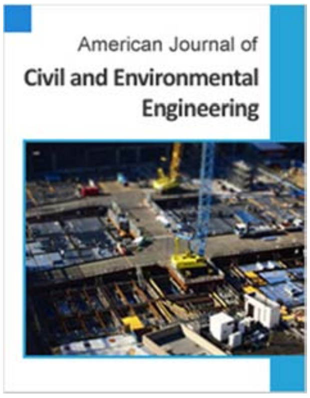
American Journal of Civil and Environmental Engineering
2017; 2(3): 21-29
http://www.aascit.org/journal/ajcee

American Association for Science and Technology



Keywords
Landslide,
Slope,
Stability,
Reinforcement,
Viaduc of Wadi Dib,
Algeria

Received: April 30, 2017
Accepted: June 4, 2017
Published: August 21, 2017

Study of Stability of the Slope of Access to the Viaduct of Wadi Dib, Northeast Algeria

Riad Benzaid*, **Mustapha Tekkouk**

Génie Géologique Laboratory, University of Mohammed Seddik Benyahia, Jijel, Algeria

Email address
benzaid_riad @yahoo. fr (R. Benzaid)
*Corresponding author

Citation
Riad Benzaid, Mustapha Tekkouk. Study of Stability of the Slope of Access to the Viaduct of Wadi Dib, Northeast Algeria. *American Journal of Civil and Environmental Engineering.* Vol. 2, No. 3, 2017, pp. 21-29.

Abstract
During the realization of the viaduct of Wadi Dib Oued (Wilaya of Mila, Northeast Algeria), it was noticed that earth movements surrounding the southern abutment block (Constantine side) started to appear, with falls invading the national road n° 27 (RN27) road and of the cracks appearing on the level of the buildings being neighbourly the site. The southern abutment foundation, concerned with these disorders accompanied by cracks, is currently constant by ties anchored in the rock on which the remainder of the abutment foundation rests. The object of this study, in more of the determination of the critical slip-circle having damaged the embankment of access to the abutment side, and to propose solutions of reinforcement, is to show the relevance of the combined use of several methods of investigation, surface and subsurface having contributed to determine in a precise way the facts of the case. Among the methods of approach which proved very instructive, we will quote: -The geological investigation and in particular the tectonic aspect of the area in the explanation of the disorders observed, - The motion study on the surface by means of topography, - The study in subsurface by means of the inclinometric and piezometric data, - The study by means of the continuous core sampling. The research of the coefficient safety minimum, corresponding to the rough surface, the software Nixes and Trolles which made it possible to confirm the accuracy of the forecasts of the preceding traditional methods.

1. Introduction

Landslides are a serious problem for the technical services of public works and construction. They are among the most damaging natural hazards in northern Algeria [1-12]. These phenomena of instability, which particularly affect the basic infrastructures, constitute a brake on the socio-economic development of several regions of our country. Unfortunately, their prediction is still a challenge to scientists dealing with landslide hazards.

Numerical modeling is considered the most promising tool for studying instability of the slope. They often allows for the achievement of satisfactory results [13]. In fact, numerical codes, based on continuous or discrete approaches, can help us better understand the mechanisms of rupture and deformation processes. On the other hand, continuous changes in kinematic behavior make the simulation of large landslides very difficult. Consequently, the choice of the code depends on the specific problem to be solved or analyzed, e.g., the analysis of the deeper surface of failure, the study of the slide kinematics, and so on.

This article focuses on the study of stability of the slope of access to the viaduct of Wadi Dib. This viaduct is of strategic importance for the whole region of eastern Algeria.

In November 1985, services of the hydraulics announced the future construction of a dam of a capacity of 800 million m^3 of water, situated on the Wadi El-Kébir to the north of the Wadi Dib (Wilaya of Mila -Algeria-). The plan of water of the dam spreads on a length of 35 km and presents a strangling between localities of Annouche Ali and Grarem (wilaya of Mila to 400 km to the East of Algiers). These new data, of major importance, was going to affect the initial axis of the road project already launched.

The project consisting in the modernization of the road linking the city of Jijel to the city of Constantine on which is situated this important structure work, continuation has this new data the red coast of the tracing must be raised. Several variants have been proposed in the first phase of project, realization of a tunnel viaduct and tracings of road new of which costs of realization come back very expensive. Another alternative has been hired by the authorities and that consists to study the possibility to bypassing by a road the plan of water of the dam and to pass to flank of the valley of Wadi Dib in the goal to reduce the cost of the project. A tracing very close to the dam and the realization of a bridge have been kept. During the realization of the bridge it has been noticed however, that of movements of earth surrounding the Southern abutment block began to appear, with debris invading the RN27 road and of cracks appearing at the level of buildings exist on the site. The foundation of the Southern abutment block, concerned by these messes accompanied by cracks, is sustained currently by straps anchored in the rock on which rests the remainder of the foundation of the abutment block. The embankment of access to the south abutment block was affected by an important system of ruptures and generalized under shape of macroscopic crack opening in surface (recovered in depth by field boring log) [14, 15].

