Study on Stability Analysis of South bank of River Brahmaputra and its Tributaries in the Reaches of Upper Assam

Khagana Buragohain[1] and P.K.Khaund[2]

[1] Jorhat Engineering College, Jorhat, India
khagana.buragohain@gmail.com
[2] Jorhat Engineering College, Jorhat, India
prasannakhaund@yahoo.co.in

Abstract. This work presents the results of an investigation aimed at evaluating the stability of riverbanks along the Brahmaputra River and some of its Southern tributaries - Burhidihing, Disang, Jhanji, Bhogdoi and Kakodonga. Continuous erosion and failure of the alluvial riverbanks have led to serious loss of land, life and property and an attempt has been made to address the same. Soil samples were collected from the seven riverbank sites and the geotechnical characteristics of the samples were determined. Stability analysis was carried out based on a Culman-type analysis of steep, cohesive riverbanks proposed by Osman and Thorne (1988). The Riverbank stability is checked for bank angles ranging from 60° to 85°. Critical bank angles are determined and the Factor of safety (FOS) is computed. Attempts have been made in this work to address the stability of the riverbanks of the proposed sites and thereby help to adopt necessary measures to mitigate such failures.

Keywords: Culman-Type analysis, Bank material property, Bank stability, Critical Bank angles, FOS.

1 Introduction

The River Brahmaputra has been the lifeline of North-Eastern India since time immemorial. This mighty river runs through China, India and Bangladesh for 2880kms. During its course from Kobo to Dhubri, it is joined by about twenty important tributaries on its North bank and fifteen on its South bank. The banks of the river Brahmaputra and its tributaries for the most part are extremely unstable. Several factors contribute towards destabilization of riverbanks, in particular erosion, which has been recognized to have a significant contribution towards the instability. During its recent history of observations, the Assam valley portion of the Brahmaputra River has lost approximately 7.4 % of its land area due to unstable riverbanks. It has caused more major human and economic disasters than the annual flooding prevalent.

In this work, an attempt has been made to identify the unstable riverbanks at the proposed sites of the Brahmaputra River and some of its Southern tributaries by computing the factor of safety (FOS) for the riverbanks. A Culman-type stability analysis of steep, cohesive riverbanks proposed by Osman and Thorne (1988) is adopted for the purpose. The analysis has been done with an aim that remedial measures will be provided to mitigate the unstable river banks identified.

2 Materials and Methodology

2.1 Materials used

The bank soil samples used for the present study were collected from seven locations i.e from near the riverbanks of river Brahmaputra (Bogibeel and Nimatighat), river Burhidihing, river Disang, river Jhanji, river Bhogdoi and river Kakodonga for the study of their geotechnical properties.

2.2 Methodology

Grain size analysis of the bank soil samples were performed as per IS: 2720 (Part 4)-1985. Sieve analysis was conducted for gradation of the respective soil samples. Fig. 1. shows the Gradation curves for different soil samples.

