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Case Study of Landslides in Kabylia Region, Algeria

Sadaoui Omar
University Mira Abderrahamane of Béjaia, Algeria

Sadaoui Samir
Bureau de Conseils et d'Enginnering, Algeria

Bahar Ramdane
University of Sciences and Technology Houari, Algeria

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Sadaoui Omar
University Mira Abderrahamane of Béjaia
Civil Engineering Department, LGEA-UMMTO
Béjaia 06000 - Algeria

Sadaoui Samir
Bureau de Conseils et
et d'Enginnering, BICS
Béjaia 06000 - Algeria

Bahar Ramdane
University of Sciences and Technology Houari
Boumediene, LEEGO – LGEA (UMMTO),
Algiers 16111 - Algeria

ABSTRACT

Kabylia is mountainous and coastline region of Algeria. Every year, particularly in the winter, it is affected by landslides displacing an important volume of detritic materials, and causing damages to infrastructures, housing and public facilities. It takes place in geological formations that are particularly favourable to this type of movement, because of the heterogeneity of their facies and the impermeability of some layers. Experience shows that the main cause of the landslides in this region is the combination of several passive and active factors, as geology, morphology, hydrology, climate and anthropic activities. The exceptional rains of winter 2012 triggered a series of landslides in this region, among which the landslide occurred at PK 226+300 of the National Road RN 24, at a place named Assoumeth-Boulimat, Béjaia department, is one of the most spectacular. The landslide caused the collapse of a section of the road of about 120 meters, with a main scarp of about 8 meters. During the firstly time of the field observation, 18 hours, the landslide mass and the road moved 10 meters. This paper describes this landslide triggered by rainfall and unfavourable geological, hydrogeological and geotechnical conditions. The geotechnical study and methodology of stabilization in two phases will be presented and discussed. Stability calculations were conducted to understand the triggering of the landslide.

INTRODUCTION

In the north of Algeria, the regions of landslide occurrence and potential are the coastal and mountainous areas. Every year, particularly in the winter, the extreme rainfall triggered enormous landslides causing infrastructure and property damages (Figs. 1, 2 and 3). Most disasters of mountain road damage of this region are similar, and in recent years more and more reinforced retaining structures were used to repair the road damages.

Kabylia mountainous region is affected by recurring landslides displacing an important volume of detritic material (marls, conglomerates and sandstone blocks). It takes place in geological formations that are particularly favourable to this type of movement, because of the heterogeneity of their facies and the impermeability of some layers. Water infiltration is always the dominating factor in the release of this mass movement, but two groups of factors predisposed the hillsides to undergo this process of erosion: passive factors as lithology, structural arrangement, and slope steepness; active factors as climate, seismic and anthropic activities.

According to data gathered from the administrations and laboratories more then 120 sites of Bejaia department were affected by landslides since 2000 to date. 40% of these landslides affect public works (roads and bridges), and 60% affect the sector of private housing and public facilities. The exceptional rains of winter 2012 triggered a series of landslides in the Kabylia region, among which the landslide occurred at PK 226+300 of the National Road RN 24, at a place named Assoumeth-Boulimat, Bejaia department, is one of the most spectacular. These instabilities are unique endemic to occur spontaneously after a rainy periods in the spring. The result is often disastrous disorders records where important sometimes to the ruin of buildings (Sadaoui, 1998) and the deviation or the temporary closure of some roads (Sadaoui et al, 2012).

This paper describes this landslide triggered by rainfall and unfavourable geological, hydrogeological and geotechnical conditions. It also presents the emergency measures to restore immediately traffic between East and Center regions and maintain the connection with the outside for neighboring village people. Numerical calculations were conducted to investigate the failure condition and to understand the triggering of the landslide. These analyses served for the final design of rehabilitation works.

Fig. 1. Landslide at Beni Amrane , Department of Boumerdes, causing damage to retaining wall, January 2003.

Fig. 2. Landslide at PK 227+110, RN 24, Bejaia, 2011.

Fig. 3. Landslide at Ain -Tork, Department o f Bouira, East-West highway A1, April 2012.

GEOLOGY OF KABYLIA REGION

Algeria partly encompasses two African domains: North Africa or Alpine zone and African Domain or Gondwana, preserved from major alpine events. North Africa or Maghrebian Belt is structured by alpine events (Cretaceous-Miocene). Most of the internal domain of the Maghrebian Belt, also called Kabylian zone, is outcropping in the two Kabylia regions (Greater and Lesser Kabylia). In Great Kabylia fourth well defined ensembles are distinguish, extending from north to south: crystalline massifs, paleozoic, calcareous range, and flyschs and molasses. Figure 4 presents the main domains and units of Great Kabylia within its geologic setting.

The internal crystalline ensemble outcrops within massifs mainly along the coast. Two groups are defined. The SABN massif is made up of granites and its autochthonous intruded schists, the whole is extruded as crocodile-like nape within paragneiss previously structured and intruded by post tectonic granites and related rocks. The remaining of Greater Kabylia is made up by a metamorphic and tectonic pile of metapelites and slices of orthogneisses. Undeformed granites intrude all the units of the ductile pile, except the crocodile SABN nape and the upper phyllite unit.