Several solutions have been proposed for the access to the abutment block, the one that has been kept initially consists in prolonging the bridge with a floor against earth by foundation on drilled well of big diameter, but it has been separated thereafter for the following reasons: the realization of foundation drilled wells doesn't bring any advantage as for the stability of slope. From a static view point drilled wells require at least 25m of depth to pass a layer of plastic marly-clay and to reach, in steady position a layer of marly-limestone. Besides this depth is indispensable to resist thrusts of lands in movement (depth of anchorage or fitting in). The solution that consists in making a bridge of access on four supports has been separated because the 3rd support is located in the volume of the land interested by the slip. The last practically retained solution is to make a bridge of access on four supports among which the third is suspended. This solution is the consequence natural of the other possible hypothesis exam that have not been kept while considering the permanent stability of slope that must assure the functionality of the structure work, and as the possible consequences on the general stability of flanks at the level of the dam [14-16].

2. Geological Setting

2.1. Regional Geology

The geological component made essentially appear of the composed sedimentary formations of clay and sandstone of the Smendou, with apparition of clay alternation more at least schistose, of black color, and of marly-limestone. The whole contains gypsum in abundance (gypsum inflates in presence of water and becomes lubricant, what will explain a part of messes observed in surface)

2.2. Regional Seismology

The studied zone is classified in zone of middle to strong seismic activities (zone II, according to the Algerian seismic code), magnitudes of earthquakes that have been recorded since 1780 until our days vary between 4 and 8 degrees according to the scale of Richter.

2.3. Local Geology

The land object of this study is located to the North-West of the city of Grarem Wilaya of Mila (Figure 1 and 2). From a morphological view point the site is characterized by irregular topography with slopes whose acceleration is variable. From a geological view point, the small valley of Wadi Dib that is crossed by the bridge (achieved already) is composed by the soils of clayey sedimentary nature to the center and rocky to flanks, these flanks have a thickness of 80m in relation to the bottom of the small valley.

The two sides of this small valley are composed by formations marly-limestone affected by the tectonics that is the important faille seat, especially on the south side toward Constantine.

The dip of layers of the marly-limestone is the order of 45° N-W for the south side of the small valley and 35° S-E for the North side. The central part is constituted, in surface, by alluvial deposits and in depth by an alternation of layers more at least affected by the tectonics. With regard to the mechanical parameters of these layers they improve with the depth, until to reach values of compacted rocks. Lands of the structure work are formed essentially of limestone, marly-limestone, marl, clay and embankment. To put in evidence this lithology one takes the core sampling that contains all existing layers of our site (Figure 3) [14-16].

Therefore two lithologic formations have been raised, it is about:

a. Limestone: they are grayish and are greatly fractured.
b. Marls: - Marl blackish gray, they are often clayey and also present a schistose aspect.
c. Blackish Marl compact (marly-limestone): they are indurate to compact.

The presence of limestone in the zone of a boring log and its absence in another and a sign of discordance that would be bound to an important zone of faults.

Figure 1. *Location of the viaduct and the study area.*

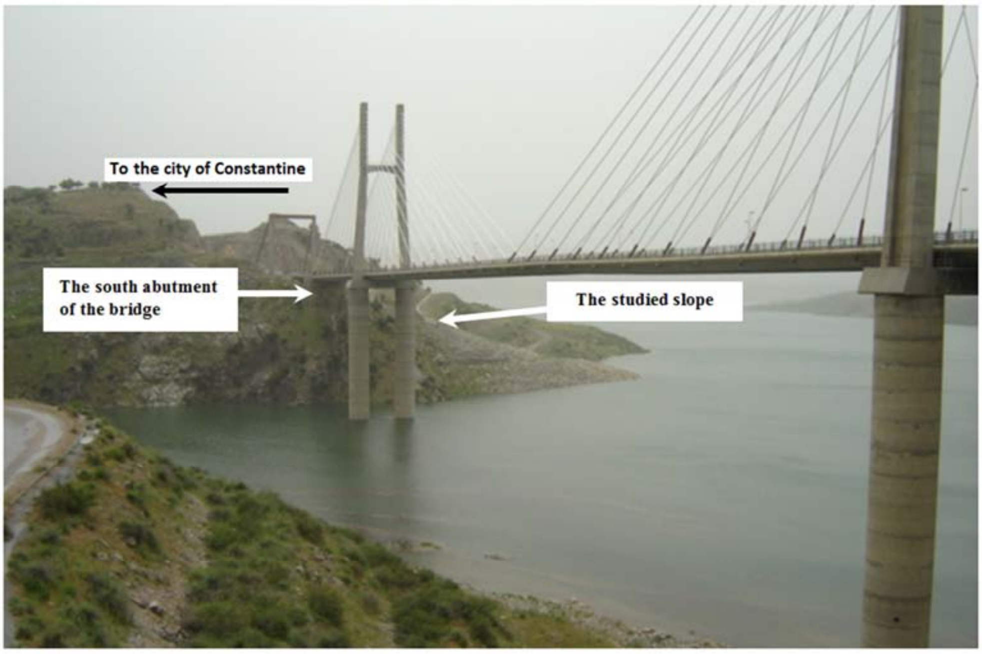


Figure 2. *Viaduct on Wadi Dib.*

2.4. Tectonic Aspect of the Site

The different tectonic phases that followed each other in the region succeeded to the setting up of an extremely complex geological structure. The limestone bench to the summit of the slip underlines contours of a regional size anticline structure oriented appreciably East-West. On the strand south of Wadi Dib strata have a dip of 30° to 45° toward the downstream. Then, more to the South, they become progressively horizontal to the summit of the hill in which is passed the axis of the road. The existence of a certain number of regional faults is obvious.

