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Embankment Stability Assessment in the Mfilou District (Brazzaville-Congo)

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Abstract: Embankment failure is a common problem in Congo Republic. Almost each year in northern part of Brazzaville City embankments are facing problems such as rupturing or landslides. Among several reasons the main causes are considered because of geologically unstable materials, inadequate method of building, seepage and sliding. The current study aims to evaluate the effect of load and influence of topographic parameters such as the gradient and height of the slope on the road embankment stability with sandy landfill in the Mfilou district, Brazzaville City (Congo republic). The evaluation of the road embankment slope stability and the discovery of the implications of topographic parameters on the embankment safety management were carried out in a hilly area. A database was created based on the site inventory from field studies complemented by experimental and desk investigation. The soils properties and values of topographic parameters were incorporated to the embankment slope model as well. So, the slope modelling was carried out in different scenarios such as different slope heights, different slope angles with and without load effect. Then embankment stability was analysed with Slide 6.0 software finding slip surfaces from limit equilibrium methods. Results showed that despite the slope instability caused by the load effect, but the variation of topographic parameters affects the embankment stability as well.

Keywords: Slope Angle, Slope Height, Limit Equilibrium, Embankment, Load, Brazzaville

1. Introduction

Roads support our quotidian life, and have a crucial role in the infrastructures for economic activities. Though, road catastrophe may be produced by diverse natural conditions of slope ruptures for example rainfall, abrupt topography, and geological conditions variation [1]. Roads infrastructures can easily be affected by natural or practical problems initiating instability. One can evaluate carefully in such a way that could certainly describe the instability mechanisms, the dangerous areas, and perhaps the corrective measures for the affected sectors.

In road engineering, failures could be started by natural risks or deficient site studies, characterised as practical problems [2]. Then to minimise the above declared problems that can be produced during the construction phase, it is vital to pay attention to the sectors which are disposed to slope instabilities and to provide corrective actions to those areas with undesirable effects on the road project to guarantee the envisioned road serviceability. In other terms, the stability study of the embankment by using limit equilibrium methods will identify the unstable areas, and can help to minimise the socio-economic effects caused by the embankment risks [3].

The embankment adversity incidences do not first cause the main catastrophe from the infrastructure point of view; but also the interference to the humanity and the economic activity. In order to mitigate such embankment ruins produced by different reasons; actions can be engaged in each stages of construction, commonly full study about the superficial geology, the subsurface situations and the construction materials. Therefore, full study on the site is required before beginning the project to provide the envisioned service of the embankment.

The term slope mentions every natural and manmade slopes. Examples of manmade slopes contain embankments, earth dams and cuts. Slopes stability evaluation remains one of the first problems confronted by geological engineers [4]. An appreciative context of topography, geology, hydrology, and properties of soils are vital to apply suitably criterion related to slope stability. Analysis can be founded on a model that perfectly signifies topographic aspects of the site, subsurface conditions, behaviour of ground, and applied loads. Decisions concerning suitable risk or factors of safety can be taken to evaluate the results of studies. These studies are commonly made at the beginning, and occasionally during the projects planning, design, construction, development, restoration, and maintenance [5].

Limit equilibrium method is used broadly for stability study in practice because of its dependability for most applied cases. Its simplified method may be only used in the initial evaluation whereas more complex study that contributes to more perfect results can be made with computer programs [6].

It is important to recognise that many engineering structures are frequently constructed close to slopes. Therefore, it is vital to evaluate the stability of a slope which is exposed to the supplement load as engineering structures. Then, the slope stability analysis remains a complex issue due to the spatial variability on topographic parameters and the intrinsic properties of natural geological materials. Such characteristics are often modified by many factors such as weathering and erosion processes, transportation agents, and sedimentation conditions [7].

In addition, the characteristic spatial variability of soils including topographic parameters, from imperfect test equipment or procedural-operator errors could affect the estimation of soil properties and slope analysis. The slope stability analysis being always one of the most attended problems, it seems to also be more attractive in existing studies. In the context of geological engineering, embankments constructions are often accompanied the road's projects. When the site presents a hilly relief with steep and unstable slopes, landslides have tendency to occur [8]. These landslides as natural phenomena are among the most common and often the most serious geodynamic phenomena on the earth's surface with very diverse and often catastrophic origins. They are considered among causes of slopes instabilities. Apart from damage to structures they can also cause, an economic impact on certain projects for which preliminary studies have not been sufficient. Stability analysis in face of a failure risk of an embankment slope is a complex issue. Embankment study involves the identification of topographic parameters of the site and soils mechanical characteristics. This is followed by embankment stability calculation to determine the failure surface where the risk of sliding is the highest. Some landslides can be seen as a site natural evolutionary process. However, it should be noted that landslides can often be triggered by human action, such as some works with modification of the original topography of the site interrupting the natural balance and cause rupture in already stable site [9].

In Brazzaville city landslides are one of the largest classes of natural phenomena and the least studied from a mechanical point of view. Their locations, their varieties of forms, their manifestations and their damaging effects have become a major concern for humanity, but also for the national economy [10]. The embankment stability analysis is generally based on the safety factor notion against sliding. This safety factor defines a potential slope stability under different conditions. So, for some work carried out with local materials, the slope safety has to find the following condition:

$$\mathrm{F}_{effective} \geq \mathrm{F}_{eadmissible}$$

In embankment fortifications, an admissible coefficient of safety is considered as:

$$\mathrm{F}_{eadmissible} = from\ 1.3\ to 1.5$$

Many limit equilibrium methods consider the general rigid body equilibrium, others separate the body in bands and study the equilibrium of all slice. Limit equilibrium methods are founded on some assumptions for the inter-slice normal and shear forces, and simple difference using these methods to understand how these forces are found or presumed [11-15].

In this work, the load effect on the embankment stability in a simple and homogeneous soil is investigated, and considering the variation of topographic parameters such as the height of slope and the angle of slope particularly. A characteristic slope model is studied using limit equilibrium methods, to evaluate the load effect on the embankment stability under different conditions with the aim of reporting results.

