Damages to railway embankments during the 1998 flood in Bangladesh

Dégâts aux talus du chemin de fer pendant les inondations de 1998 au Bangladesh

A.Siddique, M.A.Ansary & A.M.M.Safiullah – *Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh*

ABSTRACT: Bangladesh experienced one of the worst floods of the century in terms of severity, destructiveness and duration in 1998. In this paper, nature of damages that occurred in two railway embankments have been presented. Design of permanent remedial works for future protections of these embankments has been suggested. The proposed protective work consists of an anchored geotextile layer placed on re-formed compacted embankment slope of 1 : 2 (vertical:horizontal), overlain by 150 mm of aggregate drainage layer and topped by 300 x 300 x 200 mm cement concrete blocks. The cover layer, the filter layer and the geotextile are protected at the toe by a brick wall. Local stability of the embankments has also been assessed.

1 INTRODUCTION

Flood is a recurring problem in Bangladesh. The floods of 1954, 1955, 1974, 1987, 1988 all caused enormous damage to properties and considerable loss of life. In the middle of 1998, Bangladesh experienced the most devastating and prolonged flood in its history that caused serious disruption of the economy of the country. The extent of damage caused by this flood is estimated to be around 3.0 billion US dollars (FFWC 1998).

During the 1998 flood significant damages occurred to various earth structures. In this study, two railway embankments, damaged due to 1998 floods, have been investigated. Nature of the damages occurred to the embankments are presented in this paper and remedial measures for future protection of these embankments are sugggested. Geotechnical properties of the embankment soils are also discussed.

2 GENERAL CONDITION OF THE PROJECT AREA

2.1 *Physical and hydro-geological conditions*

The railway embankments requiring protective work is located within the Chalan Beel area. The railline within this area run across a very low lying plain and the height of embankment varies between 13 ft to 20 ft. The higher elevation relates to sections near bridge crossings. The highest flood level, average normal flood level and, variation in ground level and formation level of the embankment for the two routes are shown in Table 1. The datum shown is that used by Bangladesh Railway Authority.

These railway embankments are very old and therefore it is expected that most ground settlement had taken place. There is no problem with settlement except for some areas in Natore-Santahar route where some continuous subsidence is reported to have been observed. The embankments lie above water level during the dry period of the year. But during the monsoon, the water level rises very close to the embankment top. The highest flood level is reported to be RL. 38.5 ft. (railway datum) within the Ishurdi-Sirajganj route and RL. 97.00 ft. (railway datum) within the Natore-Santhahar route. During the 1998 flood, at some locations, the embankment nearly overtopped and rail communication had to be stopped for a few days. Vast water surface of the Beel area was subjected to wind pressure generating significant amount of waves that are responsible for major damage of the embankment slope in the form of soil erosion and slips on the slope.

Table 1. The various reduced levels (railway Datum) for the two routes of railway embankments.

Reduced level (railway datum)	Route	
	Ishurdi-Sirajgonj	Natore-Santahar
Highest flood level (ft)	38.50	97.00
Average normal flood level (ft) 3	4.50	92.50
Ground level (ft)	25.50-29.25	83.50-91.00
Formation level (ft)	39.00-45.00	97.00-105.80

2.2 *General soil condition at the embankment sites*

The embankment soil within the areas visited appeared to vary from clayey silt to silty clay with little or no sandy deposits. Laboratory investigations on eight samples from Ishurdi-Sirajganj route and six samples from Natore-Santahar route of the railway embankment were conducted to evaluate the soil properties at the two sites. Laboratory tests included index property tests, grain size distribution tests and Standard Proctor tests. These tests were carried out following the procedures specified by American Society of Testing Materials (ASTM 1984, 1988, 1989) and British Standards (1975).