a. So the valley of Wadi Dib marks the passage of a major faille, oriented E-W appreciably. This faille puts in contact lands of the marly Paleocene, to the South, with those of the more recent Eocene, to the North.
b. Another system of parallel fault oriented N-S appreciably is also more visible on a regional scale even though they present of shifts more at least marked. Two of these faults, separated by a ditch of downfall, delimit the course of Wadi El-Kebir.

On the slip zone we disclosed a network of fault that regroups no far from the South abutment block of the bridge.

They procure an intense fracturation and reduce the mechanical characteristics of the rock considerably (when it is about marls). Then south abutment block rests on two formations: marls and limestone.

2.5. Landslide Susceptibility Factors

The deterioration of the mechanical characteristics of formations constituting the site affected by the slip is the result of two different factors:

a. The first factor is tectonic origin and that consists in the presence of a shattered fault zone regrouped close to the abutment block and that provoked an intense fracturation (ground zones and fractured layers). This system of fracturation reduced the mechanical characteristics of the marly-limestone rock considerably.
b. The second factor is water: the alteration of a rock is bound indeed directly to its degree of fissuring, the main circulation of water takes place preferentially at the level of cracks (fracture), seat therefore of an important alteration. The preexisting fractures in the marly-limestone helped the waters of precipitations and streaming has infiltrate in the limestone rock while provoking a negative change in these physical and mechanical characteristics and modifications in its chemical composition.