Paleozoic formations outcrop in Aissa-Mimoun, Kouriet, Djurdjura and Chellata mounts. In Aissa-Mimoun, non metamorphic schists known as Upper Cambrian are in contact (cataclastic) with paragneiss of the crystalline ensemble of Great Kabylia. In Djurdjura, non metamorphic schists are known and Devonian (schists, calcareous, marly limestone, volcaniclastic terms and dolomite). Carboniferous formations outcrop as flysch facies with a sequence of micaceous pelitic layers, sandstones and conglomerates with lyddites.

The calcareous range formations are complete in Djurdjura (Great Kabylia), made up by Lias massif calcareous dolomite; middle-upper Jurassic of marly limestones, marls and limestones, red pelites, marly carbonates, nodular carbonates, carbonates with “filaments”, carbonates with thin layers bearing cherts and radiolarites; Cretaceous-Lutetian, also called “Senono-Eocene” a marly limestone (green and pink scaglia facies), black marls inferred to Albien; lower Eocene with a facies of massif limestone.

Flyschs, outcropping in the internal zone, are gathered on the basis of the age, in one ensemble: cretaceous flyschs. They have different structural positions versus the other ensembles and formations of the internal domain: they are side by side, under/over laid. The olistostromes and others such as the Numidian formations are gathered into the ensemble called Oligo-Miocene Formations, based on their ages. Kabylian Oligo-Miocene is mainly a sandy and conglomeratic formation containing detrital elements from crystalline, schists, paleozoic and calcareous range units. It is overlaying unconformably schists of the crystalline internal domain.

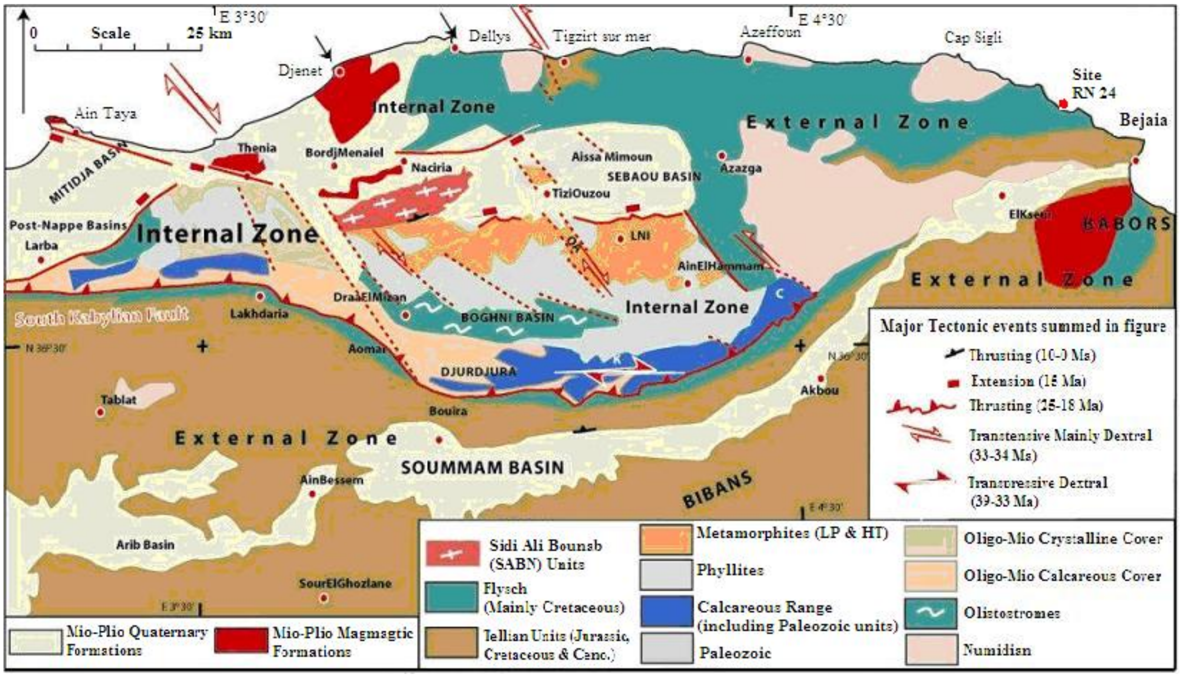

Fig. 4. Great Kabylia (Alpine Algeria) structural scheme within geologic setting (Saadallah, 1992).

LOCAL GEOLOGY

According to the geological map of Bejaia n° 26, scale 1/50.000, most of the formations encountered along the road are composed of flysch (oe) and old quaternary (q^3) layers with dips varying from 30 to 60° (Fig. 5).

The affected section is formed of a syncline schistose marl of dip 42° S-N, it is topped with a thick layer of saturated colluviums, slipping at the interface with the marl under the effect of a steep slope, hydrostatic pressures and hydraulic gradients. This lithological facies widespread along the coastal region, it consists of a conglomerate of pebbles and blocks decimetric to metric dimensions, impregnated with a clay matrix is very sensitive to the action of water (Fig. 6a). These layers of colluviums are very permeable; they attract a large volume of water infiltrating the lower slopes as resurgences or sources.

In general, training colluviums overcome dips direction (North-South) of schistose marl and marly limestone very hard and impermeable (Fig. 6b). The interface between the scree slope and marl consists of greenish clay and plastic very sensitive to water; it loses the mechanical characteristics and becomes slippery. Saturated colluviums slip at the interface with the marl under the effect of dip angle and increased hydrostatic pressure (Fig. 6b). This results in deflection of roads, slope failure, longitudinal crevice (Fig. 2). These instabilities are observed on several sections of the road RN24 especially after periods of rain (Fig. 2).