Sand, silt and clay fractions of the soil samples were determined from the grain size distribution curves. The index properties, grain size characteristics, and values of optimum moisture content and maximum dry density of the samples from different sections along Ishurdi-Sirajganj route and Natore-Santahar route are shown in Table 2. The soil samples at the two routes were classified according to Unified Soil Classification System (USCS). With the exception of one sample (CH), the soil samples at different sections of Ishurdi-Sirajganj route are either clays of low to medium plasticity (CL) or silts of low to medium compressibility (ML). The soil samples at various sections from Natore-Santahar route are in general clays of high plasticity (CH) but also contains clays of low to medium plasticity (CL). The values of maximum Standard Proctor dry density for samples at Ishurdi-Sirajganj route varied between 102.4 lb/ft^3 and 106.7 lb/ft^3 with an average of 105.1 lb/ft^3 while that for Natore-Santahar route varied between 101.9 lb/ft^3 and 109.5 lb/ft^3 with an average of 104.2 lb/ft^3. Organic matter content test on three samples from Natore-Santahar route showed a maximum organic content of only 0.32%, indicating that the samples contained almost no organic matter.

Shrinkage characteristics of clays is a reliable index to determine their degrees of expansion (Chen 1975). The swelling potential is presumed to be opposite property of linear shrinkage.

Table 2. Geotechnical properties of soil samples collected from two railway routes.

Sample location (km)	Liquid limit L_w (%)	Plasticity Index I_p (%)	Linear shrinkage (%)	Sand (%)	Silt (%)	Clay (%)	Optimum Moisture content (%)	Max. dry density γ_d (lb/ft^3)
Ishurdi-Sirajganj route								
246	52	26	10	8	71	21	21.3	102.4
247	41	15	6	16	76	8	19.8	103.9
248	38	13	6	16	75	9	18.5	106.7
249	44	20	9	7	82	11	19.1	106.7
250	43	18	8	15	71	14	18.8	105.2
251	41	14	6	11	80	9	19.6	103.9
252	36	15	6	27	67	6	15.6	106.7
257	36	10	5	12	81	7	15.3	105.0
Natore-Santahar route								
250	39	10	3	10	81	9	17.3	104.5
251	53	35	13	4	65	31	24.4	98.5
252	38	14	5	37	51	12	16.4	109.5
257	45	24	10	10	66	24	17.2	105.8
258	58	40	11	3	65	32	19.4	104.8
261	55	36	12	10	60	30	21.3	101.9

Linear shrinkage	Degree of expansion	Danger of severity
>14	High	Critical
10-14	Medium	Marginal
0-10	Low	Non-critical

On the basis of previous data for linear shrinkage of Bangladesh soils, a criterion for the degree of expansion proposed by Hossain (1983) is shown below.

Table 2 shows that the values of linear shrinkage of samples from Ishurdi-Sirajganj and Natore-Santahar routes varied from 5 to 10 and 3 to 13 respectively. Based on the above criterion, the probable degree of expansion of the soil samples of from Ishurdi-Sirajganj route and Natore-Santahar route could be considered to be low and low to medium respectively. Therefore problems associated with expansion and shrinkage is not expected for these soils.

3 NATURE OF DAMAGE DURING 1998 FLOOD

From a study of the embankment section profiles and from a video recording, it appears that most of the damage have resulted from wave action over the unprotected embankment slopes. Figure 1 shows a typical embankment section for Ishurdi–Sirajganj route after the 1998 flood. The section shows considerable erosion of the existing slopes. From an analysis of the available cross-sections, it was noted that most of the damage occurred above RL. 30 ft (railway datum) in Ishurdi-Sirajganj route and above El 84 ft (railway datum) in the Natore-Santahar route. There was no evidence of scour at the toe of the embankment suggesting that the instability of the embankment was mainly associated with high water level and wave action. It is therefore necessary that protection measures to protect slopes against wave erosion be taken to slopes lying above RL.30 ft (railway datum) at Ishurdi-Sirajganj route and that above RL. 84 ft. at Natore-Santahar route. Local conditions however, may require variations to above lowest point of coverage. The actual requirement should be determined from field survey and statistical interpretation of lowest and highest water levels and wave height.

Within the railway embankment areas studied, no evidence of deep sliding was observed. At some locations longitudinal cracks at top of the embankment were noted which appeared to be instability due to loss of soil from toe and mid portion of the embankment slope. There was evidence of very little scour near the embankment borrow pit areas.

