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STABILITY ANALYSIS DURING RAPID DRAWDOWN OF AN EARTHEN DAM REINFORCED WITH GEOGRID

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Abstract- This article examines the influence of geogrid on the behavior and stability of a small homogeneous earth dam during the rapid drawdown of the dam reservoir using the finite element method (FEM). PLAXIS 3D is used here to study the impact of the length of geogrid layers by FEM. The small Macheraa homogeneous earth dam in Algeria is considered for this analysis. The body of the dam is made of clay, while the geogrid is used as a reinforcement material for the body of the dam, where the distance between the layers of geogrid is fixed in the body of the dam while its lengths are varied according to the width of the dam's base on the one hand and the width of its top on the other. The factor of safety of the dam during rapid drawdown is calculated for the different cases of variation of the geogrid layers lengths. The results obtained show that the safety factor values gradually increase when the lengths of the geogrid layers are less than the length of the slip area, while the safety factor begins to increase significantly when the lengths of the geogrid layers are greater than the length of the slip area, i.e. there is a proportional relationship between the lengths of the geogrid layers and the safety factor value of the dam body during rapid drawdown conditions of the dam reservoir.

Keywords: Earth Dam, Stability, Geogrid, Rapid Drawdown, Plaxis 3D.

1. INTRODUCTION

A dam is an impermeable hydraulic construction that is erected across a river to create a reservoir on the upstream side of the river for holding water for various uses [1]. Simple earthen dams act as a stopgap against slipping and flipping by supporting themselves. In areas where it would be expensive to produce or import concrete, they can be quite cost-effective [2]. The earthen dam failure has the potential to result in more death and damage than the breakdown of any other man-made building, it is particularly concerning [3, 4]. Several parameters affect the stability of the earthen dams, the geometry of the dam, the geotechnical characteristics of the foundations and the materials contuating the dam body, the internal forces (infiltrations) and the external forces (earthquakes) applied to the dam [5, 6].

The stability of an earthen dam takes extensive computation and analysis of numerous site-specific uncertainties to evaluate the safety characteristics of dams in a particular design [7,8]. The behavior of earthen dams built in narrow valleys is somehow more challenging than high dams. their actions are influenced by the size, slope, and placement of the clay core. (Seed, 1973; Seed, 1979; Chatre and Muralidhar, 2010; Feng et al., 2010). Improving the behavior of an earthen dam requires on one hand reinforcing the construction materials of the dike with synthetic fibers [9, 10] and on the other hand the reinforcement of the dam body with geogrids [11]. The article presents the results of finite element modeling of the stability of Macharaa small earthen dam using the PLAXIS 3D software to determine its static stability and the reinforcement impact by geogrids. The variation of the length of the geogrids according to the width of the dick of the dam was the main parameter which was modified in the study to know the influence of this parameter on the stability of the dam.

2. METHODS AND MATERIALS

2.1. Presentation of the Study Zone

2.1.1. Geographical Situation and Parameters of the Macharaa Dam

The Macharaa small earthen dam (4002492.79 N-649248.60 E) is located 10 km from the city of Bordj Bou Arreridj in northern Algeria. Figure 1 shows the cross section with the different components of the dam. The geometric parameters of the dam are shown in Table 1.

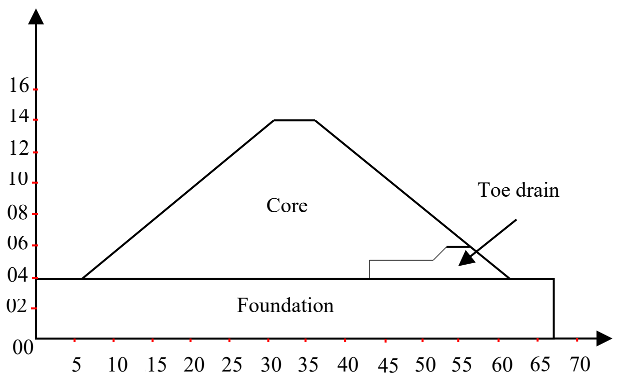

Figure 1. Standard cross-section of the dam studied [12]

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Table 1. Geometrical characteristics of Macharaa dam [12]

Characteristics of Macheraa earthen dam	
Dam height (m)	10
Crest length (m)	195
Crest width (m)	5
Max width at base (m)	10
Slop of upstream	2.5 H/1V
Slop of downstream	2.5 H/1V

2.1.2. Parameters of the Materials of the Dike and the Foundation Soils

The geotechnical characteristics of the different component of Macharaa small earthen dam are presented in Table 2.

