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Research Article

STUDY OF THE COMPLIANCE OF AN OVERLOAD SLOPE ON THE WEST CORNICE OF BRAZZAVILLE

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ABSTRACT
Slope stability problems are frequently encountered in construction projects for roads, dikes, bridges and dams. Some natural or man-made slopes can become unstable; so many ruptures can be catastrophic and cause loss of life or considerable material damage. Thus, to carry out these projects, the engineer often resorts to numerical methods which allow him to model and simulate the behaviour of complex physical systems. The aim of this work is to assess the slope stability on the right bank of the Zanga Dia Bangombe River Bridge by limit equilibrium and finite elements methods. The results obtained showed a stable slope in natural conditions, however this slope became unstable after loading by abutments of this bridge. To this end, two adequate reinforcement solutions were proposed by means of a simulation and the analysis shows the slope stability would be satisfactory after reinforcement.

Keywords: *Slope, Stability, Numerical Methods, Landslide, Reinforcement*

INTRODUCTION
Ground instabilities are one of the most common geological hazards on earth. Thousands of deaths and injuries, enormous economic losses are regrettable evidence of slopes instability all over the world. Stabilizing a landslide is one of the major tasks of geotechnical engineering where a good knowledge of the methodology is necessary. Traditional methods are mainly based on structures strength analysis to failure. The reinforcement analysis of systems that have impacts on the slope by traditional methods remains limited and not endowed with good precision (Mestat, 1997). Currently, the use of virtual reality from engineering problems simulation is more advantageous. Therefore numerical analysis methods make it possible to verify stabilization, to control the admissible displacement values, reinforcement systems efficiency or even the gain in safety provided (Sève and Pouget, 1998). This work consisted to analyse and reinforce the slope located on the west cornice of Brazzaville (Figure 1).

MATERIALS AND METHODS
Study area
The bridge slope has as geographical coordinates 4°18'27"S latitude and 15°14'21"East with an altitude of 180 m. The study area has a climate of Lower Congolese or Sudano Guinean type, characterized by a long rainy season from October to May, a small dry season from January to February and a long dry season from June to September (Samba- Kimbata J., 1978). The annual rainfall is moderate and constant, oscillating between 1250 mm and 1350 mm/year (Moukolo *et al.*, 1992). Its landscape juxtaposes the plateaus and plains reliefs. The hydrogeological system is part of the Batékés water table covering an area of 270km^2. Soils are formed on Inkisi sandstone with a sandy-clay texture there are also soils formed on alluvium, being generally sandy clay poor in organic matter (Denis, 1974; Schwartz, 1987). The geological formations encountered in the area are series made up of the Inkisi Formation and the Stanley-

Pool Series from the base to the top, respectively (Cosson, 1955; Le Maréchal, 1966; Dadet, 1969 and Boudzoumou, 1986).

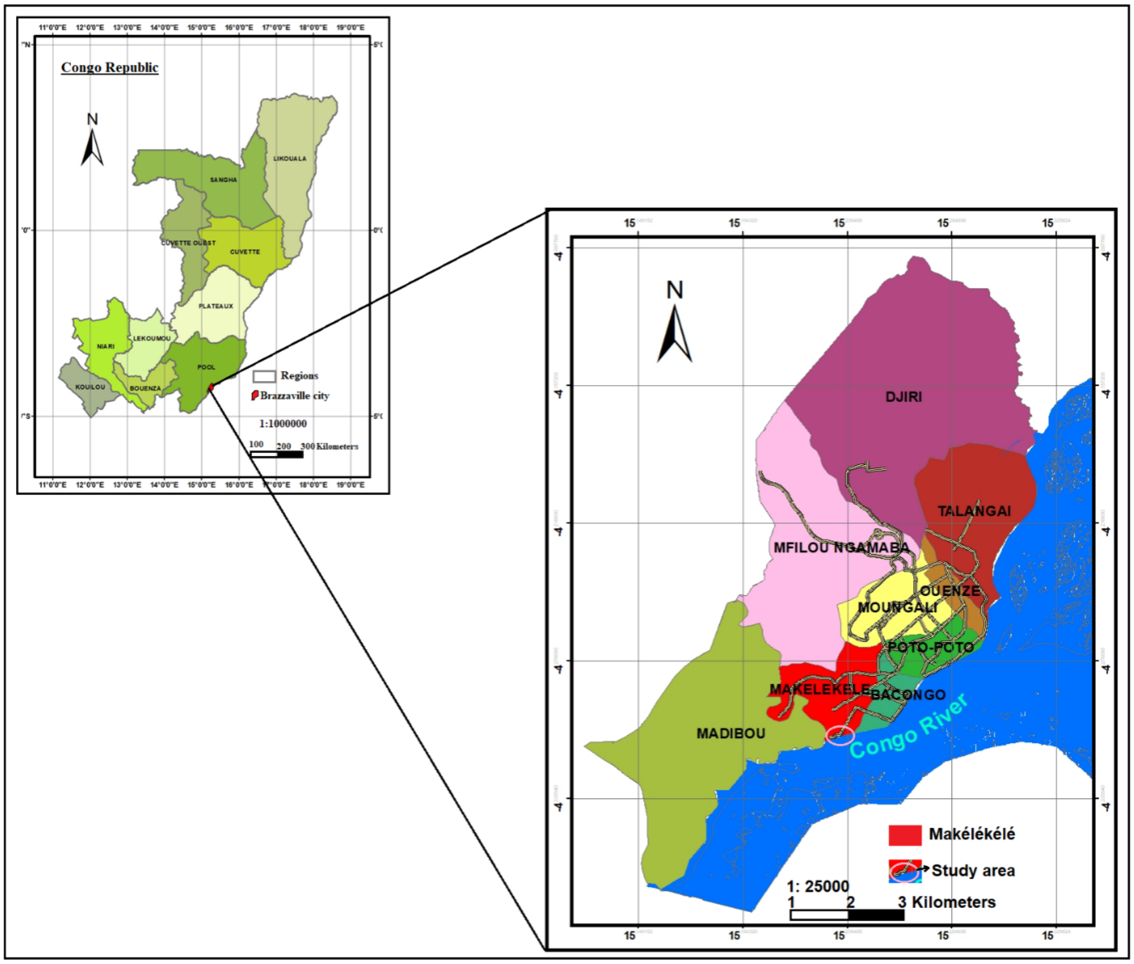

Figure 1: Location map of the study area

Diagnosis and causes of slope instability

The terrain visits allowed us to identify several causes of ground movements. The cornice in downtown Brazzaville recently experienced a landslide following the succession of heavy and prolonged rains in 2020.