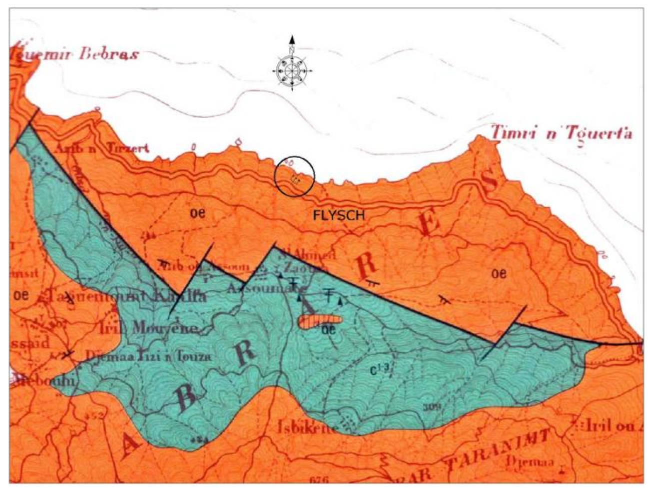

Fig. 5. Extracted from the geological map of Bejaia at the area of landslide RN24 (geology map n°26).

a) Saturated colluviums

b) Marly limestone dip (slip surface)

Fig. 6. Site lithology at PK 226+300, RN24.

The national road RN 24 through mountainous areas on the lower slopes where we encounter very thick colluvial plated on marly limestone dips to the right of synclines and benches. The large flow of water drained by the watershed rainy periods, exacerbated by deforestation (Fig. 7), leads to total saturation (Fig. 6a) of these layers furniture colluviums and total loss of shear resistance. Layer of marly limestone dip impervious 30 to 60° water accumulates, it lubricates the interface layer and soap is a preferential rupture line for colluviums due to their own weight and slope.

Additively to the loss of resistance of the layers of colluviums, the mixed cross sections are the cause of endemic instability manifested by subsidence of backfill after saturation in rainy periods. These deformations appear in the form of large cover of settlement, and are visible along the national road RN24. They are characterized by progressive movements operating under the influence of water and loads of cuttings. Section damaged by the landslide consists of a syncline marly limestone dipping 34 to 42 ° direction (S-N) very noticeable in the sea (Figs. 8 and 9), it is topped by a thick layer of colluviums thickness of 10 to 25 m in water saturated generalized movement of the dip.

Fig. 7. Deforestation hillside.

Fig. 8. Overview of landslide Assoumeth RN24, PK 226+300.

Fig.9. Overview of landslide Assoumeth RN24 PK 226+ 300

LANDSLIDE EVENT AT RN 24 ROAD

The national road RN24 traverses the mountainous areas on the lower side. On 17th April 2012, at PK 226+300, at a place called Assoumeth-Boulimat, department of Bejaia, a landslide occurred just of 100 m coastline of the Mediterranean Sea. The landslide caused the collapse of a section of the road of about 120 meters, with a main scarp about 6 to 8 meters (Fig. 8 and 9). After 18 hours, the landslide mass and the road moved 10 m during the time of the field observation in the south-north direction. In this section, the road is clamped between the Mediterranean Sea and the mountain with very steep dip (Fig. 9). All drainage systems were damaged. The road is closed to traffic between Bejaia and Tizi-Ouzou cities for more ten days, disrupting road communication which is lifeline to the two states and many villages of Kabylia. The disruption experienced by local traffic was substantial. However, the real impacts of the events were economic and social.

According to early preliminary investigation carried out on site, the perimeter of the landslide impact area is order of 2.20 hectares. The volume of material movement is estimated at 450000 m^3. The potential slide surface is deep, located about 15 to 20 meters in depth, which is the interface between the saturated colluviums and the weathered schistose marl. It is mainly caused by the circulation of groundwater drained by the catchments area and the effect of marine transgression. The exceptional rainfall in the region of Béjaia during the month of April 2012 has amplified the phenomenon.

GEOTECHNICAL AND HYDROGEOLOGICAL STUDIES OF THE SITE

One day after the landslide had occurred, specialized companies have been initiated by the Public Works Administration (DTP) to prepare temporary access to restore circulation, to perform a topographic plan for the state at landslide triggering, to establish a survey system to record the rate and the direction of the landslide movements and to perform a geotechnical investigation to find the final solution for the road.

In order temporarily stop the movements of the landslide in order to restore the traffic, it was decided in first stage to partly backfill the excavated volume using an appropriate granular material with high shear strength and installation of trench drains. The minimum amount of the backfill material necessary to reduce the movements was estimated by simplified stability calculation. In the second step, a stability study will be conducted for the final rehabilitation of the landslide.

Geotechnical investigation

A geotechnical investigation was conducted by the studies office (BICS) in collaboration with the administration (DTP). The investigation consists of three (3) boreholes; one of them was equipped with piezometer, and one (1) borehole to perform pressuremeter tests. Samples were taken from characteristic soil layers out of bore cores and were investigated in the laboratory. These tests have been located in recognition of the potential area of the landslide.

According to the logs of core drilling, the local lithology consists of a layer of rubble slope (colluviums) thicknesses ranging from 13 to 15 m overlying very hard marly limestone (pelitic). The interface between the marly limestone and colluviums contains a thin layer of very plastic greenish clay (Fig. 10). Based on core drilling and laboratory tests, the potential slip surface was encountered at 13 to 15 m deep, at the very soft greenish clay.

