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INFLUENCE OF DEFORMATION MODULI ON THE SETTLEMENT OF EARTH DAMS

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ABSTRACT: The efficiency of compaction of earth dam's embankment is influenced by the initial characteristics of the soils, namely the deformation modulus and density. These two parameters automatically affect the deformations of the dam which can directly impact on its safety. The modeling of these deformations is an essential investigation allowing the comprehension of the dam's behavior. The main objective of modeling is to analyze the behavior of the dam and compare it with monitoring data. A lot of difficulties are recorded for the estimation of embankments deformation moduli required for modeling. A parameterized analysis in relation to the variation of this parameter is necessary for the estimation of earth dam's settlement. The present study concerns the parameterized analysis of the correlation between the parameter influencing compaction, especially deformation modulus, and the deformations of the dam. An application carried out on the Boughrara dam in the region of Tlemcen in the north-west of Algeria is presented. The modeling result is compared with the monitoring measurements of dam. This study led to the verification of the compatibility, for different values of deformation modulus, between the settlement of the dam by modeling and by monitoring in order to validate the mechanical behavior of the dam.

Keywords: Earth dam, Deformation, Modeling, Boughrara, Monitoring

1. INTRODUCTION

The important deformations of the earth dam occur during the construction of embankment. These deformations are caused by the increase of the effective stresses at the level of layers during the construction as well as by creep effects. The influence of the characteristics of embankment soils, especially their deformation moduli obtained after compaction, on the settlement of earth dams is significant. The core settlement of dams has always been a concern for designers and researchers because of the difference in rigidities between this core and dam refills. The core, with a significant vertical deformation, transfer loads to stiffer refills. This load transfer occurs by shear stress arising at the interface of the two soils.

Deformability is characterized by a modulus describing the relationship between the applied load and the resulting strain. The fact that soils do not behave elastically has prompted the usage of the term modulus of deformation rather than modulus of elasticity or Young's modulus [1]. For each soil, there is not a single deformation modulus, but a large number of moduli. It remains to choose the one that is the most appropriate. Feedback experience and monitoring measurements are of highest importance [2].

The large number of moduli requires the use of modeling. Finite element method is used very often in the design or in the verification of the behavior of earth dams. The finite element method is used in the analyses of behavior through calculation of displacements, strains, and stresses in the structure caused by changeable loading or boundary conditions. The values calculated may be compared with measured values giving information on the actual behavior of the structure [3].

Monitoring is important for a better and safer design of the future dams through the verification of the design parameters where the geotechnical parameters are of the highest importance. Therefore, the comparison of the monitored data with the predicted data obtained during the design may give very important information concerning the geotechnical parameters [4].

An application was undertaken on the Boughara dam with central core at a height of 61 m. Thus, a modeling tool allowing the evaluation of the deformations of the dam in relation to the characteristics of embankment soils and their compaction conditions has been done. This modeling resulted in a parameterized analysis based on the relationship between settlements and the variation of the deformation modulus E. The analysis was carried out through the study of total stress fields and vertical deformations at the core and the refills of the dam. In modeling, we have modified the values of deformation moduli changing from 10 to 60 MPa, taking into account the differences in rigidities between the core dam and its refills. The use of monitoring measurements was introduced in order to compare the settlement predicted in the initial project and those recorded at the end of the dam construction. The monitoring measures were also used to validate the choice of deformation modules during the design of the dam.

2. BOUGHRARA DAM OVERVIEW

Boughrara dam is located on Tafna River near the city of Tlemcen, in the north west of Algeria. The dam, which started distributing water in November 1998, after 04 years of construction, has a dual objective: providing drinking water and industrial water to the region of Maghnia (county of Tlemcen) and allowing the transfer of water to the city of Oran via the Zouia mountain.

The project includes the following structures: a zoned dam, with a central core of 61m of height mobilizing 177Hm^3, main spillway weir on the right bank (Q= 3 000 m^3/s), fuse spillway embankment on concrete slabs on the right bank (Q = 2 880 m^3/s), an injection and drainage gallery below the dam and the main spillway, an intake tower, and a diversion tunnel, converted to serve as a technical gallery [5].

