

Treatment of a Landslide by Using Piles System, Case Study of the East-West Highway of Algeria

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Abstract. The use of piles to slope stability has grown in recent years through the good reported performance/time offered by this technique. In this context, we present the case of a landslide that occurred on 2nd March, 2014 on the highway East-West Algeria, a section of Tlemcen, using anti-sliding piles as the treatment solution.

Our study case (landslide) occurred near the village of Ouled Mimoun (Tlemcen), specifically between Pk52+040 ~ Pk52+220. This disorder appeared in the form of longitudinal cracks on the pavement about 50 m of length. The left side of the roadway collapsed following the slip of the downstream slope.

Surveys and Inclinometers were installed to follow the deformation of the slope in time and they showed signs of instability with a sliding depth of about 9 m near the motorway platform.

The probable causes of this instability are the removal of the bottom abutment for the upstream slope of the highway and the establishment of an earth deposit that was overloaded the slope and disrupted the flow of waters to the downstream of Pk52+000.

The study of stabilization of this slide is based on the installation of two lines of anti-sliding piles and the introduction of geosynthetic drainage system (large draining spurs made in the direction of the slope). Our study of stability analysis was carried out under static and dynamic loads and highlights that this solution is advantageous and efficient. We note that this solution was chosen by the company (Group CITIC-CRCC) chosen to repair this section of highway.

Keywords: Landslide · Stabilization · Anti-sliding piles · Dynamic study

1 Introduction

Il existe des principaux facteurs qui contrôlent le type et le taux de mouvements de masse qui pourrait se produire.

The origins of the loss of stability, both natural and artificial, are very diverse. The setting in motion of natural slopes (slow or sudden) may cause significant damage to structures, with a significant economic impact, and sometimes injury or death to humans. The study of a slope comprises, besides the recognition of the site and the selection of the mechanical characteristics of the soil, a stability calculation to determine firstly the failure curve along which the risk of slip is highest, the surface along which the factor of safety is the lowest. Landslides are diverse, both in their nature and size. Slope stability problems usually occur in the realization of roads, dikes of dams and natural slopes. The landslide passes through several chronological stages of activity. There are main factors that control the type and rate of mass movements that might occur.

The method of stabilization of the slopes by piles, the so-called anti-sliding piles, have attracted the interest of several researchers. Many studies have been conducted on the stability of slopes after introducing stabilizing piles. There are two calculation methods: limit equilibrium methods and numerical methods [1]. The kinematic approach dealing the slope with more rows of piles called “passive piles” has the effect of improving its stability. Recall that the major problem in the design of slope-pile system is determining the proper location of the piles.

We present the case of a landslide that occurred on a highway section of the East-West highway of Algeria. The landslide was treated using anti-sliding piles to reinforce the embankment seat of the body pavement. Damage and cracks were observed for the first time on the Tlemcen-Algiers route at PK 52 in November 2013. Thereafter, the pavement, became very degraded and then useless in March, 2014.

2 Presentation of the Landslide

In this article we discuss the landslide which occurred on March 2, 2014 on the section of the East-West highway of Algeria located near the town of Tlemcen (West of Algeria). Indeed, the platform at Pk52+040 ~ Pk52+093 suffered significant deformations, where the back wing moved vertically over 2 m and 3 to 4 m horizontally. Thus the left side of the road was completely stopped for traffic as it shows the Photo 1.

In PK52+093 ~ 200, the outside was completely distorted; it was subject to sliding. According to some reports, the landslide developed quickly with dense cracks in the body of the slide near the river, evident distortions in the form of shear.

Data analysis based on the inclinometer readings showed that the sliding surface was at 9 m, 7 m and 3 m as shown in Table 1 [2].

The displacements at the foot of the slope on the right side of the platform showed no sign of significant deformation during the three months following the event date.



Photo 1. Deformation of the pavement body

Table 1. Inclinator readings at level of the deformation zone.

