FLOW AND EROSION PROCESSES AT BENDS AND AROUND RIVER TRAINING WORKS IN A SAND BED BRAIDED RIVER

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CANDIDATE'S DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree.

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Mohammad Nazim Uddin

Dedicated to
My parents

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ABSTRACT

Riverbank erosion is one of the major problems in Bangladesh. Annually thousands of hectares of land are eroded along the major rivers. Millions of people became homeless and landless, and displaced due to erosion. The erosion also affects livelihood, agriculture and environment. To protect banks from erosion about thirty bank protection structures have been constructed along both banks of the Jamuna River. But almost every year some of the bank protection works are damaged. So, it is essential to investigate the insight causes of failure of the bank protection structures. It is basically a field based research. The present study has been conducted (i) to investigate flow and erosion processes at bends, (ii) to investigate flow and erosion processes around bank protection works and failure mechanism of some selected bank protection structures, (iii) to develop of an analytical erosion prediction model and finally, (iv) to integrate indigenous and technical knowledge for sustainable erosion management.

In the present study it is found that the secondary current in a bend of the third order channel within a large scale sand bed braided river is similar to that of the single thread meandering channel. But the secondary cell is divided into multi-cell due to flow over the sandbar. It is also found that the bend channel migrate downstream, lateral direction and upstream direction. The maximum rate of erosion is observed at the upstream and downstream sides of the bend. The rate of erosion is higher at upstream and downstream side of the bend due to the shear velocity is six times higher than critical shear velocity and the thalweg is near the bankline.

The flow and erosion processes around Sirajgang hardpoint, Betil and Enayetpur spurs and bandal at Randhunibari have been investigated in the present study. The radical morphological change in a sand-bed braided river is a great challenge for the structural stability of the river training works. Because the flow processes near a river training works is guided by the sandbar which is a prominent characteristic of a dynamic braided river. It is found that the strength of vortices, flow intensity and velocity considerably changes due to drastic morphological change around the Sirajgang hardpoint. From the present study it is clarified that the oblique flow a prime factor for the failure of the river training works. Other factors also accelerate the failure event of the river training works. From the analysis of flow processes and morphology around the Sirajganj hardpoint it has been investigated that the following are the

reasons of the failure of the Sirajganj hardpoint such as: generation of oblique flow by sandbar and attacked the hardpoint, washed away of sandbar adjacent to the hardpoint, thalweg shifting at the vicinity of the hardpoint, movement of five meter high dune through the channel passing adjacent to the hardpoint, riprap failure due to movement of dune, development of scour hole because of riprap failure, flow slides from the hardpoint side. The causes of failure of the Betil and Enayetpur spurs have also been investigated from the present study. The causes are as follows: generation of oblique flow as a result of upstream morphology, strong parallel flow upstream of the spurs and development of deep channel due to flow circulation normal to the spurs. It is also found from field measured data analysis that the bandal-like structure is very effective as flow diversion and sediment deposition measure. But selection of site for implementing of such structures is a major factor in a large scale sand bed braided river.

An analytical erosion prediction has been developed for the third order channel of a large scale sand bed braided river. The model is developed using the flow parameters, planform parameters, properties of bank materials and indigenous knowledge. The indigenous knowledge regarding effective period of erosion has been integrated into model. The model basically produces an envelope curve. The envelope curve covers eighty seven percent of the observed data and seventy eight percent of EGIS data. The field engineers could estimate the rate of erosion for the third order channel of a sand bed braided river.

It is evident from the present study that the riparian people are enriched with experienced based indigenous knowledge on flow and erosion processes around different bank protection works, flow and erosion processes at bends, erosion processes at the straight bankline, historical morphological change, bend development, the trend of the rate of erosion, effective duration of erosion. It is clarified from the present study that there are strong similarities among experience-based indigenous knowledge, field engineer’s knowledge, field measured result and laboratory based scientific knowledge. Interesting outcome of the present study is that the local people can guess the bank protection structure is going to be failed observing bustling out of air bubble, floating bamboo and geo-textile and turbid water. Observing such signs, the local people convey message of probable failure of the bank protection works to the BWDB personnel for taking necessary steps to avoid failure event. Therefore, management program during emergency situation should be formulated integrating the indigenous knowledge.

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ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
BARCIK	Bangladesh Resource Centre for Indigenous Knowledge
BRE	Brahmaputra Right Embankment
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
CEGIS	Center for Environmental and Geographic Information Services
DPRI	Disaster Prevention Research Institute
EGIS	Environmental and GIS Support Project
HYV	High Yielding Varieties
IFCDR	Institute of Flood Control and Drainage Research
IK	Indigenous Knowledge
JICA	Japan International Coordination Association
RCC	Reinforce Cement Concrete
FAP	Flood Action Plan
FGD	Focus Group Discussion
IWFM	Institute of Water and Flood Management
PWD	Public Works Datum

LIST OF SYMBOLS

B = channel width (m)

b = outer bank erosion width (m)

C = Chezy's coefficient

d_{50}= median particle size of bed material (m)

E_v = erosion volume

E_r = erosion rate (m/s)

h = flow depth (m)

I = longitudinal slope of the channel

K = conversion factor

M = coefficient

q_t = volumetric total load transport (m^2/s)

q_{toe} = outer bank sediment discharge (m^2/s)

q_{avg} = average sediment discharge (m^2/s)

R = channel centerline radius of curvature (m)

S = specific gravity

T = Stage parameter

V_{toe}= depth-average velocity at outer bank (m/s)

V_{avg}= one-dimensional section-average velocity (m/s)

λ = dune wave length (m)

η = dune height (m)

θ = Shields parameters

τ_{toe} = shear stress at outer bank (N/m^2)

τ_{avg} = one-dimensional average shear stress (N/m^2)

CHAPTER ONE

INTRODUCTION

1.1 River Classification

1.1.1 General

Rivers are found in different forms and geometries. Geomorphological classifications of channel type have established qualitative links between channel process, form and stability. Leopold and Wolman (1957) classified rivers as straight, meandering and braided. They separated meandering and braided rivers depending on bankfull discharge and slope of the channel (Fig. 1.1). It can be seen that for a certain bankfull discharge river planform changes from meandering to braided with increase in longitudinal slope of the channel. Against the complex range of driving variables and boundary conditions for controlling the channel form, only two parameters are considered to quantify the geomorphic threshold between meandering and braided. But there is not a distinct threshold that actually exists. From the laboratory study, Schumm and Khan (1972) represent straight, meandering and braided in terms of sinuosity versus valley slope. Schumm (1977) proposed a more useful approach to classify channel type from straight, through meandering to braided channels with no abrupt breaks in between (Fig. 1.2). While classifying the channel type, there is a continuum of planform patterns together with the use of an examination of the geomorphological features displayed by the channel. He shows a general relationship between sediment load, channel stability and channel form. Types 1 and 2 are the straight and slightly sinuous channel, resulting from fine sediment transport in suspension having highly erosion-resistant boundary material. Such channels are confined by their bank boundary, and display very slow rates of lateral bank shifting and channel evolution. This planform is very rare in the natural rivers. Types 3 and 4 are the meandering planform. Mixed-load stream with relatively mobile bed material and greater sediment supply, resistant but somewhat erodable bank, generally follows meandering courses. These channels migrate freely across the flood plain through bank erosion and point bar growth. Type 5 is a braided planform. Rivers with sufficiently high energy to transport relatively coarse sediment as significant bed load, and with weak bank material tend to have multithreaded and braided pattern. Braided channels are very unstable; they wander across their flood plains unpredictably through a combination of rapid localized bank erosion and frequent anabranch avulsion. Rust (1978) proposed a qualitative diagram for the continuum of patterns, using sinuosity and degree of channel division. He classifies four types of channels as straight, meandering, braided and anastomosed, in contrast with of Leopold and Wolman's original three. Anastomosed channels are highly sinuous anabranches separated by large, vegetated areas of land at about the same elevation as the flood plain. Different researchers classify channel on the basis of channels form, cross-section, longitudinal dimension, degree of entrenchment, gradient, width to depth ratio, sinuosity, and trend and types of morphological change (Brice, 1975; Rosgen, 1994; Downs, 1995).

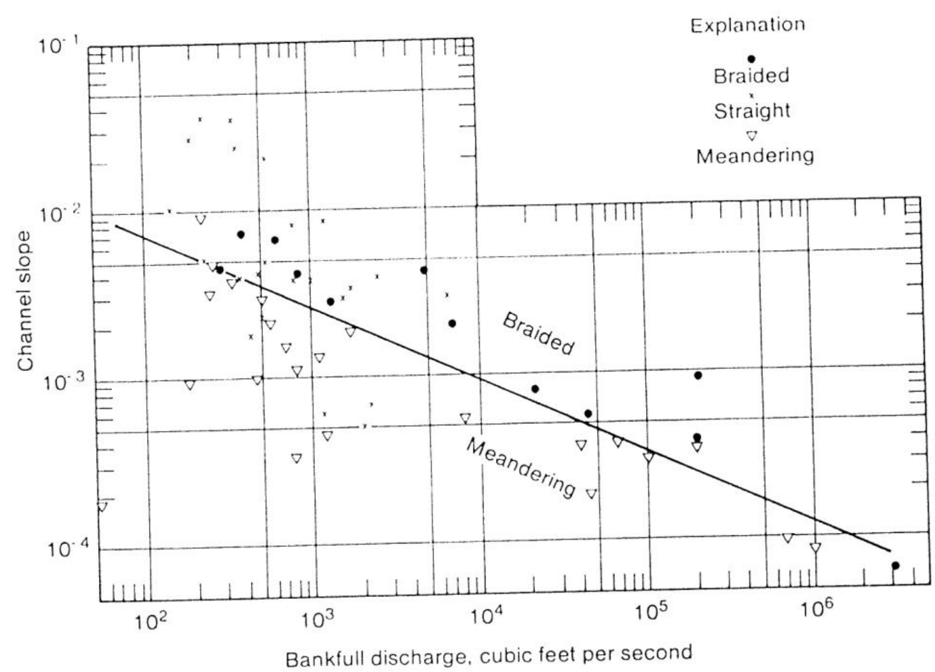


Figure 1.1: Slope discharge relationship as differentiation between meandering and braided (Leopold and Wolman, 1957)

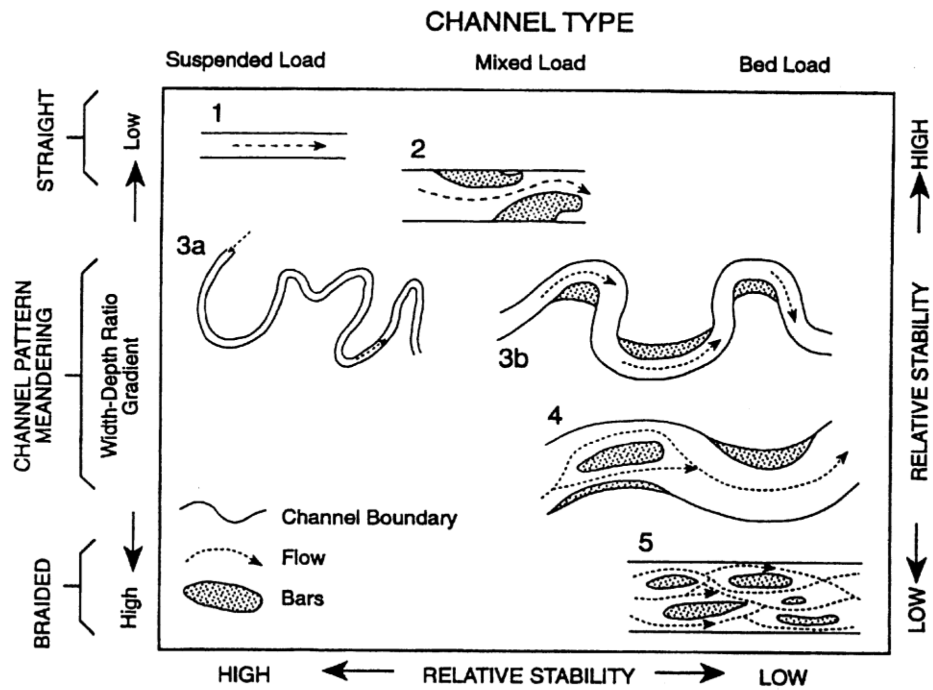


Figure 1.2: Classification of channel patterns based on sediment load and system stability (courtesy: Schumm, 1977)

1.1.2 Straight rivers

A straight river refers to one that does not have a distinct meandering pattern, and sinuosity (ratio of channel length to valley length) is nearly unity (Thorne, 1997). It is usually found that the paths of both the filament of maximum velocity and the line of the deepest point (thalweg) oscillate across the width in describing a sinuous pattern within the straight alignment of the banks. The tendency to produce a sinuous thalweg is closely related to vertical oscillation in the bed elevation termed pools (deeps) and riffles (shallows) which are clearly defined in gravel-bed rivers but can also be detected in sand-bed streams.

1.1.3 Meandering rivers

A meandering river has a sinuosity greater than about 1.5, and it consists of alternating bends and a distinct sinuous planform. Although the sinuosity varies among meandering rivers, there exists marked similarity in the ratio of the radius of curvature to channel width.