2. Materials and Methods

Before all construction activity, the site characteristics are essential. The study considered geographical, topographical and geological aspects of the site.

2.1. Study Area

The study area is located in north-west of Brazzaville City in the Mfilou district, Congo Republic. The embankment considered in the present study is located in Figure 1.

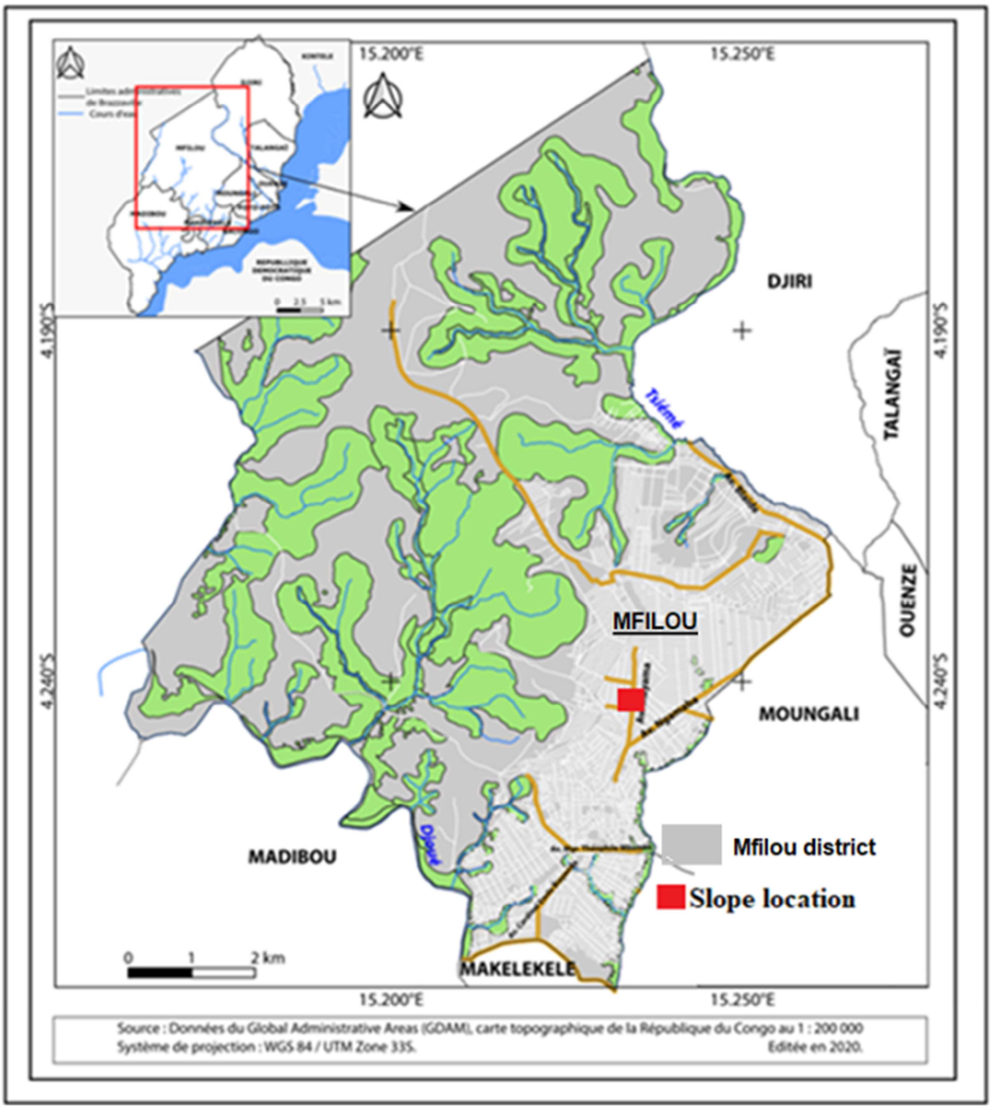

Figure 1. *Study area location.*

Morphological complex of the study area can be considered mostly into three main physiographic subdivisions: flat, valleys and hilly terrain. The study area has a maximum elevation of 980 m above mean sea level and a minimum elevation of 360 m above mean sea level. The highest section of the study area is a hill situated in the North of the Mfilou frontier, about 980 m above mean sea level. The southern section of the Mfilou district is the Mayama-Mfilou at an altitude of 560 m above mean sea level [16]. The main drainage mechanism of the area, is in a southerly direction (Figure 2). This type of drainage was caused from the floodplain of the Mfilou covered by eroded sites. Concentration of surface flow is observed in Mfilou River that runs over an important part of the site to the Djoué River. The study area is part of the hydrogeological group of the Bateke's water table, with an area of 270 km^2. The climate is tropical with a long rainy season from October to May, interrupted by a small dry season from January to February and another long dry season from June to September. The annual rainfall is moderate and constant, oscillating between 1250 mm and 1350 mm/year. We can distinguish soils formed on polymorphic Bateke's sands with different fines content. These soils are generally silty sand and poor in organic matter. The geological background is made from a Precambrian to Paleozoic age formation that supports a Mesozoic to Cenozoic sedimentary cover being unconformably above a Precambrian basement. Therefore, the Precambrian to Paleozoic basement is observed downstream from the Stanley Pool and the sedimentary cover with sandy materials outcropped upstream from the Stanley Pool [17].

2.2. Slope Stability Study

2.2.1. Topographic Attributes

The topographic data include a digital elevation model of 1 m resolution produced from 5 m contour in the 1:5.000 topographic sheet of Brazzaville map, produced in 2010. The topographic attributes obtained were slope shape, slope height and slope angle by using Surfer and ArcGis software. Slope sharp was computed and values of curvature were reclassified as concave, flat and convex [18]. Then, the curvature is convex, if $n < -0.1$, the curvature is flat, if $-0.1 < n < 0.1$, and the curvature is concave, if $n > 0.1$ (Figure 2).