Figure 2: Photo of the shear plane observed on the slope (fracture)

This same soil configuration that experienced a landslide in 2020 is observed all along the banks of the Congo River in the southern and western part of Brazzaville City. A study to verify the foundations stability of Zanga Dia Bangombe Bridge has been carried out since 2015 by the RAZEL Company and shows satisfactory stability. However, it has recently observed a progressive evolution of the shear planes on the slope where the abutment (C3) of this bridge is erected (Figure 2).

Slope stability assessment by the finite elements method

The slope stability was carried out from the slope numerical analysis by the finite elements method. This method requires input parameters to allow a sufficient calculation in order to obtain closer to reality and reasonable results for a good interpretation of the situation. The slope stability analysis by the finite elements method consists in determining the ground initial normal stresses, in highlighting displacements and elements deformations for the safety factors assessment. Therefore this work made it possible to choose reinforcement types according to the soil mechanical parameters in order to reduce displacements and deformations.

Hypothesis

The hypothesis for the slope stability analysis by the finite elements method considersthat:

- The ground is supposed to be a continuous medium,
- The strains are considered planes,
- The ground behaviour obeys the Mohr-Coulomb law,
- The water density used is 10 KN/m^3,
- The embankment modelling and the abutment wall considers the stresses and
- The applied loads to the base of the abutment side consider the embankment weight overlying the sole.

Modelling

The modelling includes specific models to each phase of slope stability analysis. It is taken the structure sizing in order to know the slope physical features including the site geographic coordinates.

Table 1: Embankment Dimensions after ground terrace

Description	**Width (m)**	**Height (m)**		**Slope**
		Slope without embankment	**Slope with embankment**	**(°)**
Embankment	35	16.60	20	37-40

Table 2: Slope geotechnical parameters

Description	**Dry density (γ_d)**	**Saturated density (γ_{sat})**	**Cohesion (C)**	**Angle of internal friction (φ)**	**Angle of dilatancy (Ψ)**	**Young's modulus (E)**	**Poisson coefficient (υ)**
	(KN/m^3)	(KN/m^3)	(kPa)	(°)	(°)	(kpa)	
Laterite-Embankment	17.2	18.9	67.5	21	0	20000	0.300
Tender sandstone a litlle thirsty	18	19	5	40	0	140000	0.370
Hard sandstone	22	23	30	45	5	40000	0.370
Tilt wall	25	-	30	45	5	50000	0.370

Source (RAZEL Company, 2020).

The site is characterized by a flat terrain which passes the Makelekele viaduct at the top of Zanga Dia Bangombe River jet point in the Congo River.

The water table absence in the study area dismisses the water influence in slope stability analysis. An abutment was erected at the top of the slope containing a wall in its upper part which supports the embankment and a sole at the base buried a few meters in the soft sandstone little altered.

Modelling by finite elements method

The modelling includes specific models to each phase of slope stability analysis.

Stability Analysis of the terraced slope

The slope is made of hard sandstone at the base and soft sandstone slightly altered at the top. There is no groundwater or load influences. The modelling procedure by the finite elements method is summarized by:

Step1: Project configuration

The design of the model geometry coordinates insertion from the Table 2, the standard blocking execution, the choice of materials geotechnical properties where these materials parameters are assigned to all layers.

Step 2: Mesh generation

The model is divided into several finite elements in order to carry out the calculation by finite elements. Finally, the fundamental elements used are triangular elements with 15 nodes. One then specified the initial conditions, while passing from the hydraulic conditions mode to the geometrical configuration mode creating the initial stresses (K_0).

Step 3: Calculation

After defining a finite elements model and generating initial stresses, the actual calculations can be performed.

Step 4: Load influence analysis on the terraced slope stability

It was added the embankment layer (the laterite), the total load and the abutment wall (C3). Without groundwater influence, the modelling is similar to previous steps. Only in this specific case the abutment wall was merged in the modelling, as well as its load in order to assess the load influence on the slope stability and the embankment influence on the wall. The difference lies in the model geometry by inserting the wall and the abutment sole. The abutment erected at the top of the slope comprises in its upper part a wall to support the embankment and a sole with a buried base at a few meters in the slightly altered soft sandstone (Table 3).

Table 3: Mechanical parameters of the plate representing the abutment sole

Element	**Standard stiffness EA (KN/m)**	**Flexion stiffness EI (KN/m²)**	**Equivalent thickness D(m)**	**Weight W(KN/m³)**	**Poisson Coefficient ν**	**Load G**
Abutment (C3)	1.000E+09	1.000E+09	3.464	25	0.370	2870.47

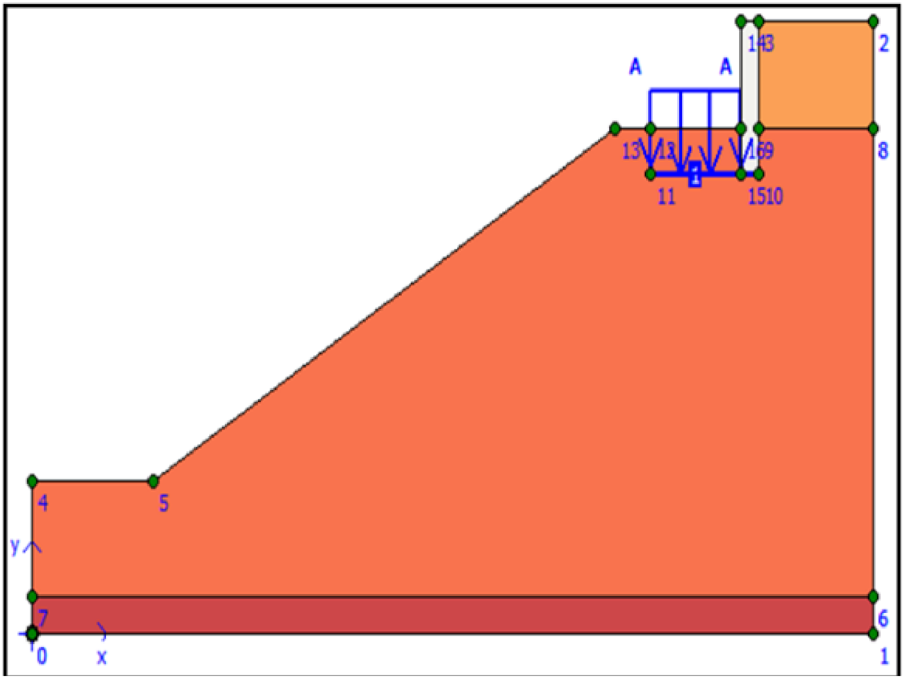

Figure 3: Geometry model of the loaded slope by Abutment (C3)

RESULTS AND DISCUSSION

Mesh generation

The total number of elements is (155) and the total number of nodes is (1319). The mesh fineness has been reinforced as shown in figure 4.

