Design of a Bank Protection System on River Brahmaputra at Jamuguri

This paper presents the design of a bank protection system on the River Brahmaputra at Jamuguri. Extreme flood condition was analysed using a two-dimensional depth averaged hydrodynamic numerical flow model.

River Brahmaputra exhibits unique fluvial morphological behavior throughout its course. The river is highly dynamic and causes large scale bank erosion, almost round the year. In 2007, the Inland Water Ways Authority of India (IWAI) approached IIT Guwahati to design a bank protection system at their proposed inland port terminal, on Brahmaputra at Jamuguri, Assam. IIT Guwahati jointly with IWAI carried out comprehensive measurements of hydrodynamics, morphology and geotechnical properties in the proposed site. Based on these inputs a numerical model study was carried out to obtain the design parameters. Following which a detailed design of the bank protection system was carried out, the details of which is presented in this paper.

Methodology

Fig. 1 shows the satellite imagery of the proposed site. The proposed terminal is almost at the summit of a meander. Due to high current coupled with helical vortex the river has high potential for bank erosion.

Hydraulic data including bathymetric, high flood level, discharge data, flow velocity, water sample and bed soil were collected at different river flow regimes. The survey was conducted over a river reach of 5 km length with transect spacing interval @ 200 m near the terminal (C/L) and @ 500 m in both upstream (U/S) and downstream (D/S). The depth of water is about 15m near the terminal site. The maximum velocity of water recorded is 2.337 m/s.

A two-dimensional depth averaged hydrodynamic numerical flow model (MIKE-21 C) was developed to study the velocity distribution and potential zone of erosion, under extreme floods. Fig. 2 shows the modeling mesh representing the simulation area, overlaid on satellite imagery. Considering the highest recorded flood level, the most probable extremely flood condition was analysed using the validated model. From this analysis the maximum velocity at the terminal, during the extreme flood, is found to be 4.04 m/sec and the depth average velocity at this location is found to be 3.1 m/sec. Therefore, the design maximum velocity was taken as 4.04 m/sec.

The soil at the terminal site is of fine soil type with interlaced sand layer. For the sandy-silt soil the angle of internal friction ($\phi$ peak) is found to be 22° and the cohesion (c) is found to be 40 kN/m$^2$. For the interlaced sand layer the angle of internal friction ($\phi$ peak) = 30°. A slope stability analysis was carried out based on which the slope angle of the bank is suggested to be about 30°.

Design Procedure

Any river bank protection system has primarily two different purposes to serve. First, it should be able to dissipate the flow energy. Secondly, it should be able to protect the bank soil against erosion. In the process it itself must be stable, therefore
it can be considered as the third potential criteria while selecting a suitable protection system. The present site being on the river meander, with high flow velocity and thereby susceptible to large scouring, is expected to undergo substantial change in topography. Therefore the protection system is expected to be subjected to large differential settlement. Hence it should be flexible enough to accommodate the large deformation induced due to differential settlement, at the same time, should be strong enough against the induced forces. Gabion mattress is widely used, world wide, in such scenario. The same has been adopted in the present case. The gabion mattress being a porous structure, allows dissipation of the flow induced pressure, thereby provides relatively better stability and lower design thickness than the conventional non porous structures.

The hydraulic model simulation shows that the flow velocity vectors are dashing on the river bank up to a distance of about 400 meters, down stream, from the center line of the proposed terminal. Beyond, the flow gets deviated into the river thereby keeping the bank free from the impact of flow. Therefore, in the down stream, the bank protection should be up to 400 meters of length from the centerline of the terminal along the river bank. Ideally, in the upstream of the terminal the bank protection should be at least 400 meters length from the center line of the terminal. In the upstream side it was observed that over 250 meters the flow vectors striking the river bank have died down to much less magnitude. This is attributed to the dissipation of the flow energy in the Nalla. Hence protection of about 250 meters in length from the center of the terminal should be good enough at this stage. In future, if any unusual bank erosion takes place to the upstream of the terminal, additional length of protection can be provided at that time. Therefore, at this stage, bank protection to be provided should be of 400 meters length in the downstream and of 250 meters in the upstream, from the center line of the proposed terminal. The total bank protection length therefore should be a total of 650 meters.

