DYNAMIC BEHAVIOUR ANALYSIS OF TIGZIRT LANDSLIDE

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Abstract: Landslides occur in unconsolidated formations at the interface over more rigid formations. Shaking the basement can help to change their dynamic evolution. This work is a contribution to the characterization and the numerical modeling of slip that affects the Tigzirt city center (Algeria) under the combined effect of the water and seismic action.

The analysis is performed using the Plaxis 2D code. Both static and dynamic results of numerical calculations, confirm the precarious state of the slope's stability. In addition, the overhead and the effect of the water have a great influence on the dynamic response of the catchment. Indeed, the influence of stress on the slope's seismic stability resulted in an increase of the maximum displacement of about 90% compared to the static case.

Keywords: Landslide, site effects, earthquake, numerical modeling.

I- INTRODUCTION

Kabylia has known in these last year's winters with particularly heavy rain. These storms are the cause of many cases of land instability especially in mountainous regions which are sometimes very close to the densely populated coastline. These landslides are extensive and are likely to cause significant morphological changes. They are always the result of two sets of factors: in one hand, the natural conditions that control the stability of the slopes and on the other, climate and/or anthropogenic related triggers (R. Dikau and al, 1996).

The Tigzirt's city is located in Great Kabylia (Algeria) on the coast of the Mediterranean Sea, 40 km north of Tizi-Ouzou, 100 kilometers east of Algiers, the capital. Conducted studies have revealed the presence of reshuffled areas at the interface between the substrate and the surface layers. Furthermore, the mechanical properties of geological formations that make up this slope are altered with the presence of water. They foster the emergence of active and widespread landslides. The sliding surface was identified by observing samples from core drilling to relatively large depths of about 10 m at the beginning of the hill and 30 meters halfway up the hillside.

However , The 1970 fracture does not correspond to a major earthquake, but to many previous shocks, related to the active neotectonic sector (Boudiaf et al., 1999; Yelles-Chaouche et al., 2006) which were able to weaken the slope by repeated pressures (Duffaut, 2003). Seismic events produce horizontal forces in addition to the pressures described above without changing the shear strength of the land (Habib, 1997).

In view of the instability phenomena's complexity, we opted for the establishment of a multidisciplinary approach involving geomorphology, geology, hydrogeology and geotechnical engineering. This approach consists on an instability analysis phase followed by a modeling.

II- DESCRIPTION AND CHARACTERIZATION OF TIGZIRT SLIDING

The instability of the Tigzirt's slope is explained by all the existing factors conditioning the site, with regards to the natural elements: geology, topography and the action of percolating water, human action, excavations and constructions, based on the unstable debris slope cover (overloading) and the lack of drainage system of surface water, underground sewage in unstable formations (sanitation defective bungalows and sewage discharge in the site).

The transition from the state of stability to an unstable one (Dikau et al., 1996) has several raisons: external (erosion, earthquakes, overload of a book); and internal (the increase in pore pressure, the alteration of a rock). The causes are regularly combined.

II-1- Morphology, hydrology and causes of slip

The urbanized site, object of this study, is located in the east of the city of Tigzirt, below the RN24. It has an angled topography, with a slope ranging from 13 ° to 15 °. The Watershed Tigzirt of region stretches from the top of the mountain to the sea. The dip is to the north and in the same direction as the general slope of the land. This structure could be a predisposition to the sliding of higher areas comparing to the lower ones.

The Tigzirt central flows stretches from the palm of Ferraoun beach to the east of the ravine Azal Creek to the west and east of the other two flows (of Agouni Rehal) and west (to the right of the road port). The eastern part of this central flow is subjected to coastal erosion and the western part completely destabilized between the RN 24 and the side with greater activity at Bungalows. The morphology of these sites has been extensively remodeled by the amenities and the ground movements.

This region's rainfalls are irregular and the climate has been described as quite cold in winter, hot and dry in summer. The highest rainfall are obtained in November (109.8 mm) and maximum temperature (30.7 °) in August. The lowest moistures are in the range of 40.8% in July and maximum of the order of 94% in February.

The Tigzirt landslide grows along the interface between the substrate and the surface layer in a planar fracture form. The sliding surface is at the fringe of the altered marly substratum which has the lowest mechanical properties. It is deeper than 30 m and has implemented several sagging compartmentalized mechanisms. This is the gravity displacement of the clay talus layer with a thickness of about 30 m, compared to the healthy marl bedrock. The fracture surface is plotted on a longitudinal section of the unstable slope (Figure 1). Indeed, the geological section of the slope was defined by using the results of the SC01 survey and the cross sections made from the SC05- SC03- SC02 and SC05-SC04 survey.

The unstable slope has undergone several deformation processes that manifest on the surface by the appearance of longitudinal and transverse tear lines. In addition, these areas can be breakout areas of stagnation and infiltration of rainwater until the fracture surface which will contribute to the evolution and the reactivation of the landslide. In addition, a significant evolution of the coastline has been observed in recent years by comparing aerial images taken at different dates.

