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STABILITY ANALYSIS OF A ROCK MASS IN SEISMIC CONDITIONS: CASE STUDY IN LEBANON

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Abstract. *The objective of this work is to analyze the rock slopes stability under seismic conditions with a real Lebanese case study. High and steep slopes characterize the topography of Lebanon. Moreover, this country could be subjected to serious earthquakes because it contains one major fault and few secondary faults where some ones have been discovered recently. In Lebanon, slope areas become overcrowded because of the high population growth and migration of the population from urban zones. In this paper, we perform a numerical analysis using the UDEC code of the seismic response of fractured rock mass slope representing a real case in Lebanon. We use the seismic loading recorded during the Kocaeli earthquake (Turkey, 1999). The effect of different configurations of fracture networks is highlighted. In the absence of discontinuities, the rock mass is stable without the registration of permanent displacement in the upper part and it behaves as in the case of the rigid block. The presence of horizontal discontinuities leads to a permanent shift in the upper part of the rock, this shift tends to increase going towards the inside of the model; A small rocking motion induced in the solid by the seismic loading and could be neglected.*

1 INTRODUCTION

Lebanon is characterized by its high urbanized mountains and steep slopes. The major structures are Mount Lebanon and the Anti-Lebanon. In general, Lebanese mountains are formed by old rocks formations varying from sedimentary rocks to limestone, dolomite and volcanic ashes. Unfortunately, due to huge demographic expansion and land development even major steep slopes were populated. The absence of a public policy of controlled urbanization, new construction settles in precarious sites, often vulnerable to natural disasters especially in active seismic zone and in poor regions.

From geological point of view, Lebanon contains one major fault and few secondary faults where some ones have been discovered recently. Severe earthquakes could then lead to great human and material losses. In the past, several destructive earthquakes have been occurred in Lebanon for example in years 551, 1202, 1759, 1837 and 1956. Recently, many earthquakes, of low magnitudes between three and five, have been registered in Lebanon during 2008. These events have increased the anxiety of Lebanese people because of the poor quality of the constructions and their behavior under moderate or severe earthquake events. The efficient way to minimize seismic effects, material and human losses, still the prevention that could be deduced from a better comprehension of the behavior of slopes during and immediately after the seismic events. Given the high seismic risk, it seems necessary to conduct stability analysis of rock masses encountered in the Lebanese mountains.

Generally a discontinuous rock mass deforms preferentially by slipping on preexisting fractures. This movement may be accompanied by an extension of existing fractures and the creation of new fractures. Tracking and morphology of a fracture after brittle deformation are strongly influenced by the texture of the material, the nature of minerals and orientation of microscopic discontinuities with respect to the direction propagation of the fracture. The observation of a natural fracture in a granite sample showed that biotite, regardless of size, is systematically fractured and fracturing borrows their differences [3].

The effect of a filler material on the shear depends on the nature of the material, its thickness and the height of the asperities ([2], [5], [6] and [8]). In general, the shear strength of a joint decreases the thickness of the filler increases.

The seismic loading propagates in the ground by different types of waves. It induces deformations and stresses in the soil. In the presence of water, it may induce a variation of pore pressure, which leads to a variation of the effective stresses of contact and in some cases a reduction of the resistance of geo-materials. Crossing of fractured rock masses, seismic waves generally induce shear stresses at the discontinuity lines, which can cause slippage between the blocs and eventually instability of the rock mass. The vulnerability of a rock to seismic loading depends on many factors, including the magnitude of the seismic acceleration, the duration of the earthquake, the strength characteristics of the mass and dimensions [1].

The objectives of this work is to analyze the seismic response of fractured rock mass slope corresponding to a real case in Lebanon. We perform a numerical modeling by using the UDEC code. will be performed using the UDEC code. We present successively the numerical approach adopted in the UDEC, the case study (geometry, properties, loading ...) and the obtained results by taking different networks of fractures.

2 PRESENTATION OF NUMERICAL MODEL

The numerical method falls within the general classification of discontinuum analysis techniques. This approach can represent the geometry of joints and their behavior and to represent the large displacements as well as large deformations.

In this work, we utilized the software UDEC (Universal Distinct Element Code) developed by «ITASCA Consulting Group». The domain is represented by an assemblage of discrete blocks. The discontinuities are treated as boundary conditions between blocks; large displacements along discontinuities and rotations of blocks are allowed.

Blocks in UDEC can be either rigid or deformable. Deformable blocks are subdivided into a mesh of finite-difference elements, and each element responds according to a prescribed linear or nonlinear stress-strain law. The relative motion of blocs is governed by nonlinear force-displacement. UDEC is based on a “Lagrangian” calculation scheme that is well-suited to model the large transformations.

The dynamic analysis is represented numerically by a time-stepping algorithm in which the size of the time-step is limited by the assumption that velocities and accelerations are constant within the time-step. The time-step restriction applies to both contacts and blocks.

The calculations performed alternate between applications of a « force-displacement » law at all contacts and Newton’s second law at all blocks. The « force-displacement » law is used to find contact forces from calculated displacements. Newton’s second law gives the motion of blocks. Then, the application of the block material constitutive relations gives stresses within the elements and equivalent forces at nodes.

The mesh imposes a finite extension of the field. It is necessary to reduce reflections «artificial» of energy to the boundary of the model. A first solution is to remove significantly the limits of the model from the area of interest. This solution leads to make meshes large sizes, which results in a considerable increase in computation time and memory storage required for results. UDEC offers another alternative by applying, at the lateral boundaries, absorbing boundary conditions of type "Quiet Boundaries" or "Free-Field" (Itasca, 2000) [4]. Conditions such as "Quiet Boundaries" simulate free-field motion that would occur in a semi-infinite solid.

3 DESCRIPTION OF THE CASE STUDY

3-1 Site Description

The rock covered in this paper is located in Jezzine and which lies 40 km south of Beirut. Surrounded by mountain, pine forests, and at an average altitude of 950 m, this site is the main resort in southern Lebanon.

There is a lack of data about this site. They were collected from different sources, including field visits, consultation of Google Earth, an analysis of the geological map from CNRS-Lebanon (National Council for Scientific Research) and discussions with professionals who have worked on the site or on adjacent sites.

The site and the rock mass are shown in Figures 1-a and 1-b. The rock mass consists in a 16m high cliff. The fractures are visible on the mountains; especially we can observe the horizontal discontinuities.

Figure 1-a: Site of Jezzine in South Lebanon- view of the cliff

Figure 1-b: Site of Jezzine in South Lebanon- Surface view

3-2 Mechanical properties

The rock mass is formed of sandstone. The morphology of the slope has been strongly affected by erosion processes that have produced cavities and voids of a various sizes. The combined effects of this erosion, the washing out of sand and silt, and the presence of discontinuities leads to rock toppling and rock falls.