Fig.1 and Fig.2, show, respectively, the plan view of the Boughrara dam structures and the typical cross section of the dam.

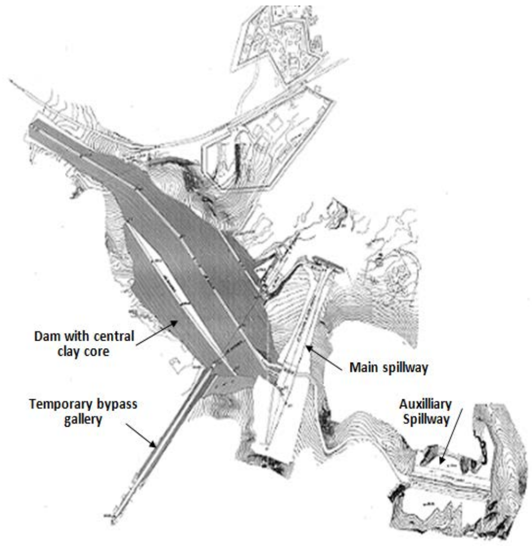

Fig.1 Plan of dam’s structures [6]

The dam is composed of a central clay core T_1 and rollers-gravels refills T_2 and T_3. For drainage and protection against regressive erosion, filters and drains denoted F are projected.

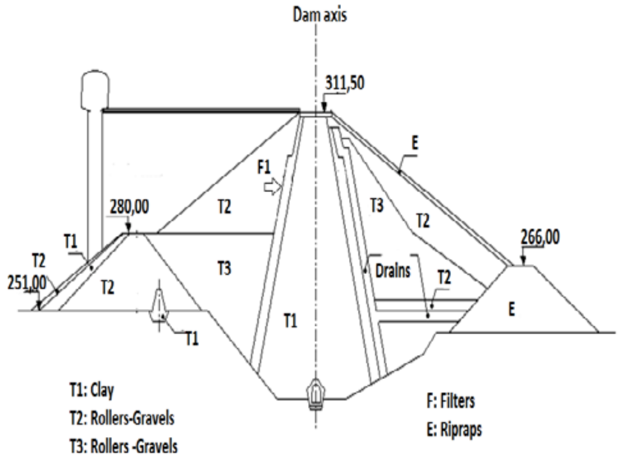

Fig.2 Typical cross section of the dam [6]

3. ANALYSIS OF THE INFLUENCE OF THE DEFORMATION MODULUS ON THE DAM SETTLEMENT

The mechanical properties of a soil vary according either to the nature of the soil, or to the density, the initial void index and the applied speed deformation. In general, the modulus of deformation of a soil depends on the level of deformations, on the density and the index of the initial voids, and on the state of stress.

For numerical modeling, the chosen module must be compatible with the law of behavior (elastic or elasto-plastic) [7].

The application of law of evolution of the deformation moduli on the calculation of the deformation of the geotechnical structures obviously passes through a validation, with a comparison of the results of calculation with the real behavior [8]. It should be noted that for the same soil, this module present a great variation and imposes some constraints for its exact choice [9].

- Clay : 2 à 30 MPa
- Sand : 10 à 100 MPa
- Soft rock : 500 à 10 000 MPa.

For a better evaluation, the moduli are derived from measurements of vertical settlement during construction and the calculated vertical load above the settlement gage [10].

3.1 Settlement distribution

Referring to Fig.3, the part of height z already in place, undergoes a vertical deformation under the effect of the overload (H-z) ɣ. The deformation d of a layer is a function of tress and of the deformation modulus. The distribution of settlements according to the height of the soil is parabolic. This relation is theoretical. In fact, the modulus of deformation is not constant over the height of the soil and the overload is triangular [11].