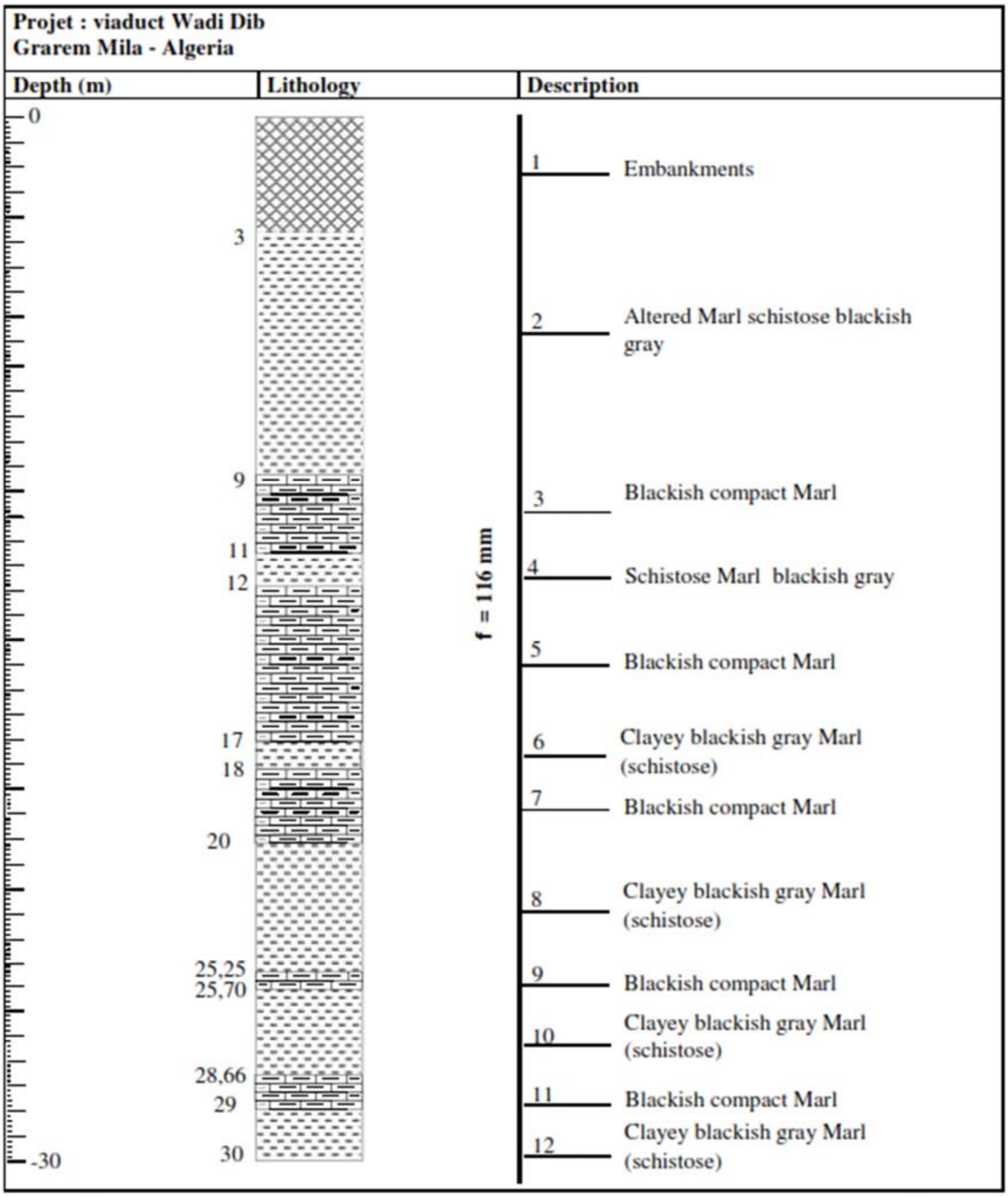


Figure 3. *Typical field boring log N°05.*

2.6. Factors of Instability

After the exam of field boring in continuous log achieved on site (distribute behind the south abutment block of the bridge) and information on the old situation of the land one can say that the evolution of the slip phenomenon, result two different reasons, of geotechnical origin, but bound one at the same time strictly to the other:

a. The presence of an embankment of thickness considerable H_{max} = 12m in the land interested by the slip with a volume of the order of 50.000m^3.
b. The presence in the subsoil of a marly clay layer to a depth varying a place to the other as well as the presence of zones ground with reduced mechanical characteristics.

The superficial water infiltration in these heterogeneous lands (embankment) and fractured (formation of subsoil) encouraged the manifestation of an instability condition along surfaces of least resistance (marly clay, crushed zone). Other exogenous factors contributed to the instability of the land: (a) the suppression of the stubborn of the slope foot caused by the erosion on banks of the Wadi, (b) the very elevated declivity of slope, (c) the very unfavorable meteorological conditions of the region.

3. Recognition of the Rupture Surface

Three investigative methods were used to more accurately determine the slope failure surface:

3.1. Observations of the Geomorphology

Landslides always accompany by shapes characteristics. One can limit zones thus therefore in movements to have indications on points of entry and exit of the slip surface. In our case we could localize the surface of rupture with cracks of traction (place of rooting up) at the level of the embankment of accesses and pads downstream.

3.2. Monitoring of Soil Movements at Depth

Slip of slope always appears especially by the horizontal and vertical displacements close to the foot of slope. When the land is unsteady, one must supervise the horizontal displacements in surface by means of landmark and topographic reference marks and in depth, by means of inclinometers, to detect starting of rupture on the one hand and on the other hand, the horizontal displacement surveillance in depth reached by these displacements. These means of measure and surveillance permit us to situate the depth of the slip.

The principle consists in equipping holes of soundings by means of special intubations (aluminum or plastic) intended to guide an inclinometer. The inclinometer permits to measure, to all depth, the slant of intubations in relation to the vertical. With the regular measures one reconstitutes the distortion of the boring and its intubations during the time [14-17].

3.2.1. Inclinometer's Readings

These measures have been done according to two A-A and B-B plans schematized in the Figure 4. Measures at the level of the sounding (S2) are represented in the Figure 5.