The exact condition under which a stream meanders and the exact mechanism of such processes are not yet known completely. The latest and widely accepted theory behind meandering is based upon the extra turbulence generated by the excess of river sediment during floods. It has been established that when the silt charge is in excess of the quantity required for stability, the river starts building up its slope by depositing the silt on its bed. This increase in slope tends to increase the width of the channel if the banks are not resistant. Only a slight deviation from uniform axial flow is then necessary to cause more flow towards one bank than towards the other. Additional flow immediately attracted towards the former bank, leading to shoaling along the latter, accentuating towards the curvature of flow and producing finally, meanders in its wake (BWDB, 2008).

1.1.4 Braided rivers

The braided river transports huge volume of sediment load. The channel shifts it courses due to deposition of the excess sediment load and rapid bank erosion (Bristow and Best, 1993). Braided rivers are characterized by having a number of alluvial channels with bars and islands in a sequence of confluence and bifurcation. In general, flow divergence is associated with flow deceleration and sediment deposition and, once sediment deposition has been initiated, the sediment accumulation is expected to promote further flow division, deposition and bar formation. The divergent flow may impinge on the bank at an increased angle leading to bank erosion, channel widening and local increased in sediment load. All of which play a significant role for developing a new braid bar.

The planform appearance of braided river can change rapidly with flow stage. At higher flow stages when the largest volumes of sediment are transported, the channel are often scoured, bars may be reduced in height or in some cases completely eroded. During falling stage maximum deposition occurs as discharge and flow capacities are reduced. Channel beds aggrade, the high stage bedforms may be modified and new bars may be formed or enlarged as sediment is deposited. As discharge continues to fall, bars may become emergent and dissected by low stage channel.

In a braided river three orders of channels are present (Williams and Rust, 1969; Bristow and Best, 1993 and Bridge, 1993). The order of channels depends upon total discharge and fluctuation of discharge. The first order comprises the whole river. Second order channels are the dominant channels within the river whilst third order channels are primarily low stage features which modify the bars deposited by the second order channels (Bristow and Best, 1993).

The difference between the bars and islands (these are features of braided river morphology) is identified by different authors (Brice, 1964; Bridge, 1993; Bristow and Best, 1993; Thorne, 1993). Bars are defined as dynamic features which are non-vegetated and submerged at bankfull stage. Islands are more stable features, emergent at bankfull stage and vegetated. In the case of the Jamuna River, Thorne et al. (1993) identified three levels of bar. First level bar corresponds to an island char and is characterized by mature, perennial vegetation, fully developed agricultural practices and permanent habitation. In terms of both elevation and land use it is very similar to the flood plain outside the braid belt. The second level corresponds to braided bars that flank the main island in the satellite image. The bars are quite different in appearance to the island. They are large sand bodies displaying loose sediment surfaces, immature and annual vegetation, seasonal cropping and no permanent habitation. The third, very low bar level is associated with dunes in the sub-channels flowing around the bars. These are much smaller features that remain inundated at the lowest flows. The present study is limited to braided river.

It is found from a study on a large scale sand bed braided river that the flow structure in a bend of an anabranch channel (i.e. second order channel) of a braided river is similar to meander bends of single thread rivers (Richardson and Thorne, 1998; FAP24, 1996). No available literature is found on the flow processes in a bend of a third order channel (which originated from the second order channel) of a braided river while some amount of flow is added to the channel. A lot of literatures are available on flow processes around abutments, groin-like structures, piers by many researchers (Melville, 1975; Hjorth, 1975; Kandasamy, 1989; Tingsanchali and Maheswaran, 1990; Rahman, 1998; Barbuiya and Dey, 2003; Salaheldin at el., 2004; Dey and Barbuiya, 2005; Kirkil at el., 2008; Zhang al el., 2009). Most of the studies were performed in the laboratory or numerical simulation.

But a very scarce study was performed based on field condition especially on a large scale sand bed braided river where the hydrological and morphological parameters change rapidly. Insufficient study was conducted on the response of the river training works due to hydrological and morphological in a braided river. We should pay attention on this issue. A lot of empirical, numerical and physical erosion prediction models are available in literature. But no erosion prediction model is available which is developed integrating indigenous knowledge. A lot of indigenous knowledge on flood and erosion prevails into the riparian community or into people living on the charland of a braided river (Schumuck-Widmann, 2001). So, it is important to investigate indigenous knowledge on flow and erosion that may play vital role in the management activity.

1.2 Major River System in Bangladesh

Bangladesh is a deltaic country that is located at the confluence of the three major rivers: the Ganges, the Brahmaputra and the Meghna (Fig. 1.3). A dense network of rivers is formed inside Bangladesh by tributaries and distributaries of these major rivers. The total drainage area of these three rivers stands at 1.72 million sq. km covering areas of China, India, Nepal, Bhutan and Bangladesh (BWDB, 2008). Almost 92% of these catchment area lies outside Bangladesh. It has been estimated that the quantity of sediments carried by these rivers varies from $1.1 \sim 1.6 \times 10^9$ tons annually (Hossain, 1993). The Ganges and the Jamuna Rivers join together at Aricha, and the combined flow is known as the Padma River. The Meghna joins the Padma at Chandpur and flows towards the Bay of Bengal as the Lower-Meghna. The huge amount of sediment load is partly transported into the Bay of Bengal and the rest deposits on the floodplain and the river bed, and brings significant morphological changes in the river system. Again, due to the flatness of the country, the longitudinal slope of the river bed is too mild to carry the sediment and water discharge during monsoon, creating overland flooding and flood related disasters (Rahman, 1998).

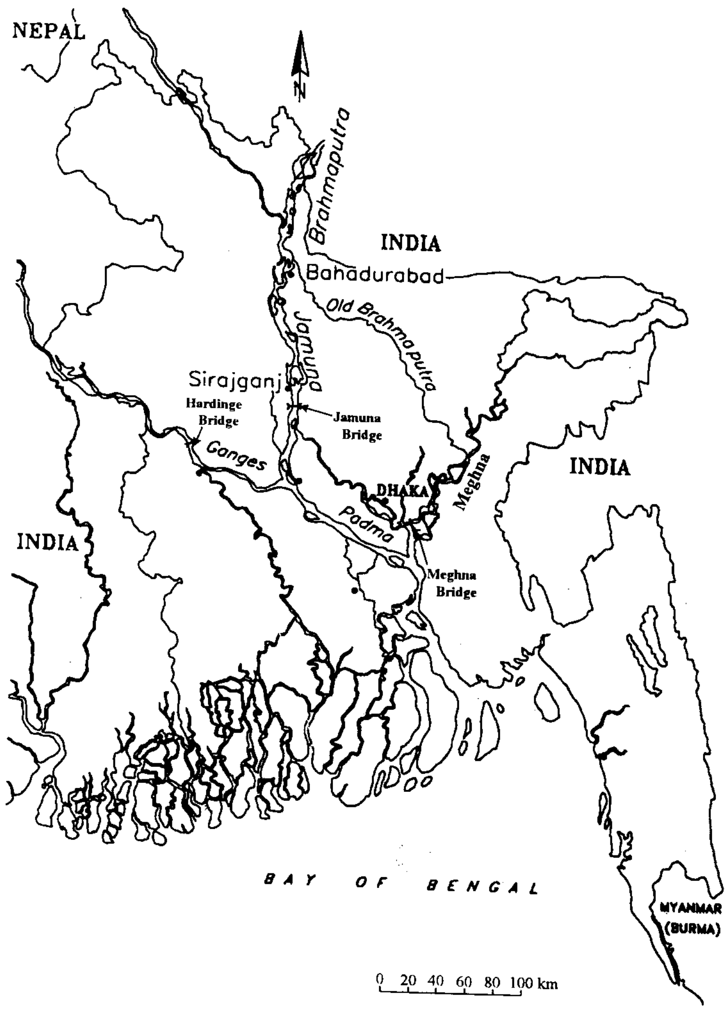


Figure 1.3: The major river system in Bangladesh

1.3 The Braided Jamuna River

The Jamuna River draining the northern and eastern slopes of the Himalayas is 2900 km long and has a drainage area of 573,500 km^2. The reach (length 240 km) of the river inside Bangladesh has several right bank tributaries such as the Teesta, the Dharla, the Dudhkumar, etc and two left bank distributaries, the Old Brahmaputra and the Dhaleswari Rivers. It is a wandering braided river with an average bankfull width of about 11 km. The channel has been widening, increasing from an average of 6.2 km in 1834 to 10.6 km in 1992. Having an average annual discharge of 19,600 m^3/sec, the river drains an estimated

620×10^9 m^3 of water annually to the Bay of Bengal. The discharge varies from a minimum of 3,000 m^3/sec to a maximum of 100,000 m^3/sec, with a bankfull discharge of approximately 48,000 m^3/sec. The average water surface slope is 7 cm/km. The range of variation of Brice braiding index of the Jamuna River is 4 to 6 (FAP 21/22, 2001).

1.4 Erosion and River Training Works

Braided rivers are very unstable, and they wander across their flood plains unpredictably through a combination of rapid localized bank erosion and frequent channel changes. It is investigated from an analysis of the historical map that the Jamuna River has migrated westward at a rate of 50 m/year since the avulsion of the river from the east of the Madhupur Tract to its present course about 200 years ago (BWDB, 2008; CEGIS, 2005). The river shifted its course towards western direction up to 10 km in some reaches (Klaassen and Vermeer, 1988). From 1973 to 2009, erosion and accretion along the Jamuna river was 90,830 ha and 10,140 ha respectively (CEGIS, 2009). The rate of erosion varied over time. From 1970 to1990 the Jamuna River widened at a very high rate; both the banks migrated outward at an average rate of about 70 m/year. Since the early 1990s, the rate of outward migration of both banks has reduced to 30-50 m/year (CEGIS, 2005). Due to the dynamic equilibrium characteristics of the Jamuna River, it always changes its courses within the braided belt (FAP 24, 1996).

1.4.1 Erosion problem in the Jamuna River

Riverbank erosion is one of the major natural hazards of Bangladesh (Fig. 1.4 a-b). Erosion has rendered millions of people homeless and landless, and has created a major social hazard. Most of the slum dwellers in large urban metropolitan towns and cities are victims of river bank erosion (CEGIS, 2009). Some erosion affected people take shelter on Brahmaputra Right Embankment (BRE) and some live into the char (high sandbar). In 2008, about 1820 ha land is eroded by the Jamuna River and about 18,000 people are displaced by riverbank erosion. The livelihood strategy of charland people is described by Schmuck-Widmann (2001) and Sarker et al. (2003). Every year, embankments, roads, educational institutions, bazaars, health centers and different government offices are damaged by erosion. Related to river bank erosion, detailed studies were carried out on population displacement, resettlement, economic impact and human response to riverbank erosion hazard by different researchers (Elahi, 1991; Halli, 1991; Haque, 1991).

1.4.2 River training work in the Jamuna River

The rate of erosion along the right bank of the Jamuna River is higher than that of the left bank. The Brahmaputra Right Embankment (BRE) was built during the late 1950s and mid 1960s to protect the flood plain against flooding. On-going bank erosion has led to breaches of the BRE at several locations. The FAP1 (1994) component was formulated to study on short term and long term protection along the right bank of the Jamuna River. Out of 10 locations, 6 priority vulnerable locations were selected for bank protection measures. Under this component, construction of hardpoint was suggested to stabilize the boundaries of the braided belt. During 1998, hard points have been built at Sirajgang, Sariakandi and Mathurapara. The construction costs of the hardpoint were very high.

Later on, BWDB introduced a new low cost RCC spur for bank protection. Recently, River Research Institute has introduced bandal-like structures for the erosion management along the Jamuna River using the field experience of Bangladesh Inland Water Transport Authority (BIWTA), research experience of Kyoto University, Japan and BUET. Therefore, mainly three types of bank protection structures have been constructed along both the banks of the Jamuna River in different times. These are: (1) bank parallel revetment-like structure, (2) normal to the bankline groin-like structure, and (3) temporary bandal-like structure.

(a) (b)

Figure 1.4: Erosion at Shuvogacha bend along the right bank of the Jamuna River

Revetment-like structure is a well known bank protection method. It is practiced in the whole world and very common in Bangladesh. A revetment is a structural protection against wave and current induced loads covering the existing river bank or an embankment. It is not an offensive structure like a groin. It does not disturb the flowing river. It has several components e.g. cover layer; intermediate layers between cover and core material. The material layer is required for drainage and filtering to allow for a stable foundation of the overall system and toe. The cover layer must resist the design impacts of current and wave. Toe protection is required in case currents and/or waves scour and undermine the toe of a bank or an embankment, which is likely to result in the sliding of the slope. The sliding of the slope endangers the overall stability and function of the revetment which is very common in Bangladesh. Normally, the revetment works are done with CC blocks, boulders, mattresses, open asphalt concrete, etc. Geo-bags are being used in Bangladesh over the last several years. It was being mainly used for emergency works to protect the river bank erosion. Now it is being used for revetment works for the protection of river bank erosion. Sand-filled geo-bags are used instead of CC blocks. The groin-like structures are permeable and impermeable. The permeable groins are built with piles of different materials. The impermeable groins are simply constructed with an earthen shank covered with CC blocks. The above mentioned RCC spur is constructed in combination with an earthen shank and RCC part. Different strategies were proposed under FAP 22 component for the medium-term and long-term training of the Brahmaputra-Jamuna River. Under FAP 22 component, the effectiveness of some recurrent measures was tested in prototype scale. The bandal has potentiality as accelerating sedimentation and flow diversion structures (FAP 21/22, 2001; Rahman et al. 2007).