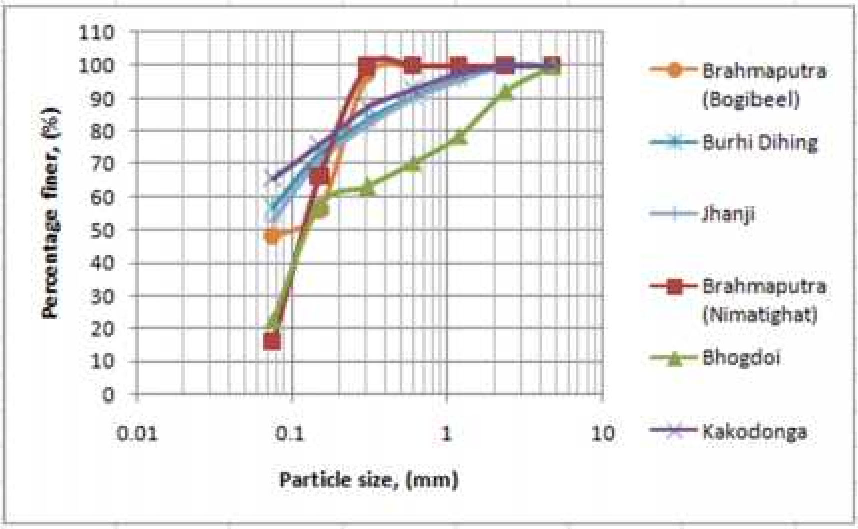


Fig. 1. Gradation curve for different soil samples

The liquid limit, plastic limit and plasticity index were determined following established standard procedure (IS: 2720, Part V, 1965).Table 1.1 shows LL, PL and PI of respective riverbank soil samples.

Table 1.1: LL, PL and PI of respective riverbank soil samples

Riverbank	Liquid limit (LL) (%)	Plastic limit (PL) (%)	Plasticity Index (PI)
Brahmaputra(Bogibeel)	30.45	25.9	4.55
Burhidihing	32	24	8
Disang	36.9	25	13.18
Jhanji	34	25	9
Brahmaputra(Nimatighat)	31	26.2	4.8
Bhogdoi	23.17	18	5.17
Kakodonga	43	20.5	22.5

From the gradation curves (% finer vs grain size) and the plasticity chart, the types of soil were determined. The soil samples under study were grouped as SM (silty sand), ML (silt with low compressibility), MI (silt with medium compressibility) and CI (clay with medium compressibility) types.

The different engineering properties viz. water content, bulk unit weight, dry unit weight, shear strength (cohesion and angle of internal friction) and co-efficient of permeability of the soil samples collected from the field were determined in the laboratory to study the stability of the river banks. Experiments performed for the study were standard proctor test, direct shear test and falling head permeability test. All tests performed were as per the respective IS standards. Fig. 2. shows the compaction curves of the bank material of sample locations. Fig. 3. shows the shear strength parameters (C & φ) of the bank material of sample locations. The engineering properties of the bank material of sample locations are tabulated in Table 1.2.

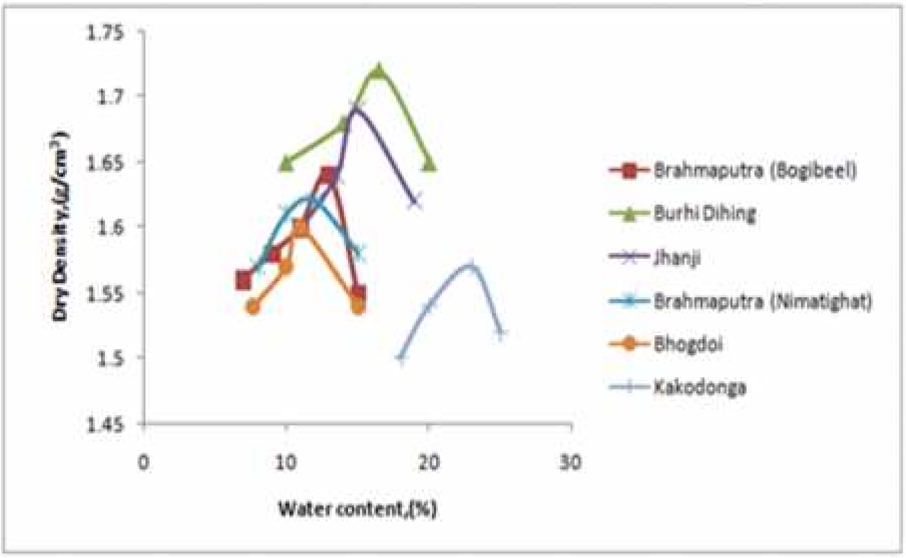


Fig. 2. Compaction Curves of the bank material of sample locations.