From Figure 1, it is apparent that originally the embankment had an uniform side slope of 1 (Vertical) : 2 (Horizontal), which has now been considerably modified by process of removal of soil by erosion, particularly within the zone of waves action. The present slope shown in Figure 1 reflects typical S-shaped profile usually generated by wave action on a slope.

The general strategy for preventing damage to embankment during flood is to provide appropriately designed revetment to cover the embankment slope within the portion vulnerable to wave attack. In addition to wind generated waves, waves may also generate from boats navigating close to the embankment which should be considered in designing the revetment work.

At one location, revetment system with aggregate filter and cement concrete (CC) blocks were installed by the Railway Authority. The protective system appeared to be quite effective against wave attack during the 1998 flood. But at some points damage to revetment system was noticed due to loss of soil particles underneath aggregate filter resulting in subsidence of the CC blocks. Therefore adoption of a design similarly that already used may be considered adequate provided provision is made to prevent migration of soil particles underneath the CC blocks. Use of a geotextile layer should serve such purpose.

4 DESIGN OF THE PROPOSED PROTECTIVE WORKS

4.1 *Block size*

From Table 1, considering the elevation of ground level and the highest flood level the water depth near the railway embankment will be between 2.7 m (9 ft) and 4 m (13 ft) at Ishurdi-Sirajganj route and between 1.8 m (6 ft.) and 4.1 m (13.5 ft.) at Natore-Santahar route. The maximum wave height in shallow water can be found from the following expression:

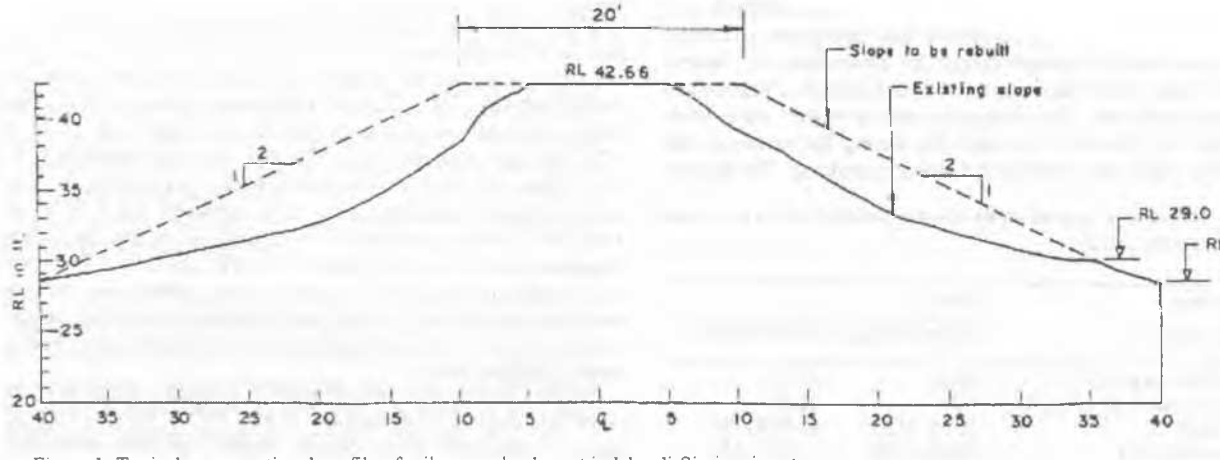

Figure 1. Typical cross-sectional profile of railway embankment in Ishurdi-Sirajganj route.

$H_s=0.5h$ (1)

where, H_s = wave height; h = depth of water at the toe of the revetment. The corresponding wave height as per Equation (1) below would be between 1.4 m and 2 m (4.5 ft and 6.5 ft) for Ishurdi-Sirajganj route and between 0.9 m and 2 m (3 ft and 6.75 ft) for the Natore-Santahar route. The above height of waves appeared to be on the higher side compared to the video recordings seen for 1998 flood.