About 30 river training structures have been constructed along BRE mostly during the last decade. Bangladesh Water Development Board (BWDB) has mixed experiences of both failures and successes of such projects for the protection of BRE (Uddin, 2007). During the period of 1999-2002, fifteen RCC spurs have been constructed at different locations of BRE with variable length and spacing. Out of these, five were damaged due to poor construction and lack of repair and maintenance works (Uddin, 2007). The various modes of failure of different structures were observed during field investigation in 2007, 2008 and 2009. The modes of failure are shown in Fig. 1.5 (a-f).

(a) Slip circle failure of the earthen shank of the Chandanbaisha spur (2007)

(b) Failure of bellmouth of the Baniajan spur (2007)

(c) Mass failure of the Ranigram groin (2007)

(d) Slip circle failure of the earthen shank of the Enayetpur spur (2007)

(e) Failure of the Sirajganj hardpoint (2008)

(f) Failure of the Sirajganj hardpoint (2009)

Figure 1.5: Modes of failure of different river training works in the Jamuna River

The different modes of failure in 2007 have been discussed in a technical report prepared by Hoque et al. (2008). The primary causes of failures of different bank protection structures are flow slide, oblique flow towards bankline or structure and generated excessive local scour around bank protection structures (BWDB, 2008; BWDB, 2006; BWDB, 1999). Repair and maintenance works are very important for the river training works even around very expensive structures such as the hardpoint (BWDB, 1999). Every year a lot of money is required for the repair and maintenance works of the river training structures.

It is important to investigate the insight causes of failure of the bank protection structure. It is essential to take appropriate steps to remove or overcome the causes for sustainability of the structures. The main aims of the present study are to investigate flow and erosion process at a bend, to develop an erosion prediction model, to investigate flow and erosion processes around bank protection structures and finally to clarify failure mechanism of some selected bank protection structures along the Jamuna River.

1.5 Objectives with Specific Aims and Possible Outcome

The major objectives of the study are:

a) To investigate flow and erosion processes at a bend along the sand bed braided river.

b) To investigate flow processes around bank protection works along the sand bed braided river and to clarify failure mechanism related to changes in flow and morphology, development of scour hole and dune movement.

c) To develop an analytical model for the prediction of the erosion rate.

d) To integrate indigenous or local knowledge and technical knowledge for sustainable erosion management.

It is expected that the flow and erosion processes at bends would be clarified. It is also expected that the research output would clarify the flow and erosion processes around bank protection works. The failure mechanisms of different bank protection works would be clarified. The developed analytical erosion prediction model would be capable of estimating the rate of erosion along the third order channels (adjacent to the bankline) having meandering planform within a braided river. The predicted rate of erosion would be helpful for the planning process. The investigated indigenous knowledge would be useful for sustainable erosion management.

1.6 Scope of the Study

The present study is very useful to realize the actual problem near bank protection works and what measures should be taken to alleviate the problem. After all huge funds may be saved which would be allocated for repair and maintenance of different bank protection. It may be forecasted what area would be eroded during a flood season using the developed erosion prediction model. The vulnerable people may shift their property to safer place following the forecasting. As a result, the loss of property would be reduced. The local knowledge could play a vital role in the sustainable erosion management programme.

1.7 Limitations of the Study

Major limitations of this study are summarized below:

(i) Only single set field data is used in the case of Shuvogacha, Betil-Enayetpur and Randhunibari sites except Sirajganj hardpoint for analyzing the flow and erosion processes. But the flow phenomena always change with the variation of water levels in the Jamuna River. Therefore, results should be used with special care for practical problems. For academic analysis, using the limited data set would generate new knowledge on the topic.

(ii) To investigate local knowledge on flow and erosion processes, only four study sites are selected out of about 30 different types of bank protection works along the Jamuna River. But the site specific problems and their solutions may differ case by case.

(iii) The country boat is not perfectly suitable for data collection. For practical problems, specially designed boat may provide better quality of data.

1.8 Outline of the Dissertation

This report consists of additional seven chapters excluding Chapter 1.

Chapter 1: The background and present state of the problem, objectives, outcome, scope, limitations of the study have been briefly discussed in this chapter.

Chapter 2: Literature reviews have been summarized in this chapter on: (i) flow and erosion processes at bends and around river training works; (ii) causes of failures of riprap; and (iii) indigenous knowledge.

Chapter 3: The methodologies for achieving the selected objectives have been discussed in this chapter.

Chapter 4: The detailed descriptions on the selected study sites have been given in this chapter.

Chapter 5: The flow and erosion processes at bends of a sand-bed braided river have been discussed in this chapter. The methodology for the development of an analytical erosion prediction model has also been explained.

Chapter 6: The flow and erosion processes around some selected bank protection works are analyzed. The causes of failure of the Sirajganj hardpoint and Betil and Enayetpur RCC spurs have been clarified from the flow processes, changing morphology, dune movement and development of scour hole. The effectiveness of the bandal-like structures has been discussed as a flow diversion and bank protection structures in field level.

Chapter 7: The available indigenous knowledge has been brought together in this chapter on: (i) overall flow and erosion processes in a sand bed braided river; (ii) flow and erosion processes around bank protection works; and (iii) indication of failure of the bank protection works.

Chapter 8: The overall conclusions of the present study and the recommendations for further study have been discussed in this chapter.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

A critical review is presented in this chapter on all available literature relevant to the present research work. Different issues of meandering have been discussed here such as: geomorphological studies, stability analysis, flow processes at bends, experimental studies on meandering with bank erosion and computational methods of bank erosion. A brief overview is given on the commonly used bank protection methods in Bangladesh. How flow processes are changed around a bank protection work is also discussed. How the riprap is affected by dune movement. The structural failure of revetment, groin, abutment and pier occurs as a consequence of riprap failure. Comprehensive indigenous knowledge has been practiced by the different communities in the world for a long time. The practicing of indigenous knowledge, in a variety of fields including flood and erosion hazard, cyclone hazard, agriculture, health care and environmental conservation etc., is a long history in Bangladesh.

2.2 Studies on Bend Channels

A systematic research on meandering appears to have been initiated towards the end of the 19th century. Since then, a voluminous literature has been produced on various aspects of meandering channels such as mechanics of meandering flow, initiation of meandering, time growth of their loops, modeling of meandering channels, their bed topography, etc.

2.2.1 Geomorphological studies

The rapid development for the understanding may be traced back to the basic contribution by Kinoshita (1957, 62) and Leopold and Wolman (1957). They observed the development of alternate sequence of pools and riffles in the straight and meandering reaches of rivers, which are the basic features of meandering channels. Langbein and

Leopold (1966) attempted to characterize the planform of meanders in terms of a generalized geometrical shape. Fig. 2.1 shows four types of curves proposed by them. They found that the sine-generated curve is an idealized one to represent most of the meandering channels. This curve closely approximates the curve of least work in turning around the bend, and they explained that this is the reason why natural rivers follow the shape of a sine-generated curve.

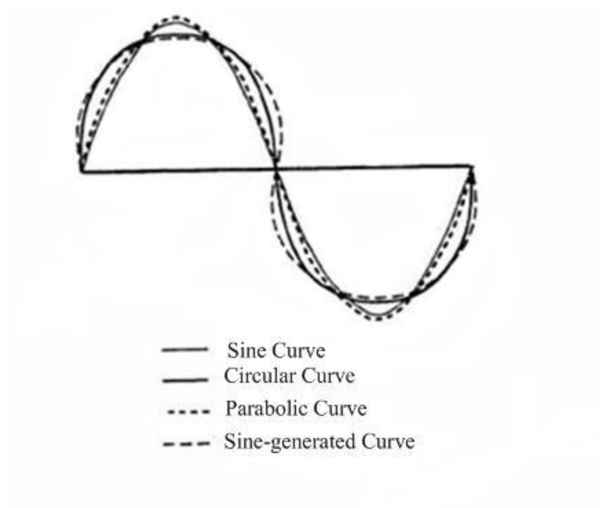


Figure 2.1: Geometric curves investigated by Langbein and Leopold to define meander shape (courtesy: Langbein and Leopold, 1966)

2.2.2 Theoretical studies: Stability analysis

After the pioneering study by Engelund (1974), theoretical studies on meandering channels have been advanced to a high level of understanding. The theoretical researches on meandering channels so far, according to Parker and Johannesson (1989), can be divided into two main groups, namely, the “T” problem which corresponds to free alternate bar topography and the “B” problem that corresponds to meander bends and curvature induced forced point bars. The former problem is relatively easy and solved almost completely in order to understand the development and growth of alternate bars in the straight channels (e.g. Callander, 1968; Engelund and Skovgaard, 1973; Fredsøe, 1978; Kuroki and Kishi, 1985).

The “B” problem can be further divided into two: the “C” problem, related to bend curvature and “F” problem which corresponds to curvature induced point bars. The “C” problem is equivalent to Engelund‟s (1974) second approximation where the inertia term of the transverse component of flow equation was ignored. Then a little modified flow equation was used by Ikeda, Parker and Sawai (1981) and Parker and Andrews (1986) in their bend growth treatments. On the other hand, the “F” problem is identical to “T” problem, except that the sediment bars here are the curvature induced forced point bars, rather than the free alternate bars.

Hasegawa (1984) analyzed the “B” problem including the inertia term in Engelund‟s (1974) analysis. He derived the condition for meander development using approximate solution by Galarkin‟s method and tested the validity of the developed theory comparing with their experimental results in meandering channels with a one-side erodible bank. The “B” problem was further treated by Blondeaux and Seminara (1985), as a unified bar-bend theory of the river meanders. In their rigorous solution, they detected the resonant relation between the bend and the point bar in the steady state condition. It was pointed out that the bar-bend resonance occurs at the natural wave number of alternate bar theory. Recently, Nakamura, Hasegawa and Toyabe (1995) have discussed the resonance theory by conducting a series of experiments in meandering channels having wide ranges of bend angles and wavelengths.

2.2.3 Studies on flow processes at bends

The flow in meandering channels under centrifugal acceleration induces a secondary current or transverse circulation and super-elevation in water surface. A secondary current grows upon entering a bend. The growth and decay of a secondary current, as explained by Rozovskii (1957), is due to the interaction of centripetal force and turbulent shear stress that the flow has to overcome in transforming from the secondary pattern into a parallel flow and vice versa. Research in meandering channels has established that patterns of primary isovels and pathways of bed material transport are strongly influenced by a secondary current (Thorne et al. 1985). At bends with steep outer banks, the secondary current consists of a main cell and an outer bank cell of reverse circulation (Bathurst et al. 1979). The influence of secondary currents on a flow and sediment dynamics causes meander shifting through river bank erosion and bar formation in a typical meandering river (Thorne, 1991; Thorne and Hossain, 1995). It is found from a study on the Jamuna River that the flow structure in a bends of an anabranch channel (i.e. second order channel) of a braided river is similar to meander bends of single thread rivers (Richardson and Thorne, 1998; FAP24, 1996). The evolution and decay process of secondary currents in a doubly meandering compound channel and the influence of water depth on the position and strength of the secondary currents in the main channel have been investigated by Islam et al. (1999). The effect of bed slope on flow pattern in a doubly meandering compound channel is also studied by Islam et al. (2007). They found that the flow patterns in the cross-over sections are different between mild and steep slopes. Erosion often occurs at the outer banks of a meander bends as a result of amplified flow velocities and shear stress. A relationship has been established by Thorne et al. (1995) between section-averaged velocity and outer bank velocity which is related to meander geometry such as channel width and the radius of curvature.

2.2.4 Experimental studies on meandering with bank erosion

The only reported studies so far are by Kinoshita (1962), Whiting and Dietrich (1993), Toyabe, Watanabe and Shimizu (1996) and Rahman, Nagata and Muramoto (1996, 1997). Kinoshita studied the meandering planform deformation processes qualitatively by photo observation. In his experiments, the linear wavelength varies from 10~43 channel-width. All of the experimental conditions are in fully developed meanders, and shingled bars (more than two bars in a meander wavelength) were formed in the large amplitude bends. The similar type of shingled bar development was also found in the studied by Whiting and Dietrich. Again, Toyabe et al. tested the effect of bank protection on meander bend development. From their experimental study, it was found that the construction of protection works along the outer bank can help to check the development of meander bends and sectional changes just downstream of the protection works.

2.2.5 Computation of rate of bank erosion

Bank erosion is caused by hydraulic forces acting on the bank surface, and the failure of the bank due to geotechnical instability of the bank is the most commonly observed bank erosion phenomenon in nature. The rate of bank erosion, the approach by Ikeda at al. was among the pioneering works addressing bank erosion when studying alluvial river processes. In their approach, the rate of bank erosion is linearly related to the excess near-bank velocity, which is the difference between depth-averaged velocity and cross-sectional mean velocity. If the near bank velocity is greater than zero, the bank retreats otherwise it advances. Odgaard (1989a) suggested that the bank erosion rate could also be correlated to the near-bank flow depth instead of the excess near-bank velocity. The universal bank erosion coefficient by Hasegawa (1989) relates the bank erosion rate to the cross-sectional mean velocity, which was validated using data from alluvial channels in Japan.

