STUDY OF THE DISPLACEMENT OF A SOIL STABILIZED BY PILES USING FINITE ELEMENTS METHOD

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ABSTRACT

The road network in the North of Morocco is often subject to the sliding phenomena leading to slope instabilities which require rapid and expensive interventions. Indeed, significant disorders due to a landslide have occurred at the 34 kilometer point (KP34) on the highway connecting Tangier to Ksar Sghir. In this article, the deformation of a soil stabilized by reinforced concrete piles is studied using finite element modeling. The soil-pile system is modeled using the Elasto-plastic Mohr-Columb Model for the soil and the Elastic model for the pile. Inclinometers were installed on the site to measure soil deformation over time. Results show that the horizontal displacement of the soil is close to that measured in situ. Also, the measured displacements revealed that the method of reinforcement by piles used in some areas of the study is effective in stabilizing landslides, and not for others.

Keywords: landslide, finite element method, deformation, pile, modeling.

INTRODUCTION

The slope instability is one of the problems that often affect the stability of highways. These unstable slopes have often led to excessive damages resulting in high budgets to maintain these highways. Often these slopes are considered to be natural slightly adapted during excavation work or are made by embankments.

There are several slope stabilization techniques which can be grouped into three major categories: Drainage, geometric changes (Unloading, Reshaping and Substitution) and Reinforcement. The choice of reinforcement method varies firstly with the characteristics and the conditions of each site (soil type, drainage conditions and overloads) and secondly with the economic cost (when there are several reinforcement solutions) like site accessibility, the time of year chosen for the works, landslide kinematics, and safety conditions towards environment, including the risks of disorder in the process of work.

The use of piles to stabilize landslides as a preventative measure in a stabilized slope has succeeded in recents years and proved the efficiency of this solution. Also the piles can be easily installed without disturbing the slope equilibrium. The success of this technique has been described by several authors [1-5].

The soil-pile interaction is a complex phenomenon, because of the three-dimensional nature of the phenomenon and its dependence on several parameters such as the behaviour of the pile, the soil, the nature of the load and the effects of different interface.

In many cases, piles are used to support the lateral movement of the soil when they are used to stabilize unstable slopes and potential landslides. Some researchers have used numerical methods such as Limit Equilibrium Method (LEM) [6-8] and the Finite Element Method (FEM) [9-12] to analyze slope stability reinforced by piles.

In this study, we analyze the stability of an unstable slope located on the Highway connecting Tangier to Ksar Sghir located at the North of Morocco. Indeed, the 34 kilometer point (KP34) of this highway has faced important disorders due to a landslide. Many signs of movement were observed in the site such as the breaking of the concrete ditch, uprising of the road pavement and the breaking of the median strip (Figure-1). These signs were observed in bad weather conditions.

Previous studies led to stabilize the slope by six rows of piles of 1.2m in diameter and 35m in length. Inclinometers were installed at the feet of the slope to measure and monitor the horizontal displacement of the soil over time.

The objective of this study is to estimate the soil deformation surrounding the implanted piles using finite element analysis. The soil-pile system is modeled in 2D plane strain condition.

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Figure-1. Uprising of the road pavement and breaking of the median strip.

SITE DESCRIPTION AND HISTORICAL EVENTS

The backslope is located at the junction of the Highway (Tangier - Ksar Sghir) with the railway Figure-2. This backslope is located in the lower part of a topographic ridge that presented many signs of instability, it is located right at the same topographic ridge of the backslope that overcomes the railway built before the highway, and which was the subject of work reinforcement. Visible disorders on the highway platform are located at a hundred meters north of the rail bridge. The topographic ridge has as frame a gray pelitic ground covered by beige areas.

The backslope that dominates the East side of the highway was the seat of a slip during 2009 that affected the highway pavement causing an uprising of the road about thirty meters centered on KP34 + 950.

The backslope was cashed and then masked along 200m with a mask using materials (dimension 0/150) with 2 to 5 m thickness. The backslop was originally sloped at 1V / 3H. After roadworks, the slope has been locally softened and the slope foot was increased by fifteen meters. A drainage trench with a 150mm drain has been incorporated in the pavement panel with an outlet to the hydraulic structure under the rail bridge.