The mechanical properties of the rock were determined from the data available in the literature and discussions with professionals and researchers in Lebanon. This step was the main difficulty of this work because it has only few data. These parameters give an indication of the stability of the domain. A parametric study is carried out in order to investigate the effect of key parameters on stability.

The characteristics of the rock mass are summarized in Table 1: we have a soft rock with a Young's modulus of 6 GPa and a Poisson's ratio of 0.25.

Parameters		Sandstone
Deformation Modulus	E (GPa)	6
Unit weight	γ (KN/m^3)	24.7
Poisson's ratio	Γ	0.25

Table 1: Mechanical characteristics of the rock mass (Sandstone).

The mechanical parameters of discontinuities are summarized in Table 2. The normal stiffness is taken equal to the modulus of deformation of the rock. The tangential modulus is equal to half the normal module. The values attributed to the cohesion and of the friction angle are influenced by the filling and cementing of the joints. The tensile strength is neglected.

Parameters		
Normal Stiffness	Kn(MPa/m)	$6x10^3$
Shear Stiffness	Ks(MPa/m)	$3x10^3$
Cohesion	c (MPa)	0.02
Friction Angle	ϕ (°)	28
Tensile Strength	σ_t (MPa)	0

Table 2: Mechanical parameters of horizontal discontinuities.

Mechanical damping is used in the distinct element. The approach is conceptually similar to dynamic relaxation, proposed by Otter et al. [7]. The equations of motion are damped to reach a force equilibrium state as quickly as possible under the applied initial and boundary conditions. Damping is velocity-proportional (i.e., the magnitude of the damping force is proportional to the velocity of the blocks).

3-3 Seismic loading

Due to lacking of seismic records in the site, we have adopted for the seismic loading the data related to the Kocaeli earthquake occurred August 17, 1999 in Turkey. Figures 2-a and 2-b respectively give the variation of the horizontal component of the velocity and its spectrum. We note that the duration of the earthquake is about 30 s with a maximum speed of about 40 cm/s (reached after 5 seconds). The velocity spectrum shows that the loading frequency is mainly concentrated between 0 and 2Hz with a major peak at 0.9 Hz. The effect of the vertical component is neglected.

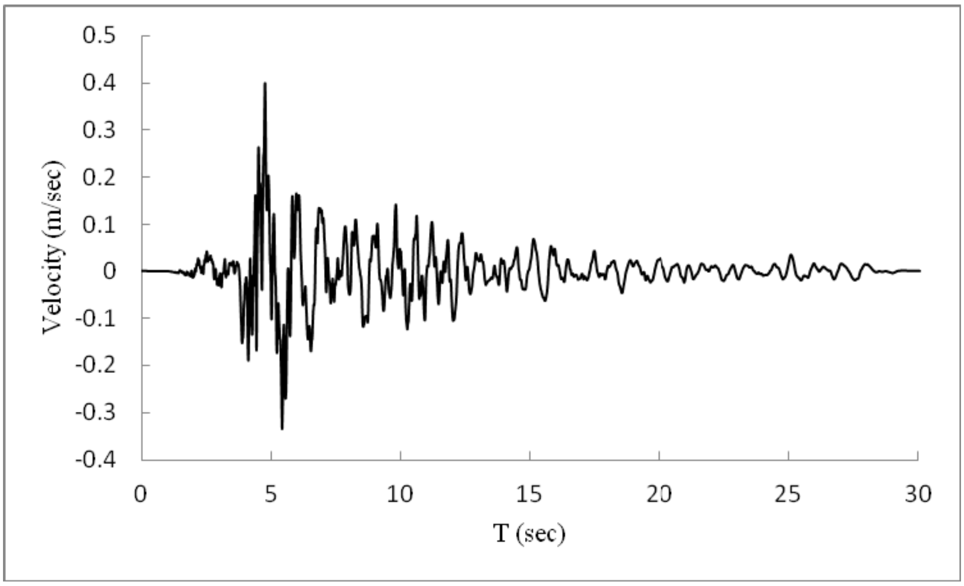

Figure 2-a: Horizontal component of seismic action (Kocaeli – 1999)

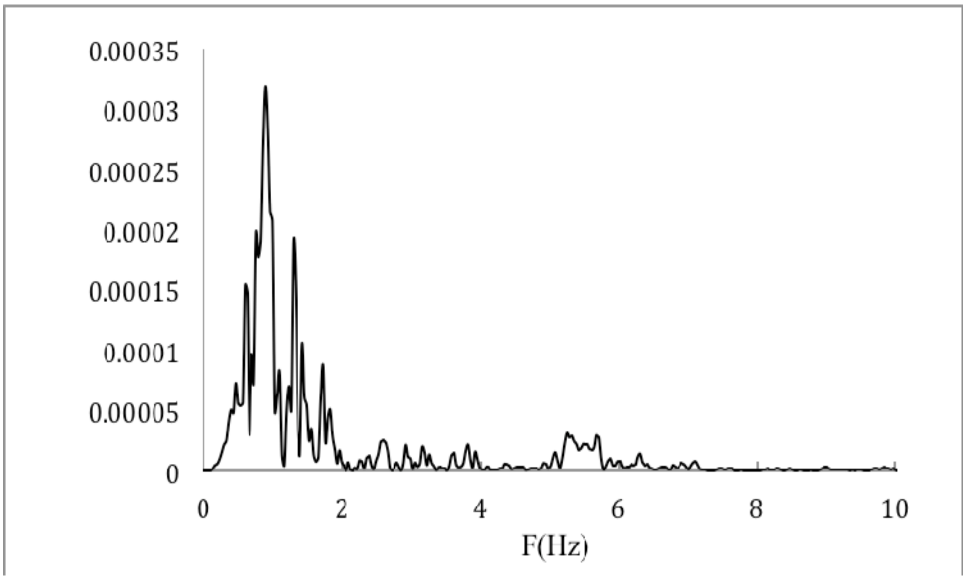

Figure 2-b: Power Spectrum of the horizontal components of the seismic action (Kocaeli-1999)

4 ANALYSIS OF THE SEISMIC BEHAVIOR OF THE ROCK MASS (WITHOUT DISCONTINUITIES)

In this section, we present an analysis of the seismic behavior of the rock mass without discontinuities. This step allows us to define the reference case used later for comparisons.

Figure 3 shows the area considered in the modeling with the horizontal discontinuities. Strong cohesion has been attributed to these discontinuities conditions to ensure perfect contact between the blocks. This figure also defines the position of the points (A, B, C, D, E and F) that will serve as reference points in our interpretation of the seismic response of the massif.