All along the bank protection, additional gabion mattress is to be provided on the river bed, flush with the bank, to protect the toe of the bank from scour, whose failure would otherwise lead to the instability of bank protection system. The width of the gabion apron should extend over a distance of a minimum of two times the anticipated depth of scour. This will ensure that the gabion apron reaches just beyond the outer limit of the anticipated scour hole that may form. Since there is no reported literature for estimating the maximum scour depth in river Brahmaputra, the formula proposed by Maynord (1996) in case of Mississippi river, whose flow characteristics are close to that of river Brahmaputra, has been used in estimating the maximum possible scour depth in the present case, as presented below.

\[
\frac{D_{mxb}}{D_{mnc}} = SF \left[ 1.8 - 0.051 \frac{R_c}{W} + 0.0084 \frac{W}{D_{mnc}} \right]
\]

Where,
- \(D_{mxb}\) = maximum water depth in the river bend
- \(D_{mnc}\) = average flow depth at the upstream of the river bend
- \(SF = 1.2\)
- \(R_c = 2460\ m.\)
- \(W = 630\ m.\)

Substituting these values in Eq.1, \(D_{mxb}\) is found to be = 17.1 m. Since bank height is about 7 meters the depth of scour hole = 17.1 - 7 = 10 m.

Width of gabion apron = twice the depth of scour hole = 2 \times 10 = 20 m.

Hence the width of gabion apron to be provided on river bed flush with the bank for protecting the toe against bed scour = 20 meter.

For stability of the gabion mattress size of infill rock has to be designed. Maynord (1995) based on test results and field data suggested a procedure for finding out the desired rock size range to be filled in the gabion. Based on this approach the average size of the rock infill in the gabion mattress, in the present case, is found to be 0.13 m, with minimum and maximum size range of 0.1m-0.175 m. Maynord (1995) based on results of experiments conducted by Simons et al. (1984) has proposed that the thickness of gabion mattress should be a minimum of two times the average diameter of rock infill. For the present case the average diameter of the rock fill is 0.13 m. Therefore the minimum thickness of the gabion mattress should be 0.26 m (i.e. 2 \times Dm = 2 \times 0.13). Since the computed thickness is not equal to the standard gabion thickness available in the market, the next higher size is to be adopted. Hence for bank protection, the gabion apron.
mattress thickness should be 0.3 m. For the toe mattress, to be provided on river bed as an apron, all the conditions are same as that of bank except that the local vertex influence might induce further turbulence. In view of this, the thickness of the toe mattress is taken as the next available higher size = 0.5m.

A geotextile filter is designed such that it would have adequate permeability to drain out the design discharge at the same time its pore size should be such that it should be able to retain majority of upstream soil to avoid soil piping. It is found that the permittivity of the geotextile at the design surcharge pressure (i.e. 7.8 kN/m²) should not be less than 1.218 × 10⁻⁴ sec⁻¹. For the sandy silt soil, less than 50% of soil mass are fines (i.e. finer than 75 micron). The site is subjected to severe wave attack. Therefore, as suggested by Luettich et al. (1992) the O₉₅ size of the geotextile should be less than d₅₀ of the soil mass. For the present case the d₅₀ of the sandy-silt soil is 0.08mm. Hence, the O₉₅ size of the geotextile filter should be less than 0.08 mm.

Since the interlaced sand layer has fines fraction lesser than the sandy-silt soil, the same geotextile, with O₉₅ < 0.08 mm, would be able to properly retain the soil mass. Hence, geotextile with O₉₅ < 0.08 mm, should be adopted for the filter layer.

Since the river bed, presently is sloped and this slope would increase substantially in the event of scouring taking place, the gabion mattress should be anchored adequately, against the impending sliding. A suitable nailing arrangement has been designed for the same. Fig.3 depicts atypical section of the designed bank protection system.

Summary

The present site being on the river meander, with high flow velocity and thereby susceptible to large scouring, is expected to undergo substantial change in topography. Therefore the protection system is expected to be subjected to large differential settlement. Hence it should be flexible enough to accommodate the large deformation induced due to differential settlement, at the same time, should be strong enough against the induced forces. Gabion mattress is widely used, world wide, in such scenario. The same has been adopted in the present case. Considering the highest recorded flood level, the most probable extremely flood condition was analysed using a two-dimensional depth averaged hydrodynamic numerical flow model. Based on which the design maximum velocity was taken as 4.04 m/sec. The average size of the rock infill in the gabion mattress, in the present case, is found to be 0.13 m, with minimum and maximum size range of 0.1m-0.175 m. A geotextile filter is designed such that it would have adequate permeability to drain out the design discharge at the same time its pore size should be such that it should be able to retain majority of upstream soil to avoid soil piping.

Reference