The Basic Wind Map in Bangladesh National Building Code shows a wind speed of 60 m/s for the study area. This speed represents 50 years building load under stormy condition. Therefore under normal peak flood condition a wind speed of 30 m/s may be assumed in calculating wave height. Using wave forecasting diagram for deep water waves (PIANC 1987) and assuming wind speed of 30 m/s and a fetch length of 3 km in the wind direction, the height of waves travelling in deep water can be estimated. Based on above values, the significant wave height is about 0.9 m. With this value of wave height, a period of 3.1 seconds (from wave fore-casting diagram), a 1:2 slope and using Equation (2), the wave breaking parameter value of 2.04 has been obtained. Hence, the wave breaking characteristics may be considered as collapsing to plunging. The wave braking parameter is given by the following expression:

$$\xi=\frac{\tan\alpha}{\sqrt{H_s/L_0}}=1.25\frac{T}{\sqrt{H_s}}\tan\alpha \tag{2}$$

where, α = bank slope; H_s = significant wave height; L_0 = wave length in deep water; T = wave period. The value of ξ determines how the wave breaks which in turn effects the stability of the cover layer and height of wave run-up. Here, behaviour of concrete blocks under current attack is not important, wave attack usually provide the determinant load. Hence the thickness is governed by wave considerations.

The thickness required for the CC cover blocks may be estimated from Pilarczyk method using the following equation:

$$\frac{H_s}{\Delta_m D}=\psi\frac{Cos\alpha}{\sqrt{\xi}} \tag{3}$$

where, D = thickness of block; ψ = strength coefficient; ξ = wave breaking parameter given by Equation (2); Δ_m = relative block density = $(\rho_c-\rho_w)/\rho_w$; ρ_c = density of block unit; ρ_w = density of water.

The strength coefficient depends on type of wave, the type of block and the type of sublayer (if any). For loose blocks on granular sublayer on good clay, the value of ψ lies between 5 and 6 (PIANC 1987). Using the strength coefficients ψ equal to 5.5 and a 1:2 slope (α = 26.57°) and ξ = 2.04 and a relative density of 1.4 for blocks in Equation (3), a CC Block thickness of 187 mm is obtained. Hence a thickness of 200 mm suggested for the CC blocks of the cover layers has been proposed.

4.2 *Stability of block revetment*

If the geotextile filter and coverlayer are of relatively low permeability compared with the subsoil, they will be subject to uplift forces caused by the outflowing water. If the uplift forces are not fully counteracted by the self-weight of the filter and cover layer then the consequences of uplift pressures are severe. Firstly the effective weight of the cover layer is reduced, reducing friction between it and the underlying layer, so that sliding of the coverlayer becomes possible. Secondly, although the effective normal stresses within the filter layers and subsoil are reduced, the shear stresses (due to self-weight) remain the same hence causing the possibility of S-shaped deformations of the embankment. The determination of uplift pressure is therefore an important part of the design procedure for revetment stability.

Determination of uplift pressures is rather difficult in view of the number of parameters, which are involved. As a guideline no uplift pressure will occur if the permeability of each layer beneath and including the coverlayer is 20 to 50 times greater than the permeability of the underlayers (including the subsoil). Since the 150 mm thick granular sublayer to be used will consists of particles ranging from 6 mm to 25 mm, this layer will have permeability much higher than the geotextile and also due to 25 mm gap between CC Blocks much of the uplift pressure will be released. Above considerations coupled with use of a toe wall will provide adequate stability for the revetment blocks.

Table 3. Values of various parameters used to assess susceptibility to downslope migration of soils of two railway routes.

Sample location (km)	Percentage of particles ≤0.06 mm	Uniformity coefficient $Cu=D_{60}/D_{10}$	Percentage of particles in the range of 0.02 mm to 0.10 mm	Ratio of clay fraction to silt fraction	Plasticity Index	Remark*
Ishurdi-Sirajganj route						
246	92	20.6	19	0.30	26	S
247	84	12.3	47	0.11	15	S
248	84	14.6	54	0.12	13	S
249	93	13.6	33	0.13	20	S
250	85	15.4	29	0.20	18	S
251	89	10.4	42	0.11	14	S
252	73	11.9	45	0.09	15	S
257	88	8.8	48	0.09	10	S
Natore-Santahar route						
250	90	11.3	52	0.11	11	S
251	96	-	18	0.48	40	N
252	63	56	54	0.24	14	S
257	90	-	20	0.36	24	S
258	97	-	13	0.49	42	N
261	90	-	16	0.50	36	N

