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A Numerical Study of Landslide Treatment Techniques Applied in the Algerian Highway

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Abstract

Slope stability is a significant concern and a widely researched topic in geotechnical engineering, particularly in the design of backfill and dikes for dams. There are multiple techniques used for treating landslides, including the utilization of anti-sliding piles and geosynthetic-reinforced embankments. In this context, we present two cases of landslides that occurred on the East-West highway section in Algeria, specifically in the Tlemcen area. The first case involves a landslide that occurred on July, 2009, which was retrospectively recorded. Two lines of cracks were observed on the roadway at kilometer point PK110. The treatment solution adopted for this case was the implementation of a reinforced embankment with layers of geotextiles. The second case involves a landslide that occurred on March, 2014, also retrospectively registered, at Pk52. For this particular case, the chosen treatment solution was the use of anti-sliding piles. Stability analysis of these two landslides was conducted using numerical models developed with Plaxis 2D software and the analysis considered for both static and dynamic loads. The results highlighted the advantages and effectiveness of these treatment solutions, which are further discussed in the paper in terms of various parameters.

Keywords: *Landslide, Slop Stability, Anti-Slidings Piles, Geotextiles, Plaxis.*

Article Highlights

- The reinforced geotextile backfill has more stability than other solutions for the treatment of landslides.
- The slope stabilization with piles may permanently resolve the problem of landslide.
- It's suggested to submit the numerical model to both static and seismic loads at the same time.

1. INTRODUCTION

The stability of a slope is essentially controlled by the ratio between the available shear strength and the acting shear stress, which can be expressed in terms of a safety factor "F_S". A slope can be globally stable if the safety factor, calculated along any potential sliding surface from the top of the slope to its toe, is always greater than 1.

Slopes which are stable under static loading condition may not be stable under seismic loading due to the incorporation of extra added inertia force. In such situations, either the slope is to be flattened, embankment soil is to be replaced by higher strength soil, or the soil is to be reinforced by introducing reinforcements (Fellenius *et al.* 1936).

Volume 63 | Issue 01 | January 2024
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Numerous methods used in the treatment of slope stability such as piles, geotextiles, and nails. The use of geosynthetics is one such method and their advantages are multiple. In addition to the increase in strength of the slope soil, it also absorbs seismic energy and waves and transmits lesser energy to the next upper soil.

The study of slope under static loading conditions is carried out by several researchers (Fellenius *et al.* 1936, Bishop 1955, Janbu 1954, Clough and Pirtz 1956).

The uncoupled analysis method is the most prevalent and used in the stability of slopes, where considering the slope stability and the pile response separately, and effected by the load transfer of pile groups subjected to lateral soil movements in slope (Munawir *et al.* 2013, Nian *et al.* 2008). On the other hand, the analysis with coupled approach considers the whole system of slope stability and pile response simultaneous. A lot of numerical research studies have been recently accomplished with coupled approach for pile reinforced slopes (Belghit *et al.* 2020, Bourdim *et al*. 2020, Tran *et al.* 2019, Xu *et al.* 2018, Li *et al.* 2011).

So, the present study aims in first time to show the effect of the used geotextiles layers to reinforce the embankment through a practical pathological case of a landslide that occurred on the highway East-West of Algeria "A1", at the section of Tlemcen (North-West of Algeria) on July 14th, 2009. The numerical analysis are conducted both on geosynthetic-reinforced slopes and on the slop with the presence of a retaining wall in two different configurations (wall only and wall rests on piles) as proposed solutions.

The second aim is to show the efficiency of the treatment solution using the anti-sliding piles to reinforce the slop through a numerical analysis of another practical pathological case of a landslide occurred on 2nd March, 2014, also at the section of Tlemcen on the highway East-West of Algeria.

The numerical analysis has been performed by Plaxis 2D software under static and dynamic loads and highlights that these solutions are very advantageous and efficient which is represented in this paper in terms of different and significant parameters.

2. LANDSLIDE OF PK 110+500

The geotechnical profile of the site as determined by the company (CITIC-CRCC) shows that the area has a sloping profile with an average slope of 15°. Soil layers consist of a 5m thick embankment, followed by a 5m thick layer of plastic clay overlying a layer of strongly altered marl that goes beyond the depth of 30 meters.