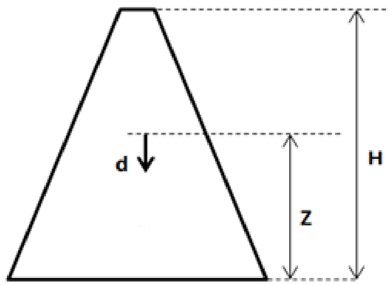

Fig.3 Deformation of dam's layers (central core) depending on overloads

3.2 Settlement of the dam

The ANSYS calculation code used for modeling is based on the finite element method. This program adapts to several types of structural behavior such as linear and nonlinear elasticity and plasticity. The stress-strain curve includes the elastic slope and the tangent modulus. The criterion of plasticity used is that of Von Mises.

The objective of the modeling is to analyze the influence of the variation of the mechanical parameter "deformation modulus E" versus the deformations of the dam. In this work, several modeling cases were considered. In order to analyze the influence of the deformation modulus on the settlements, this parameter was varied for the material of the core. This variation involved 11 modeling cases for a modulus varying from 10 to 60 MPa with a step of 5 MPa.

The characteristics of the materials used for modeling are summarized in Table 1.

Table 1 Characteristics of the dam materials [5]

Materials	Core	Refills
γ_h (KN/m^3)	19,70	21
E (KN/m^2)	2,8.10^4	9,45.10^4
C' (KN/m^2)	22,1	0
ϕ'(°)	19,5	30

For each case, the settlement of the dam was evaluated. Fig.4 to Fig.7, respectively, show the geometrical model of the dam, the vertical deformation fields, the vertical stress fields as well as the global settlement of the dam as an example of modeling.

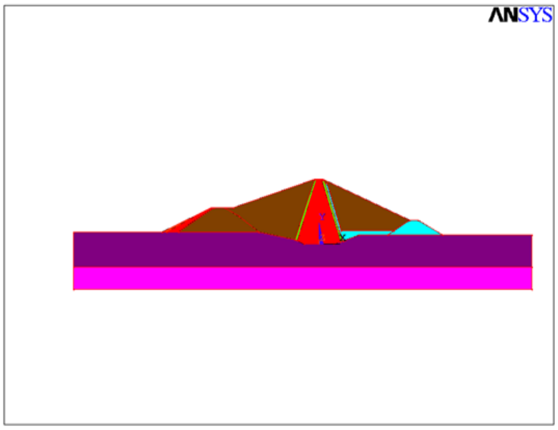

Fig.4 Representation of the dam's geometrical model

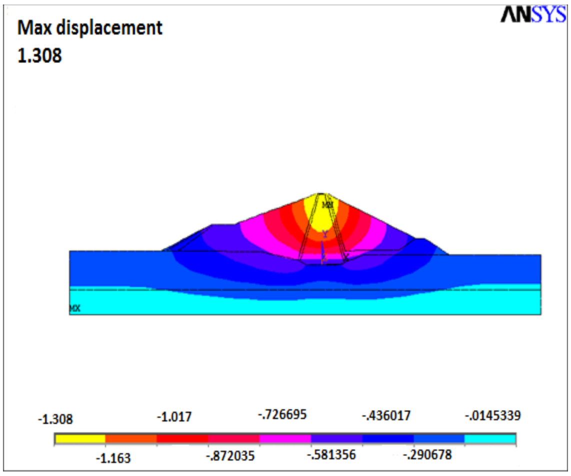

Fig.5 Dam's deformation fields (m)

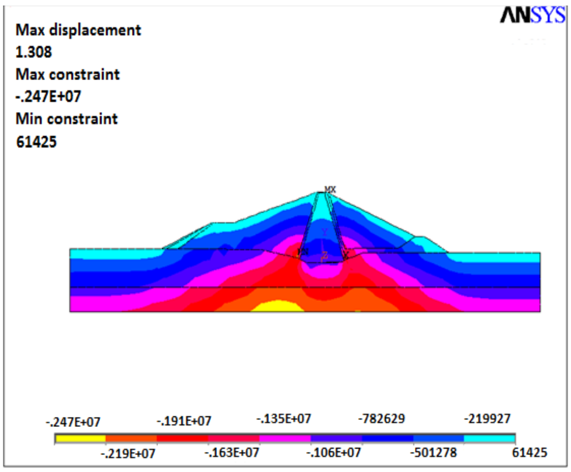

Fig.6 Dam's constraint fields (N/m^2)