N° of drilling	Date of first measurement	Date of the end of measurement	Sliding depth (m)	Cumulative displacement (mm)
S01	13-12-2013	29-12-2014	9	26.99
S02	18-12-2013	30-12-2013	7	–
S03	25-12-2103	02-03-2014	3	58.81

3 Landslide Causes

The vertical displacement of the sliding object platform is about 2 m, a fill section. Observing the collected core samples showed a very variable lithology, containing a large pebble content in holes drilled. According to the order of destruction of inclinometer surveys, the borehole located next to the bank of the river was the first hole damaged, and that is the hole near the destroyed platform. The slide then develops due to traction from the bottom upwards. In addition, there is no deformation in the hole that is on the right side of the roadway. Waters of the wadi on the front edge of the slide quickly caused the appearance scour.

A day before the drama, i.e. 03/01/2014, torrential rains lashed the region and caused seepage water and a rise in the level of groundwater in the body of the bank, providing a lubricating action that has accelerated the phenomenon of the sliding mechanism.

4 Geological and Geotechnical Profile Site

The geotechnical profile of the site as determined by reconnaissance, six boreholes to a total depth of 127.4 m, shows that the area has a sloping profile. The soil layers consist of backfill of average density, followed by mainly disturbed brownish to yellowish silty clay in the trough left of the plot. This plastic soil is homogeneous interspersed with little pebbles and sand. Shale beds have completely altered to very plastic green yellow clay structure with sandwiched sand. The structure is of variable depth of 13 to 24.5 m in different boreholes with a tendency to flow in the direction of the slope (Fig. 1).

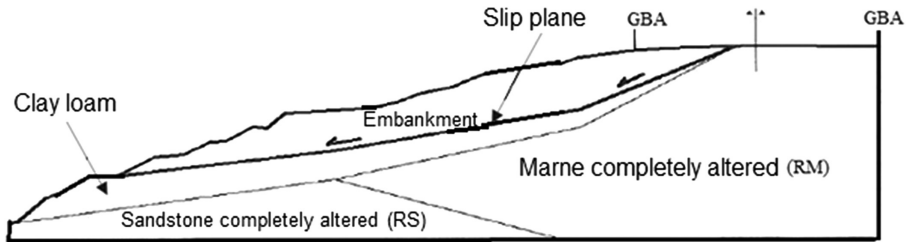


Fig. 1. Geotechnical profile site

Table 2 summarizes the values of the geotechnical properties of soil layers provided by the company of the laboratory conducting the project (CITIC-CRCC).

Table 2. Geotechnical parameters of soil layers [2].

Sol	Volumic weight γ (kN/m ³)	Drained cohesion C (kPa)	Friction angle (°)	Natural water content w (%)	Liquidity limit w_l (%)	Plasticity limit w_p (%)	Void ratio e
Backfill	19.2–19.9	15	27	21.6–23.4	–	–	–
Silty clay	18.2–20.8	14.7	22	20.4–28.7	53.1–58.2	21.9–27.5	0.59–0.92
Marne completely altered (RM)	18.3–20.5	14.7	22	13.9–24.8	26.0–57.5	14.5–23.5	0.53–0.80

For the underlying layer of sandstone that is completely altered (RS), no value has been provided by the laboratory, but it was mentioned that it is a fine sandstone of bad rock characteristics and belongs to the category relatively soft rock.

5 Treatment of Landslide

A static calculation of the stability of the slope using code Plaxis 2D [3] showed that the slip circle passes through the artificial slope (see Figs. 2, 3, 4 and 5).