Table 1. Geotechnical properties of different component of Macharaa dam [12]

No	Soil designation	γ (KN/m^3)	C (KN/m^2)	φ (°)	E (KN/m^2)
1	Core	21	2	27	1500
2	Filter	20	00	38	30000
3	Foundation	21	1	35	50000

2.2. Processing and Application

One of the most commonly used methods for calculating the stability of slopes in general and for calculating the stability of earthy dams in particular is the method of finite element method. Because of its algorithmic assumptions which are used for analysis in continuous environments, the FEM has a good efficiency in the studies of soils and alluviums. Plaxis 3D software is one of the geotechnical software's that have been introduced and developed to analyze stability, subsidence, deformation, compaction, leakage and consolidation under static and dynamic conditions.

In the present study, we consider a homogeneous earth dam formed on an impermeable foundation. The dam is first studied without using geogrid reinforcement (Figure 2) and then vertical geogrid layers are added to the cross section of the dam. To fully understand the different cases studied in this paper, the different lengths of the geogrid layers is denoted by *Li*, *b* The width of the crest of the dam and the width of its base is denoted by *B*. The geogrid material is a uniaxial type with a rigidity value of *EA*=100kn/m and the distance between geogrid layers is fixed at 1m. Five study cases with different lengths of the geogrid layers a, Figures 2-6.

- Case 1: Barrage without reinforcements.
- Case 2: $0.25b \leq L_i \leq 0.25B$
- Case 3: $0.5b \leq L_i \leq 0.5B$
- Case 4: $0.75b \leq L_i \leq 0.75B$
- Case 5: $b \leq L_i \leq B$

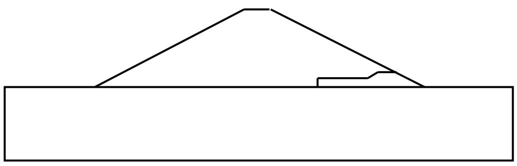

Figure 2. Numerical model of the Macharaa dam without reinforcement

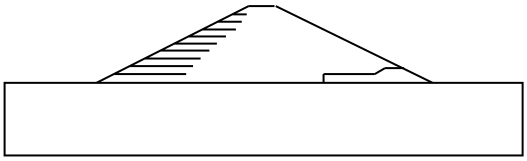

Figure 3. Numerical model of the Macharaa dam with reinforcement by geogrid for $0.25b \leq Li \leq 0.25B$

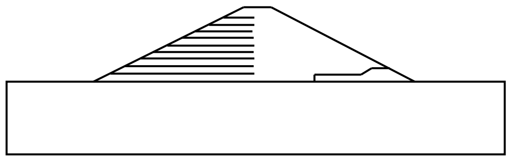

Figure 4. Numerical model of the Macharaa dam with reinforcement by geogrid for $0.5b \leq Li \leq 0.5B$

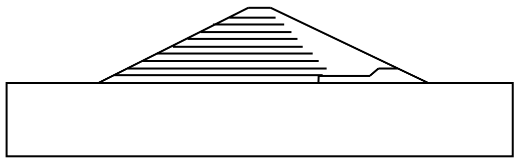

Figure 5. Numerical model of the Macharaa dam with reinforcement by geogrid for $0.75b \leq Li \leq 0.75B$

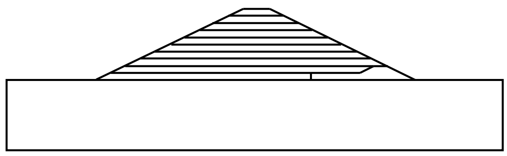

Figure 6. Numerical model of the Macharaa dam with reinforcement by geogrid for $b \leq Li \leq B$

3. SIMULATION RESULTS

Figures 7-11 present the mesh deformation and the maximum value of the total displacement of all the cases studied.