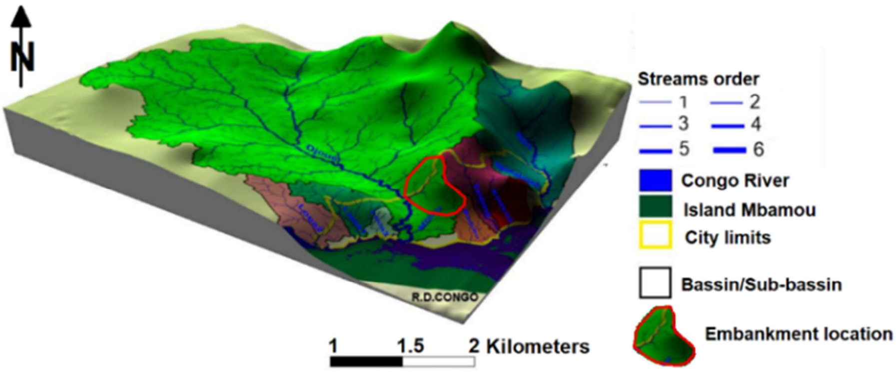

Figure 2. *Topographic aspect.*

2.2.2. Limit Equilibrium Methods

Limit equilibrium analysis is a vulgarization of the further rigorous limit theory, and has become the favourite method for repetitive slope stability study in soil mechanics. In limit equilibrium study, the slip surface can be assumed. Generally, the shear strength of the material is defined by the criterion of Mohr-Coulomb. No one of the basic equations of continuum mechanics concerning equilibrium, deformation and particular behaviour are satisfied absolutely. The material deformation is not considered at all, and the equilibrium condition is generally satisfied merely for forces. The exemption is a circular sliding surface in a cohesive soil with an angle of friction equal to zero ($\phi=0$), in Mohr-Coulomb materials, which produce a higher bound solution. Though, the higher assured solution is not conventional, and judgments with lesser assured solutions are insufficient. In the investigation carried out by Ireland [19], both lesser and higher bound solutions were comparable with results from limit equilibrium study. It was noticed that limit equilibrium method produced perfect outcomes for homogeneous slopes, however miscalculated the heterogeneous slopes stability with low angles of slope. In the modest form of limit equilibrium method, only the forces equilibrium is satisfied. The amount of forces acting to produce sliding is compared with the amount of the forces to resist failure. The ration between these two sums of forces is defined as the factor of safety (FS):

$$FS = \frac{\sum(Resisting\ forces)}{\sum(Driving\ forces)} \quad (1)$$

The safety factor can also be expressed as a ratio of the real cohesion or slope friction angle and the cohesion or friction needed for slope to be in stable state [20], or with consideration of terms of resisting and driving moments, for the circular analysis of shear failure. A factor of safety less than 1.0 shows that failure is probable. If there are different modes of potential failure or different sliding surfaces that were computed factors of safety less than 1.0, in this case the embankment can fail. It is significant to understand that the limit equilibrium condition severely means that the one permissible safety factor is 1.0 at this moment, the resisting and driving forces or moments maintain the balance on the slope each other.

2.2.3. Slope Stability Study

The analysis method consists of entering the topographic and soils parameters into the Slide 6.0 software in order to detect the failure surface which corresponds to the state of the soil limit equilibrium with a corresponding factor of safety (FS).

2.2.4. Methods of Calculating the Safety Factor

The safety factor calculation to assess the embankment stability has been done by the slice method known as limit equilibrium methods. The slice method is a method which consists in dividing the area into several vertical slices and considering equilibrium forces or equilibrium moments in the safety factor calculation. In this study we used the Bishop Simplified, Spencer and Janbu Simplified methods for the safety factor calculation.

(i). Slice Method

In this method the potential failure surface in the section is assumed to be a circle arc with a center O and a radius r. The soil mass (ABCD) above the failure surface (AC) is divided into slices of width and b is the height, h is the measured height on the center line and inclined at an angle α with respect to the horizontal as shown in Figure 3.

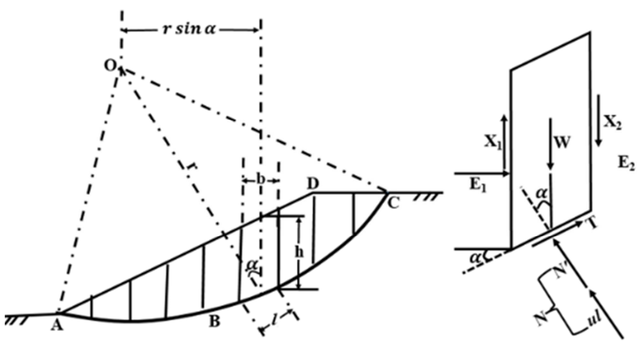

Figure 3. *Forces acting on a slice.*

The analysis is based on the use of a safety factor (FS) defined as the ratio of the available soil shear strength (τ_f) over the minimum shear strength [14] required to maintain the limit equilibrium (τ_m). The safety factor is considered to be the same for each slice which implies that there must be mutual support among slices. Then the forces acting on a slice are:

1) Total weight of the slice, W = γ_{bh} (γ_{sat} if applicable);
2) Total normal force on the base, N = σl in general, this force has two components: the effective normal force N' (equal to $\sigma' l$) and the limiting water force U (equal to ul), where u is the pore water pressure at the center of the base and l is the length of the base.
3) Shear force on the base, T = $\tau_{m/}$;
4) Total normal forces on the sides, E_1 and E_2;
5) Shear forces on the sides, X_1 and X_2.