Fig 1: Cracks on the body of the roadway

Volume 63 | Issue 01 | January 2024
DOI: 10.5281/zenodo.10628307

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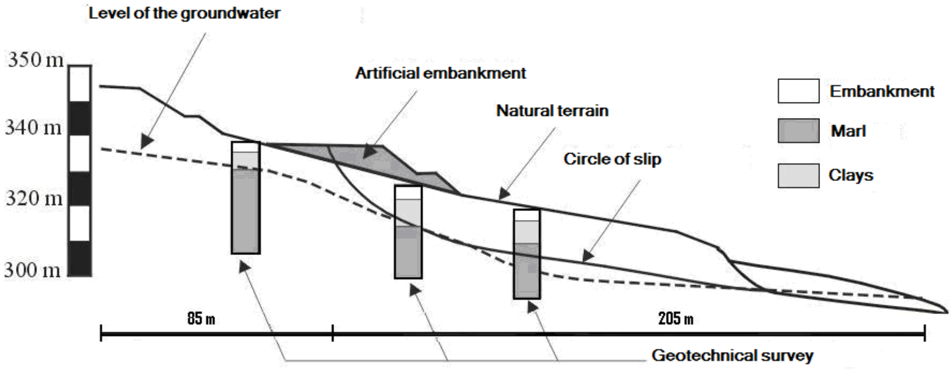

Fig 2: Geological an geotechnical site profile

A static calculation of slope stability showed that slip circle passes through the artificial embankment along roughly the clay-marl interface. Landslide concerns an area of about 57,000 m² and a volume of approximately 700,000 m3. Its length along the road is approximately 200 meters (CITIC-CRCC, 2010). This leads us to believe that the main cause of the landslide, in addition to local geotechnical and geomorphologic conditions of the site and the presence of groundwater, is the loading head of the artificial backfill.

2.1. Material Properties

For layers of soils, geotechnical parameters were provided by the laboratory of the company carrying out the project and are summarized in Table 1 given below.

Table 1: Geotechnical parameters of soil layers (CITIC-CRCC, 2010)

Parameters	Backfill	Plastic Clay	Marne Strongly Altered
Young's modulus E (kN/m²)	12000	50000	96600
Shear modulus G (kN/m²)	4615	18800	35780
Poisson ratio ν	0.3	0.33	0.35
Unit weight γ (kN/m^3)	20	17	22.5
Drained cohesion C (kPa)	5	20	23
Internal friction angle (°)	30	22	26
P-waves velocity V_p (m/s)	89	207	260
S-waves velocity V_s (m/s)	47	104	125

The soil model assumed for the analysis is Mohr-Coulomb linearly elastic perfectly plastic. However, the interface elements were used with reduced properties (2/3 relative to the soil). On the other hand, the mechanical property of the geotextile layers is 190 kN.

2.2. Assessment of dynamic behavior

The proposed treatments of slop have been subjected to a static and dynamic modeling in plane strain using Plaxis 2D software version 8.2. They were, also, exposed to a combination of loads (dead load, live load and seismic loading). Surcharge load of the traffic is assumed as 10kPa, placed at 1.50 m from the edge of the road.

Volume 63 | Issue 01 | January 2024
DOI: 10.5281/zenodo.10628307

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. The input signal was the E-W component recorded at Kedarra Station (Figure 3).

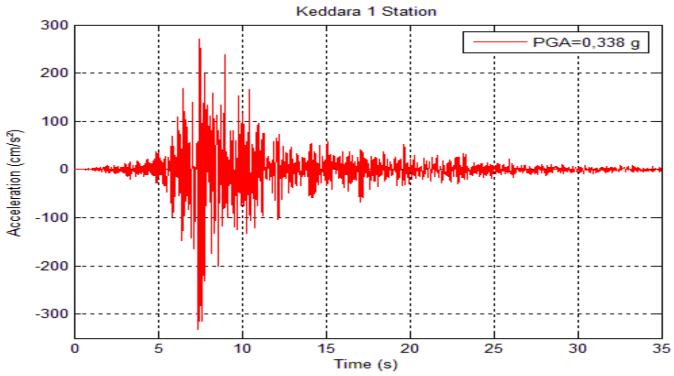

Fig 3: The seismic loading applied

Although various simulations were carried out, we present the deformed meshes at the end of the seismic loading (t = 35 sec). These deformations are shown in Figure 4.

It should be noted that the maximum value of displacement and stresses corresponding to the peak acceleration (PGA=0.34 g arriving at t=7.28 sec). The amplification begins with arrival of shear waves.