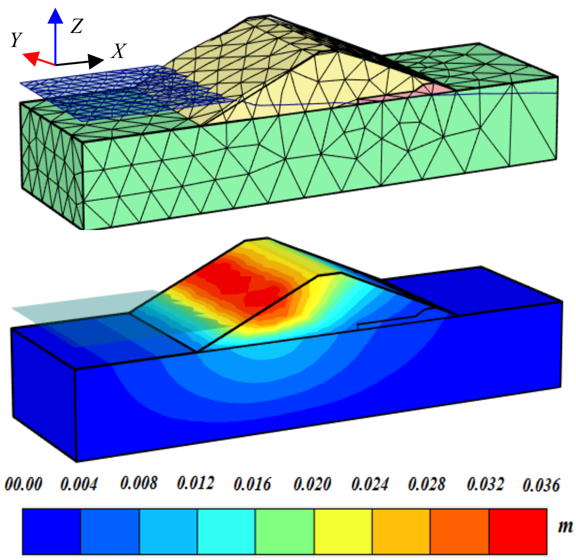

Figure 7. Deformation mesh and total displacements of Macharaa dam without reinforcement (maximum value 0.0365m)

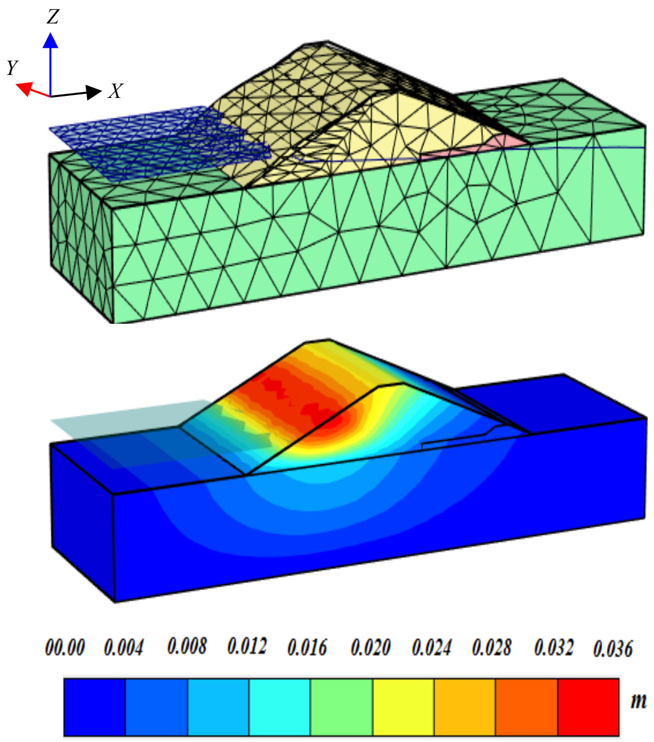

Figure 8. Deformation mesh and total displacements of Macharaa dam with reinforcement by geogrid for $0.25b \leq Li \leq 0.25B$ (maximum value 0.0360 m)

