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Numerical Analysis and Influence of the Parameters on Slope Stability

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Abstract**—**A designing of a structure requires its realization on rough or sloping ground. Besides the problem of the stability of the landslide, the behavior of the foundations that are bearing the structure is influenced by the destabilizing effect of the ground's slope. This article focuses on the analysis of the slope stability exposed to loading by introducing the different factors influencing the slope's behavior on the one hand, and on the influence of this slope on the foundation's behavior on the other hand. This study is about the elastoplastic modelization using FLAC 2D. This software is based on the finite difference method, which is one of the older methods of numeric resolution of differential equations system with initial and boundary conditions. It was developed for the geotechnical simulation calculation. The aim of this simulation is to demonstrate the notable effect of shear modulus « *G* », cohesion « *C* », inclination angle (edge) « β », and distance between the foundation and the head of the slope on the stability of the slope as well as the stability of the foundation. In our simulation, the slope is constituted by homogenous ground. The foundation is considered as rigid/hard; therefore, the loading is made by the application of the vertical strengths on the nodes which represent the contact between the foundation and the ground.

Keywords**—**Slope, shallow foundation, numeric method, FLAC 2D.

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I. Introduction

A soil mass can have a stress state dependent both on the type of the soil and on the history of the stresses undergone by this mass. Numerical modeling of geotechnical problem involving a massive soil and a foundation near a slope requires, therefore, the determination of the initial solid state. If the geometry of the massive is complex-presence of slope, for example- this initialization must be performed numerically. The need to model the deformations of soils under various solicitations imposes a realization of models of behavior through numerical calculation codes [6], [7]. The history of the stresses will be taken into account through the strain hardening variables of the behavior law, reflecting the memory of the material, from simplified numerical procedures reproducing different historics of a slope creation in a soil mass. It is important to check the stability criterion and the one of strain localization simultaneously to better understand the failure mechanism and to detect the slippage area, independently of numerical parameters such as meshing.

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As we have already said, this study is about the elastoplastic modelization, [10], [11]. We will focus on doing a two-dimensional stability analysis of the material applied to a slope with a foundation loading at its edge, and this is done in order to know the various factors affecting its stability.

The stress state in a soil mass in place is highly dependent on the history of the stresses undergone by the massive over time. The modeling of a geotechnical problem by the finite difference method within a soil mass thus poses the problem of initializing the stress field.

When the resistant soil is shallow, we carry out what is called shallow foundations. In the other case, we make deep foundations or semi-deep foundations. The scope for building footings is defined by [1].

For the footings of civil engineering buildings, we refer to the technical rules of modeling and calculation of the foundations of civil engineering structures [2].

Within the meaning of [1], the scope of shallow foundation is defined by a relative depth:

$$D / B < 6 \tag{1}$$

and an absolute depth of 3m, beyond we have deep foundations.

Within the meaning of [2], we consider that a foundation is superficial when its recessed height D is less than 1.5 times its width:

$$D / B < 1.5 \tag{2}$$

II. Modeling of a Soil Mass with a Slope

Numerical modeling of materials is an essential step for the design of structures. This numerical method provides the strain fields, constraints, and failure mechanisms.

The FLAC^{2D} [5]-[8] calculation code used in our modeling is based on the finite difference method. A concept called "Lagrangian method elements" that has been used by the creators of this code. It is a non-traditional application of the explicit finite difference method [3].

The finite difference method is one of the oldest methods of numerical solution of differential equations with initial conditions and boundary conditions [4].

The majority of methods using this technique have recourse to the discretization of the media exclusively with a rectangular meshing.

In this article, we will focus on a two-dimensional stability analysis of the material applied to a slope with an edge

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foundation loading in order to know the different factors affecting its stability.

A. Geometrical Characteristics of the Model

The geometry and dimensions of the model considered are defined on Fig. 1. The solid is subjected to its own weight and has a slope of height h. The surface is inclined at an angle β relative to the horizontal.

Numerical analysis is treated in plane strain in the plane (o, x, y), with boundary conditions in displacements: horizontal displacements are null on the massif vertical limits and the vertical displacements are null at the base. The massif length is 100m while its height is 50m (Fig. 4).