Bank erosion occurs by the combination of two processes: basal erosion due to hydraulic forces and mass failure under the influence of gravity (Osman and Thorne 1988). Basal erosion refers to the fluvial entrainment of bank material by flow-induced forces that act on the bank surface drag force, resistance force, and lift force. Bank failure occurs due to geotechnical instability (e.g., planar failure, rotational failure, sapping, or piping). Osman and Thorne (1988) developed a physical-based model to predict the slab-type failure process in cohesive bank materials by the stated two processes. They ignore the pore-water pressure and hydrostatic confining pressure in the stability analysis. Darby and Thorne (1996) developed the stability analysis model considering the pore-water pressure and hydrostatic confining pressure. But the bank materials are considered non- layered and homogenous. A depth-averaged two-dimensional erosion prediction model is developed by Chen and Duan (2008). The rate of bank erosion is a function of bed degradation and lateral erosion rather directly related to near-bank velocity. In addition, bank height, bank slope, and thickness of cohesive and non-cohesive layers on the bank surface were considered when determining the rate of bank erosion. Roddriguez and Garcia (2000) developed a bank erosion model, combining meander migration model and bank failure model. The meander migration model treats bank erosion in an extremely empirical way, considering it as a continuous process linearly related to the near bank velocities. On the other hand, the bank failure model is more physically based; it proposed a threshold-driven phenomenon (bank collapse).

Hickin and Nanson (1975) established a relation between the rate of lateral migration of a channel bend and the ratio of radius of curvature to width of the bend (e.g. R/B). They found that the rate of meander migration reached a maximum value when the value of R/B approximated 3, and the rate of bend migration rapidly decreased with R/B value less or greater than 3. Begin (1981) established the relationship between bend migration and the curvature ratio R/B in a different way. Based on momentum equation for the flow in a bend, the force per unit area which the flow exerts on the outer, cut banks is expressed in terms of flow characteristics (density and mean velocity), sediment characteristics (the coefficient of dynamic friction), and bend geometry (the bend deflection angle and the curvature ratio). Assuming all parameters is constant except curvature coefficient which is dependent on the force per unit area acting on the outer bank. The coefficient of curvature reaches a maximum value when force per unit area is expected to be the maximum within a range of $2.0 < R/B < 4.1$. This value well accords with the observation of Hickin and Nanson (1975), who showed that the bank erosion in meander bends of the Beatton River is the maximum of $2.4 < R/B < 3.3$.

Richardson (2002) has developed a simplified erosion prediction model to estimate the rate of erosion in a meander bend. As input data, the centerline radius of curvature and width of the meandering river are used in the model. A conversion factor is derived for shear stress at bends based on the assumption that the ratio of outer bank velocity to section average velocity is equal to the ratio of channel centerline arc length to outer bank arc length. The ratio of outer bank shear stress to average shear stress is assumed to be directly proportional to the square of velocity.

Klaassen and Masselink (1992) studied the bank erosion rate along the outer banks of channels in the Jamuna River. They established the relation between relative bank erosion rates and relative curvature of the channel based on the work of Hickin and Nanson (1984) on meandering rivers. The study carried out by Klaassen and Masselink using satellite images yielded a relation between the relative erosion rate E_{max}/W and the relative radius of curvature R/W for the Jamuna River. In their analysis, they considered the width and radius of curvature of the secondary channels of the Jamuna River as observed in dry season satellite images. They found that the maximum relative rate of erosion is at relative curvature in between 3 to 4 for the Jamuna River.

Under the framework of FAP 1, Halrow *et al.* (1994) studied the long-term bank erosion processes of the Jamuna River, using time-series images. They also developed a method for predicting line migration on a long-term basis. Halcrow *et al.* estimated the life span of eroding bends and assessed the number of retirements of the Brahmaputra Right Embankment (BRE). The study was based on the satellite images for the period of 1973-1992.

EGIS (2002) developed an empirical erosion prediction method based on the sedimentary features of the Jamuna River. These sedimentary features are: contraction bars, sharpened bars, sand wings, sand tongues and bankside bars. The sediment features are identified from satellite images and they are considered indicators of morphological behavior. The data extracted from the satellite images are divided into two groups based on the presence and absence of sedimentary features, and correspondingly, two sets of prediction tools are developed for morphological processes or erosion prediction. Using this erosion prediction tools CEGIS forecast probable erosion extent each year to warn floodplain dwellers and management organizations such as the BWDB, local government, NGOs, and the Disaster Management Bureau, against bank erosion along the Jamuna River.

CEGIS (2007) has studied on the long term erosion processes of the Jamuna River. It is found that the long term erosion processes along the Jamuna River are very complex. The magnitude and rate of erosion vary temporally and spatially. They have also studied that the life span of meandering bends of the main channel varies widely from one year to several years. The average life span of such channels along the right bank is 4 to 5 years, whereas it is about 2 to 4 years for the channels along the left bank. Recent CEGIS (2010) prepared technical reports on predicting bank erosion along the Jamuna forecasted that downstream of the Sirajganj town is erosion vulnerable zone. CEGIS prepared erosion prediction report on the Jamuna, the Ganges and the Padma in the yearly basis.

2.2.6 Summary

A lot of empirical, numerical and physical erosion prediction models are available in literature. Some of them are developed fully based on the physical parameters of the channels. Some of them are based on the hydraulic impact in combination with mass failure under the influence of gravity. The existing erosion prediction methods for the Jamuna River are based on the physical parameters or sediment feature. There is a scope to develop erosion prediction model for the third order channels (adjacent to the bank line) within a braided river based on the physical parameters of the bend channels, hydraulic parameters, properties of bank materials and indigenous knowledge. There is also a scope how the flow process at bends (third order channel within a braided river) is changed due to flow over sand bar.

2.3 River Training Works

2.3.1 River training strategies

There are different river training concepts to stabilize any alluvial river, especially for wandering braided rivers, which have not only been studied but also implemented in the present world. For river stabilization, any one of them can be followed whereas a combination of these approaches is also possible. Some of the proposed concepts are summarized in the following section.

Depending upon the purposes for which a River Training programme is undertaken, the River Training works may be classified into the following three broad categories:

High Water Training or Training for discharge: The primary purpose is flood control. It, therefore, provides sufficient river cross-section for the safe passage of maximum flood.

Low Water Training or Training for depth: Low water training is undertaken with the primary purpose of providing sufficient water depth in navigable channels during low flow periods.

Mean Water Training or Training for sediment: Mean water training aims at efficient disposal of suspended load and bed load, and thus, to preserve the channel in good shape.

The maximum accretion capacity of a river occurs in the vicinity of mean water or dominant discharge.

2.3.2 Different concepts of river training

The chief aim of River Training is to achieve ultimate stability of the river with the aid of river-training measures. The stability of a river does not mean that changes like scouring and siltation of bed, advancement of delta into the sea, etc. will take place. It only means that the river attains an equilibrium stage, and no significant change occurs in its alignment, slope, regime, etc. Some training methods have been described below:

Active Channel Training

This is an approach where the river behavior is monitored and where, when there is something wrong counter measures are taken. For example, it is sometimes required to divert a flow to another location instead of its present undesirable course. This can be done by the construction of a pilot channel and by putting a submerged sill in the original channel, ultimately and when the measures are successful, the flow will adjust itself to the new alignment. The construction of the pilot channel can be done by dredging. Such types of recurrent measures can be applied as and when necessary to stabilize a river. The concept is suitable for smaller scale, but in large braided rivers like the Jamuna, there will be a large amount of logistics involved.

Stabilization of Nodal Reaches

In general, braided rivers have two types of reaches, notably, wide and diverging reaches, and narrow converging reaches. The wide reaches have a dispersed flow, many sand bars and the width is more than the average width of the river, whereas the narrow reaches, normally in the confluence of anabranches, have smaller width than average. These narrow reaches are often called nodal points or nodal reaches. Coleman (1969) proposed two possible explanations for the occurrence of nodes in braided rivers. First, they may result from the presence of erosion resistant material in the bank i.e. they are geologically controlled; secondly, the nodes may develop as part of the braiding process. They are morphologically controlled.

For the stabilization of any braided river, these nodal points can act as a support base for training works. These are the reaches which have to be stabilized first. This concept is very suitable for the wandering types of rivers. When the nodes are stabilized, the channels in between them have only limited freedom of movement. But in the method there is no direct control over the bank erosion in the places in between the nodal points. Different types of measures are to be taken in addition to stabilization of nodes to control that erosion as well. The distance (L) between the nodal points is an important aspect; the closer the points are, the more effective will be the control over the reaches in between them.

Bend Stabilization

According to our present understanding of the fluvial processes in alluvial rivers, a meandering river with bends can maintain a stable river pattern. The major bends are considered the key points for stabilization in this method. The first work is to stabilize the major banks of the anabranches on both sides of the wide reaches of a braided river. These are also the places where most of the bank erosion takes place. For this control the river may respond by shifting its nodal reaches, so stabilization of nodal points is also important in this approach. The main advantage of a bend control scheme is that it can fully utilize the function of the guiding of the bend flow, and make the flow pattern gentler, and consequently, the scour holes in front of the training works are shallower. The different structures "cooperate" whereby extreme attacks are prevented. With this method the wandering type of Braiding River can be transformed into a river having a smaller number of anabranches. For this approach it may also be required to stabilize the permanent chars (islands) and to close off the less important branches.

(a) Single meandering channel

With the approach of bend stabilization, attempts can also be taken to change the braided stream into one meandering channel. A lot of closure of secondary channels, stabilization of long reaches of banks may be necessary to do this. The prediction of long-term response of the river for this change is an important aspect of the program.

(b) *Lighter construction*

To stabilize bends with revetments a major investment will be required for a large river like the Jamuna River. All critical hydraulic parameters like maximum scour depth, maximum velocity, etc. are to be considered while designing these revetments. It is also possible to stabilize bends with lighter constructions, which may be damaged partly after each flood. In that case, it would be repaired to prepare for the next flood. The maintenance cost of this type of structure will be higher than any permanent type of construction. But in this approach the initial investments will be less.

Hard point concept

In this concept the river is not directly modified; rather, the aim is to stabilize the present pattern of the river by limiting the boundaries of the local width of a braided belt. Some important places on the bank line are protected by creating „Hard points" which are isolated bank revetment works with upstream and downstream terminations. These hard points are connected with the flood embankment with the help of cross bars to prevent outflanking of the hard points. The function of the hard point is to limit the extent of erosion. The length and spacing of the hard point determine the extent of area protected from the erosion, and thus, the maximum allowable "depth" of the embayment that is permitted in the locations between the structures. A disadvantage of the hard point concept is that if they are constructed on one side of the river, then the river can start shifting towards the opposite bank.

2.3.3 Types of river training works

The following types of river training works are commonly used:

a) Revetment works

b) Groynes or Spurs

c) Embankments or Levees

d) Cutoffs

e) Closures of secondary channels

f) Miscellaneous methods like bandals, panels

(a) Revetment works

Riverbank erosion is a common feature in all alluvial rivers. Bank protection with revetment works is the method in order to reduce or stop this erosion process. The river bank can be divided into an upper and a lower section. The lower part, the part below the low water level, acts as a foundation for the upper part. Erosion of this lower bank, especially at the toe, causes the failure of the bank. The upper part can be eroded by wave attacks too. The condition is severe when the current directly attacks the bank. Bank failure can also occur due to the so-called piping (effluent) effect; during the low stages, piping may occur due to the motion of ground water towards the river. This ground water may carry finer material away from the soil, causing the failure of the bank.

Revetment work is a well known bank protection method. It is practiced in the whole world and very common in Bangladesh. A revetment is a structural protection against wave and current-induced loads, covering the existing river bank or an embankment. It is not an offensive structure like a groyne. It does not disturb the flowing river. It has several components e.g. cover layer, intermediate layers between cover and core material required for drainage and filtering to allow for a stable foundation of the overall system and the toe. The cover layer must resist the design impacts, mainly on current and wave. Toe protection is required in case currents and/or waves scour and undermine the toe of a bank or an embankment, which are likely to result in the sliding of the slope. This sliding of the slope endangers the overall stability and function of the revetment which is very common in Bangladesh. Normally, the revetment works are done with CC blocks, boulders, mattresses, open asphalt concrete etc. During revetment works, the slope pitching is normally done with 1:2 to 1:3 slopes according to the soil characteristics and hydrological boundary conditions. Sometimes it is seen that the eroding bank is not uniform. Its slope varies along the bank, and in certain locations, it is seen very stiff. In that case, it should be built with desired slopes by using sand-filled gunny bags. Otherwise the local scour along the bank will not uniform, and in some locations, the actual scour could be more than the anticipated value, and the revetment will fail.

Bank protection with geo-bags: Geo-bags are being used in Bangladesh for a last couple of years. It was being mainly used for emergency works to protect the river bank erosion.

