -15° for all cases of analysis.

2.3 Modelling of the Analysis Case

For the modeling of the analysis case, slopes with heights of 10m and 20m were evaluated; for each of the heights, 3 different slopes were taken, thus generating 6 analysis cases; and for each of the cases, a variation in the size of the support surfaces was proposed. In order to carry out an adequate modeling of the anchorage, it was guaranteed that the bulb zone was located outside the fault surface as shown in Figure-3.

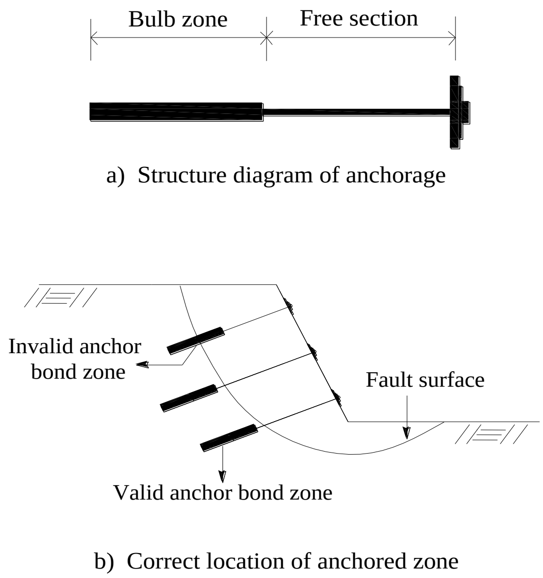

Figure-3. Anchorage system characteristics (modified from Zhang *et al*, 2016) [5].

The numerical modeling was done on the vertical axis of the anchors, guaranteeing a vertical separation (S_v) between the axes of 3m, and a horizontal separation (S_H) of 2.4m as shown in Figure-4. This geometric configuration was carried out, bearing in mind the typical separations of the anchors in stabilization projects developed in the country.

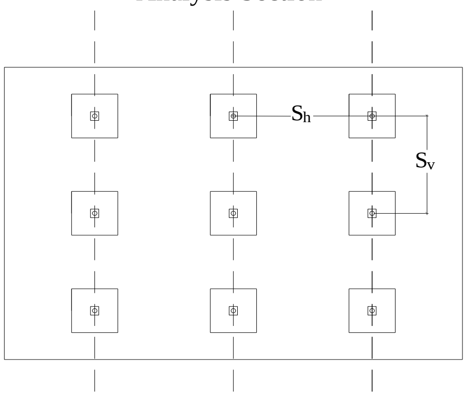

Figure-4. Modeling analysis section.

For the simulation of soil behavior, the *Hardening Soil Hyperbolic Model* was considered. This constitutive model of non-fixed surface allows predicting soil deformations due to loss of lateral confinement, a typical soil condition during the implementation of this type of stabilization system [6].

To evaluate the incidence of the mesh in the analyzed sections, the *Strength Reduction Method* was used, which consists of making a reduction of the parameters that control the shear resistance through the variation of the safety factor, as indicated in the following equation [5].

$$C' = \frac{c}{F_s} \;, \qquad \varphi' = arctan\left(\frac{\tan\varphi}{F_s}\right) \qquad (1)$$

2.4 Analysis Sections and Parameter Variation

Based on the 6 analysis cases raised (see Table-2), variations were made for each of the cases in the size of the concrete blocks and the type of reinforcement. With respect to the size, dimensions ranging from 0.5m to 3m were considered. Regarding the type of reinforcement, *Type A* and *Type B* systems were considered. Based on these variations, 12 sections were considered for each of the 6 cases, for a total of 72 analysis sections. For greater clarity on the variations in terms of dimensions of support surfaces and types of reinforcement, the 12 analysis sections of case 1 are presented in Table-3.

Once the analysis sections were defined for case 1, the same variations were proposed for the other cases, and were obtained from 72 analysis sections as shown in Table-4.

Table 2. Cases used in the parametric analysis.

Case analysis	
Case 1	H=10 m; H:V=0,5:1
Case 2	H=10 m; H:V=0,75:1
Case 3	H=10 m; H:V=1:1
Case 4	H=20 m; H:V=0,5:1
Case 5	H=20 m; H:V=0,75:1
Case 6	H=20 m; H:V=1:1

Table-3. Variation in the dimensions of the support surface, for Case 1 of analysis with height 10m and slope ratio 1:1. B-0.5m represents a reinforcement system with active anchors supported on 0.5m wide concrete blocks as a support surface; and BM-0.5m corresponds to the use of a single torsional mesh strutted with anchors supported on 0.5m wide concrete blocks.