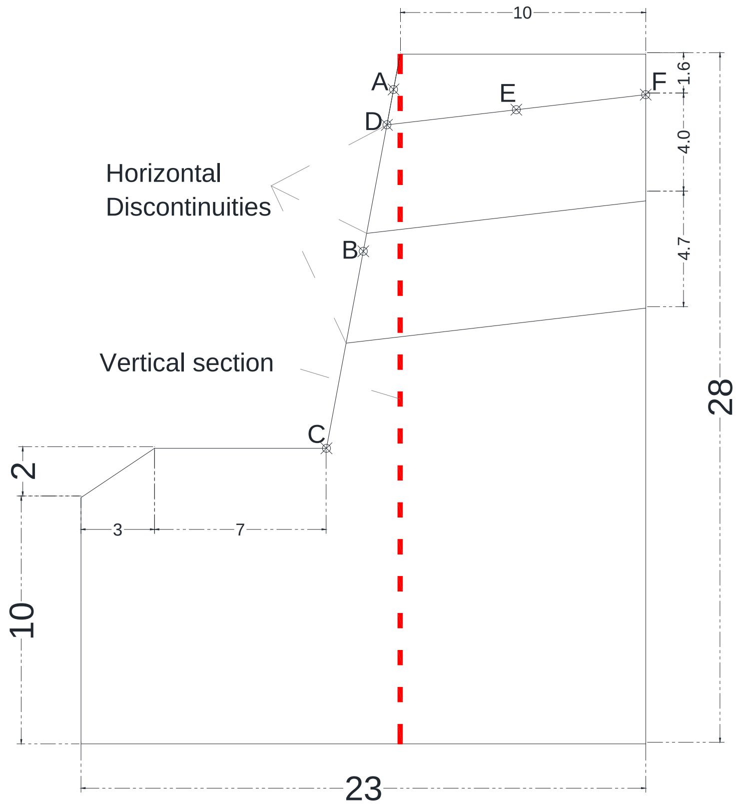

Figure 3: Domain considered in the modeling of the rock mass in jezzine

4-1 Initial state - static calculation

In a first step, a static calculation was performed to determine the initial constraints due to the weight of the mass. Figure 4 shows the displacements obtained. We note that these movements are directed downwards (settlement) resulting from the application of its own weight. These displacements are small (less than 1.5 mm), which indicates a good stability of the rock mass under its own weight.

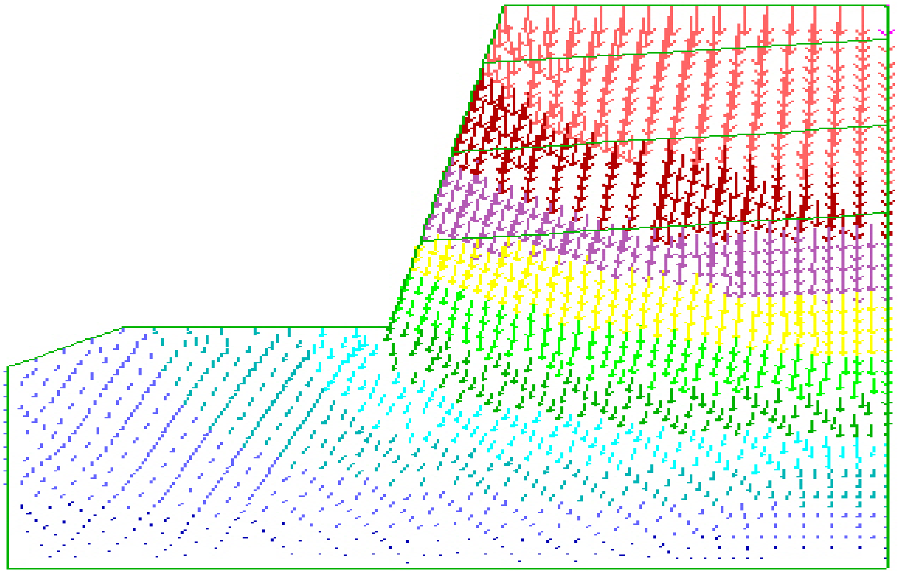

Figure 4: Initial displacement of the rock mass (due to own weight only)

4-2 Seismic Analysis

The calculation was carried out by applying the data of the Kocaeli earthquake (Figure 2-a) at the base of the rock. Boundary conditions of type "quiet boundary" imposed on the lateral boundaries of the domain.

Figure 5 shows the horizontal displacements at points A, B and C induced by seismic loading. We note that these movements have the same shape as the imposed loading (Figure 2-a). A maximum displacement of about 6 cm occurs when the seismic loading reaches its peak (at time t = 5 s). We note the following attenuation of lateral displacement to cancel at the end of seismic loading. We can conclude that there is no permanent displacement at the end of loading.

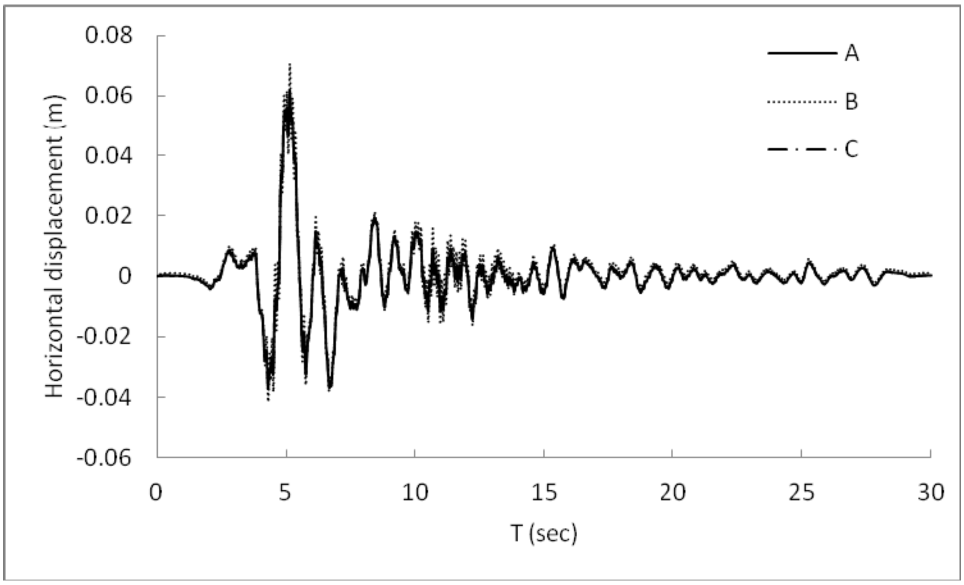

Figure 5: Horizontal displacement induced by seismic loading at three points of the rock mass (Rock mass without discontinuities)

Figure 6 shows the profile of the lateral displacement along a vertical section. There is a movement almost constant with depth, indicating that at the beginning of the loading mass undergoes a motion block with a lateral translation. A slight deformation appears at t = 5 s (peak load speed). Note the almost cancellation of lateral displacement at the end of loading (t = 25 s). In the absence of discontinuities, the rock behaves as in the case of a rigid block.

