GeoScience Engineering

THREE-DIMENSIONAL NON-LINEAR ANALYSIS BASED ON THE TEMPORAL EVOLUTION OF AN RCC DAM INCLUDING THE ALLUVIUM EFFECT

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ABSTRACT

This article discusses the seismic response of roller-compacted concrete dams by interpreting their behaviour under the effect of static and dynamic loads applied to a real case study: the Boussiaba dam. A three-dimensional finite element numerical modelling was undertaken using the Midas GTS- NX 2017 calculation code. The geometric model was established in Autocad taking into account the actual geomorphology of the terrain and the existing dam and then exported to GTS-NX. The dynamic solicitation, i. e. the earthquake, was generated from two accelerograms 0.25 g and 0.35 g amplitude respectively recorded in the Mila region located less than 20 km from the dam site. The initial static load being constituted by the dead weight, the water thrust and the sludge thrust at the bottom of the dam. Several reference points were chosen on the dam body to study the different parameters adopted. The results obtained during the dynamic numerical analysis show that the overall behaviour of the dam during earthquakes was satisfactory, without endangering the structural integrity of the structure.

Keywords: Dynamic; Finite elements; Midas GTSnx; RCC dam; Three-dimensional.

1 INTRODUCTION

RCC dams owe their name to the use of roller-compacted concrete. They are not considered a new type of dams, but rather as gravity dams including a new type of material. The first RCC dam to be built was Shimajigawain in Japan [1], which was completed in 1980. Since then, their construction has increased because this type of dam is characterised by low cost, better use and shorter construction time. It has become a more logical choice than conventional concrete gravity dams.

Due to their strategic interest, dams are subject to rigorous design criteria, particularly with regard to the risk of exposure associated with earthquakes. With the improvement of seismic engineering knowledge and the development of more reliable methods for estimating earthquake magnitude at different sites, new methods for seismic analysis of structures are being developed. They include the effects of complex parameters in the evaluation and seismic risk analysis of structures [2].

Finite Element Method (FEM) is one of the most important numerical methods for seismic slope stability analysis. This method has been used to evaluate the dynamic response of a number of dams [3–6]. Although three-dimensional models of RCC dam have been developed [7–8], the consideration of the complex geometry of the terrain has not been taken into account.

This article focuses on the seismic response of an existing roller-compacted concrete dam: the Boussiaba dam in the Jijel City (Algeria). The choice of this dam is not insignificant given the fact that the region is known for its

Vol. 67 (2021), No. 1
pp. 11–20, ISSN 1802-5420
DOI 10.35180/gse-2021-0047

seismic activity. Two accelerograms are recorded in the region [9] that simulates the seismic load and the whole is modelled by finite elements in three dimensions reflecting the exact geomorphology of the site.

The reminder of the paper is organised as follows: Section 2 presents the geographical and geological context of the case study, while Section 3 focuses on the geometric model. Section 4 discusses the results of this case study. Section 5 summarises this work and draws conclusions.

2 GEOGRAPHICAL AND GEOLOGICAL CONTEXT

The Boussiaba dam is situated on the *oued* (river) of the same name at a distance of about 7km northeast of the city of El Milia. Oued Boussiaba is an affluent on the right bank of Oued El Kebir (Fig. 1). The dam site is located about 3 km upstream of the confluence between Oued Boussiaba and its right bank affluent, Oued M'Chat (sometimes referred to on map as Oued Demena di Kouider).

Figure 1. *Geographical localisation of Boussiaba Dam*

The Boussiaba area is located at the western extremity of the crystallophyllian region of Kabylia of Collo, which is an integral part of Little Kabylia, a vast coastal range that constitutes the Tellian Atlas (Fig. 2).