Now it is being used for a revetment works for the protection of river bank erosion. Sand-filled Geo-bags are used instead of CC Blocks. ADB is financing this project through a foreign consultant. It is an ongoing project for the protection of the bank erosion from the Jamuna and the Meghna Rivers. The slope pitching and falling apron are both constructed with the geo-bags.

Assorted geo-bags are being used to build the falling apron. The dumping is being done with barges and by making grids so that the apron can be built uniformly. After building the apron it is checked whether any gaps remained there. They are using better equipment and process to implement the project. It is also a new project to make the revetment works with Geo-bags.

(b) Groins or Spurs

Groynes are structures built from the river bank into the river. There is a preferred angle between the groin and the bank, depending on the purpose of the groin. Groins are constructed with stone, gravel, rock, earth or pile structures. Generally, groins are used to divert the river flow away from the critical zones of the bank to protect it from the erosive action of the river; they are also used to constrict the width of the river so that the river will increase its depth, which is important for navigation. The main design criteria to be considered during the design are spacing of groins, length of groins, the crest level of groins (i.e. either at flood plain level or at embankment level), and the possible scour at the head of the groin. Stabilization of the river bank with series of groin is very effective. Bank protection with a single groyne is not effective and wise. Most of the time, single groin creates adverse conditions in the surrounding area. Series of groynes can make the flood flow line parallel to the bank which is not possible by a single groin.

Groins can be classified in different ways: according to the method and materials of construction, according to whether they are permeable or impermeable, according to the height of the spur below high water-submerged and non-submerged groins, and according to the function served-attracting and repelling groins.

Permeable groins: Permeable groins consist of series of piles; these piles may be bamboo, RCC or steel. Generally, permeable groins are used to slow down the current of the flow so that the flow loses some of its erosive energy. Impermeable groins are made of stones, gravels or earth. They are used to deflect the flow away from the critical zones of the bank, thus pushing the river to a more suitable alignment. As the zones between the groins have reduced velocities, sedimentation can take place there.

Submerged groins: Submerged groins are designed to go under water during high flow. Generally, permeable groins are submerged because, when not submerged floating debris can create extra pressure on the piles. Moreover, this accumulation of debris and increased flow velocity may cause extra scour at the foot of the piles. So, they are best suited submerged condition. Impermeable groins, on the other hand, are often designed to be non-submerged, as submerged condition such solid groins may be susceptible to erosion.

Attracting groins: Attracting groins attract the flow towards the bank. Groins pointing downstream are of this type. They are never used in concave banks. Groyins pointing downstream are repelling types which deflect the flow away from the bank towards the opposite bank.

Repelling type groins: Repelling-type groins are also constructed in such a way that it deflects the flow away from the bank. This type of groin is pointed upstream, and scour holes caused by the formation of vertical eddies are developed away from the bank and near the head of the groins. Upstream pointing is generally used on concave banks. The perpendicular alignment is generally used on convex banks.

(c) Embankment or Levees

An embankment or levee may be defined as an earthen embankment extending generally parallel to the river channel and designed to protect the area behind it from overflow by floodwater. The embankments or levees can be natural or man-made. In general, the man-made levee consists of an earth-fill dyke with or without a revetment. The main purposes of an embankment are to protect life and property from flood. The important design parameters are crest level, alignment, and slope, resistance to flow on the river side, and scour depth at the toe. The flood level of the river determines the crest level of the embankment. What flood should be considered to determine the level depends on the degree of safety to be provided for the protected area. Important areas like towns or cities require better protection than agricultural land. A freeboard is considered in addition to the standard high water level. For example, the Brahmaputra Right Embankment (BRE) has a freeboard of one meter above the highest flood level, which is l in 100 years flood. The alignment of the embankment is generally determined by the development of land use on both sides of the embankment and by the river behavior. Generally, some space between river bank and the embankment is allowed, which is called the setback distance. The slope is determined from geotechnical aspects like slope stability. The outer slope should be such that it can withstand the erosive force of flow and wave during flood.

(d) Cutoffs

Cutoff processes are characteristic of the alluvial meandering river. When a river is flowing through a bend, under favorable condition this bend may become a large loop with a narrow neck. With the increased narrowing of the neck, a short-cut channel can be created. So cutoffs are short channels across the neck of the river bends. But in this process a river straightens and shortens itself. Cutoffs can be natural and man-made. Though this process is a very characteristic feature of a meandering river, it can also be observed in anabranches of braided rivers. This cutoff processes have some beneficial effects like reduction of flood levels, shortening of the river course, exclusion of reaches with excessive curvature along which regulation structures can be maintained, to stop severe bank erosion, etc. To achieve these beneficial effects, a cutoff can be used as a means of river training. For example, when a river reach in an outer bank of a bend experiences erosion problems, the flow can be diverted by the process of cutoff. Cutoff of bends can be initiated artificially by dredging a pilot channel of adequate dimension, so that the flow can start to flow through this channel. This flow can further scour the channel to the required dimensions.

(e) Closure of secondary channels

A wandering type of braided river always has a tendency to create a new channel while abandoning its original one, but this new course may not be always in good position in the view of river stabilization. Under such circumstances, the main course, the flow can be forced through the original course by dredging and by closing the secondary channel. The spoil dredged from the main channel can be used to close the secondary channel, thus stabilizing the flow of the river. There are two types of closures, either a complete closure or a partial closure. What preferred depends on the purpose of the closing. In case of a complete closure of a secondary branch, a new condition will be reached when all the flow and sediment will follow the remaining branch. The remaining branch will adjust itself by changing its depth and slope to achieve a new equilibrium condition. When it is the intention to use only the main channel during the low flow and both channels during the peak flow, then the secondary channel can be closed-off by a dam which is overtopped during the high water level, and which can close off the secondary channel. This type of closing can be classified as partial closure.

(f) Recurrent river training methods like bandals and panels

Bandals: These are mostly temporary types of river training works, i.e. those types of works whose influence may exist for one or two years. Dredging for navigation in an untrained river may be an example of temporary works. The bandalling system has been developed in the Ganges and the Brahmaputra River in India and Bangladesh (Opdam, H.J., 1994, Rahman et al., 2007). Bandals are screens placed on both sides of a channel, which is required to be improved. They concentrate the flow into the channel; the velocity of the flow is increased and the sediment transport in the middle decreased, which will in the result scouring of the channel. Bandals are placed in the riverbed in such a way that sediment can pass under the bandals and deposit behind them, where the velocity of the flow is comparatively low. Bandals are effective for small variation of water depth, so their use is not so effective where large variation of water stage occurs. The difference between bandals and panels is that helical flow generated by panels will take the sediment out of the navigation channel, while for bandals, sometimes sediment can be brought back into the channel. The feasibility of the bandalling system depends on a number of conditions such as:

- sand must be present on at least one side of the channel to be eroded and preferably on both banks

- sand must not be too course or too fine
- the river level must not fall too fast, because sufficient erosion can be achieved after a number of weeks.

Panels

Panels are of two types:

- surface panels and
- bottom panels

Surface panels: The system of surface panels was developed in Russia in 1936. Surface panels are placed obliquely in the current, which causes deviation of a surface flow and due to acceleration under the panel, deviation of bottom flow in another direction takes place. The result is the helical flow down the panel, which causes increased sediment transport under the surface panels. The principle has been applied for the protection of water intakes against sedimentation and reduction of erosion of the outer bends.

Bottom panels: The principle of bottom panels is also based on the generation of helical flow. The panels are placed at an angle of about 45 to the current at the edge of the channel to be eroded; the panels are about 25 m long and spaced by about two and a half times in their own length. The helical flow starts behind the panel and results in a movement of sediment along the panel. Sediment is withdrawn along the channel thus decreasing sediment supply along the channel towards the next panel. Therefore, the degradation becomes wider and deeper in the downstream direction. Bottom panels have not only been applied for creation of navigable channels but have also been used for the enclosure of secondary river branches. Bottom panels have also been used in the Brahmaputra River in India (Joglekar, 1971). Bottom panels may be left in the river even during floods.

2.3.4 Flow and scouring around revetment-like and groin-like structures

River bank erosion is generally protected by different types of bank protection works like revetment, groin etc. When this type of structure is constructed protruding from bank line towards the river, it is well known that 3-D complex flow field is generated around the structure. The complexity is further provoked by the dynamic interaction between the flow field and the movable bed with the development of scour hole in the vicinity of the structure. Numerous researches were conducted on the flow field and scouring process around abutments, groin-like structures, piers by many researchers (Melville, 1975; Hjorth, 1975; Kandasamy, 1989; Tingsanchali and Maheswaran, 1990; Rahman, 1998; Barbuiya and Dey, 2003; Salaheldin at el., 2004; Dey and Barbuiya, 2005; Kirkil at el., 2008; Zhang al el., 2009). Most of the studies were performed in the laboratory or numerical simulation, and very few in field condition. The flow and scouring process around spur dykes and other similar structures such as bridge piers and abutments is shown in Fig. 2.2. The flow field around a groin-like structure, revetment or abutment-like structure and pier is characterized by several vortex systems of different sizes, which initiates and controls the local scour and provides the basic scour mechanism (Zhang, 2005; Salaheldin at el., 2004; Ettema at el., 1998; Raudkivi, 1990; Dargahi, 1990; Kandasamy, 1989; Melville, 1975; Hjorth, 1975). Due to the blockage effect, the flow will be divided into two parts as it approaches the groin-like structure. One part approaches the edge of the groin-like structure and separates. Another part goes directly ahead of the spur dyke, which decelerates and is deflected to form an upward flow and a downward flow. The upward flow makes some kind of surface roller which is generally termed bow wave. Near the free surface, the water depth is increased, and the highest stagnation pressure occurs. The pressure is rapidly decreased downwards due to the steep vertical velocity gradient. As a result, the downward flow is driven and acts as an impinging jet on the channel bed. With the development of the scour hole, a primary vortex (also known as horseshoe vortex or primary necklace vortex) develops (Kirkil at el., 2008).

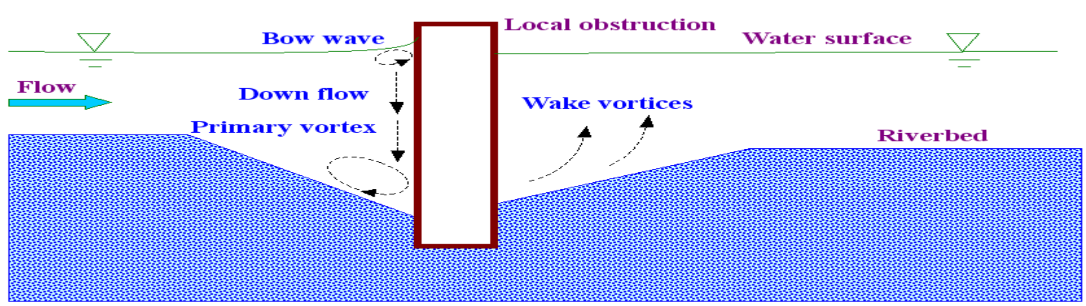


Fig. 2.2: Schematic diagram of the flow and local scour around abutment or groin like structure (Courtesy: Zhang, 2005).

The primary vortex extends to the downstream of the groin-like structure and loses its identity after some distances. The flow detaching from the groin-like structure accelerates and leads to the development of concentrated cast-off vortices in the interface between the flow and the wake behind the groin-like structure, which are termed wake vortices. The wake vortices are directed upward to the free surface and have almost vertical axes. These vortices are transported downstream and function as vacuum cleaners to suck and suspend the bed sediment into the main flow. If the groin-like structure is submerged, the flow structure becomes more complex. The over-topping flow has a significant impact on the nature of the vortices around the groin-like structure.

Rajaratnam and Nwachukwu (1983), and Ahmed and Rajaratnam (1998, 2000) investigated the flow fields at piers and abutment respectively. They found that the shear stresses at the abutment corner were amplified up to five times as compared to the approach shear stress. The increase in the shear stress above the critical value that is required for sediment entrainment is commonly accepted as the cause of the local scour. The pier and abutment scour might be expected to be similar in some respects. Because an abutment and its mirror image in the channel wall resemble a pier. Nevertheless, the abutment flow patterns have also been thought to be different due to the influence of the channel boundary, the lateral flow and the flood plain. Dey and Raikar (2007) investigated how the flow and turbulent characteristics of the horseshoe vortex change with the development of the scour hole at a circular pier.

Uijttewaal (2005) conducted a laboratory experiment with five types of groin fields, i.e., standard reference groins, groins with a head having a gentle slope and extending into the main channel, permeable groins consisting of pile rows, and hybrid groynes consisting of a lowered impermeable groin with a pile row on top. Flow velocities were measured by using particle-tracking velocimetry. The design of the experiment was such that the cross-sectional area blocked by the groin was the same in all cases. Depending on the groin head shape and the extent of submergence, variations in the intensity of vortex shedding and recirculation in the groin field were observed. The experimental data are used to understand the physical processes like vortex formation and detachment near the groin head. It is demonstrated that the turbulence properties near and downstream of the groin can be manipulated by changing the permeability and slope of the groin head. It is also observed that for submerged conditions the flow becomes complex and locally dominated by three-dimensional effects. He found that relatively small adaptations to the design of a groin can have profound consequences for the turbulence properties at the river-groin-field interface. This will have consequences not only for the morphology of the river bed, but also for the total resistance felt by the flow as well as for the transport and dispersion of matter. These findings will be of use when considering optimization in the river system with respect to navigation, ecology or flood prevention.

