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Dynamic Modelling of a Landslide in the Region of Dellys due to the Earthquake of May 21, 2003

Use of the Seismic Loading and Dynamic Calibration Strategy

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***Abstract*— The evolution of slope stability analysis in the geotechnical field followed closely the developments in soil mechanics and rocks as a whole to manipulate the risk of slipping. Since the static analysis methods to evaluate its own weight slope where static loads to seismic analysis methods that introduce the effect of the earthquake on the stability of a slope. Recently methods of finite or dynamic programming elements are widely used to model failure mechanisms slides made for the evaluation of the stability of slopes and less difficult to better characterize. This paper focuses on numerical analysis of earthquake effects on slopes considering the history of the seismic loading as an acceleration time history and using a new dynamic calibration strategy (for good results in adjustments the frequency domain) to determine the permanent displacement in the slope; this new method is applied to a landslide in the region of Dellys following the earthquake of 2003 May 21.**

Keywords*— Numerical Analysis; Permanant Displacement; Real Seismic Loading; Dynamic Calibration

I. INTRODUCTION

The earthquake of 21 May 2003 that hit hard the region of Boumerdes and Algiers is a destructive earthquake of magnitude Mw = 6.8 (from USGS) which caused several landslides, including that of Dellys located on the map topographic (fig.1); which implies the need to understand the phenomenon of sliding under the effect of the earthquake.

In recent years, several researchers have identified the importance of advancing the slope stability calculations to methods based on probabilistic appearance. These methods use the characteristics of the seismic risk (eg, spectral acceleration, the fundamental period, etc.) to estimate a probability of displacement equal to zero or non-zero displacement. However, finite element methods and dynamic programming are widely used to model failure mechanisms of landslides.

Using a computer code such as PLAXIS, SHAKE 2000 made the assessment of the stability of slopes less difficult. For this it is advantageous to evaluate the history of permanent displacement in the slope considering the history of loading in time (in terms of acceleration) and using a new dynamic calibration strategy.

A simple method for calibrating damping settings and a few suggestions on how to reduce false lateral border effects on wave propagation are presented. Several key aspects should be taken into account for such calibration. So there we discuss in particular the importance of using real seismic record in the analysis of slope stability by finite element calculations to ease the task.

Fig. 1. Location of the study area (Dellys region localized in red)

I. DESCRIPTION OF THE LANDSLIDE

A. Geodynamic context in the the region of Dellys :

The permanent displacement of the slope depends on the ratio between the critical acceleration and maximum acceleration. Obviously, the sliding block model predicts zero permanent displacement of the slope if the accelerations induced by the earthquake never exceed the critical acceleration (a_y / a_{max} ≥1) as shown in *Fig.3 (a).*

Local geology: According to the geological map of Dellys and Tizi-Ouzou, our study area consists of formations Tellian unit of Dellys. This formation is represented by marl, made the preliminary investigations enable us to say that we are in the presence of a soil composed of gray marl.

Site Hydrology: Given the lithological nature of our industry which essentially consists of shale and marl, one cannot expect the large presence of water table; any time of infiltrations may occur particularly in the weathered marl layers and Schistose through the cracks and the cleavage plane, the movement of such water into the ground is done by gravity and according preferential paths.

Seismicity of the area: The settlement Algerian earthquake (RPA99, v2003) ranks among the region of Dellys areas of high seismicity (Z III). Dellys region has been shaken by several earthquakes in the Tell Atlas, to different degrees; it cites some examples (Table 1):

TABLE I. SOME EARTHQUAKES THAT HIT THE REGION OF DELLYS

Date	Epicenter	intensity-MERCALLI scale	intensity-RICHTER scale
03-08-1960	Boufarik	VI	4.9
10-10-1980	Oued Foudda	VI	4.9
31-10-1988	Oued Djer	V	4.3
29-10-1989	Mont de Chenoua	VI	4.9
21-05-2003	Zemmouri		6.8

B. Description of the studied landslide:

Slope geometry: This slope movement started at a height of 42.30m in height, length of 450 m, depth of 17.40 m and slope height of about 10m. The slope is thus an inclination α = 18.26 ° (Figure 2).