Any external forces should also be included in the analysis. The problem is statically indeterminate to obtain a hypothesis solution. It must be done concerning the intercalary forces E and X. In general, the resulting solution for the safety factor is not exact. If we consider the moments around O the sum of the shear forces moments T on the rupture arc AC must be equal to the soil mass moment ABCD. For any slice the lever arm of W is r sinα and therefore:

$$\Sigma T\ r = \Sigma Wr \sin\alpha;\ T = \tau_m l = \frac{\tau f}{F} l;\ \Sigma \frac{\tau f}{F} l = \Sigma W \sin\alpha;\ F = \frac{\Sigma(\tau f) l}{\Sigma w \sin\alpha} \quad (2)$$

For an analysis in terms of effective stresses:

$$FS = \frac{\Sigma(C' + \sigma' \operatorname{tg} \phi') l}{\Sigma w \sin\alpha} \quad (3)$$

(a). Fellenius Method (Circular Rupture)

Fellenius made the simplifying assumption that dHn = dVn = 0; one then has immediately [11].

$$FS_{\text{(Fellenius)}} = \frac{\Sigma[(\gamma h_n \cos^2\alpha_n - u_n)] \tan\emptyset \frac{1}{\cos\emptyset_n}}{\Sigma \gamma h_n \sin^2\alpha_n} \quad (4)$$

(b). Simplified Bishop Method

The simplified Bishop's method [12] is undoubtedly one of the most widely used limit equilibrium calculation method for stability analysis. It makes it possible modelling embankments with a complex geometry comprising several soils layers with varied hydraulic conditions. This method is based on the following hypothesis: the sliding line is always circular, the vertical inter-slice forces are zero and the safety coefficient F is constant throughout the failure surface. By Bishop's simplified method in which it is assumed that only the horizontal components of the inter-slice forces balance out the shear forces are zero.

$$FS_{\text{(Bishop)}} = \frac{\Sigma\left[\frac{c\, l \cos\alpha + W\, tan\varphi}{cos\alpha + \sin\alpha \tan\varphi / Fs}\right]}{\Sigma W \sin\alpha} \quad (5)$$

(c). Simplified Janbu Method

The simplified Janbu method [13] is similar to the simplified Bishop method except that the Janbu method satisfies only the global balance of horizontal forces but not the global moment equilibrium. This method only considers the normal inter-slice forces and ignores the inter-slice shear forces. When the sliding surface deviates too much from the circular shape Junbu suggests considering the force and equilibrium moment of a typical vertical slice and the equilibrium force of the entire sliding soil mass (Figure 4).

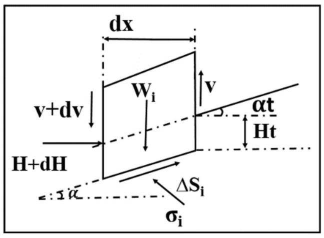

Figure 4. *Stresses on a slice according to the Jambu's method.*

Horizontal equilibrium gives us F:

$$F_{(Janbu)} = f\ (\Sigma\ (dxi\ si\ 1 / \cos2\ \alpha i) / \Sigma\ witg\alpha i) \quad (6)$$

With:

$$si = (ci + (wi / dxi)\ tg\varphi i) / (1 + (tg\alpha itg\varphi i / F)) \quad (7)$$

F is an empirical correction coefficient. This coefficient depends on the d/L ratio (depth of the sliding surface to its length) and the soil nature.

(d). Spencer's Method

Spencer developed two safety factor equations, one with respect to the equilibrium of moments and another with respect to the equilibrium of horizontal forces [15]. It adopted a constant ratio between the inter-slice shear and the normal forces and through an iterative procedure changed the inter-slice shear/normal forces ratio until the two safety factors were identical. Finding the shear/normal force ratio which makes the two safety factors equal means that the balance between moments and forces is satisfied. This method considers the inter-slice forces as parallel to each other: Vi/Hi = tgθi = λ. then, λ is a parameter to be determined, the angle θi must be between the angle of the slope β and the angle α_i that the base of the section makes with the horizontal. Q_i is the resultant of inter-slice forces. It makes an angle at (α-β) with the base of the slice. By projection we get Σ Qi Rcos (αi- θi) = 0, if we admit that the sliding surface is circular and R is its radius (R = Constant), therefore: Σ Qicos (αi- θi) = 0 (Figure 5).

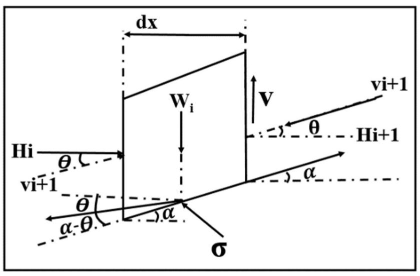

Figure 5. *Stresses on a slice according to the Spencer's method.*

Table 1. *Limit equilibrium methods for slope stability and equilibrium equations that satisfy [4].*

Method	Satisfaction of Force Equilibrium		Satisfaction of Moment Equilibrium
	Horizontal	Vertical	
Ordinary Method	No	No	Yes
Bishop Simplified	No	Yes	Yes
Janbu Simplified	Yes	Yes	No
Spencer	Yes	Yes	Yes

The fact that the slope stability formulation is based on limit equilibrium terms as a statically uncertain problem, the number of equations is fewer than the number of unknowns and all methods based on the slices method use simplifying assumptions. The selected method to analyse a particular slope problem has to be proper for the slope conditions under study [19].

The Slide software programs used for slope stability analysis in the current study, incorporates limit equilibrium analysis in its platform for determining global stability. In the limit equilibrium method, a sliding surface is supposed in the determination of the mobilised shear resistance along the surface. The sliding surface form differs and can be a noncircular, circular, or log-spiral. The shear strength obtained classically obeys the criteria of Mohr Coulomb failure.

(ii). Circular Failure Surface - Simplified Bishop Method

Despite all limit equilibrium methods used for comparative study in the current study, the Simplified Bishop's Method was retained for results discussion using the software program SLIDE. But, it is important to note that the Simplified Bishop method is not the one method that can be used in the slope stability analysis, being an exception for the current study. The Simplified Bishop method considers a circular slip surface and adopts that the inter-slice forces are horizontal without inter-slice shear stresses between all slice. This approach satisfies to the equilibrium of vertical forces and all equilibrium of moments around the center of a circular slip surface. However, the equilibrium of horizontal forces is not satisfied. The moment equilibrium of all slice is determined around the circle center. The Simplified Bishop method accepts that the Factor of safety is identical for all slice.