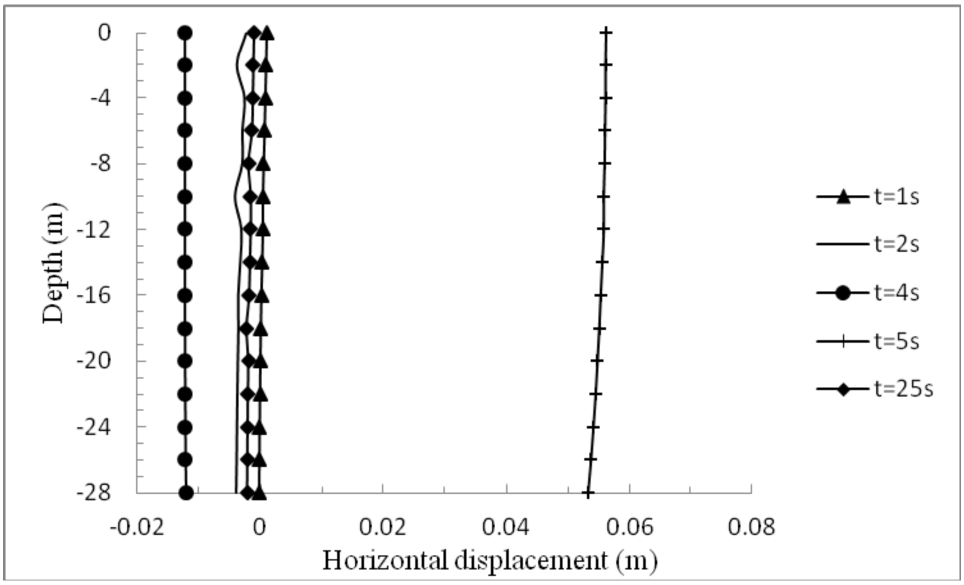

Figure 6: Lateral displacement along the vertical section of the rock mass (rock mass without discontinuities)

Figure 7 illustrates the variation of the lateral velocity at point A. This velocity reaches its maximum value at the same time of that of input loading (at time t = 5 s). By comparing the maximum value of the speed (1 m/s) with maximum speed imposed on the basis of the model (0.4 m/s), we obtain a dynamic amplification equal to 2.5.

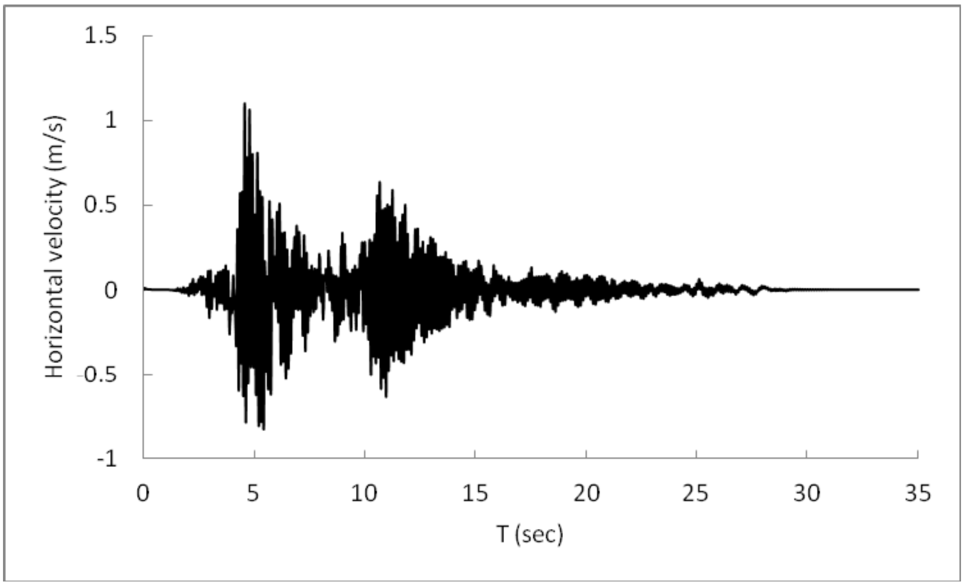

Figure 7: Variation of the velocity at point A of the rock mass (Rock mass without discontinuities)

5 ANALYSIS OF THE SEISMIC BEHAVIOR OF THE ROCK MASS - NETWORK OF HORIZONTAL FRACTURES

In this section, analyzes are performed considering the network of horizontal discontinuities (slight slope of 6.6 °). Three lines of discontinuities are considered in the calculation (Figure 3) with the mechanical properties given in Table 2.

5-1 Initial state - static calculation

A static calculation was performed to determine the initial constraints due to the weight of the mass. The displacement field obtained is close to that obtained in the previous case (Figure 4). Displacements obtained are small and rock mass is stable under the action of its own weight.

5-2 Seismic Analysis

Figure 8-a shows the induced horizontal displacements at points A, B and C of the cliff. At the beginning of loading, the displacements are identical in the three points. The maximum value of 6 cm is obtained 6cm at t = 5. Then, shapes are significantly different with a significant gap between the point C (at the foot of the cliff) and points A and B (at the top of the cliff). At the end of the load, there is a return from the point C to its initial position and a permanent displacement of 5 cm and at point B and 6 cm at point A. Such a trend shows that the seismic loading induced, in the presence of horizontal discontinuities, permanent sliding in the upper part of the rock.

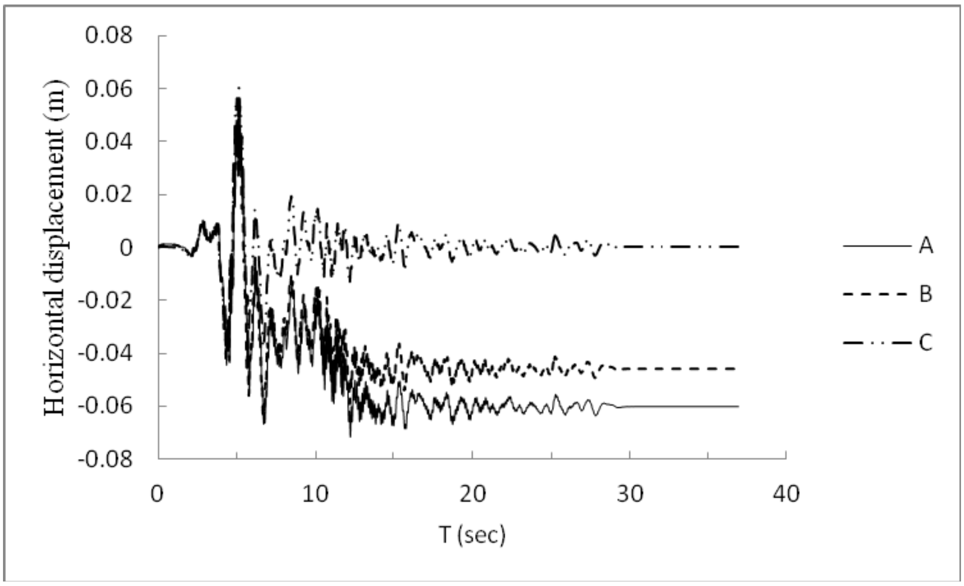

Figure 8-a: Lateral displacement induced in three points of the rock mass (Rock mass with horizontal discontinuities)

Figure 8-b shows the variation of horizontal displacement along the top discontinuity (DEF). We can note the presence of a permanent displacement along the discontinuity tends to increase when moving from point D to point F (inward massif, Figure 3).