The physical and mechanical parameters measured in the laboratory are summarized in Table 1. The specific density of marly limestone is 25.6 kN/m^3, indicating a very hard soil. The shear test performed on a sample colluviums clay component provides low shear parameters (c_u=20 kPa and φ_u=7°). The pressuremeter test results reveal that the pelitic marl is very hard, it has a limit pressure p_l= 3.5 MPa and a pressuremeter modulus E_m= 253.8 MPa (Fig. 11). The Young's modulus of this marl is in order of 280 MPa.

Analysis of rainfall and piezometric data

Piezometer installed in the landslide area has detected water in June at -14m/TN. It was damaged by earth moving equipment.

Figures 12 show annual records covering periods from 1923 to 2010 (ANRH, 2011). Figure 13 shows the monthly variation of rainfall of the rainy year. These data show that the average rainfall along the cycles recorded is 831 mm. The last two decades are characterized by an average rainfall of 750 mm. The representation of rainfall is characterized by irregularities inter-seasonal and inter-annual. As a general, the relative distribution of 28.94% from September to November, 39.96% from December to February, 27.30% from March to May and 3.,8% from June to August.

Almost all rainfall is concentrated over a period ranging from November to March, not exceeding five (05) months: two-thirds (2/3) of the total rainfall is recorded during this period. In addition, according to the data, a peak rainfall was recorded in April with a maximum monthly rainfall of 278 mm (Fig. 13), which justifies the initiation of the majority of landslides in the Kabylia region during the spring period. In April, the hillsides were in a saturated condition following a relatively wet spell during the preceding weeks.

Table 1: Laboratory test results

Layers	Colluviums	Marly limestone
Thick (m)	13 to 15	≥ 15
Water content w (%)	14 - 20	-
Saturated index	76 - 97	-
Dry density (kN/m$^{3)}$	17.5 – 18.0	-
Wet density (kN/m$^3{}_)$	20.5 – 21.0	24.6 – 26.6
Cohesion c (kPa)	20	160
Friction angle φ (°)	7	25
Modulus E (MPa)	10	280

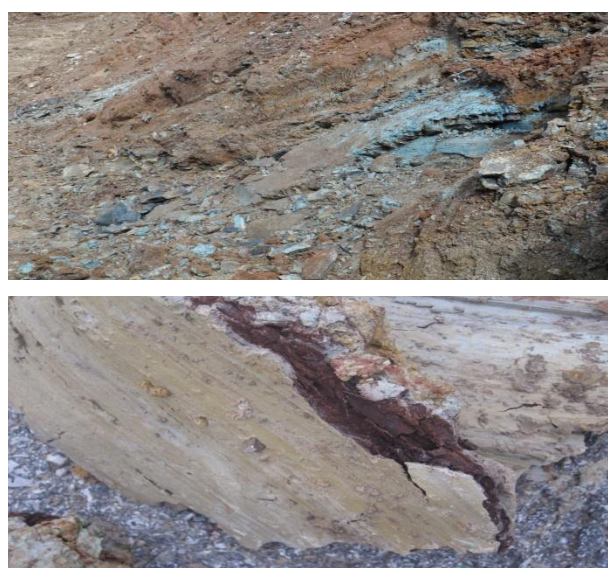

Fig. 10. Very plastic greenish clay interface between colluviums and marly limestone.

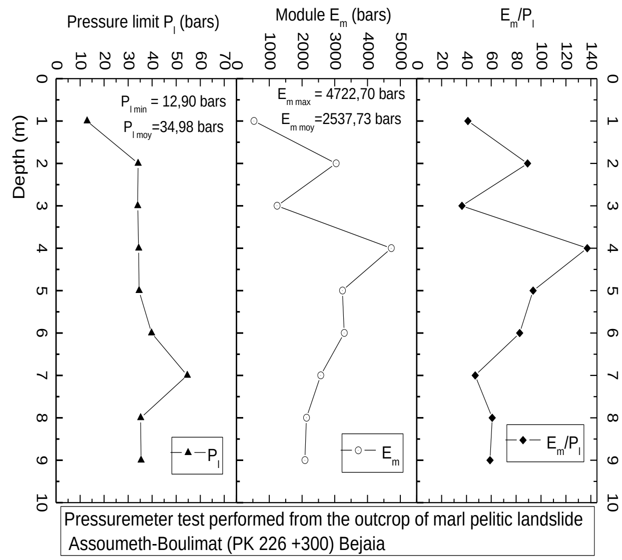

Fig. 11. Pressuremeter test results.

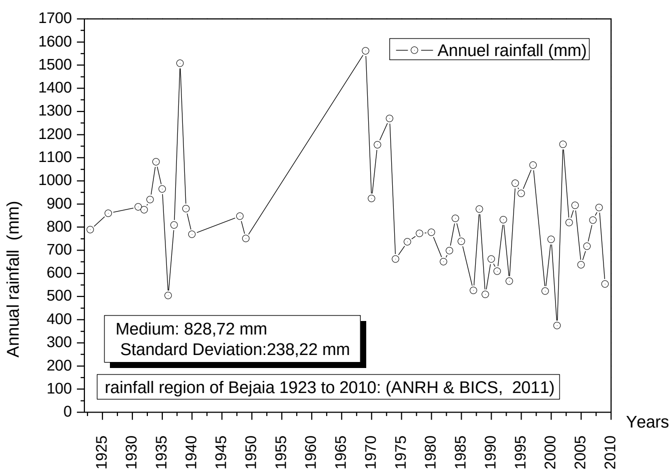

Fig.12. Rainfall region of Bejaia 1923 to 2010 for pluviometry station of Tifra (ANRH, 2011)

