Failure of a Bridge due to Flood in Bangladesh - A Case Study

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Abstract

Bangladesh experienced an unprecedented flood in 1998 and the existing infrastructures underwent a great havoc leading to damage of about 400 nos. of small and medium size culverts and bridges in the country. The 67 m long Turag-Bhakurta Bridge with a width of 3.70 m near Dhaka, the capital city, was constructed under the jurisdiction of Local Government and Engineering Department (LGED) of Bangladesh in 1994. The bridge came under flood attack even before 1998 flood in the year 1995. During 1995 flood the first piers of the bridge from Dhaka-Aricha National Highway side settled down by about 1.61 m. After recession of flood, the affected piers were rehabilitated with additional 30 m long piers but during 1998 flood it was washed away except the rehabilitated piers. This paper is an attempt to find out the causes of its failure. It came to be clear that the causes of failure of the bridge were hydraulic (high velocity of water and non-prediction of flow path), morphologic (high scour at bridge piers) and hydrologic (inadequate bridge opening), but hydrological cause together with the flow path of floodwater came to be the dominant factor. The area of the catchment of the bridge was negligible but lack of knowledge in taking into account of spilling water from a major river Dhaleswari in hydrological calculation leaded it to failure.

Keywords: Scour; Opening length; Constriction; Discharge

Introduction

Flood is an annual event in Bangladesh. But unusual devastating floods like 1954, 1987, 1988 and 1998 are considered the worst ones on record, which caused widespread sufferings and loss of lives. Flood of 1998 with its duration and magnitude surpassed all past records putting heavy thrust on our country. Many existing infrastructures underwent a great havoc leading to damage of about 400 nos. of small and medium size culverts and bridges in the country. A study was undertaken to evaluate the impact of the 1998 flood on major bridges. A total of eleven bridges were studied (Hoque et. al. 1999, Hoque et. al. 2002). A 67 m long bridge called Turag-Bhakurta Bridge over the river Turag close to Dhaka, the capital of Bangladesh, is one of them. The Turag-Bhakurta Bridge with width of 3.70 m was constructed under the jurisdiction of Local Government and Engineering Department (LGED) of Bangladesh in 1994. The bridge came under flood attack even before 1998 flood in the year 1995. During 1995 flood the first piers of the bridge from Dhaka-Aricha National Highway side settled down by about 1.61 m (Photo 1). After recession of flood, the affected piers were rehabilitated with additional 30 m long piers but during 1998 flood the bridge was washed away (Photo 2) except the rehabilitated piers and two abutments. This paper is an attempt to find out the causes of its failure. Location of the damaged bridge is shown with river network and existing structures in Fig. 1. At present a 100 m long bridge has been newly constructed over the section (Photo 3).

Methodology

LGED office at Dhaka collected hydrological and morphological data of the relevant bridge after 1995 and 1998 floods. LGED engineers made detail physical inspection of the catchment after 1995 flood. Survey of cross-sections at inflow and outflow points was carried out to ascertain incoming and outgoing discharge. The river network around the catchment was also looked into to see the flow path and the influence of river upon it. During the survey of cross-section, flood related information was collected to find the energy slope in between the two remote inflow and outflow sections.

The cross-section survey through the central line, at upstream and downstream of the bridge was carried out. The pre construction information including the detail design of bridge was checked. The soil investigation report of the bridge site was studied and D_{50} was fixed. The information on 1 km Turag-Bhakurta road section and about its survey work during the flood 1995 was checked. The rehabilitation design work of the affected bridge piers after 1995 flood was verified. The collected data are graphically presented. Regime opening of the flow section as well as regime scour and local scour were verified and compared with the design bridge length and pile length and scours formed during 1995 and 1998 floods.

Regime opening length was determined as per Lacey's regime formula:

$$L = 4.75\sqrt{Q} \quad (1)$$

where, Q is flow through the bridge section, m^3/s ; L is regime opening length, m.

