A Comparative Study of the Dam Stability at Various Stages using Numerical Modeling and in Situ Measurements

The Case Study of the Taksebt Dam, Tizi Ouzou, Algeria

Naas Allout
Laboratory of Mechanical and Materials Development, Civil Engineering Department, Ziane Achour University of Djelfa, Algeria
naasallout@yahoo.fr
(corresponding author)

Taha-Hocine Douara
Laboratory of Mechanical and Materials Development, Civil Engineering Department, Ziane Achour University of Djelfa, Algeria
tahahocine@gmail.com

Salim Guettala
Laboratory of Civil Engineering Research, Civil Engineering Department, Ziane Achour University of Djelfa, Algeria
guettalasalim@yahoo.fr

Hicham Charrak
Laboratory of RISAM, Civil Engineering Department, Abou Bekr Belkaid University of Tlemcen, Algeria
c.hicham1988@gmail.com

Tounsia Boudina
Civil Engineering Department, University of Bejaia, Algeria
boudina_tounsia@yahoo.fr

Received: 20 January 2023 | Revised: 29 January 2023 | Accepted: 31 January 2023

ABSTRACT

Earth dams remain the most used means of water mobilization in Algeria, due to their lower cost compared to concrete gravity dams and their capacity to resist better to seismic excitations. A study of the hydraulic structure was carried out in this paper, according to simple rules and empirical approaches. During the last decade, several high earth dams have suffered significant failures of the upstream or downstream slopes at the end of construction, after the initial impoundment, and under seismic loads. To prevent this occurrence or to minimize the damage in these hydraulic structures, a reexamination of the earth dams' behavior using more elaborate calculation methods is necessary. The purpose of the current study is to numerically model the behavior and analyze the stability of earth dams in terms of displacements at the end of construction, after the initial impoundment, during an earthquake, and compare these displacements with those measured in situ. A case study was conducted for the Taksebt - Tizi Ouzou dam by using the Plaxis 2D calculation code and the finite element method. The comparison of the obtained results shows a close concordance with the monitoring results of the dam carried out by various specialized organizations.

Keywords-earth dam; failure; stability; slope; earthquake; finite element modeling; Plaxis

I. INTRODUCTION

Homogeneous or zoned earth dams are important constructions commonly used in Algeria [1, 2]. These structures are subjected to displacements during construction, at the initial impoundment, and throughout the years of exploitation. Their safety requires monitoring of their behavior in order to prevent hazards susceptible to happen. The in-situ monitoring from geotechnical and geodetic measuring devices is doubtless the most used and most reliable means nowadays [3, 4]. However, this technique is not sufficient and cannot escape some difficulties of interpretation of some local aspects inside the dam body, which can neither be measured nor interpreted from in-situ measurements [5, 6]. One of the possibilities to improve the knowledge on the behavior of earth dams is to generate information from an analysis of the phenomena that intervene inside the dam and its different boundaries [7]. In this concept, numerical modeling and simulation form an essential tool, which allows the prediction of the response and the behavior of the dam with respect to various loading cases [8, 9]. The finite element method is widely used in the modeling and simulation of complex physical phenomena. It is very well suitable for the modeling of earth dams by considering loading conditions, complex boundaries, irregular geometries, and material characteristics. It enables simulation of their behavior using various behavior laws, resulting in a more realistic imaging [10, 11]. Based on these considerations, it can be concluded that the measurements provided by geotechnical and geodesic methods and the results obtained by FEM can only be complementary [12]. The prediction of the dynamic response of an earth dam to seismic loads is an important issue in the safety assessment of these structures in seismic zones. The failure of a dam or a dike, when it occurs, usually has heavy consequences, either in terms of cost or in terms of human lives [8, 9, 13].

Numerical modeling is one of the most complex applications in the study of zoned earth dams. This study involves different numerical models, associated to each load case and submersion level. It requires the recognition of the various geotechnical characteristics, the variation of which is depending on the considered zone state (dry or submerged) and on the behavioral models to be retained.

The purpose of this paper is to present a methodology for modeling a zoned earth dam to simulate its behavior in terms of displacement for stability verification using FEM through Plaxis software and compare these displacements with those measured in situ [14]. The Taksebt zoned earth dam is considered as the case study. The calculation of the displacements of the dam is carried out in three steps: after the completion of its construction, during its initial impoundment, and during an earthquake.