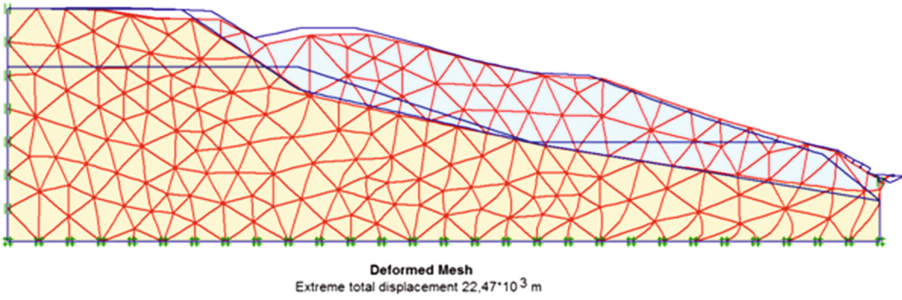


Fig. 2. Mesh of deformation due to self weight of the slope

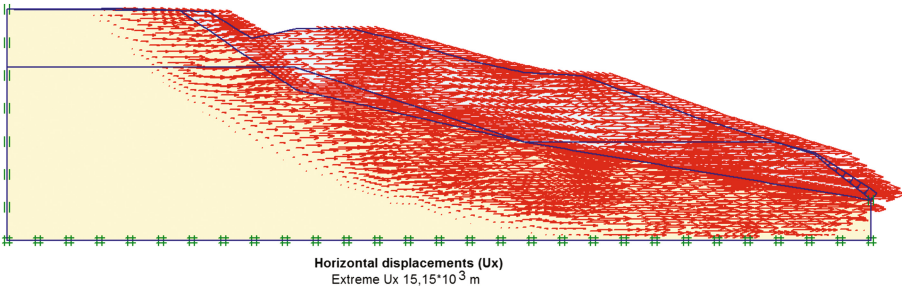


Fig. 3. Fields of horizontal displacements

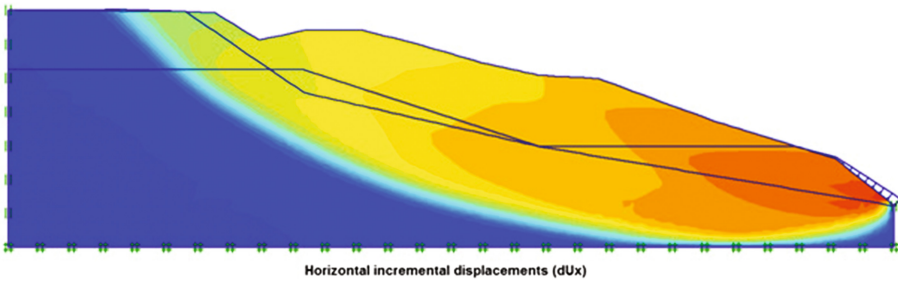


Fig. 4. Critical slip surface

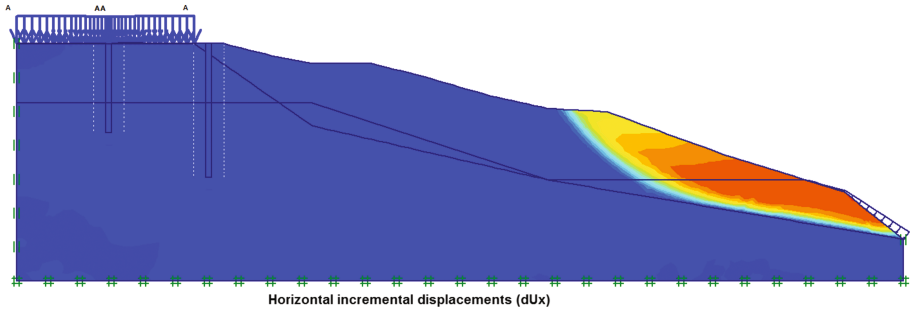


Fig. 5. Failure mechanism and sliding surface after introduction of the piles

The solution chosen for the treatment involves the installation of 11 emergency anti-slip piles in a single row at the edge of the slip surface (middle of the road) to ensure the safety of users of the highway. This is followed by the installation of a row of 60 piles on the left side of Pk52+040 ~ 220 PK52 with a beam connecting the piles together at the heads.