Regime scour depth was also computed following the Lacey's formula:

$$D_r = 0.47\left(\frac{Q}{f}\right)^{1/3} \quad (2)$$

where D_r is regime scour and f is silt factor which is determined as per Lacey's suggestion

$$f = 1.76\sqrt{D_{50}} \quad (3)$$

where, D_{50} is mean average grain size, mm

Received 18 November 2003, Accepted 6 November 2004

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Photo 2 Damaged 67m bridge during 1998 flood on Turag-Bhakurta road near Amin Bazar

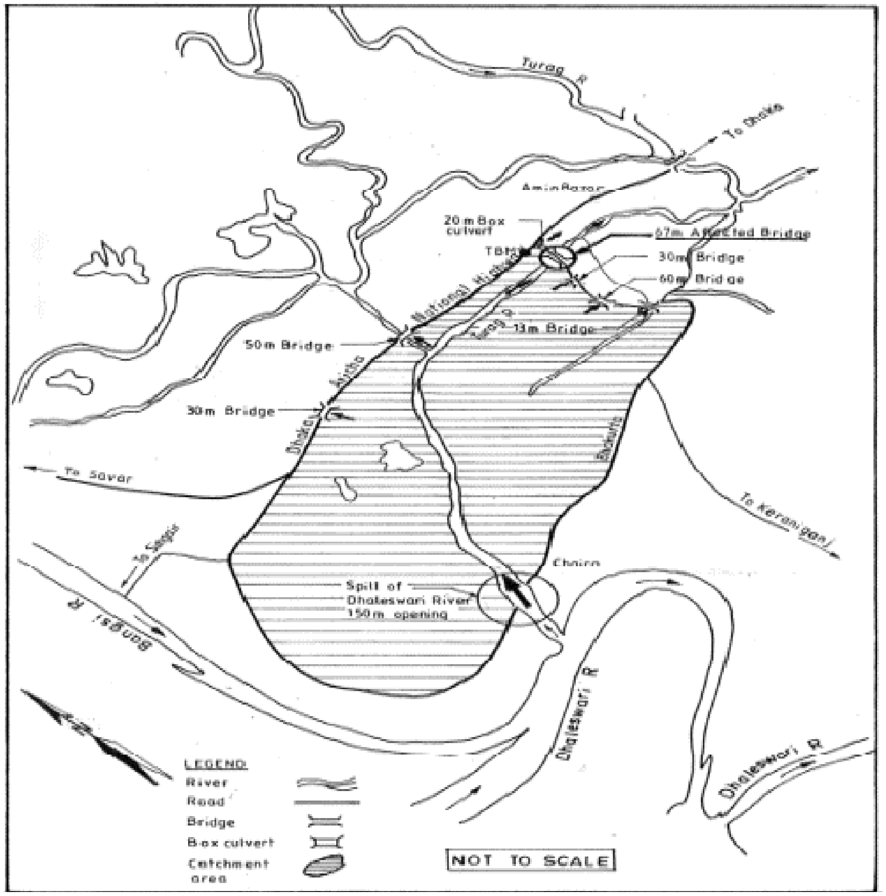

Fig. 1 Location map of the damaged bridge together with existing structures and river network

Photo 3 Newly constructed 100 m bridge in place of damaged 67 m bridge (After: Haque et al., 2002)

Scour due to constriction was computed from the following formula:

$$D_{con} = D_r \left(\frac{L}{Lnet}\right)^{2/3} \quad (4)$$

where,
D_{con} is scour due to constriction of regime opening length, m
L_{net} is net opening length at bridge section, m

Local scour due to obstruction of pier and piles was computed using recommendations of Farraday (1983):

$$D_{pier} = 1.5 * a \quad (5)$$

where,
D_{pier} is local scour due to pier obstruction, m
a is width of pier, m

$$D_{pile} = b * n \quad (6)$$

where,
D_{pile} is local scour due to pile obstruction, m
b is width of pile, m
n is no. of piles at first row,

Total local scour was computed as summation of local scours at pier and piles.

$$D_{local} = D_{pier} + D_{pile} \quad (7)$$

Total Scour (D_{total}) at bridge pier would constitute the summation of scour due to constriction of regime length and total local scour due to obstruction of pier and piles. Total scour at bridge section would constitute:

$$D_{total} = D_{con} + D_{local} \quad (8)$$

As per methodology, regime length and total local scour were determined for both floods in 1995 and 1998 and comparison of results was made for both floods. Accordingly, conclusions were derived from the findings of the study.