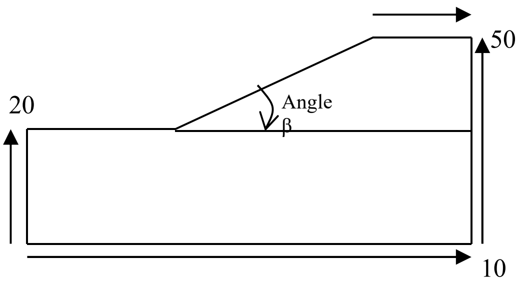

Fig. 1 Slope dimensions

In our procedure, we adopted the elastic-perfectly plastic model, associated to Mohr-Coulomb. For elastic properties of geomaterials, it is preferable in the FLAC code to use the Bulk modulus (volumetric elastic modulus) K and the shear modulus G than the Young's modulus E and the Poisson's ratio ν. [9]-[12].

The slope model has a maximum width of 100 m and a height of 50 m. The slope angle equals (30°). This soil is homogeneous.

TABLE I
MATERIAL (SOIL) PROPERTIES

SYMBOL	QUANTITY	VALUE
γ	density (kg/m3)	2000
K	bulk modulus (MPa)	10
G	shear modulus (MPa)	100
ϕ	friction angle (°)	20

B. Numerical Modeling

Numerical simulations are carried out in large deformations using the finite difference method with the FLAC 2D software. Fig. 2 shows the mesh model of our slope.

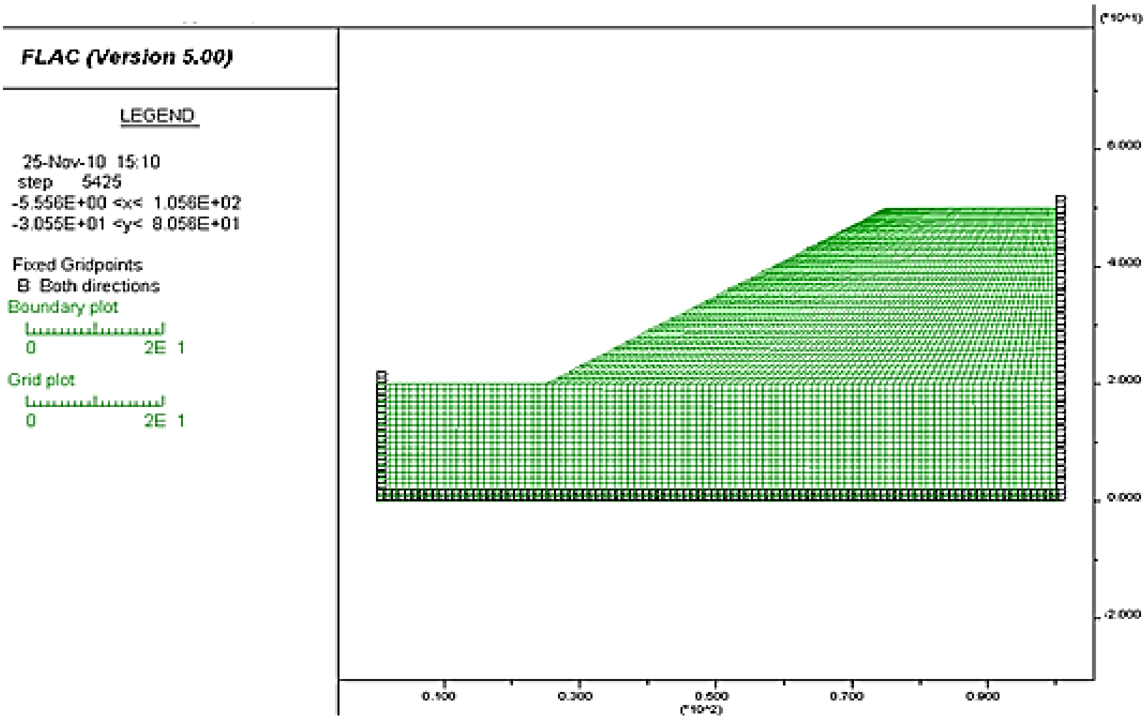

Fig. 2 Boundary conditions with Mesh Massif

III. NUMERICAL SIMULATION, RESULTS AND DISCUSSION

For the simulation process, the foundation is considered rigid, so the loading is done by applying a vertical force on the nodes that represent the contact between the foundation and the soil. Then we record the load through the nodal forces resulting from all the nodes under the foundation.