The piles have a diameter of 1.2 m, while the depth is 15 m for the first line of the 11 stakes and 19 to 23 m for the second line of the 60 piles. They are spaced 3 m apart. The design strength of the concrete used for the piles is 35 MPa while the Young's modulus is $E = 35982 \text{ MPa}$. The specific gravity used for the concrete equals 25 kN/m^3 . Soil-concrete contact interface elements were used with reduced properties (2/3 compared to that of the soil).

The Fig. 5 shows an analysis of the stability of the slide after the introduction of two rows of anti-sliding piles. Operating overload vehicles on the road are taken equal to 10 kN/m^2 are arranged 1.50 m from the edge of the roadway. It is clear that the bank is more stable compared to the previous configuration with increased safety factor. The roadway is now in a safe condition.

6 Dynamic Analysis

The slip treatment proposal was the subject of plane strain static and dynamic modeling using the PLAXIS 2D Version 8.2 software [3, 4]. It was subjected to a combination of load (dead load, operating load and seismic load).

The seismic loading applied is that of the 2003 Boumerdes earthquake (May 21st), characterized by a magnitude of 6.8 and a PGA (Peak Ground Acceleration) of 0.34 g [5]. The input signal was the E-W component recorded at Keddarra Station (Fig. 6).

Note that the numerical model used was calibrated to previous work [6]. Several suggestions that different investigators made relative to Plaxis parameters such as the choice of the digital model borders [7], system damping [8], coefficients of Newmark [8], refinement degree of the mesh [9] and the number of dynamic sub steps [8] were adopted.

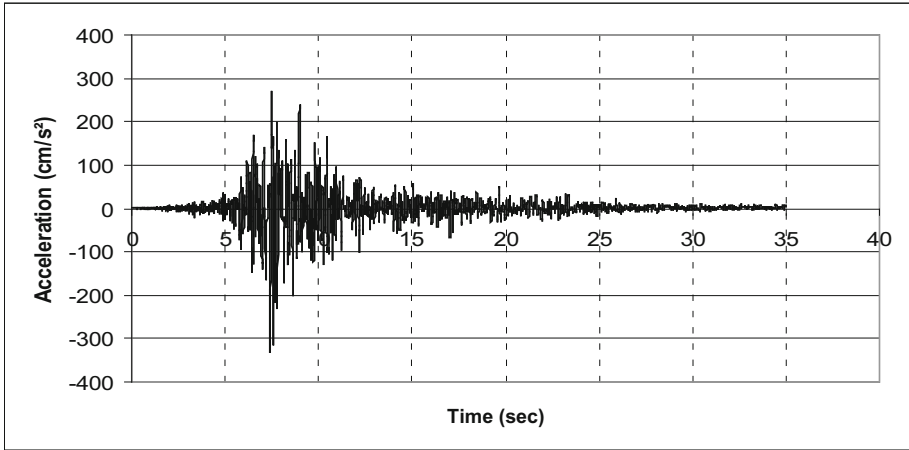


Fig. 6. The seismic loading applied

Although various simulations were performed, we present only the deformed mesh of the configuration at the end of seismic loading ($t = 35$ s). This deformation is shown in Fig. 7.

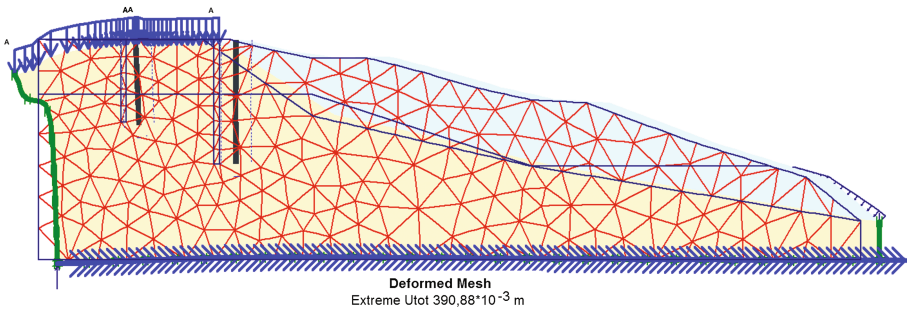


Fig. 7. Deformed mesh of the slide with piles

Figure 8 represents the distribution of horizontal displacements in the slope body.