* S = Susceptible to downslope migration; N = Not susceptible to downslope migration

4.3 *Requirement of granular sublayer*

An investigation in to the susceptibility of the embankment soils to downslope migration were carried out in order to check the rquirement of granular sublayer. The numerical values of different parameters used to identify susceptibility to downslope migration of the soils from Ishurdi-Sirajganj and Natore-Santahar routes are shown in Table 3. These parameters were compared with the recommended identification criteria to examine whether downslope migration of soil particles will occur. It has been found that majority of the samples are susceptible to downslope migration. It, therefore, appeared that measure should be taken to prevent downslope migration of soil particles at both routes of the railway embankment. This can be achieved by incorporating a granular sublayer of intermediate permeability (greater than permeability of the subsoil) between the geotextile filter and the coverlayer of CC blocks. A granular sublayer of 150 mm thick has been suggested to provide between the geotextile and the CC coverlayer for the prevention of downslope migration of particles.

4.4 *Local stability*

Local stability condition include, local sliding, local bearing failure, scour, piping, soil migration, liquefaction, pumping, settlement and heave. The sliding condition may develop in the interface between present slope and the bottom of the reconstructed fill of the embankment. Analysis of such condition would require knowledge of available shear strength at the soil interface. As the soil at this interface is above water table and dry, it is unlikely to develop sliding condition. Also use of 90% Proctor Compaction should provide adequate resistance against local sliding condition. Placement of toe wall also would provide additional resistance against local sliding. It is however, recommended that a slope stability analysis be carried out on the basis of available soil strength before construction is started.

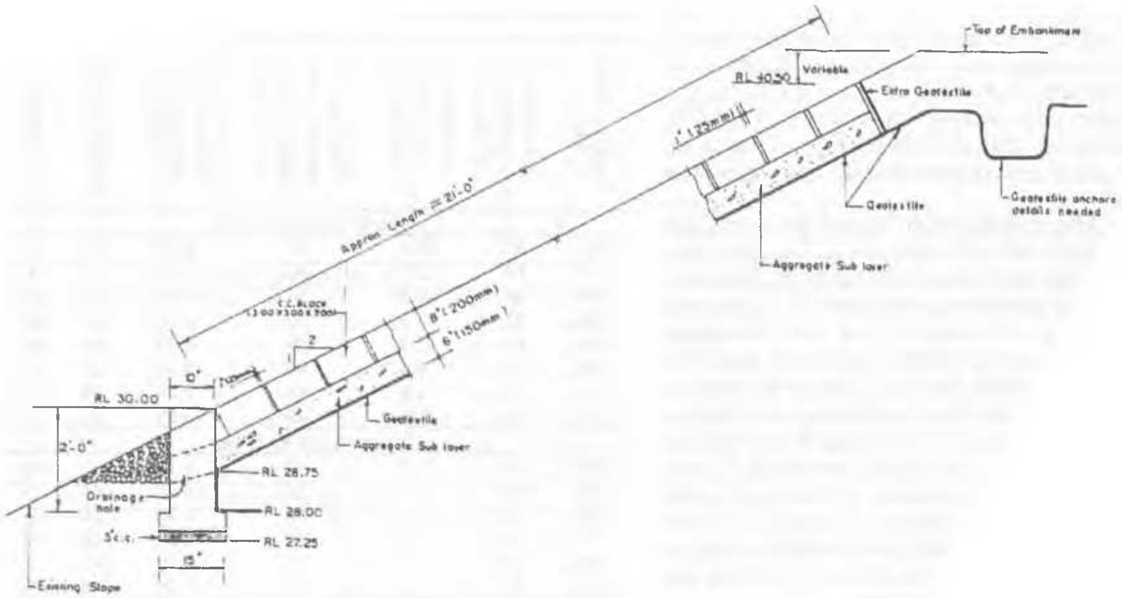

Figure 2. Suggested typical section of permanent protection works for railway embankments.

