SCOUR DEVELOPMENT ALONGSIDE RIVERBANK PROTECTION IN A BRAIDED RIVER - SELECTED CASES FROM BANGLADESH

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Riverbank protection in alluvial rivers of great mobility often faces unpredictable and suddenly changing conditions. Designers need to know possible rates of scour development, in order to protect their work against undermining and sudden failure. Because various types of scour and combinations thereof can occur, systematic analysis of measurements is necessary before design depths and rates of scour formulas can be established for particular environments.

Key Words : *River, bank protection, scour, systematic data analysis*

1. INTRODUCTION

To mitigate land loss from riverbank erosion, Bangladesh is developing riverbank protection that can be applied cost-effectively along longer river reaches where the adjacent land is mainly used for agriculture. New designs can benefit from past experience with a number of works built since the mid-1990s. Some of these works were continuously monitored, providing unique data for a better understanding of the behavior of large alluvial rivers alongside riverbank protection.

The Brahmaputra / Jamuna River, which flows from north to south through Bangladesh until it joins the Ganges (**Figure 1**) is characterized as a braided sand-bed river. It averages nearly 12 km wide between the outer limits of the braided channel pattern. The 100-year discharge is about 100,000 m^3/s and the bankfull discharge is around 45,000 m^3/s [1)]. Water levels rise about 7 m from a minimum in early March to a maximum in July, August, or early September, when maximum scouring occurs. During the construction season from mid-December to mid-April there is normally less scouring, but in some places erosion still occurs and deep scour holes are observed.

Preliminary results on rates of erosion and sedimentation were published by Oberhagemann and Noor[2)]. This article presents a more systematic analysis and an extension of the data series through the monsoon period, covering the main months of erosion. Five locations are analyzed to arrive at design values for this river in terms of maximum scour depths and rates of scour development

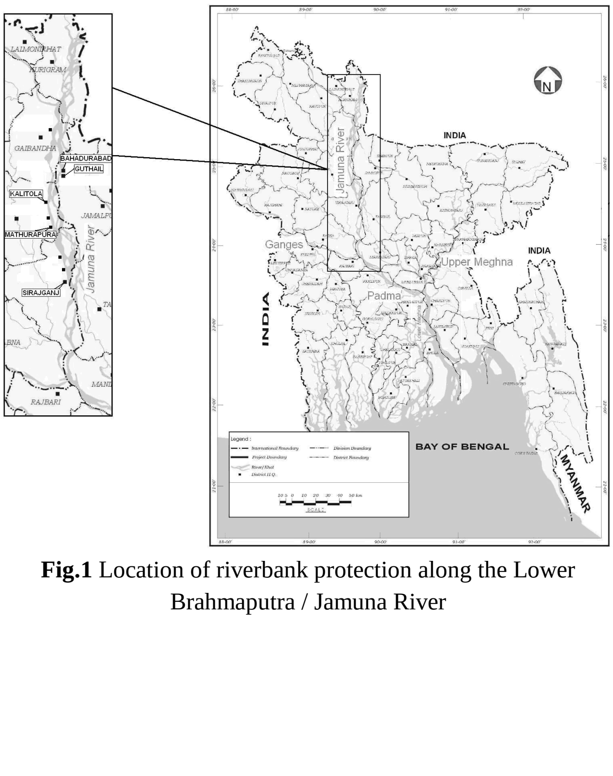

Fig.1 Location of riverbank protection along the Lower Brahmaputra / Jamuna River

2. RIVER RESPONSE TO BANK PROTECTION

(1) Locations

The five sites described are all situated along the lower Brahmaputra / Jamuna River. Two revetments at Bahadurabad and Guthail are situated on the east or left bank, whereas a revetment at Sirajganj and spurs at Kalitola and Mathurapara are situated on the west or right bank. All these works experienced at least one major attack during the 1997-2007 decade.

In general, two main types of attack on riverbank protection can create maximum scour: outflanking, and angular attack (**Figure 2**)[3].