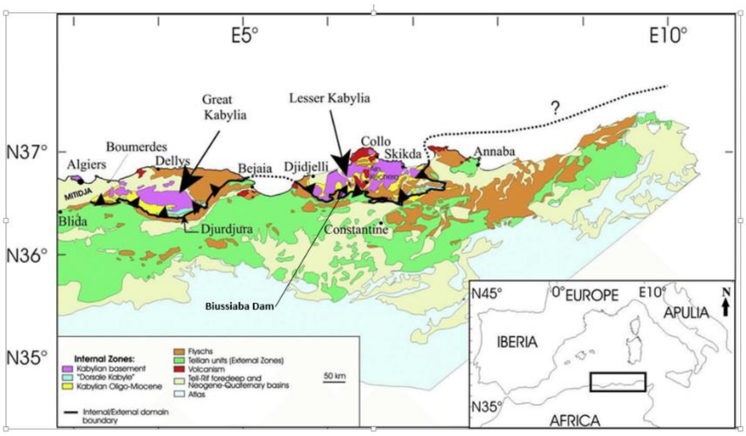

Figure 2. *Structural map of the region covered by the Boussiaba dam (modified according to [10])*

Vol. 67 (2021), No. 1
pp. 11–20, ISSN 1802-5420
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3 GEOMETRIC MODEL

The geometric model selected is an accurate reflection of the existing state (Fig. 3). The natural terrain was digitised from the topographic survey and was modelled in three dimensions directly on Midas GTS-NX. It has a dam height of 50,65 m and a crest length of about 310 m. The section slope of the upstream facing is vertical while it is 0.75H / 1V, then vertical above the 72.50 NGA (General Levelling of Algeria) for the section slope of the downstream facing.

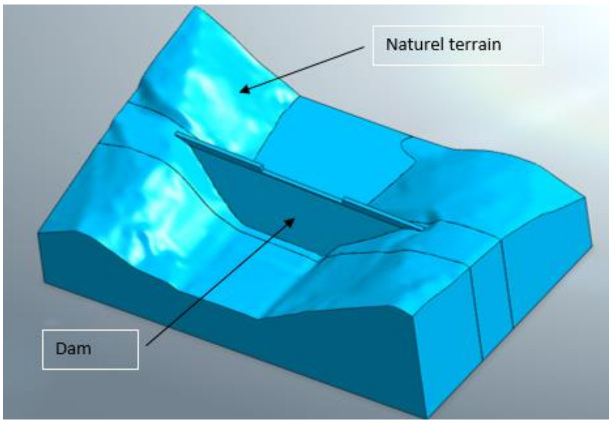

Figure 3. *Geometric model of the Boussiaba dam*

3.1 Numerical model development

The Boussaiba dam's numerical model was developed using Midas GTS-NX finite element calculation code. The model includes 14,114 nodes and 23,708 elements with a variable density mesh size ranging from the finest to the coarsest as one moves away from the dam.

The analysis was carried out by plasticity calculation. The initial static load consisted on the dead weight, the water thrust (74.40 m), and the sludge thrust at the bottom of the dam (43 m). The characteristics of the materials are summarised in Table 1.

Table 1. *Mechanical properties of materials*

	Model	**Elasticity module *E* (kN/m^2)**	**Poisson coefficient *η***	**Cohesion *C* (kN/m^2)**	**Angle of internal friction *φ* (deg)**	**Specific weight *γ* (kN/m^3)**
Foundation	Mohr-Coulomb	27.10^6	0.3	500	45	27
Dam	Mohr-Coulomb	20.10^6	0.2	150	40	23
Alluvium	Elastic	64.10^2	0.4	-	-	14

Two boundary conditions were applied to the model. The first condition applied to the base of the model consists of fixing the displacement in x, y, and z of the nodes. The second consists of assigning a free displacement field (free field boundary) allowing the model to interact in the dynamic solicitation.

The perfectly plastic elastic model of Mohr-Coulomb (M-C) was adopted to simulate the behaviour of the dam/foundation while an elastic model was chosen to simulate the effect of mud thrust. The Numerical model of the Boussiba dam is presented in Figure 4.

