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Full Length Research Paper

Nomograms for calculating the safety factor of homogeneous earth dams in long-term stability

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The slope stability analysis is routinely performed by engineers to evaluate the stability of embankment dams, road embankments, river training works, excavations and retaining walls. To ensure the geotechnical safety of the dam, the slope of embankment must be correctly designed and constructed. In this work, by applying the modified method of Bishop, an attempt was made to construct sets of nomgrams for the calculation of the safety factor of homogeneous earth dams under long term stability, which allow the user to get the optimal safety factor of the dam, immediately, according the material classification and the parameters of design, height and slope.

Key words: Nomograms, safety factor, homogeneous earth dams.

INTRODUCTION

In the state of Annaba, Eastern Algeria, the construction of homogeneous earth dams increased, especially in areas dominated by agriculture. By considering the questions of security, it is absolutely necessary to study their stability in the various cases of loading especially in long-term case. The most popular method for stability analysis of these structures is the limit equilibrium method (LEM), this method is widely used by engineers and researchers and it is a traditional and well established method. Although the (LEM) does not consider the stress strain relation of soil, it can provide an estimate of the safety factor of a slope without the knowledge of the initial conditions, with the result that the (LEM) is favored by many engineers. The LEM is well known to be a statically indeterminate problem, and assumptions on the distributions of internal forces are required for the solution of the safety factor (Cheng, 2006). A relatively large number of methods have been developed. Among them, the slices method. In this method, the material above the slip surface being divided into a number of usually vertical slices.

Improvements in the methods have aimed on reducing the error due to oversimplifying the shape of the slip surface and the resulting incorrect determination of the normal stress. The latter is potentially important for frictional materials where the shear strength will depend on the normal stress. The principal methods are described in the papers of Fellenius (1936), Bishop (1955), Morgenstern (1965), Janbu (1973), and Sarma (1979). In this work, by applying the modified method of Bishop, an attempt was made to construct sets of nomograms for calculating the safety factor (SF) which characterizes the stability of these homogeneous structures. As such, many calculations would be carried out starting from the structure of simplified cross of the dam. Lastly, nomograms remain a contribution approach based on variations of the main properties in the long-term stability (Lakehal, 2011).

METHODOLOGY

Data

The data used are related to the geometrical properties of the works, mechanical properties of materials, and software employed (Lakehal, 2008).

Geometrical properties of the works

In Figure 1, the simplified cross adapted for calculations, which represent the inclination (1/X, X in meter) for the upstream and

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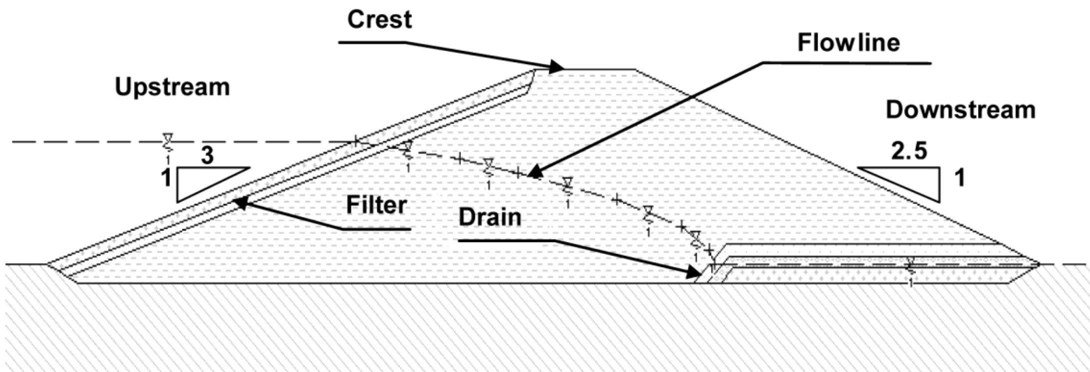

Figure 1. Cross simplified adapted for calculations.

downstream slope, are 1/3 and 1/2.5, respectively. A filter of two layers was seen for the upstream slope with a thickness of 0.2 m fine sand and 0.3 m coarse sand, while a drain with length fixed at 1/3 of the width of dam with a thickness of (1 m) constituted the three layers (0.3 m fine sand, 0.3 m coarse sand, 0.4 m gravel) (Lakehal, 2008; Alonso,1996; Colomer, 2009). The geometrical characteristics of the embankment taken into account are:

The width of the crest (b) corresponds roughly to the formula of Knnapen,

$$b=1.65\sqrt{H} \quad (1)$$

H: height of dam in meter, the unevenness {D = Hp + R} (Alonso,1996; Lakehal, 2011).