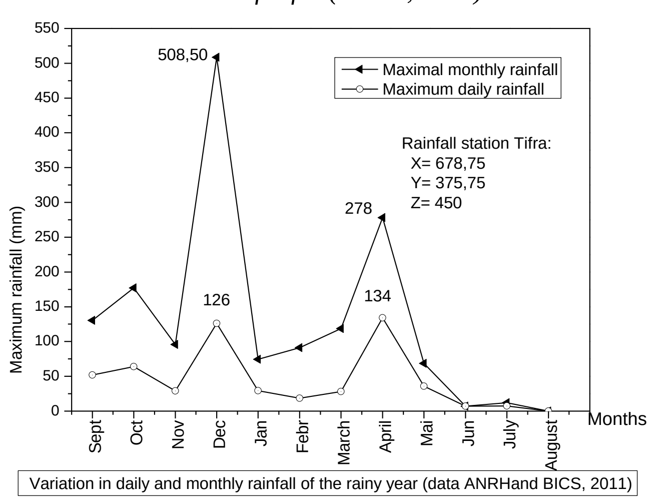

Fig. 13. Variation in daily and monthly rainfall of the rainy year (ANRH, 2011)

TEMPORARY AND FINAL REHABILITATION MEASURES

Preventive measures and preliminary work

Taking into account the importance of this road especially in the summer (tourist area), its failure is a real handicap for user traffic of neighboring villages and regions East - Centre. The emergency measures were to restore immediately traffic and maintain the connection with the outside for neighboring village people. Moreover, the landslide is characterized by its depth slip surface (between 13 and 15m), a natural fall (≥ 60%), escarpment relief and abundant presence of groundwater. According to the topographic plan drawn up on 19 April 2012 (Fig. 14), the displacement of the axis road to the south requires earthworks very important and risk other landslides.

For this case study, the temporary reinforcement solution possible technically and economically within an acceptable time (phase1) is the partial substitution of the slipped ground by an appropriate compacted granular material. This substitution should be anchored in marly limestone stratum after reprofiling its slope (Fig. 15). In the second phase, a support by nailing reinforced concrete bored piles Φ100 cm will be made to achieve safe use of the reconstructed national road.

The works of the preliminary and temporary solution are:

- Securing perimeters impact of landslides and setting up adequate signage of the road,

- Deviation of all water from the site, a drainage nozzle is recommended. Achieve water nozzle ditches outside the landslide (Fig. 16),

- Realization of ramps with maximum slope of 5% either side of the collapsed area to access the purge,

- Earthwork total disturbed masses up to the consistency calcareous marl layer.

- Creation of a trench drain in pebble and nozzles for PVC dry zone of accumulation of groundwater seepage in the vicinity of profile n° 2 and its connection to the outlet (Fig. 14 and 17).

- Substitution materials should be performed by well compacted layers of 30 cm thick.

Figure 18 shows the temporary road and the state during the preliminary work started in July 2012. Figure 19 shows a long cross section profile of landslide area for three states: initial state before landslide, landslide triggering and after emergency solution work.