Vol. 67 (2021), No. 1
pp. 11–20, ISSN 1802-5420
DOI 10.35180/gse-2021-0047

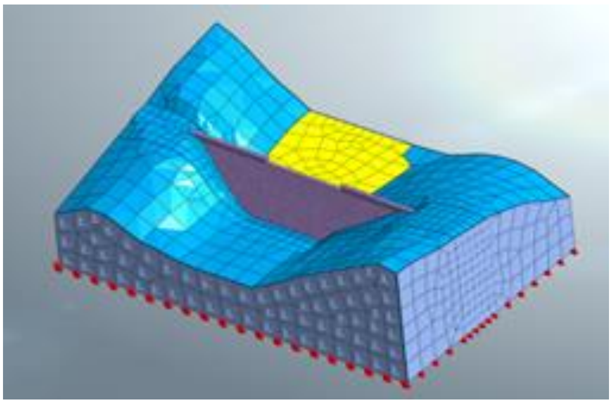

Figure 4. *Numerical model of the Boussiaba Dam*

3.2 Calculation stage

First, the EIGENVALUE module of Midas GTS-NX was used. Eigenvalue analysis was used to analyse the dynamic properties inherent in soil/ structure behaviour, and to obtain the natural mode (form of mode), the natural period (natural frequency), the modal participation factor, etc. These properties were determined by the mass and rigidity of the structure [11].

The results obtained were integrated into the calculation of depreciation. The seismic load was obtained using the accelerograms shown in Figure 5 [9].

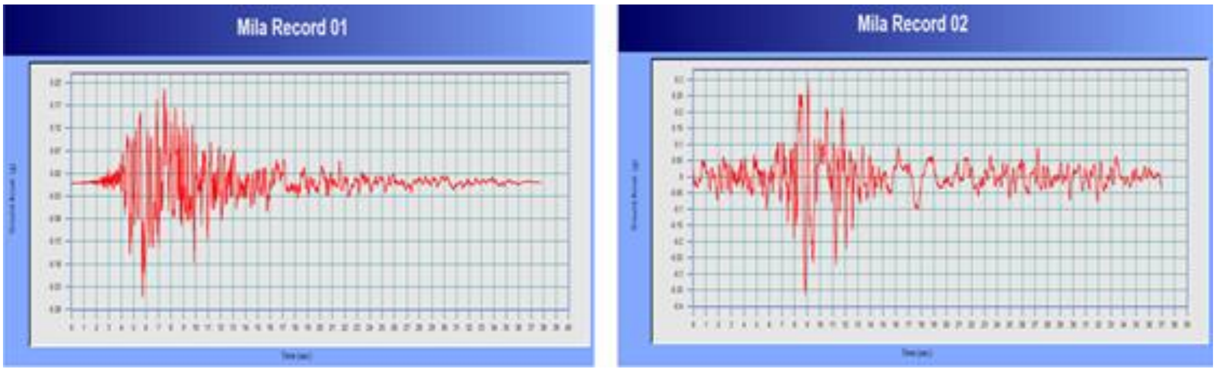

Figure 5. *Dynamics definition by accelerographs 1 and 2*

4 RESULTS AND DISCUSSION

The main parameters of the dam behaviour analysis are couple of constraints/deformations. As a result, it will provide useful information on the areas most in need of preventive reinforcement. Velocity and acceleration during the earthquake were also taken into consideration in the structure behaviour analysis. As the dam was unsymmetrical due to the terrain topography, four reference points were chosen for the analysis (Figure 6).

Vol. 67 (2021), No. 1
pp. 11–20, ISSN 1802-5420
DOI 10.35180/gse-2021-0047

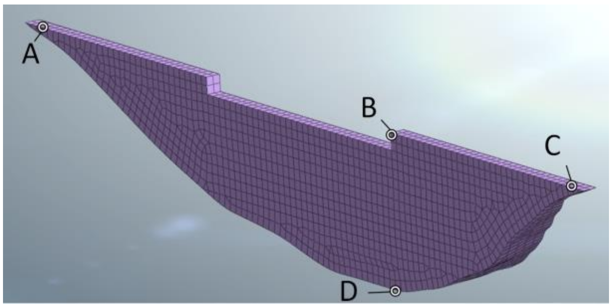

Figure 6. *Reference points for the behaviour dam analysis*

4.1 Velocity and acceleration analysis

The curves representing the velocities observed during the two earthquakes are given in Figures 7 and 8.