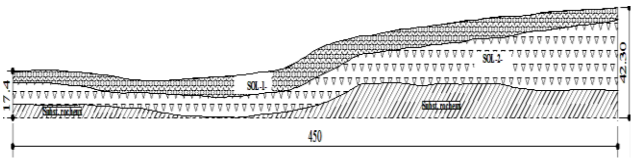

Fig. 2. Geological and topographic features of the designed landslide

Material properties and soil behavior: In-situ tests carried out have established a lithological section of the site (Figure 3). According to this work, the slope is composed of greenish gray marl little plastic gypsum (G-1) and gray marl slightly bluish slate (G-2). The properties of these soils are shown in Table 2.

The presence of water in the study area has not been detected; marl layers are usually waterproof, so they cannot acquire constituted an important reserve. So the water level is assumed below or rock outcropping "bedrock".

To assume the stiffness increases with depth a linear law is supposed to describe the evolution of the shear modulus G and shear wave velocity (Figure 3) with depth z (power exponent m = 1/2) :

$$G = G_0(1+az)^{2m} = G_0(1+az) \qquad (1)$$

$$V_S = V_{S0}(1+az)^m = G_0(1+az)^{1/2} \qquad (2)$$

Or: $\mathbf{V_{S0}}$ is the shear wave velocity at the free surface,

a is a coefficient that represents the level of heterogeneity.

TABLE II. PHYSICAL AND MECHANICAL PROPERTIES OF MATERIALS

Property	Design.	Unity	Soil-1-	Soil-2-
Material model	Model		Mohr - Coulomb	Mohr - Coulomb
Material behavior	Type		Drained	Drained
Dry unit Wight	γ	kN /m^3	17.9	19.4
Poisson coefficient	υ	-	0.3	0.3
Young modulus	E_{ref}	MPa	1.30 E+5	1.11 E+5
Wave velocity	V_s	m/s	165.50	148.30
	V_p	m/s	309.80	277.5
Cohesion	C_{ref}	kPa	40	49
shear modulus	G_{ref}	MPa	49000	42690
Friction angle	φ	°	10	13
Dilatation angle	ψ	°	0	0

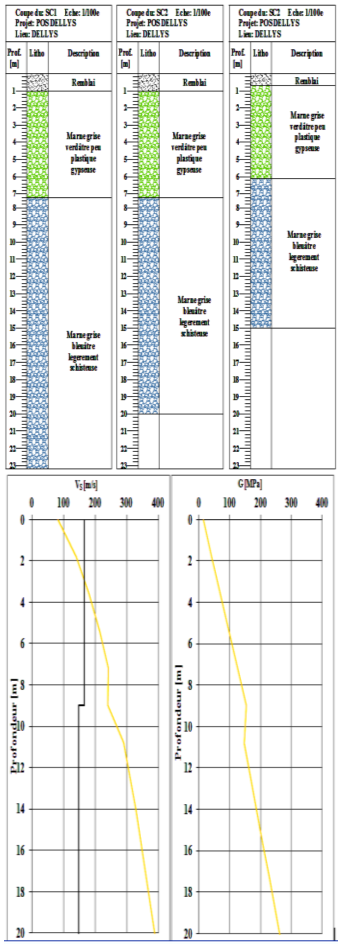

Fig. 3. Lithological Cups of three core drilling; shear wave velocity profile vs and shear modulus Profile G.

Seismic loading: The seismic loading is used for loading is the NS component of the accelerometer recording the Keddara station for the main shock of the earthquake in Boumerdes May 21, 2003 (magnitude 6.8).

The data were collected to a 0.005s no time for a total of 7000 record dots. The maximum acceleration is 0.33g reached at t = 7.415s (recording acceleration and Fourier spectrum of the signal are shown in Figure 4). The intensity of arias is equal to 0.669 m/s.

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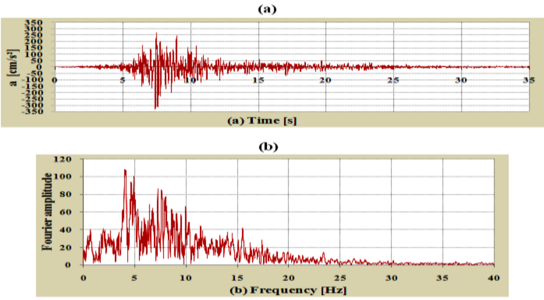

Fig. 4. Earthquake data: (a) the accelerogram ; (B) Fourier spectrum of the Keddara station.

II. STABILITY EVALUATION OF THE CASE STUDY

A number of analytical techniques based on the limit equilibrium analysis and stress-strain are valid for the analysis of seismic stability of a given slope and are widely categorized and based on a level of sophistication and opportunities. To analyze the behavior of the slope under the action of earthquake, considered the seismic loading is used. The stress-strain analysis of the seismic slope stability are performed using dynamic finite element analyzes by the Plaxis software and dynamic analyzes SHAKE 2000.