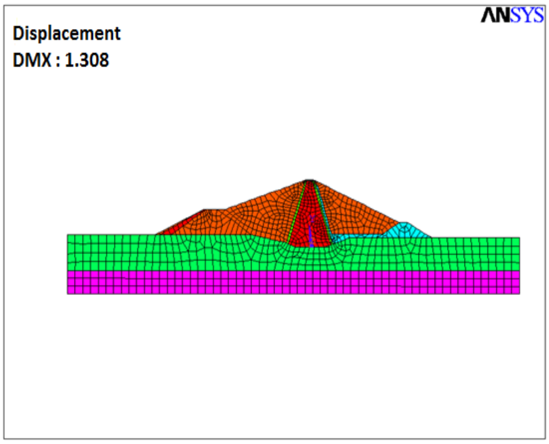

Fig.7 Total settlement of the dam (m)

In table 2, the dam settlement for different values of deformation moduli is reported. The rates of reduction of the deformation were estimated in relation to the variation of the deformation moduli in order to demonstrate the estimated influence of the variation of deformation moduli on the settlement of the dam. The highest settlement value (2325 MPa) was obtained for a deformation modulus E = 10 MPa. The relative settlement deviations were also calculated in relation to this maximum value.

Table 2 Influence of deformation moduli E on the values of dam settlement

Deformation moduli (MPa)	Dam settlement (mm)	Relative deviations of the settlement (%)
15	1893	18,6
20	1579	32,07
25	1377	40,76
30	1222	47,45
35	1020	56,13
40	900	61,29
45	750	67 74
50	650	72,04
55	500	78,49
60	400	82,80

Fig.8 and Fig.9 represent the variations of the global settlements of the dam and the relative deviations of the deformations as a function of those related to the various deformation moduli E.

The compaction operation leads to a reduction of the voids filled with air without expulsion of water. It appears that if absolute settlement is greatly reduced, the differential settlement will be also decreased.

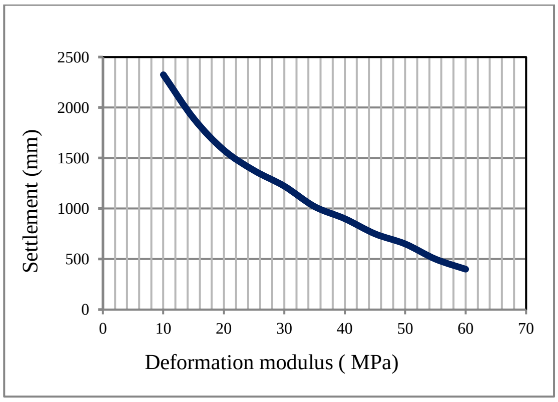

Fig.8 Variation of settlement of the dam in relation to the values of the deformation moduli

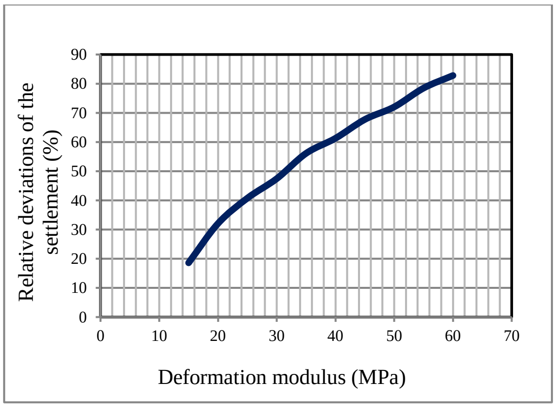

Fig.9 Relative deviations of the displacements depending on the variation of the deformation moduli E

When a soil is tight, the relative movements of the grains are reduced or eliminated. The high densities have the same effect [12].