II. MATERIALS AND METHODS

The Taksebt dam is located on the Oued Aissi, main stream of the Oued Sebaou [15], 10km southeast of the Tizi-Ouzou city and at 100km from the Algeria Capital. This dam is an embankment made of silty-gravelly alluvium with a core of degraded clay, its crest level is 171.5m, and its height from the valley bed is 76m. The regular annual volume of sand is 180×10^6m^3 with a total capacity of 175×10^6m^3 and a watershed of 448km^2. The dam is mainly made of several materials placed in layers 0.3m thick and its foundation is mostly composed of weathered shale. The physical and mechanical characteristics of the materials used are presented in Table I. Sealing is provided by a centered clay core 53m in width at the base and 8.6m in width at the top [15].

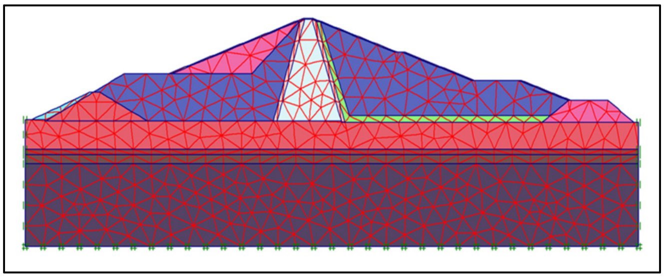
The analysis of the static behavior of the dam is carried out by the finite element method with Plaxis using triangular elements with two degrees of freedom per node, i.e. the displacements Ux along X and Uy along Y. The transversal profile of the considered dam has an asymmetrical trapezoidal shape and it will be modeled by a 2D plane geometric model. The reference model is realized by triangular elements with 15 nodes, in a total of 926 elements and 7589 nodes. We adjusted the fineness of the mesh (global coarseness), as shown in Figure 2. The Mohr-Coulomb model was used on all layers of the dam to calculate displacements and safety factors at the end of construction and during reservoir filling [10, 16].

TABLE I. MATERIALS OF TAKSEBT DAM AND ITS FOUNDATION

Material type	**Saturated unit weight (kN/m^3)**	**Cohesion (kN/m^2)**	**Friction angle (°)**	**Modulus of elasticity (kN/m^2)**	**Permeability (m/s)**
Clay core	19.7	10	15	15000	**10^{-8}**
U/S D/S rockfill	23.1	2	30	90000	**10^{-5}**
Filter	21.2	2	32	120000	**10^{-5}**
Drain	21.8	2	28	30000	**10^{-3}**
Riprap	22.5	2	40	190000	**10^{-3}**
Upstream cofferdam	22.3	5	35	190000	**10^{-2}**
Alluvium	21.5	2	38	30000	**10^{-5}**
Weathered shale	21.8	20	28	300000	**10^{-8}**

The settlements at the end of the construction of the hydraulic structure may vary significantly from one structure to another [11]. They depend, among other factors, on the compressibility of the materials used, the height of the structure and the level of compaction. The settlements related to the filling may reach up to 1 to 2% of the height of hydraulic structure for central core dams. These settlements are typically more favored when the height of the hydraulic structure is high and the rockfill has low compressive strength. In general, for earth dams with a central core, there is an acceleration of the settlement of the structure crest due to the pressure exerted by the water [13]. To study the seismic response of the dam, the system was applied to the accelerations of the Boumerdes earthquake on May 21st 2003, as shown in Figure 2 recorded at station No. 2 of the Keddara dam (the east west E.W. Component), the velocity of the recorded peak is estimated at

0.10m/sec, the acceleration at peak is 0.338g. The viscous damping ratio was equal to $\xi = 5\%$. The values of Rayleigh coefficients were $\alpha_R = 0.19$ and $\beta_R = 0.012$ and the values of the integration parameters are taken as $\gamma = 0.5$ and $\beta = 0.25$ with $\Delta t = 0.005$ time step [17].