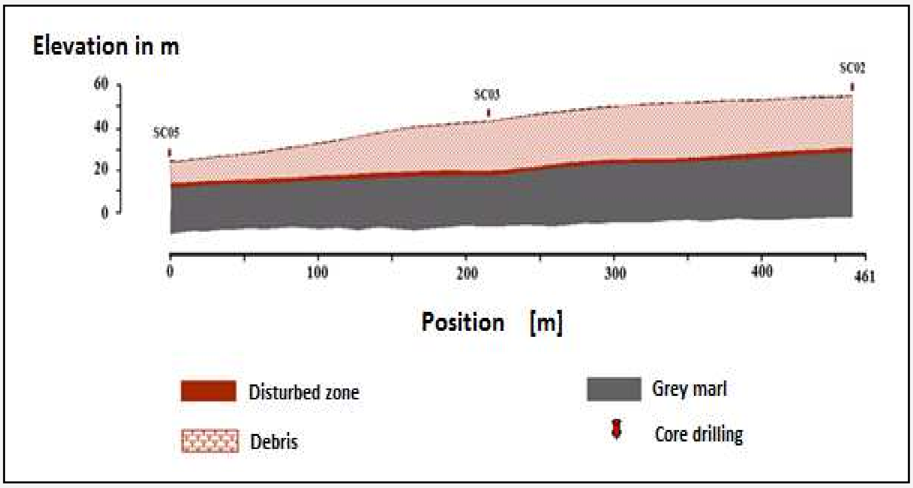


Figure 1: Geological profile produced according to the SC05-SC03-SC02 survey.

Given that the precarious stability of the Tigzirt site does not support hydrologic modification or abrupt geometric, any small change can cause rupture of the slope. In addition, the absence of drainage systems for surface water (gutters, drains ...) and the effect of accidental water infiltrated into the unstable formations (which come from faulty sewage systems) also contribute to the onset of instability. Failure to respect the environment and the unpredictable and varied developments (such as the clearing of forests carried out to develop Tassalast and Ferraoun beaches) is also one of the main causes of landslides in this area. Furthermore, buildings are an aggravating factor for the stability of this area.

Micro-destabilizing mechanisms are manifested by the gradual transformation of the marl materials into reworked materials under the action of water.

The available records and morphological evidence observed at the surface reveal the existence of old movements, which, however, have not been listed before 1970. Since the winter of 1970, the activity of landslides and surface disturbances keep increasing.

II-2- Geological and geotechnical data

To identify the different soil layers constituting the swiped region, a detailed analysis of boreholes drilled proves to be indispensable. The soil profile that slipped can be represented by two main formations: a first layer on the surface of Quaternary deposits consisting of debris clayey sandstone and a second deep layer of marl bedrock (Figure 1) with a disturbed zone with a thickness of about 2 m at the interface between these two formations. The minimum and maximum geotechnical properties of two clay layers are shown in Table 1.

Table 1: Range of values for the properties of the layers Tigzirt site.

Property Material	γ_d [KN/m^3]	Ip	φ’ [°]	C’ [KPa]	E [MPa]	υ
Debris clayey sandstone	17,3	38	30	0	800	0.33
Altered marl	14,8	28	26	0	200	0.3
Healthy marl	22,6	24	30	100	1700	0.3

The topsoil consists mainly of silty clay heterogeneous materials, sometimes sandy, containing blocks of sandstone. The second layer is a revamped marl horizon consists of a clay altered somewhat consistent fringe of marl bedrock underlying and an average thickness of about 2 m. Finally the third is healthy marl bedrock consists of marl schist flow levels.

Direct shear tested allow attributing to this debris clayey sandstone surface layer of low permeability the following average values of friction angle: $\varphi = 30$º. Below this layer is an altered one, thick reworked made of marl, of 2 low characteristics meterss and a friction angle of about 26 ° C. In the marl bedrock, realized direct shear tests give the following average values of cohesion and friction angle $C \geq 100$ KN/m^2 and $\varphi = 30$º.

II-3- Specificity of the study area and seismicity

Coastal Landslides significantly affect the ecosystem. The gravitational movement of the slope towards the sea causes an increase in sea level and so the flooding of certain areas of the catchment. This phenomenon is observed in the coastal town of Tigzirt. Using MapInfo mapping tool and exploiting aerial images of Tigzirt taken in 2006 and 2011, there has been a significant evolution of the coastline at Tigzirt. Flood zones were observed on the east and west boundaries of the slip while at the level of the slip zone advanced the coastline were observed. The latter is due to the formation of a bead foot due to ground movement. Indeed, from (Besson, 2005), the morphology of unstable slopes is characterized by the observation of a lifting area of land at the foot of the slide called foot front bead or bead.

This hydro-climatology acts negatively on the stability of slopes in different ways:

- As a result of surface erosion due to runoff;
- The effect of waves on the foot of the slope which removes major stops;

- The effect of water flow in the river. Two types of flows are observed for this site (a flow in the direction of the river due to water infiltration and an upward flow of saline water under the influence of waves);
- The effect of salt water on the marl bedrock (marl Tigzirt is very sensitive to climate and water assault).

Regional tectonics earthquake may cause sudden rupture of unstable Tigzirt slope (as this city is located in an active tectonic zone (Fig. 2)). Indeed, the unstable Tigzirt site is bordered by several major active breaks. They are located either on the mainland or offshore (Fig.2). Among the most important are: the Thenia break direction N120 ° E (Boudiaf et al., 1998), the break of Isser - Tizi Ouzou which is a reverse break and reverse break Zemmouri consists of a series of discontinuous fractures, located at sea.

