

# Soil Reinforcement Methods for Environmental Protection of Slope Failure Against Landslides

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## To cite this article:

Kempena Adolphe, Obami Ondon Harmel, Boudzoumou Florent, Rafael Guardado Lacaba, Antonio Olimpio Gonçalves. Soil Reinforcement Methods for Environmental Protection of Slope Failure Against Landslides. *American Journal of Environmental Protection*.

Vol. 12, No. 1, 2023, pp. 11-17. doi: 10.11648/j.ajep.20231201.12

**Received:** December 8, 2022; **Accepted:** December 26, 2022; **Published:** January 10, 2023

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**Abstract:** Slopes are not stable due to the variations of slope gradient combined with the driving forces including the groundwater action, producing shear stresses in the slopes, which are contradicted by the soil shear strength. The slopes instability may cause the displacement of the mass of soil downstream recognised as landslide. Consequently, landslides are one of the most significant catastrophic phenomena observed on the earth surface. This phenomenon can be considered as a major concern on the social and economic point of view and for the quality of life of a local population, including also the environmental impact on the ground water level, blockage of rivers, road destruction, forests and ecosystems destruction, etc. Therefore, soil reinforcement has become one of the best forms of embankment protection against slopes failure. This work used soil reinforcement methods by using retaining structures, slope design with low gradient and vegetation cover to stabilize the embankment. The usage of the shear strength reduction technique was carried out to evaluate the stability of embankment slope. This process has tendency to reduce shear strength as rarer as failure is produced. This study is achieved along with pseudo-static and static methodologies. Varied parameters influence on the stability of slopes are revealed by accomplishment of many studies. To end, the Static method findings are acceded to comparison with the ones found by Pseudo-Static method. The results showed that the stability of reinforced slopes was reached and the slope can resist against landslides.

**Keywords:** Slope, Landslides, Environment, Impact, Landslides

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## 1. Introduction

Slope stability is one of the actual traditional and important subjects associated to geotechnical engineering, embankment engineering, dam engineering and landfill engineering. Because of the catastrophic consequence produced by slope failure, many reinforcement methods have been advanced, such as drainage systems, stabilizing piles, reinforcement of vegetation, among others. Because of its ecologically friendly features compared to soil nails, geosynthetics, retaining structures, gabions and shotcrete, the reinforcement of vegetation, such as grass and shrubs, on the

slope stability, has been gradually recognized as well, and there are a cumulative number of slope protection engineering with vegetation grew on the slope in current years. In fact, vegetation-soil interaction and plant-soil-atmosphere interaction are slightly complex, therefore the mechanism and efficiency of vegetation reinforcement on slope stability are important and it has engrossed much attention of academics.

The word landslide refers to the downward movement of a mass of soil caused by gravity action. The landslide occurrence depends on the shear stresses development inside the soil when they exceed the soil strength. Landslides causes

can be associated with liquefaction of layers of fine grain of because of a general failure, considering the increase of loads from earthquake occurrence which increases pore pressure and reduces the soil shear strength [1].

In general, the Congo Republic with a complexity of geological structure and tectonic stress, in the past time and now has suffered and still suffers always from the destructive effects of these phenomena [2]. Therefore, it is necessary to evaluate the slope stability in order to develop techniques which are able to solve this problem. Then, it is also indispensable to know about the effects or impacts caused by landslides and the failure mechanisms they present as well, in order to go on with the slope stability analysis and the computation of an adequate factor of safety.

Slopes problems is often noticed in Congo republic mostly in the northern region of Brazzaville City. Buildings are ruined by land movements each year. Manifestation regularity of this disaster is up during the rainy periods. Everywhere 70% of the total rainfall in Congo Republic takes place in rainy season. Hence, landslides event is more concentrated in this rainy period [3]. Construction works accompanied by deforestation of friable soil found on steep slopes is the origin of slope insecurity and the complex tectonic features existing in City as well. Among all the damages produced by slopes instability in Brazzaville City, 45% of losses is found in mountain areas [4].

Slope stability Analyse remains one of the main subjects in environmental engineering because of particular slope behaviour when earthquake occurs, and its modest application has been advanced rapidly in current years. So, some approaches have been expressed for slopes stability analyse. The limit equilibrium approach is one of the more widespread methods for slopes stability analyse [5]. This method uses horizontal constituents, in its place of vertical constituents for studying slope soil stability. The vertical constituent's technique collects forces that not appear among constituent's boundaries. Various methods are based on defining critical slip surface [6, 7]. The Rectilinear slip surface is considered for the slope's stability analyse by using limit equilibrium approach. Deplorable findings of rectilinear slip surface made scientists advise other types of sliding surface. Among optional slip surface tactics, log-spiral slip surface can remain as one of the utmost precise and valid methods. Additional uncertainties of studying stability of slopes by limit equilibrium approach is the non-existence of distortions estimation occurring on the time where the soil behaviour on slip surface is supposed to be stiff and plastic. Moreover, the limit equilibrium approach, other techniques counting numerical codes for example Finite Element and finite difference methodologies, the stress conditions method and other advantageous methods were applied as well, respectively [9-13].