The damaged part of the highway pavement was remade. Disorders have been produced again in the winter of 2009-2010. The pavement has undergone at KP 33 + 900 an uprising with a transverse shear on the renovated pavement.

Figure-2. Location of the study area.

GEOTECHNICAL INVESTIGATIONS

Ten geotechnical core drilling up to 35 m depths above natural ground were performed on KP34, these core drilling are paired with pressuremeter tests and the installation of inclinometers and piezometers. Analysis of geotechnical investigations conducted in the KP34 of the highway Tangier - Ksar Sghir revealed the existence of slip planes located at greenish marl interface of surface and indurated pelite and the mass of altered dark-gray pelite. These plans have also a hydraulic gradient.

This core drilling (Table-1) shows several categories of soil displacement (landslides) that could impact the resilience of the highway such as:

Slip at surface level less than 6m, according to the core drilling positions, at the green marl interface and indurated gray pelite. These slip do not reach the pavement; they stop at the slope processed by the mask.

Deep slip that raises the road pavement is located between 6m and 14m depth in the dark-gray to black altered pelite layer.

Very deep deformations: They exist in altered pelites beyond 20m depth; but their impact on the pavement is balanced by the weight of the earth above.

The dark-gray to black altered pelite is the seat of a hydraulic gradient towards the pavement; it has a residual mechanical characteristic lower than the indurated pelite.

Previous studies have led to stabilize the slope by six rows of piles. These reinforcements were implanted over a length of 150m at the berm of excavation; they are constituted by reinforced concrete piles of 1.2 m diameter with a 4m distance between them.

The depth of these piles is 35 m crossing the layer of underwater pelite and anchored in healthy pelite.

This reinforcement solution was completed with the necessary work such as the realization of drainage trenches to lower the level of water table and the drainage system.

Table-1. Slip depths with different geotechnical investigation points.

Slip	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
Interface, greenish marl with indurated pelite	12m	12m	*	7m	9m	*	6m	8m	6m	*
Dark-gray to black altered pelite	24m	24m	6m	15-17m	21-26m	14-24m	14m	17m	16-20m	24m

*: The slip circle is out of the slope treated by mask.

FINITE ELEMENT ANALYSIS

A two dimensional finite element software Plaxis 2D was used in this study to model the soil-pile system [13]. The modeling was performed in plane strain condition with two translational degrees of freedom per node (Figure-3). The Soil was modeled using 15-node triangular elements as an elasto-plastic frictional material obeying Mohr-Coulomb failure criterion [14]. The pile was modeled by beam elements, based on Mindlin's beam theory, (Elastic behaviour). The properties of the soils and the piles are presented in Table-2.

Table-2. Material properties and geometries.

| Materiel	Model	Properties	
Underwater pelite	Mohr-Coulomb	Unit weight (kN/m³)	20
		Friction angle(°)	23
		Poisson's ratio	0.3
		Young modulus (MPa)	17
		Cohesion(kPa)	3
		Coefficient of earth pressure at rest, K0	0.43
Healthy pelite	Mohr-Coulomb	Unit weight (kN/m³)	20
		Poisson's ratio	0.3
		Young modulus (MPa)	50
		Cohesion(kPa)	6
		Friction angle(°)	26
		Coefficient of earth pressure at rest, K0	0.43
piles	Elastic	Unit weight (kN/m³)	24
		Poisson's ratio	0.15
		Flexural rigidity(kN.m²/m)	2.54E6
		Normal stiffness (kN/m)	2.11E7
		Diameter (m)	1.2
		Length (m)	35

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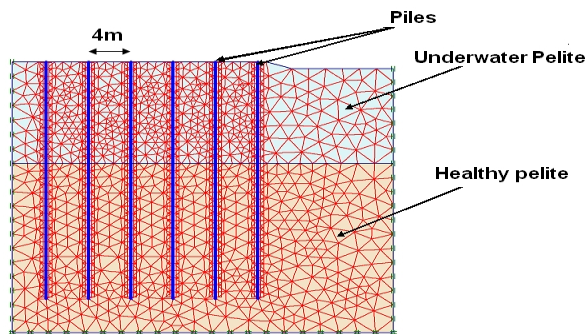
Figure-3. Finite element mesh of soil-pile system.