Mechanical stress induced by the earthquake in the catchment and probable uprising relatively recent in geologic pouring from the play of the Thenia break (break causing the Boumerdes earthquake) may have increased the vulnerability this coastal slope precarious stability and which is already weakened by the significant development of urbanization; this led to the beginning of a field instability affecting about 136 Ha.

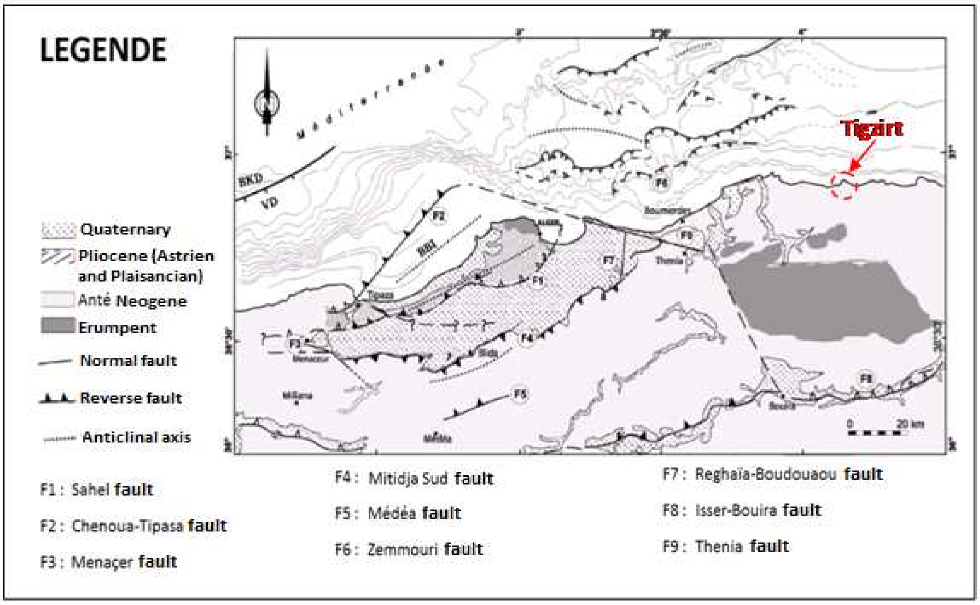


Figure 2: Structural Framework for the Algiers region (Yelles-Chaouche et al., 2006).

The activity of the landslide has not however been deeply influenced by the Boumerdes earthquake, which generated only light damage in the town. However, the hypothesis of a potential seismic site effect due to the topography and the presence of unstable formations into a thickness of 30 m, largely saturated with water and resting on a solid substratum (more strong seismic velocity), cannot be ruled out. This site effect significantly amplifies the horizontal components of vibration on the surface and thus would be extremely unfavorable for stability under dynamic stresses slope. However, it could be demonstrated that equipping the seismic stations on site and outside the landslide, whose site has no station currently.

III- MODELLING OF TIGZIRT LANDSLIDE

The finite element method was chosen for the numerical modeling of Tigzirt landslide with calculations using the code PLAXIS 2D Version 2011. This code provides the ability to manage large plane strain with the updating of the mesh after each iteration calculation. This method is inspired by classical stability analysis methods to limit equilibrium (Fellenius, Bishop, etc.), but without imposing a fracture surface beforehand.

The study of slope stability is based on the reduction of mechanical properties is an option available in PLAXIS (1999) called 'Phi-C reduction' and which calculates safety factors. In the approach "Phi-C reduction, the characteristic angles of friction (tanφ) and cohesion (C) of the ground is reduced progressively until rupture.

III-1- Presentation of the model

The model is composed of three main layers: a surface coating composed of clayey sandstone’s debris, compact marl bedrock topped with an altered fringe of a thickness of about 2 m. The Mohr-Coulomb law (elastic perfectly plastic) was chosen to simulate the long-term behavior of cohesive soils up the slope. It requires knowledge of six parameters: density, Young's modulus E, the Poisson’s ratio ν, cohesion C, angle of friction φ and dilatancy angle ψ (considered to be zero for the soil at an angle of less than or equal to 30 ° friction).

The profile used is spread over a length of approximately 1330 m (Fig. 3) and crosses all the unstable area from the main escarpment down to the sea. The maximum height of the profile is 270 m and the minimum is approximately - 60 m (under the sea level). The selected mesh consists of 2499 triangular elements at 15 knots with 12 integration points per element. The boundary conditions are defined as such (Fig. 3):

- Vertical geometric lines for which the abscissa (x) is equal to the smallest or the largest of the abscissa (x) of the model are locked horizontally ($U_x = 0$),
- The geometrical lines, for which the side (y) is equal to the smallest ordinate (y) of the model are fully blocked ($U_x = U_y = 0$).