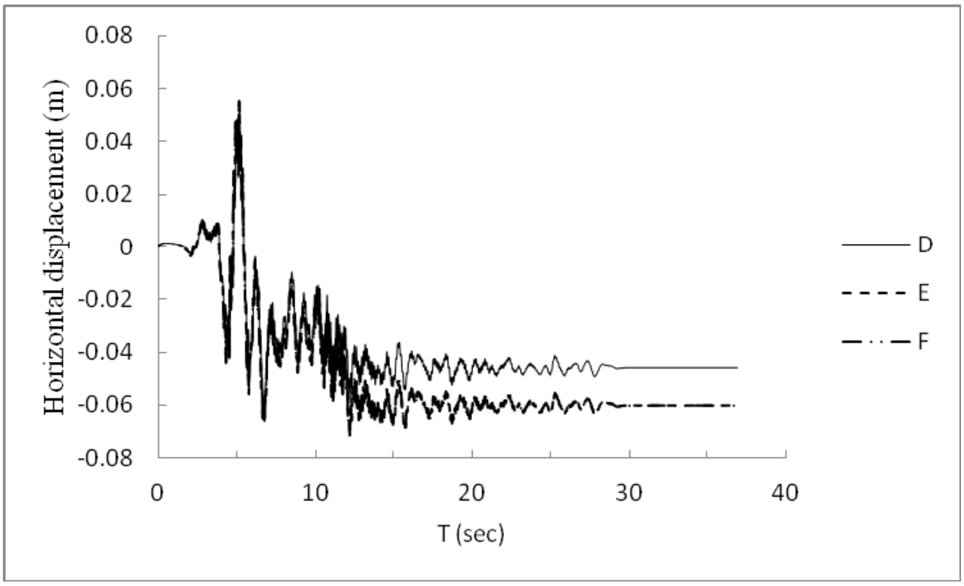

Figure 8-b: Lateral displacement induced at the top discontinuity (DEF) (Rock mass with horizontal discontinuities)

Figure 9 shows the profile of lateral displacement along the vertical section inside the area (Figure 3). At the beginning of loading (t = 2 s), there is a movement almost constant with depth, indicating a rigid block motion. At time t = 5 seconds, corresponding to the maximum loading, there is a shift of the upper part of the rock mass relative to the lower part. At the end of loading (t = 25 s), we note the return of the lower block to its original position (no lateral movement) and the presence of permanent sliding in the upper blocks.

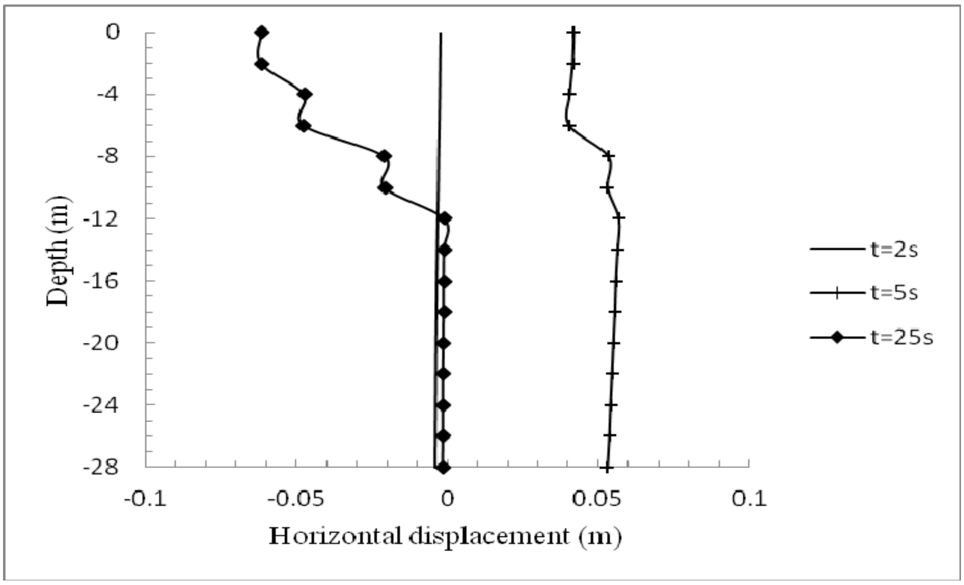

Figure 9: Lateral displacement along a vertical section (Rock mass with horizontal discontinuities)

Figure 10 shows the variation of the horizontal component of the velocity at point A. Note that this speed reaches its maximum (1 m/s) at the same moment of the maximum value of the applied load (t = 5s). As in the case without discontinuities, the amplification of the speed relative to the base is equal to 2.5.

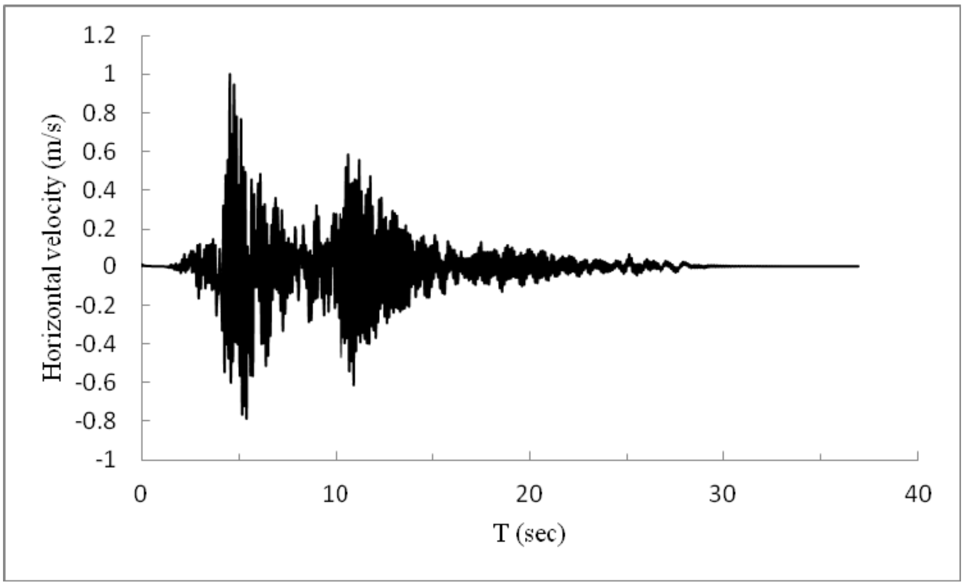

Figure 10: Variation of the horizontal component of the velocity at point A (Rock mass with horizontal discontinuities)