A. Dynamic analysis and calculation by SHAKE2000:

The geometry of the model studied is presented as a stratification layer in the soil profile (Figure 5) where we opted for a thickness of 2.22 m layer division.

The positioning of the columns is selected and (1 "Column No.2" and 2 "Column No.3") is shown in Figure 6

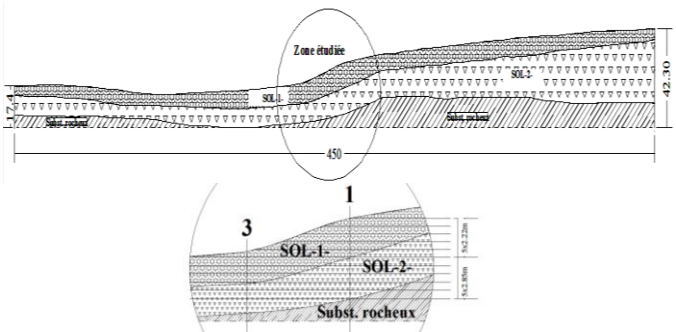

Fig. 5. Configurations layers and columns selected for analysis in SHAKE2000.

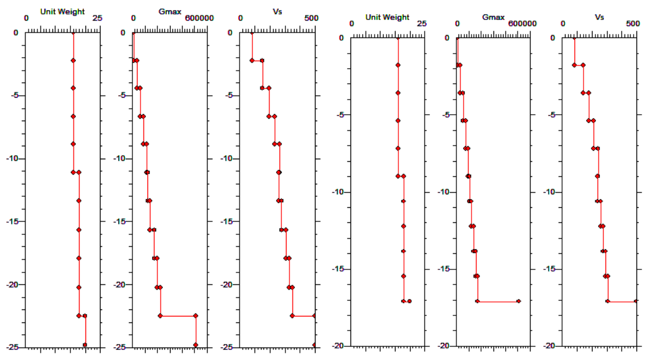

Fig. 6. Introduction of the soil profile in the SHAKE 2000 "Column No.2 (right) and No.3 (left)."

In SHAKE2000, two approaches are used to create the algorithm of Newmark method as recommended by Huston et al. 1987 and Franklin Chang, 1977.

1) the approach to Huston et al. Considers the negative component of the critical acceleration (upward movement).
2) The Franklin Chang approach considers only the negative part of the critical acceleration (downward movement only).

The displacement curve obtained after this analysis using the Franklin Chang approach is shown in Figure 7. The maximum displacement being 0.229 m.

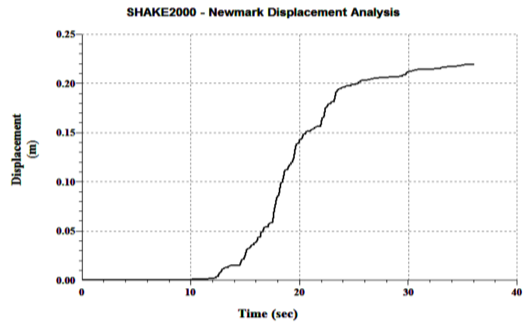

Fig. 7. Resulting Displacement from the analysis of Newmark.

The SHAKE has a very important tool in the calculation of displacements according to Newmark method based on the principle of rigid block; By introducing the load calculation and the static safety factor.

B. Dynamic analysis and calculation by PLAXIS:

To develop a digital model EF for dynamic analysis of the incorporated slope, the dynamic modulus of the Plaxis 2D v.8.4 (Brinkgreve, 2002) was used. The basic configuration of the static model has been maintained; however, many subtle changes had to be incorporated to allow proper functionality of the dynamic model. Such modifications can be set as the calibration of the model (DEY A. et al., 2011). Several key aspects must be taken into account for such calibration, and they are listed and discussed as follows:

Constitutive model and material properties: For the dynamic analysis, the soil is modeled as Mohr-Coulomb material. The built slope was modeled using the previously specified properties by adding depreciation Rayleigh:

Damping settings: In most dynamic EF codes, the viscous damping is simulated by the well-known Rayleigh formulation using two coefficients, α_R and β_R as:

$$C = \alpha_R M + \beta_R K \qquad (8)$$

According to the wording of Rayleigh (used Plaxis code), modal damping $\xi_n = \xi(\omega_n)$ depends on the natural circular frequency of ω_n system by:

$$\xi_n = \frac{1}{2}\left(\frac{\alpha_R}{\omega_n} + \beta_R \omega_n\right) \qquad (9)$$