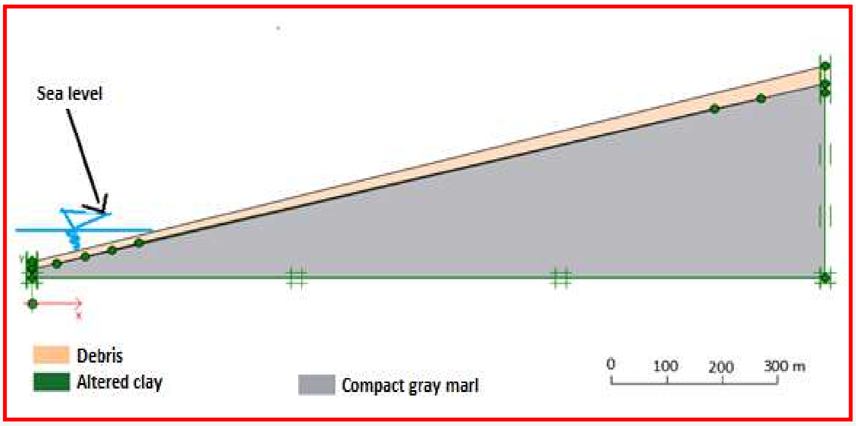


Figure 3: Tigzirt landslide Profile.

III-2- Presentation and interpretation of results

Four periods were considered in this study: a dry period when the clayey marl layer is not saturated and a wet period when this layer is considered saturated and an intermediate period when the water table fluctuates between 3 and 9 m. The wet period is normally characterized by the winter months and early spring, when heavy rains and melting snow have an effect on the supply of ground water, and the saturation of its layers. Thus four calculations are launched simultaneously taking into account the seismic excitation, the effect of overloading and slick but varying the water table in increments of 3m depth to reach a depth of 12m.

¬ *Water table surface*

This case is represented by the application of an overload of 10 KN/m on the slope of the foot and an excitation of 0.34g at the base. This allows us to detect the most sensitive area in terms of instability.

The results obtained show that the maximum displacement obtained with this configuration is of the order of 12.92 m. (Fig. 4). This displacement is six times higher than that found without application of the overload and without seismic excitation. Amplification of the seismic movement was observed at the altered clay layer with a response of the soil in peak acceleration of about 0.58 g (Fig. 6), while there had not amplification when application of the same seismic excitation without overload. Plasticity zones generated by these three effects accentuated and aggravated movement and disturbed zone widens (Fig. 5). The resulting safety factor which is of the order of 0.93 shows the instability of the slope (Fig. 7). There has been a site effect that amplified seismic excitation 0.58g.

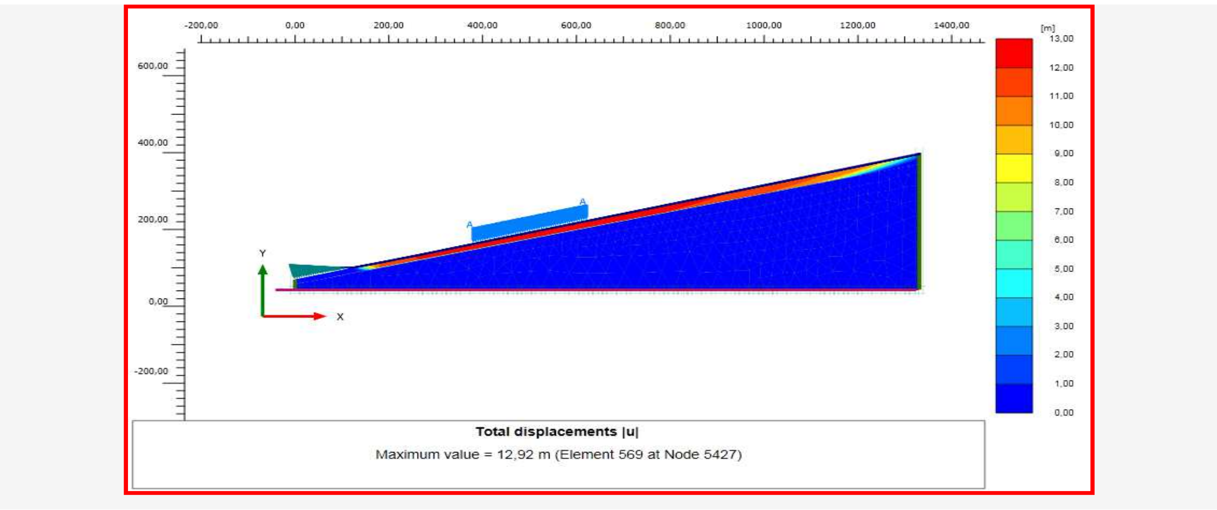


Figure 4: IIUII = 12.92m watershed field trip under the effect of the overload of urbanization and seismic excitation.