Mechanical properties of materials

The materials used in construction of these homogenous structures are intact or compacted fine materials, these materials have values of cohesion (c') and friction angle (φ') seldom out of the following natural limits: (5 to 30 kPa for c' and 15 to 40 for φ'), that is to say a fork of 25 kPa and 25°. We can obtain characteristics which are very poor (c' = 10 kPa and φ' = 20), excellent (c' = 25 kPa and φ' = 35) or average (c' = 20 kPa and φ' = 25) (Alonso, 1996; Degoutte, 2002; Duncan, 2005), the value of the density of these materials is chosen as the average value (USBR, 2001). In this case the density is taken as 20 kn/m^3 (Alonso, 1996; Colomer, 2009).

Software used

The nomograms are results of several calculations by the Geostab software (version 2004) based on limit equilibrium methods. The method of calculation is that of Bishop modified (Géostab, 2004; Hammouri, 2008).

Methods

In this work a series of nomograms for calculating the safety factor of the slope of an homogenous earth dam have been produced (Colomer, 2009).

The first set can be used for dams with height equal 10 m, 20 m and 30 m, with (1/2.5) value of inclination for downstream slope, the values of materials properties varied between: 10° to 35° for effective friction angle (φ'), and 10 kps ,20kps and 30 kps for effective cohesion (c') (Alonso, 1996; Degoutte, 2002; Lakehal, 2008).

The second sets for height equal 10 to 30 m, with different inclinations for downstream slope were analyzed, their values being: 1/2 to1/4 (Lakehal, 2008; Colomer, 2009), with the type of materials very poor (c' = 10 kPa and φ' = 20) and average (c' = 20 kPa and φ' = 25) (Degoutte, 2002; Lakehal, 2008) .

The nomograms developed in this study allow the user to know immediately the safety factor (SF) of dam with a known height, inclination and mechanical properties of materials.The value of safety factor SF =1.5 is set as a minimum value to ensure the stability of earth dam in long-term stability (Alonso, 1996; Degoutte, 2002). The stability of downstream slope should be analyzed (US Army, 2003).The first nomograms are represented in Figure 2 for downstream slope.

Figure 2 show results for embankments with a height of less than 30 m and inclination of (1/2.5), the nomograms have a decimal scale to interpolate values of SF in the case when the interpolation is required.The second nomograms are represented in Figure 3 for downstream slope.

Figure 3 show the results for embankments with a height of less than 30 m with different values of inclination (1/2.5 to 1/4), in this case the user can determine the optimal safety factor from the height of the dam, type of materials and the inclination of slope. It can also determine the optimal inclination adopted for an optimal safety factor in the opposite sense.

RESULTS AND DISCUSSION

Practical implementation

In Figure 2, four different nomograms are shown, in which tow practical implementations have been applied:

(i) The implementation of the nomograms on an earth dam with a height of 10 m, the inclination of downstream slope is (1/2.5) and the width of the crest is 5 m, the effective cohesion: c' = 22 kps, effective friction angle: φ' = 15°, the result of SF is located between: 1.9 to 2.1 and by interpolation, the result of SF is 2.056. For the same dam, we can obtain the optimal safety factor SF =1,5 with the values of materials proprieties: c' = 17 kps, φ' = 12°.