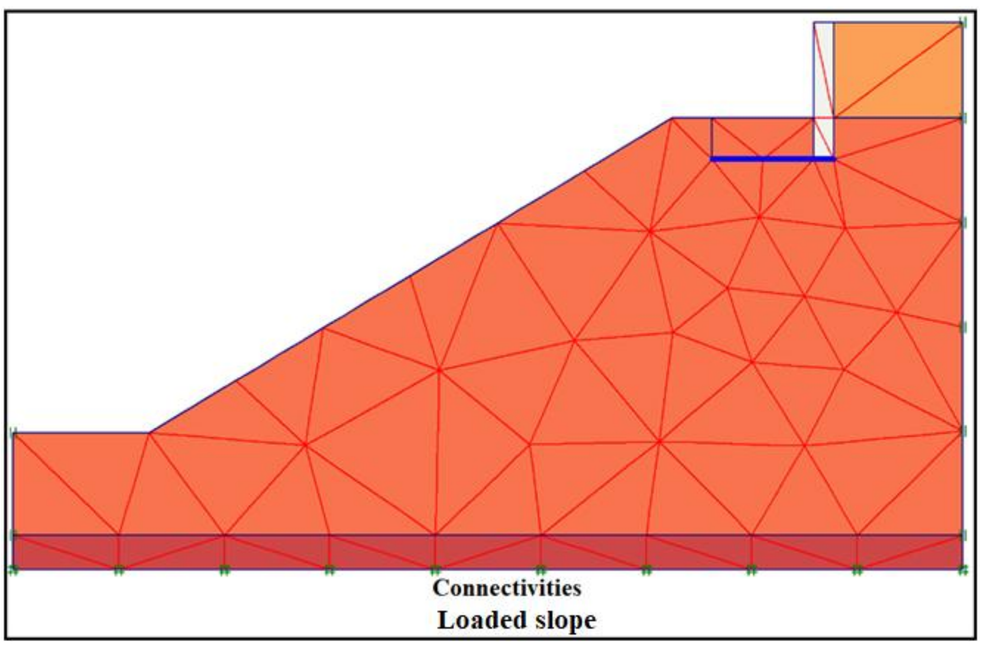

Figure 4: Mesh of the embankment loaded by the abutment (C3)

Initial conditions (generation of initial land stresses)

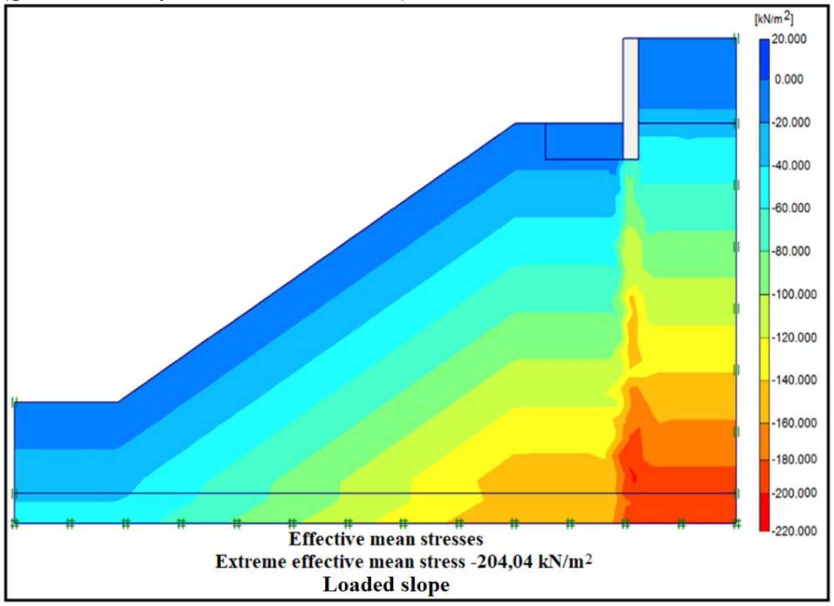

Figure 5: Total initial stresses distribution (-204.04KN/m²)

Deformations, displacements and safety factor:

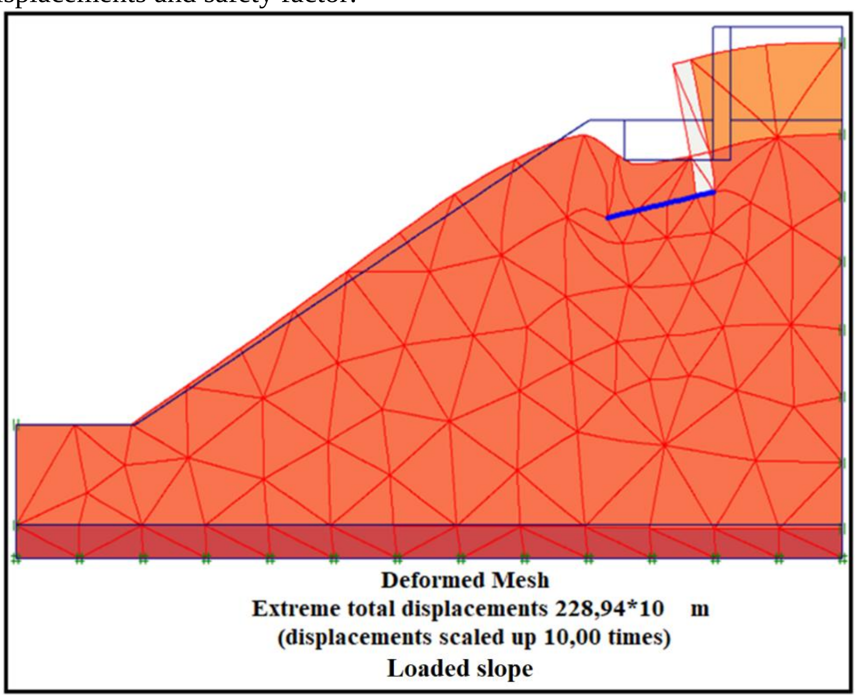

Figure 6: Deformed mesh

Total displacement

Arrows indicate the movement direction and intensity (Figure 7 a).The horizontal displacement of 169.01.10-3 m (Ux = 16.90 cm) with respect to the mesh initial (Figure 7 b).

