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SLOPE STABILITY ANALYSIS OF THE LEFT BANK OF ARIAL KHAN RIVER OF BANGLADESH

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Abstract

Slope instability is one of the major problems in geotechnical engineering where loss of life and property are in hazardous situation. Therefore, it is essential to check the stability of slope. Such an important earthen structure is river bank slope. Here an attempt has been made to analyze the slope stability of the left bank of Arial Khan River at Khas Char Bachamara. Slope stability has been analyzed through geotechnical investigation with parameters cohesion, angle of internal friction, unit weight, slope angle and slope height etc. Geo05 software has been used for slope stability analysis. For slope stability analysis the two methods such as Bishop simplified and Janbu methods have been used for finding safety factor. Here safety factor of Bishop simplified has been considered as it gives low value of safety factor. Accordingly, from the slope stability analysis it has been observed that left bank of Arial Khan River at Khas Char Bachamara is stable at the coordinates (204966.442E & 2589225.303N) and (204765.552E & 2589425.425N) however, at the coordinate (204864.521E & 2589699.255N) the bank is not stable of the study area according to safety factor 1.50 of slip circle. Safety factor less than 1.50 recognize the river bank is unstable and a design engineer may reconstruct with reinforcement through injecting cement.

Keywords: *Arial Khan River, Geotechnical Investigation, Left bank, Slope stability.*

Introduction

Bangladesh is a broad deltaic plain and it has complex river system. The plain is largely formed by the Ganges, the Brahmaputra and the Meghna. Different rivers bring sediments from areas of different geology. There is active bank erosion almost in all major rivers in the country. The failure of riverbank is a common problem in Bangladesh. Erosion expedites the river bank failure occurring among many of the river bank failure criteria. Riverbank erosion occurs both for hydraulic and geotechnical instability. River bank slope instability is one of the major issues in geotechnical engineering. Therefore, it is utmost important to check the stability of slope of the river bank.

Seepage induced slope instability is a complex phenomenon which has not been quantified and not even fully understood as a wide range of factors affect a slope's ability to resist seepage induced instability (Terzaghi and Peck, 1948) They concluded that this work provides a possible solution to describe seepage-induced slope instability utilizing critical state soil mechanics. They also concluded that further work will be required to determine stability for natural slopes. Watson *et al.* (2006) studied on stream bank erosion with a review of processes of bank failure, measurement and assessment techniques and modelling approaches. They stated that stream bank erosion depends mainly on flow pattern, bank material composition, bank geometry, channel geometry, bank soil-moisture conditions, vegetation, and man-induced factors. Inamul (2010) explains that the river bank can collapse depends on a number of factors predominating the geotechnical characteristics. He also expressed that river bank failure can be caused when the gravitational forces acting on a bank exceed the forces hold the sediment together.

Failure depends on sediment type, layering and moisture content. Fatema and Ansary (2014) studied on an embankment at Basuria in Sirajganj near the bank of Jamuna River. They observed that grain size of the soil contains 63% sand, 35% silt and 2% clay. They found the maximum safety factor 2.255 for soil at dry condition with a slope 1:2 while the minimum factor is 0.66 at rapid drawdown condition with 1:1 slope. Islam *et al.* (2014) worked on dry and wet in-situ soil sample in the laboratory for showing the major cause of bank erosion. They found that the soil samples are silty clay with friction angles of 40° and 24° at dry and wet condition respectively. The factor of safety (FS) is similar and are more than 1 at dry condition while it is ~0.7 at wet condition. Harabinova and Panulinova (2019) studied on the influence of change in shear strength parameters on the factor of safety. They observed that the factor of safety of the slope changes with varying cohesion c and internal friction angle ϕ. They recommended that the factor of safety can be correctly obtained only if the critical failure surface of the slope is accurately identified, and shear strength parameters are correctly measured.