(2) Selected Data

Some key features of the five sites referred to below are listed in **Table 1**.

a) Bahadurabad

The Bahadurabad revetment (see **Figure 1** for location) extends about 600 m along the left bank of the Brahmaputra / Jamuna River, plus two ends curving into the bank. For test purposes, different types of protection were used in each 100 m length. The work was attacked in two subsequent years by parallel flow. **Figure 3** shows details of water and bed levels over an 8-year period, together with rates of scour development in two attack episodes, as observed near the downstream end.

b) Guthail

The Guthail revetment is shorter than the Bahadurabad revetment and is situated around 3 km downstream (**Figure 1**). The revetment provided basic coverage only to an important ferry terminal, with the intention that the implementing agency should reinforce it, if major attack occurred. This reinforcement did not happen, and only limited emergency works could be undertaken. However, the work survived even though damaged. **Figure 4** shows levels and rates of development, as for the Bahadurabad site.

c) Kalitola

Reinforcement of the Kalitola spur, which protrudes approximately 150 m into the river at about 90 degrees to the bank, was completed in 1997. Subsequently the spur came under repeated attack from approach flow more or less parallel to the river bank, resulting in deep scouring and repeated failures, the last during the 2007 flood. **Figure 5** shows data as for the preceding sites.

d) Mathurapara

The T-head spur at Mathurapara, located only about 5 km downstream of Kalitola spur, had not come under major attack as of later 2007, because the upstream Kalitola spur resisted the main attack of the river. **Figure 6** shows data as for the preceding sites.

e) Sirajganj

Sirajganj Town Protection represents the downstream extension of a pre-existing spur. It has protruded progressively into the river due to heavy erosion upstream. It came under major attack just after completion during the 1998 flood, and ever since has been subject to periodic strong river attack, more and more from outflanking flows. After the 1998 scour event, an extensive apron around the upstream end was placed, consisting of geotextile containers and bags of different sizes, to keep the deep scour away from the slope. Up to 2007, this apron had been successful. **Figure 7** shows data as for the preceding sites.

Name	Completion Date	Special features	Periods and number of observations	Falling apron type	100-year flood level [m+PWD]	Deepest scour level [m+PWD]	Design scour level [m+PWD]	Attack
Bahadurabad Revetment	1997	Test structure	5 years, 225 observations	concrete blocks. boulders, sand-filled geotextile bags, gabion sausages	20.98	-12 m (Sep 1997)	-14m upstream - 12m downstr	Parallel
Guthail Revetment	2000	Test structure	4 years, 101 observations	Concrete blocks (35 to 45 cm)	20.71	-18 m (Jul 2005)	- 5 m	Outflanking
Kaitola Spur	1998	High spur	7 years, 97 observations	Concrete blocks (45 to 65 cm)	19.77	-33 m (Sep 2003)		Parallel
Mathurapara Spur	1998	T-head type spur	6 years, 88 observations		19.45	-13 m (Sep 2000)		Parallel
Sirajganj Spur	1998	Protruding as the upstream end incorporates old spur	6 years, 239 observations	Initially concrete blocks (45 to 65 cm), since 1999 later geobags, (A…B…C… pillows, cushions, blankets)	15.75	-33 m (Sep 1998)	-18 m	Outflanking

Table 1 Investigated erosion protection features

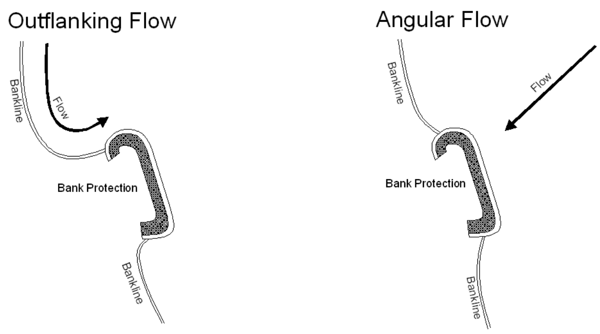

Fig.2 Water surface and scour elevations at Bahadurabad during the observation period

