# ANALYSIS OF THE DYNAMIC BEHAVIOR OF EARTH DAM

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**ABSTRACT:**

The presented work has for objective to study the behavior of the earth dam with central core of sealing (clay), built on a homogeneous layer of soil, with the taking into account the interaction soil-structure and the nonlinear behavior of soil materials. We studied also the influence of density and rigidity on the variation of structure's displacements and its deformation modes.
For that, an analysis by the finite element method is carried out in order to study the dam's behavior and its response in the elastic and plastic case, by using essentially the Ansys software.
Several digital simulations were led to study and to identify the role of various parameters of materials constituting the dam on the total answer of the system soil-structure.

**KEYWORDS:** Interaction, frequencies, natural modes, numerical analysis, earth dam, Ansys.

## 1. Introduction

The dams always require a great reliability as regards security, as well in static mode, and dynamic mode.
Many researchers are particularly leaning on the study of the dynamic behavior of the embankment structures in general and the earth dam in particular because more of the three-quarters of the dams of the world are in fill.
The fundamental objective of the analyses of interaction soil-structure is to determine the reciprocal influence of the soil and the structure on their mechanical behavior.
For that the present study relates to the analysis of earth dam's behavior, based on the finite element method, by taking account of the nonlinear behavior of materials constituting the dam.

### *1.1. Issues:*

The problems that can attack the earth dams [1]:

- Breaking by sliding of the foundation;
- Sliding slope of the dam;
- Foxes caused by the opening of cracks in the seal;
- Submersion of the structure…

The following figures show the effects cited, as one saw during the rupture of the San Fernando dam in 1971 (figure1) [2].as other earth dams, which occurred in India, in Turkey, and Taiwan(Shih Kang Dam) (figure2) [3].

Figure 1 : Break of the San Fernando Dam

Figure 2: Break of the Shih Kang Dam

### *1.2. Principal characteristics of the earth dams:*

The earth dams can be regarded as weight dams, i.e. they resist the pressure of water by their own weight, which explains their section of trapezoidal form.
Three types of dams are found: homogeneous dam, dam with core, dam with mask upstream [4].
In a dam with core, the functions of resistance and sealing are to some extent separate. Resistance is ensured by the refills placed on the sides of the structure, and the impermeability by the core.
The core in the center of the structure will be made up of the most impermeable possible ground (see figure 2).

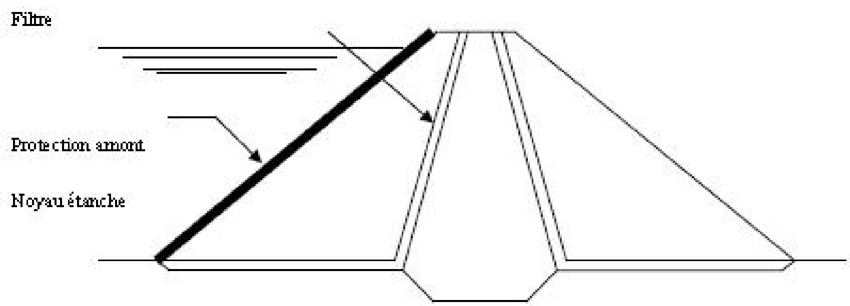



Figure 3: dam with core

### *1.3. Stress-strains*

- **Stress-strains in the elastic case:**

One considers an isotropic, elastic material linear, the relation stress-strain is written [5]:

$$\sigma_{ij} = E.\varepsilon_{ij} \tag{1}$$

The problems of plane elasticity can be divided into two distinct groups:
The problems of plane constraints and the problems of plane deformations.

In the first case, the structure has asmall thickness compared to its other dimensions and, the normal constraints with the plan are neglected, while in the second case the structure has a very large dimension compared to its other dimensions and the normal deformation with the plan load is worthless (the case of the earth dams figure 4) [5].