The modeled slope is subjected to a vertical and uniform loading, namely: a raft of 10m width, which is considered non recessed and transmits uniform vertical pressures q imposed to our massive, exactly on the head of the talus, with $q= 150000KN$ (Fig. 3).

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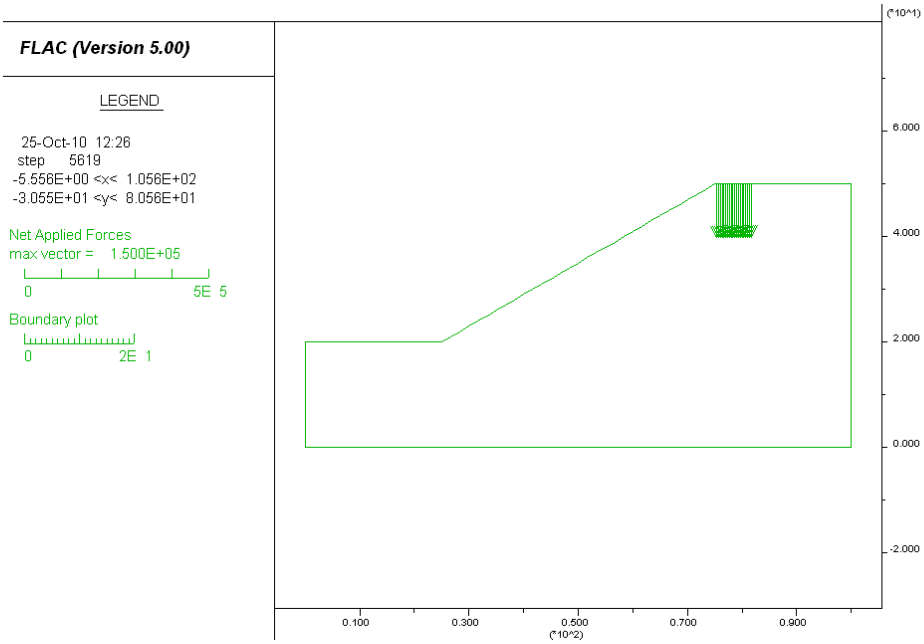

Fig. 3 Localization of the applied load

In our simulation, we are interested to know the different factors influencing the stability of our slope. For this, we vary some characteristics:

A. Slope Angle Variation

The changes in the inclination of the slope may be caused naturally or by artificial causes (water erosion or excavations). In this simulation we are interested much more in displacement vectors where the value of the displacement vector is maximum. This is done by varying the slope angle.

TABLE II
MAX DISPLACEMENT VECTORS ACCORDING TO THE SLOPE

Slope (°)	Max displacement vector (m)
30	1,260E-01
35	1,286E-01
40	1,299E-01
45	1,302E-01
50	1,302E-01
55	1,309E-01

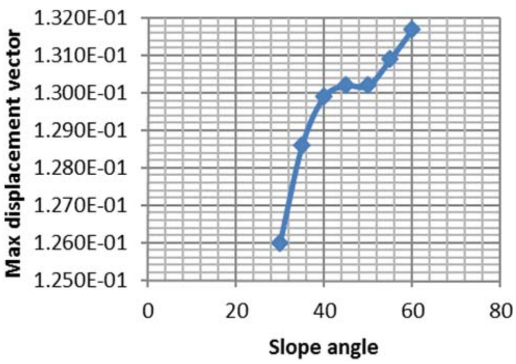

Fig. 4 Max displacement vectors curve according to the slope angle

The increase in the slope gradient causes a stress change in the ground. The highest shear stresses disturb the equilibrium conditions; thus, the displacement increases. So the increase of this angle is a destabilizing factor in our slope. This requires reducing it at maximum; otherwise, we will have to follow certain building methods.

B. Shear Modulus Variation

In order to know the influence of the shear modulus on the stability of our slope subject to this load, we vary the shear modulus and retain the same characteristics of our slope and the loading of the foundation. (Fig. 5) shows the results of modeling.

TABLE III
MAX DISPLACEMENT VECTORS VALUES ACCORDING TO THE SHEAR MODULUS

Shear modulus (Pa)	Max displacements vector (m)
1,00E+09	1,260E+00
1,10E+09	1,259E+00
1,20E+09	1,257E+00
1,30E+09	1,256E+00
1,40E+09	1,254E+00
1,50E+09	1,254E+00
1,60E+09	1,252E+00
1,70E+09	1,252E+00
1,80E+09	1,251E+00
1,90E+09	1,250E+00

Our curve is decreasing. It is clear that the displacement decreases by increasing the shear modulus. We can say that the module *G* has a remarkable influence on the movement, since it is noticed that the smallest displacement is obtained with the greatest shear modulus *G*. So we can deduce that the shear modulus *G* is an important factor for the slope's stability; that is why, we must try to increase this parameter.