Type A - square concrete blocks of 0.5m width as support surface (B-0.5m).
Type A - square concrete blocks of 1m width as support surface (B-1m).
Type A - square concrete blocks of 1.5m width as support surface (B-1.5m).
Type A - square concrete blocks of 2m width as support surface (B-2m).
Type A - square concrete blocks of 2.5m width as support surface (B-2.5m).
Type A - square concrete blocks of 3m width as support surface (B-3m).
Type B - square concrete blocks of width 0,5m as support area and simple torsional mesh (BM-0,5m).
Type B - square concrete blocks of width 1,0 m as supporting surface and single torsional mesh (BM-1m).
Type B - square concrete blocks of width 1,5 m as supporting surface and single torsional mesh (BM-1,5m).
Type B - square concrete blocks of width 2,0 m as supporting surface and single torsional mesh (BM-2m).
Type B - square concrete blocks of width 2,5 m as supporting surface and single torsional mesh (BM-2,5m).
Type B - square concrete blocks of width 3,0 m as supporting surface and single torsional mesh (BM-3m).

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Table-4. Number of sections analyzed.

Cases of analysis	Number of sections analyzed
Case 1 (C1): H=10 m; H:V=0,5:1	12
Case 2 (C2): H=10 m; H:V=0,75:1	12
Case 3 (C3): H=10 m; H:V=1:1	12
Case 4 (C4): H=20 m; H:V=0,5:1	12
Case 5 (C5): H=20 m; H:V=0,75:1	12
Case 6 (C6): H=20 m; H:V=1:1	12
Total of sections analyzed	72

3. RESULTS AND DISCUSSIONS

The 10m and 20m high slopes were evaluated for different slopes and bearing surface dimensions. The dimensions of the square blocks varied from 0.5m to 3m wide, and it was found that the safety factor is directly proportional to the size of the concrete blocks. On the other hand, it was observed that the use of the single torsional mesh does not have an impact on the factor of safety, since it did not present significant variations for any of the cases of analysis (see Figure-5). It should be noted that for the determination of the % of length covered, the relationship between the length of the support surfaces with respect to the axis of analysis, and the total length of the face of the slope was taken (see Figure-4).

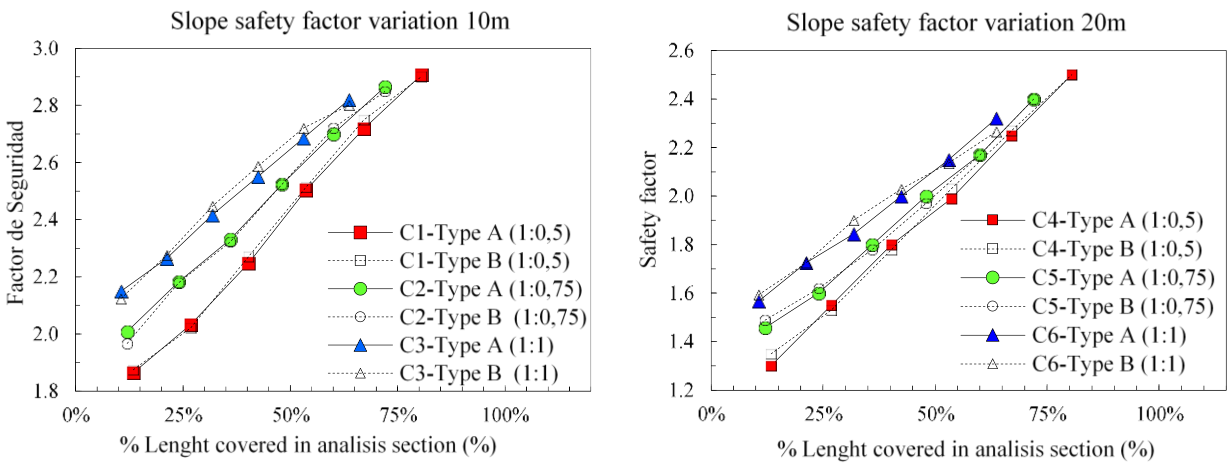

Figure-5. Variation of the safety factor vs. the % of area covered by the individual concrete

Figure-6 shows how the horizontal forces on the face of the slope vary for the two types of reinforcement: *Type A* reinforcement system (0.5m concrete blocks (D-0.5m)) and *Type B* reinforcement system (single-twist mesh insulated concrete blocks). According to the results, it was found that the use of the single torsion mesh does not influence the stress distribution on the face of the slope, and it can be observed that the stresses are concentrated under the concrete blocks regardless of whether or not the single torsion mesh is used [1, 7, 8].