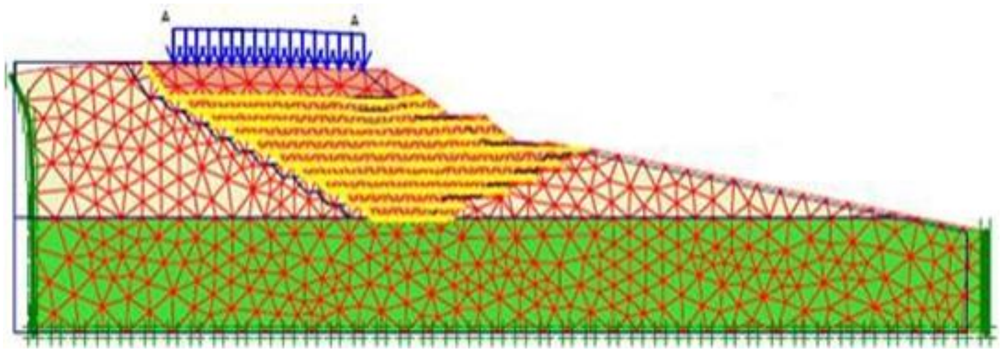

Fig 4: Deformed mesh of the 3rd configuration, Geotextile-reinforced backfill

2.3. Discussion

The displacements values are recorded for the proposed system quite similar and relatively low. For the shear stresses, the values are relatively far from the failure mechanism except in areas where backfill-layers of geotextiles interfaces are very close to the shear strength. This is due to the interface parameters (cohesion and friction backfill-layers of geotextiles) that are made in the calculations, which are, in fact, very low.

3. LANDSLIDE OF PK 52+040~093

3.1. Description of the landslide

In this section we discuss the landslide which occurred on March 2nd, 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 2m and 3 to 4m horizontally. Thus the left side of the road was completely stopped for traffic as it shows the photo in Figure 5.

Volume 63 | Issue 01 | January 2024
DOI: 10.5281/zenodo.10628307

Fig 5: Deformation of the pavement body, PK 52+040~093

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.

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

3.2. Landslide cause and the geotechnical profile of the site

One 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. The vertical displacement of the sliding platform is about 2m at the 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 "wade" on the front edge of the slide quickly caused the appearance scour.

The geotechnical profile of the site as determined by reconnaissance, six boreholes to a total depth of 127.4m, 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. The structure is of variable depth of 13 to 24.5m in different boreholes with a tendency to flow in the direction of the slope. Table 3 summarizes the values of the geotechnical properties of soil layers provided by the company (CITIC-CRCC, 2014).

Table 3: Geotechnical parameters of soil layers

Soil	Volumic weight γ (kN/m^3)	Drained cohesion C (kPa)	Friction angle φ (°)	Natural water content *w* (%)	Liquidity limit *wl* (%)	Plasticity limit *wp* (%)
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
Marne completely altered (RM)	18.3~20.5	14.7	22	13.9~24.8	26.0~57.5	14.5~23.5

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.

Volume 63 | Issue 01 | January 2024
DOI: 10.5281/zenodo.10628307

3.3. Treatment of landslide

A static calculation of the stability of the slope using code Plaxis 2D showed that the slip circle passes through the artificial slope (Figure 6).

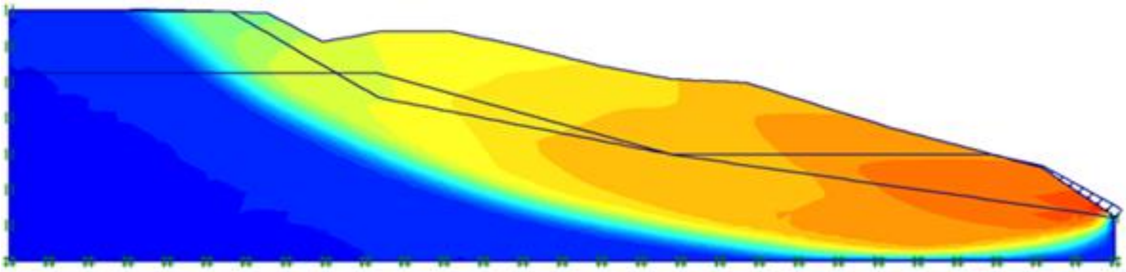

Fig 6: Critical slip surface

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 with a beam connecting the piles together at the heads.

The piles have a diameter of 1.2 m, while the depth is 15m for the first line of the 11 stakes and 19 to 23m for the second line of the 60 piles. They are spaced 3m apart. The design strength of the concrete used for the piles is 35 MPa while the Young's modulus is E=35982MPa. 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).

Figure 7 show 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/m² are arranged 1.50m 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 has become in a safe condition.