MATERIALS	LEGEND
Clay core	
U/S D/S Rockfill	
Filter	
Drain	
Riprap	
Upstream cofferdam	
Alluvium	
Weathered Shale	

Fig. 1. Finite element mesh of the Taksebt dam with its materials.

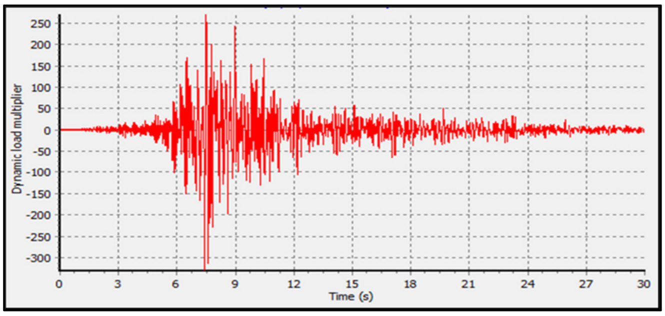


Fig. 2. Recording of the E.W. component of the Boumerdes earthquake (May 21st, 2003. Acceleration).

III. RESULTS AND DISCUSSION

A. Displacements at the End of the Construction of the Dam

Figures 3 and 4 show the vertical and horizontal displacements at the end of the dam construction. The maximum obtained displacements show the cumulative displacement during the construction phases. The maximum horizontal displacement is equal to 0.43m and the maximum vertical displacement is equal to 0.58m which means a settlement that represents 0.76% of the dam height. The maximum settlement calculated is 0.68m at the bottom upstream side of the dam, representing 0.89% of the dam height. It is inferior to 2% of the dam height, which is in accordance with the expected behavior of a rockfill dam with a clay core during the filling operation.

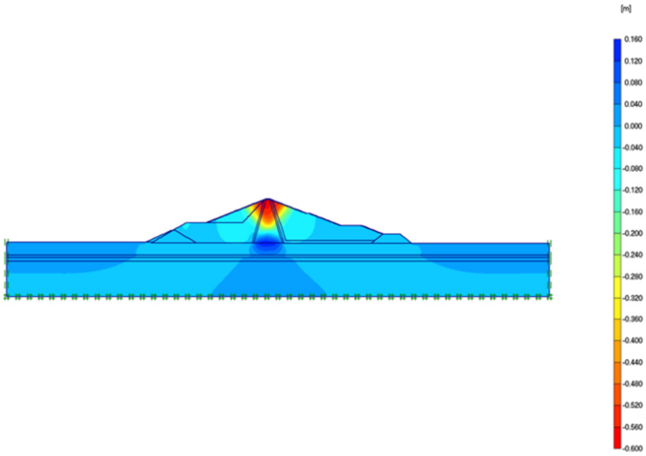


Fig. 3. Vertical deformations at the end of the construction.

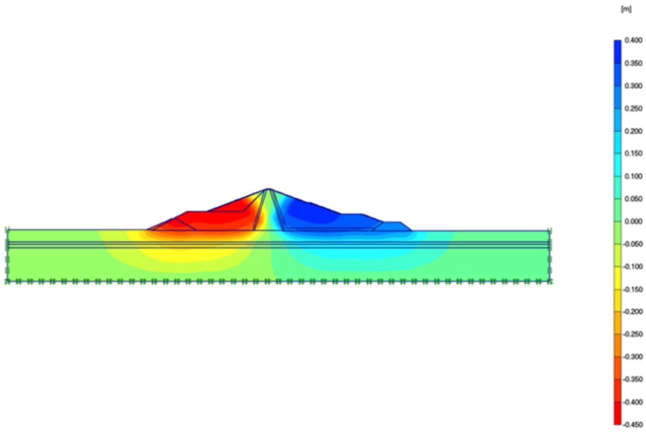


Fig. 4. Horizontal deformations at the end of the construction.

B. Settlements after the Intial Impoundment

Figures 5 and 6 show the vertical and horizontal displacements of the dam body for the normal reservoir level of 165m.