(iii). Search for the Critical Failure Surface

The supposition of some shape and location for the slip surface in a slope and applying any slice methods only yield one safety factor value, or the collapse load. This cannot be the lowermost value; therefore, the slip surface may not be the maximum critical one. Thus, it is required to attempt many potential slip surfaces and experience the computations for all slope.

It can be complicated mathematical problem to obtain the minimum of the factor of safety or collapse load. A generally used search method for circular slip surfaces was to outline a grid in which all point signifies a circular arc center. Different radios of the slip surface are before verified for all node, and the corresponding safety factor is computed for all of these potential sliding circles. When an amount of potential failure surfaces has been investigated, the minimum safety factor values in every node are contoured above the definite grid. When closed contours are produced, a local lowest of the safety has been met. Then, a greater search grid will be defined. The local minimum safety obtained does not certainly must be the one minimum value of the factor of safety. There might be some local minima, then only one agrees with the critical failure surface. The gird-search method is humble but it may be time consuming for big problems [11].

The Slide software is inclusive in the slope stability analysis that can carry out sensitivity and probabilistic investigation, and model design. The software can use nine different methods, counting Simplified Bishop, Corps of Engineers #1, Corps of Engineers #2, Morgenstern-Price, Janbu Simplified, Janbu Corrected, Low-Karafiath, Ordinary/Fellenius, and Spencer. The design approaches used in the analysis are determined by the user. Therefore, Slide 6.0 Software was retained for this study.

(iv). Data Input Used for Embankment Slope Model

Slide as a slope stability program allows the slope stability analysis with loads. So the addition strength parameters will be entered. Then, one may have a consideration of how the design technique designated for analysis can determine the safety factor to define how the inclusion of load would be input into the software program. The Simplified Bishop method, Simplified Janbu method and Spencer Method were used in the current study, and the input of the allowable loads as well.

In order to model the actual embankment considered in the current study, the parameters listed in Table 2 represent the real materials of embankment construction, and were served as input parameters in computer analysis with Slide software; in the convenient geometry of the slope layers. Slide as a 2D software of slope stability by limit equilibrium method was used to calculate the safety factor for 2 horizontals to 1 vertical (2H: 1) slope located on underlying built and natural layers, containing a geo-material with high friction angle [20]. The slope stability is influenced by geological conditions, material properties, and topographic parameters including slope geometry. Then these factors were all obeying the strength criterion of Mohr-Coulomb.

The analysis involves the entrance of material parameters into Slide 6.0 software to create the sliding surface which agrees with the condition of the soil limit equilibrium through an equivalent safety factor. The slope geometry model used in the current study involves homogeneous material. The material properties are shown in Table 2. The geometric model of the slope is inserted into Slide 6.0 software as shown in Figure 6.

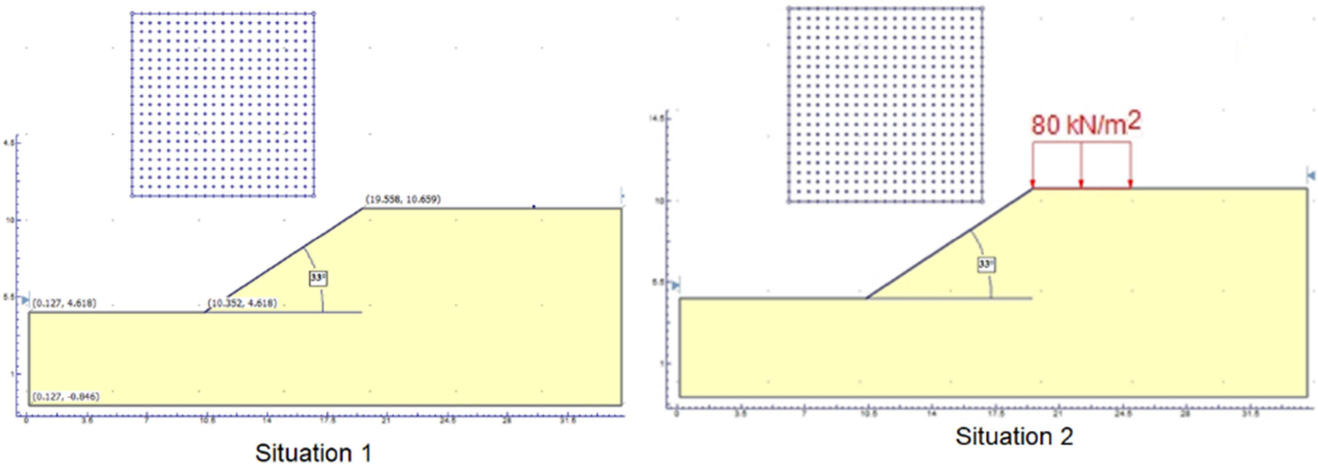

Figure 6. *Slope models: 1. Simple slope model; 2. Overloaded slope model.*

(v). Safety Factor Calculation

A whole safety factor of slope stability was calculated for the given slope geometry, soil properties, loading, and the defined search criteria. The soil structure design was modified until the minimum safety factor of whole slope stability (FS) is met or exceeded. Once completed the design, the Slide Interpreter post-processing module was designated to display the output. The output delivers the nominal load effect, considered as the driving force at the slip surface location for the minimum safety factor.

The safety factor calculation was based on the slope model correctly representative of the ground conditions. The slope model was created for the undrained soil slope. The particular slope model signifies the most destructive situation due to the height variation, with the effect of load on the embankment stability, if inappropriate slopes were indicated. Considering the embankment height, there are more configurations of the embankment that can be investigated according to the safety factors against sliding. Three alternatives of embankment analysis were considered, as follows:

1) Condition 1: Embankment, without surcharge;
2) Condition 2: Embankment with surcharge;
3) Condition 3: 1:2: embankment Slope with load effect.