Analyses and Discussions

River Network

A major river Bangshi, having its off-take from the Old Brahmaputra, passes near Bhakurta village where the river Dhaleswari joins the river Bangshi and then passes downwards by the name river Dhaleswari (Fig. 1). A branch from the river Dhaleswari, now a stable channel, gets spill water from the river and passes through inflow point Chaira at village Bhakurta (Fig. 1). During rainy season this spilling branch gets enormous spilling water and becomes very active. Heavy river traffic movement towards Dhaka starts through the inflow section, as the route is the short-cut monsoon riverine route towards the capital Dhaka. The opening length of spilling section at Chaira is about 150 m with maximum depth about 15 m (as per cross section measurement carried out in 1995). The spill water from the river Dhaleswari flows towards the river Turag through the catchment and major hydraulic thrust was felt at the damaged bridge. Locally the river over which 67 m bridge was constructed is called the river Turag. The river Turag is the major one that flows near Mirpur, Dhaka and at downstream it flows by the name Buriganga on the bank of which the capital Dhaka is situated. The catchment flow after exit through the existing structures joins the river Turag (Fig. 1). There are other minor locally interrelated channels that get activated during rainy season. There are also numerous low-lying beels in and around the catchment.

Inflow and Outflow Sections of the Catchment with Existing Structures

A map of the catchment showing inflow point at Chaira and outflow points on Dhaka-Aricha National High Way and on Turag-Bhakurta road is shown in Fig. 1. Inflow section is only one at Chaira and it is open. There are two bridges on Dhaka-Aricha National High Way acting as outflow sections (Fig. 1). At present there are five existing structures on 1 km Turag-Bhakurta road, which was simple pedestrian before construction of the structures, and had been upgraded and raised after the construction. The five structures function as outflow sections on Turag-Bhakurta road for the catchment (Fig. 1). During 1995 flood, there were only two structures on the road – the damaged 67 m bridge close to Dhaka-Aricha National High Way and another 13 m bridge close to Bhakurta village. So almost the total upgraded road went under water during 1995 flood and worked as outflow section. But during 1998 flood there were already 5 structures on the Turag-Bhakurta road. As 1998 flood was unprecedented, so during the peak time of the flood, the upgraded portion of the Turag-Bhakurta road also went under water and again worked as an outflow section. But at the beginning of flood, five structures on the road functioned as outflow sections. As the floodwater level was gradually rising, the design freeboard kept for the damaged bridge also was slowly reducing and touched the superstructure at the peak time of the flood and high velocity together with an enormous hydraulic pressure of floodwater was put on the bridge. As a result, the two girders together with piers were washed away fully.

Evaluation of Hydrological and Morphological Changes after 1995 and 1998 Flood

Survey of the Catchment Area after 1995 Flood

A survey of the catchment area was carried out immediately after 1995 flood. Temporary Bench Mark was considered on top of divider on Dhaka-Aricha National High Way near the damaged structure. The value of TBM was taken as 10.00 m. The catchment is bounded by Dhaka-Aricha National High Way to the east, high land of Bhakurta village to the west, Turag-Bhakurta road to the south and high land of Savar to the north (Fig 1). It was found that inflow channel through Chaira at village Bhakurta becomes an active dominant river during rainy season and keeps high velocity. According to local information, since long time the inflow point at Chaira has been getting spill water from the river Dhaleswari and it has been converted into a natural big river. High river traffic movement is commenced through the section during flood time. Before the construction of the bridge, the 1 km Turag-Bhakurta road was not developed and spill water passed through the section naturally towards the river Turag at Mirpur near Dhaka. The main flow was directed through the damaged section of the 67 m bridge. After the construction of the 67 m bridge, the 1 km road was upgraded and raised. As a result, during 1995 flood enormous flow of floodwater passed through the bridge section. The road section was cut and opened to reduce the hydraulic pressure through the bridge section. However, the structure with two adjacent girders and the relevant piers got settled. There were existing two bridge openings (30 m and 50 m) on Dhaka-Aricha National High