Some problems found in slopes stability study is modelling the forces produced by earthquake. But, some simulations were performed using pseudo-static approach earlier. Moreover, vertical forces produced by earthquake has been ignored in some prior studies [14]. In the current study, the

shear strength reduction technique is used for slope stability from finite element skill. Currently, the shear strength reduction approach has been advanced significantly than earlier. Supremacy of this technique to limit equilibrium approach has advanced this approach and various software. In this research work, stability of slope was performed by using static approach and considering seismic forces. The modelling of seismic forces was carried out using pseudo-static approach. Modelling remained achieved using Plaxis 2D software. Factors of Safety were determined in different methods and the soil parameters effects on the stability of slopes were assessed as well. The outcomes were before succumbed in comparison with the ones found by others authors from modelling implemented over Finite different technique.

## 2. Material and Methods

Study of Case (Figure 1).

In general, determining factor of safety for a slope is considered as quantity of soil shear strength to the minimal shear strain necessary for producing initial failure. Into shear strength reduction tactic, soil shear strength is progressively reduced by using finite element software given that the principal signs of failure are perceived. Factor of Safety is computed as the value of reducing shear strength. The method of shear strength reduction remains impressive to the other approaches studying stability of slopes [8]. Its improvements stay in the requirement to largely estimate the critical slip surface. This method assesses the stability of slope using the technique of shear strength reduction, and the modelling performance uses a ratio of safety factors as experimental error. This method evaluates the stability of slope as soil resistance properties like this:

$$C^{trial} = \frac{1}{F^{trial}} C \quad (1)$$

$$\varphi^{trial} = \arctan\left(\frac{1}{F^{trial}} \tan\varphi\right) \quad (2)$$

Where  $C$  is the cohesion and  $\varphi$  the angle of friction considered as reduced strength parameters of soil correspondingly to the actual method ( $C$ ,  $\varphi$ ). As can be shown from Equations 1 to 2, the increment in factor of safety reduces the strength parameters of soil and make the slope stable. Obviously, larger factor of safety means considerably more predisposition of a slope to remain stable against destabilising forces and avoids landslides occurrence.

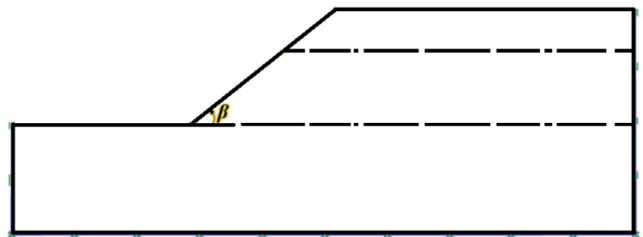


Figure 1. Slope model.

### 3. Results

#### 3.1. Slope Stability Analysis

A slope with less cohesive soil of 5 m height was erected above a cohesive soil's bedrock with 7 m of height (Figure 1). Table 1 illustrates physical properties of soils strength. The filling was erected in 3 weeks and 5 days. The modelling of soil slope was carried out by using Plaxis 2D software and the model agenda is in sequence method.

The filling analyse along x direction was fixed with zero displacement. The inferior boundary of filling along x and y directions was fixed as well. The modelling of soil comportment was carried out by elasto-plastic model and

Mohr–Coulomb perfect. Table 2 outlines the outcomes found from slope stability study with different values of friction angle and cohesion with 5 m of groundwater level for distinct values of slope gradient ( $\beta$ ). The findings indicated that safety factor of slope decreases with the increment of slope angle and slope runs a higher sliding risk. Table 3 illustrates the outcomes found from slope stability study considering the slope angle and groundwater levels for distinctive angles of friction ( $\phi$ ). The findings of Table 3 indicate that the friction angle increment contributes to the safety factor increase and supplementary stability for the slope. Table 3 analyses the groundwater level influence on the stability of slope.

Table 1. Properties of soil parameters.