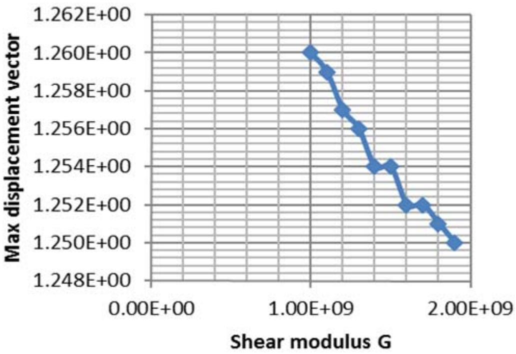

Fig. 5 Max displacement vectors curve according to the shear modulus

C. Cohesion Variation

In this analysis, the "C" Cohesion is variable and the other characteristics of our slope and loading are constant.

A decreasing curve is obtained; cohesion has a remarkable influence on the max displacement vector. We note that the smallest result is obtained with the greatest cohesion so that the cohesion ensures stability since there is a contact between the grains.

D. Load Distance Variation

For this simulation we are interested in some precious places that are located on the surface of our slope, these areas are characterized by four points *A*, *B*, *C* and *D* from the head to the foot of the slope (Fig. 7).

TABLE IV
MAX DISPLACEMENT VECTORS VALUES ACCORDING TO THE COHESION

Cohesion(Pa)	Max Displacement vector (m)
8,00E+04	1,365E-01
8,20E+04	1,339E-01
8,40E+04	1,314E-01
8,60E+04	1,291E-01
8,80E+04	1,268E-01
9,00E+04	1,249E-01