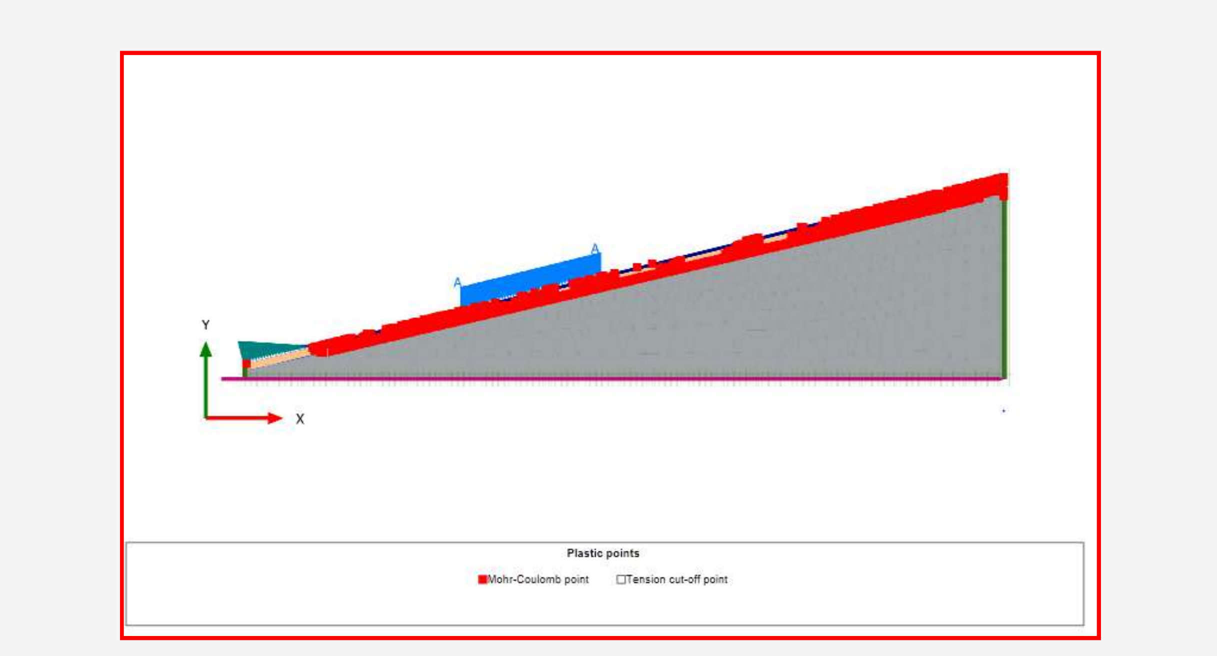


Figure 5: Map of laminated catchment areas for the case of a water table at surface and under the overload and a seismic excitation effect.

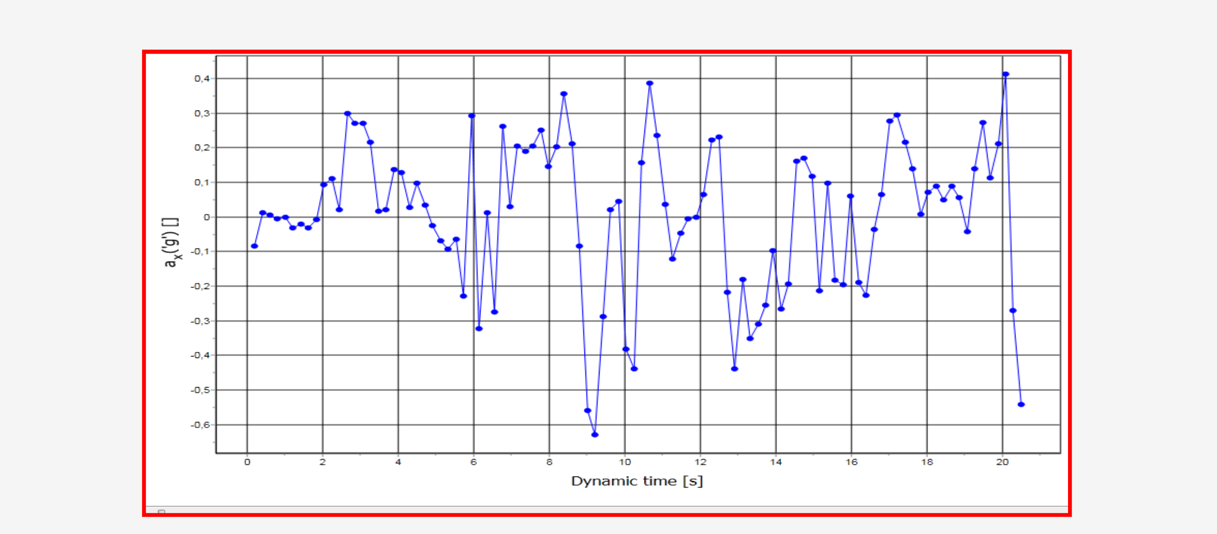


Figure 6: Amplification of the seismic signal at the altered layer under the overload effect.

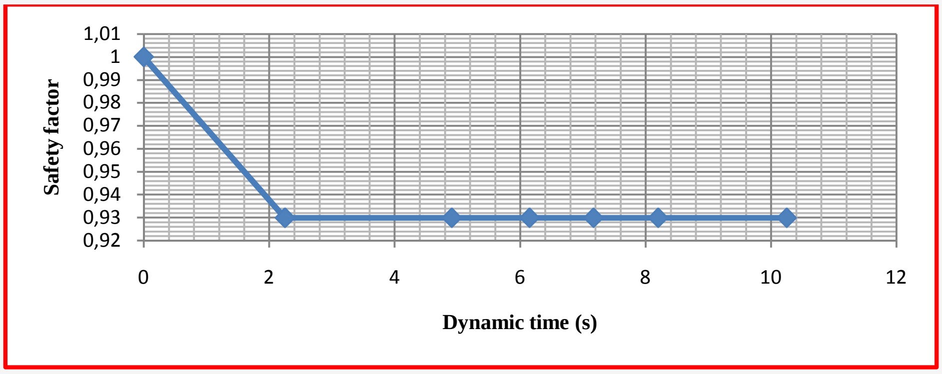


Figure 7: Evolution of the safety factor under urbanization overload and earthquake with a water table in the natural ground level.