RESULTS AND DISCUSSIONS

The horizontal displacement of the soil is measured by the inclinometers I23, I24 and I25 by placing the A+ toward the highway as shown in Figure-3. The horizontal displacement of the soil obtained by numerical simulation was compared with that measured by the inclinometer I23. Figure-5 shows the results of simulations and those measured in-situ.

The horizontal displacement measured by I23 is maximal at the ground level (9mm) and null at the failure surface which correspond to a depth approximately -22m (Figure-6.left). The simulated displacement and that measured by the inclinometer I23 have approximatively similar forms with little overestimation especially for depths between -12m and -25m. The mean square error between the measured and simulated displacement is around 1.62 (Figure-5). Under -30m depth, there is a remarkable difference between the simulated and measured displacement probably due to problems related to the boundaries of the domain simulation (Figure-5).

Figure-6 (left and center) shows that the shape of the distribution of displacements with depth at the inclinometer I23 is completely different from that measured at the inclinometer I24. The surface displacements at I24, is about 4 times higher than those measured at I23. The form of horizontal displacement of the soil at I24 (Figure-6.centre) is triangular: between -22m and -35m of depth , the displacement varies between the values 0 and 6mm (the soil stabilized with small deformation), but above -22m and natural ground, the displacement increases and reaches a maximum value of 32mm at the natural ground, which indicates a soil's movement.

Figure-6 (center and right) shows that the shape of the distributions of displacements at I25 is close to that measured at I24. At I25, the horizontal displacement of soil at a depth of -15m is 12mm, (value not significantly higher in comparison with large deformation). But above depth -15m, the displacement increases suddenly and reaches a maximum value of 40mm at natural ground level, indicating a soil movement between -15m depth and natural ground.

The gap between the displacement measured during January and March at I24 is maximum, probably due to rainfall during winter 2014 causing ground movement particularly for shallow depths (Figure-6.center). At I25, the displacement has stopped since January 23, 2014 to the depths below -12m (Figure-6.right). We also notice a change in displacement measured at I23 for depths above -25m (Figure-6.left): the maximum displacement was recorded during January, then it decreases during March, after it increases during April. This may be due to the nonlinear behaviour of the soil.
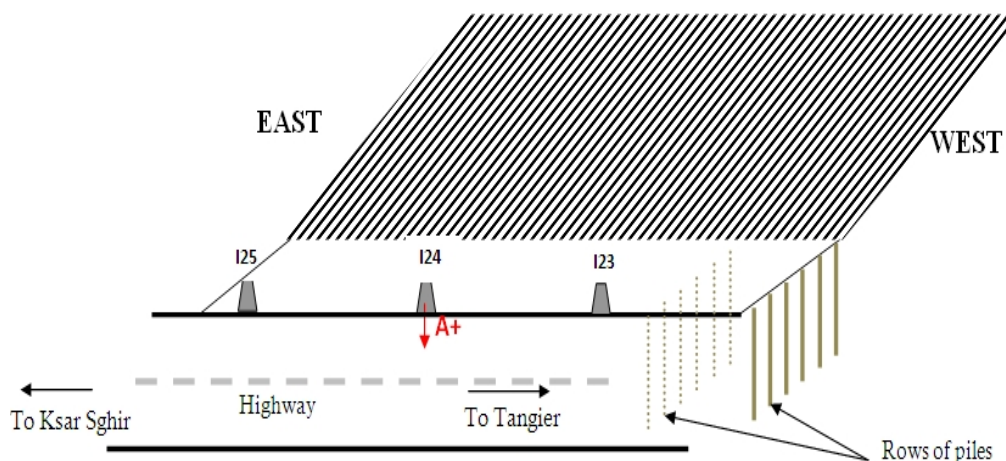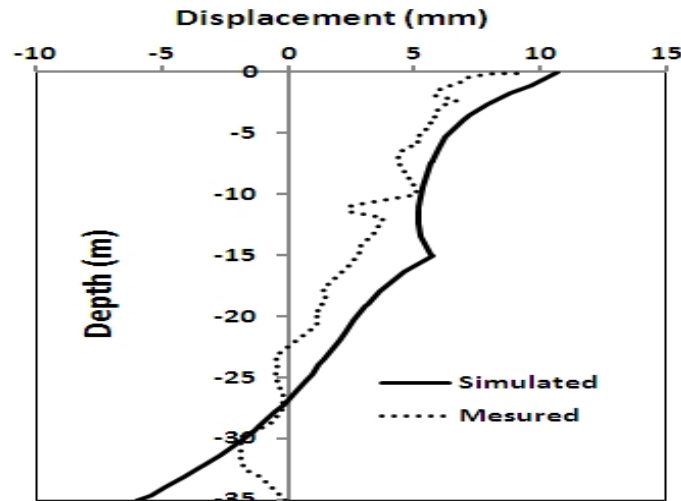