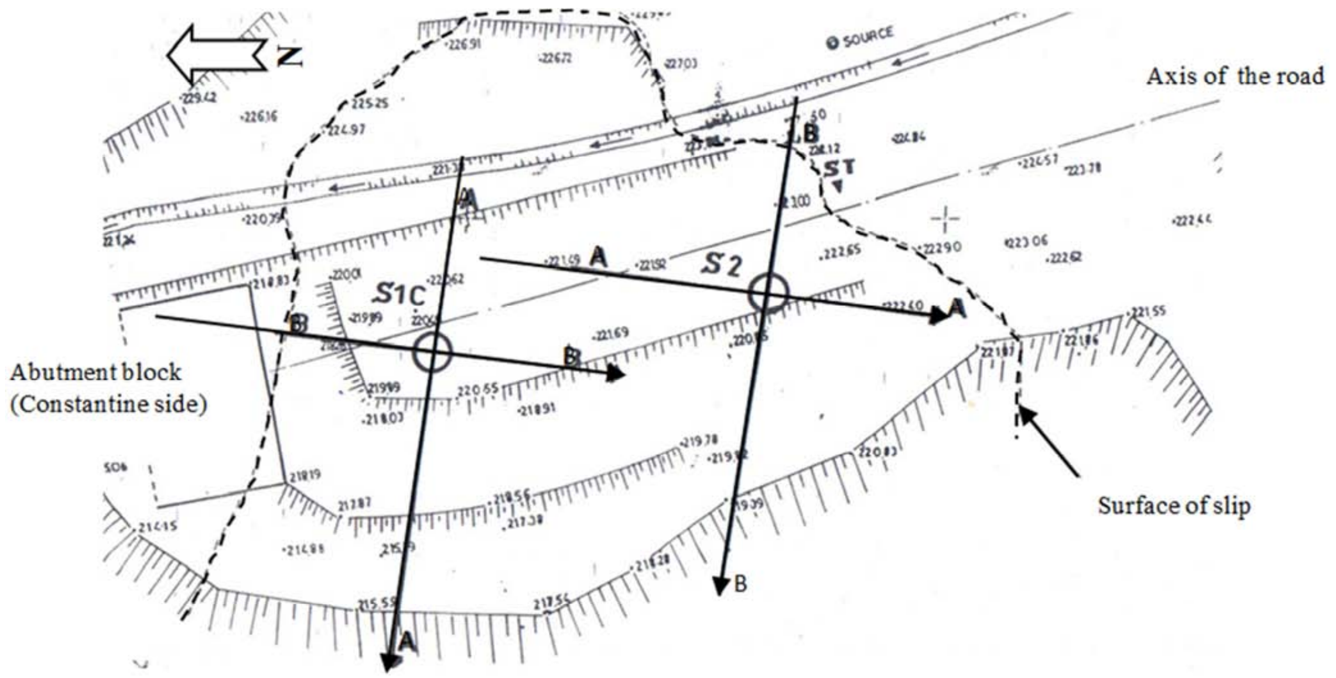


Figure 4. *Implantation of inclinometers.*

3.2.2. Interpretation of Inclinometer's Measures

Two soundings on the five have been equipped by inclinometer S1C and S2 (Figure 4). For a total of ten readings (one reading per month) three measurements only were taken. Our procedure was carried out in two comparisons: first, we calculated the difference of displacement between 1st and 2nd reading. In the second step, we calculated the difference between the 1st and 3rd readings in order to be able to construct the relative distortion of the corrected tube for each measurement. The three readings taken can at least give us an idea of the depth of the sliding surface at the level of every inclinometer.

I. Slip Depth at the Level of (S1C)

The depth of the slip surface given by the first comparison is 9m from the surface of soil, corresponding to an equal maximum displacement to 9.80mm (face AA). This same depth been confirmed by the second comparison with a maximum displacement of 12.63mm (face AA). Therefore at the level of the sounding S1C the depth of the slip surface is 9m and can go until 12m (face BB).

II. Slip Depth at the Level of (S2)

The depth of the raised slip surface from the first comparison is 9m with an equal maximum displacement to 18.55mm (face BB). For the second comparison is to 9m of depth one has record a maximum displacement of 19.55mm (face BB). The exploitation of inclinometer's data permits us to fix the minimum depth of the slip surface to 9m. This depth is going to be confirmed or invalidated by the calculation of the safety coefficient (Fs).

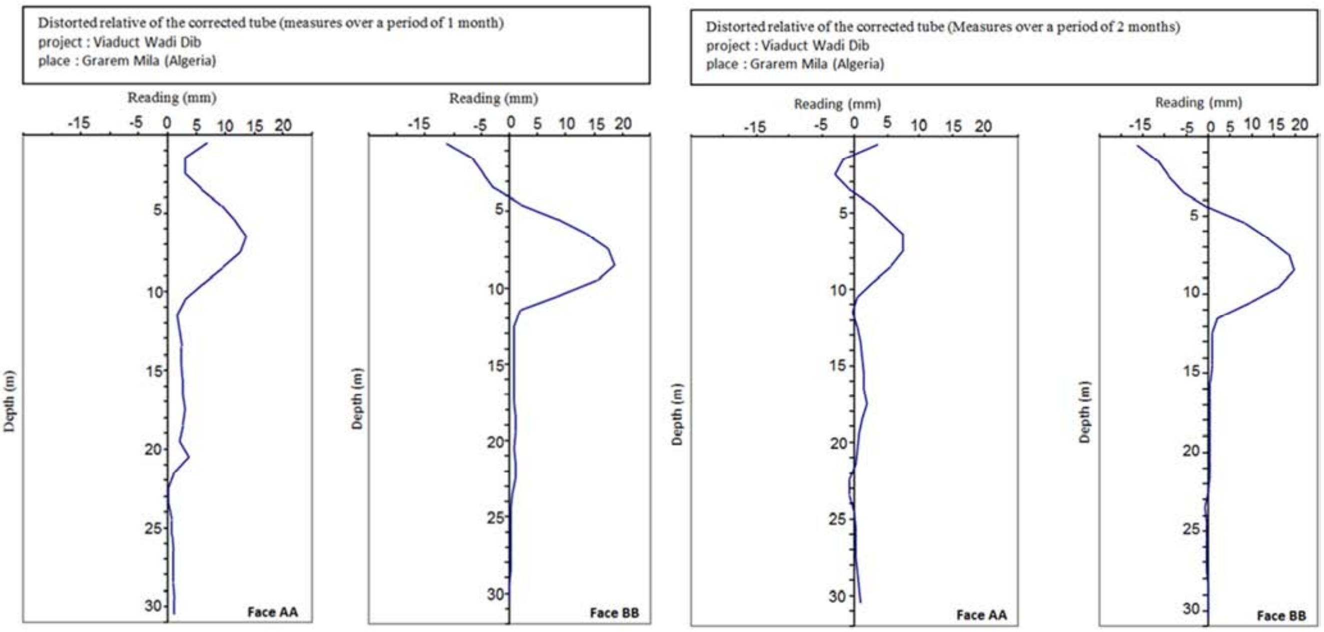


Figure 5. Inclinometer's measures (sounding S2).

3.3. Surveillance of Displacements in Surface

In the site object of topographic surveillance, the principle of the method consists in creating a system of local coordinates and to affect to every point of measure its relative coordinates to this local system. While doing of news measures of all points with the help of a topographic device one can calculate their displacements and can verify the stability of every point. Indeed, if points of measures are of good quality, distribute well on the land and measures well spread out in the time, one can delimit the surface affected by the slip while doing to pass a line between the steady points and the unsteady points (Figures 4 and 6).