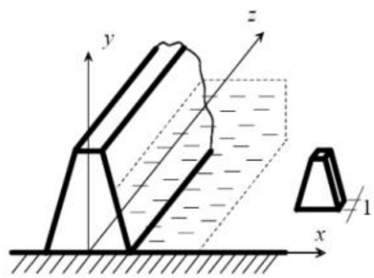


Figure 4 : Conditions of deformation planes (example of an earth dam)

- **Stress-strains in the elastoplastic case**

The total deformation is divided into an elastic part and a plastic part [5]:

$$\varepsilon_{ij} = \varepsilon_{ij}^{e} + \varepsilon_{ij}^{p} \quad (2)$$

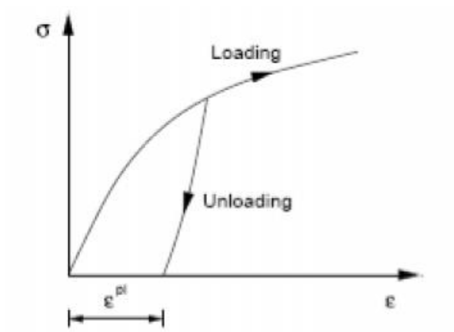


Figure 5: Uniaxial plastic behavior

**2. Application of the finite element method**

***2.1 Modeling of the system dam-foundation:***

The studied example is an earth dam located in the area south of Morocco, composed of elastic materials. The height is 64.4 m and 235m of width.

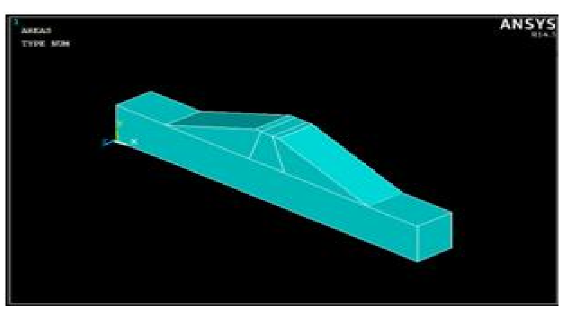


Figure 6 : Geometry of the dam

It is modeled in 3D by the finite element method by using software ANSYS. The interaction of water reserve and dam is neglected (the effect of the hydrodynamic pressures of the water reserve is neglected).
The dam can be subdivided in two sub-structures: dam and foundation.
In our case, the dam is composed of a core, the face downstream and upstream, is represented by a grid of finite element in the same way standard (triangular finite element with three nodes). The material constituting the dam is considered homogeneous, elastic and isotropic in the case of the linear analysis, and in the case of the nonlinear analysis is considered elastic perfectly plastic.
The foundation limited by a rigid horizontal surface, was as modeled in standard finite element in the same way as the dam and in the same way standard of material for the linear and nonlinear case.

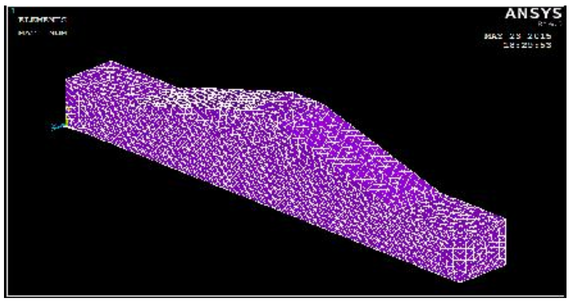



Figure 7: Grid of dam+ foundation

### *2.2 Properties of materials :*

Each various ground considered is modeled by a material linear-elastic whose characteristics are the following ones: the density (γ), the Young modulus (E) and the Poisson's ratio (υ). The mechanical properties of the dam are recapitulated in table 1:

Table 1: Mechanical properties of the dam

| | **Density γ (t/m3)** | **Poisson's ratio υ** | **Young modulus E (MPa)** |
|---|---|---|---|
| **Foundation** | 2.2 | 0.25 | 1000 |
| **core** | 1.98 | 0.3 | 30 |
| **refills** | 2.13 | 0.3 | 60 |

## 3. Results and discussions:

### *3.1 Response of the dam in the linear case:*

One starts with the study of dam's behavior alone and after taking into account the interaction soil-structure.
The following table recapitulates the natural periods of dam alone for the first five modes of vibration.