To compute the stability analysis for the selected slope model, the slide software makes automatically slope analysis meeting critical sliding surface and the corresponding safety factor. The computation methods used in Slide software were Fellenius, Bishop and Janbu. The slope model insertion into the software, was accompanied by considering the sliding surface shape as circular, and an admissible safety level of 1.3. The slope analysis was based on the configuration of the slope geometry of the embankment by interchanging 1:2 slopes conditions, with and without effect of the load. Then, an effort to find the ideal slopes equivalent to the embankment at great level of safety factor was made as well. In keeping with materials data, the soils properties corresponding to the concerned embankment are shown in Table 2. In accordance with USCS, the soil is the silty sand with consideration of E= 14000 kPa as deformation modulus. The embankment filling material is a coarse local material made of gravel and sand classified as (GP-SP) with 73000 kPa of deformation modulus.

Table 2. *Properties of soils.*

Soil type	Parameters	Symbol	Value	Unit
	Internal friction angle (degree)	φ'	32.7	°
Silty sand (SM)	Cohesion	c	0.0	kPa
	Unit weigth	γ	19	kN/m^3
	Internal friction angle (degree)	φ'	36	°
Filling material (gravel and sand (GP-SP)	Cohesion	c	0.0	kPa
	Unit weigth	γ	22	kPa

A rolling layer with the traffic effect has an initial load equal to 25 kN/m^2 and considered as disturbed load in all direction applying simulation with variation from 25 to 80 kN/m^2.

3. Results and Discussion

3.1. Results

Table 3 shows the values of safety factors from computations carried out with three analysis methods: Fellenius, Bishop and Janbu. In addition, results will be interpreted through Bishop Method. The other two methods were used to confirm the results obtained by using Simplified Bishop's method, and they will not reflect in the work discussion as mentioned above.

Table 3. *Safety factor values obtained by different methods.*

Methods	Safety factor		
	Situation 1	**Situation 2**	**Situation 3**
Bishop	1.75	0.75	0.78
Janbu	1.62	0.68	0.76
Spencer	1.68	0.66	0.73

In Simplified Bishop's method the minimum surface falls in range of the most slope stability once the slope is not overloaded, where the dominant minimum surface and global minimum surface pass through the slity sand soil. Depending on the method used, certain or all of the inter-slice forces can be discounted. In the slice method, the observation of a thrust line that connects the inter-slice forces can be shown when using a rigorous analysis method that satisfies whole equilibrium [6]. The ignorance of the inter-slice forces by certain methods, not complete the equilibrium satisfaction. Slope stability analysis is determined by the safety coefficient, being an idea of the equilibrium condition of the slope under study with consideration of the limit equilibrium. The slopes stability that is not in the condition of limit equilibrium is determined from the safety factor computation. This factor of safety then is considered as the relationship between resisting forces and driving forces (Figure 7).

