Effect of Flood on Earth Structures: A Case Study

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Abstract

Flood is a recurring problem in Bangladesh. 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. All the major rivers of the country namely the Padma, the Meghna, the Brahmaputra and the Jamuna flowed above the danger level during the 1998 flood. During this flood, earth structures such as flood, rail and road embankments, bridge abutments and piers were threatened. The road links between the capital city and other major cities were disrupted. About two-third of the country went under water. In order to develop strategies to mitigate the miseries of people in the event of a future flood, it is necessary to record and analyze the damages that had occurred due to the 1998 flood. In this study, two damaged earth structures have been analyzed and measures to protect earth structures have been suggested.

INTRODUCTION

In 1998 Bangladesh experienced one of the worst floods in terms of severity, destructiveness and duration. The rivers went above danger level in July 1998 and remained above the danger mark up to the second half of September 1998. Never in the history of flood in Bangladesh, it was so protracted and the sufferings of the people so great. Incessant rainfall for days together added to the misery of people. All the major rivers of the country namely the Padma, the Meghna and the Brahmaputra and the Jamuna flowed over the danger level.

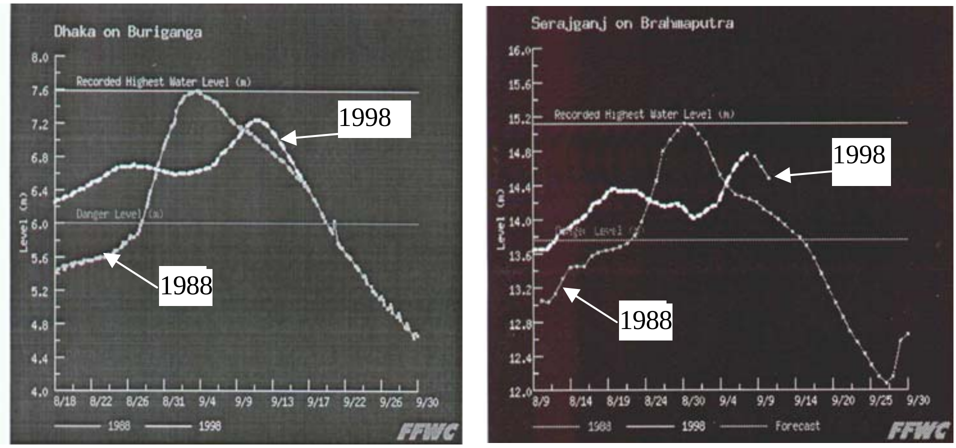
People felt helpless in the hand of nature. Earth structures such as flood, rail and road embankments, bridge abutments and piers were threatened. The road link with the capital city was disrupted. The two-thirds of the country went under water. Many people left their houses for a shelter. Some lived on embankments and on raised lands under the open sky. Those who did not move from their home, lived on the roofs of their houses along with their livestock. Men, women and children had to swam through floodwater to fetch drinking water, food, fuel and medicine.

In order to develop a strategy to mitigate the miseries of people in the event of a future flood, it is necessary to record and analyze the damages that had occurred due to this flood. To rehabilitate damaged infrastructures, it is essential to note the nature of damages that had occurred during the flood. Extent of damage and its nature and cost for repair in terms of money and capital need to be assessed to arrive at a rehabilitation and repair strategy and also in planning and design of future infrastructure facilities. This study is a compilation of information on damages of earth-structures during the 1998 flood. The study also looks into the nature of damages and aims at classifying them and suggests possible remedial measures.

CHARACTERISTICS OF THE 1998 FLOOD

In the monsoon of 1998, due to excessive rainfall in the upper catchment areas from July to September, and intermittent rainfall within Bangladesh, all the rivers of the country experienced significant increase in flow far above the danger level. The flood situation started to become alarmingly worse from the middle of July. By this time the low-lying areas of the country had already gone under water. At that time, about 45,000 square kilometer areas of 37 districts of the country were affected by flood. Although flood situation started improving in early August, the flow of the two main rivers Padma and Brahmaputra-Jamuna increased significantly in the middle of August due to heavy rainfall in the upper catchment areas. By the end of August flood situation became worse and about 60,000 sq.km area of 42 districts were affected. During the early September the flow of the major rivers increased abruptly worsening the situation. The flood situation became worst in the second week of September and about 75,000 sq.km area of 52 districts were affected during that time. The flood prevailed from early July to the last week of September, for more than three months at different places in different magnitudes. Thus the flood of 1998 became the most prolonged flood in the history of Bangladesh.