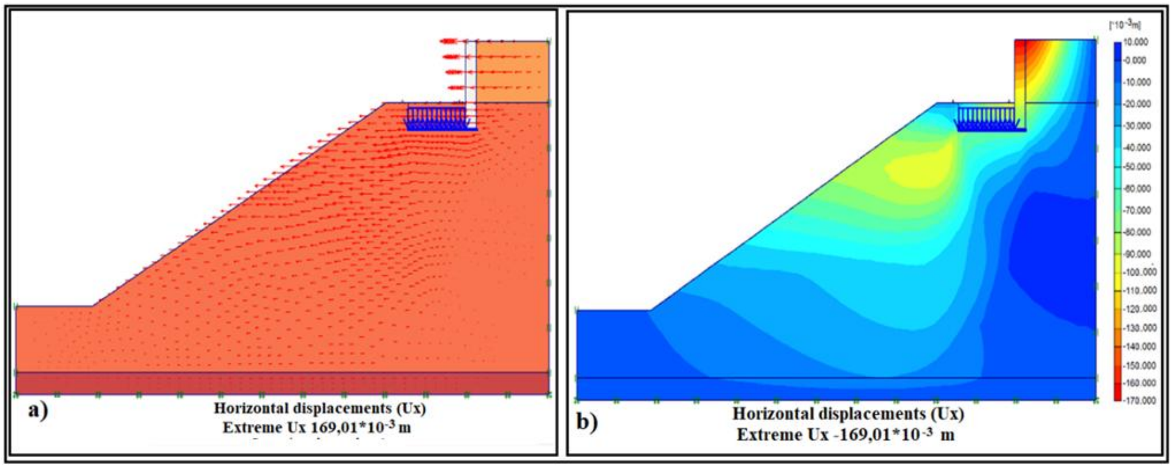

Figure 7: horizontal displacements

After calculation there is a settlement or a vertical displacement of 217.34.10-3 m (Uy = 21.73 cm) (Figure 8).

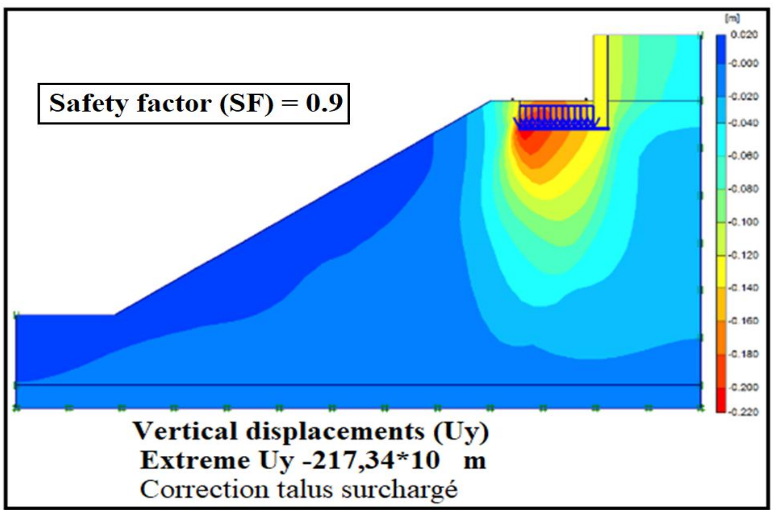

Figure 8: Settlement due to the abutment load

The safety factor resulting from calculations of this analysis phase is 0.9. This shows that the load participates in the slope instability (Figure 8).

Simulation of the reinforcement influence on the slope stability loaded by the abutment (C3)

Depending on the physical and morphological properties of slope elements, as well as the mechanical properties and reinforcement's feasibility, two solutions were proposed in this simulation phase as ground anchor and a sheet pile wall system. Table 4 shows the mechanical properties of these solutions.

Table 4: Mechanical properties of ground anchor and a sheet pile wall system

Parameters	Name	Sheet pile	Anchor	Geogrid
Behaviour type	Material type	Elastic	Elastic	Elastic
Normal stiffness (KN / m)	EA	$1.2x10^7$	$2x10^9$	$8x10^5$
Bending stiffness (KN / m)	EI	$1.2x10^7$	-	-
Spacing (m)	LS	-	1	-
Equivalent thickness (m)	D	3.464	-	-
Weight (KN / m)	W	5.250	-	-
Poisson coefficient	ν	0.15	-	-

Source: Boulon M. (1989)

Anchors associated with Geogrids: Model geometry

It was used a geometric model (2D) supported by fifteen (15) anchors, each one equipped with a geogrid.

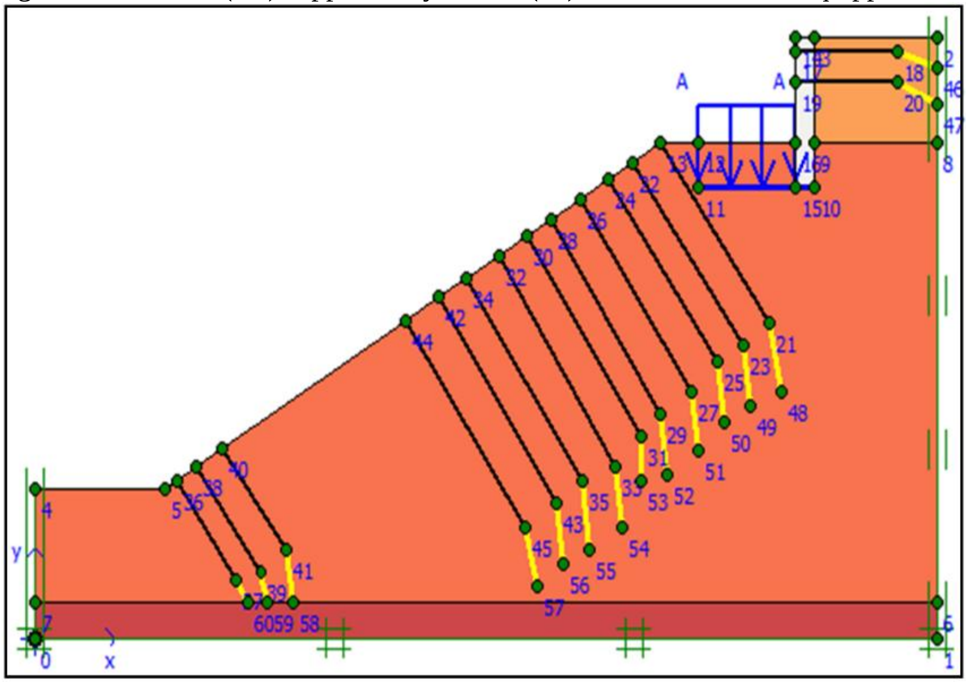

Figure 9: Slope reinforced model by anchoring associated with geogrids

Mesh generation

The total number of elements is (270) and the total number of nodes is (2261). The mesh fineness was reinforced (global Coarseness) on "Medium", as shown in Figure 10.

