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Riverbank Slope Stability Analysis

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Abstract. A comparative riverbank slope stability analysis has been made in the alluvial riverbanks of the River Brahmaputra in Majuli Island and its Southern tributaries- Dhansiri ,Dikhowand Lohit River in Assam. The geotechnical and engineering properties of these bank materials are used to stability analysis of the riverbank slopes. Culman type method of stability analysis as stated by Osman and Thorne (1988) for cohesive riverbank is selected for the study. The analysis is carried out for steep bank angles greater than 60º considering the bank geometry. Driving force FD and Resisting force FR are calculated based on the bank heights, bank angles and shear parameters of the bank material. This has continued with the determination of the Factor of safety for the stability analysis. Riverbank slope is concluded as stable at FOS more than 1 and unstable where FOS is less than 1. The riverbank fails at FOS 1.

Keywords: Riverbank stability; Culman method; FOS

1 Introduction

Slope stability analysis in geotechnical engineering is primarily reported in terms of the factor of safety, FOS. The riverbank slope stability is also analyzed by using the similar concept of the slope stability analysis in the geotechnical engineering. Stability of the riverbank depends upon several factors such as bank geometry, bank material properties, hydraulics of flow in the adjacent channel, structure of the bank and climatic conditions (Thorne, 1978). Literature reviews state that there are different methods of riverbank stability analysis, put forwarded by different researchers in different times. Most of the riverbanks of the Brahmaputra River and its tributaries in Assam are formed by the deposition of the transported soil in layers by the river flow for a long time. The bank slopes with very low value of the shear parameters of the bank materials become unstable due to frequent erosion and flood in every year. Therefore, the stability analysis of these slopes in this region becomes significant for different construction projects to be implemented in the riverbanks and in the nearby locality of these rivers. The stability analysis method proposed by Osman and Thorne in 1988 is considered for the present study. The bank materials are collected from Majuli Island and the left banks of the Dhansiri River, Dikhow River and Lohit River in the upper Assam region and properties of these materials required for the analysis are determined. This is an experimental study to investigate the stable slopes for the theoretical condition of factor of safety, i.e. stability at FOS=1.00 in the considered riverbank slopes.

2 Methodology

In the present analysis, steep banks are considered assuming the bank materials to be cohesive and homogeneous without considering the surface run off, vegetation density types, water table existence and seepage as per the adopted Culman method. The failure is assumed to be planar and the failure surface passing through the toe of the bank. As the steep banks are more prone to erosion hence, the bank angles greater than 60º are considered here. The slope stabilities are reported using the stability graphs for bank angles 60º, 70º and 80º. The bank materials of the selected sites are inorganic silt with low plasticity, silty sand and clayey sand with low cohesion and angle of internal friction. The bank material properties required for the method are mentioned in Table 1.

Table 1. Bank material properties used for the analysis

Riverbanks	Submerged unit weight, γ (KN/m^3)	Effective Cohesion, c' (N/cm^2)	Effective Angle of Internal Friction,φ' (º)
Dhansiri	17.02	0.95	23.5
Dikhow	13.30	0.73	26
Lohit	16.36	0.99	22.5
Brahmaputra	12.15	0.69	33

The bank materials have low shear parameters as shown in the table 1. In this study, submerged unit weights are used for the geometry as shown in the figure 1 which considers the bank height from the bed level to the top surface of the bank. Also the shear parameters are taken as the effective cohesion and effective angle of internal friction for the submerged condition of the respective riverbanks.

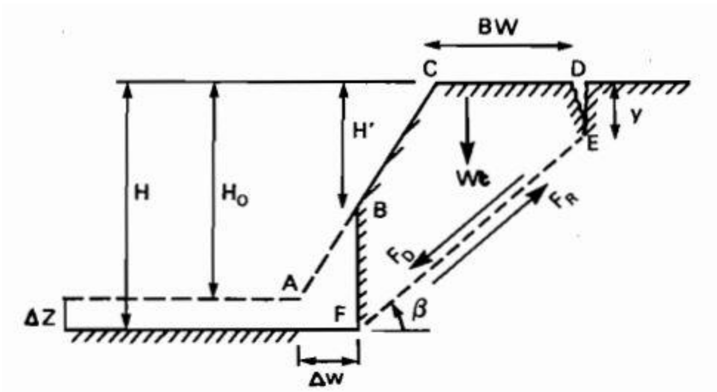

Fig. 1. Bank geometry considered for the present analysis [3]

In the figure 1, H is the total height of the bank, β is the failure plane angle, y is the tension crack depth and W_t is the weight of the failure block. Δw is the lateral erosion distance that is not considered in the stability analysis part of the selected method. The weight of the failure block of the soil (W_t) acts as the driving force that is given by,

$$F_D = W_t \sin\beta \quad (1)$$

$$\text{Where, } W_t = \gamma/2[\{(H^2-y^2)/\tan\beta\}-\{(H'^2)/\tan i\}] \quad (1.1)$$

$$\beta = 1/2\times [\tan^{-1}\{(H/H')^2(1-K^2) \tan i\} +\varphi'] \quad (1.2)$$

The resistance force is given by,

$$F_R = \{(H-y) \times c'\}/\sin\beta + W_t \cos\beta \tan \varphi' \quad (2)$$

Where, y=KH in which K depends on the effective angle of internal friction and is inversely proportional to it.