Ettema and Muste (2004) conducted a series of flume experiments to determine scale effects in small-scale models of flows around a single spur dike (wing-dam, groin, or abutment) placed in a channel whose bed is fixed and flat. The flow features of primary interest are flow-thalweg alignment (line of maximum streamwise velocity) around a dike, and area extent of the flow-separation region (wake) immediately downstream of the dike. The scale effects use small length scales together with a bed-shear stress parameter (e.g. Shields parameter) as the primary criterion for dynamic similitude. Small-scale models, especially micro-models, are often used for investigating channel-control issues. Also, the shear-stress criterion is commonly used for models of a flow in loose-bed channels, whereas Froude number commonly is the primary similitude criterion for models of fixed-bed open-channel flows. The experiments show that the use of a shear-stress parameter as the primary criterion for dynamic similitude influences the flow thalweg and flow separation region at a dike. It does so by distorting pressure gradients around the model dike and by affecting turbulence generated by the dike. It also is shown that, for a range of small models, the thalweg alignment and the extent of separation region do not scale with model length scales.

A number of researchers developed numerical models to simulate flow and erosion processes around different types of hydraulic structures. Zhnag et al. (2009), classify these numerical models into three groups: (1) the numerical modeling of flow field with planar or unscoured bed (Ouillon and Dartus, 1997); (2) numerical modeling of flow field with scoured beds (Rasheduzzaman et al., 2007, Zhnag et al., 2009) and (3) the numerical modeling of flow fields and bed deformation with movable beds (Nagata et at., 2005). Some of these models are reported to well resolve the typical horseshoe vortex in the scour hole area (Nagata et al., 2005), and some are concentrated on the reasonable reproduction of the reattachment length behind the spur dyke (Ouillon and Dartus, 1997).

A study was conducted jointly by IFCDR and JICA (1997) on flow and morphological processes about 11 km of the Meghna River reach including Meghna bridge site. The numerical model was applied to simulate the flow field and local scouring near the abutment of the Meghna Bridge. The calculated results were compared with the observed ones. It was verified that the numerical model is a useful tool for simulating flow and scouring processes near the Meghna bridge site.

Summary: Many researchers were carried out studies on flow processes around abutments, piers and groin like structures. Most of the studies are performed on the basis of either experimental or numerical simulation. There are insufficient evidences on field-based research in a large scale sand bed braided river. Especially in the river where frequent failure event occurs of the river training works due to rapid morphological change. Therefore, we should pay attention to conduct field-based research so that the existing problem may be solved effectively.

2.3.5 Flow and scouring around bandal-like structure

Bandals have been used for improving navigational condition during the low flow in rivers since the British Colonial Period on the Indian sub-continent (Rahman et al., 2007; Schumck-Widmann, 2001). Bandals are made of naturally available low cost materials such as bamboo and wood. The working principle of bandals is shown in Fig. 2.3. The sediment load of the river is transported as bed load and suspended load. A large portion of the sediment load is concentrated within the lower half of the depth of a flow and, within the upper half portion of the depth, water discharge is more. The bandals are placed at an angle; with the main current there is an opening below it while the upper portion is blocked. Usually, fifty percent of the flow area is blocked to accelerate the flow. The surface current is being forced to the upstream face, creating significant pressure difference between the upstream and downstream sides of the bandal. The flow near the bed is directed perpendicular to the bandal resulting in near bed sediment transport along the same direction. Therefore, much sediment is to the one side of the channel, and relatively much water is transported to the other side. The reduced flow passing through the opening of the bandals is not sufficient to carry all the sediment coming towards this direction. As a result, sediment is deposited over there. On the other side, more water flows with a small amount of sediment, and the resulting bed is eroded on that side. Earlier bandals were used without any experimental investigation.

In the present decade some researches were carried out at Ujigawa Hydraulics Laboratory, DPRI, Kyoto University, Japan and at IWFM, BUET. A significant insight investigation is achieved on bandal structures. It is found that the bandal structures diverted the flow towards the main channel. The bandal structure is very effective in the formation of the navigational and stable channel (Rasheduzzaman et al.; 2007; Rahman et al., 2005; Rahman et al., 2004). At the IWFM laboratory, the effect of bandal spacing and alignment on the formation of navigational channel is tested. It is investigated that funnel shaped arrangement with a spacing of 1.5b (b = projected length of bandal measured perpendicular to flow) and an extension towards the downstream are the best arrangement (Das at el., 2007). Under FAP 21/22 (2001) project, a field test was executed for the bank protection by using bandalling. Later, RRI constructed bandal structures at Randhunibari (2007) market place as erosion protection measures.

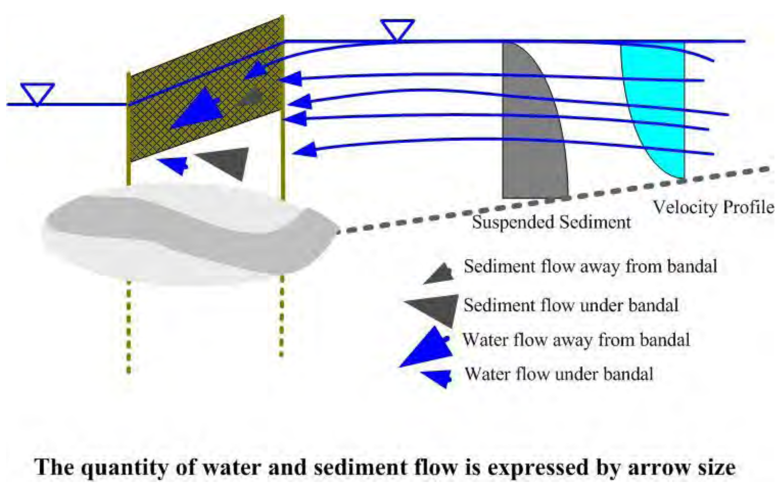


Figure 2.3: Working principles of bandal (courtesy: Reproduced from Rahman et al., 2003)

Bangabandhu Bridge Authority constructed 1.5 km long bandal structures (2009) to prevent erosion on the left bank of the Jamuna River and to ensure safety at the upstream of the east guide bund of the Bangabandhu Bridge. RRI provides all technical support, while Bangladesh Army provides monitoring support. IWFM, BUET provided advisory services to the project. It should be necessary to study how effective the bandalling is as a flow diversion structure in the field level in a large scale sand bed braided river.

2.3.6 Bed features

Simons and Richardson (1961) classified flows in alluvial channels as the lower flow regime and the upper flow regime, with a transition in between, based on the form of bed configuration, the mode of sediment transport, the process of energy dissipation, and the phase relation between the bed and water surface. The bed forms in an alluvial river are associated with flow regimes. In the lower flow regime, flat bed, ribbons and ridge, ripples and dunes are observed. There are differences in the scale of bed features observed in laboratory studies and field investigation (Coleman, 1969). Coleman identified four groups of bed features in the Jamuna River as ripples, megaripples, dunes and sand waves. He investigated the characteristics of different bed features of the Jamuna from field measurement which is discussed in section 6.2.6 of chapter 6. He conducted the study on bed feature while no major structure was present in the Jamuna River. But the characteristics of the bed features may be changed with the structural influence.

Dunes have an asymmetrical (triangular) profile with a rather steep slope leeside and a gentle stoss side. A general feature of dune type bed form is leeside flow separation resulting in strong eddy motion of the dune crest. To investigate a flow field along a dune experiment were carried out at Delft Hydraulics (1988). Velocity was measured using Laser-Doppler velocity meter. A recirculation zone was observed downstream of the dune crest. Reattachment and acceleration of the flow does occur on the stoss side of the dune. The formation of dunes may be caused by large scale eddies. Due to the presence of large (low frequency) eddies, there will be regions at regular intervals with decreased and increased bed-shear stresses, resulting in the local deposition and erosion of the sediment particles (van Rijn, 1984).

Kennedy (1963), Yalin (1972), Allen (1970), Fredsøe (1975), van Rijn (1984), Julien and Klaassen (1995) and other researchers developed methods for determining dimensions of bed forms.

Yalin (1972) argues that the wavelength (λ) of the bed form is proportional to the depth of flow (h), say,

$$\lambda = 2\pi h \qquad 2.1$$

Allen (1970) established a relation of dune length and flow depth for h> 10m by

$$\lambda = 1.16\, h^{1.15} \qquad 2.2$$

Fredsøe (1975) proposed an expression for dune steepness by

$$\frac{\eta}{\lambda} = \frac{1}{8.4}\left[1 - \frac{0.86}{\theta} - 0.4\theta\right]^2 \qquad 2.3$$

Where, η = dune height, λ = dune wave length and θ = Shields parameters

$$\theta = \frac{u_*^{\,2}}{(s-1)gd_{50}} \qquad 2.4$$

Based on flume and field van Rijn (1984) established a relationship between the dune height and length as follows:

$$\frac{\eta}{h} = 0.11\left[\frac{d_{50}}{h}\right]^{0.3}\left[1 - e^{-0.5T}\right]\left[25 - T\right] \qquad 2.5$$

$$\frac{\eta}{\lambda} = 0.015\left[\frac{d_{50}}{h}\right]^{0.3}\left[1 - e^{-0.5T}\right]\left[25 - T\right] \qquad 2.6$$

T = Stage parameter

$$T = \left(\frac{u_*}{u_{*c}}\right)^2 - 1$$

From above two equations an expression can be derived:

$$\lambda = 7.3\ h \qquad 2.7$$

Julien and Klaassen (1995) proposed the average dune height and the average dune length in a large sand-bed river as:

$$\lambda = 6.5\ h \qquad 2.8$$

$$\eta = 2.5\ h^{0.7} d_{50}^{\ 0.3} \qquad 2.9$$

2.3.7 Causes of Failures of Bank Protection Works

Common causes of failures of bank protection works

Causes which may lead to damage or failure may be classified as follows:

1. Environment and Nature

i) river current and wind-generated waves, causing direct erosion (scour) with outwash and undermining as well as abrasion and displacement of armour units; Impact forces caused by breaking waves on impermeable or poorly permeable revetments may cause liquefaction of granular subsoil which may lead to the failure of the revetments. Repeated wave loadings are conducive to the internal instability of subsoil and fatigue of protective layers.

ii) the outflanking of river channels due to morphological or hydrodynamic changes etc.;

iii) geotechnical instability and failure of the subsoil which are also influenced by natural calamities like earthquake, heavy rainfall, etc., resulting in liquefaction, flow slides etc.;

iv) flooding during high water stages causing soil saturation, and overtopping sloughing or sliding may occur due to seepage at receding water levels;

v) ground water movements causing piping;

2. Construction

i) faulty supply of protection materials or elements e.g. less in quantity or inferior in quality;

ii) poor workmanship due to:

- inadequate under water coverage, creating heaps in one area and gaps in other areas;
- unavailability of proper equipments, or skilled labour
- improper and difficult execution of protection work due to turbid water, great depth and high flow velocity.

3. Human Factors

i) Inadequate investigations of natural conditions (hydrodynamic, morphological, topographical and subsoil surveys etc.);

ii) faulty design, e.g. by
   - wrong interpretation or insufficient consideration of subsoil, hydrological and morphological conditions, loads, etc.;
   - insufficient terminations (wing protection), resulting in outflanking;

iii) insufficient or no maintenance or repair of damage in time.

iv) excessive surface loading (surcharge);

v) damaging through
   - vandalism;
   - excavation too close to the structure, or

<u>Revetment Failure</u>

A revetment may fail due to:

i) instability of the cover-layer caused by external loads (current, waves etc.) or internal loads (e.g., due to pore water pressure),

ii) insufficient toe protection and instability or improper launching or falling behavior of the apron materials,

iii) sliding of cover layer over intermediate layer, and

iv) different micro-and macro-instability arising from geotechnical characteristics of soil and changed boundary conditions e.g., due to rapid scour development or water level changes.

Macro-instability is the deformation or displacement of relatively large soil masses that may occur gradually or very abruptly; *Micro-instability*, on the other hand, is related with the individual grains or protection elements on the slope. The finer particle size and low relative density of bed and bank materials of the major rivers of Bangladesh are very much susceptible to micro- and macro instability.

Previous experiences with major revetment damages in the Jamuna River have identified several mechanisms of failures. Development of flow slides in the sub-aqueous slopes is one of the main mechanisms which occur normally during rapid development of the underwater slope by scouring. The loose micacious sandy soil of the Jamuna River is very susceptible to liquefaction and flow slides due to its low relative density (in many places less than 50%). Once one or multiple flow slides occur under water; the slope retreates towards the structure. The falling apron may become ineffective in shielding the developed scour profile at this stage and flow slides regress underneath the apron.

Again, low integrity and lack of continuity between the cover layer and filter layer and also between the static part (main slope protection) and moving part (falling apron) of the structure in working condition may appear as a reason for extensive damage of the structures. Improper construction method and lack of monitoring and timely repair are human factors behind failure in those cases.