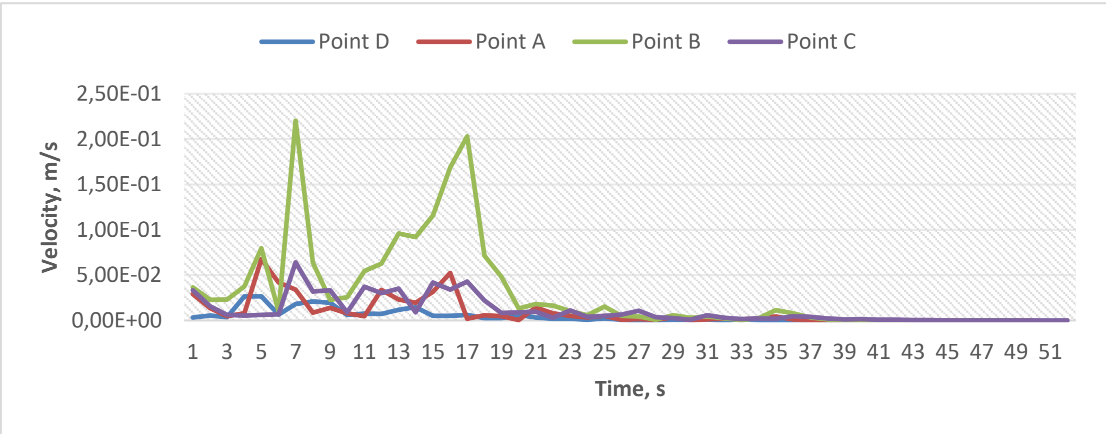

Figure 7. *Velocity-time curve for the first earthquake*

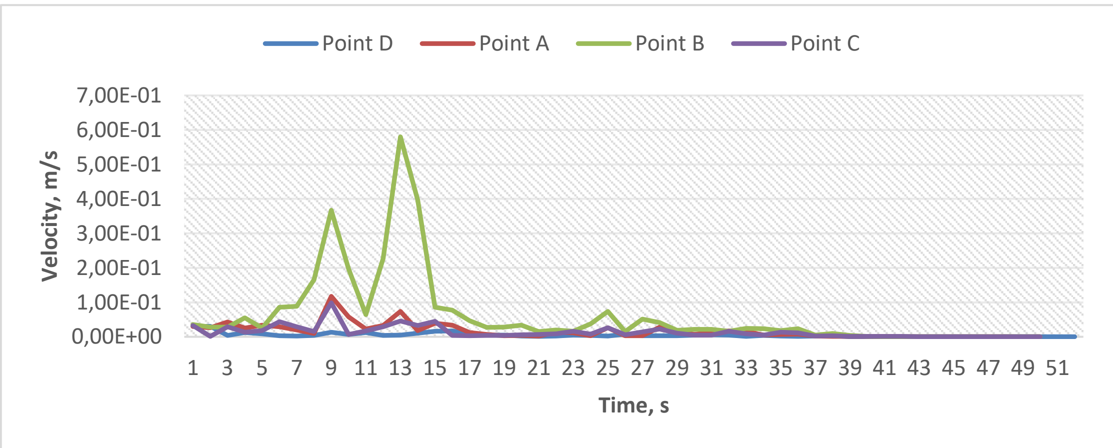

Figure 8. *Velocity-time curve for the first earthquake*

Vol. 67 (2021), No. 1
pp. 11–20, ISSN 1802-5420
DOI 10.35180/gse-2021-0047

Points A, C and D have slight variations in velocity due to the proximity of the foundation, which acts as an energy dissipator. On the other hand, point B presents high-velocity variations defining the most solicited zone of the dam. For the first earthquake, with a maximum intensity equal to 0.25 g, raised in 4 s, a maximum displacement velocity of 5.38 10^{-1} m/s in 5.8 s was noticed. The gap between the acceleration peak and the velocity peak is due to the dam's response.

The same pattern is observed for the second earthquake of maximum intensity equal to 0.35 g, raised in 9 s and a maximum displacement velocity equal to 7.6 10^{-1} m/s in 9.3 s.

The observed acceleration peaks (Figures 9 and 10) for the first and second earthquakes are 1.28 m/s^2 at 7.2 s and 1.74 m/s^2 at 8.8 s respectively.

Due to the damping induced by the energy absorption over the entire dam, the accelerations recorded are lower than the earthquake accelerations.