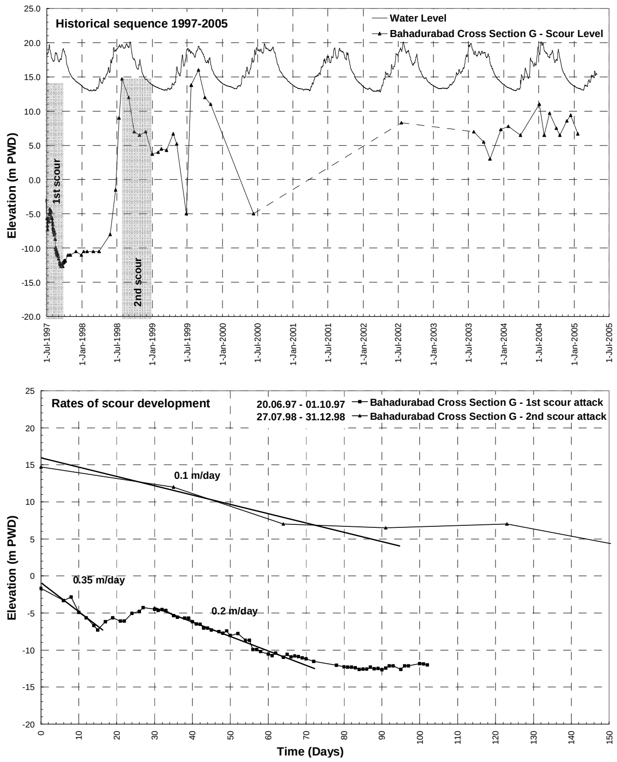

Fig.3 Water surface and scour elevations at Bahadurabad during the observation period

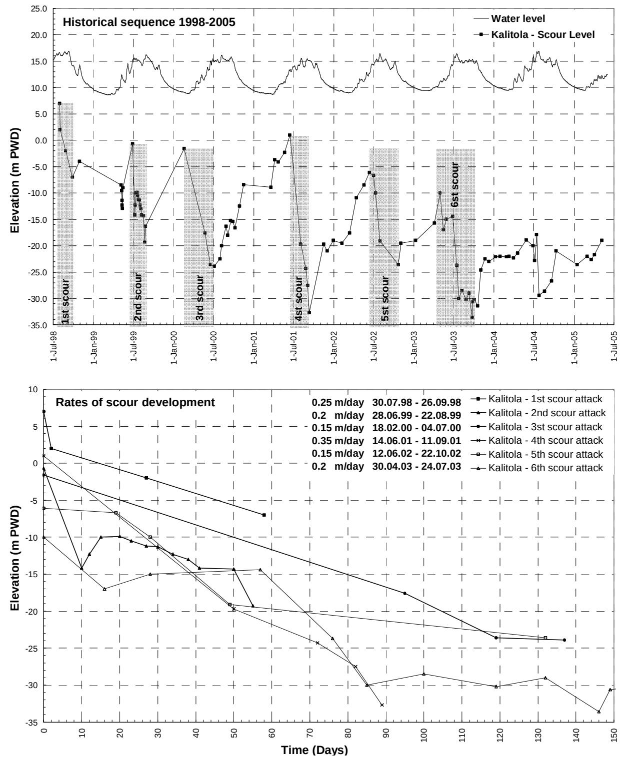

Fig.5 Water surface and scour elevations at Kalitola during the observation period