(ii) The implementation of the nomograms an earth dam

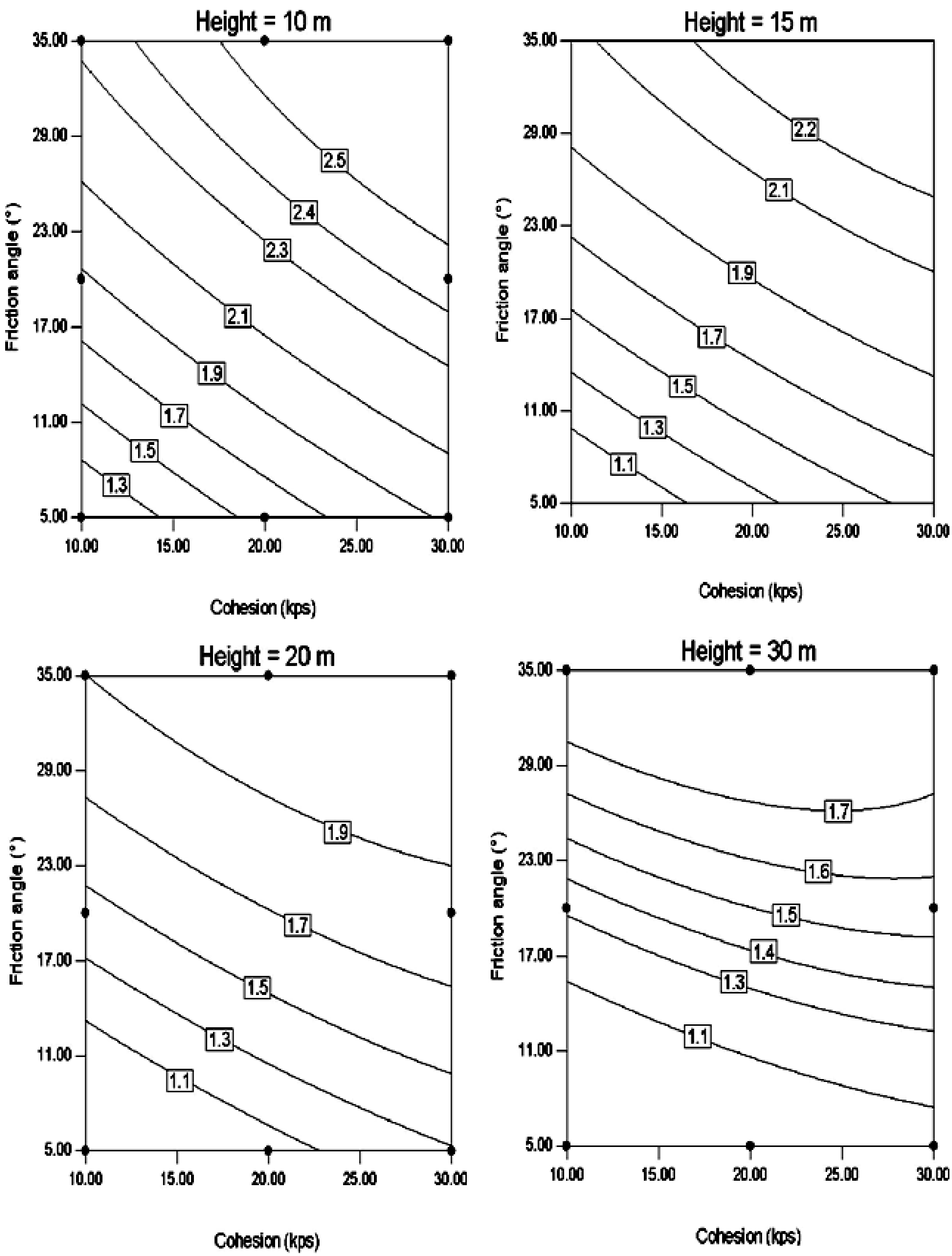

Figure 2. Set of nomograms for calculating the SF of earth dam between 10 to 30 m height.