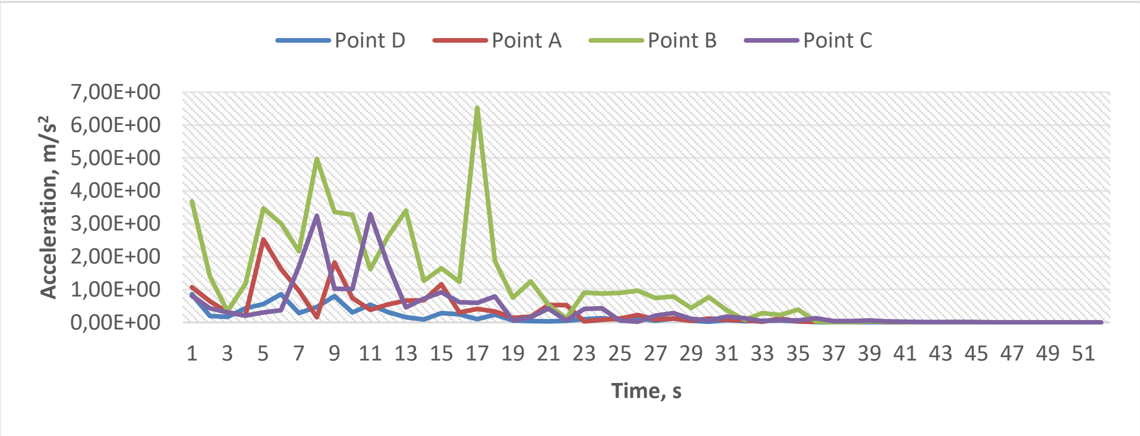

Figure 9. *Acceleration-time curve for the first earthquake*

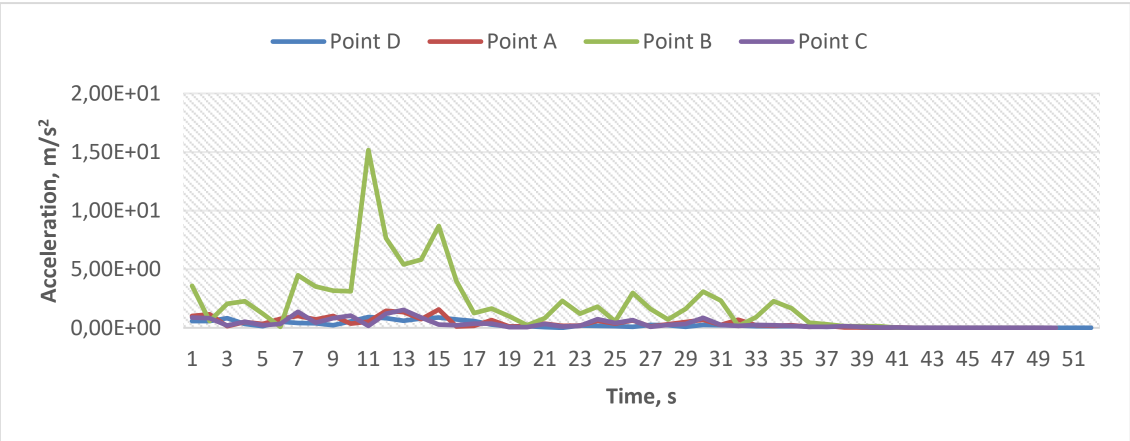

Figure 10. *Acceleration-time curve for the second earthquake*

Vol. 67 (2021), No. 1
pp. 11–20, ISSN 1802-5420
DOI 10.35180/gse-2021-0047

4.2 Displacement Analysis

Figures 11 and 12 show the curves representing the displacements observed during the two earthquakes.

The loads applied at the RCC Dam of Boussiba at its initial state (t = 1s) are dead weight, the water thrust (74.40 m), and the sludge thrust at the bottom of the dam (43 m).

Those loads at this moment have produced a minimal effect on the dam, i.e. no displacement was observed at the dam. The seismic effects start to appear especially in the crest of the dam.

Points A, C and D always have the same reference, i.e. a slight displacement. Earthquakes 1 and 2 concluded that the maximum displacement was respectively 1.84 10^{-1} m at 17 s and of 4.66 10^{-1} m at 15 s and no longer evolving until the end of the earthquake showing a state of plastic deformation.