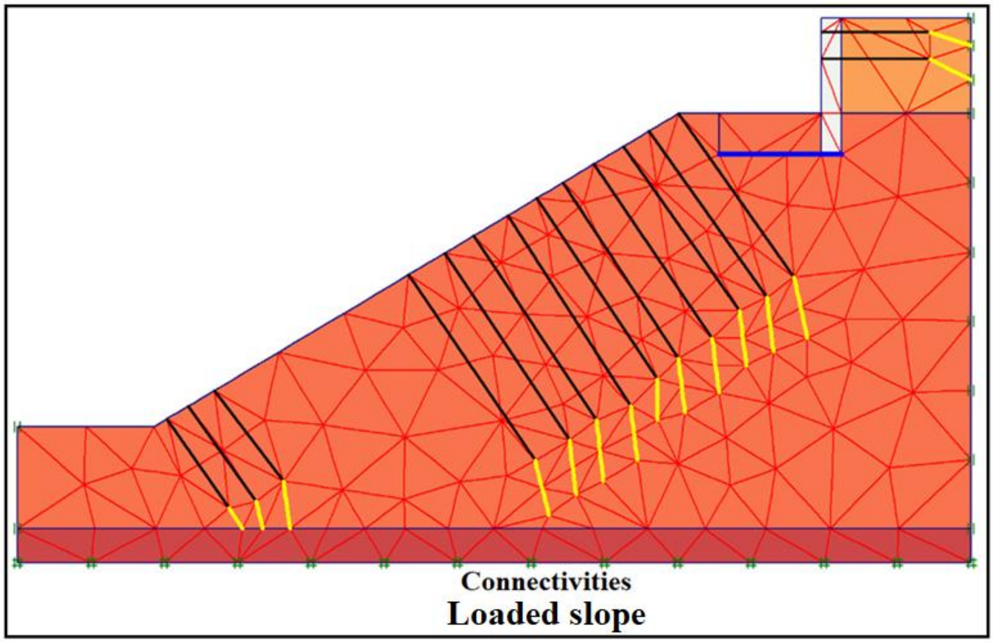

Figure 10: Slope mesh reinforced by anchoring

Initial conditions (generation of initial land stresses)

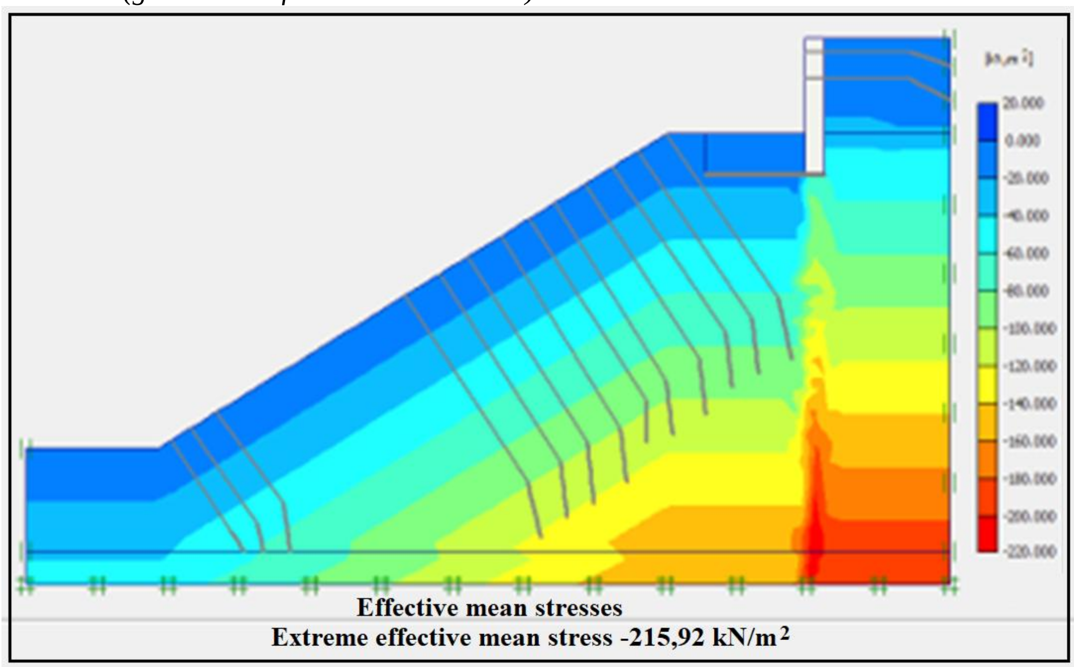

Figure 11: Total initial stresses distribution (-215.92KN / m²)

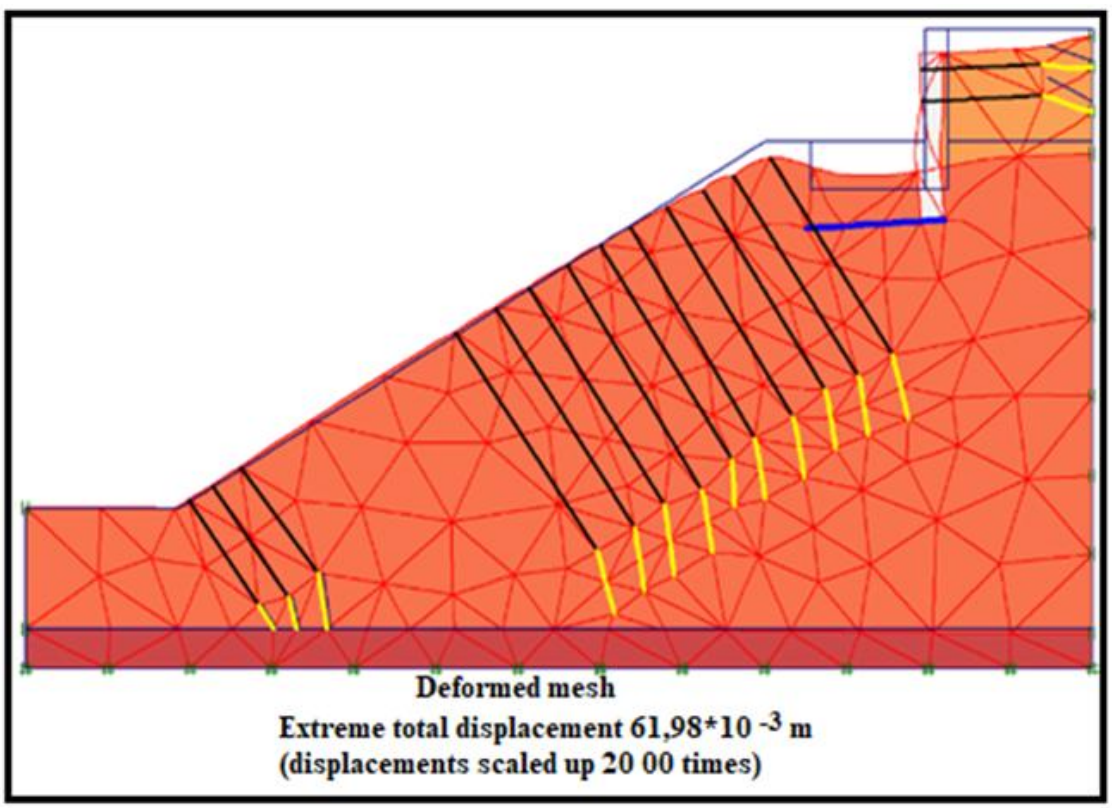

Figure 12: Deformed mesh

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Displacements of reinforced slope