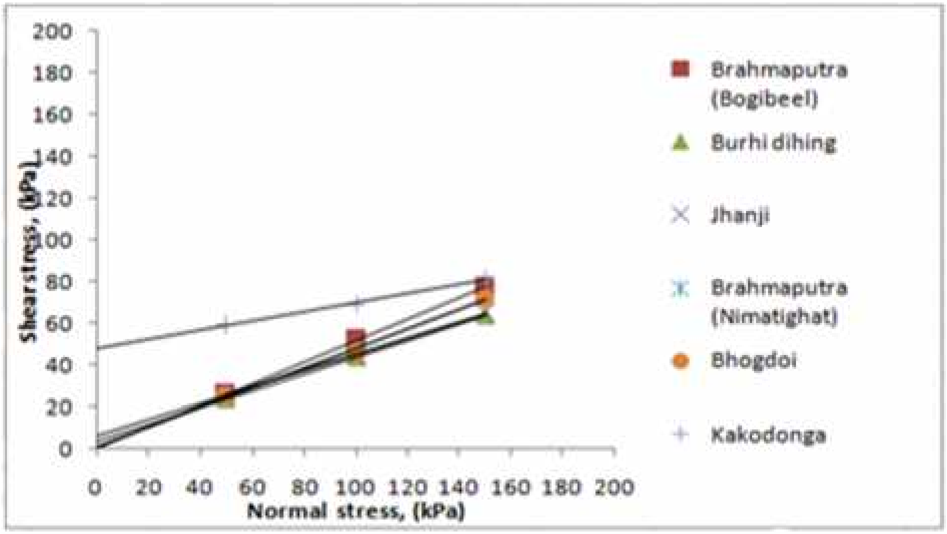
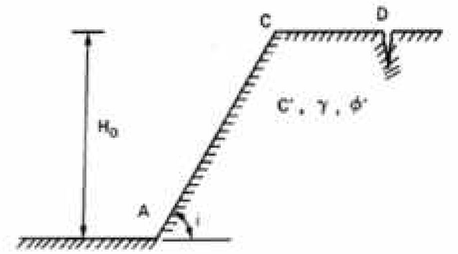


Fig. 3. Shear strength parameters (C & φ) of the bank material of sample locations.

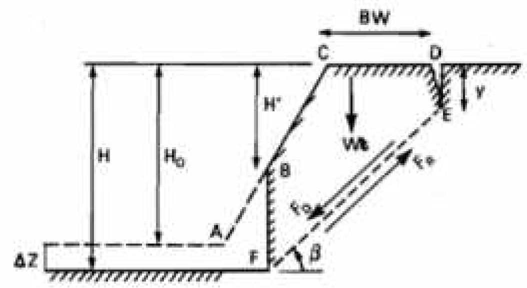
Table 1.2: Engineering properties of the bank material of sample locations

Riverbank	Water content (w) (%)	Maximum dry density, γ_d (g/cc)	Optimum moisture content, Omc (%)	Bulk unit weight, γ (g/cc)	Permeability K, cm/sec
Burhidihing	34	1.72	16.5	1.84	6.93 × 1[illegible]
Disang	38	1.68	17	1.85	1.78 × 1[illegible]
Jhanji	36.54	1.69	15	1.84	4.28 × 1[illegible]
Kakodonga	45.54	1.575	23	1.83	2.56 × 1[illegible]
Brahmaputra (Bogibeel)	32.99	1.64	13	1.744	1.23× 1[illegible]
Brahmaputra (Nimatighat)	33.54	1.62	12	1.73	2.4 × 1[illegible]
Bhogdoi	25.71	1.60	11	1.71	1.60 × 1[illegible]

For the Bank stability analysis, a Culman-type stability analysis of steep, cohesive riverbanks proposed by Osman and Thorne (1988) is adopted. Instability of cohesive riverbanks due to bed degradation and lateral erosion is analyzed herein. These are the two processes that most commonly cause bank instability. The stability of the bank depends on the soil properties and bank geometry. The stability relations developed here on the basis of these parameters can be used to predict the stability of the banks due to bed degradation, lateral erosion or a combination of both these processes.