We have a network of topographic measure points relatively dense and distributed well on the slope. The topographic measures are also spread out well in the time to permit some reliable interpretations. One admits in general that factors of displacement speeds in surface are parallel to the surface of slip to the aplomb of the point considered. Results of measures are presented below in the Table 1.

Table 1. Amplitudes and speeds of displacements.

Topographic Stations	Amplitude of displacement (cm)	displacement speeds (cm/day)
ST1	110	0.180
B6	155	0.117
ST2	113	0.199
ST3	32	0.05

The evoked stations are represented above on the Figure 6.

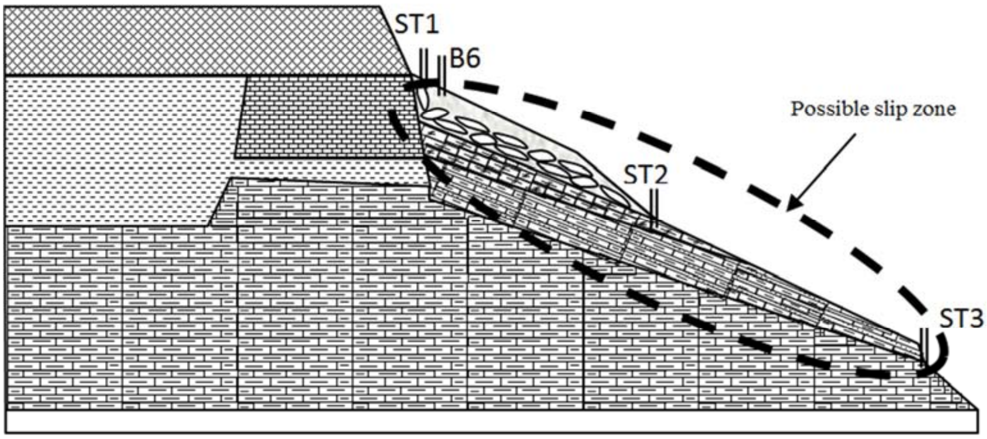


Figure 6. *Displacements in surface (Possible slip zone).*

One notices that amplitudes of first three station displacement (ST1, B6 and ST2) as well as their speeds are considerably near in spite of the difference of altitude and the existing spacing between these stations. Whereas the one of the station (ST3) is too weak. It permits us to imagine two levels of lands: The first moves with a middle speed of 0.165 cm/day and that reaches a middle amplitude of displacement equal to 126 cm. The second land moves with a very weak speed that is the order of 0.05 cm/day and reaches an amplitude of 32 cm that is a weak value compared with the one of the first land.

4. Stability Study

After the analysis of all available data and according to the planimetry and altimetry of the unsteady zone; we chose five representative profiles of slope. The middle values of the physical and mechanical characteristic of soil adopted for the study of stability are regrouped in Table 2:

Table 2. *Physical and mechanical characteristic of soil.*

Nature des couches	γ(t/m^3)	φ (degree)	C_u (bars)
Embankment	1.90	30	0.0
Clayey Marne	2.00	10	0.1
Marly-limestone (very fractured, crushed zone)	2.00	20	0.0
fractured Marly-limestone	2.20	35	0.0
compact Marly-limestone	2.50	38	0.5

4.1. Stability in Non-circular Rupture

Research by manual way of the critical circle (case where the rupture is probably circular) requires the calculation of several circles often, what is a complicated operation, whereas in the case where the rupture is non-circular the calculation will be very difficult without computer that permits to execute iterations quickly and to study numerous hypotheses. The method of calculation consists in calculating the coefficient of security for every circle (non- circular rupture case), the circle or the curve that will present the minimum of the safety coefficient will be kept like "critical slip-surface" [18-21]. Knowing that, safety coefficient of the landslide $F_S = \Sigma$ Resistant moments / Σ Mobilising moments.

4.2. Interpretation of Results Gotten

After the exam of the results of the safety coefficients, we noted that none of rupture circles doesn't present a coefficient of security lower to 1.00. What implies that the surface of slip is non-circular [18-21]. On the other hand one to noticed that the safety coefficient decreases with the decrement of the ray until to reach a value more lower to 1.50 to some meters of the surface of the land. After several tentative of determination of the rupture surface (for the non-circular rupture case) that didn't give a critical circle, one proceeded to the calculation of security coefficients for the non-circular curves, while constructing spindles of rupture in order to localize the critical curve (presenting a safety coefficient: Fs < 1.00). After groping one succeeded to a critical spindle (Figure 7) in which is the critical curve represented on the Figure 8.