¬ ***Water Table 6m deep***

In this case, a decrease in the rate of displacement was observed which is of the order of 95% (Fig. 8), relative to the dynamic case with a water table surface. The resulting safety coefficient is 1.12 (Fig. 9); this proves that the slope is in precarious stability condition. In addition, the displacement rate increased by 61% compared to the dynamic case without overload; which reflects the danger to the urbanized Tigzirt. The water table also plays an important role both in area and depth. Indeed, it weakens the weight of the slope by introducing a driving force.

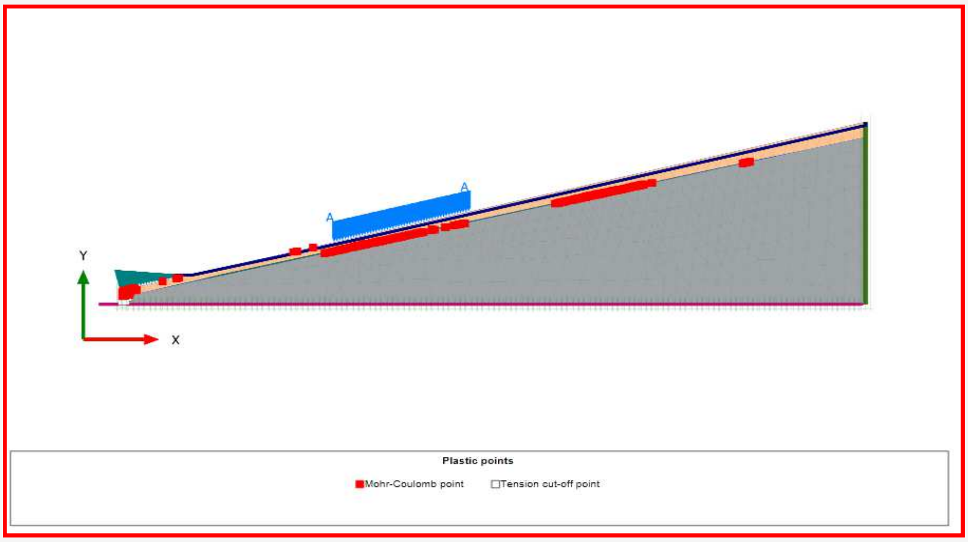


Figure 8: Map of laminated catchment areas for the case of 6 m depth to water table and under an overload and a seismic excitation effect.

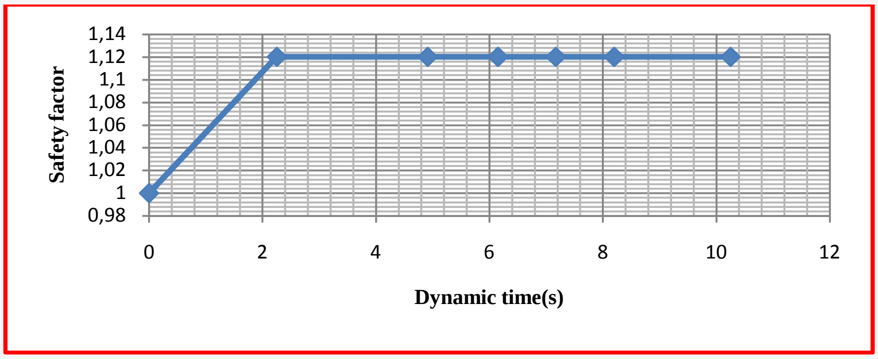
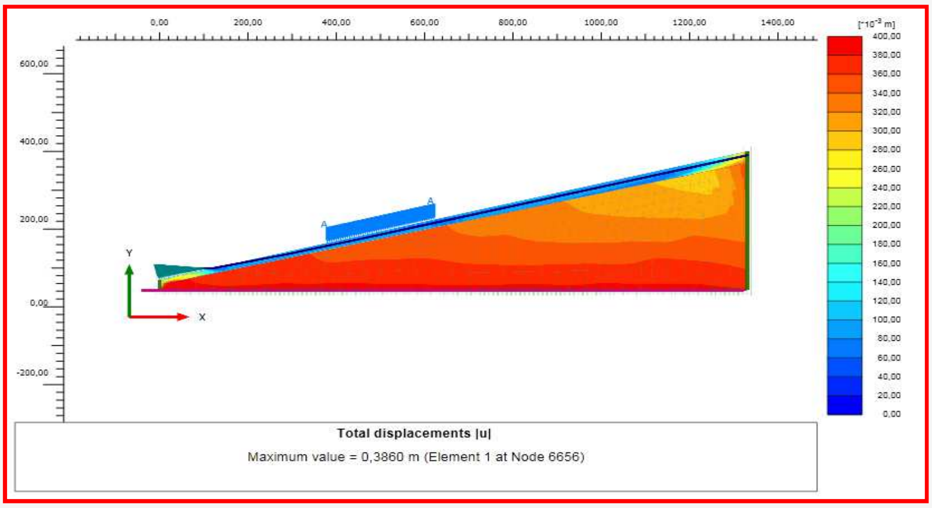


Figure 9: Evolution of the safety factor under urbanization overload and earthquake.