4. VALIDATION OF MODELING RESULTS BY MONITORING MEASUREMENTS

4.1 Dam monitoring device for settlement measurements

The monitoring device of the dam includes seven monitoring profiles, P1 to P7 for pore pressure measurements, groundwater levels, flow rates of leakage and drainage, settlement and deformation. For monitoring deformation, nine settlement gages, named TA with magnetic headlines were installed on the dam. They penetrate 10 m into the rock foundation. Fig.10 shows the distances between monitoring profiles and Fig.11 gives the localization of monitoring profiles and position of settlement gages. The settlement gages also serve as inclinometers [5].

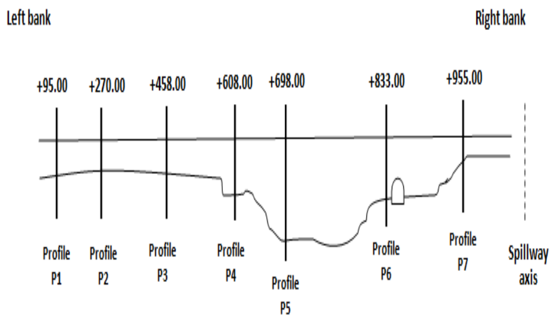

Fig.10 Distances between monitoring profiles [6].

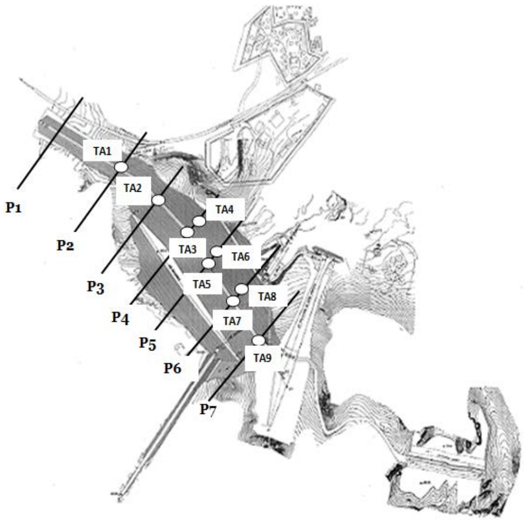

Fig.11 Location of monitoring profiles and position of settlement gages [6].

4.2 Study of the core settlement

The monitoring database used for the study is based on the monitoring measurements performed between 1997 and 2009 [13].

The study was conducted by considering the total settlement for the different settlement gages installed. Fig.12 shows the comparison between the settlements recorded in different profiles of the dam core.

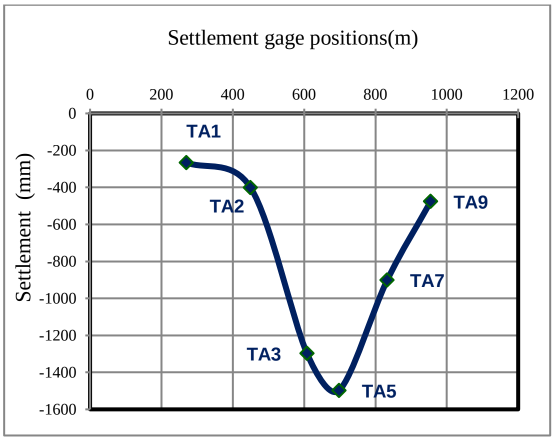

Fig.12 Settlement in different monitoring profiles (Dam's core)

The global settlement in the core was recorded at the settlement gage TA5 (1497 mm). The variations of settlement versus the time for the settlement gage TA5 located in the central section of the dam are illustrated in Fig.13.

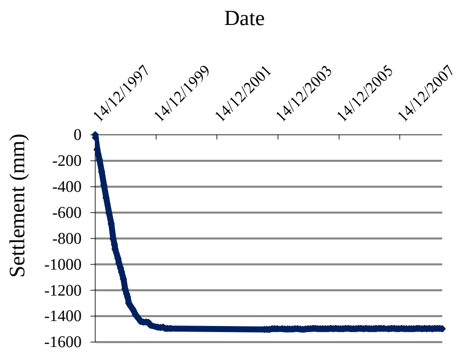

Fig.13 Settlement of settlement gage TA5 depending on time (Dam's core)

For the dam core, the most important settlement was recorded during the construction of the dam.