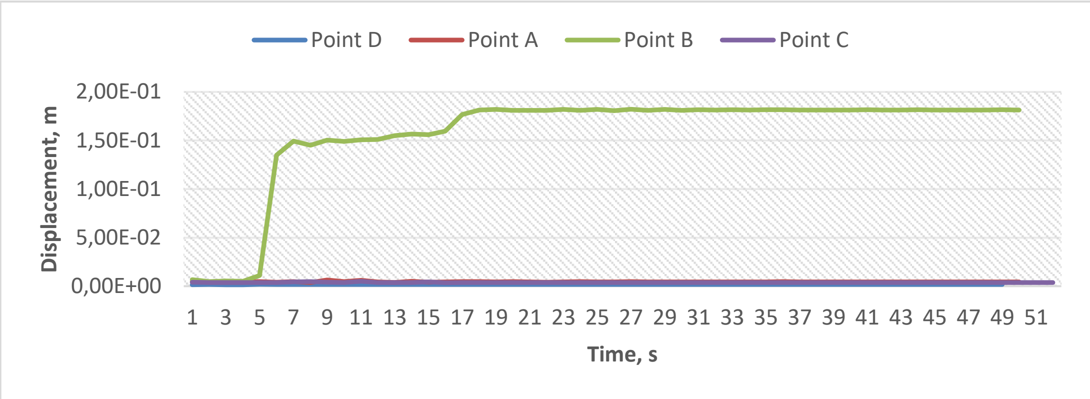

Figure 11. *Displacement-time curve for the first earthquake*

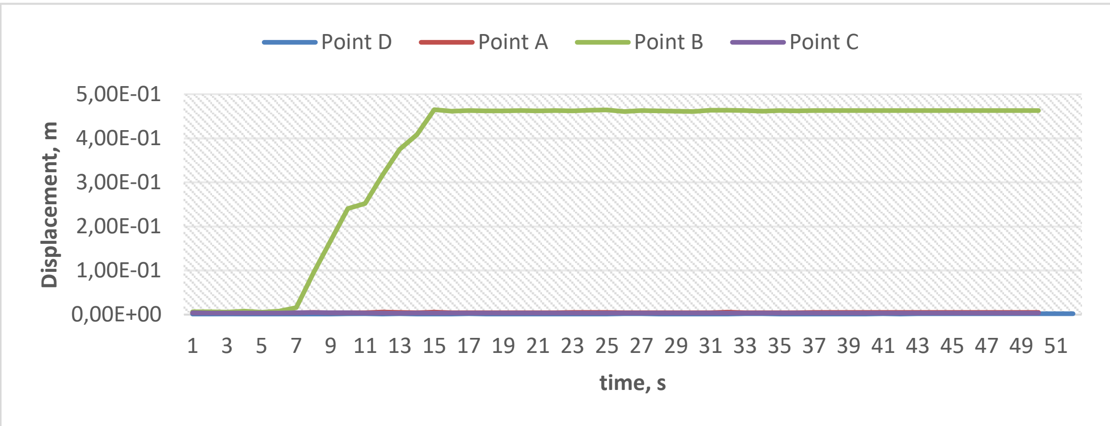

Figure 12. *Displacement-time curve for the second earthquake*

Figures 13 and 14 show the final displacement of the dam at the end of the earthquake with a pattern radiating from point B and decreasing as the distance from it increases. This observation can be explained by the fact that the dam is rigid and the interaction foundation-structure play a main role as dissipator of energy. Dam modelling has shown that the maximum displacements are not symmetrical with respect to the spillway. In addition, due to the high intensity of the second earthquake, the displacement of the dam is higher than the first earthquake.