¬ *Water table 9m depth*

In this case, the rate of displacement decreases by 36% (Fig. 10), compared to the previous case (dynamic case with overload and 6m deep water table) and a slight increase of 4% in the dynamic case without overload. So the water table is more deeply, more overload will not have the same effect as the water table is on the surface. In this case, the safety factor is unstable and varies 0,65 ≤ Fs ≤ 1.3 (Fig. 12); which means that the side will not gain some stability than in the dynamic case without overload where Fs is 1.2.



Total displacements |u|

Maximum value = 0,3860 m (Element 1 at Node 6656)

Figure 10: IIUII = 0.386m watershed Field trips under the effect of the seismic excitation and a 9 m depth to water table.

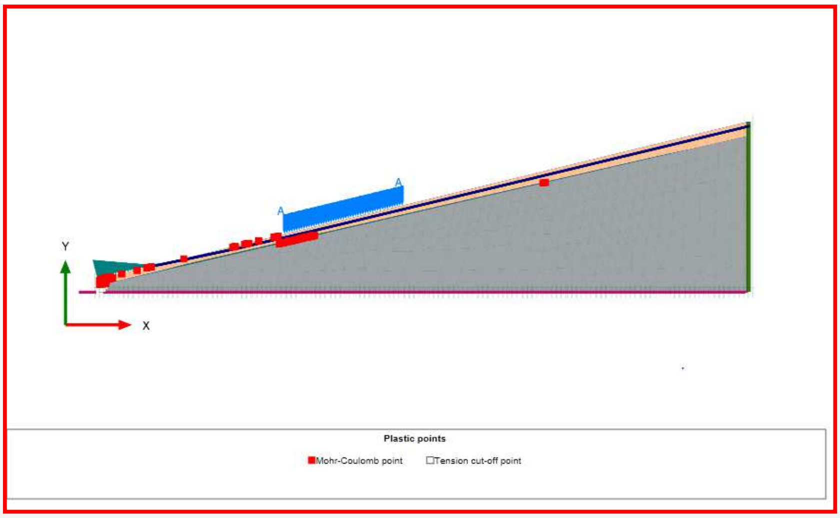


Figure 11: Map of laminated catchment areas for the case of a 9 m deep to water table and under the effect of urbanization overload and the seismic excitation.

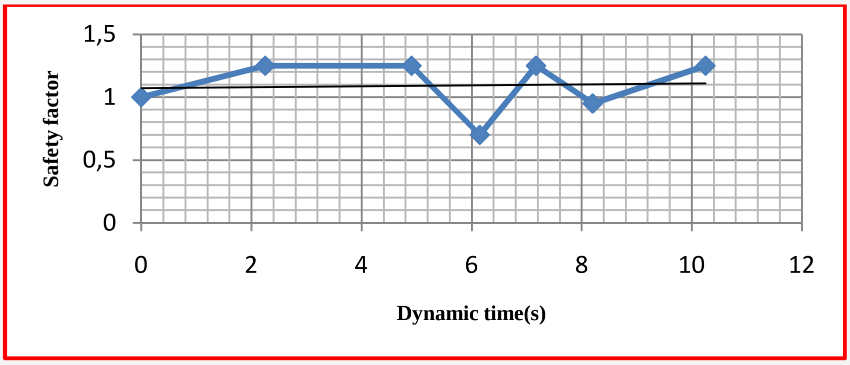


Figure 12: Evolution of the safety factor under urbanization overload and earthquake for a table at the depth of 9 m.

¬ *Water table 12m depth*

In this case, there will be no change (Fig. 13), compared to the previous calculation (depth 9m) at the rate of displacement that has remained virtually constant, which is 0.386 m. So there has not been any influence on the rate of displacement when the water table exceeds 9m depth. On the side of the safety factor, it reached a value of 1.3 (Fig. 15); which ensures the stability of the slope.

The slope of Tigzirt for this case is simultaneously subjected to a seismic excitation and overload due to urbanization. The recorded displacement rate is important mainly when the water table is at the natural terrain. It is in the de 12.92m order. When the water table is at the level of 6m depth, there is a significant decrease in the displacement rate of the order of 95%. When this water table is at a depth of 9m, displacement rate continues to decrease slightly, but as soon as this layer exceeds the depth of 9m, this rate remains unchanged due to the presence of bedrock.

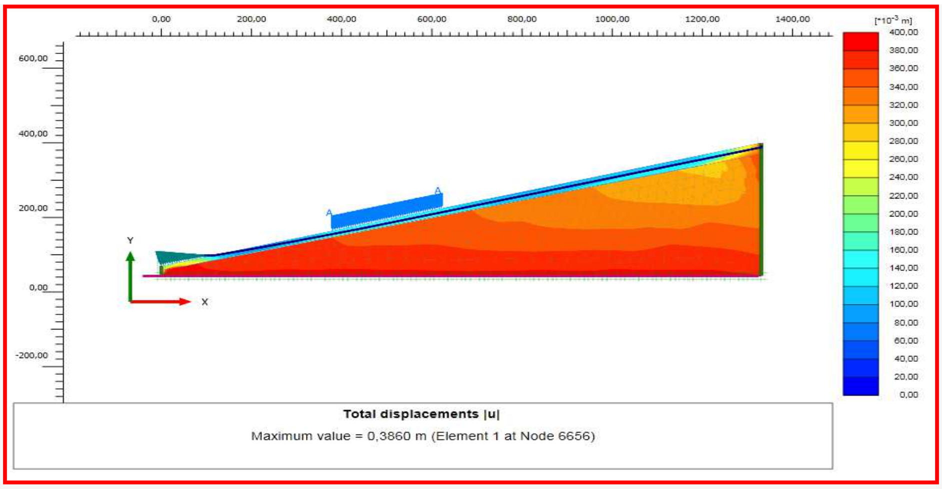


Figure 14: IIUII = 0.386m watershed field trip under the effect of the seismic excitation and a 12 m depth to water table.