Figures 1 shows hydrographs of 1988 and 1998 floods for river Buriganga at Dhaka and Brahmaputra-Jamuna at Serajgonj. In 1998, the river stage at the Hardinge Bridge point exceeded all its previous records. It can be observed from the hydrographs that although flood stage for 1988 flood was higher at most places, duration of water level above danger mark was much longer during the 1998 flood.



(a) **(b)**

Figure 1: Flood hydrographs of (a) Buriganga River at Dhaka and (b) Brahmaputra River at Sirajganj, during the 1988 and 1998 floods

FLOOD DAMAGE

The 1998 flood broke all previous records for its duration and devastation. Large-scale damage occurred all over the country. According to The Annual Flood Report (1998), this flood affected about 68 per cent area of Bangladesh. Table 1 shows statistics on damages due to 1998 flood, which was provided by the Emergency Operations Center (EOC, 1998) of the Ministry of Disaster Management and Relief.

According to Bangladesh Institute of Development Studies (BIDS, 1998), the 1998 flood may have caused a damage worth Tk.. 10,228 crore to different sectors of the national economy including infrastructure, industry and agriculture. The agricultural sector topped the list of the worst affected sectors, with estimated damages to the extent of Tk. 5052 crore, of which crop sector alone accounted for Tk. 4377 crore and non-crop sector Tk. 675 crore. Infrastructure suffered damages worth Tk. 3949 crore, including Tk. 1087 crore in roads and bridges. Tk. 153 crore in the railways, Tk. 313 crore in embankment and irrigation canals, Tk. 273 crore in educational institutions, Tk. 33 crore in health centres and facilities and Tk. 2090 crore in the residential sector. The damage to industries was estimated to be Tk. 1227 crore of which large industries lost Tk. 222 crore, small and medium industries lost Tk. 904 crore and cottage industries lost Tk. 100 crore.

Table 1: 1998 Flood damage statistics (EOC, 1998)

Number of affected districts	52
Number of affected thanas	366
Number of affected unions	3323
Number of affected people	3,09,16,351
Crop damage (acre)	14,23,320
Number of damaged houses	9,80,571
Number of deaths	918
Number of dead livestock	26,654
Damaged road in km	15,927
Damaged bandh (embankment) in km	4,528
Number of damaged bridge/culverts	6,890
Number of damaged educational institutions	1,718
Number of damaged shelters	2,716
Number of sheltered people	10,49,525

The severe flood of 1998 damaged most of the infrastructures including the National, Regional and Feeder roads under RHD. At present RHD owns about 20,285 km road network (2,862 km National Highway, 1,565 km Regional Highway and 15,860 km Feeder roads) and during the 1998 flood 1381 km National Highway, 784 km Regional Highway and 7458 km Feeder roads were submerged. Figure 2 presents percentage cost of road damages according to RHD zones and Fig. 3 presents comparison between some damaged and undamaged roads. Figure 4 shows that the damage to road pavements have been extensive in most greater districts.

EFFECT OF FLOOD ON DIFFERENT STRUCTURES

The structures under this study are from infrastructure projects such as road-communication network, flood protection embankments and irrigation projects. The patterns of damage observed in different civil structures due to the 1998 flood are briefly summarized below; details are available in Safiullah and Ansary (2000).

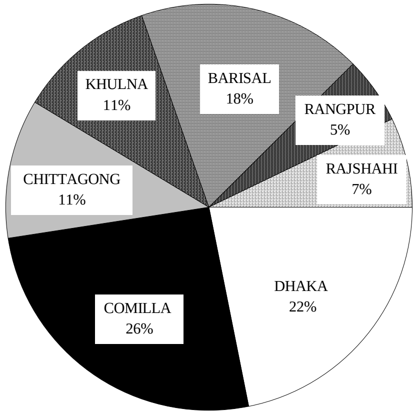


Figure 2: Percentage of total cost resulting from road damages according to RHD zones

Figure 3: Comparison between damaged and undamaged roads

Damage to Road and Railway Embankments

Overtopping

This is very common in road embankments where the road top level is set below high flood level. In such situation, when adequate allowance for flood water level or ground settlement is not considered at design and construction stage, water rises above the top of the embankment. The usual practice to prevent overtopping during emergency is to create a floodwall on the two sides of the road usually by dumping bags filled with soils. There is considerable amount of seepage through this temporary barrier and provision is needed for pumping out seeped water.

Pavement Damage

This is a common occurrence when flood level reaches the base of the pavement. Due to running of vehicles high pore water pressure develops below the edge of the pavement. High pore water pressure during wheel traction may pump out soil from underneath the pavement edge thereby progressively damaging the pavement structure. A variety of damages such as development of pot holes, ruts, etc may develop as a result.