The amplification function (Roësset, 1970) for a soil layer resting on a rigid substrate (Figure 9) is:

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$$A(f) = \frac{1}{\sqrt{\cos^2\left(2\pi \frac{H}{V_s} f\right) + \left(2\pi \frac{HD}{V_s} f\right)^2}} \qquad (10)$$

In previous cases, the n[th] natural frequency f_n:

$$f_n = \frac{\omega_n}{2\pi} \approx \frac{V_s}{4H}(2n-1) \quad (11)$$

In terms of the amplification function (equation (10)):

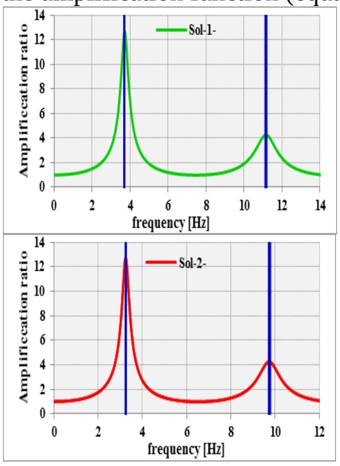

Fig. 8. Amplification function of soil layers

In terms of amplification function (Figure 8), Rayleigh parameters are: Soil -1- $\alpha_R = 1.74$; $\beta_R = 0.00107$ and Soil-2 $\alpha_R=1.86$; $\beta_R = 0.00036$

Using a calibration technique, leading to EF results (2D) comparable to those obtained by equivalent linear analysis of the frequency domain. the Rayleigh damping parameters are:

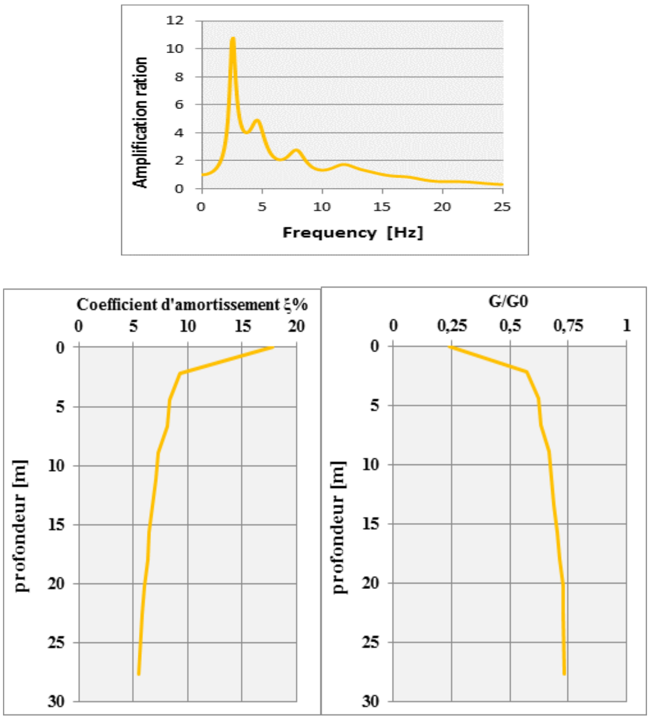

Fig. 9. Amplification function of the slope resulting from 1D analysis SHAKE; The profiles of G and D assumed in the EF analysis.

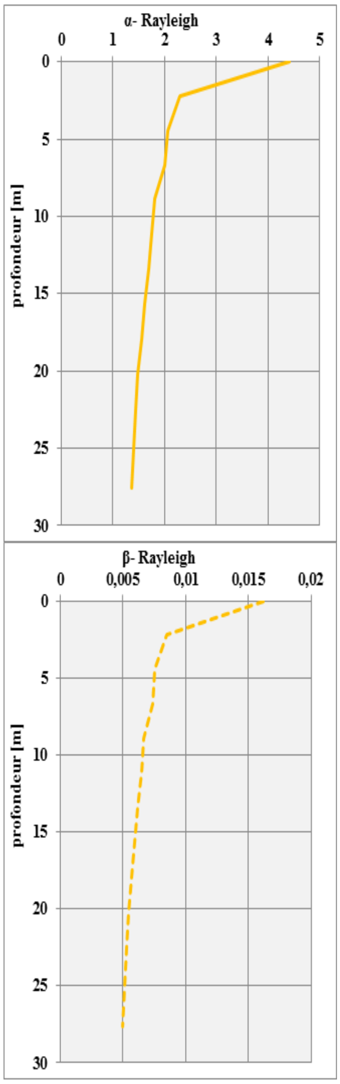

Fig. 10. Profiles α_R and β_R paid for EF analysis by calibrating.