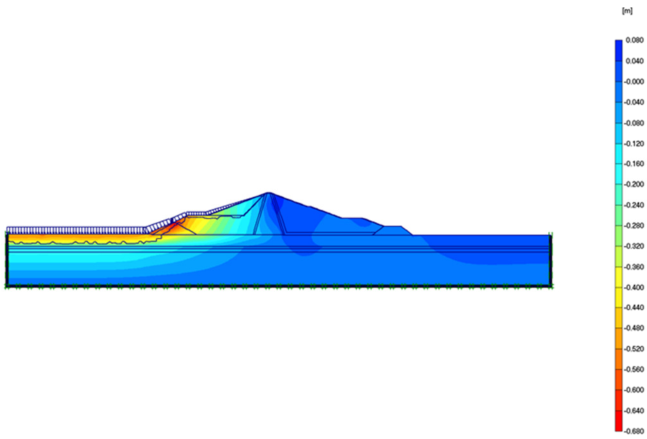


Fig. 5. Vertical deformations for the normal reservoir level of 165m.

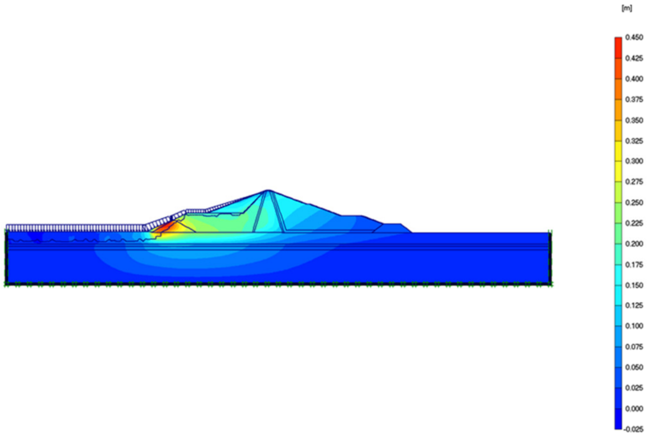


Fig. 6. Horizonal deformations for the normal reservoir level of 165m.

C. Settlements at the end of the Earthquake

The obtained results of the vertical and horizontal displacements are shown in Figures 7 and 8. The maximum horizontal displacement is approximately 0.42m and is located in the downstream side near the crest. The maximum vertical settlement is approximately 0.07m and is located in the upstream side near the crest. The crest of the dam is displaced toward downstream by 0.37m [9].

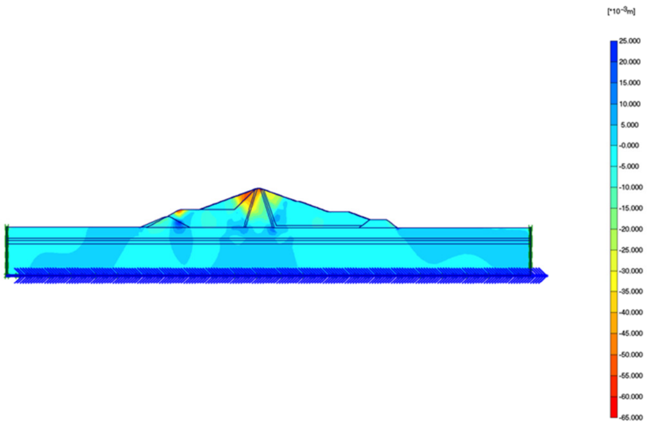


Fig. 7. Vertical displacements at the end of the earthquake.

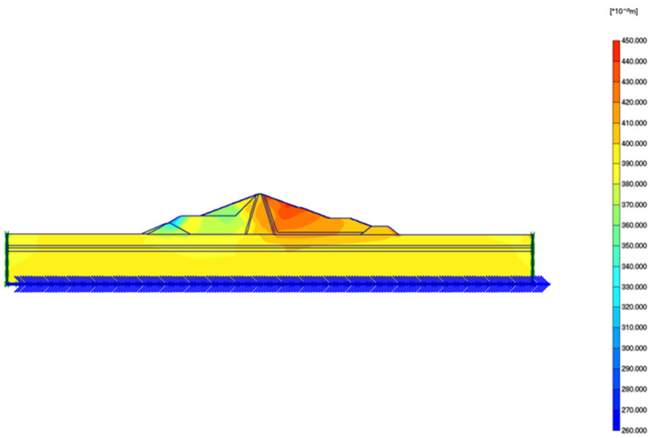


Fig. 8. Horizontal displacements at the end of the earthquake.