4.3 Study of the settlement refills

Fig.14 shows the comparison between the settlements, recorded in different profiles of the dam's refills.

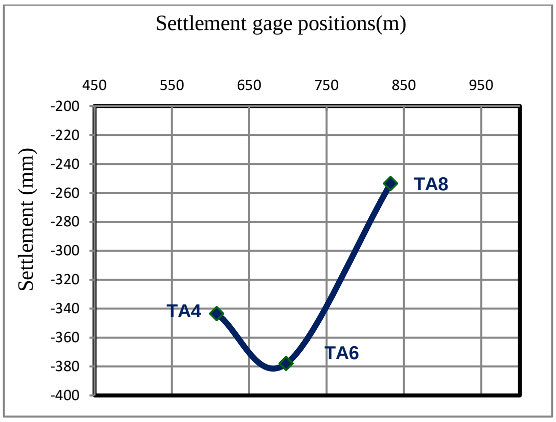

Fig.14 Settlement in different monitoring profiles (Dam's refills)

The global settlement in the refills was recorded at this settlement gage TA6 (378 mm).

Similarly, it was considered as the variation of total settlement versus the time of settlement gage located at the refills. These variations are shown in Fig.15.

For the dam refills, settlement continued during the period of dam operation.

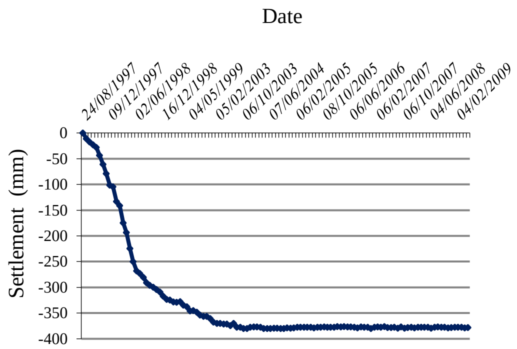

Fig.15 Settlement of settlement gageTA6 versus the time (Dam's refills)

During the dam construction period (until November 1998), the cumulative settlement was 300 mm. For the period from November 1998 to June 2008, this settlement reached a value of 379 mm.

4.4 Comparison of results between modeling and monitoring

In order to validate the mechanical behavior of the dam, Table 3 illustrates the values of settlements obtained by modeling and those measured in settlement gages of the dam.

Table 3, also gives the deformation moduli used for modeling and those used in initial study of the dam.

Table 3 Comparison of settlement between modeling and monitoring in the core and refills of the dam

	Core of the dam	Refills of the dam
Deformation modulus Modeling (MPa)	25-30	>60
Settlement modeling (mm)	1222-1377	400
Deformation modulus Project (MPa)	28,1	94,5
Settlement monitoring (mm)	1497	378

The comparison of the results of modeling and those obtained with the monitoring of the dam, show a fairly good compatibility on the settlement values for the core and dam's refills.

5. CONCLUSION

In all profiles of the dam, the deformations are proportional to the different heights of the embankments.

The increase of the deformation moduli E is inversely proportional to the calculated deformations.

The variations of the values of the moduli E induce an important influence on the deformations. Indeed, for an increase on the modulus of deformation of 20 MPa (core of the dam), the average relative reduction of deformations is about 47.5%, while an increase on the deformation modulus of 50 MPa, leads to 82,8% of relative reduction of deformations.

The values of the deformation moduli fixed at the level of modeling and giving similar settlement with the monitoring are E = 25-30 MPa and E > 60 MPa, respectively for the core and the refills of the dam. These values confirm the validation of the mechanical behavior of the dam in relation to the initial study.

The results of the modeling with regard to the settlement were validated by the monitoring measurements carried out on the dam.

The results of dam monitoring are important for the validation of conceptual choices in dam studies.

6. ACKNOWLEDGEMENTS

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