Figures 11-a and 11-b show the variations of normal and tangential components of the stress at point D. It may be noted that the normal stress is positive (compression), reaching its maximum value (1.2 MPa) at the moment when the seismic loading is maximum (t = 5 s). This constraint becomes almost zero beyond t = 15 s. Shear stress undergoes significant variations with the loading with a similar shape to that of the variation of the horizontal speed (Figure 10). Its maximum value is equal to 0.4 MPa. Figure 11-c shows the stress path in the plane defined by the axes normal stress and shear stress. The path obtained lies within the boundary surface:

$$|\tau| = c + \sigma_n tg(\varphi)$$

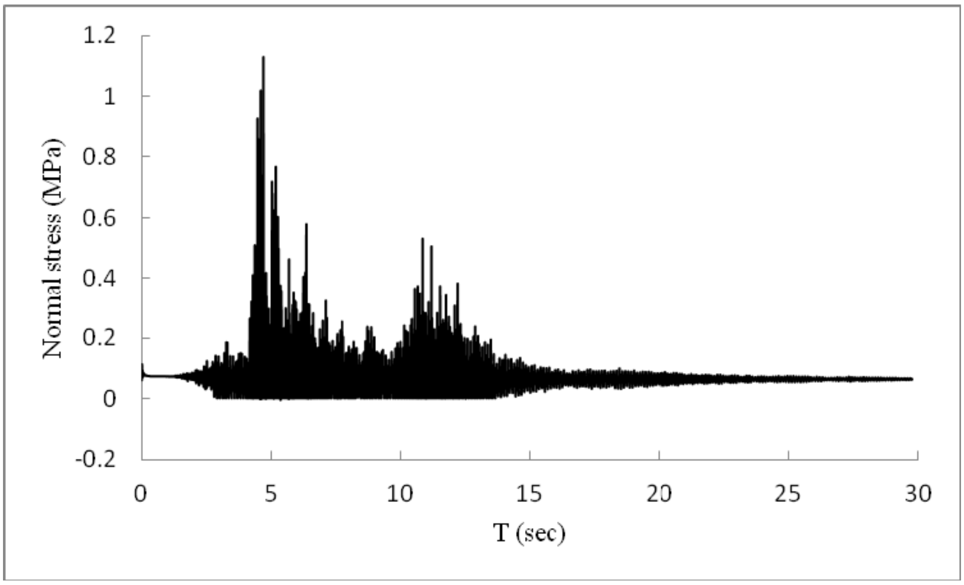

Figure 11-a: Variation of the normal stress in joint at point D (Rock mass with horizontal discontinuities)

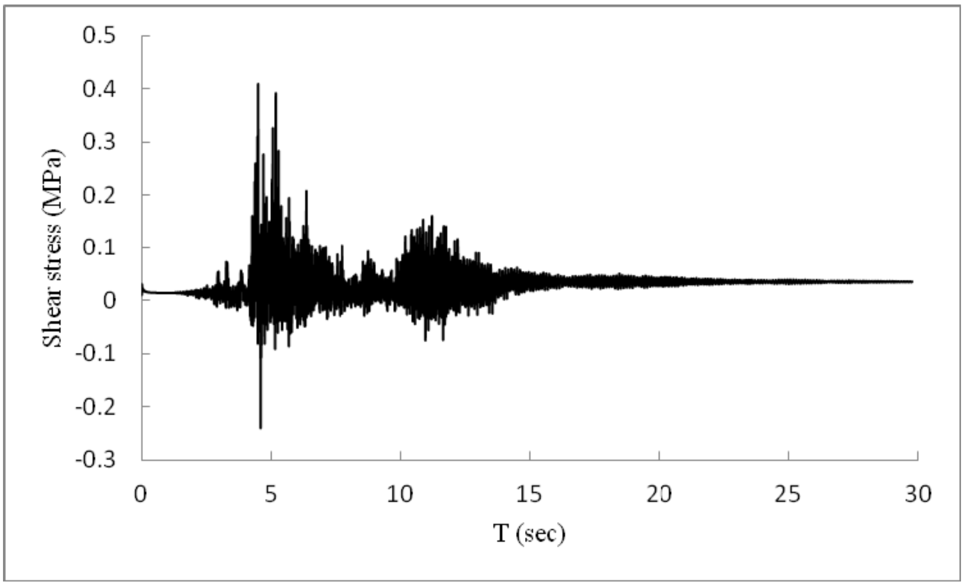

Figure 11-b: Variation of the shear stress in joint at point D (Rock mass with horizontal discontinuities)

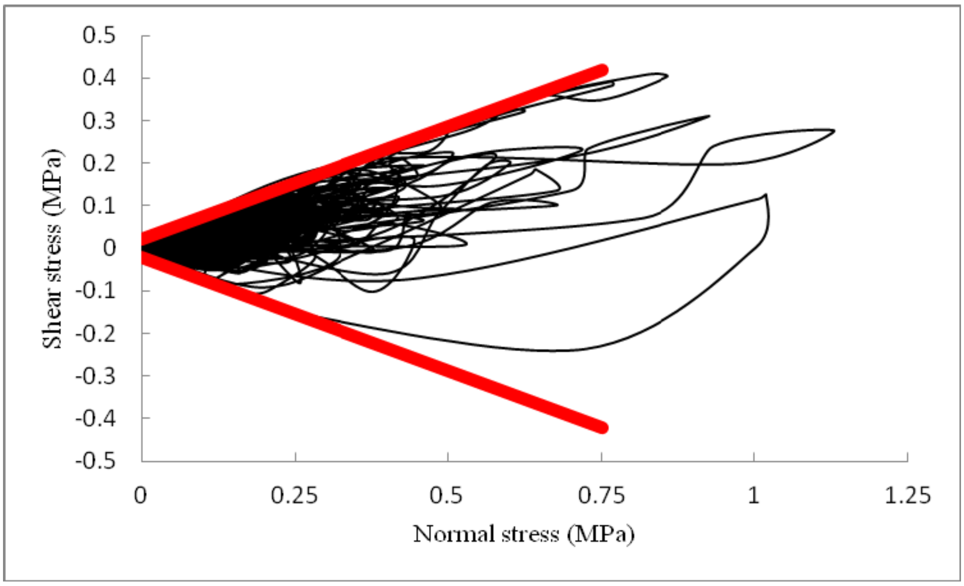

Figure 11-c: Path of stress in joint at point D (normal stress – shear stress) (Rock mass with horizontal discontinuities)

5-3 Parametric study

In this section, we present the influence of the strength joint (Friction angle and cohesion) on the seismic response of the massif:

Influence of joint strength

At first, we studied the influence of the angle of friction of the joint on the seismic response of the rock mass. The calculation was performed with a value of friction angle equal to zero.