Way and one 13 m bridge opening on Turag-Bhakurta road near the village Bhakurta. The road itself was affected. So, all these openings worked as outflow sections (Fig. 1).

Measurement of cross sections at inflow and outflow points was carried out during survey work. Fig. 2 shows the comparison of cross section before and after 1995 and 1998 floods at damaged bridge section. High Flood Level at Chaira during 1995 was 8.46 m and at damaged bridge site was 7.88 m. As per information of LGED, surface velocity of water through bridge sections (at Chaira and bridge section) was about 2.00 m/s through the mainstream of the section. Haque et al. (2002) carried out a riverbed survey during dry period of 2001 at newly constructed 100 m long bridge for study of scour at abutments and piers. The contour of scour bed as per their survey is shown in Fig. 3.

Discharge Computation during 1995 and 1998 Floods

Slope-Area Method was used to compute the discharge through the sections. Slope was determined from water surface slope attained during flood time. Distance in between Chaira (inflow section) and damaged bridge (outflow section) was about 5 km. Water surface slope during 1995 flood, as per survey work, was 0.000112. The water surface slope of 1995 flood was quite high, as spill water of the river Dhaleswari through high land of Bhakurta village made substantial head at Chaira. So, high velocity of water was observed at both inflow and outflow section during flood time. Moreover, the catchment is a low-lying area bounded by highland and road network. Computed discharge at Chaira (inflow section) during 1995 flood was 1994 m^3/s, while discharge at damaged 67 m bridge section was 1047 m^3/s.

For computation of discharge at Chaira (inflow section) during 1998 flood, water surface slope and cross-section had been considered as measured in 1995 flood. Discharge through Chaira for 1998 flood came to be about 2774 m^3/s, while discharge at damaged 67 m bridge section was 1370 m^3/s. It was observed from cross-section measurement that high scour had been occurred along the central line of the damaged bridge after the 1998 flood. It would lead to erroneous discharge if pre construction cross-section would be considered for computation of discharge. Hence, cross-section at bridge section just following the completion of construction and after first flood i.e., after 1995 was considered to be more acceptable.

Computation of Regime Opening Length and Scour Depth as per 1995 and 1998 Floods

According to regime theory of Lacey, length through the bridge section during 1995 flood should be about 154 m. But the actual design length of the bridge was 67 m. Hence heavy morphologic change or scour had happened at affected bridge section. The regime scour theory of Lacey gave the regime scour depth about 7.13 m. The silt factor ‘f’, which is determined from D_{50} (here 0.03 mm) came to be about 0.30.

As the bridge length was considered much less than the regime length, so due to constriction of regime length, scour depth was increased to a great extent. Scour depth for constriction came to be, according to Lacey, 12.71 m.

Local scour due to obstruction of pier and piles was computed using the recommendation of Farraday et al, (1983) and it came to be 2.88 m. Hence total scour at damaged bridge section would constitute (12.71 m + 2.88 m) = 15.59 m. Existing scour depth after 1995 flood at bridge section was found to be 14.48 m. Computed total scour and existing scour depth came to be almost equal and difference was only -1.11 m. Design pile length was 6.75 m. Maximum scour hole at pier was about –6.60 m from the original bed elevation.