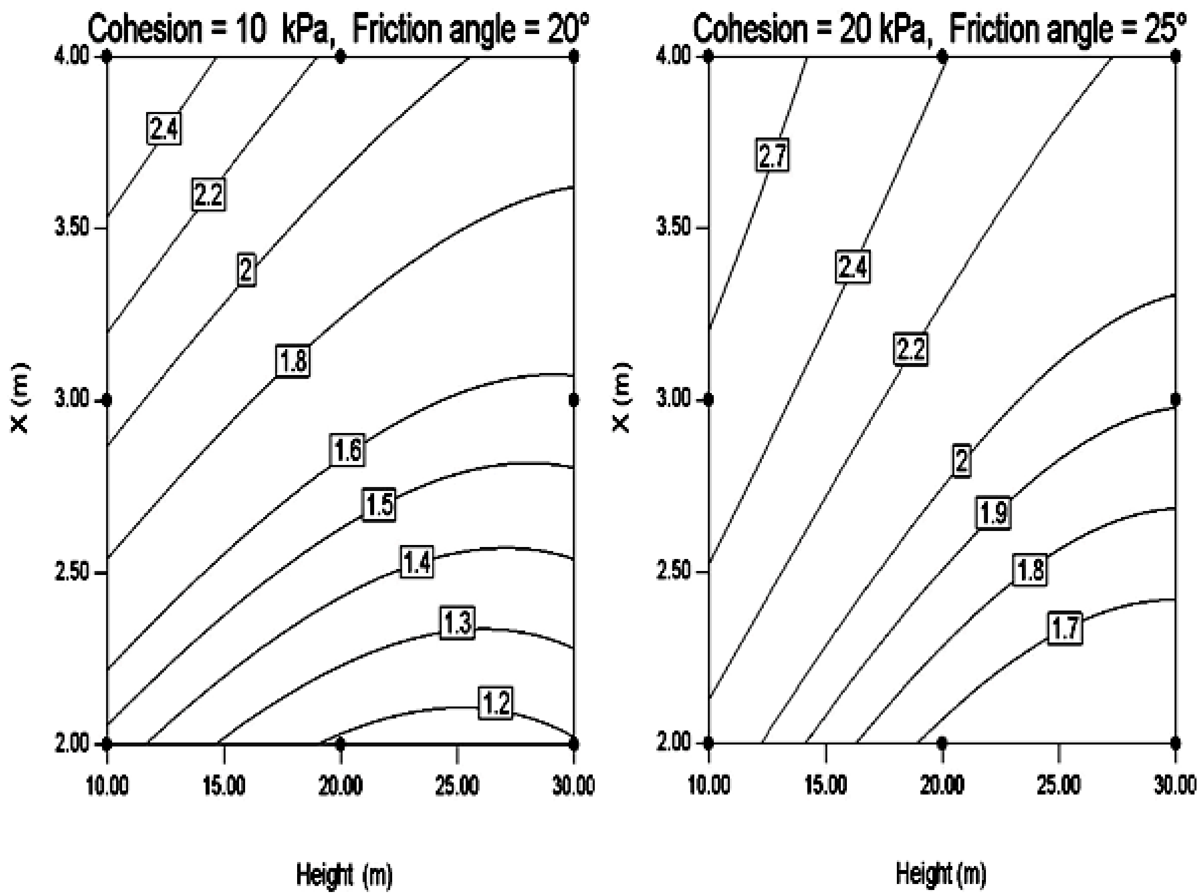

Figure. 3. Set of nomograms for calculating the SF of earth dam between 10 to 30 m height.

with a height of 20 m, the inclination of downstream slope is (1/2.5) and the width of the crest is 7 m, the effective cohesion: c' = 22 kps, effective friction angle: φ' = 15°, the result of SF is located between: 1.3 to 1,5, is lower than 1,5, to get a value of SF equal 1.5 or higher one needs to increase the inclination of downstream slope at (1/2.75). In Figure 3, the implementation of the nomograms an earth dam with a height of 20 m, the inclination of downstream slope is (1/2.75) and the width of the crest is 7 m; with the type of materials is very poor (c' = 10 kPa, φ' = 20°), the result of SF is located between: 1.5 to 1.6 and, by interpolation, the result of SF is 1.575, the process is similar as in other nomograms.

Conclusion

The nomograms shown in this paper are a suitable tool for quickly calculating the SF of homogenous earth dams (up to thirty meters high). They do not need complicated calculations or computer programs. It is only necessary to know its mechanical and geometrical properties (height and inclination of slope).

Every nomogram allows the inclination of the slope in a dam to be optimized. Hence, for a given height of dam, and according to the type of material and optimal safety factor, the nomogram will give the optimum inclination of a slope that is stable. Although, the nomograms remain a contribution approach based on variations of the main properties in the long-term stability.

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