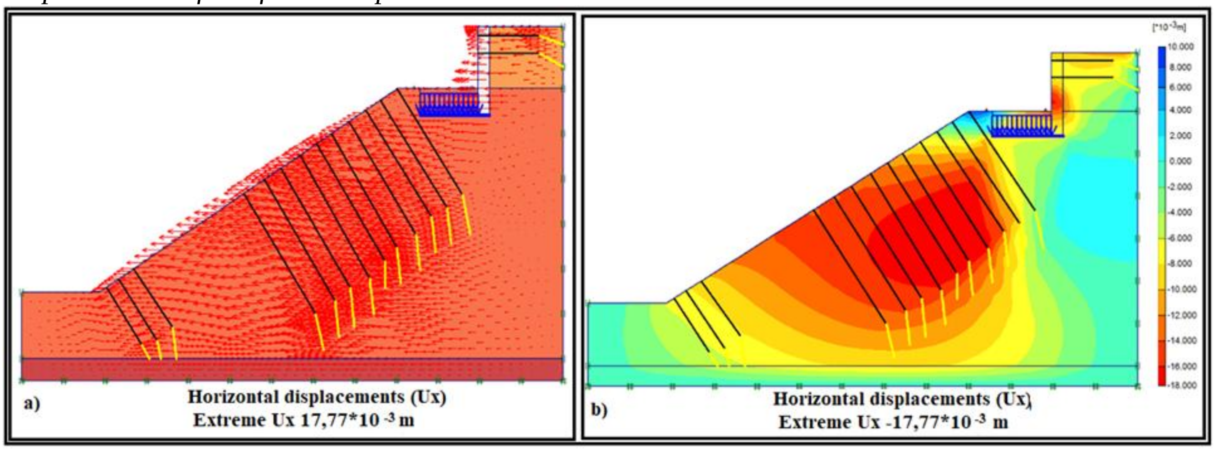

Figure 13: Horizontal displacements

The horizontal displacement is of $17.77.10^{-3}$ m (Ux = 1.77 cm) compared to the initial mesh after calculation. The arrows indicate displacements direction and intensity. Colors indicate stresses displacement areas.

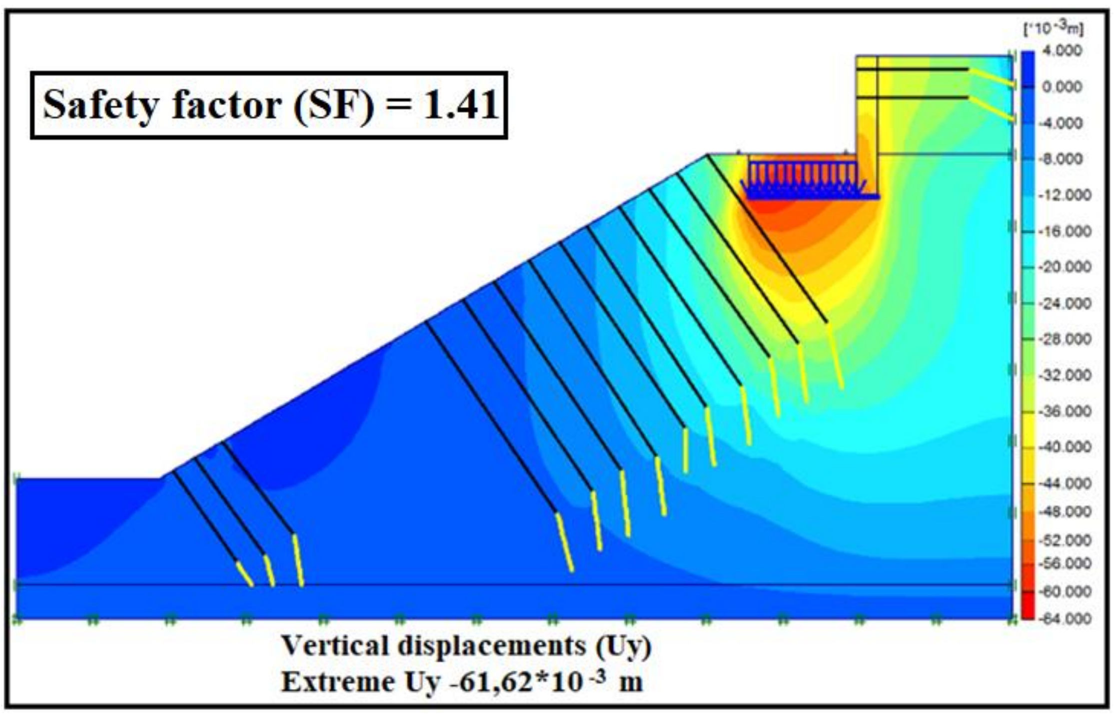

Figure 14: Settlement after reinforcement by anchoring

The settlement is 61.62.10-3 m (Uy = 6.16 cm) and the safety factor resulting from third phase is 1.41 (Figure 14).

Sheet pile wall system

Model geometry:

It was used the same geometric model. The reinforcement consists of a sheet pile wall system made up of six (6) sheet piles associated with the anchor-geogrid pair (Figure 15).

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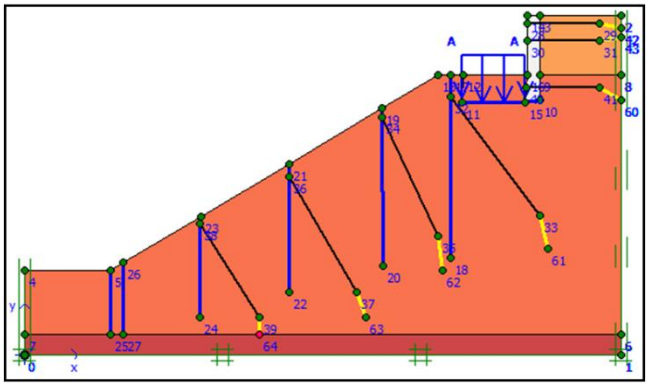

Figure 15: Slope model reinforced by a sheet pile wall system

Mesh generation

The total number of elements is (346) and the total number of nodes is (2881). The mesh fineness has been reinforced on "Medium" as shown in Figure 16.