Islam *et al.* (2023) studied on the riverbank erosion of the Surma River due to slope failure using both liquid equilibrium and finite element method and showed that the river banks are eroding mainly due to slope failure in the wet condition. The factor of safety (FS) and shear reduction factor (SRF) values are similar and are more than 1 at dry condition while it is ~0.7 at wet condition. They recommend that the steep slope of the Surma River should training with support like cement concrete (CC) block. Aryanti *et al.* (2018) studied on slope stability analysis in Lusi River, Kedungrejo through characteristics of soil mass using limit equilibrium method with comparing Bishop, Janbu and Spencer method using Slide 6.0 Program. They found that study area is composed of clay with the firm to stiff structure. They analyzed the result of slope stability using Bishop simplified method and obtained the factor of safety is 1.680 and 1.14 based on Slide 6.0 program, the smallest factor of safety 1.130 is obtained using Janbu simplified method (Slide 6.0 Program Software). They classified the slope stability is unstable in condition according to the Terzaghi and Peck

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(1976) factor of safety criteria. They conclude that reinforcement is required for improving the slope stability. Oo *et al.* (2013) studied on numerical analysis of river bank slope stability during rapid drawdown of water level. The results of computation showed that rapid drawdown of river water level most easily leads to the slipping of the slope of the river bank and the stability of the slope of the river bank gradually increases with the dissipation of the excess pore-water pressure. The contribution of the matrix suction to shearing strength increases with the enlargement of unsaturated soil region, which has remarkable action on raising the stability of the slope of the river bank. They concluded that the monitoring of the river bank soil body should be intensified during rapid drawdown of river water level so as to avoid the occurrence of slipping of the slope of the river bank.

Tseng (1975) conducted a review study of river bank stability and slope movements in the Winnipeg area of Manitoba in Canada. In this study, residual strength parameters were used in effective stress analysis, using the simplified Bishop's Method of Slices for a circular slip surface and a modified rigorous Janbu solution for a non-circular failure surface. It has been observed that factor of safety has been improved and safety factors for the given pore water pressure conditions were more reasonable. It has also been observed that the rate of slope movement varied according to the groundwater conditions and reflected the state of riverbank stability.

Fig. 1. Bank of Arial Khan River.

Arial Khan Riveris one of the biggest distributaries on the right bank of the Padma River at Sadarpurthana in Faridpur district and Shibcharthana in Madaripur district. The river maintains a meander channel through its course and is erosion in nature and very difficult to identify its left and right bank (Ashrafuzzaman *et al*., 2020). The river bank is somewhere very steep and somewhere is plain to flood plain. The bank scenario of Arial Khan River has been shown in **Fig. 1**.

A number of settlements have already been destroyed due to severe river bank erosion and the process is ongoing. Therefore, bank protection is one of the prime necessities for poverty alleviation and national growth. Before that stability analysis is an utmost important work for the bank protection. Over the last few decades, many numbers of river bank are protected through many engineering ways. In this regard, it is often noticed that conventional designs are adapted to protecting the river bank. Such protecting works are failed before the return period. As a results, the government is compelled to fund a significantly larger amount than the actual budget. So, it needs appropriate measure through proper investigation and engineering implication. Here an attempt has been made to analyze the slope stability of the left bank of Arial Khan River at Khas Char Bachamara of Shibcharthana of Madaripur district of Bangladesh through geotechnical investigation.

The objective of this study is to analyze the stability of the slope of the left bank of Arial Khan River located at Khas Char Bachamara of Shibchar thana through geotechnical investigation.

Methodology

The data have been collected from River Research Institute (RRI) report (2023). The study area is located at Khas Char Bachamara of Shibcharthana of Madaripur district. The coordinate of the boreholes are at #BH-1 (204966.442E & 2589225.303N), #BH-2 (204765.552E & 2589425.425N), #BH-3 (204864.521E & 2589699.255N) at the left bank of Arial Khan River from where soil samples have been collected. The study area has been shown in the river map in **Fig. 2**.