Groin Failure

The groin fields constructed for bank protection are sensitive to morphological activities like the shifting of river channels. Two reasons are very important for failure of the groin. *The first one* is the outflanking of the groin field due to the extreme shifting of the upstream channel in a single-thread meandering channel. *The second one* is the abrupt change in the angle of flow attack in the groin field due to the shifting of a char and intensification of an oblique deeper channel flowing towards the bankline. In both cases severe damage of the groin field would occur and the whole groin field may become ineffective in a few flood seasons if proper rehabilitation programmes are not undertaken rapidly.

Failure of impermeable earthen-core Groin:

The failure mechanisms of conventional earthen-core impermeable groins are almost similar to revetments when the groin head and side slopes are normally protected employing the same methods as revetments. With a nominal toe protection along the shank and traditional toe protection along the head, which is the general approach, the experience may be quite different. Stages of damage and failure may be as follows:

i) At the first stage, a scour hole is created due to generation of vortices at the groin head.

ii) When the scour hole develops at a very high rate and attains sufficient depth, a sequence of flow slides may occur. These flow slides may penetrate the bottom of the apron, which is unable to react rapidly to flow slides. Inadequate launching and coverage of the apron and sinking of apron materials may worsen the situation.

iii) At the third stage, local break-out and the sliding of the lower part of the groin head slope would occur and the filter materials may also disintegrate.

iv) At the final stage, hydraulic action becomes dominant again when the cover layer is progressively dismantled and the exposed slope is eroded very rapidly.

v) Due to morphological changes of the river, a parallel flow along the shank may develop and that may induce a scour hole at any location along the upstream of the shank. The shank with nominal toe protection may fail detaching the head from the shank and finally invite the collapse of the whole system.

Local slip failures arc also observed in the groin head and shank due to characteristics of sandy soil, especially in the Jamuna (Fig. 1.5a and Fig. 1.5d). These require continuous monitoring and repair maintenance of the structures. Impermeable groins are a type of dam constructed of stone, gravel, rock, sand, sandbags etc. The weight of the groin causes compression of the subsoil resulting in settlements of the groin. Possible failure mechanisms such as foundation failure and slope failure depend mainly on the type and condition of the subsoil. Penetrations, settlements and subsidence arc to be expected.

Failure of RCC Spurs:

The RCC spurs are built with a long earthen shank and a RCC head (150 m long). The failure modes of these spurs are different compared to the earthen-core structures. The structure may fail due to the failure of different components as follows.

i) The transition between the earthen part and RCC part may fail because of high hydraulic loads due to the oblique flows, diverted flows or back eddies generated by the head.

ii) The upstream slope of the earthen shank may fail due to the parallel or oblique flow. The scour near the earthen shank may exceed the design limit, and slides may develop along the side slopes. The active channel then easily outflanks the RCC part.

iii) The RCC part may fail due to large scour development in front of the middle part of the vertical face. When the sheet piles are not sufficiently deep, the bottom of the structure may open forming large eddies and more scour downstream. The protection in the transition may also fail at this time.

Failure of Permeable and composite Groins:

The interaction between the piles of a permeable groin and the subsoil is the same as with other pile structures exposed to horizontal loads from wave attack and currents. However, the possibility of a cyclic load on the piles and the soil depending on the wave period must be taken into account.

The pile rows may fail due to rotation of an individual pile caused by insufficient pile embedment length. The piles may face such situations when the excessive local scour occurs due to extra loading like increase of head difference between two sides of the pile rows due to unexpected accumulation of floating debris (e.g., uprooted banana trunks, bamboo bundles, heap of partially decomposed water hyacinth etc.) accumulation and thus creating high-velocity underflows.

In case of composite groins, the protection in the transition between the impermeable and permeable part may fail by sliding instigated by the deep scour hole developed at the downstream side. The deeper scour hole may be the result of direct high-velocity flow attack on the transition zone from a shifting oblique channel. Failure of piles near the transition may also result in flow concentration and high scour.

Riprap Failure Modes

Riprap placed in an apron is subject to similar failure mechanisms as riprap placed about a bridge pier (Fig. 2.4). Blodgett (1986), Chiew (1995, 1997), Chiew and Lim (2000), Unger and Hager (2006) and Melville et al. (2006) have classified riprap failure in different ways. Chiew and Lim (2000) investigated riprap failure at bridge piers. They identified four failure mechanisms i.e. shear failure, winnowing failure, edge failure, and bed-form undermining. Shear failure occurs where the riprap stones are unable to resist the hydrodynamic forces induced by the flow and are therefore entrained by the flow. Winnowing failure describes the action of turbulence and seepage flows, which can entrain the underlying bed material through voids between the riprap stones. A filter is often recommended to resist winnowing failure. Winnowing failure is more likely to occur in sand-bed risers than in coarser bed materials. Edge failure occurs where scouring at the periphery of the riprap layer undermines the riprap stones. Riprap is vulnerable to edge failure in conditions where there is an insufficient lateral extent of the protective layer. Shear, edge and winnowing failure mechanisms can occur under clear-water conditions, whereas bed-form undermining failure is a process that occurs only under mobile-bed conditions (Fig. 2.5). Bed-form undermining is a process where the migration past the abutment of the troughs of large dunes undermines the riprap layer, which settles as a consequence (Fig. 2.6). Bed-form undermining was observed to be the controlling failure mechanism at bridge piers founded in riverbeds subject to migration of dunes, especially sand-bed rivers.

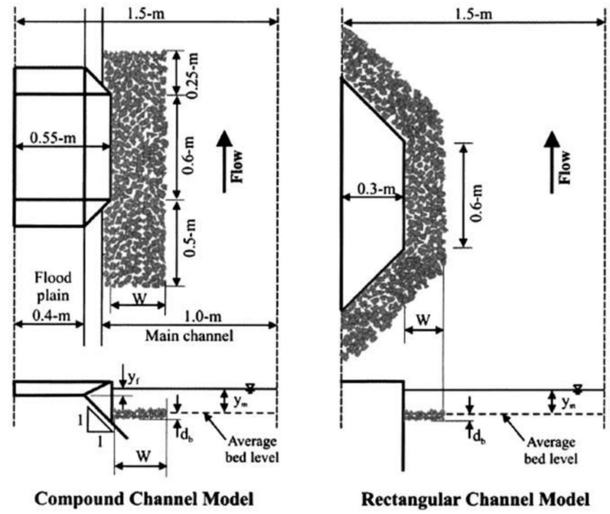


Figure 2.4: Placement of riprap (After: Melville et al., 2006)

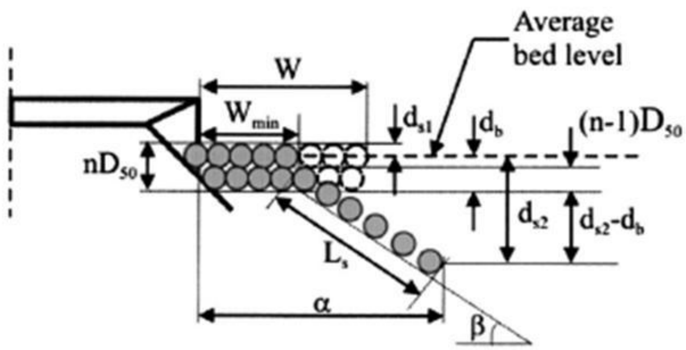


Figure 2.5: Deformation due to undermining or edge failure of an idealized riprap (After: Melville et al., 2006)

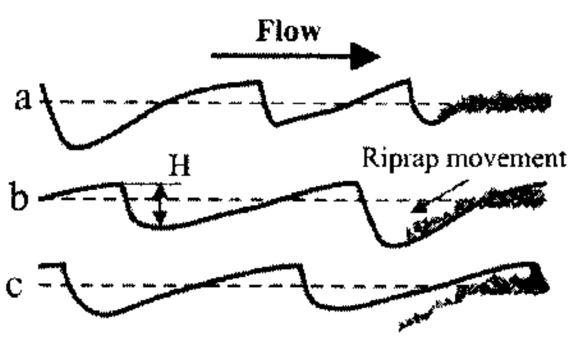


Figure 2.6: Riprap movement in response to bed-form propagation (After: Melville et al., 2006)

Flow Slides

Miscellaneous particles (such as mica), which have a plate-like shape, have an enormous influence on the behavior of the sand. The presence of it within sand increases its void ratio (porosity), modifies its volume-changing characteristics and introduces collapse potential particularly when under low stress and when sheared in extension. Shear testing with different mica percentages have shown that the angle of repose increases the higher the mica percentages are in the sand. When the process of sedimentation is not disturbed, the mica minerals cover the sand grains in a thin layer. The risk of flow slide due to mica increases when the mica minerals form a texture (due to different settling velocity), in which a thin and impermeable or nearly impermeable skin of mica flakes encloses the permeable but saturated granular particles.

Below the water table the sand is saturated, and flow slides may be observed in places due to quick change of stress level in the area of the toe. Change of stress level can occur due to:

- *Scouring:* a scour occurs in a very short time, balance of pore water pressure cannot be achieved due to a short period (FAP 21 considered a velocity of formation of a scour of 0.2 - 0.4 m/day to be dangerous for the Jamuna soil. In the Jamuna River the formation of a scour has been: 5 m per day, 12 m in 10 days and 20 m in less than one month).

- *Hydraulic dredging:* If executed too fast and the slopes undercut, it will produce the same effects of scouring. Therefore dredging has to be conducted at a very slow rate; excavation in front of the toe shall be less than 0.2 m/day.

Flow slides normally start in the area of the toe of slopes and continue in a retrogressive manner. Flow slides and erosion have nothing to do with the mechanism of geo-mechanical slope failure.

2.4 Indigenous and Technical Knowledge

The people of Bangladesh are living through practicing a lot of indigenous knowledge in different fields. Bangladesh Resource Centre for Indigenous Knowledge (BARCIK) has taken in preservation, documentation, and dissemination of indigenous knowledge in a variety of development related fields including agriculture, health care and environmental conservation. BARCIK already published some papers written by many authors (Khan, 2000; Sillitoe, 2000; Khan, et al, 2000; Amin, 2000; Alam and Khisa, 2000; Rashid and Rashid, 2000; Shafie, 2000; Karim, 2000; Haque, 2000; Haque, 2000, Hassan, 2000) on indigenous knowledge for sustainable biodiversity conservation, health development, wise use of water and watershed resources, sustainable agriculture, and everyday survival. Besides indigenous knowledge published by BARCIK, numerous rhymes named Khanar Bachan are in the mouths of the rural people as guidelines for tillage of the soil, plantation, harvesting, etc. Here I mainly will discuss erosion related indigenous knowledge.

The people of rural Bangladesh have developed through a process of innovation and adaptation a variety of coping-strategies and techniques that are fine-tuned to the local environment, economy and socio-cultural system. The major natural disasters in Bangladesh include cyclones, tornadoes, tidal bores, floods, river erosion, droughts, and earthquakes. The people inhabiting a disaster-prone country in particular have their localized knowledge and practices, developed through cumulative experience, that constitute a survival strategy in the face of natural disasters (Haque, 2000). Bangladesh possesses a rich heritage of indigenous knowledge and practices, much of which has been lost due to their non-documentation. However, people in disaster-prone areas still nurture such knowledge in their myths, beliefs and traditions.

2.4.1 Indigenous knowledge

Haque (2000) defines indigenous knowledge as “Indigenous knowledge refers to the local and traditional knowledge used by rural people for agriculture, natural resource management, fisheries, livestock, healthcare practices and other activities”.

Khan et al. (2000) put the following definition, "Indigenous Knowledge essentially connotes a holistic system of knowledge, comprising values, concepts, beliefs and perceptions which are naturally located amongst people living in a local (often rural) environment". Indigenous Knowledge is typically originated, augmented and transmitted in relation to the local people‟s diverse and complex livelihood and survival strategies. It entails a wide range and variety of elements including forestry, medicine, linguistics, botany, zoology, agriculture, handicraft, pastoral studies, ethnology, and environment.

Sillitoe (2000) argued, "It is indisputable that local people will be well qualified to define problems and will be experts on their crops, pests and soils. We have something to learn from them. Furthermore, scientific knowledge may not be relevant to some problems and may even worsen them by overlooking local issues. Indigenous knowledge is extensive and systematic, taking into account complex interconnections which narrowly focused reductive scientific disciplines may overlook, with possible unanticipated spin-offs. Sympathetic investigation has revealed that far from being stagnant and closed- minded, indigenous knowledge is flexible, adaptive and innovative".

The sustainable development can only be achieved by developing a science based on the priorities of local people, and by creating a technological base that includes both traditional and modern approaches to problem solving (Rahman, 2000).

2.4.2 Technical knowledge

The term technical or scientific knowledge is attributed to some facts and principles that are acquired through the long process of inquiry and investigation. The investigation takes a long time because it goes through various aspects to come to a conclusion and the aspects include all the laws, theories, concepts and models. The definition can also be expressed in another way and we can say that it is a kind of knowledge that is acquired by the systematic study and is organized in accordance with some general principles.