Parameters	Unit	Soil types		
		1-Sand (SP)	2- Sandy Clay (SC)	3- Organic clay (CL)
		Drained condition	Un Drained condition	Un Drained condition
Unit weight ( $\gamma$ )	(kN/m <sup>3</sup> )	17	15	12.50
Saturated unit weight ( $\gamma_{sat}$ )	(kN/m <sup>3</sup> )	21	19	16
Cohesion (c)	(kPa)	1	5	10
Friction Angle ( $\phi$ )	(°)	32	21	-
Elasticity Modulus (E)	(MPa)	100	25	18
Poisson's ratio ( $\mu$ )	-	0.3	0.25	0.5

Table 2. Safety Factor versus slope gradient.

Angle of slope, $\beta$	Factor of Safety, FS
10	1.61
30	1.35
50	1.12
70	0.67
90	0.54

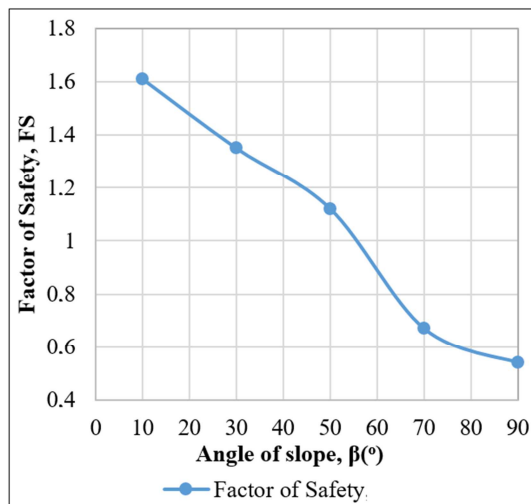


Figure 2. Safety Factor versus slope gradient.

Table 3. Level of Ground Water vs Factor of Safety.

Level of Ground Water	Factor of Safety
0	1.89
1.25	1.84
2.5	1.61
3.75	1.41
5	1.14

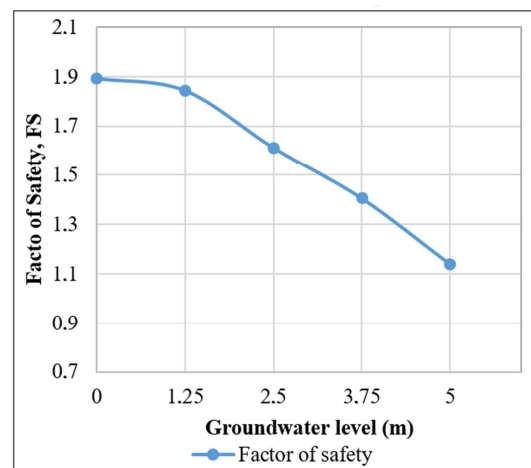
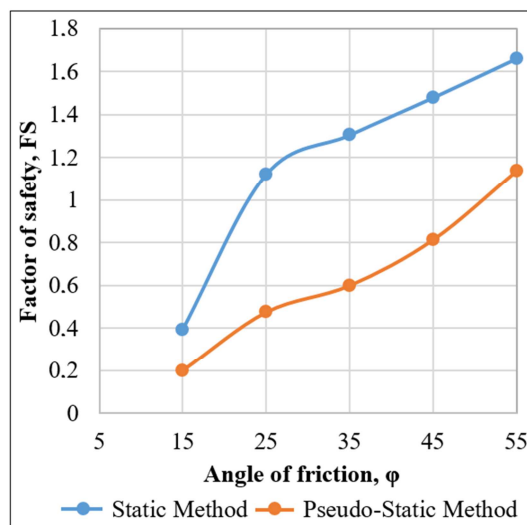


Figure 3. Safety Factor versus groundwater level.

Table 3 and Figure 3 show findings along with the increase of groundwater level, decreasing the safety factor and conducting the slope to higher sliding risk. The outcomes reached until now have been found from the analysis of slope under static approach without seismic force influence on the slope. But, as much as we discern, the majority of slopes instabilities are produced under an earthquake influence. Therefore, it is indispensable to understand the seismic forces modelling.

Certain standards are used in pseudo-static approach for shortening computations; such as: neglecting time, neglecting difference of stage, and neglecting oscillatory behaviour of earthquake. Even though the illusory expectations of pseudo-static technique in seismic study for slopes, but recurrent applications offer satisfactory outcomes for a short time. At

this point, the modelling considered seismic forces in a pseudo-static routine. Horizontal and vertical acceleration coefficients ( $K_h$ ) and ( $k_v$ ), were used with values of 0.2 and 0.0, correspondingly. Computations were performed considering different values of slope angle and angle of internal friction including 5 meters of groundwater level. Table 4 and Figure 4 make comparison of the results found once a slope is under the seismic forces influence applying pseudo-static approach then the results found using static method without seismic forces influence on the identical slope. According to the outcomes of Figure 4, the slopes below the influence of seismic forces produced factor of safety inferior to the static method, which shows minor slopes stability under seismic approach. Now, we analyse the slope stability with 12 m of height and  $55^\circ$  of friction angle by the Finite Element Code using Plaxis 2D.