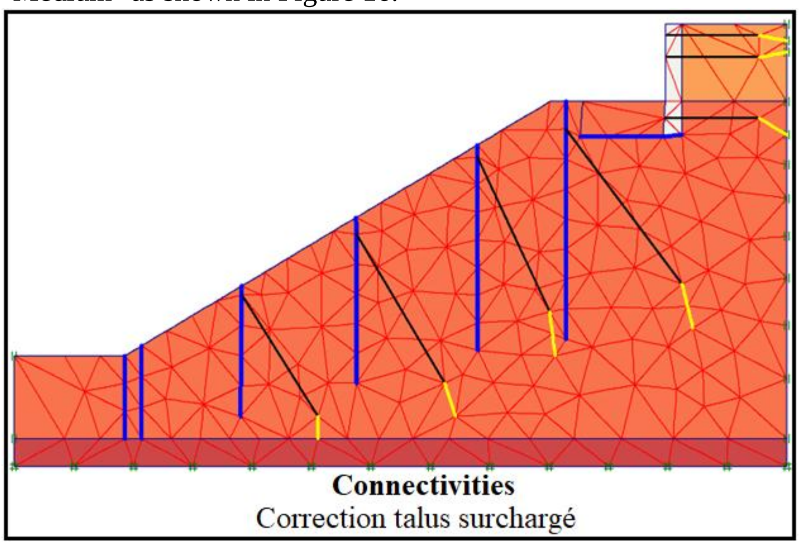

Figure 16: Mesh of the slope reinforced by a sheet pile wall system

Initial conditions (initial land stresses generation)

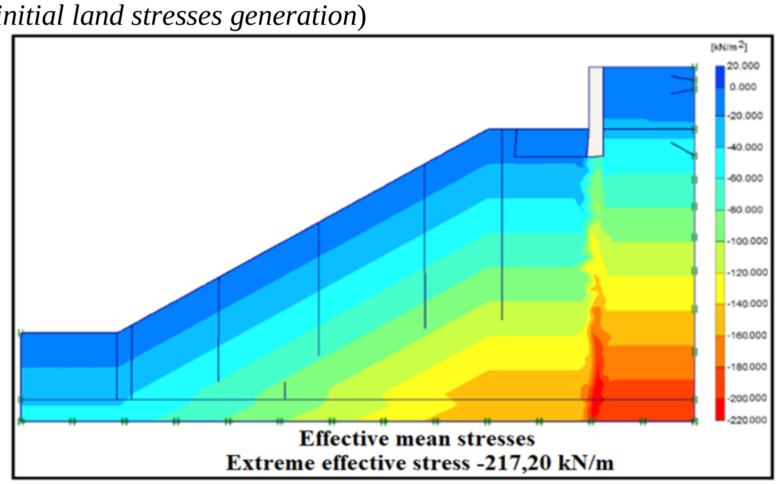

Figure 17: Total initial stresses distribution of the (-217.20KN / m²)

Procedure for calculating deformations, displacements and safety factor

The model remains more or less intact, showing the significant reduction in displacements and deformations within the slope (Figure 18).

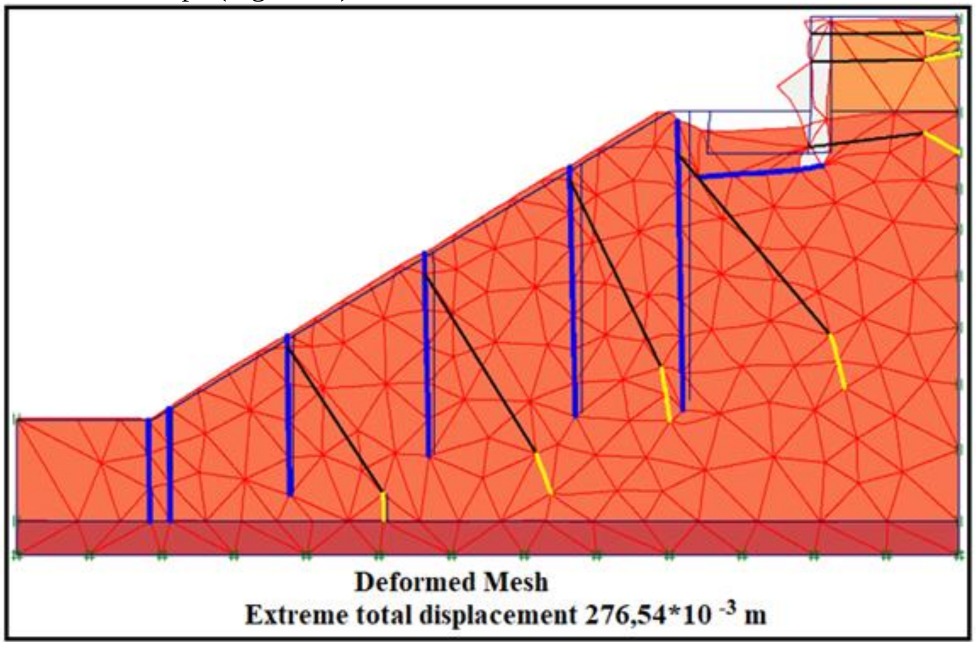

Figure 18: Distorted mesh

Total displacement:

After calculation, there is a settlement of 55.15.10-3 m (Uy = 5.52 cm) and a horizontal displacement of 14.30.10-3 m (Ux = 1.43 cm) compared to the initial mesh. The arrows indicate the displacements direction and intensity. Colors indicate stresses displacement areas (Figure 19).