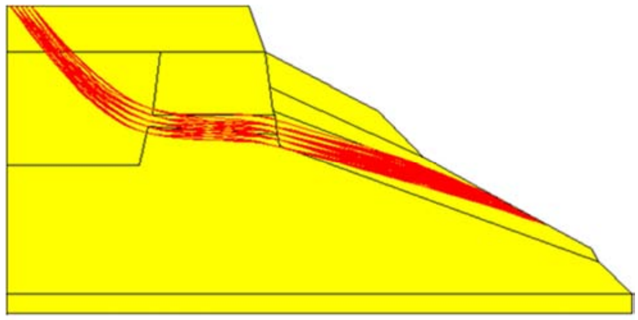


Figure 7. *Critical spindle.*

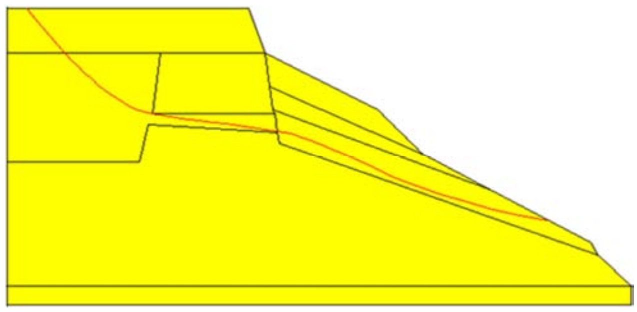


Figure 8. *Slip surface (critical curve giving Fs = 0.7843).*

Calculations showed that the pace of the slip (critical curve) pass by two formations of weak mechanical characteristics that are; the clayey marl and the marly-limestone (very fractured) with passage of crushed zone. On the other hand the overcharge (volume of the embankment) important contributed to the instability of slope.

4.3. Recommended Reinforcements

The stability of the embankment of access to the viaduct of Wadi Dib requires the following chronological operations:

a. Denude the part downstream of slope until the natural land, and reuse of the material cleared in embankment and enrockment.
b. Achieve a stubborn of foot in reinforced concrete anchored to the rock by means of bar of steel of 30mm of diameter.
c. Support the foundation in concrete by enrockments to improve the general stability and to assure drainage of the streaming waters.
d. Execute the embankment of the enrockment by layers of less than 30 cm, with a slope of less 20° (slope lower to the friction angle of the contact layer that makes 25°).
e. Downstream the adjacent abutment block of the main thalweg, to foresee ditches in concrete intended to drain the streaming waters.
f. General drainage of zones limiting the embankment and the abutment block by means of ditches in concrete of head and foot of slope.

4.4. The New (FS) After the Reinforcements

After these propositions of reinforcement, we submitted the whole to new calculations of stability by means of the software Nixes and trolls. The exploitation of the data leash to appear a good improvement of security coefficients for the same circles critiques whose coefficient becomes superior to (1.00). So, the recommendations of treatment of the foundation with (gravel-cement) improved the physical and mechanical characteristics of lands concerned by the instability. Besides, reducing the natural slope to 20° and its reinforcement by enrockment improved the general stability.

5. Conclusion

The detailed geotechnical study of instability factors of slope of access to the viaduct of Wadi Dib showed that the main reasons are the following:

a. The foundation on which had to rest the structure work of access proved to be an embankment, whose main component is only other of rubbles and materials of recuperation put in place at the time of the terracing of the rocky trench. Besides, this embankment has not been spread out and compacted according to the requisite norms, what didn't let him the time to normally stabilize.
b. The tectonic regime of the region to encourage the instability insofar as one put in evidence an active and important faille network, aggravated by the important humidity of the region, accelerated the instability.
c. Methods of reinforcement recommended, to the report (cost/security) very advantageous showed their relevance at the level theoretical by an appreciable improvement of the security coefficient of critical circle raised at the time of the diagnosis of messes.
d. Today these recommended measures showed their relevance.

However, the detailed analysis of the tectonics of the region can constitute a risk for the limestone flanks of the dam constructs under the viaduct and situated in the sense of out-flow of waters and the preferential directions of the brittle tectonics, if they came to replay.

As a preventive measure, we recommend, at the time of the exploitation of the dam (of which the mobilizable water volume is 800.000.000 m^3), will generate some immense efforts so much on the arch in concrete that on the rocky flanks of the dam to supervise by means of "hydraulic jacks", the beginning, the direction and the evolution of cracks may result from a possible resumption of the tectonic activity.

These cracks, localized once can be plugged by means of grout of cement with the progression of their apparition. The absence of surveillance of these cracks and their treatment as advisable can caused the crack of the arch in concrete of the dam, what could entail some more important messes.

Finally, this study permitted us to verify on a real case, the relevance of the simultaneous use of the different methods of geotechnical investigating and that were for our case: (a) a detailed geological survey and in particular tectonic aspect that permitted to consist of a big part of messes and to permit to find them the most adequate solutions; (b) sets of surface measures by means of topographic methods of surveillance of land movements in surface; (c) inclinometer’s measures in depth that permitted to confirm displacements raised in surface, as well as the pace and the depth of the slip surface; (d) a research by computer of the critical circle of slip that confirms data advanced by methods of surface and subsurface.

All this information has enabled us to propose the most suitable method of reinforcement for the site to ensure the safety and durability of the structure.

References

[1] Machane D., Bouhadad Y., Cheikhlounis G., Chatelain JL., Oubaiche EH., Abbes K., Guillier B., Bensalem R. (2008), “Examples of geomorphologic and geological hazards in Algeria”. Natural Hazards 45: 295–308.