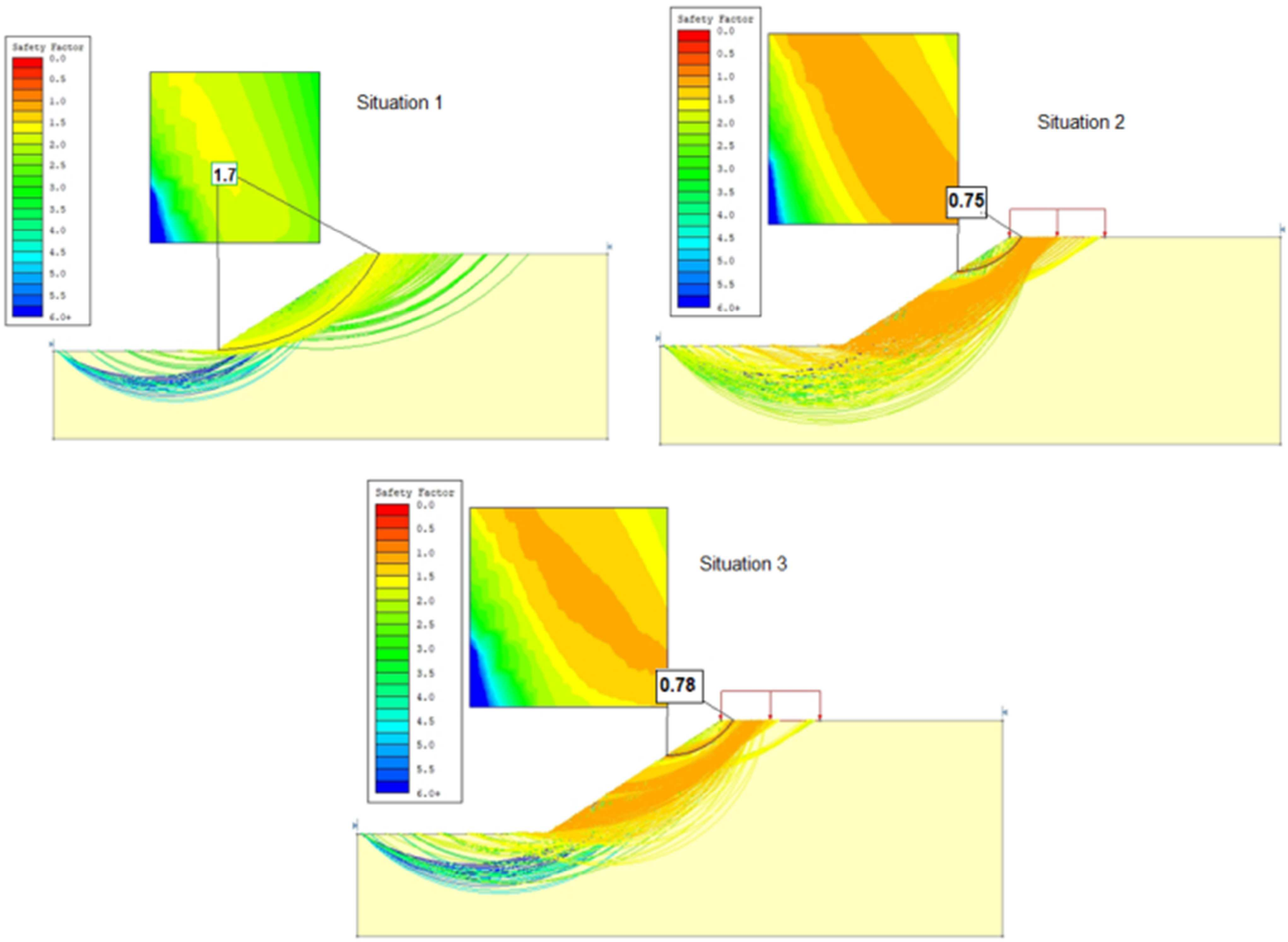

Figure 7. *Sliding surfaces (simplified Bishop's method).*

3.2. Surcharge Load Effect on the Embankment Stability

The slope configuration can reduce the slope safety factor due to the load variation which is practically similar excluding the higher values of the safety factor with lesser rates of load as can be seen in Figures 8, 9 and 10. It is noticed that the increase in surcharge load has an effect on the value of safety factor. The slope height effect on the slope stability for certain angle of slope and load variation can be seen in Figures 8 and 9, respectively. It is noted that the safety factor decreases with the increase in the slope height and the slope angle as well.

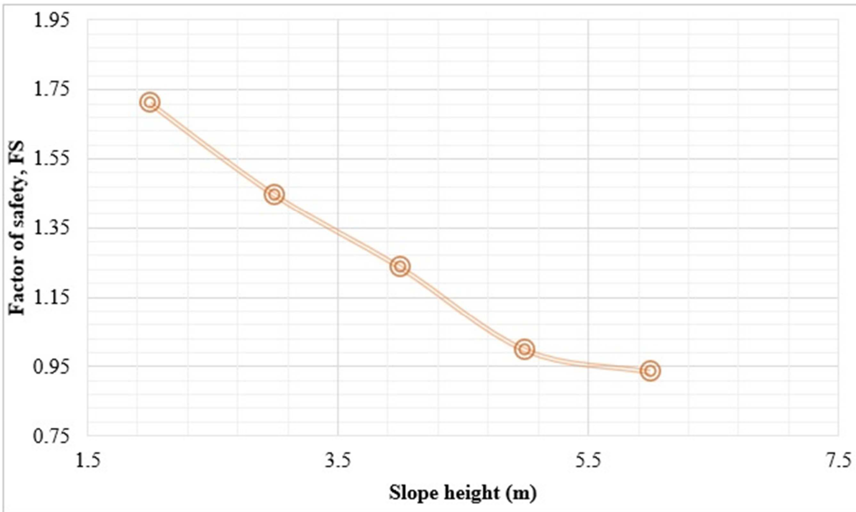

Figure 8. *Slope height versus factor of safety using Bishop's method.*

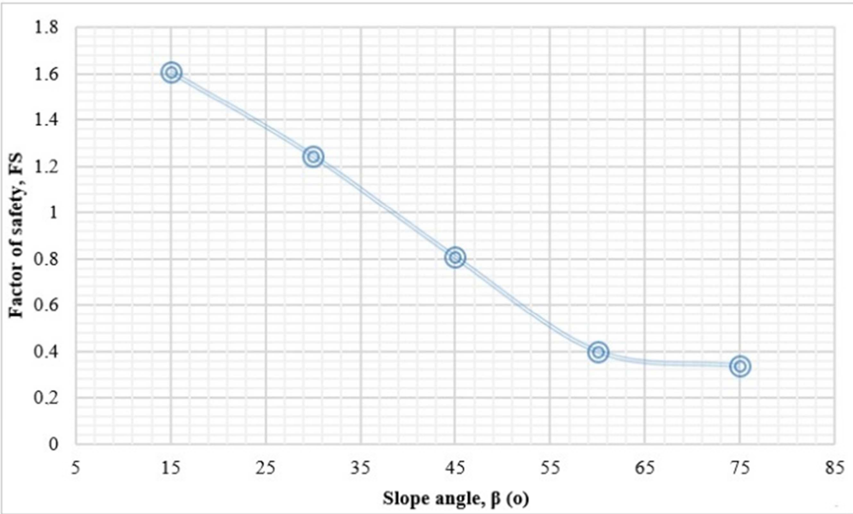

Figure 9. *Slope angle versus factor of safety using Bishop's method.*

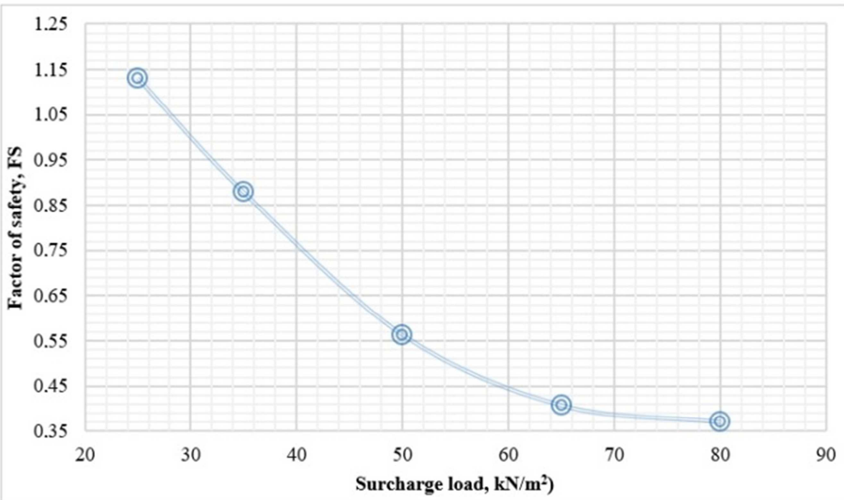

Figure 10. *Surcharge versus factor of safety using Bishop's method kN/m^2.*

The sliding surfaces of homogeneous slope for different slope heights and load variation from 25 to 80 kN/m^2 are observed in Figures 9 and 10. The values of safety factor obtained by computing from the usage of Slide software considered different conditions, which indicate that the slope tends to be stable without overloading, but it becomes unstable with the presence of load [21].