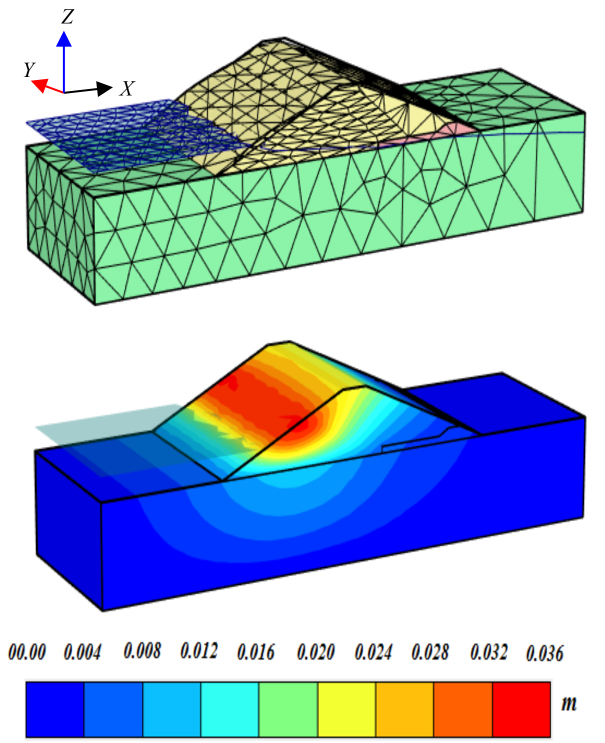

Figure 10. Deformation mesh and total displacements of Macharaa dam with reinforcement by geogrid for $0.75b \leq Li \leq 0.75B$ (maximum value 0.0356 m)

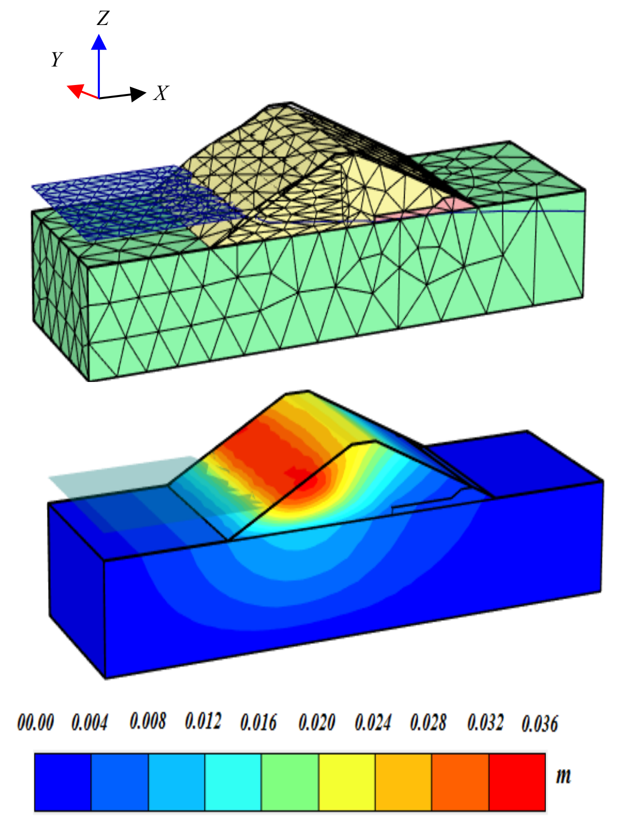

Figure 9. Deformation mesh and total displacements of Macharaa dam with reinforcement by geogrid for $0.5b \leq Li \leq 0.5B$ (maximum value 0.0358 m)