High Flood Level in 1998 Flood at bridge site was attained 9.70 m in respect to TBM. High Flood Level in 1998 was marked with red color by LGED personnel on plate fixed with rail post of the bridge at Dhaka-Aricha National High Way side. High Flood Level at Chaira was considered 10.28 m taking into account the water surface slope of 1995 flood

Following the same methodology as has been done for 1995 flood, regime opening length and scour depth were computed for 1998 flood for the damaged bridge. A comparison between 1995 and 1998 flood parameters for the damaged bridge is made and shown in Table 1.

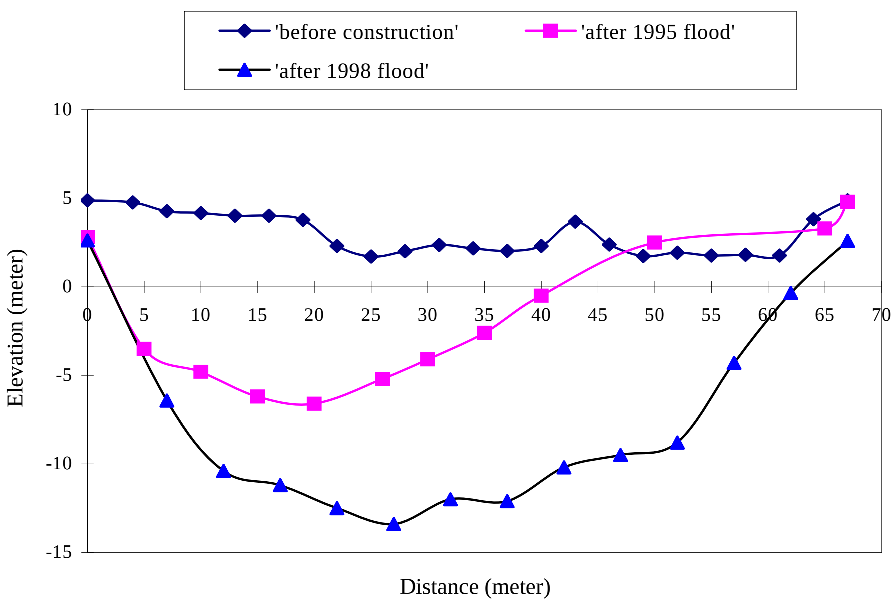

Fig. 2 Elevation of river bed along the central line of the bridge before construction and after 1995 and 1998 floods

Depth-contour

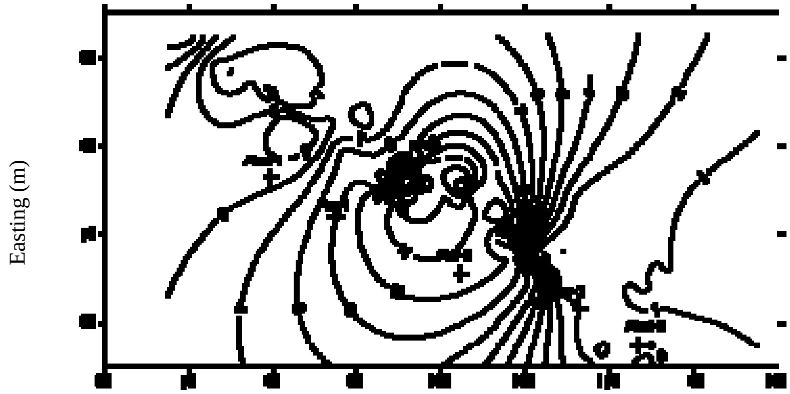

Fig. 3 Contour of scour depth at piers and abutment of newly constructed 100 m bridge in place of affected 67 m bridge measured during dry period of 2001 (After: Haque et. al. 2002)

Table 1 Flood parameters during 1995 and 1998 floods for the 67m damaged bridge

Parameters	**Flood 1995 (Bridge Partially Damaged)**	**Flood 1998 (Bridge Almost Washed Away)**
Flood Level at damaged bridge, m (TBM kept on top of divider on Dhaka-Aricha High Way)	7.88	9.70
Discharge, m^3/s	1046	1370
Regime opening length, m	154	176
Regime scour depth, m	7.13	7.80
Constricted scour depth, m	12.71	15.20
Local scour due to pier and piles, m	2.88	2.88
Total computed scour depth, m	15.59	18.08
Flood scour depth, m	14.48	23.10
Existing scour at pier, m	-6.60	-13.40
Computed average velocity, m/s	1.67	1.83