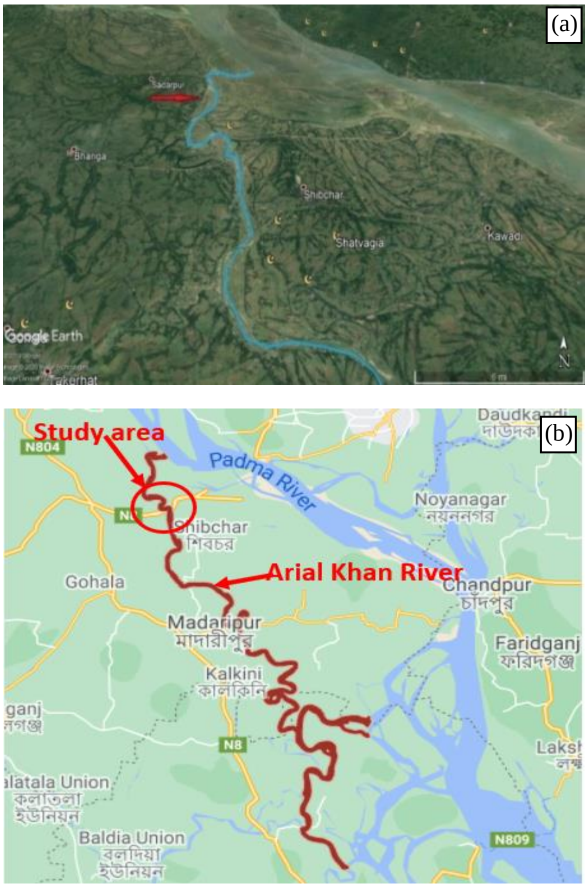


Fig. 2. (a) Image map of Arial Khan River (Source: Google Earth) and (b) Study area.

Field and laboratory investigation have been conducted for geotechnical investigation. Field investigation includes standard penetration resistance for test SPT-N values, soil strata depth wise, ground level, ground and surface water level etc. For slope stability analysis the soil parameters such as unit weight, cohesion, angle of internal friction are usually used. These parameters have been collected from direct shear test and which have been tested in the soil mechanics division of RRI. Field parameters such as slope angle slope height, ground water level etc. have been collected from the study area. In this study, Bishop's Simplified Method has been used for slope stability analysis compare it with and Janbu method. Numerical Geo05 Software has been used for slope stability analysis. In the Bishop method the safety factor is defined 1.50 for circular slip surface according to Terzaghi and Peck (1948).

Direct Shear Measurement

The test is carried out on remolded samples prepared by three layers of soils by tamping according to soil density index in the laboratory of soil mechanics division of geotechnical research directorate of RRI using direct shear apparatus. The specimen was prepared for the direct shear test within the direct shear mold. A normal load was applied to the specimen sample and the specimen was shared across the pre-determined horizontal plane between the two halves of the shear box. This procedure was repeated for three remolded samples. Measurements of shear load, shear displacement and normal displacement were recorded. From the results, internal angle of friction and cohesive strength were measured using Coulomb's shear strength equation.

$$\tau_f = c + \sigma_f \tan \emptyset \qquad \text{Eq. (1)}$$

Where τ_f= shearing resistance of soil at failure, c =apparent cohesion of soil, σ_f = total normal stress on failure plane, ϕ = angle of shearing resistance of soil (angle of internal friction). The values of these parameters such as cohesion, angle of internal friction and unit weight were used to determine factor of safety.

Limit Equilibrium Method

The conventional limit equilibrium methods for investigating the equilibrium of soil mass tending to slide down under the influence of gravity are used. Transitional or rotational movement is considered on assumed or known potential slip surface below soil or rock mass. All methods are based on comparison of forces (moments or stresses) resisting instability of the mass and those that causing instability (disturbing forces). Limit equilibrium methods are still currently mostly used for slope stability analysis. These methods consist in cutting the slope into fine slices so that their base can be compared with a straight line, then to write the equilibrium equations (the equilibrium of the forces and/or moments). According to the assumptions made in the efforts between the slices and the equilibrium equations considered. The Bishop's simplified method is also applicable to non-homogeneous slopes and cohesive soils where slip surface can be approximated by a circle. It is more accurate than the Ordinary Method of slices, especially for analyses with high pore water pressures. Moreover, the Junbo generalized procedure is applicable to non-circular slip surface. Here it is mentioned that Bishop's simplified method and Janbu's simplified method are in limit equilibrium method.

Bishop's simplified method

Arora (2010) explained that a simplified method of analysis gave Bishop (1955) which considers the forces on the slides of each slice. Bishop's simplified method is a primary slope stability method where the inter slice shear forces are neglected and regardless of whether the slip surface is circular or composite that is based on the equation. The requirement of equilibrium is applied to each slice. The factor of safety of the assumed failure surface determined by the equation.

$$F_s = \frac{\Sigma \frac{1}{m_\alpha}[c'b+(W-ub)\tan\varnothing']}{W\sin\alpha} \qquad \text{Eq. (2)}$$

Where, $m_\alpha = (1+\tan \varnothing' \tan \alpha/F_s) \cos\alpha$, b is the width of the slice c' and ϕ' is the shear strength parameters for the center of the base of the slice, W is the weight of the slice, is the inclination of the bottom of the slice, u is the pore water pressure at the center of the base of the slice.