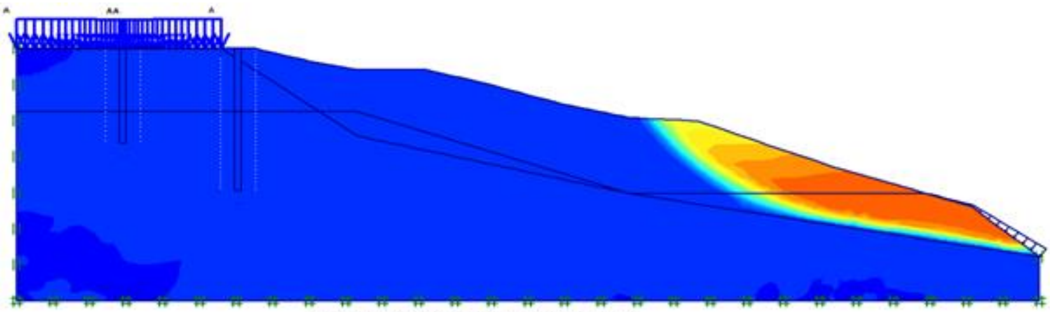

Fig 7: Failure mechanism and sliding surface after introduction of the piles

3.4. Dynamic Analysis

The slip treatment proposal was the subject of plane strain static and dynamic modeling using the Plaxis 2D Version 8.2 software. It was subjected to a combination of load (dead load, exploitation load and seismic load). The seismic loading applied is the same as that used in the previous analysis of the treatment of PK 110 landslide. The applied seismic loading is the 2003 Boumerdes earthquake (Figure 5).

Volume 63 | Issue 01 | January 2024
DOI: 10.5281/zenodo.10628307

Note that the numerical model used was calibrated to previous work (Yun-Suk 2000, Kuhlemeyer and Lysmer 1973). Several suggestions that different investigators made relative to Plaxis parameters such as the choice of the digital model borders, system damping, coefficients of Newmark, refinement degree of the mesh and the number of dynamic sub steps, were adopted.

Although various simulations were performed, we present only the deformed mesh of the configuration at the end of seismic loading (t = 35 sec). This deformation is shown in Figure 8, where the extreme displacement $U_{tot\ max}$ recorded is around of 0.39m.

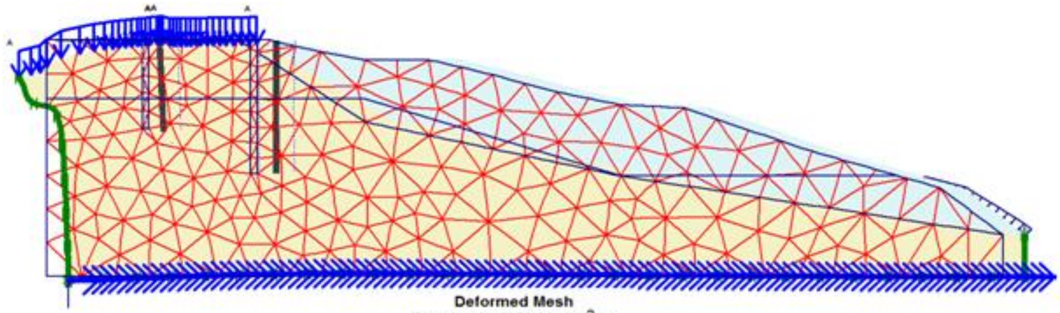

Fig 8: Deformed mesh of the slide with piles

3.5. Discussion

The calculation carried out shows that the treatment solution has more stability compared to the case of the slope in its initial state. This is justified by the value of the maximum horizontal displacement recorded at the end of the dynamic loading is 22 cm. This value is insignificant towards the large scale of the slope and almost zero under static loading. The maximum values of displacements and stresses was found at t=8sec and correspond to the PGA=0.34g, when the amplification begins with the arrival of shear waves.

The distributed of shear stresses and the values are relatively far from the failure except in some areas around the pile, that is to say at soil-piles interface, they are very close to the plastic limit. This is due to reduced parameters of the interface (soil-piles friction) which are taken into account in the calculations which are very low.

It should also be noted that the second row of piles brings more stability to the sliding section. The first row, made up of 11 piles was planned as an emergency solution. This was confirmed through the diverse simulations carried out under Plaxis 2D software.

In addition, the introduction of riprap at the foot of the slope provided optimal stability of the slope, essentially resulting in a minimization of deformations.

4. CONCLUSION

Several models were carried out within the framework of this work in particular the analysis under static and dynamic loading.

The company carrying out the work of the treatment of landslide at PK110+500, Chinese company CITIC-CRCC, was not based on our analysis to establish their choice; but the dynamic calculation performed in this article shows that the geotextile-reinforced embankment has more stability compared to other proposals. Thus, this solution has other advantages,

Volume 63 | Issue 01 | January 2024
DOI: 10.5281/zenodo.10628307

including the quantities of materials and completion time, ease in carrying and flexibility in the behavior, the choice is clear itself.

About the treatment of landslide at PK 52+040~220, the vertical piles were used to stabilize the roadway on the right side of the highway section in Algeria. 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 two rows of piles. If we add to the benefits of this solution compared to other conventional solutions, the quantities of materials and construction time saved, the anti-sliding pile solution is very beneficial. This technique of slope stabilization with anti-sliding piles may permanently resolve the problem of landslide particularly under seismic loads, is primarily applicable to slopes of clay soils, sometimes soft or sensitive.

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Volume 63 | Issue 01 | January 2024
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