**Figure 4.** Safety Factor from Static and Pseudo-Static methods using Shear-Strength Reduction technique.

**Table 4.** Safety Factor from different methods.

Angle of friction	Static Method	Pseudo-Static Method
15	0.39	0.20
25	1.12	0.48
35	1.31	0.60
45	1.48	0.82
55	1.66	1.14

The slope analysis carried out, identified and classified the environmental impact of the embankment failure as follows: the embankment failure changed the usual river functioning and caused substantial changes in hydrology and downstream flowing waters in the study area, and in the sediments transport as well. This change may produce important changes to the existing ecosystem before the embankment failure occurrence in the site.

### 3.2. Proposition of Measures for Protection and Stabilization of the Embankment

The embankment protection measures proposed are based on the rationality of instant rehabilitation and are considered

insignificant intervention. They include retaining structures, design of slope with low gradient, usage of benching and vegetation cover, especially the vetiver grass in combination with a site drainage system to collect and remove both surface - rain and underground rainwater [15].

#### 3.2.1. Restraining Measures

A precondition for an adequate retaining system construction is based on the geotechnical survey which takes care of the presence or absence of loose or soft soil materials with potential instability problems during the excavation construction of the retaining elements. But also, the existence of extremely permeable soil layers such as sands and gravel and the existence of underground aquifers and its level.

#### 3.2.2. Support Measures

Geogrids may be used to substitute a natural arming materials. They reinforce the granular layers for the loads distribution in arrays of piles. They are also use as anti-erosion protection of unstable soils, in natural or artificial slopes. For economical reasons, it is often important to reinforce slopes for achieving the stability state. So, it is conceivable the usage of soil materials with lower quality to help a design project by reducing significantly the environmental impact, creating supple structures with the slightest probable site occupation. The main benefits of geogrids usage is environmentally approachable, preventive intervention in environmentally sensitive sites. They reduce the quantity of essential soil materials and permit the usage of nearby accessible soil materials with simple and quick construction. They also produce a significant reduction in the granular material thickness without loss of resistance and improve the embankment condensation and the control of differential subsidence.

#### 3.2.3. Plant-Cover

Plant cover constitutes the last phase of a slope treatment, especially associated to surface, layered slides. Slopes showing profound sliding levels are not intercepted by vegetation roots, but this contributes to reduce the infiltration of the surface water in the slope and consequently participates into the slope stabilisation. When the vegetation is grown it protects the slope against erosion and facilitates the flowing waters as well. Even though, it is very difficult for plant to grow on dry soils in different types of regions, but, generally, in the time it adapts easily to the environment [16]. Profounder slopes stabilisation is reached by using trees with extensive deepness roots into the ground combined with anchors system. The degree to which vegetation in reinforcing the slopes stability is mostly dependent on the roots percentage in the soil and the roots distance associated to soil formation [17].

#### 3.2.4. Slope Stabilisation by Using Biological Engineering

There are many methods used to stabilise unstable slopes by using biological engineering, so in the present work these methods are: Hand seeding, bush-mattress construction, clusters, fence planting, cluster fences, seedling planting,

straw crushing, seed layers, hydroseeding, erosion control-geotextiles, long brush barriers, branch blades and woodfences [17].

## 4. Discussion

Despite the role played by retaining structures in the landslides stabilization, the addition of vegetation certainly increases the slope stability of the embankment in this engineering situation because of the existence of the roots in soils, though, the increasing percentage is relatively low, which is mostly different from that in [18]. The increasing percentage of safety factor can be even high closing to 17% for the matured vegetation reinforcement. This kind of difference can be caused by different mechanisms of slope failure. For the slope in [19], it would have tendency to be a failure with a shallow sliding surface, and the vegetation roots increase the soil cohesion around the potential sliding surface, which in turn makes the sliding surfaces modification profounder under the ground surface. As a consequence, the slope safety factor significantly increases because of the vegetation reinforcement. Whereas for the slope in this real case, the probable sliding surface is in a quite profounder position, which is past the extent of the root sector. Consequently, changing the type of vegetation give the impression to not contribute to a huge increase in Safety factor. In order to guarantee the efficiency of vegetation reinforcement, the roots of the vegetation must cross the probable failure areas. Furthermore, to avoid the slope failure, the cohesion addition because of vegetation roots in the potential failure areas must be necessary to resist the soils failure in these areas.