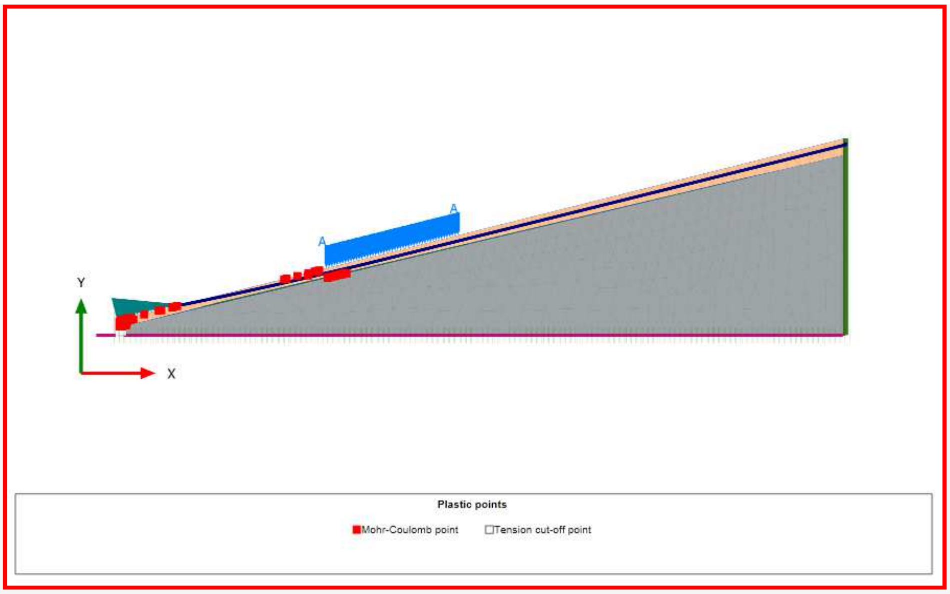


Figure 15: Map of laminated catchment areas for the case of a 12 m depth to water table and under the effect of an overload and a seismic excitation.

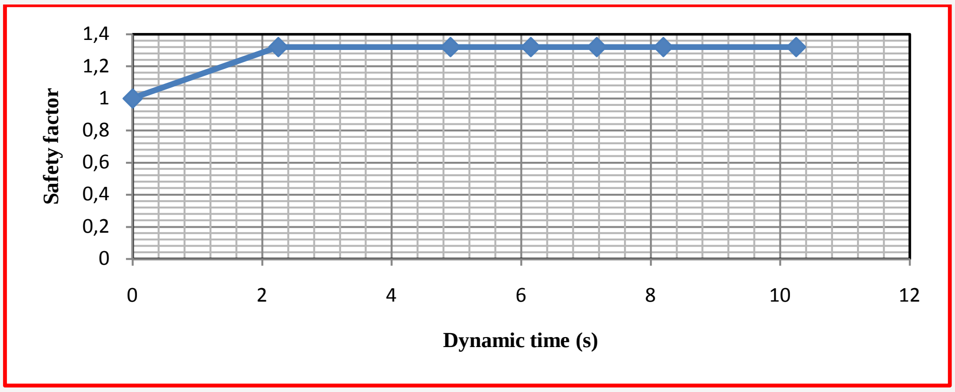


Figure 15: Evolution of the safety factor under urbanization overload and earthquake for a 12 m depth to water table.

The slope moves in a revised flat layer. Its degree of remodeling varies depending on the variation of the water table. It is at its maximum when the water table is on the surface. A 6m deep, the redesign is smaller and does not touch the top. A depth of 9 m, the disturbed zone is localized in overload and foot. Once the water table above that level, there will be not influence on the transformation zone.
The stability of the slope depends on three conditions: the slick surface, the seismic loading and the overloading (urbanization of the catchment Tigzirt). When the water table is on the surface, the safety factor Fs = 0.93 and it creates instability of the slope. However, in the case of a 6m depth in water, the slope is in a precarious state of stability with Fs = 1.12. When the Water table is at 9m depth, the safety factor is between $0.5 \leq Fs \leq 1.2$ and the slope cannot be considered as stable and as soon as the water table reaches 12m depth slope stability is ensured with Fs = 1.3.

IV-CONCLUSION

The results of the numerical analysis performed showed that the slope of the Tigzirt region is strongly influenced by water table, urbanization and seismic activity. Indeed, for a slick surface, a significant amplification of the seismic signal is observed for the level of the disturbed zone of the slope. Thus, the plasticity zones generated by these three effects accentuated and aggravated the movement and the disturbed zone widened. Recorded displacements are maximum when the water table is on the surface. When the water table declines, we observe a significant decrease in the rate of displacement which stabilizes when the water table reaches 9m. Thus the degree of reworking of the soap layer (disturbed zone) varies with the change in the water table.

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