**a. dam alone:**

Table 2: Natural periods for the first five modes of vibration of the dam alone

| **Modes** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| **Periods (s)** | 0.4139 | 0.2744 | 0.2631 | 0.2016 | 0.1822 |

The following figures represent the variation of displacement (Ux, Uy, Uz) for the first mode of vibration:

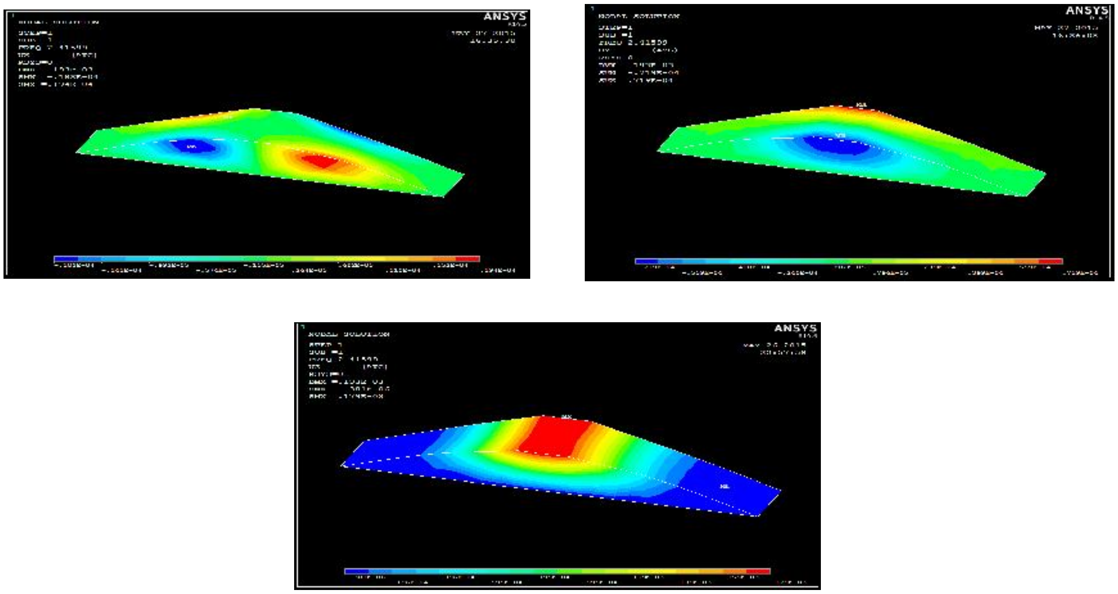



Figure 8: Distribution of displacement for the first mode of vibration

### b. Influence of the density and rigidity :

By choosing two soils, one studies the influence of the density and the rigidity of the material which constitutes it and on which the dam rests:

Table 3: Values of the density and the rigidity of soil

| | **Soil 1** | **Soil 2** |
|---|---|---|
| **Density (t/m3)** | 2.1 | 1.85 |
| **Rigidity (MPa)** | 100 | 30 |

For better understanding the effect of the interaction dam-foundation, one will take account of various conditions of system and will see their influence on the characteristics of free vibration of the dam:

### c. System dam-foundation(soil1) :

Table 4: Natural periods for the first five modes of vibration of the system dam-foundation1

| **Modes** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| **Periods (s)** | 2.4642 | 1.6976 | 1.6318 | 1.2374 | 1.2065 |