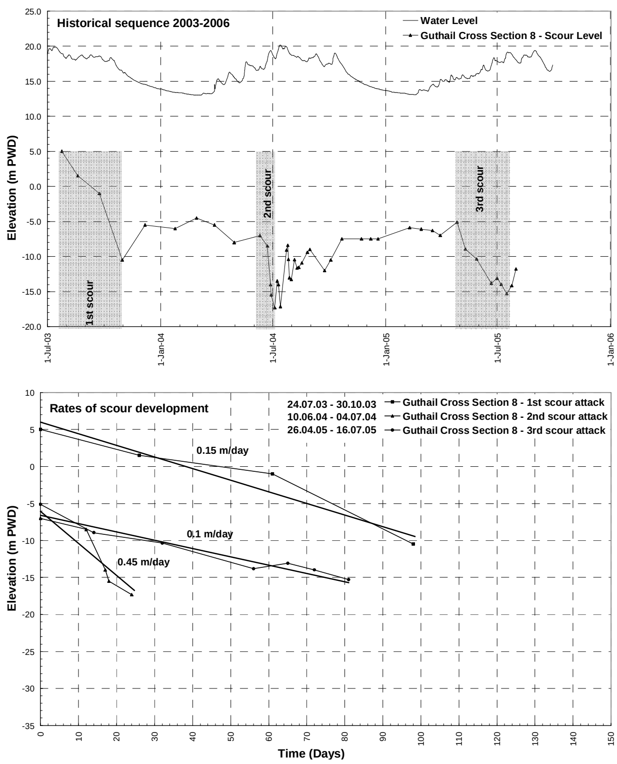

Fig.4 Water surface and scour elevations at Guthail during the observation period

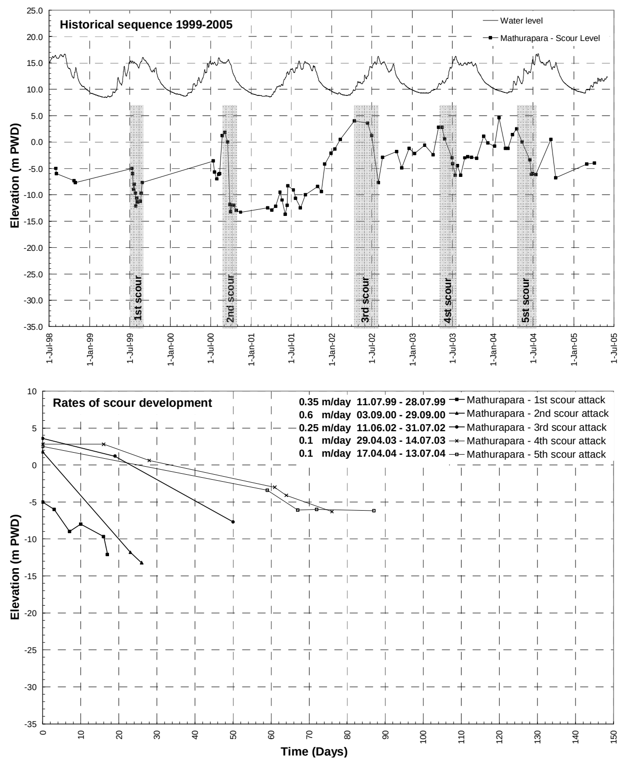

Fig.6 Water surface and scour elevations at Mathurapara during the observation period

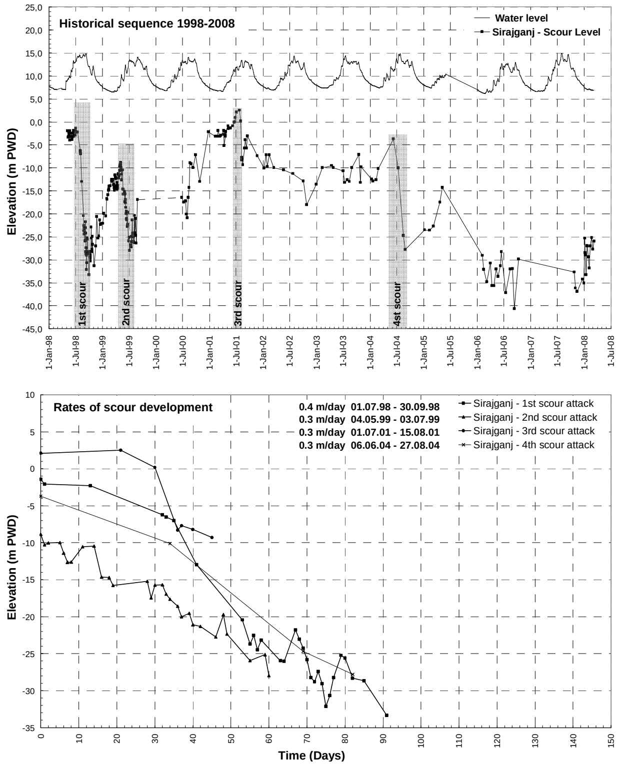

Fig.7 Water surface and scour elevations at Sirajganj during the observation period

3. ANALYSIS

The present analysis focuses on scour depths and especially on rates of scour development. The scoured bed elevation at a particular site was measured at the deepest point. Whenever a systematic cross-sectional survey was available, this was used to determine the deepest scour at that location. If not, the deepest scour observed at the upstream end of the work was used.