(a)



(b)
Fig. 4. (a) Riverbank before erosion; (b) Riverbank after erosion
(Osman and Thorne, (1988))

Fig. 4. (a) shows the geometry of a steep riverbank. Fig. 4. (b) shows the geometry after erosion. ΔZ is the degradation depth, H_0 is the initial bank height above the bed, and $H^/$ is the bank height above point B in Figure 4(b). The term *i* is the initial bank angle, β is the angle that the failure plane makes with the horizontal, y is the depth of tension cracking and H is the bank height above the riverbed. The term $C^/$, γ and $\varphi^/$ are the effective cohesion, specific weight and the effective angle of friction respectively.

In this analysis to achieve acceptable results, a few conditions have been considered and assumed for the present study. The soil mass is considered relatively homogeneous and isotropic in nature, so that average soil properties can be applied. The failure surface passes through the toe of the bank. Other types of failure are not considered in the analysis since toe failures are most commonly observed. Factors such as vegetation density and type, water table, surface runoff, and seepage need not be considered directly in the analysis, although these factors may be important at particular locations and might be accounted for by modifying the analysis. Stability relations are developed herein only for steep banks and has been checked for bank angles ranging from 60^0 to 85^0. The soil samples are collected under submerged condition thereby C and φ are taken as effective cohesion and effective angle of internal friction respectively. The degradation depth i.e ΔZ is taken based on field measurements and data collected from Water Resource Department, Govt. of Assam. For the depth of tension cracking, y=K×H, K is taken based on the angle of internal friction obtained for the different bank soil samples. The factor of safety (FOS), is defined as

$$\text{FOS} = \frac{\text{Resisting force}}{\text{Driving force}} = \frac{F_R}{F_D} \quad (1)$$

The resisting force ($\mathbf{F_R}$) is proportional to the effective cohesion $C^{/}$ and angle of friction, $\varphi^{/}$, and is defined as:

$$\mathbf{F_R} = \mathbf{C}^{/}\text{FE} + \text{N} \tan \phi^{/} \quad (2)$$

Where N = component of the weight, W_t, normal to the failure surface = W_t cosβ; and FE = length of the failure surface = (H-y) / sinβ.

Hence,

$$\mathbf{F_R} = \frac{(\text{H}-\text{y})\text{C}^{/}}{\sin\beta} + \mathbf{W_t} \cos\beta \tan\phi^{/} \quad (3)$$

The driving force, $\mathbf{F_D}$, is given by

$$\mathbf{F_D} = \mathbf{W_t} \sin\beta \quad (4)$$

Where $\mathbf{W_t}$ = weight of the failure block, given by

$$\mathbf{W_t} = \frac{\gamma}{2}\left(\frac{H^2-y^2}{\tan\beta} - \frac{H^{/2}}{\tan i}\right) \quad (5)$$

Hence,

$$F_D = \frac{\gamma}{2}\left(\frac{H^2-y^2}{\tan\beta} - \frac{H^{/2}}{\tan i}\right) \sin\beta \quad (6)$$

Failure plane angle,

$$\beta = \frac{1}{2}\{\tan^{-1}[(\frac{H}{H'})^2(1-K^2)\tan i] + \varphi\} \quad (7)$$

If FOS computed is less than 1, the bank slope is considered to be unstable and if greater than 1, the bank slope is considered to be stable. If FOS = 1 then the bank slope is considered to be critical. Table 1.3 shows the parameters considered for checking the riverbank stability. Table 1.4 shows the computation of FOS for different bank angles of respective riverbanks.

Table 1.3: Parameters considered for checking the stability of riverbank

Riverbank	Degradation depth, ΔZ, (m)	Tension crack depth, y (m)	Cohesion, C (kN/m^2)	Angle of internal friction,φ
Brahmaputra (Bogibeel) (SM)	0.35	1.35	7.5	32
Kakodonga (CI)	0.15	1.29	48	20
Brahmaputra (Nimatighat) (SM)	0.3	1.29	6.5	32.23
Bhogdoi (SM)	0.15	0.85	7.8	31
Burhidihing (ML)	0.25	1.16	10	24.23
Jhanji (ML)	0.15	1.14	9.9	23
Disang (MI)	0.20	1.22	10.5	22