Vol. 67 (2021), No. 1
pp. 11–20, ISSN 1802-5420
DOI 10.35180/gse-2021-0047

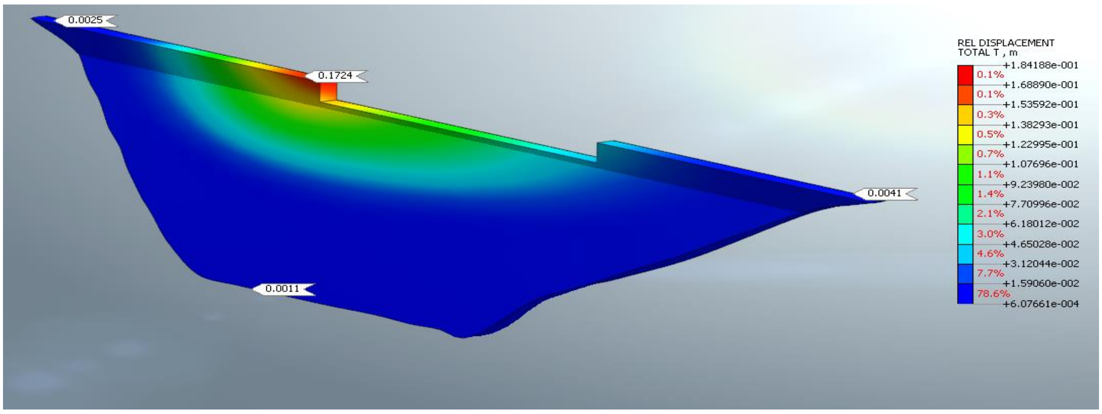

Figure 13. *Displacement at the end of the first earthquake*

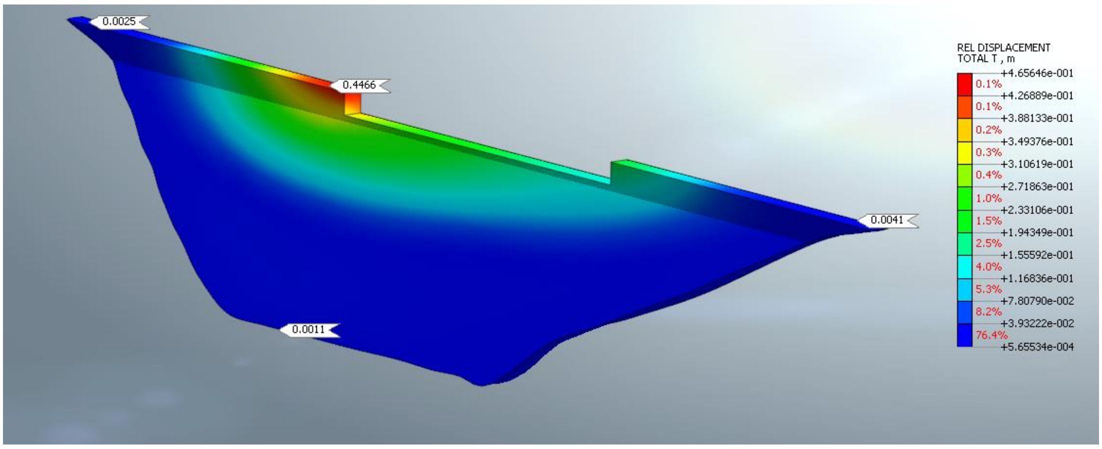

Figure 14. *Displacement at the end of the second earthquake*

4.3 Dam plasticity state

The appearance of crack in the body of the dam begins as the seismic intensity accelerates. Theses cracks affect practically, the entire structure at the time of their appearance. In addition, they intensify on the base.

Figures 15 and 16 show the plasticity state of the dam for both earthquakes. The parts with cracks follow the same pattern as the displacements recorded with larger cracks for the second earthquake due to its higher intensity.

In addition, there is a high concentration of cracks, although superficial, in the dam's contact zone, the base indicates that the latter acts as a load amplified by the earthquake requiring structural reinforcement.