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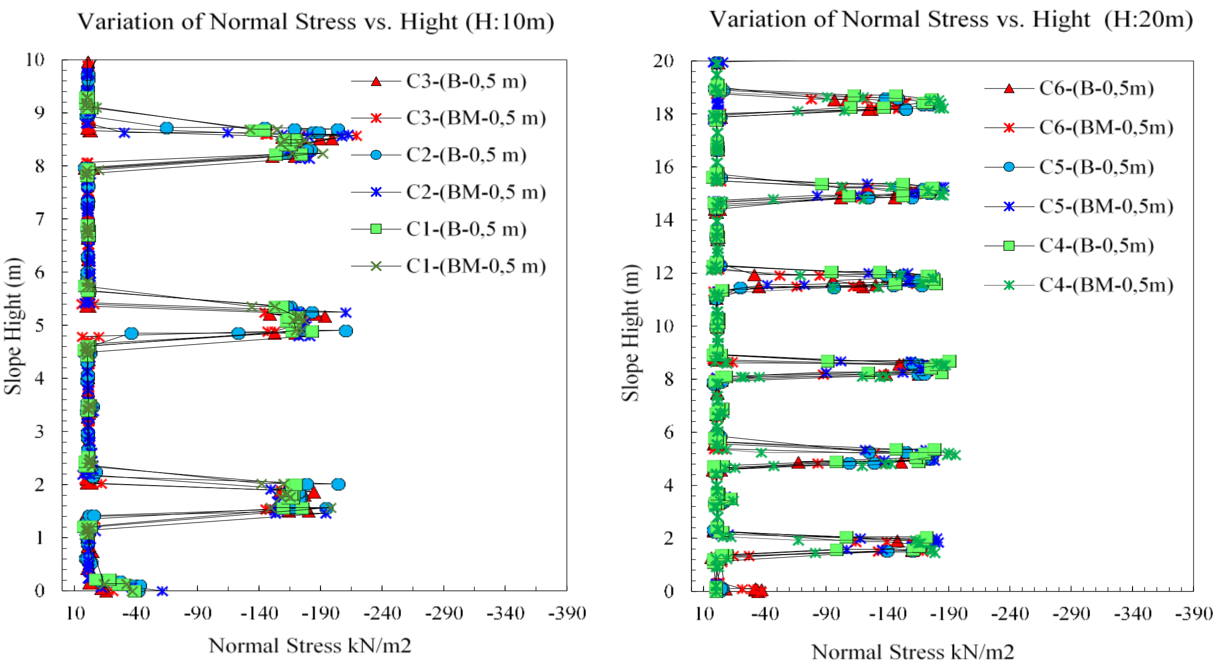

Figure-6. Variation of normal stresses on the face of the slope for the 6 analysis cases.

CONCLUSIONS

An analysis of the influence of the use of single torsional mesh on the reinforcement of slopes with active anchors supported on individual surfaces was carried out. The analysis allowed to clarify different doubts about the influence of the mesh on the factor of safety, and the distribution of stresses on the face of the slope.

The horizontal deformations and safety factors found in the *Type A* and *Type B* reinforcement systems did not present any differences. This is because the use of the mesh does not provide an active confining force on the soil above the face of the slope, and its main function in practice is to reduce erosion problems on the face of the slope.

A concentration of normal stresses was found under the concrete blocks in the *Type A* and *Type B* reinforcement systems. Therefore, the areas not covered by the concrete blocks do not have any active containment.

Slopes that are reinforced with anchors supported by concrete blocks are susceptible to erosion problems, and the use of mesh can help control this problem.

ACKNOWLEDGEMENTS

The authors thank Surcolombiana University, National University of Colombia and EAFIT University for their collaboration during the development of this study.

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