- <u>Variation of displacements:</u>

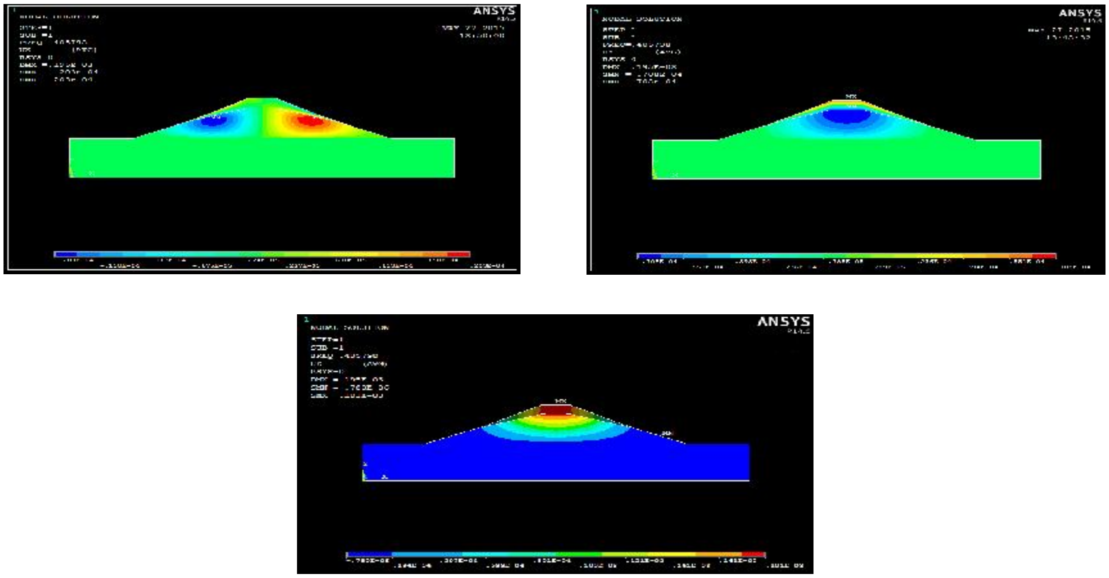



Figure 9: Distribution of displacement for the first mode of vibration

**d. System dam-foundation(soil2) :**

Table 5: Natural periods for the first five modes of vibration of the system dam-foundation2

| **Modes** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| **Periods (s)** | 5.1546 | 3.0191 | 2.3237 | 2.2163 | 2.0829 |