Vol. 67 (2021), No. 1
pp. 11–20, ISSN 1802-5420
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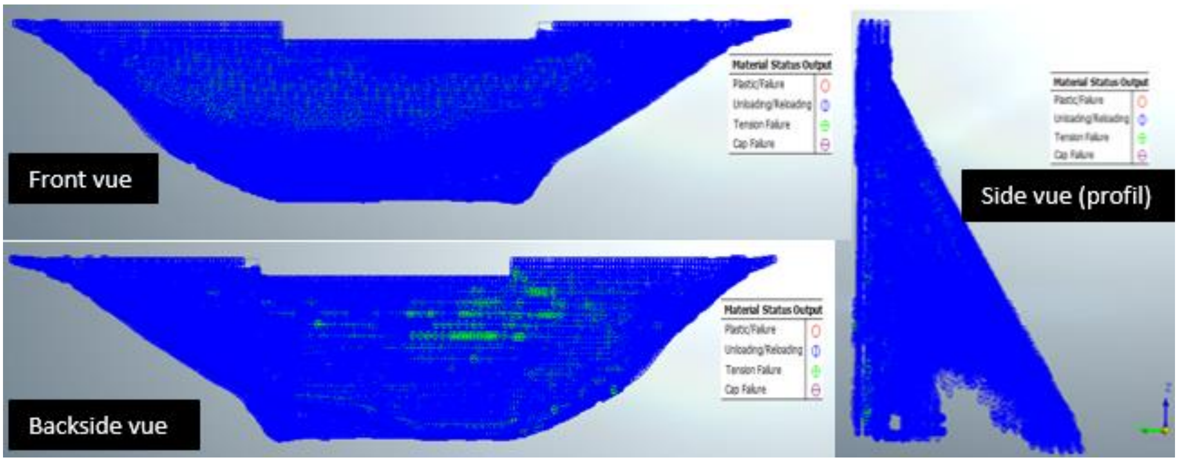

__Figure 15.__ Plasticity state of the first earthquake

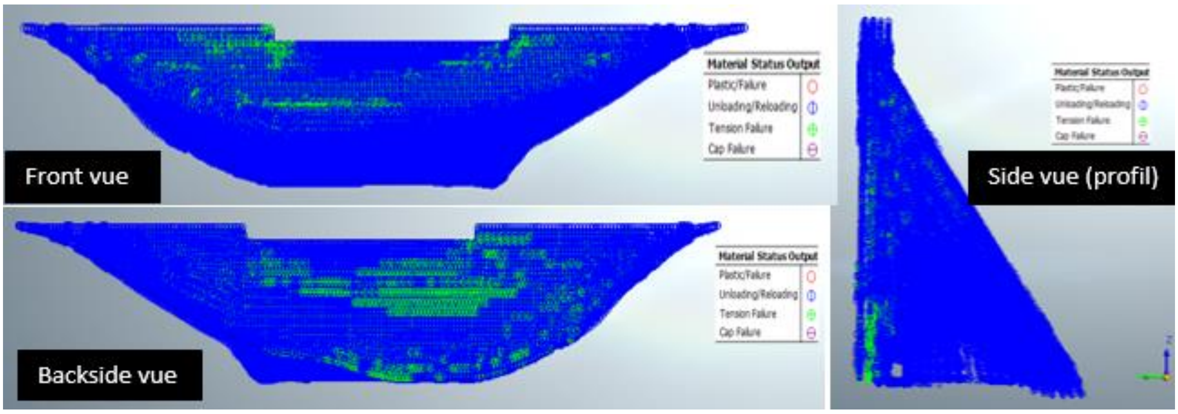

__Figure 16.__ Plasticity state of the second earthquake

5 CONCLUSIONS

Dams are complex structures that must function as systems. Although, dams were built centuries before the years of industrialization, the analytical methods that deal with stability problems of dams are very recent. Because of the failure of dams could result in major loss of life, the earthquake design is very important. Because of scientific development, calculation methods become more and more sophisticated [12, 13].

In our study, the Boussiaba dam was numerical modelled to evaluate its rheological behaviour under the seismic loads of two earthquakes of different intensity. The numerical model was developed using GTS NX based on the exact terrain geometry and the geotechnical characteristics of materials. Four strategic points were chosen in the dam to monitor the evolution of velocity, acceleration and displacement during the two earthquakes and to determine the plastic state of the dam in its entirety at the end of earthquake.

Velocity, acceleration and displacement analysis shows that the same pattern is observed in the tow earthquake i.e. points A, C and D have slight variations in velocity and acceleration and displacement due their approximation

Vol. 67 (2021), No. 1
pp. 11–20, ISSN 1802-5420
DOI 10.35180/gse-2021-0047

of the foundation. On the other hand, point B, which is the crest, is most stressed part of the structure. In addition, the gap between the acceleration peak and the velocity peak is due to the dam's response.

The contact zone of the dam with the base has the highest concentration of cracks compared to the entire structure, especially during the second earthquake with higher intensity. Finally, in our case study, RCC dam of Boussiaba was subjected to different seismic acceleration, and had proportional reaction to the degree of the earthquake.

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