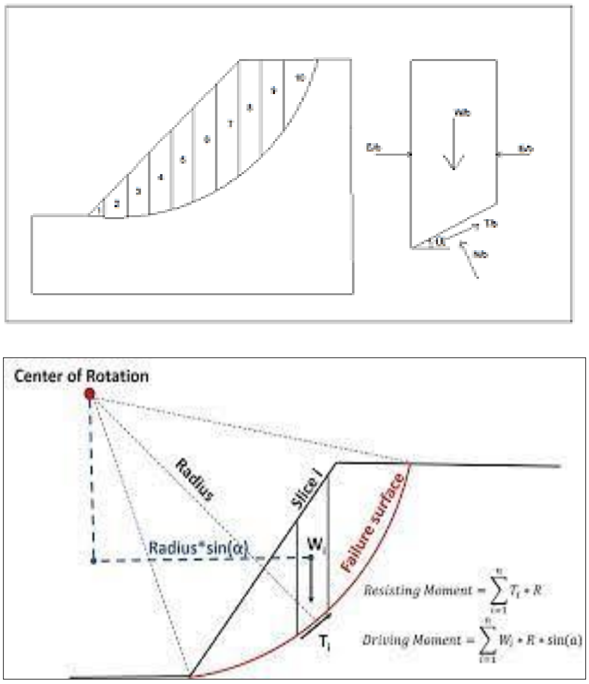


Fig. 3. a) Ordinary method of slices b) Slope stability-The Bishop Method of Slices (Source: Salunkhe, *et. al.*, 2017).

Janbu's Simplified Method

The Janbu's simplified (1956) method is similar to the Bishop's simplified method except that the Janbu's simplified method satisfies only overall horizontal force equilibrium but not overall moment equilibrium. The Janbu's simplified factor of safety is too low, even though the slices are in force equilibrium. Since force equilibrium is sensitive to the assumed inter slice shear, as in the Junbu's simplified method, makes the resulting factor of safety too low for circular slip surfaces.

$$F = c'\text{l} + \text{P} - \text{ul} \tan \phi' \cos \alpha P \sin \alpha \pm A \qquad \text{Eq. (3)}$$

Where, c' is effective cohesion intercept, ϕ' is effective angle of internal friction, l is the length of the failure surface at the base of each slice, P is the total normal force on the base of the slice, A is the resultant external water forces, α is the angle between the tangent to the center of the base of each slice and the horizontal.

The assumptions made by Janbu's method are that the inter slice forces acting on a single slice.

where, W = the weight of the soil above the failure surface, Xi-1, Xi+1, Vi-1, Vi+1= the inter slice reactions from the adjacent slices, N′=normal effective force, T= Shear component force, U= the boundary water force.

Janbu's method suggests that the normal interslice forces are equal and can be neglected.

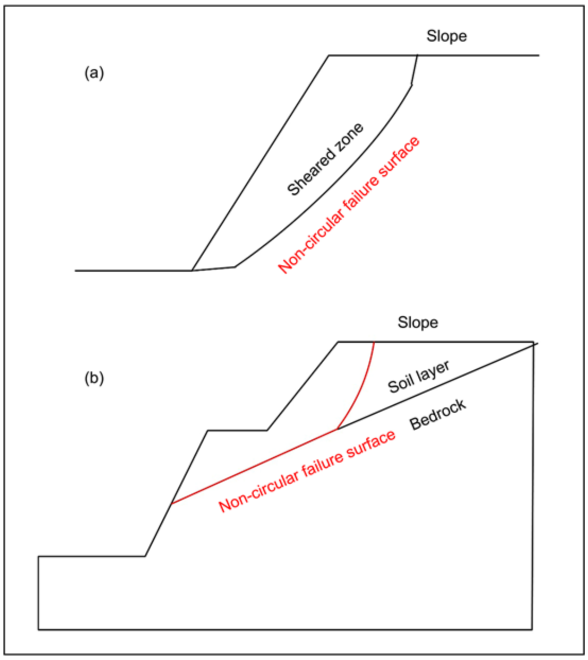


Fig. 4. (a) Failure surface that passes through a sheared zone, and *(b)* a failure surface that begins as circular but is then interrupted by a stronger geological formation (bedrock).