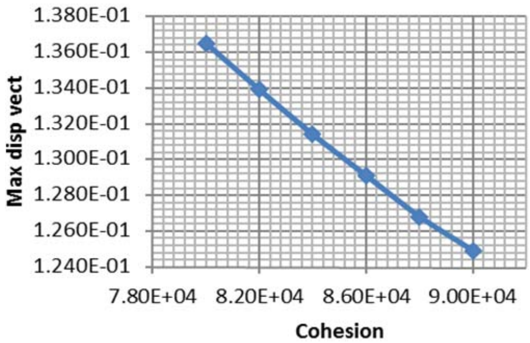

Fig. 6 Max displacement vectors curve according to the cohesion

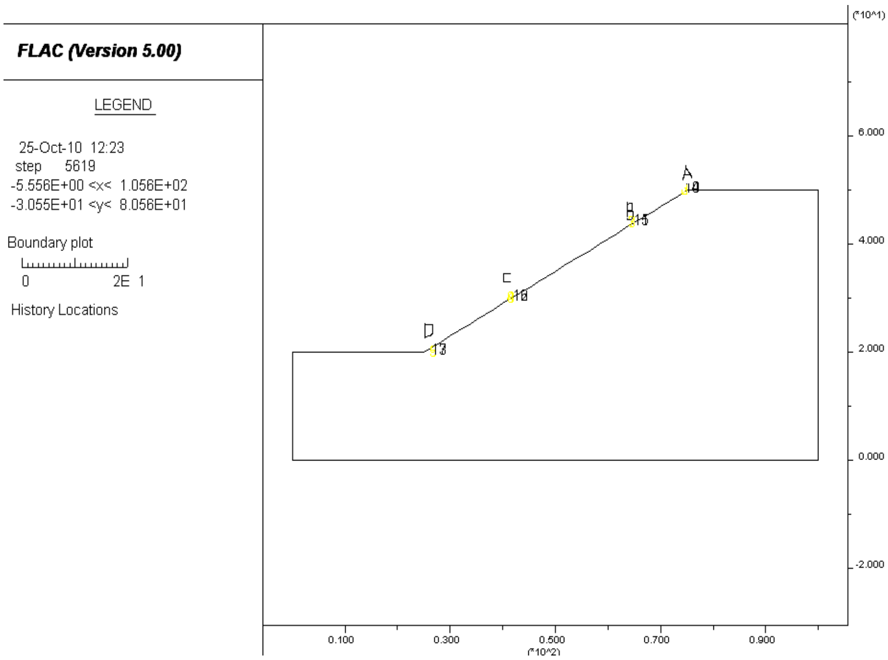

Fig. 7 Localization of the different points of the slope

In our model, the analysis of all horizontal displacement curves clearly shows that the largest horizontal displacements are obtained in the points that are in the middle of the surface of our slope namely the points *B* and *C*, whereas small displacements are observed at the two ends of the slope, and this is due to the different loading distances from to the talus head. From this, it can be considered that in our case the critical areas are those in the middle of the slope, where there is the largest displacement, whereas for the vertical displacement curves, larger displacements are obtained at the highest points *A* and *B*, and this is due to the different loading distances from to the talus head. (Fig. 8)

To observe the influence of the slope on our foundation, we are interested in knowing the state of stresses and

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displacements in the vicinity of this latter (foundation). For this, we keep the same simulation and we will focus on the historic displacements curves (horizontal and vertical) and on the historic constraints curves (horizontal and vertical) corresponding to the node situated in the middle of the foundation base (Fig. 9).

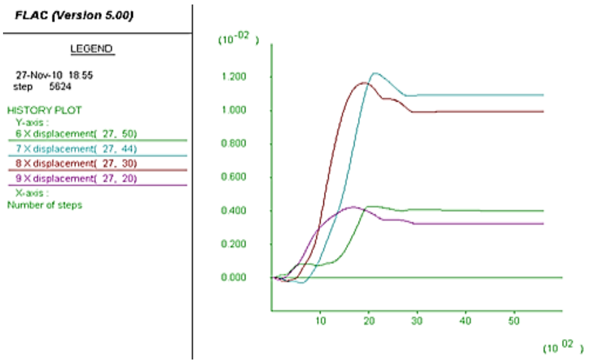

Fig. 8 Historic of horizontal displacements

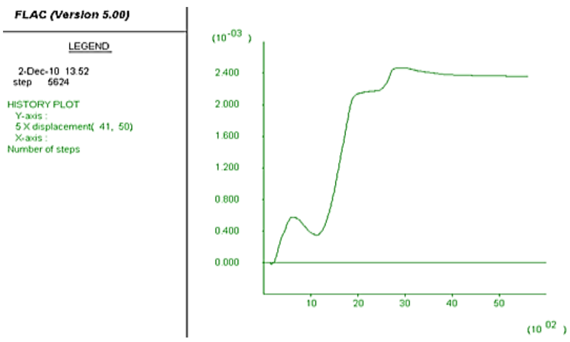

Fig. 9 Horizontal displacements historic

TABLE V
MAX HORIZONTAL DISPLACEMENTS ACCORDING TO THE LOAD DISTANCE

Distance from load to the talus head (m)	Max horizontal displacements (m)
0	1,260E-01
5	1,286E-01
10	1,299E-01
15	1,302E-01

We deduce that the slope is a destabilizing factor as it largely influences the stability of the shallow foundations. This requires to move away the constructions from slopes.

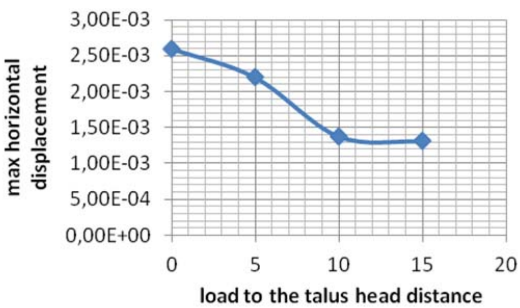

Fig. 10 Max horizontal displacement curve depending on the distance of the load to the head of the talus

IV. CONCLUSION

The numerical analyses performed in this paper allow interpreting:

- The influence of the shear modulus, cohesion and the slope angle on the maximum displacement vector, which means their influence on the behavior of our massive, namely our slope stability.
- The influence of the distance from the foundation to the talus head (distance between the foundation and the talus head is variable), and knowing the critical areas where there is the largest displacement, and this is based on the horizontal and vertical movements' stories and on the horizontal and vertical constraints.
- The influence of the slope on the behavior of the shallow foundation (slab) by varying the distance between this latter and the head of the talus, and this by trying to know the stress state and the displacement in the vicinity of the foundation, (in the middle of its base).

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