Table 1.4: Computation of FOS for different bank angles of respective riverbanks

Riverbank	Bank angle, i	Bank height, H,(m)	Critical bank angle, i_{cr}	Failure plane angle, β	FOS
Brahmaputra (Bogibeel) (SM)	60°	4	76.12	54.44°	1.15
	65°			55.30°	1.09
	70°			56.11°	1.05
	75°			56.87°	1.01
	80°			57.59°	0.97
	85°			58.30°	0.94

Kakodonga (CI)	60	2.5	-	49.62	3.84
	65			50.64	3.70
	70			51.58	3.57
	75			52.48	3.45
	80			53.34	3.34
	85			54.18	3.24
Brahmaputra (Nimatighat) (SM)	60	4	72	54.99	1.12
	65			55.85	1.06
	70			56.64	1.02
	75			57.39	0.98
	80			58.11	0.94
	85			58.81	0.91
Bhogdoi (SM)	60	2.5	73.44	55.93	1.08
	65			56.80	1.05
	70			57.61	1.02
	75			58.37	0.98
	80			59.09	0.96
	85			59.80	0.93
Burhidihing (ML)	60	2.5	80	52.14	1.14
	65			53.09	1.11
	70			53.96	1.06
	75			54.79	1.03
	80			55.58	1.00
	85			56.35	0.97
Jhanji (ML)	60	2.5	80	51.44	1.15
	65			52.39	1.11
	70			53.29	1.06
	75			54.13	1.03
	80			54.94	1.00
	85			55.72	0.97
Disang (MI)	60	2.5	81	50.87	1.15
	65			51.84	1.10
	70			52.75	1.07
	75			53.59	1.04
	80			54.42	1.01
	85			55.21	0.97

3. Results and Discussion

The bank stability analysis has been done by determining the driving force and resisting force based on the bank material properties of the riverbank soil samples and bank geometry. Stability has been checked for bank angles ranging from 60^0 to 85^0. It is seen from the analysis carried out that an increase in bank height, degradation depth and tension crack depth causes an increase in the driving force. Failure plane angles have been determined for each bank angle for the analysis and it is seen that it increases as the bank becomes steeper. Critical bank angles have also been determined for different riverbanks based on the FOS obtained. It is seen from Fig. 5. and Fig. 6. that FOS decreases as bank becomes steeper. The Brahmaputra (Nimatighat) riverbank (SM) is found to be the least stable (Fig. 5.) with Kakodonga riverbank (CI) being the most stable (Fig. 6.). The SM riverbank is found to be stable for a critical bank angle (FOS =1) of 72^0 beyond which the bank becomes unstable. The CI riverbank is found to remain stable even at an angle of 90^0. This can be attributed to the fact that clayey soils have cohesion in them thus enabling them to even stand laterally unsupported to a particular depth. The Brahmaputra (Bogibeel) and Bhogdoi riverbank composed of SM soil is found to be stable for a critical bank angle of 76.12^0 and 73.44^0. Similarly the Burhidihing and Jhanji riverbank composed of ML soil is found to be stable for a critical bank angle of 80^0. The Disang riverbank composed of MI soil is found to be stable for a critical bank angle of 81^0.

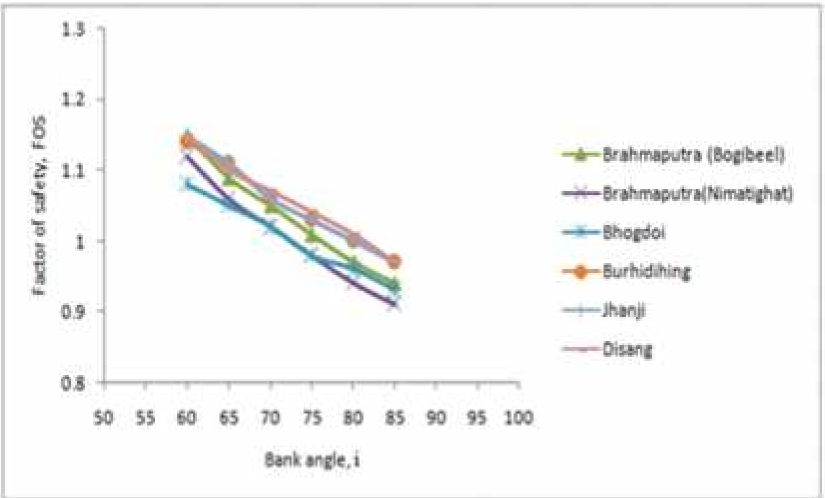


Fig. 5. Stability graph of respective riverbanks.