- <u>Variation of displacements:</u>

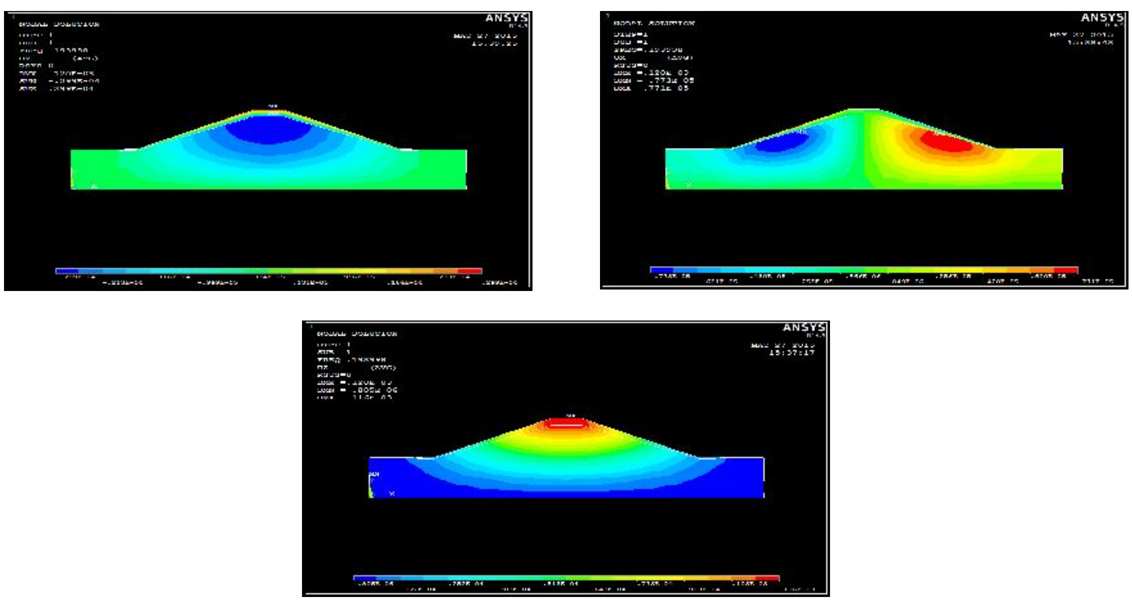
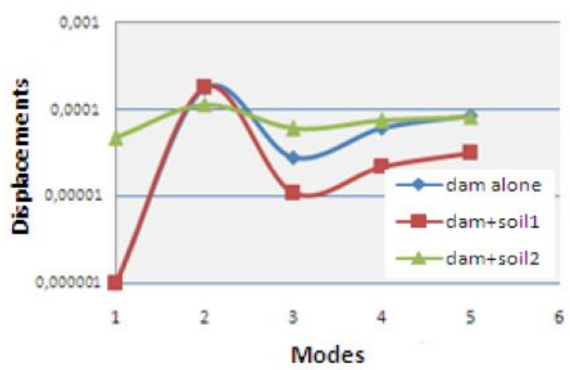
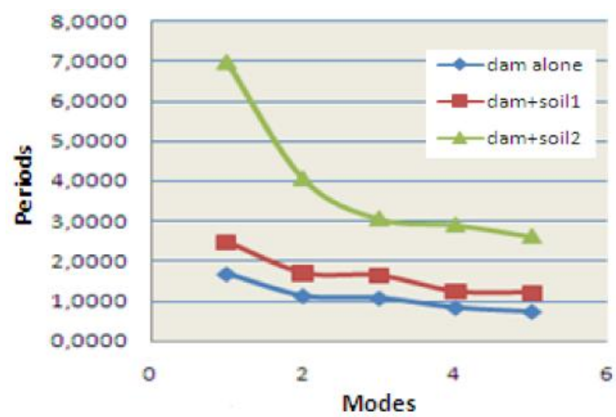



Figure 10: Distribution of displacement for the first mode of vibration

- **Curve of displacement's variation :**




**Curve of period's variation :**




**Result 1:**

- By comparing the results got for the case of the dam alone and those obtained for the system dam-foundation, one notice that the taking into account of the foundation tends to lengthen the vibration's periods of dam;
- In the case of a flexible soil, the vibration's periods are higher than those obtained for a case of rigid soil;
- With the increase in the foundation's rigidity, the vibration's periods converges on the natural periods in the case of a dam considered embedded at its base.

➢ In the case of the structure resting on a solid soil, of which rigidity and natural frequencies are less important than that embedded in a rigid soil, it may be that more amplified displacements appear. This indicates that the properties of the soil have an effect significant on the dynamic behavior of the structure. Reciprocally, the soil's behavior can be modified by the presence of the structure.

### *3.2 Response of the dam in the nonlinear case:*

Is kept the same example as the previous one (Figure 6), the parameters of Drucker Prager model are given in Table (Table 6):

Table 6: Mechanical properties

| | Density γ (t/m3) | Poisson's ratio υ | Young modulus E (MPa) | Cohesion c' (Pa) | Fric.angle φ (°) | Flow angle Ψ (°) |
|---|---|---|---|---|---|---|
| **Foundation** | 2.2 | 0.25 | 1000 | | | |
| **Core** | 1.98 | 0.3 | 30 | 0.1E6 | 15 | 3 |
| **Refills** | 2.13 | 0.3 | 60 | 100 | 35 | 10 |

- Variation of displacements:

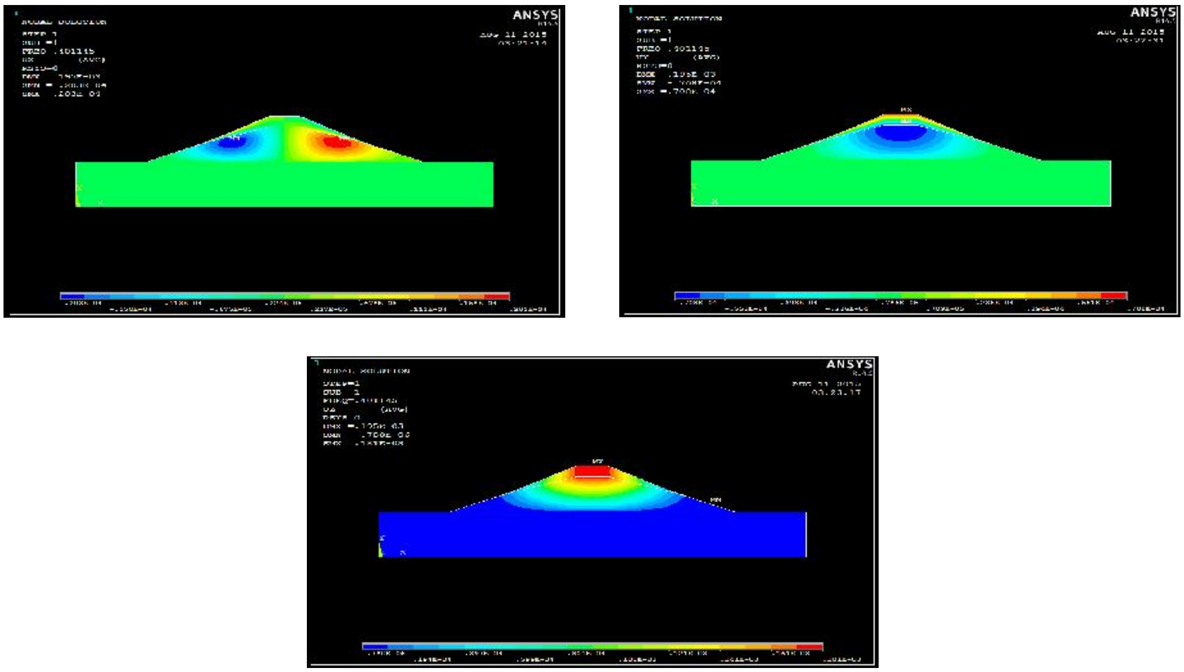



Figure 11: Distribution of displacement for the first mode of vibration in the nonlinear case

**Result 2:**

- Note that plasticity is concentrated in the refills while what is almost zero in the core;
- The displacement in the plastic case is closer to displacement in the elastic case;
- Plasticity induces the variation of horizontal and vertical stress, and attenuation of shear stresses;
- Nonlinearities generated at soil-structure interface and soil play a significant role in terms of energy dissipation.

### *3.3 Comparison of frequencies and displacements in linear and nonlinear case :*

| **Frequencies** | | | **displacements** | |
|---|---|---|---|---|
| Linear case | Nonlinear case | Percent change (%) | Linear case | Nonlinear case |
| 0.40581 | 0.40114 | | 0 | 1.95E-04 |
| 0.58906 | 0.58230 | | 1.08E-04 | 1.25E-04 |
| 0.61282 | 0.60579 | 1.16 | 2.86E-05 | 1.72E-04 |
| 0.80814 | 0.79885 | | 6.22E-05 | 1.36E-04 |
| 0.82884 | 0.81931 | | 8,71E-05 | 1.82E-04 |

## 4. Conclusion :

This study concerns the analysis of earth dam's behavior based on the finite element method taking into account soil-structure interaction and the nonlinear behavior of the materials constituting the dam.
The comparison between the response of the elastic and elastoplastic analysis shows that the presence of plastic deformation leads to the attenuation of frequencies in the dam and slight increase of displacement, this result is assigned to the dissipation of energy by deformation plastic. By comparing this study we found that the results are almost identical to those of previous literatures.

To better describe the dynamic behavior of the dam, it is necessary to combine numerical results with those obtained from experimental tests, focusing on another type of analysis (spectrum) and seismic safety of the dam and that will be the subject of the next article.

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