Erosion of Slopes and Scour

Erosion of slopes may develop due to various reasons but the most common mechanism is soil removal at water level due to wave action on the slopes. Removal of soil from wave level creates a undercut steep slope which later collapses due to instability and as a result waterline regresses inwards. Sometimes scour may result at the toe of the slope inducing slope failure.

Damage to Flood Embankments

The difference between flood and road embankment is that in the former case a considerable difference in water level exists on two sides of the embankment. This results in well-established seepage lines. Various conditions that may deteriorate the stability of a flood embankment include: (a) Seepage, (b) Leakage, (c) Overtopping, (d) Piping, (e) Settlement, (f) Scour, (g) Attack by Rodent, and (h) Slope Failure.

Damage to Bridges

Common types of failures of bridges due to high flood usually result from development of scour around piers or abutments and removal of soil support near the toe. Instability to bridge pier or support system and slope stability may result from: (a) Scour of pier support/abutment, (b) Removal of soil providing passive resistance, (c) Progressive erosion/scour and bypassing through road embankment, and (d) Failure of bridge support system.

Damage to Houses and Buildings

Floodwater may submerge buildings and induce damages of various degrees from peeling of plaster to total collapse depending on the nature and condition of flood and of the building. Scouring of soil cover over foundation may reduce bearing capacity of shallow foundations and thereby foundation instability may result.

Damage to River Bank Protection Work

River bank protection works include riprap and falling apron over a considerable length of the riverbank. High velocity currents during flood may remove the protective covers resulting in bank failures. The mechanisms that may interplay to destabilize riverbank protection works include: (a) Scour, (b) Slope failure, (c) Removal of protection layer, and (d) Collapse.

TWO CASE STUDIES OF FLOOD DAMAGES

In this paper, case studies of an affected railway embankment and a damaged riverbank protection work have been presented.

Permanent Protective Work for Railway Embankment along Ishurdi-Sirajganj Route

The Railway Embankment requiring protective work is located within the Chalan Beel area. The rail line within this area runs across a very low lying plain and the height of embankment varies between 13 and 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 route is shown in Table 2. The datum shown is that used by Bangladesh Railway and not related to PWD datum.

Table 2: Ground, formation and flood levels for the railway embankment

Reduced Level (Railway Datum)	**Ishurdi-Sirajganj Route**
Highest Flood Level in 1998 (ft)	38.50
Average Normal Flood Level (ft)	34.50
Ground Level (ft)	25.50 – 29.25
Formation Level (ft)	39.00 – 45.00

The railway embankment is very old and most of the ground settlement has already taken place. There is no problem with settlement in the embankment. The embankment lies 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 at RL 38.5 ft. (railway datum). It was learnt that during the 1998 flood, the embankment nearly overtopped at some locations and rail communication had to be stopped for a few days. Vast water surface of the beel is subjected to wind pressure and wind generated waves were responsible for major damage of the embankment slope in the form of soil erosion and slips on the slope.

Figure 4 shows typical cross-section of railway embankment in Ishurdi-Sirajgonj route after the 1998 flood. The section shows considerable erosion of the existing slope. From an analysis of the available cross-section, it was noted that most of the damage occurred above RL. 30 ft (railway datum). 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. Protection measures to protect slopes against wave erosion may be taken to slopes lying above RL.30 ft.

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 be generated from boats navigating close to the embankment and this should be considered in designing the revetment work. Within the Railway embankment areas visited, no evidence of deep sliding was observed. At some locations longitudinal cracks at the top of the embankment were noted which appeared to have resulted from 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 Fig. 4, it is apparent that originally the embankment had a uniform side slope of 1 (Vertical): 2 (Horizontal), which was considerably modified by the process of removal of soil by erosion, particularly within the zone of waves action. The present slope shown in Fig. 4 reflects typical S-shaped profile usually generated by wave action on a slope.

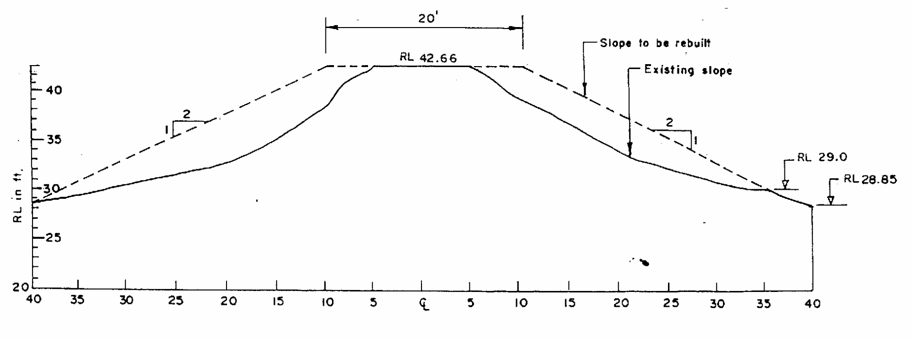


Figure 4: Typical cross-sectional profile of railway embankments in Ishurdi-Sirajganj route