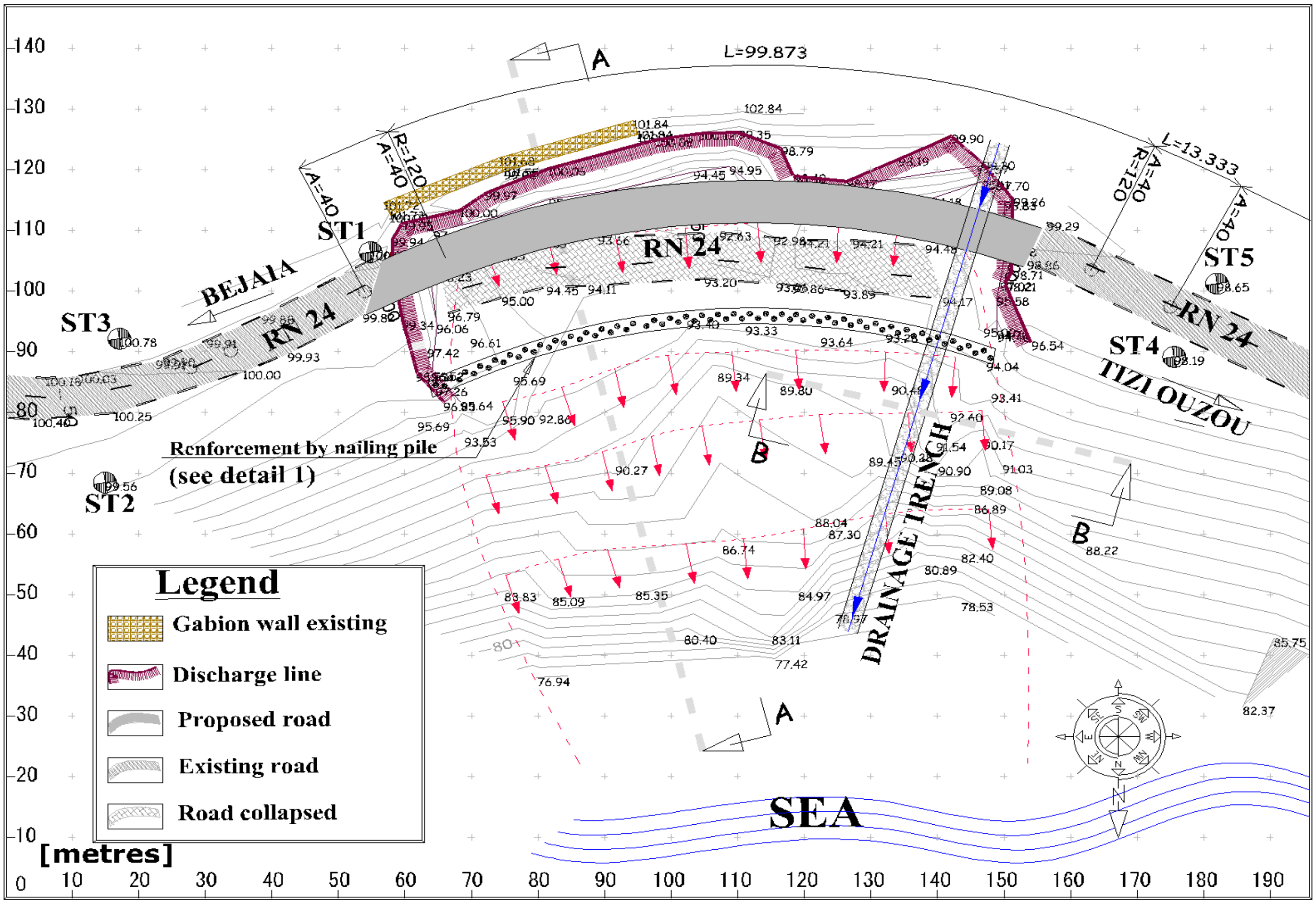

Fig. 14. Topographic plan showing the emergency and final measures to stabilize the landslide.

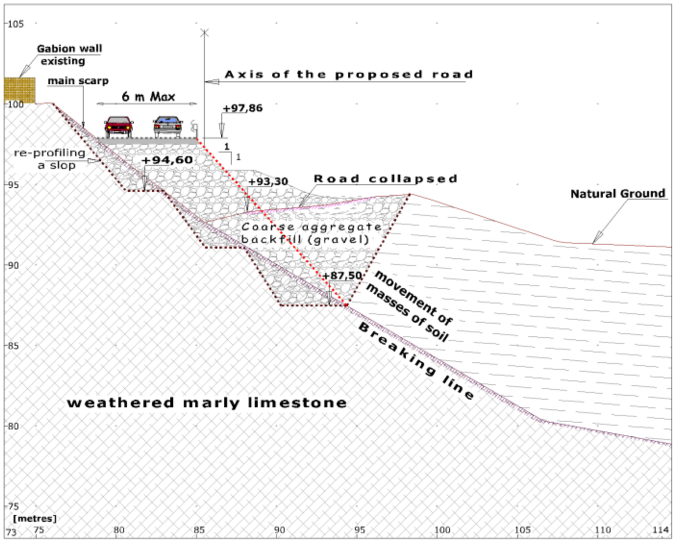

Fig. 15. Typical cross-section (A-A) of the emergency treatment RN 24 landslide at PK 226+300.

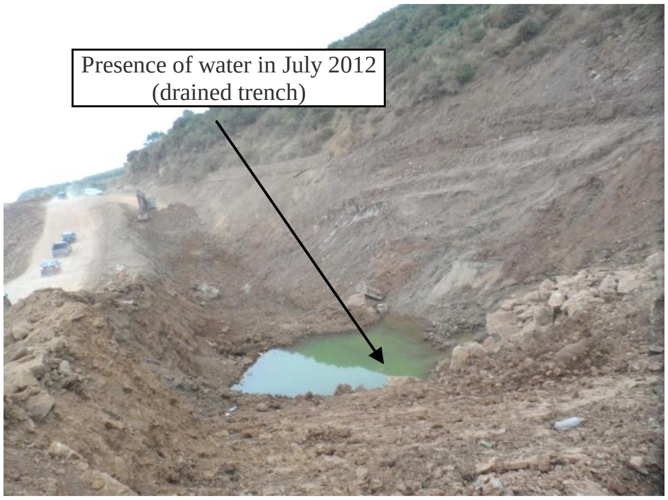

Fig. 16. Presence of groundwater in July 2012 during the emergency work.

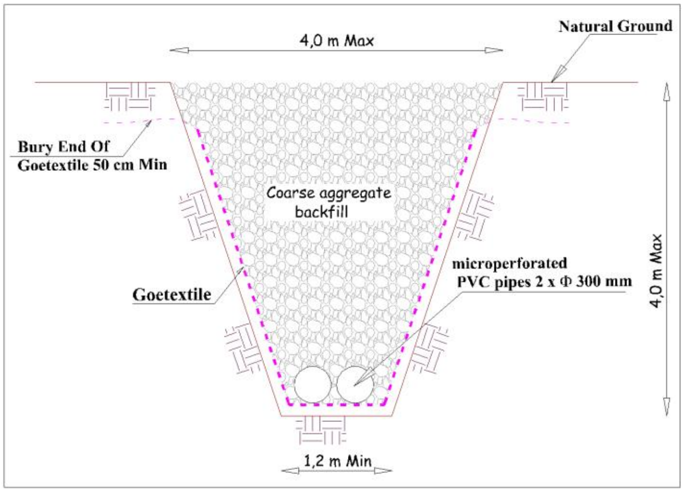

Fig. 17. A typical cross section af trench drain.