In the situations 1 and 2, it can be noticed that the governing force that overcomes the embankment stability is the load of 80 kN which had significant effect observed in the Bishop analysis compared with the situation 1. Besides the slope height and the friction angle have also decisive effect on the values of the safety factors (Figure 11). The full results can be seen in Figures 8, 9, 10 and 11. The load effect can be considered as the driving scenarios which affect the embankment stability. For circular slip surfaces, the simplified Bishop's method can be strongly recommended for use [4]. A summary of the embankment slope stability relative to the use of conditioning topographic parameters can be seen in Figures 8 and 9. The slope stability with respect to the slope height and slope angle is shown in in Figures 8 and 9.

The relationship between slope stability and different topographic parameters was studied using the graphic of slope height versus factor of safety and graphic of slope angle versus factor of safety, respectively. The slope height variation from 1.5 to 5.5 m showed a negative relationship with the safety factor. Then it is kept the same negative relationship between the slope angle and the safety factor.

Nugraha [22] noticed higher slope instabilities at higher slope heights than lower heights. So, as the study area is predominated by steep slopes, the slope angle controls the destabilising forces on the embankment [23] and therefore abrupt slopes are more disposed to landslides. Commonly, in the present study, the slope in a stable state was present on the lower values of height and angle of the slope for the embankment under study. While, the opposite is noted in the case of the higher values of height and angle of the embankment slope (Figures 8 and 9). As explained by Zhuang [24] on lower slope angles, the embankment susceptibility to landslides is low since the terrain is placid and requires higher levels of water to start slope failures. Similarly, at very excessive slope angles, the susceptibility to landslides is high since the terrain is very abrupt [24].

The safety factor values indicate that the embankment would be in an adequate state of stability with safety factor value greater than 1.4. The applied load of 80 kN/m^2 (Figure 10) decreases the safety factor value until sliding occurrence. This decrease in safety factor values is due to the load presence which is increasing the sum of the forces or driving moments able to cause the slope failure [24].

The effect of angle and height of the slope on the safety factor including also different load values can give a well understanding on the embankment slope stability. Safety factor progressively decreases with the increase in slope angle [24]. The reduction of the safety factor due to the load variation is nearly similar except that the safety factor values are higher once the load is lower. The slope height effect on the factor safety is shown in Figure 11 for particular slope angle and load are shown in Figures 8 and 9, respectively. It is noticed that the decrease in safety factor was caused by the increase in the height and the angle of the slope.

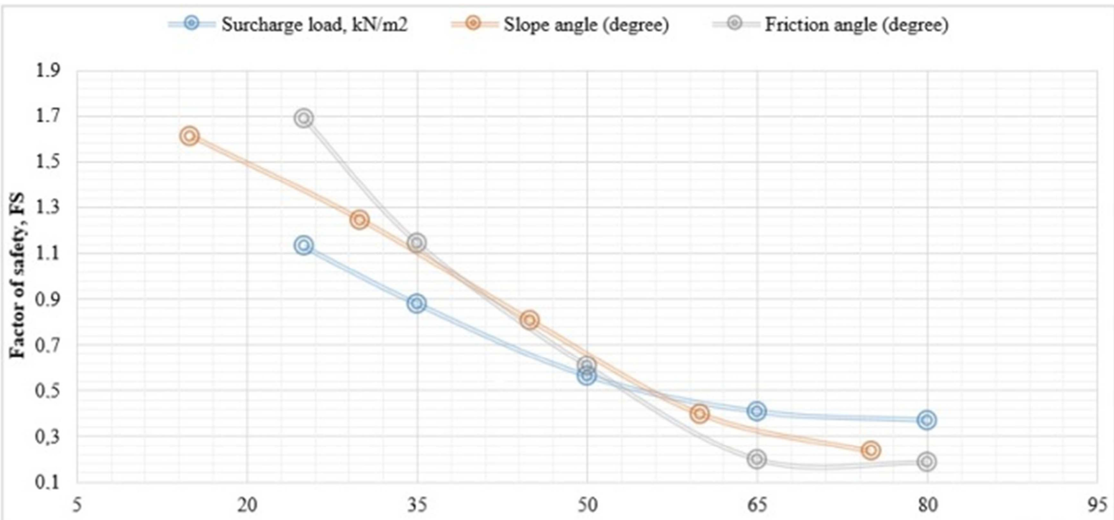

Figure 11. *Effect of Surcharge load, friction angle and slope angle on slope stability by using Bishop's method.*

4. Conclusion

This work shows a methodology to assess the embankment stability with a limited height and angle of embankment slope. Empirical formulations were mentioned in the current study, and an additional analysis which determined the stability of embankment on sandy soils was carried out as well.

The slope stability evaluation is indispensable for its safe preservation. Different safety factor values were obtained for the equivalent problem, basing on the Bishop's method for the selected slope model.

Understanding the process that conduct to the slope instability is reasonably a complex charge requesting for a long and complete study. It could even find not as good as if absence of main data is there. But the susceptibility of slope failure was checked by using limit equilibrium analysis which helps to give a consideration about the embankment slope stability.

In this study, the load effect on the slope stability is analysed by using the Limit equilibrium methods founded on the Slide software. The effect of the slope angle and height of slope is analysed as well. The evolution of different loads applied to the slope and slope angles and slope height variations are observed as well. It is noticed the decrease in the factor of safety with the increase in slope angle and the decrease in factor of safety with the increase in load. The safety factor also decreases once the slope height increases to a certain value; showing the negative effect of the variation of slope height and load on the slope stability.

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