[2] Bouhadad Y., Benhammouche A, Bourenane H., Ait Ouali A., Chikh M., Guessoum N. (2010), “The Laalam (Algeria) damaging landslide triggered by a moderate earthquake (Mw = 5.2)”. Natural Hazards 54: 261–272. Doi: 10.1007/s11069-009-9466-0.

[3] Djerbal L, Melbouci B. (2012) “Le glissement de terrain d’Ain El Hammam (Algerie): causes et évolution”. Bulletin of Engineering Geology and the Environment 71: 587–597. Doi: 10.1007/s10064-012-0423-x.

[4] Hadji R., Boumazbeur A., Limani Y., Baghem M., Chouabi A., Demdoum A. (2013), “Geologic, topographic and climatic controls in landslide hazard assessment using GIS modeling: a case study of Souk Ahras region, NE Algeria”. Quaternary International 302: 224-237. Doi 10.1016/j.quaint.2012.11.027.

[5] Guettouche M. S. (2012), “Modeling and risk assessment of landslides using fuzzy logic. Application on the slopes of the Algerian Tell (Algeria)”. Arabian Journal of Geosciences 6: 3163-3173. Doi: 10.1007/s12517012-0607-5.

[6] Bouhadad Y. (2013), “Occurrence and impact of characteristic earth-quakes in northern Algeria”. Natural Hazards 67: 1573-0840. Doi: 10.1007/s11069-013-0704-0.

[7] Bourenane H., Bouhadad Y., Guettouche M. S., Braham M. (2015), “GIS-based landslide susceptibility zonation using bivariate statistical and expert approaches in the city of Constantine (Northeast Algeria)”, Bulletin of Engineering Geology and the Environment 74: 337–355. Doi 10.1007/s10064-014-0616-6.

[8] Zaagane M., Benhamou M. Donzé F., Refas S., Hamimed A. (2015), “Morphometric analysis of landslides in the Ouarsenis area (west Algeria): implications for establishing a relationship between tectonic, geomorphologic, and hydraulic indexes”. Arabian Journal of Geosciences 8: 6465-6482. Doi 10.1007/s12517-014-1711-5.

[9] Hadji R., Hamed Y., Chouabi A., Boumazbeur A., Gadri L., Raïs K. (2016), “Application of linear indexing model and GIS techniques for the slope movement susceptibility modeling in Bousselam upstream basin, Northeast Algeria”. Arabian Journal of Geosciences 9: 192. Doi: 10.1007/s12517-015-2169-9.

[10] Bourenane H., Guettouche M. S., Bouhadad Y., Braham M. (2016), “Landslide hazard mapping in the Constantine city, Northeast Algeria using frequency ratio, weighting factor, logistic regression, weights of evidence, and analytical hierarchy process methods”. Arabian Journal of Geosciences 9: 154. Doi 10.1007/s12517-015-2222-8.

[11] Meziani B., Machane D., Bendaoud A., Cheikh-Lounis G., Oubaiche E., Chabane S., Bensalem R., Moulouel H. (2017), “Geotechnical and geophysical characterization of the Bouira-Algiers Highway (Ain Turck, Algeria) landslide”. Arabian Journal of Geosciences 10: 117. Doi: 10.1007/s12517-017-2926-z.

[12] Achour Y., Boumezbeur A., Hadji R., Chouabbi A., Cavaleiro V., Bendaoud E. (2017), “Landslide susceptibility mapping using analytic hierarchy process and information value methods along a highway road section in Constantine, Algeria”. Arabian Journal of Geosciences 10: 194. Doi: 10.1007/s12517-017-2980-6.

[13] Jing L., Hudson J. A. (2002), “Numerical methods in rock mechanics”. International Journal of Rock Mechanics and Mining Sciences 39: 409–427. Doi.org/10.1016/S1365-1609(02)00065-5.

[14] Marcofissore - Giccostruzaini (1996), “Rapport de synthèse sur la stabilité du remblai d’accès du viaduc de Oued Dib, Mila, Algérie”. (In French).

[15] Volter copota inco ingenir consultini (1997), “Rapport d’analyse géométrique du glissement du remblai du viaduc de Oued Dib - Algérie”. (In French).

[16] S. E. T. A (2003), “Rapport d’étude géotechnique du versant sud du viaduc sur Oued Dib, Algérie”. (In French).

[17] Peignaud P., Perrin J. (1973), “Inclinomètre”, Bulletin de liaison des laboratoires des ponts et chaussée, N° spécial, Remblais sur sol compressible, 297-304. (In French).

[18] Fang H-Y. (1991), “Foundation engineering hand book”, 2nd edition, Chapman and Hall, New-York, 923 p.

[19] Philipponat G., Bertrand H. (2003), “Fondations et ouvrages en terre”, Eyrolles, 548 p.

[20] McCarthy David F. (2002), “Essentials of soil mechanics and foundations, Basic geotechnics”, Pearson Prentice Hall, 6th edition, 850 p.

[21] Raulin P., Rouques G., Toubol A. (1974), “Calcul de stabilité des pentes en rupture non circulaire” Rapport de recherche LCPC, N° 36. (In French).