Fig. 18. During emergency work.

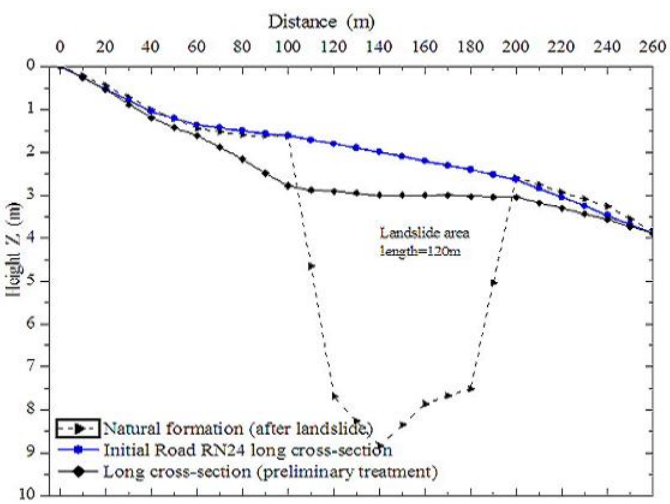

Fig. 19. Long section profile of landslide area for three states: initial state before landslide, landslide triggering and after emergency solution work.

Final rehabilitation measures

Several possibilities were considered for the final rehabilitation of the landslide. Drainage is the obvious solution, however clogging drains, inefficiency in impermeable soils and deep landslides make it unsuitable. Conventional retaining walls shall not apply to the reinforcement of deep landslides. For this case study, the use of nails by piles of large diameter ($\Phi \geq 80$ cm) can be a solution to stabilize the unstable masses on bedrock without much rework the ground by earthworks. This method has its origins in a rustic old practice, currently experiencing a significant development.

Sloping areas are particularly prone to landslides especially in seismic zones. The weathering of the soil, the erosive action of groundwater and alteration of the land are the main factors enabling the landslide.

The effectiveness of this technique relies on the one hand, the transfer of the landslide efforts to bedrock nailed by piles and, secondly, on an overall strengthening of the deformable mass by the contribution of effects and group vault due to the density of the nails (Cartier, 1986; Cartier and Morbois, 1986).

Stability analysis

The displacement of the ground causes a pressure p (z) to soil contact inclusion. It results in internal stresses M, N and T on the sliding surface. These forces are balanced by the shear strength of the soil anchor (Cartier, 1986). The low spacing between stakes and their implementation in staggered contribute to mobilization a vault effect (Fig.14).

The soil nailing by bored piles will be efficient only if:

- The pile is not broken by bending or shear,

- The pressure at the soil-pile interface does not exceed a permissible value for the ultimate ground; otherwise the plastic flow develops,

- The depth of the sliding inclusion under the sliding surface must be sufficient to avoid a second slip deeper.

The finite element code LCPC-CESAR (ITECH-LCPC, 2004) was used to analyze the stability of the landslide. The standard elastoplastic Mohr-Coulomb was used for soil behavior. Stability calculations were conducted for two stages; the state at landslide triggering and the state with nailing reinforcement. According to the geological survey, the residual soil parameters considered for the moved mass (colluviums) are c=20 kPa, $\varphi=7°$, E=10 MPa and $\nu = 0.35$). Fig. 20 shows the results of stability calculations of the state at landslide triggering. This figure shows the instability of the slope, the safety factor F is equal to 0.85. Large displacements, about 1.4 m, of the basin are noted. The results indicate clearly that the state remains unstable after sliding. Hence, the importance of the emergency work proposed to stabilize the ground and the road by a soil reconstitution by compacted granular material.

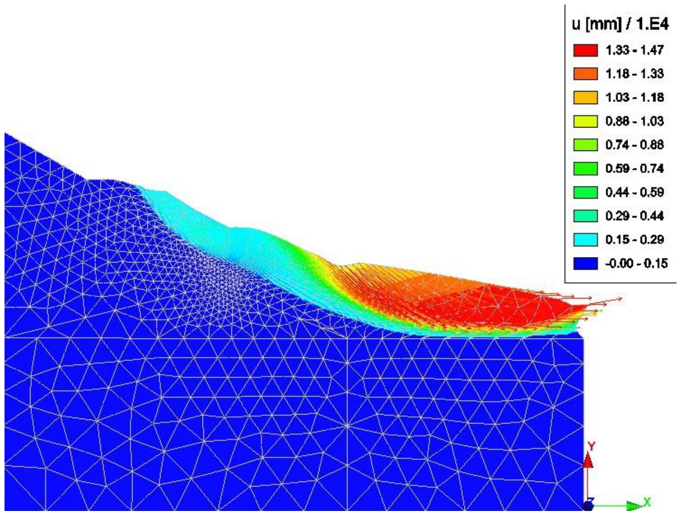

Fig. 20. Displacement vectors at the state landslide triggering.