As there has been no recorded incidence of local scouring, it is not considered important in the design of the protective work. Also it has been observed from the embankment sections that the most of the damage occurred above ground level.

Provision of geotextile will eliminate possibility of piping, soil migration and pumping of soil under the cover layer. From the geotechnical analysis it is found that the soil within the project area has low to medium expansion potential. Hence, little deformation and volume change is expected on wetting and drying.

4.5 *Design details*

Proposed revetment section drawings for the railway embankments is shown in Figure 2, which shows approximate volume of work at standard sections. The reduced levels shown in these figures are based on interpretation of average conditions made from sectional drawings received from Bangladesh Railway Authority.

5 CONCLUSIONS

Damages occurred to two railway embankments during the 1998 flood have been presented in this paper.The railway embankments are located within the Chalan Beel area along two routes namely, Ishurdi-Sirajganj route and Natore-Santahar route.. During the 1998 flood, at some locations, the embankment nearly overtopped and rail communication had to be stopped for a few days. Vast water surface of the area had been subjected to wind pressure generating significant amount of waves that are responsible for major damage of the embankment slope in the form of soil erosion and slips on the slope. From a study of the embankment section profiles and from the video recording, it appeared that most of the damage resulted from wave action over the unprotected embankment slopes.

For the prevention of damages to the embankments during flood appropriately designed revetment to cover the embankment slope within the portion vulnerable to wave attack was essential. At one location of the embankment, revetment system with aggregate filter and cement concrete (CC) blocks were installed. The protective system appeared to be quite effective against wave attack during the 1998 flood. But, at some points damage to revetment system was noticed due to loss of soil particles underneath aggregate filter resulting in subsidence of the CC blocks. Therefore, adoption of a design similarly that already used has been recommended, provided provision is made to prevent migration of soil particles underneath the CC blocks. The suggested protective work consists of an anchored geotextile layer placed on re-formed compacted embankment slope of 1 : 2 (vertical:horizontal), overlain by 150 mm of aggregate drainage layer (and topped by 300 x 300 x 200 mm CC blocks. The design thickness (200 mm) of the CC blocks is based on the wind speed, wave height and the fetch length catchment. The cover layer, the filter layer and the geotextile are protected at the toe by a brick toe wall. The CC blocks are to be individually placed with a gap of 25 mm between the blocks. Above considerations coupled with use of a toe wall will provide adequate stability for the revetment blocks.

Local sliding condition may develop in the interface between present slope and the bottom of the reconstructed fill of the embankment. As the soil at this interface is above water table and dry, it is unlikely to develop sliding condition. Also use of 90% Proctor Compaction should provide adequate resistance against local sliding condition. Placement of toe wall also would provide additional resistance against local sliding. Provision of placement of geotextile will eliminate possibility of piping, soil migration and pumping of soil under the CC blocks. From the geotechnical analysis it is found that the soil within the project area has low to medium expansion potential. Hence, little deformation and volume change is expected on wetting and drying.

REFERENCES

Flood Forecasting & Warning Centre (FFWC) 1998. *Annual Flood Report 1998*. Bangladesh Water Development Board.

ASTM 1984. *Annual Book of ASTM Standards*. Volume 04.01, Cement; Lime; Gypsum.

ASTM 1988. *Annual Book of ASTM Standards*. Volume 04.02, Cement and Aggregates.

ASTM 1989. *Annual Book of ASTM Standards*. Volume 04.08, Soil and Rock, Building Stones; Geotextiles.

BS1377 1975. *Methods of Tests for Soils for Civil Engineering Purpose*. British Standard Institution, Gaylord and Son Ltd.

Chen, F.H. 1975. Foundation on Expansive Soils. Developments in *Geotechnical Engineering Vol. 12*, First Edition, Elseveir Science Publishers B.V., The Netherlands.

Hossain, M. M. 1983. *Swelling Properties of Selected Local Soils*. M. Sc. Engineering thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh

Permanent International Association of Navigation Congress (PIANC) 1987. *Guidelines for the Design and Construction of Flexible Revetments Incorporating Geotextiles for Inland Waterways*. Report of Working Group of the Permanent Technical Committee I, Belgium.