At one location revetment system with aggregate filter and cement concrete (CC) blocks was installed by the Railway. 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 underneath aggregate filter resulting in subsidence of the CC blocks. Therefore adoption of a design similar to that already used may be considered adequate, provided provision is made to prevent migration of soil particles from underneath the CC blocks. Use of a geotextile layer may serve this purpose (Safiullah and Ansary, 2000).

Serajgonj Town Protection

The construction of the 2.5 km long revetment works at Sirajganj forms part of the Phase I Priority Works of the River Bank Protection Project (RBPP) on the right bank of Jamuna. One of the major components of the Works is the construction of a bank stabilization structure comprising a precast concrete block armoured revetment laid on a geotextile filter, with a falling apron. Following some slides during construction, the revetment slope was modified for parts of the Works and the apron level was also raised at some locations. On 15th August, 1998, when the Works were nearing completion, a part of the revetment (around 60 m long extending from A260 to about A320) collapsed. Further slides occurred upto 18th September, the total length of damaged sections being about 300 meters. The Construction Supervision Consultants (CSC), in co-operation with the Contractor, initiated some mitigatory measures, which included dumping of CC blocks. A team of specialists mobilised by CSC reviewed the damage and a report was submitted to BWDB on 20th October 1998.

The water levels and near bank velocity assumed in design are based on a 100-year return period using simulation over a 25-year period (1965-89). However, during 1993-95 considerable additional data were collected under FAP24 (River Survey Project), which do not appear to have been used by the Consultants while reviewing/updating the design. A comparison of scour depths obtained by different methods shows that none of the predicted scour depths were less than 40 m with respect to 100-year flood level. The formulae yielded an average value of 48 m from 100-year flood level. The Consultant's design of falling apron, however, considered 33 m scour depth for the upstream face and 29 m for the straight part, although the maximum scour depth obtained in the physical model tests was 43.5 m. The observed scour depth during the flood of 1998 matched very closely with the scour depth predicted in the Physical Model Study, while the design scour depth was much less than the observed scour depth. The setting level of the falling apron (–4.2m PWD) appears to be too high.

One of the surprising features of the whole project is the lack of field information on geotechnical parameters. Most of the geotechnical parameters used in the design and reported in the analysis of slope stability, relate to general soil conditions without being site specific. The only boring was performed after the 1998 flood at one location. An analysis of the data shows that most of the soil down to –2m PWD is in a very loose state with N-values between 4 and 7. From this depth downward, the soil density increases slightly, down to –14m PWD, below which the soil is very dense. The percentage of fine material is very high, particularly when compared with the soil in the West Guide Bund (WGB) of JMBP. Whereas the fine content of the soil in WGB is limited to 12% only, it is as high as 80% in the upper 25 m of soil in Sirajganj. After the flow slides during construction of WGB in late 1995 and early 1996, the Consultants for the RBPP project were asked to review the design at Sirajganj. It appears that they failed to recognize the differences in the soil parameters in the two locations. The relative density of the soil at Sirajganj between +11m PWD and –2m PWD is less than 30%. Sand size mica content has been found to be around 5% to 10%, but it is the resultant low value of relative density, which determines the slope stability. No effort appears to have been made by the Consultant to assess the relative density during original design or review of design after WGB, JMBP failures. Calculations based on the slope failure records during construction suggest that a mobilized angle of friction ϕ between 17^o and 18^o would produce failure of the dredged slopes. Above –10m PWD, the RBPP site has a much lower relative density (<30%) than the WGB, JMBP site. However, below –10m PWD, soil at WGB site has a lower relative density (< 40%) compared to Sirajganj site. As the soil above –12m PWD at Sirajganj RBPP site has a relative density less than 40%, it is likely to develop flow slides.

The maximum water level during the 1998 flood at Sirajganj was +14.76m PWD that was approximately 1 m below the design high flood level (HFL). The peak discharge of Jamuna was around 90,000 m^3/s, which has a return period of nearly 20 years. Velocity measurement at structure B2, Sirajganj during 14-16 September 1998 gave a maximum velocity of 3 m/s while the design velocities for revetment along straight section, upstream termination and head of groyne are 3.7, 4.4 and 4.8 m/s, respectively. Thus the flood of 1998 in the Jamuna at Sirajganj was not unusual in terms of peak stage, peak discharge and velocity. The 1998 flood was extreme in terms of total duration of flood flow, but took a serious turn with the third failure of structure at Sirajganj on the 27th August 1998.