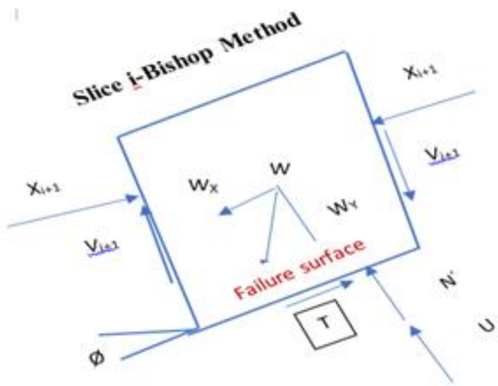


Fig. 5. Showing inter-slice forces acting on a single slice at Janbu method (Salunkhe *et.al.*, 2017).

Results and Discussions

Field and laboratory investigation results of soil density, particle sizes, specific gravity, cohesion, angle of internal friction, etc. have been presented in the tabular form in **Table 1** and the stability analysis results have been shown in **Table 2**.

Table 1. Showing the test results of cohesive and non-cohesive soils of different boring holes of Khas Char Bachamara of Shibcharthana of Madaripur district.

Name of the parameters	Khas Char Bachamara	
	Cohesive Soil	Non-cohesive Soil
Soil Density	Very soft to stiff	very loose to dense
Sand in %	1-48	42-92
Silt in %	52-91	8-55
Clay in %	3-35	0-3
Specific Gravity, Gs	2.678-2.682	2.670-2.671
Unit Weight in kNm^{-3}	18.22-18.44	17.58-18.22
Plasticity in %	25-26	-
Cohesion, c in kNm^{-2}	22-30	0-3
Angle of internal friction, ø in degree	2-20	24-32
Permeability in cm s^{-1}	10^{-6}-10^{-4}	10^{-4}-10^{-2}
Compression index, Cc	0.168-0.336	-
Colour	Light brown to grey	
Height of the slope in m	3-6	
Slope angle in degree	22-85	

Table 2. Slope Stability Analysis of the different coordinates of the left bank of Arial Khan River.

Location	Easting	Northing	Factor of Safety by Bishop Method	Factor of Safety by Janbu Method
Khas Char Bachamara	204966.442	2589225.303	3.10	4.67
	204765.552	2589425.425	7.42	7.79
	204864.521	2589699.255	1.37	1.90

Slope Stability Analysis by Bishop Method

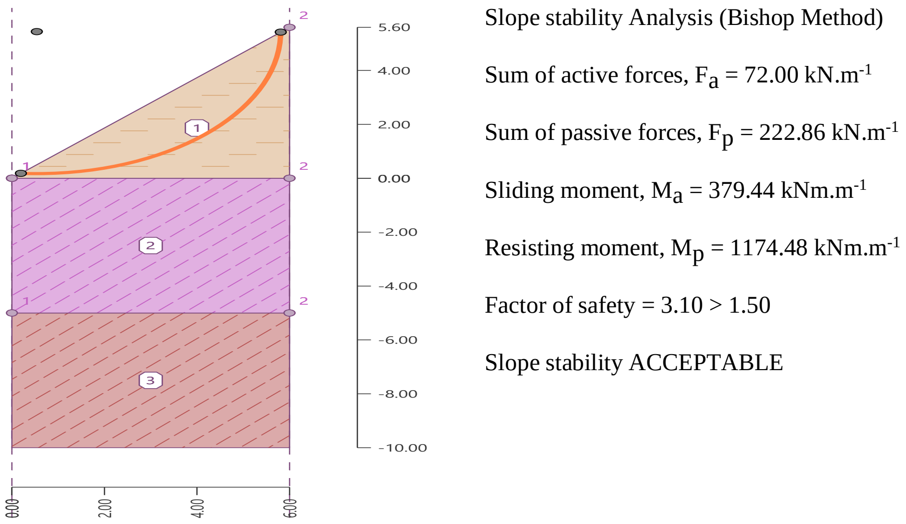


Fig. 6. Slope Stability Analysis at the coordinate (204966.442E &2589225.303N).