After iterative calculations taking into account the depth of the slide surface and the minimum anchor of piles in the marl stratum, the minimum diameter and length of piles giving an acceptable safety factor are 100 cm and 14 to 16 m respectively. To design the piles in the slope in order to achieve the required safety factor, the stability of the final state was checked by the modified Fellenius expression (eq. 1) with the introduction of a shear mobilized by the nailing piles (Cartier, 1996; Philipponnat, 2006). The design of structural members was done according to Eurocode standards. The stability calculations and resistance led to the scheme of the Figures 21 and 22.

$$F = \frac{\sum_{1}^{N}\left[c_i^{'}.l_i + W_i^{'}\cos\alpha_{i.}\,\tan\varphi_i\right] + \dfrac{T}{\cos\alpha_i}}{\sum_{1}^{N} W_i.\sin\alpha_i} \quad (1)$$

F: Safety factor improved by the nailing contribution. In general, the trade-off between safety and cost optimized comfortable leads in fact to hold a 20 to 40% (Cartier 1986, Cartier & Morbois, 1986).

c_i: Cohesion slices of ground

α_i: angle of inclination of the tangent to the circle of critical failure (in our case, it is the angle of substratum)

W_i: Weight of slices (i) soil,

T: Shear mobilized nailing piles.

The shear found by improving the stability of 40% is 808 kN per pile.

The pile wall in a length of 85 m will be located at a distance of 29.5 m from the road axis. The slope between the road and pile wall will adopt an inclination of 2:3. The construction of bored piles ϕ100 cm in lengths from 14 to 16 m The spacing between the piles in the longitudinal and transversal direction is 2.40 m and 1.6 m respectively. The piles are connected at the top by a capping beam reinforced concrete. Details of the proposed stabilization of the landslide is shown in figure 21. This solution was proposed to state road authorities for approval.

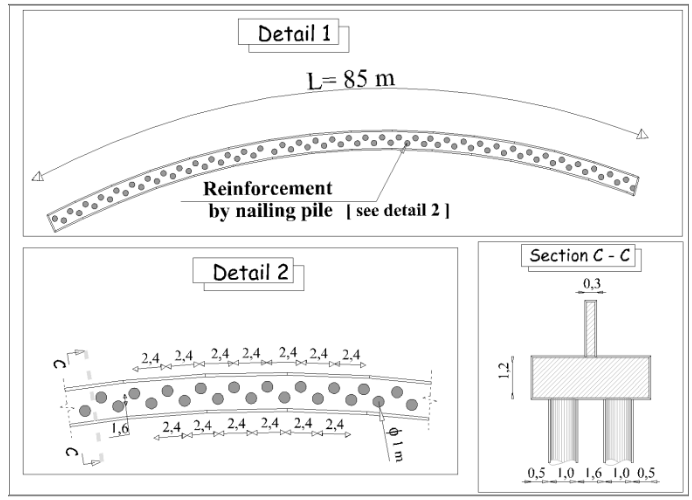

Fig. 21. Schematic view of nailing piles.

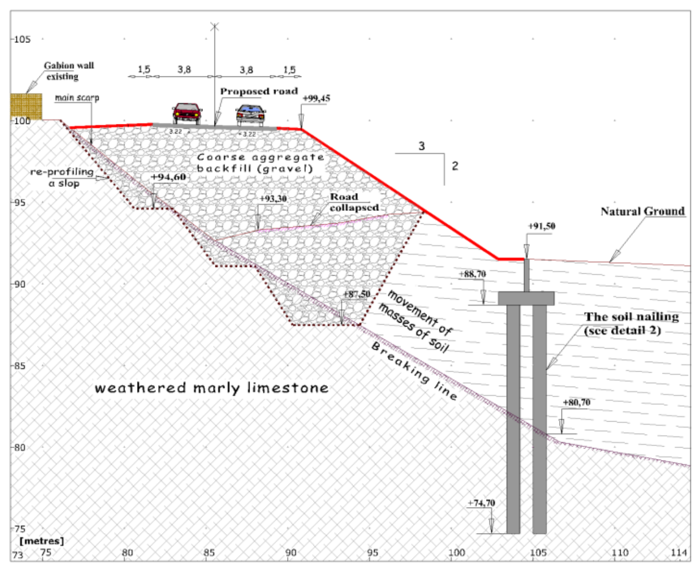

Fig. 22. Cross section of the final rehabilitation measures.

CONCLUSIONS

Kabylia mountainous region is affected every year by recurring landslides. The extreme rainfall triggered enormous landslides causing infrastructures and property damages. The lithological facies widespread along the coastal region consists of colluviums very sensitive to the action of water overlying very hard marly limestone (pelitic).

The national RN 24 is a coastal road that connects the east central, north of Algeria. It traverses the mountainous areas on the lower side. At PK 226+300, a landslide occurred near coastline of the Mediterranean Sea, causing the collapse of a section of the road of about 120 meters, with a main scarp about 6 to 8 meters. At the landslide area the interface between the marly limestone and colluviums contains a thin layer of very plastic greenish clay. Based on site investigations, the slip surface was encountered at this very soft layer, 13 to 15 m deep.

The emergency measures were to restore immediately traffic between East and Center regions and maintain the connection with the outside for neighboring village people. The temporary reinforcement solution possible technically and economically within an acceptable time is the partial substitution of the slipped ground by an appropriate compacted granular material.

Based on extensive geological, geotechnical and hydro-geological investigations, comprehensive of the landslide analyses were made using limit equilibrium and finite element method. The analyses fully confirmed the sliding mechanism observed on site and served for the final design of rehabilitation works. The analyses show that the nailing reinforced concrete piles connected by a capping reinforced concrete beam can be a solution to stabilize the landslide and to achieve safe use of the reconstructed national road. With regard to the complex hydro geological condition of the ground, for a successful rehabilitation, it is necessary to provide proper drainage.

ACKNOWLEDGEMENT

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