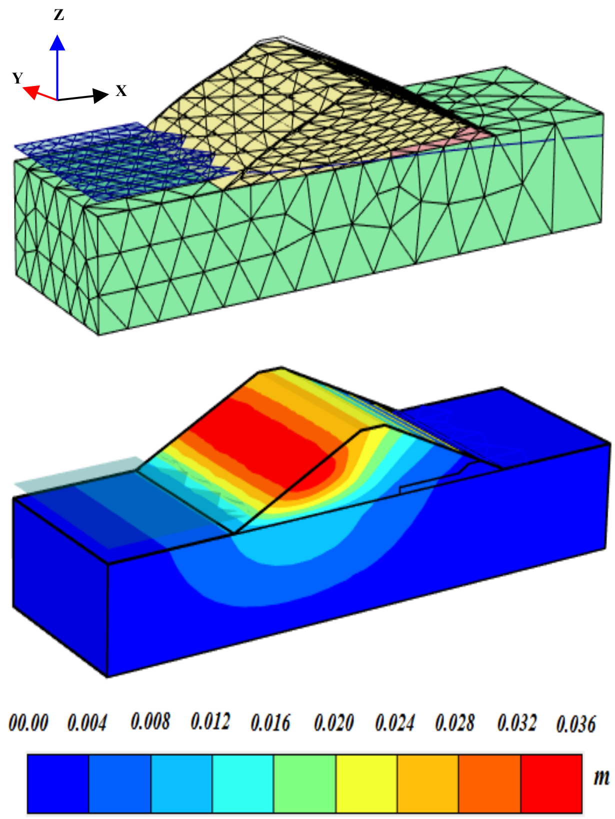

Figure 11. Deformation mesh and total displacements of Macharaa dam with reinforcement by geogrid for $b \leq Li \leq B$ (maximum value 0.033 m)

- The comparisons between Figures 7 and 8 show that the maximum value of the total displacement of the case 2 ($|u|$=0.036 m) has decreased with 1.39% from the case 1 ($|u|$=0.0365 m).
- The Figure 9 show that the maximum value of the total displacement of the case 3 ($|u|$=0.0358 m) has decreased with 0.56% from the case 2 ($|u|$=0.036 m).
- The Figure 10 show that the maximum value of the total displacement of the case 4 ($|u|$=0.0356 m) has decreased with 0.56% from the case 2 ($|u|$=0.0358 m).
- The Figure 11 show that the maximum value of the total displacement of the case 5 ($|u|$=0.033 m) has decreased with 7.3% from the case 2 ($|u|$=0.0356 m).

Table 3 shows the calculated safety factor values of the Macharaa small homogeneous earthen dam for the different cases studied.

Table 3. The results of calculation of the safety factor

Case study	Without reinforcement	With reinforcement by geogrid			
		$0.25b \le Li \le 0.25B$	$0.5b \le Li \le 0.5B$	$0.75b \le Li \le 0.75B$	$b \le Li \le B$
Safety factor value	1.39	1.47	1.73	1.87	2.3

The results found demonstrated that:

- The value of safety factor of the case 2 (F_s=1.47) has slightly increased by 5.76% compared to the case 1 where the dam is not reinforced by the geogrid (F_s=1.39), i.e. the lengths of the geogrid layers are less than the length of the slip zone of the upstream slope and the conditions of the lengths of the geogrid layers are not obvious in this case (Table 3).
- The safety factor value for the case 3 (F_s=1.73) has been significantly increased by 17.69% compared to the case 2 and increased by 24.46% compared to the case 1 where the dam is not reinforced (F_s=1.39) and this shows that the lengths of the layers of the geogrid in this case are slightly greater than the length of the slip zone of the slope upstream of the dam (Table 3).
- The safety factor value (F_s=1.87) for case 4 has slightly increased by 8.09% compared to the previous case (F_s=1.73) and considerably increased by 34.53% compared to the case where the dam is not reinforced (F_s=1.39) and this shows that the lengths of the layers of the geogrid in this case are always greater than the length of the slip zone of the slope upstream of the dam (Table 3).
- The safety factor value (F_s=2.3) has increased significantly by 22.99% compared to the previous case (F_s=1.87) and increased significantly by 65.47% compared to the case in which the dam was not reinforced (F_s=1.39) and this indicates that the lengths of the layers of the geogrid in this case are always greater than the length of the slip zone of the upstream slope of the dam and the dam body is fully reinforced (Table 3).

4. CONCLUSIONS

The following conclusions can be summarized:

- Geogrids have very effective reinforcement mean to improve the behavior of earthen dams.
- The type of geogrid, the distance between the layers and the length of the layers has a very important influence on the behavior and safety of the earthen dam especially during the rapid drawdown of the dam reservoir.
- The length of geogrid layers is in a direct proportion with the safety factor value during rapid drawdown., i.e. there is a proportional relationship between the value of the lengths of geogrid layers and the safety factor value during the rapid drawdown of the dam reservoir.
- The reinforcement is not reliable when the lengths of the geogrid layers are less than the lengths of the slip circle (the reinforced zone will be localized in the slip circle).

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