Causes of Failure of the Bridge during 1995 and 1998 Floods

1. It is evident that scour depth at pier-1 during 1995 flood reached to the pile length (6.60 m). As a result, the pier got settled with adjacent deck slab and girder, while during 1998 flood, it was 13.40 m. The scour depth 13.40 m is almost double than that of 1995 flood. So, the bridge was washed away except the rehabilitated pier with 30 m length.
2. Inflow discharges through Chaira during 1995 and 1998 floods were about 1994 m^3/s and 2775 m^3/s respectively. According to regime theory of Lacey, safety exit lengths should be 212 m and 250 m respectively for those floods. But the total existing bridge opening length on the 1 km Turag-Bhakurta road was not adequate. As a result, during both the floods, the bridge was affected.
3. According to discharges passed through the damaged bridge section in 1995 and 1998 floods, the adequate opening should be kept 154 m and 176 m respectively. The bridge length 67 m was inadequate. So, deep scour was occurred at bridge pier during 1995 and 1998 floods due to inadequate opening length of bridge i.e., constriction of regime length.
4. 1998 flood level was 9.70 m at bridge site, which almost submerged the super structure of the bridge and made enormous hydraulic pressure on super structure as well as on substructure due to inadequacy of freeboard.
5. Fig. 1 shows that the catchment of the affected bridge is negligible but spilling water from the river Dhaleswari through the inflow section at Chaira was quite high, which was not taken into consideration during the hydrological computation of inflow through the damaged bridge section.
6. It is also evident from the study that scour depth due to constriction of Lacey's regime length played major role in the increase of scour at bridge piers during flood time.

Conclusions

1. The case study of the failure of the bridge during 1995 and 1998 floods proved the inadequacy of hydrological

investigation as well as inadequacy of finding out the influence of spilling of floodwater of surrounding rivers through the catchment.

2. Enormous morphologic changes - scour occurred around abutment and piers of the damaged bridge due to inadequate bridge opening length i.e., constriction of the regime length of the bridge.
3. In a riverine and flood prone country like Bangladesh, where intensive road network is still an ongoing process, it is very important to ascertain the probable flow path of floodwater during flood time.
4. Upgrading of any road section together with structures needs very careful study of inflow of spilling water in the concerned catchment.
5. A substantial part of Bangladesh gets inundated during a normal flood, while a major part undergoes floodwater during a rare flood event like 1998, when direction of floodwater path gets very complex making its prediction difficult and affects hundreds of structures on dense road network of Bangladesh.

Recommendations

1. The natural opening length in a natural flowing channel in Bangladesh is recommended to keep in tact.
2. It is recommended, as far as possible, to take into consideration of spilling water as well as its flow path in hydrological computation for determination of safe opening length of a hydraulic structure in Bangladesh.

References

Farraday RV and Charlton FG (1983). Hydraulic factors in bridge design. *Hydraulic Research,* Wallingford, Hydraulic Research Station Ltd., 35-7.

Hoque MM, Bala SK, Ahmed SMU, Haque MA and Mamun SA (1999). *Erosion and Local Scouring around Bridges due to 1998 Floods,* Institute of Flood Control and Drainage Research (IFCDR), BUET, Dhaka.

Hoque MM, Bala SK, Ahmed SMU, Haque MA and Mamun SA (2002). Impact of the 1998 flood on the morphology of rivers around bridges. *Engineering Concerns of Flood 1998 Perspective,* Directorate of Advisory, Extension and Research Services (DAERS), BUET, Dhaka, 201-12.

Haque MA, Rahman MM and Kabir MR (2002). *Erosion around Bridge Pier in a Compound Channel,* Institute of Flood Control and Drainage Research (IFCDR), BUET, Dhaka.