Figure 9 illustrates the relative shear stresses at the end of the seismic loading for the case of reinforcement of the slope with piles.

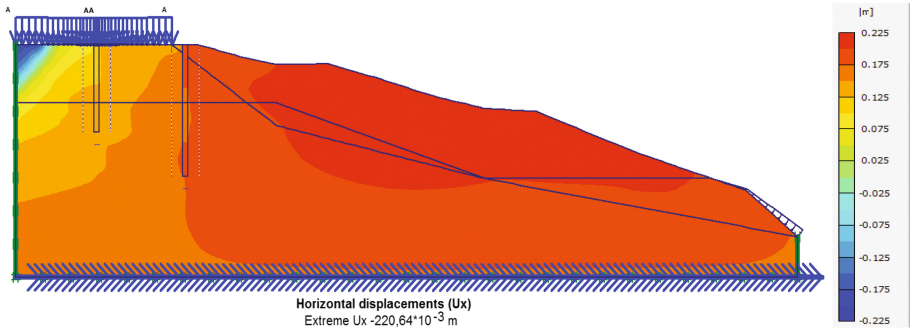


Fig. 8. Field of horizontal displacement with maximum value of 22 cm

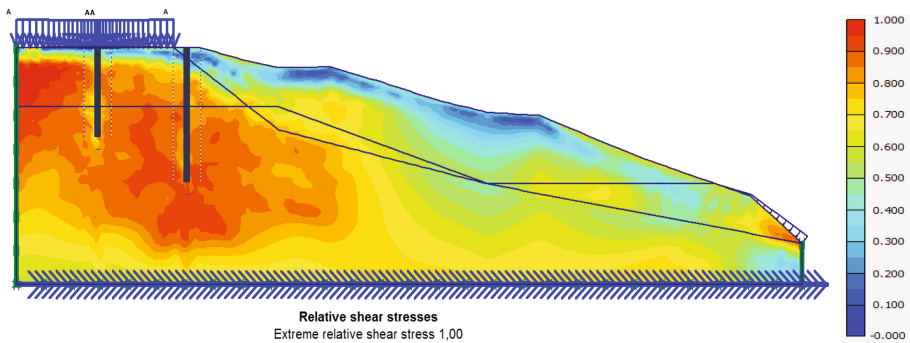


Fig. 9. Relative shear stresses in the case of the slide with piles

7 Discussion

While the time calculation is not given here, it was found that the maximum values of displacements and stresses correspond to the peak acceleration (PGA = 0.34 g arriving at $t = 8$ s). Amplification begins with the arrival of shear waves.

For deformation, the recorded maximum displacement is 22 cm. This value is negligible vis-a-vis the large scale of the slope. For shear stresses, Fig. 9 shows that the values are relatively remote from the failure except in some areas around the pile that is to say, soil-piles interface they are very close to the plastic limit. This is due to reduced interface parameters (soil cohesion and friction piles) that are taken in the calculations, which are very low [10].

8 Conclusion

Vertical piles were used to stabilize the roadway on the right side of the highway section of PK 52 in the boundary between the wilaya of Tlemcen and Sidi Bel Abbes in Algeria. The company carrying out the work was not required to adopt our analysis to establish the treatment of this landslide. Nevertheless the calculations, both static and dynamic, show that the treatment solution has more stability compared to the case of the slope in its initial state. This is demonstrated by the maximum value of recorded movement which is very low and the safety factor found to be equal to 1.86 after the introduction of the piles. If we add to the benefits of this solution compared to other conventional solutions, the quantities of materials and construction time saved, the pile solution is very advantageous.

Based on studies of the stabilization of PK 52 slopes with dynamic analysis using an accelerogram of strong seismic movement, Boumerdes 2003, we conclude that slope stabilization with piles may permanently resolve the problem of landslide. This technique is primarily applicable to slopes of clay soils, sometimes soft or sensitive.

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