Figure-4. Location of inclinometers.

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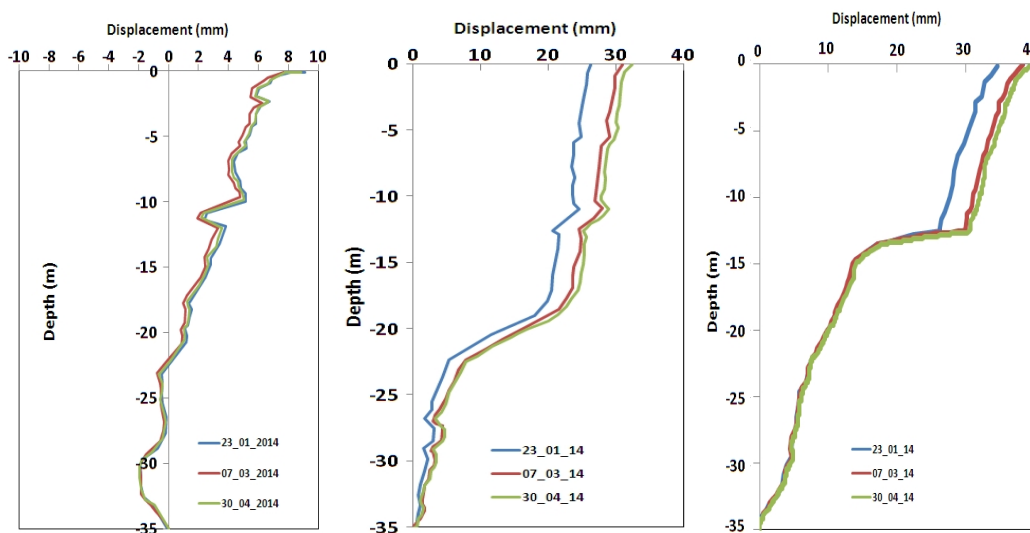**Figure-5.** Simulated displacement versus measured at I23.

Figure-6. Measured displacement during January, March and April 2014 at I23 (left), I24 (center)
and I25 (right).

CONCLUSIONS

In this article, we have described the application of a method using finite element for modeling the soil displacement around the pile. Simulation results were close to in-situ measurements. The finite element method has proven to be effective in the analysis of soil-pile system. However, further simulations should be performed with more refined setting to improve the simulation results.

Inclinometers measurements were revealed that the solution of reinforcement by reinforced concrete piles has stabilized the studied site in areas whose displacement did not exceed 10 mm. However, areas whose movements exceeded 30 mm the stabilization were less evident. This is probably due to the reactivation of ancient landslides by the various works carried out in the study areas.

Measurements taken during different periods showed that the horizontal displacement of the soil has accelerated during certain periods of the year and has slowed in others. This is probably due to the heavy rainfall recorded in the northern region of Morocco in recent years and the rise of the level of the water table and also due to the soil characteristics since all measures were carried out during the winter and early spring.

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