The factor of safety, FOS= Resisting force/ Driving Force (3)

The resisting force is offered by the shear parameters of the bank materials and is dependent on the bank geometry. The bank geometry parameters that are used in the analysis are shown in the Table 2.

Table 2. Bank geometry parameters considered in the analysis

Name of the Riverbanks	Initial Bank height H_0(m)	Degradation depth, Δz(m)	Tension crack depth, y(m)
Dhansiri (ML)	2.4	0.25	1.14
Dikhow (SC)	2.6	0.25	1.11
Lohit (ML)	2.5	0.25	1.23
Majuli (SM)	3.5	0.35	1.13

Table 2 shows different initial bank heights of the riverbanks along with degradation depth which are calculated from the data collected from the Water Resource Department of Govt. of Assam. The stability analyses of the riverbanks are expressed in Table 3.

Table 3. Factor of safety and stable slope determination for three different steep bank angles

Riverbank	Bank Angle, i	Weight of the failure block, W_t (kN)	Driving force, F_D (kN)	Resisting force, F_R (kN)	Factor of Safety, FOS	Stable slope at FOS=1.00
Dhansiri	60º 70º 80º	29.82 30.53 31.23	23.41 24.57 25.65	26.31 25.73 25.23	1.12 1.05 0.98	1H:4.3V
Dikhow	60º 70º 80º	26.47 27.20 27.89	21.19 22.26 23.26	23.58 23.11 22.56	1.11 1.04 0.97	1H:4.0V
Lohit	60º 70º 80º	31.00 31.70 32.39	24.14 25.32 26.43	27.41 26.77 26.16	1.14 1.06 0.99	1H:4.7V
Brahmaputra (Majuli)	60º 70º 80º	40.40 42.00 43.29	33.88 35.38 37.54	36.62 36.09 35.61	1.08 1.02 0.95	1H:3.24V

From the Table 3, it is observed that the driving force increases with the increase in the weight of the failure block. The FOS decreases with the increase in bank angle. Also, it is observed that the F_D and the F_R values increase with the increase in the bank height in the Brahmaputra Riverbank with SM type of soil in Majuli.

3 Result and Discussion

From the present slope stability investigation for the selected riverbanks, the banks with silty sand (SM), inorganic silt with low compressibility (ML) and clayey sand (SC) type of soil are found to have effective cohesion ranging from 0.69-0.99 N/cm^2. The angle of internal frictions range from 22.5º to 33º and the submerged unit weights vary from 12-17.02 kN/m^3. The bank heights range from 2.4-3.5 m, degradation depths range from 0.25-0.35 m. For reporting the stability of these riverbanks, the theoretical approach is considered. i.e. a riverbank slope is considered to fail at factor of safety, FOS=1.00. The slope is reported as stable when the FOS>1.00. For FOS<1.00, the slope is unstable. The stability graphs are plotted between the FOS and the bank angle i, as shown in the figure 2.

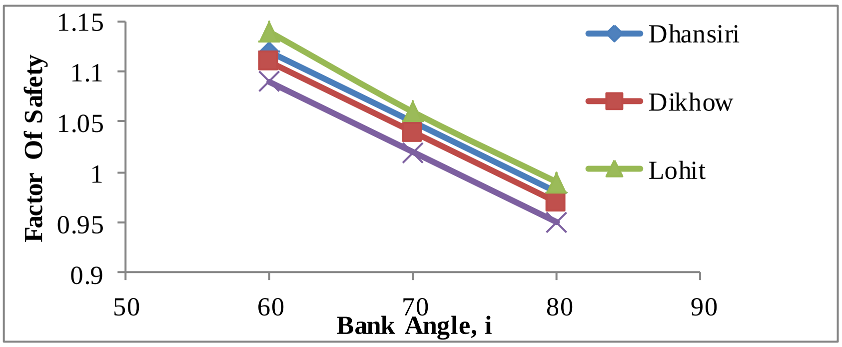

Fig. 2. Slope stability graphs for the riverbanks

From the fig. 2, it is observed that the selected steep riverbank slopes are stable mostly between 1H: 2V to 1H: 3V where FOS is greater than 1.00. The considered left banks of the rivers Dhansiri, Dikhow and the Lohit and the Brahmaputra in Majuli are stable up to slopes 1H:4.3V, 1H: 4V, 1H: 4.7V and 1H:3.24V respectively at FOS=1.00. Slopes greater than 1H: 5V are identified as unstable for these riverbanks.

4 Conclusion

The slope stability analysis of the riverbanks of river Dhansiri, Dikhow and Lohit and the Brahmaputra (Majuli) using the method proposed by Osman and Thorne, is an investigative study to perceive the idea about the slope stability against failure due to massive erosion and flooding in the riverbanks in the upper region of Assam. The study has taken the theoretical condition of factor of safety (FOS=1.00) for this stability analysis process of steep bank slopes. The analysis has concluded that the considered riverbanks with different types of bank material properties are stable at slope range 1H: 2V to 1H: 3V for factor of safety greater than 1. The slopes greater than 1H: 5V are considered to be unstable, where the factor of safety less than 1. The average stable slope range for the considered riverbanks is 1H: 3V to 1H: 5V for the factor of safety equal to 1.00. The slope stability ranges show that, steeper slopes are less stable and hence are more prone to erosion. Therefore, this slope stability analysis can help to identify the most vulnerable slope and to take the necessary protection actions in that site.

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