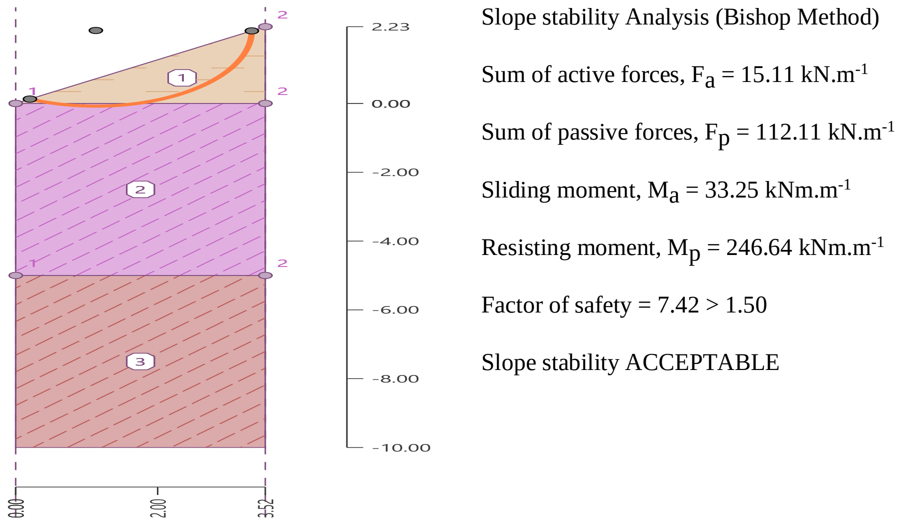


Fig. 7. Slope Stability Analysis at the coordinate (204765.552E & 2589425.425N).

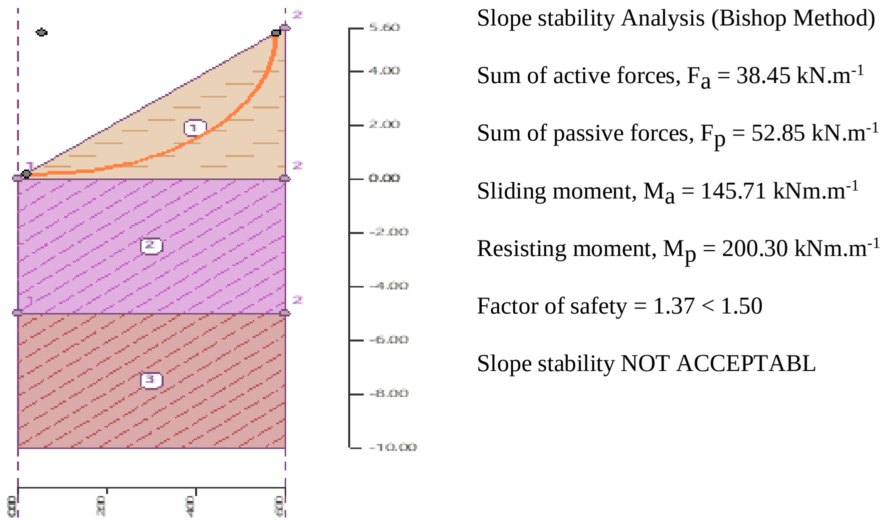
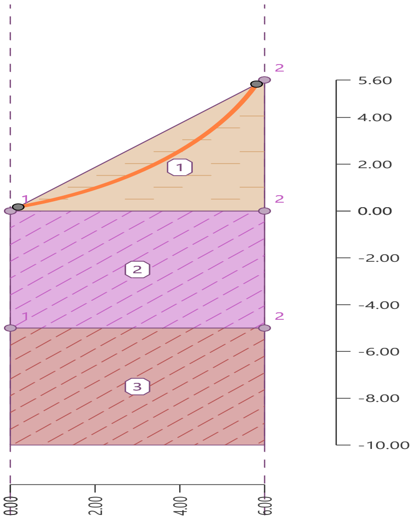


Fig. 8. Slope Stability Analysis at the coordinate (204864.521E &2589699.255N).