We started previously an equivalent linear analysis using the SHAKE2000 code, which executes an automatic iterative process. The final profile of G (z) and D (z) calculated by SHAKE2000 can then be used to define the hardware settings in Plaxis (Bilotta et al, 2007; Visone et al, 2010).

Using a calibration technique, leading to EF results (2D) comparable to those obtained by equivalent linear analysis of the frequency domain.

This method of calculation shows that Rayleigh's parameters are not actually constant values but vary depending on the depth. So a good estimate of the amortization calculation model (A. Amorosi et al, 2010)

Meshing and input excitation (Figure 9): Whenever a numerical analysis is performed, the influence of the mesh must be examined. Kuhlmeyer and Lysmer (1973) suggest an element size:

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$$\Delta l < \frac{\lambda}{10} = \frac{V_s}{10\,f} \qquad \text{or:} \quad \Delta l < 1.18\,m$$

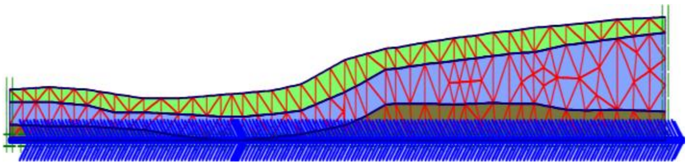

Fig. 11. Mesh of the model by triangular elements with 15 nodes.

Boundary conditions: An absorbing boundary is referred to absorb the increments of stress on the boundaries caused by dynamic loading, which would otherwise be reflected inside the soil body (C1 = 1 and C2 = 0.25). It can be seen that as the field width increases, the quality of spectra also improves. This can be interpreted due to the reduction of interference of the domain boundary on the reaction of the medium due to the reflection of the waves at the border. Therefore, it may be advisable to consider a field width of more than 10 times the size of the model to simulate reliably the actual situation.

Numerical Attenuation: The iterative process in Plaxis code for dynamic analysis is defined by the dynamic sub-steps, the two constants α and β.

The permanent displacement: Displacement of points A and B (selected at the bottom and top of the slope) versus time seismic loading are shown in Figure 10.

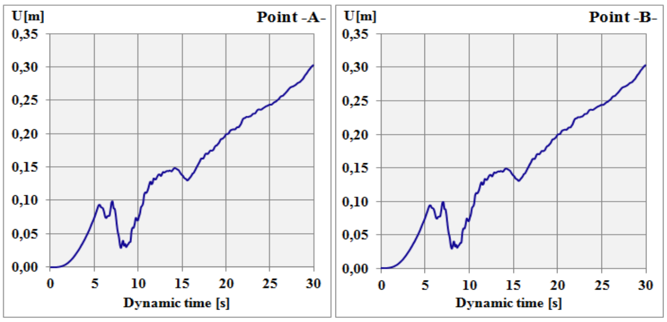

Fig. 12. Total displacements of points A and B .

Note that the slope has undergone a displacement of around 0.30m which exceeds the limit of the authorized travel for an urbanized slope.

This explains that the earthquake has evoked a movement in the slope, gold has been the phenomenon triggering the slide

III. CONCLUSION

Dynamic finite element analysis can be considered among the most comprehensive tools available in geotechnical earthquake engineering for their ability to provide information on the deformation / movement and distribution of soil stresses and forces acting on the structural elements that interact with the earth (PIANC, 2001) .However, they require at least a constitutive model suitable soil, proper characterization of ground by the tests in-situ and laboratory and a proper definition of the seismic excitation . The reaction of a finite element model is also conditioned by the arrangement of several parameters influencing the sources of energy dissipation in time domain analysis. The amount of damping exhibited by a discrete digital system is determined by the choice of (after C. Visone, 2008):

1. Constitutive model (materiel damping); models the effects of viscous and hysteretic dissipation of energy in the soils.
2. Equations integration scheme (numerical damping); appears as a consequence of the numerical algorithm of the dynamic equilibrium of solution in the time domain.
3. Boundary conditions; affect how the digital model transmits the specific energy of the stress wave outside the area.

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