Figures 12-a and 12-b show the variations of normal and tangential components of the stress at point D. We note that the variation of this stress has a similar shape to that obtained with a friction angle of 28° (Figure 11-a) but with an amplitude of about 50% greater. The shear stress varies cyclically between -0.02 MPa and 0.02 MPa (i.e between – c and + c; c being cohesion) during the first 15 seconds of the load; then it decreases to finally cancel loading.

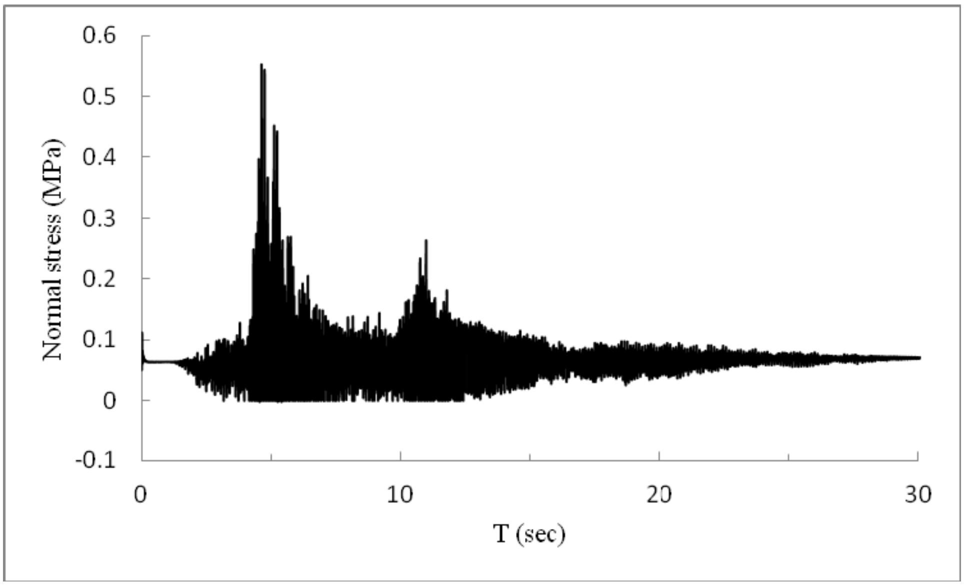

Figure 12-a: Variation of the normal stress at point D with an angle of friction in joint equal to zero(Rock mass with horizontal discontinuities)

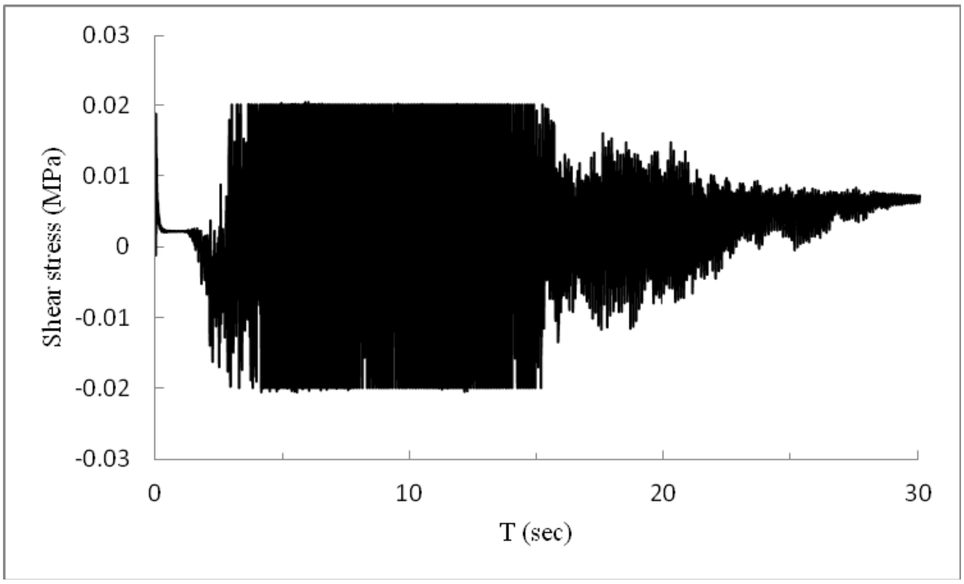

Figure 12-b: Variation of the shear stress at point D with an angle of friction in joint equal to zero (Rock mass with horizontal discontinuities)

Figure 13 shows the influence of the friction angle of the horizontal displacement along a vertical section (Figure 3). Note that this angle does not influence early answer (t = 2 s). Subsequently, we note that the disappearance of friction along the joints resulting in a significant increase in the displacement of the upper block. At the end of the load (t = 25 s), the reduction of the friction angle from 28° to 0° leads to an increase in the movement of the upper block from 6 cm to 21 cm.

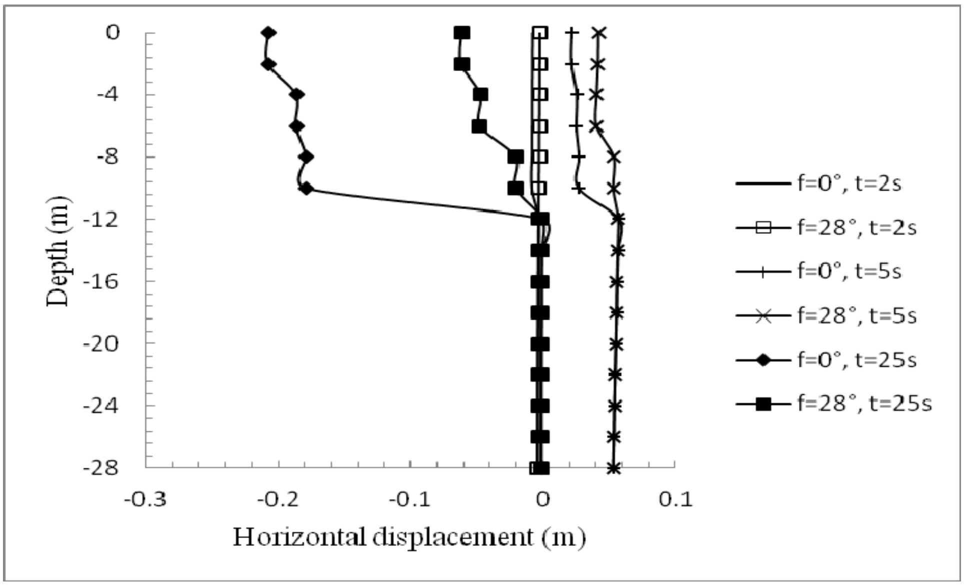

Figure 13: Effect of the friction angle on the horizontal displacement along a vertical section (Rock mass with horizontal discontinuities)

To investigate the influence of cohesion on the seismic response of the rock mass, calculations were made for a friction angle of zero, with two new values of cohesion c = 0.2 MPa and 2 MPa. Figure 14-a shows the influence of cohesion on the movement at point B. We note that the increase in cohesion results in a significant reduction of the horizontal displacement at this point with a return to its original position at the end of loading. This indicates that the discontinuity is in the elastic range when the cohesion is 0.2 MPa. Figure 14-b shows the influence of cohesion on the side profile of the movement in a vertical section. This figure confirms the result in Figure 14-a, we note that from a cohesion of 0.2 MPa, the blocks do not undergo any massive shift.