Slope Stability Analysis by Janbu Method

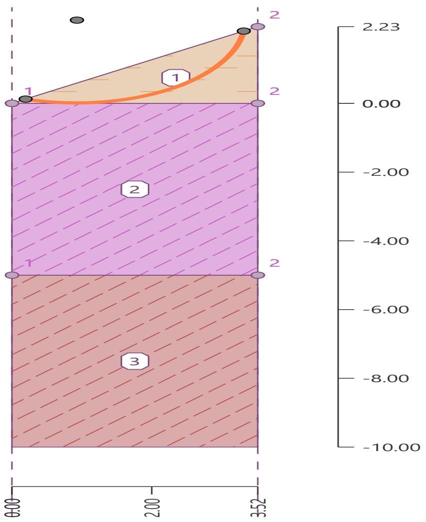


Slope stability analysis Janbu Method

Factor of safety = 4.67 > 1.50

Slope stability ACCEPTABLE

Fig. 9. Slope Stability Analysis at the coordinate (204966.442E & 2589225.303N).

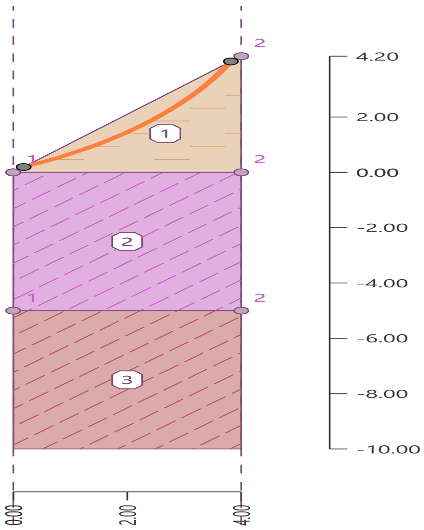


Slope stability analysis Janbu Method

Factor of safety = 7.79 > 1.50

Slope stability ACCEPTABLE

Fig. 10. Slope Stability Analysis at the coordinate (204765.552E & 2589425.425N).



Slope stability analysis Janbu Method

Factor of safety = 1.90 > 1.50

Slope stability ACCEPTABLE

Fig. 11. Slope Stability Analysis at the coordinate (204864.521E &2589699.255N).

Aryanti *et al.* (2018) studied on slope stability analysis in Lusi River, Kedungrejo and mentioned the ranges of minimum total factors of safety defined by Terzaghi and Peck (1976) and the Canadian Geotechnical Society (1992) in the tabular form in **Table 3**.

Table 3. Showing the value of minimum total safety factors.

Failure Type	Category	Safety Factor
Shearing	Earthworks	1.3-1.5
	Earth retaining structures, excavations	1.5-2.0
	Foundations	2.0-3.0

Garg (2009) expressed that the overall factor of safety should be 1.50 for stability of the foundation against shear. Arora (2010) stated that the factor of safety determined by Bishop's simplified method is on the safe side as its error is generally less than 2% and not more than 7% even in extreme case.

From the slope stability analysis of Bishop Method, it has been observed that left bank of Arial Khan river at Khas Char Bachamara is stable at the coordinates (204966.442E & 2589225.303N) and (204765.552E & 2589425.425N) as their safety factors are 3.10 & 7.42 whereas the safety factor of the coordinate (204864.521E & 2589699.255N) is 1.37 which is unstable. Because the stable safety factor less than 1.50 of slip circle of slope stability analysis considered unstable according to Terzaghi & Peck (1976), Canadian Geotechnical Society (1992) and Garg (2009). On the other hand, the slope stability analysis of Janbu Method provides the left bank of Arial Khan River at Khas Char Bachamara is stable at all the three coordinates as their safety factors are 4.67, 7.79& 1.90. In comparison of Bishop and Janbu method it is observed that the three coordinates are stable according to Janbu method. However, the bank is stable at the two coordinates which are mentioned according to the analysis of Bishop method as there are less error in this method (Arora, 2010). Consequently, the coordinate (204864.521E & 2589699.255N) of the bank of Arial Khan River may be reconstructed.

Conclusion

From the slope stability analysis, it has been observed that left bank of Arial Khan River at Khas Char Bachamara is stable at the coordinates (204966.442E & 2589225.303N) and (204765.552E & 2589425.425N). However, at the coordinate (204864.521E & 2589699.255N) of the study area is not stable according to stable safety factor 1.50 of slip circle of slope stability analysis. Therefore, it is recommended that the coordinate (204864.521E & 2589699.255N) of the study area is unstable and a design engineer may reconstruct with reinforcement through injecting cement which can enhance the stability of the riverbank of Arial Khan River.

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