The flow slide that occurred in the Sirajganj structure in the 1998 flood was due mainly to the presence of loose micaceous sandy soils present in the banks of the Jamuna. Studies on the Jamuna soil indicate that it exhibits wholly contractant behavior at relative density of 55%. These soils may show contractant behavior even at a relative density value of 60% for simple shear and triaxial extension shear stress paths. Due to contractant behavior of sand, pore pressure is induced in these soils during undrained deformation making them prone to failure by flow sliding. A number of failures of similar nature during construction of the West Guide Bund of the Jamuna Multipurpose Bridge (late 1995 to early 1996) testify to the susceptibility of the Jamuna river bank soil to flow sliding.

Available information indicate that between depth +13.5m PWD and –16.0m PWD the soil in the right bank of the Jamuna river has a very low relative density with a mean value of only 32% and standard deviation of 7%. This soil has virtually no reserve shear strength as established in various previous investigations. The first flow slide occurred on the 15th of August when the bottom of scour hole was at depth of –17.0m PWD, which is the level of scour assumed in design. At this depth of scour, had the slope been properly designed, the protection works should have prevented the slope from collapse. This failure, which occurred at this depth of scour, indicates that some important parameter had not been taken into consideration in the design. A study of the available information points to the fact that very low value of relative density of soil is the main factor responsible for failure. As low value of relative density is a common phenomenon in the Jamuna bank soils, the Consultants should have taken into consideration its effect in their design.

According to the BRTC-BUET report (1998), bed levels around the failure sections are much lower than –17m PWD. Thus it appears that the river has already played most of the hydro-morphological activities by scouring at the vicinity of the upstream termination of RBPP. In the event of future flood with magnitude and duration similar to the 1998 flood, the scour depth likely to occur will be comparable to the 1998 event. It is also likely that the scour depth at the upstream termination would not be exceeded significantly in the future flood events. Hence if any remedial measures are taken using the existing geometry of scoured area (which is to some extent trapped), it is likely to be stable against future floods and is expected to provide long-term solution. The idea behind this solution is to stabilize the existing slope profile from the top of the scar to the deepest part of the scour hole. The main work may be divided into two parts: (a) filling up of the depression over the scar face to form a slope not steeper than 1:3.5, and (b) placement of armour such as CC blocks or stone (Madhyapara hard rock) of appropriate thickness over the filled up slope.

The filling of the depression over the scar face may be done by using four alternative materials as indicated below in order of decreasing cost: (i) Sand filled jumbo-size geotextile bags: This is the most costly alternative but has the advantage that geotextile bags will act as a filter and separation layer in retaining soil; (ii) Madhyapara hard rock (stone): Assorted sizes of rocks may be used but use of graded material is preferable as grading may be designed to enhance filtration and separation capability. Also use of rock materials will permit a slope steeper than 1:3.5 for the filled section; (iii) Sand filled polypropylene bags: These bags will serve the purpose of filtration and separation, but may not be as effective as the geotextile bags. Such sand filled polypropylene bags have been used by the BWDB in the Sailabari groyne; (iv) Sand filled gunny bags: This may serve a function similar to sand filled polypropylene bags but has the disadvantage that the bags are likely to tear during handling and deteriorate with time.

Developing a slope covered by filler materials and armour layer from the deepest part is likely to stabilize the existing slope and arrest probable future soil flow towards the deep trough. The work should be carried out in a careful manner so as to ensure correct thickness of armour as well as correct aerial coverage.

CONCLUSIONS

The major floods, like the one of 1998 have significant impact on the earth structures of Bangladesh. Even though the 1998 flood exceeded their respective design flood levels, different flood protection projects were able to withstand the flood because of the preventive measures taken by the concerned Government Agencies. In this study two damaged earth structures were studied in detailed and development of strategy to protect earth structures during the floods were discussed.

Two case studies reported in this study show different types of attack during high flood of 1998. In the first case, it is seen that a significant damage can result from wave action during high flood. Most embankment structures in Bangladesh are built with silty clay with low cohesion and is likely to be eroded unless wave protection works are undertaken. The second case shows the effect of bed scour due to high flow velocity at bed level. In this case local scouring at the bed level of the earth structures make the slope steeper and subsequently collapse at some parts of the structures take place. So some type of preventive measures have to be undertaken to protect the structures.

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