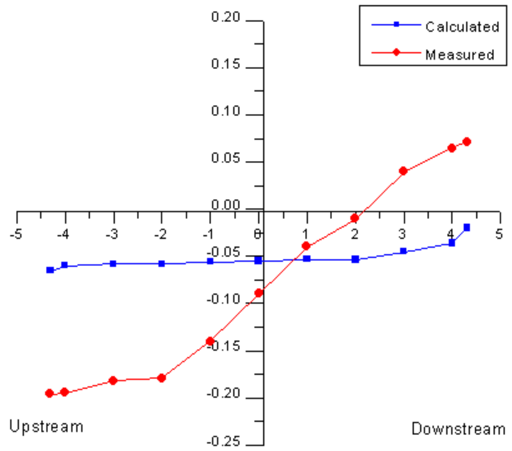


Fig. 9. Comparison between the calculated and measured displacements at the crest of the dam during the earthquake.

Fig. 10. The displacement on the earth dam's crest.

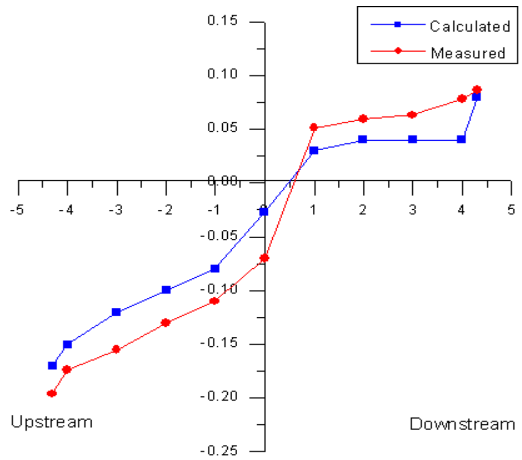


Fig. 11. Comparison between calculated and measured displacements at the crest of the dam during its initial impoundment.

Figures 9 and 11 show the comparison between the calculated and the measured displacements at the crest of the dam during the Boumerdes earthquake in May 21st, 2003 and between the calculated and measured displacements at the crest of the dam during its initial impoundment, respectively. Figure 10 shows a real picture of the displacement on the dam's crest.

Concerning the vertical displacements at the level of the crest after the initial impoundment, Figures 9 and 11 show that on the upstream side, the calculated displacements are inferior to the measured ones. This can be explained by the deformation due to the creep of the rockfill, which is not considered by the calculation model. On the contrary, on the downstream side, a slight swelling of the wet clay that is not loaded can be seen.

IV. CONCLUSION

The analysis of the dam in the three stages of its life (at the end of the construction, after the initial impoundment, and under seismic loading) gave the following results:

The maximum displacements obtained show the cumulative displacement during the construction phases. The maximum horizontal displacement is equal to 0.43m and the maximum vertical displacement is equal to 0.58m which means a settlement that represents 0.76% of the dam height.

On the first filling of the reservoir, it was concluded that the displacements are maximum on the upstream side of the dam. The settlement calculated at the crest of the dam is less than 2% of the height, which is in accordance with the expected behavior of a rockfill dam with clay core.

The maximum settlement calculated at the crest is approximately equal to the settlement measured in situ but slightly less. This can be explained by the deformation due to the creep of the rockfill which is not considered by the calculation model.

For the seismic computations, this work gives encouraging results: very good seismic stability of earth dams is found, and the displacements observed do not affect the stability of the structure. The numerical results obtained are in perfect accordance with the in-situ observations and the results of expertise carried out by various organizations.

Predicting the values and location of maximum displacements in earth dams is critical to the appropriate design of the instrumentation system for monitoring the actual behavior. In seismically active areas, earth dams are constructed using deformable materials that eventually must adjust to the varying loading conditions caused by the tectonic activity.

REFERENCES

[1] *Rapport Général sur les Barrages en Algérie*. Algiers, Algeria: Agence National des Barrages et Transfer, 2012.