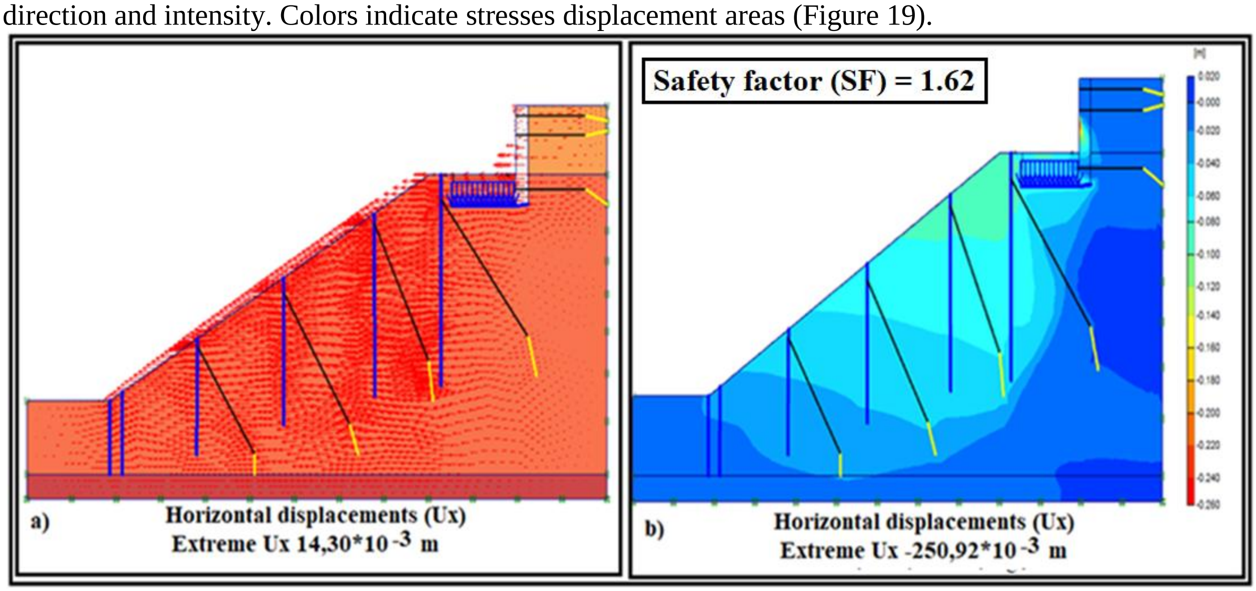

Figure 19: Horizontal displacement

Safety factor:

The safety factor resulting from the fourth phase of analysis is 1.62 (Figure 19).

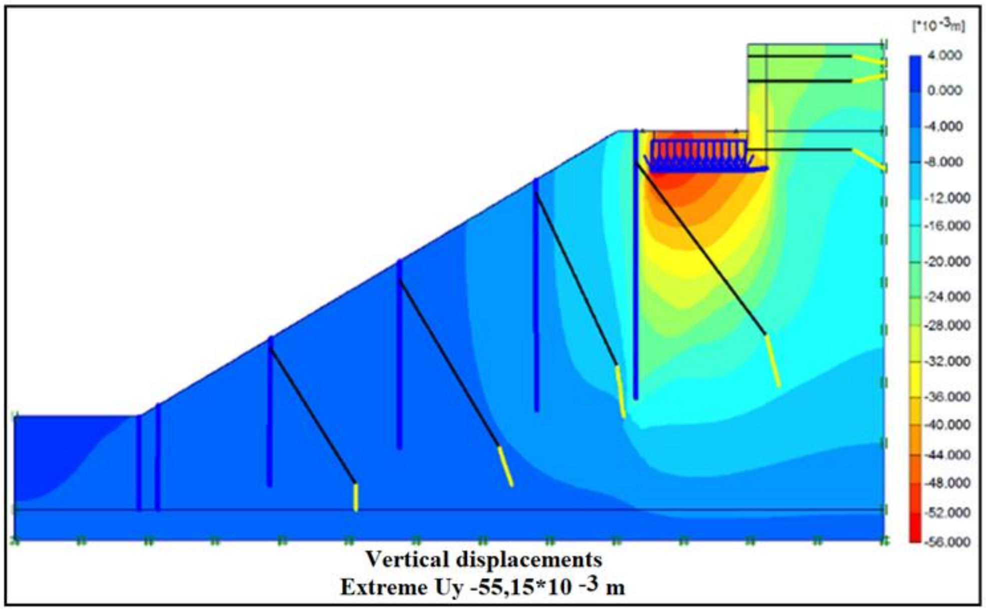

Figure 20: Settlement after reinforcement by a sheet pile wall system

Table 5: Summary of results obtained by the finite element method

Analysis phases (P)	Initial stresses (KN / m²)	Settlement Uy (cm)	Horizontal Displacement Ux (cm)	Safety security
P1: Slope loaded by the abutment (C3)	-204.04	21.73	16.90	0.93
P2: Slope reinforced by anchors	-215.92	6.16	1.78	1.41
P3: Slope reinforced by sheet pile walls	-217.20	5.52	1.43	1.62

Safety factors (SF)

Indeed, the stability analysis of the terraced slope with load gave a value of SF = 1.00. This value is low and less than 1.5 (Fs≤1 <1.5). This is due to the load applied to the top of the slope increases the sum of destabilizing forces or moments that cause rupture (Sibille, 2017). Thus, this analysis therefore highlights the slope instability in short-term and shows risk in long-term by the load brought by the abutment (C3) (G = 2870.47 KN/m^2). Therefore it will be necessary to provide a stabilization solution for this slope, in order to reduce the load influence and the slope rupture risk. It is in this perspective that through a simulation, it is proposed two (2) reinforcement solutions:

Reinforcement by anchors

After calculation, the analysis gives a value of SF = 1.41 (1.00 <SF<1.50). This value shows that the safety factor of the reinforced slope is assured, although it is moderately satisfactory. Therefore it is noticed an improvement of about 75.2% in the slope safety factor when it is reinforced with an anchoring system, each one equipped with a geogrid. For this purpose, anchors increase the stabilizing forces or moments which contribute to the slope stability.

Reinforcement by a sheet pile wall system

After calculation, the analysis gives a value of SF = 1.62 (SF > 1.50). This safety factor value shows a very satisfactory stability of the reinforced slope which is very close to that of the stable natural slope. Therefore there was a marked improvement of approximately 86.4% in the slope safety factor after reinforcement by a sheet pile wall system.

DISCUSSION

Previous verification studies on the Zanga Dia Bangombé bridge carried out by the RAZEL Company in 2020 show that the abutment (C3) resting in the slope was justified with regard to the bearing and overturning criteria according to the NFP 94-261 standard. Likewise, a sliding stability study under this support was carried out and it emerges that there is no sliding under the abutment (C3) because the minimum safety factor found was greater than 1.5 (SF_{min}> 1. 5). But, these studies were based only on the limit equilibrium method (Bishop, 1945) with the following hypothesis:

- Efforts weighting and parameters not were considered;
- The descent of loads is under basic ultimate limit equilibrium combinations;
- The embankment modelling not considered stresses.

While the present work showed a slope instability which is already manifested by failure planes along the slope although it is protected (Figure 2). So if it does not consider the proposed reinforcement solutions, this construction handiwork will risk collapsing because it runs a great risk of sliding.

CONCLUSION

One of the important points that emerges from this parametric study is the direct impact of the slope geometry, the sizing and the characteristics of the retaining structure which serves to reinforce and stabilize the slope. However, this research proves the opposite by stating that:

- Calculations showed the overloaded slope instability before reinforcement.
- Thanks to the finite elements method it was possible to distinguish the stress areas and the strong displacements where it must aim for reinforcement.
- Reinforcement by anchors, sheet pile walls and geogrids is certainly more stabilizing than reinforcement by a simple retaining wall.

This is the result of our experience and past experiences in the slope area on the right bank of the river bridge zanga dia ba ngombe, makelekele, Brazzaville which indicate that the best solution to counter the landslide is the anchors, sheet pile wall with geogrids.

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