Given the spatial changeability of the soil strength parameters, using minimum soil strength parameters plainly undervalues the security of slope, whereas using average soil strength parameters may overvalue or undervalue the slope safety. That is, the dependability of the slope safety is substantial to give a rational and scientific assessment of the slope stability. Likewise, the cohesion addition of soil because of vegetation reinforcement is reliant on the roots density, the roots length, the soil porosity and other inducing factors, which leads to the comparatively higher spatial consistency of the cohesion addition when considering vegetation reinforcement. Therefore, the variability effect of the cohesion addition because of vegetation reinforcement would also be considered through the analysis and assessment of the slope stability. The consistency of the stability of the traditional slopes has been studied by many academics, though the related studies on the consistency of vegetation reinforcement on slope stability are silent rare, which should be given more care in the upcoming.

Really, the vegetation effect on slope stability is not only reliant on the cohesion addition of roots on soils but also predisposed by the change of water seepage path due to the existence of root systems [20]. It has been documented that the soil permeability was dependent on the vegetation root age, and matured or decaying roots usually amplified the soil

permeability [21].

Laboratory results specified that vegetation roots also influenced the behaviors of water retention in the soils [22]. Furthermore, soil suction can be changed because of the greater evaporation produced by vegetation roots, particularly on summer days [23]. Thus, in the situation of rainfall, the vegetation roots may affect the water flow; whereas in the situation of dry weather, the dampness may be captivated by the root for its growth. Both of the above-mentioned situations will make the restructuring of the humidity compared to that without vegetation, which in turn changes the pore water pressure distribution, capillary pressure, and eventually affects the effective stress of the soil matrix [24]. Then, slope stability is essentially determined by the effective stress of the soil matrix within the slope, therefore those factors can certainly affect the slope stability when it comes to vegetation reinforcement. Capobianco, et al. [25] have assessed the vegetation reinforcement using SEEP/w by considering both the cohesion addition and the potential evapotranspiration, which offers a practicable way to consider the coupled hydro-mechanical reinforcement of vegetation. Even if permeability change because of vegetation roots has also been included to study the reinforcement efficiency on soil slope stability [26], more inquiries on the permeability change because of vegetation roots should be conducted to further quantitative label their relations. Globally, the vegetation roots effect on the moisture content distribution is much less, while some academics have just studied the coupled interaction between the soil, humidity and vegetation roots [27]. Furthermore, the experimental results confirmed that the integrated friction angle increased up to a maximum value of 40 degree because of the presence of vegetation roots [28]. Later, the effect of vegetation on slope stability must be more studied in a more general way which must take not only the root effect on cohesion addition of soils but also the dampness redistribution because of the existence of roots, as well as their relationships with root profiles [29].

## 5. Conclusion

The present study carried out determined certain aspects of the slope behaviour such as: slope stability study using the method of shear strength reduction managed to particular humble analyses producing satisfactory outcomes.

Considering the increase of slope angle with the factor of safety decrease, the slope runs to more devastations.

The increment of angle of internal friction for a filling conducts to slope in a stable state. While, the groundwater level determines the increase of slope failure risk in part.

The safety factors findings from static method are higher than the ones obtained from pseudo-static approach. Reduction method of Soil shear strength makes deductions of distortions produced on the time.

The landslides probability considering the effect of earthquake inertia forces is contingent with landslides may have wide social and economic costs, then, except the



financial load because of the technical work collapse or of then transportation interruption, it is frequently escorted by the natural environment degradation and the loss of human lives.

The antiseismic design of slopes and embankments is a main question at a world-wide level, largely owing to the environmental and economic impacts of their failure.

The environmental impact resulting from slopes and embankments failures are primarily the momentous impact on factors and variables of the natural and man-made environment that conduct to deforestation, desertification and extinction of biological species, as many endemic species are particularly sensitive to disturbance.

The landslide occurrence reduces the biodiversity because of the habitat destruction, water pollution and disturbances in the flow and natural environment of streams in the failure occurrence in embankment slope.

Using average or minimum soil strength parameters may overvalue or undervalue the slope safety due to soil parameters the variations in spatial. It is essential or important that using random field and consistency theory for the slope stability assessment. The spatial variability of the additional cohesion because of vegetation is similarly expressive to judiciously assess the slope safety.

The vegetation addition certainly increases the slope safety, whether the slope is under a dry condition or a rainfall condition. In practice, the vegetation reinforcement design must be evaluated in advance.

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