In order to produce enveloping curves of all the scour development data, the change in bed elevation (ΔE) was calculated for all measured scoured bed elevations (E_i) within one scour period (Δt) as follows (see **Figure 8**) [4]:

$$\Delta E = E_{i+\Delta t} - E_i$$

Where $\Delta t = 1,2,\ldots,100$ days

E_i = measured bed elevation at the time i

For example, if there were subsequent daily measurements during two weeks of scouring, scour rates over 1 day, 2 day, 3 day periods, etc. up to 14 days were calculated. Similar calculations were also made for rates of re-filling or deposition. Results for each site were then plotted on a graph like **Figure 9,** where values below zero show scouring and values above zero show deposition. The enveloping curves indicate the greatest observed change in bed levels, in terms of either scour or deposition. **Figure 10** shows a consolidation of enveloping curves like those of **Figure 9**, covering all five sites. Based on the enveloping curves, changes in bed elevation over time periods of 2, 7, 14 30, 60 and 90 days are summarized in **Table 2**.

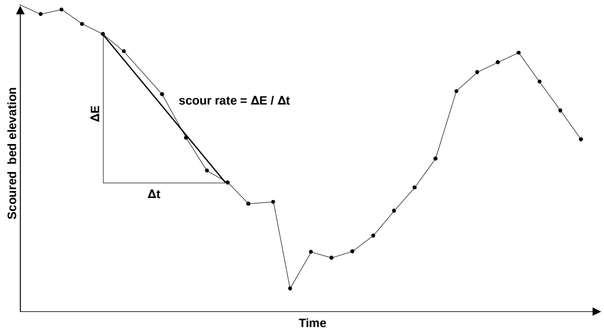

Fig.8 Definition sketch for rates of scour

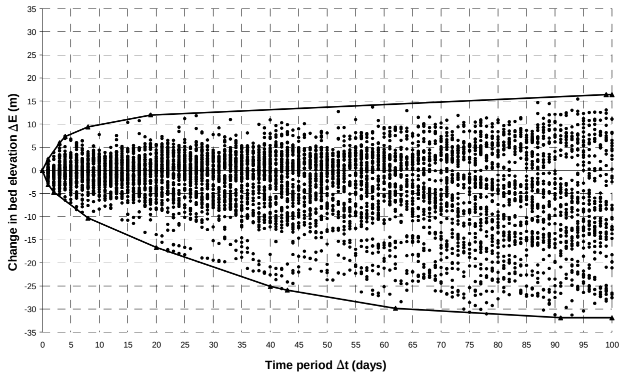

Fig.9 Example enveloping curve for all scour and deposition data at Sirajganj indicating maximum change in bed level (+ of -) within a given time interval