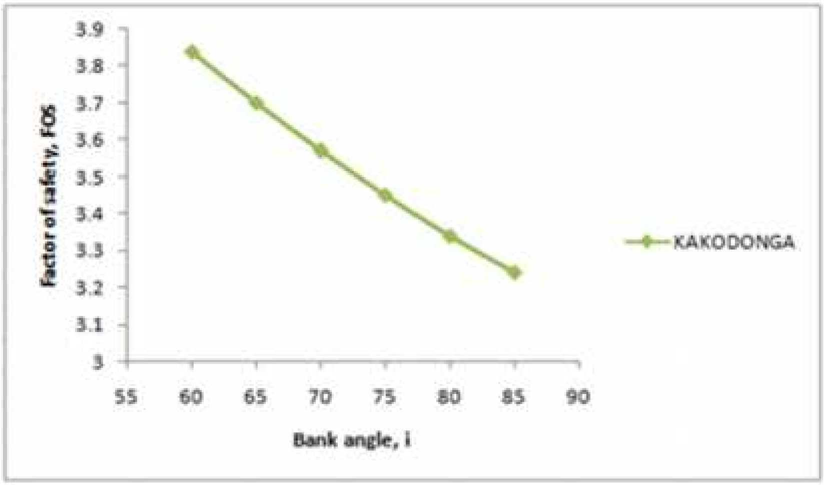


Fig. 6. Stability graph of Kakodonga riverbank.

4. Conclusion

The geotechnical properties of the bank soil samples and bank stability analysis along the Brahmaputra River and its tributaries have provided valuable information in relation to instability of riverbanks. Almost all the riverbanks under this study were found to be constituted of SM, ML and MI soils having low plasticity index (PI) and low cohesion value making it erodible except the sample of Kakodonga riverbank (CI) which was found to be more cohesive having a plasticity index (PI) > 15. The permeability of the bank soil samples were also found to be very low. The bank stability analysis carried out based on Culman's method showed that the Brahmaputra (Nimatighat) riverbank composed of SM soil was the least stable with Kakodonga riverbank (CI) the most stable. The riverbank (SM) was found to be stable for a critical bank angle (FOS =1) of 72^0 beyond which the bank became unstable. The riverbank (CI) was found to remain stable even at an angle of 90^0. This could be attributed to the fact that clayey soils have cohesion in them thus enabling them to even stand laterally unsupported to a particular depth. A much more promising and accurate result can be obtained by adopting the FEM methods. In FEM methods the FOS for critical bank angle is automatically obtained, i.e trial and error calculations are not required to find out the critical bank angle because the failure occurs through the zone of weakest material properties and automatically the critical bank angle is determined. Also, displacements, stress and strains at various nodes in the slope domain are obtainable from FEM method. The technique also makes it possible to visualize the development of failure mechanisms. However due to the very limited experience engineers have had with the methods of FEM and the limited published information on the quality/accuracy of its results it has not received widespread acceptance among geotechnical engineers. The stability of riverbanks is a multifaceted issue thereby it is expected that this type of integrated study along with other geomorphic studies will help to allocate necessary base line information relating to instability of riverbanks. Also the problem of unstable riverbank slopes can be mitigated by 1) strengthening the bank: Riverbank riprap and retaining walls, Bioengineering and vegetation, 2) reducing hydrodynamic force: Flow control structure. Such mitigation measures to check and control the unhindered loss of land, life and property due to riverbank erosion can be undertaken.

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