[2] H. Charrak, N. Smail, and B. Rouissat, "Parameterized analysis relating to the influence parameters of injections and drainages in dams foundations. Case of El izdihar dam, Sidi Abdelli, Algeria," *Modeling Earth Systems and Environment*, vol. 8, no. 3, pp. 2991–3004, Sep. 2022, https://doi.org/10.1007/s40808-021-01277-3.

[3] G. Hunter and R. Fell, "The deformation behaviour of embankment dams," The University of New South Wales, Sydney, Australia, UNICIV Report R-416, Feb. 2003.

[4] Y. Z. Oral, "Deformation Behaviour of a Clay Cored Rockfill Dam in Turkey," M.S. thesis, Middle East Technical University, 2010.

[5] A. Szostak-Chrzanowski and M. Massiéra, "Modelling of Deformations During Construction of a Large Earth Dam in the La Grande Complex, Canada," *Technical Sciences*, vol. 2004, no. 7, pp. 109–122, 2004.

[6] C. Silvani, "Une Modélisation Discrète Du Comportement Mécanique Des Enrochements," Ph.D. dissertation, Université De Provence Aix-Marseille I, 2007.

[7] A. Bashir, R. Chaudhry, A. L. Qureshi, U. Memon, and N. Bheel, "Understanding the Seepage Behavior of Nai Gaj Dam through Numerical Analysis," *Engineering, Technology & Applied Science Research*, vol. 12, no. 1, pp. 8085–8089, Feb. 2022, https://doi.org/10.48084/etasr.4560.

[8] H. Belmihoub, A. Hamza, and N. Mesboua, "Modelling of in Earthen Dam Under the Effect of Seismic Loading, Case of the Taksebt Dam (Algeria)," *Journal of Applied Engineering Sciences*, vol. 12, no. 1, pp. 17–26, May 2022, https://doi.org/10.2478/jaes-2022-0003.

[9] S. M. Nasrollahi, "Determination of Excess Pore Pressure in Earth Dam After Earthquake," in *14th World Conference on Earthquake Engineering*, Beijing, China, Oct. 2008.

[10] A. H. Bhutto, S. Zardari, G. S. Bhurgri, M. A. Zardari, R. Bhanbhro, and B. A. Memon, "Post Construction and Long Term Settlement of an Embankment Dam Computed with Two Constitutive Models," *Engineering, Technology & Applied Science Research*, vol. 9, no. 5, pp. 4750–4754, Oct. 2019, https://doi.org/10.48084/etasr.3070.

[11] A. H. Bhutto *et al.*, "Parametric Analysis of an Embankment Dam's Stability," *Engineering, Technology & Applied Science Research*, vol. 9, no. 6, pp. 5016–5020, Dec. 2019, https://doi.org/10.48084/etasr.3180.

[12] N. B. Abdel-Mageed, M. H. Hadid, and A. N. El-Hazek, "Numerical and experimental modelling of slope stability and seepage water of earthfill dam," *Journal of Water and Land Development*, no. 44, pp. 55–64, 2020, https://doi.org/10.24425/jwld.2019.127046.

[13] N. S. Mahmood, S. A. Aude, H. H. Abdullah, S. O. Sulaiman, and N. Al Ansari, "Analysis of Slope Stability and Soil Liquefaction of Zoned Earth Dams Using Numerical Modeling," *International Journal of Design & Nature and Ecodynamics*, vol. 17, no. 4, pp. 557–562, Aug. 2022, https://doi.org/10.18280/ijdne.170409.

[14] *Plaxis 3D-Reference Manual*. 2008.

[15] *Rapport Général Sur Les Travaux Du Barrage Taksebt, Algérie*. Algiers, Algeria: Agence National des Barrages et Transfer, 2001.

[16] A. H. Bhutto *et al.*, "Mohr-Coulomb and Hardening Soil Model Comparison of the Settlement of an Embankment Dam," *Engineering, Technology & Applied Science Research*, vol. 9, no. 5, pp. 4654–4658, Oct. 2019, https://doi.org/10.48084/etasr.3034.

[17] R. W. Jibson, "Methods for assessing the stability of slopes during earthquakes—A retrospective," *Engineering Geology*, vol. 122, no. 1, pp. 43–50, Sep. 2011, https://doi.org/10.1016/j.enggeo.2010.09.017.