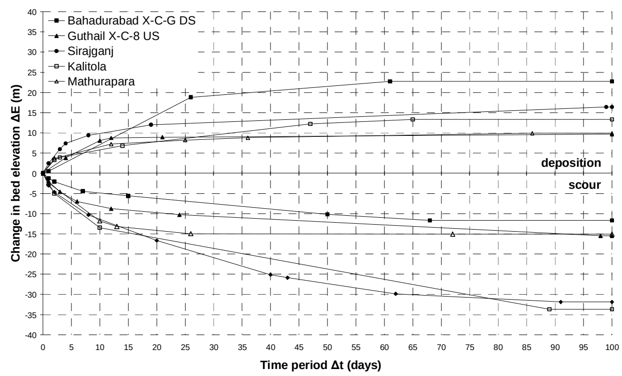

Fig.10 Summary enveloping curves for scour and deposition

Maximum changes in bed elevation at:						
	Site	Bahadurabad	Guthail	Kalitola	Mathurapara	Sirajganj
Deposition	2 days	1 m	2 m	3 m	4 m	4 m
	7 days	5 m	6 m	5 m	5 m	9 m
	14 days	10 m	9 m	7 m	7 m	11 m
	30 days	19 m	9 m	9 m	8 m	13 m
	60 days	23 m	9 m	13 m	9 m	14 m
	90 days	-	10 m	-	10 m	16 m
Scour	2 days	-2 m	-3 m	-5 m	-4 m	-5 m
	7 days	-4 m	-7 m	-10 m	-9 m	-9 m
	14 days	-6 m	-9 m	-15 m	-13 m	-14 m
	30 days	-8 m	-11 m	-19 m	-15 m	-21 m
	60 days	-11 m	-13 m	-26 m	-	-29 m
	90 days	-12 m	-15 m	-34 m	-	-32 m

Table 2 Summary of maximum scour and deposition over various time periods (from Figure 10)

4. SUMMARY OF EXPERIENCE

The observation period for calculating scour and deposition extend up to 100 days at all sites. Some key results from the preceding data and analyses are as follows:

(1) Revetments and spurs exposed to sharply angled or outflanking flow can produce an increase in maximum scour depth that is double the equivalent amount of works subjected to more or less parallel flow.

(2) Maximum short-term scour rates (over less than two weeks) are similar for the three spur-type structures at Kalitola, Mathurapara, and Sirajganj. Of those three, the Mathurapara site shows less severe long-term rates because it did not experience severe long-term attack within the observation period.

(3) As noted above, the two parallel revetments behave differently from the spurs in the long term. However, outflanking attack at the Guthail revetment led to high scour rates during the first week, nearly as high as for spurs.

(4) The highest long-term deposition rates were observed at the Bahadurabad revetment, as a result of major morphological changes to the river in this area.

5. CONCLUDING REMARKS

Various authors have assumed a general pattern of live bed scour development whereby under more or less steady flow conditions, scour develops fast in the initial phase and then decelerates until a temporary equilibrium is reached. However, the above descriptions of scour development at particular sites indicate a somewhat different pattern on the Bramaputra / Jamuna River, as shown in **Figure 11**. In the pre-scour Equilibrium Phase, scouring and sediment inflow are nearly in balance. Significant scour begins in the Initial Phase following increased large-scale turbulence and higher sediment outflows associated with rising water levels and velocities. The rate of scour development then goes through Acceleration, Constant and Deceleration Phases until either a final Equilibrium Phase is reached, or the process is interrupted by geotechnical failures, maintenance work or deployment of falling aprons.

It appears that design of bank protection works on the Bramaputra / Jamuna River should assume that up to 35 m of vertical scour at protruding structures and 15 m at parallel revetments can occur in the course of one flood season. Contingency toe protection or falling aprons need to have sufficient volume to survive during the flood season if no emergency measures are planned or possible. Spurs and protruding structures face greater risks, not only because of the deeper scouring but also because it is more difficult to place emergency protection in the highly turbulent three-dimensional flow around the structure. In addition, the launching on a three-dimensional cone shaped geometry might lead to less satisfactory coverage than along a two-dimensional plan parallel to the bank.

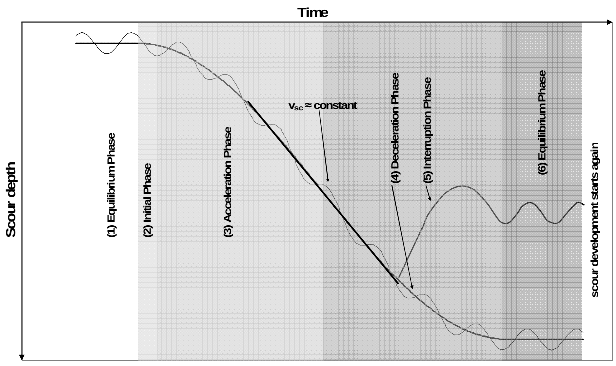

Fig.11 Pattern of scour development with time

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