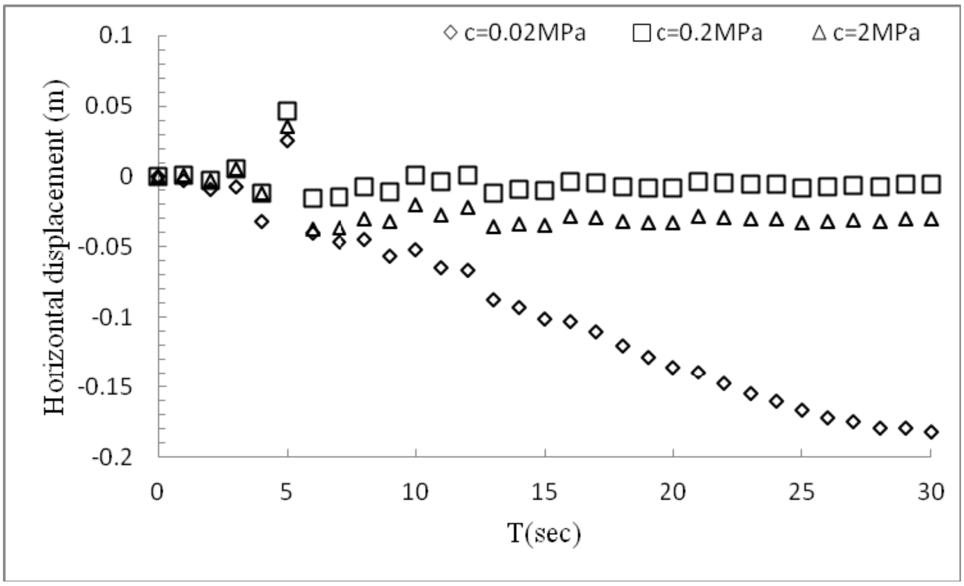

Figure 14- a: Effect of cohesion on the horizontal displacement at point B (φ= 0°; Rock mass with horizontal displacement)

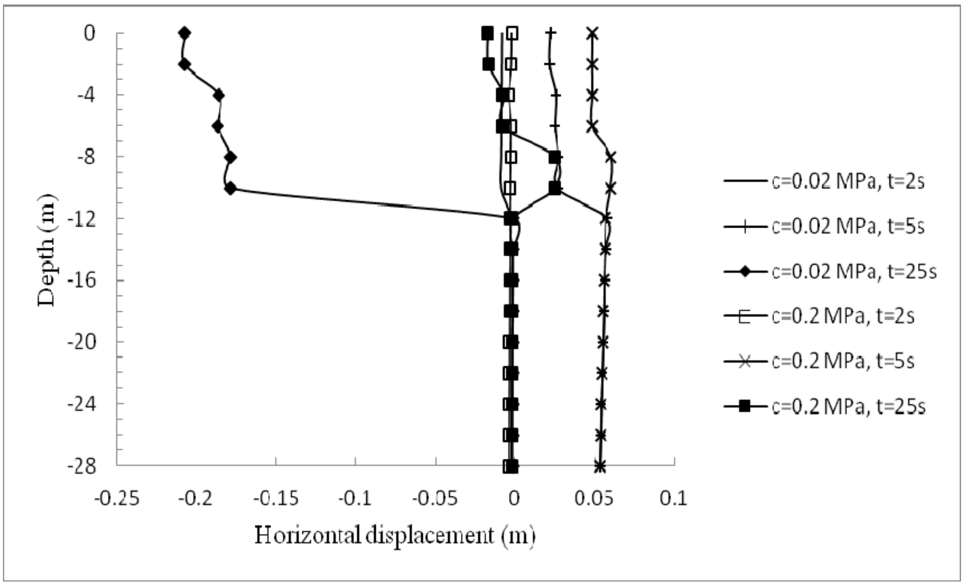

Figure 14-b: Effect of cohesion on the profile of the horizontal displacement along a vertical section (φ= 0°; Rock mass with horizontal discontinuities)

CONCLUSION

A fractured rock in an earthquake zone is exposed to hazard of instability with the possibility of slipping or (and) falling blocs. In such case, we can obtain significant damage that leads to important losses of properties and human lives. So, the analysis of this type of risk is therefore required for rock masses located in seismic zones.

This analysis is particularly important for Lebanon, a country that is predominantly composed of fractured rock and located in a seismic zone where a major earthquake could be expected in the coming years. The objective of this paper is to analyze types of cases encountered massive and study cases of vulnerability stabilization devices.

The behavior of fractured rock is mainly influenced by fractures (discontinuity surface) which are generally the potential locations of relative motions with slippage and separation. These massifs are generally vulnerable to seismic loads, including the lateral component of the load. This paper has been dedicated to the analysis and the numerical modeling of the behavior of rock joints. The approach of separate elements is the most appropriate because it allows good model surfaces of discontinuity and considers large displacements and large deformations.

The numerical modeling of a real case in Lebanon has lead to the following main conclusions :

- The rock mass is generally discontinuous, anisotropic, homogeneous and not elastic;
- The rock mass is stable under its own weight, initial state, in the absence of discontinuities and in the presence of horizontal discontinuities;
- Under seismic loading, and in the absence of discontinuities, we note that the rock is stable without permanent displacement in the upper part and it behaves as in the case of the rigid block;
- A dynamic amplification of the velocity of seismic loading applied to the base of the model;

- Under seismic loading and in the presence of horizontal discontinuities, there is a permanent shift in the upper part of the rock, this shift tends to increase going towards the inside of the model;
- A small rocking motion induced in the solid by the seismic loading and could be neglected;
- The stress path in the plane defined by the axes normal stress and shear stress obtained is well within the boundary surface:

$$|\tau| = c + \sigma_n tg(\varphi)$$

- The reduction of the friction along the joint results in a significant increase in the displacement of the upper block and leads to an increase in the movement of the upper block;
- The discontinuity is in the elastic range when increasing the value of the cohesion to 0.2 MPa and the blocs do not undergo any massive shift from this value.

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