2.4.3 Comparison of indigenous and technical knowledge

A distinction between the indigenous and scientific knowledge systems made by (Agrawal, 1996; Ataur, 2000) on the following grounds: (1) *substantive grounds*- because of differences in the subject matter and characteristics of traditional and scientific knowledge; (2) *methodological and epistemological grounds*- because the two forms of knowledge employ different methods to investigate reality; and (3) *contextual grounds*- because traditional knowledge is more deeply rooted in its environment.

The format of indigenous knowledge system is mostly *tacit* – hard to articulate with formal language. This knowledge is embedded in the experiences of indigenous or local people and involves intangible factors, including their beliefs, perspectives, and value systems. The technical knowledge system is essentially in *explicit* format-can be articulated in formal language including grammatical statements, mathematical expressions, specifications, manuals, and so forth. This kind of knowledge thus can be transmitted across individuals formally and easily. This has been the dominant mode of knowledge according to the (Western) scientific philosophy. Indigenous knowledge is still not as well known as the coded and circulated objective language and the printed products of scientific discourse. The technical knowledge is an explicit or "codified" knowledge that is transmittable in formal, systematic language.

2.4.4 Indigenous knowledge on flood and erosion in Bangladesh

Perception of Causes of Riverbank Erosion*:* The perception of the local people of Kazipur Upazilla regarding the causes of river bank erosion, more than 58 percent of the respondents express their opinion that the high velocity is a major cause of the hazardousness of erosion in the floodplain. But about 34 percent of the people perceive the occurrence of erosion as the "will of Allah". More than 20 percent of the sample elicited high flood as a major cause of erosion, similar proportion also indicated high discharge in the channel as a principal cause of erosion (Haque, 1991). Apart from the above reasons, huge number of char, shallowness of the Jamuna River, high precipitation in the region, unconsolidated soil of the floodplain and the nature of the river are the causes of erosion. Schumuck-Widmann (2001) also mentioned that the char people believe that erosion occurs by the desire of Allah.

Indigenous Response Strategies from Erosion: The inhabitants of floodplain are more dependent on indigenous strategies to cope with river bank erosion. Haque (1991) summarized the indigenous strategies to cope with erosion (Table 2.1). Due to strong religious belief, lack of extended reproduction system and capital formation and low level of technology, the floodplain inhabitants receive corrective types of responses at individual levels rather than preventive measures. The *corrective measures* include purposeful attempts to modify the event or change the location or resource use to minimize the loss. The *preventive measures* usually involve control works and other structural-engineering schemes to technologically control or prevent the effects. Haque (1991) distinguished indigenous response strategies *incidental* and *purposeful*. They use such housing materials as thatch, bamboo, wood and corrugated iron sheets instead of brick iron and steel. They use these materials, they can be dismantled, transported and rebuilt within a short time in an emergency situation (Schumuck-Widmann, 2001; Haque, 1991). The char people usually live in a clustered form. The clustered settlement strategy helps the char people to reduce economic losses and moral and emotional recovery from the hazard effect. The Kazipur, locality is to possess different modes of transport such as country boats (local name *dingis* or *noukas*), bicycles and bullock carts. They use country boats to transport bulky material including housing material in an emergency situation. Sometimes they build protective bamboo crates and fences (locally called *chegar*) and place them on the waterfront (Islam, 2009; Schumuck-Widmann, 2001; Haque, 1991). They adopted this strategy in order to protect cultivable land and homestead plot erosion. This preventive strategy is based on indigenous bamboo technology. It is used for protecting their land and other properties from the attack of river bank erosion as it involves a small amount of capital cost. This preventive strategy built on indigenous knowledge, skills, and resources is found to be insignificant because of the higher tendency of erosion-attack towards a river bank.

Indigenous Knowledge to cope with the Jamuna: Farmers plant the creeper *kumli* or the reed *shon* to identify a field border. The char people make kinship with the mainland people through marriage of sons or daughters so that they can take temporary shelter during high flood and erosion. For crisis management, besides farming, they also engage themselves with trade in cattle, timber and consumer goods. For minimizing risk the char-farmers cultivate local varieties of rice with High Yielding Varieties (HYVs).

Table 2.1: Types of indigenous response strategies to cope with the problem of river bank erosion.

Response Strategies	Purpose	Types of Response
Use of corrugated iron sheets, wood, bamboo and thatch as housing materials	To provide easy and rapid means for salvaging housing structure and to keep their resalable value	Incidental/ purposeful
Country boats (dingis) bullock carts, bicycles	To provide means of transportation during abnormal flood and rapid river encroachment	Incidental
Planting different crops in different zones of the floodplain	To adapt crops to different characteristics of soil	Incidental
Maintenance of close social ties among Samaj and Gusthi members	To mobilize necessary manpower and assistance in emergency situations	Incidental
Investing in livestock and other movable assets	To provide easy means of transferring or selling assets in emergency situations	Incidental
Building bamboo fences (çhegar on the water front)	To protect land and houses from physical impact of erosion	Purposeful
Building bamboo crates and placing them on the water front, filled with bricks	To protect land from sub-aqueous erosion	Purposeful
Building embankments with earth	To protect settlements from river encroachment	Purposeful

The local varieties have high demand on the mainland market due to their high nutritional value and good taste. The charland people plant catkin reed to protect the char from erosion and promote the established new land (Sarker, at el., 2003). They made rafts with banana and bamboo for animals. To save their stock of food, they dismantled some bamboo posts of huts and tied the big clay pots to them so that the pots would not sink. They cooked food on a portable oven. During 1988 flood, they used water from the boiled rice for drinking purpose. The char people raised their homestead using reference point of 1988 flood level. When a char is emerged they start agricultural activity there. Then one or two families settle as a trial basis. If they feel the char is stable, then the rest of the community people live there.

Stock of Experience of the Char People: The experiences of the char dwellers are expressed in three perspectives i.e. the development of the Jamuna from meandering to braided one, erosion and flood. The char dwellers stated that the Jamuna was only one river. But at present there are several channels in the Jamuna River. The deterioration is started when the Jamuna developed from a meandering into a braided and unstable river and forced the char people to frequently make a move. In the late sixties, the river bed began to widen (the river became crazy), and the Jamuna divided into several channels (Sarker and Thorne, 2006). The channels were shallow and the flow velocities became stronger at one place but slower at an other place. They feel that this situation is created by a change in the kind of sediment. In earlier times the river transported more fertile sediment, silt (*doash*) and fertile silt (*pulla-mati*) but present time the river carries most of the sand. Due to sand deposition on the crop-growing field and on the river bed it became shallower. As a result, the river has less space and the char is eroded. Nowadays the rising and falling of water level are faster than previous time. The cause of the faster rising of water level in the river is the construction of the sluice gate at the off-takes of the Jamuna which hindered the equal distribution of flood water in entire flood plain. This information is also found from the recent field visit. Sometimes the erosion is continued in the dry season. Due to the construction of the Bangabandhu Bridge, many villages situated on the stable char were washed away within a couple of weeks. They can describe with sketching where the location of the channels were. The stock of knowledge is continuously changing to survive on a char. They are experienced in how to cultivate on the sandy soil before it was unknown to them. They had a type of knowledge before the construction of the bank protection works or Bangabandhu Bridge. But after the construction of those structures the river became unpredictable.

The knowledge of the char people divides into two types*:* general knowledge and special knowledge. General knowledge is accessible to all members of a group or society. Special knowledge is in principle also accessible to everybody, but it is transmitted only to the role holder (*matabor*) concerned. The *matabors* have a special knowledge about the behavior of the Jamuna. Knowledge about a certain field or special knowledge can result from the main occupation of a person, if he frequently plies on the river as trader or fisherman, and travels around the region. But not all *matabors*, traders and fishermen have the same degree of knowledge of the river.

According to local people, there are three methods of development of knowledge about the Jamuna River: the observation of river phenomenon, experience through boat trips and measuring. They can understand easily whether the channel is deep or shallow. Where it looks white, it is shallow. And where it looks black, it is deep. After long experience they can understand this phenomenon. They use bamboo as a depth-measuring tool. They observe the changes of location of shoals because shallow water is not suitable for navigation. So, through boat trips the boatmen and passenger from charland update their knowledge about morphological development. Bridge, house and human body have practical use to measure the flood level.

To prepare for a rise in the water level, the char-people pay attention to signals given by the climatic conditions and their own bodies. Thus, they expect a rise in the water level about one week"s time after they observe clouds gathering like treetops, then flattening out in the following days and moving with strong winds for at least three days from South to North. The color and temperature of the river water change. In addition to this, the char-dwellers report heavy sweating like fever, rheumatic pains and uncommon exhaustion. Usually, the water rises slowly, by a few inches per day. In extreme cases, however, the water level rises more than one foot in twelve hours. The floods will only stop rising, according to the experience of the char-people, when over a period of three days no unusual clouds can be seen in the sky. "Thunder in the East" signals an end of the flood peak and a falling of the water level. Yet it can also fall without this thunder. The moon is also said to have an influence on the floods.

The char-people explain that a char is eroded through the interaction of several factors, the soil condition and height of the char itself playing a subordinate role. The direction of the flow of the channels around the char, the location of other chars, the behavior of the channels upstream and the sediment load of the water are some of these factors. The most important factor is the number of flood peaks and the speed of the respective rise and fall of the water levels. To be able to assess the need for move, and when they would have to take precautions, the inhabitants of a homestead close to a bank make precise observations. But a channel can, against all prognoses, go in another direction within a short time, and so the char-people can never say with certainty that they really will have to move. Yet by observing the situation some kilometers upstream they can make precise statements. If a channel permanently attacks a bank, one can be sure of the erosion of the char. Towards the end of the flood-time, they claim that it is possible to make predictions without such analysis, because with the eventual fall of the water level the river channels would not change in an unexpected way anymore.

To the younger char-generation, the reports of their parents and grandparents serve as an explanation for their attitude to the life-world they are born into. This stock of experience also provides the young with knowledge necessary for survival on the chars. Elderly char-people describe the change of the natural conditions and their influence on agricultural production. Farming methods had to be adapted to the changes, new crops tested and familiar crops abandoned. Until now they think that they do not regard their adaptation process as over because they expect further changes. For the char-people, the river is unpredictable, as experiences with the erosion of homesteads in particular confirm. The high level of precision with which the char-people describe particular experiences, even if these events are a matter of course and fixed parts of the life-world, is surprising, It is the detailed observation of river behavior which enables them to prevent heavy losses and to recover from the frequent crises.

Char-people are able to find every village in a radius of about ten kilometers from early childhood onwards. They have cognitive maps of the whole region which they constantly update. Cognitive mapping is “an abstraction covering those cognitive or mental abilities that enable us to collect, organize, store, recall, and manipulate information about the spatial environment”. Each human being produces such maps in order to find his way in his surroundings. Through cognitive mapping the char people can describe different activities as memorizing events and experiences with erosion, journeys on the river, observing and measuring, communicating and discussing.

Every char-dweller knows for example that during the erosion of a bank the opposite one is safe, as soil is usually deposited there. The char-people can forecast erosion and accretion for a majority of the river sections up to three years ahead; probable developments and tendencies can be predicted for three to five years; and beyond this period they are only able to make assumptions. Before forecasting erosion some char people observed certain phenomena which make erosion recognizable: (i) when two major channels flow around a char, the danger of erosion is very high, and (ii) when the flow attacks a bank directly and the banks are steep and the water deep. Since the construction of the Jamuna Bridge the behavior of the river has changed. According to char people the river did not behave anymore according to its laws. Especially accurate forecasts, say the char-people, can be made as soon as the water level starts to rise at the beginning of the flood season. If the river is already causing certain bank to erode, even more precise predictions are possible. The char-people emphasize that all developments depend on the strength of the floods, the speed of the rise and fall of the water level, and the number of floods in a monsoon season. Heavy floods do not necessarily cause severe erosion; they might also lead to exceptionally high sedimentation in certain areas. As an example they refer to the 1988 floods, which enlarged the char of Rulipara. Some char-dwellers point out that during strong floods less erosion occurs, because the water can flow across the chars and thereby became large. The char-dwellers believe on the following proverb: “Three years strong floods, three years weak floods”.

2.4.5 Summary

From the above discussion it is clear that a lot of indigenous knowledge on flood and erosion is prevailing into the riparian community or into people living on the charland. The people, who are living into the charland and along the bankline of the Jamuan River, struggle with flood and erosion hazards using their existing indigenous knowledge. Therefore, we should evaluate their indigenous knowledge on flood and erosion. We should also pay attention to critically investigate the indigenous knowledge on flow and erosion processes of the riparian population so that their indigenous knowledge can play important role in the erosion management program.

2.5 Concluding Remarks

In this chapter a brief overview is given on research carry out on several issues such as: (i) research carried out on various aspects of meandering channels such as mechanics of a meandering flow, initiation of meandering, time growth of their loops, modeling of meandering channels and their bed topography, etc; (ii) erosion prediction methods:

empirical, numerical and physical; (iii) flow and erosion processes around different types of hydraulic structures, bed features and failure mechanism of riprap; and (iv) indigenous knowledge on flood and erosion. There are scopes to study carried out on the following issues: (i) development of erosion prediction model based on physical parameters of the bend channels, hydraulic parameters, properties of bank materials and indigenous knowledge on erosion; (ii) field-based research on flow and erosion processes around bank protection works along the braided Jamuna River; (iii) failure mechanism of different bank protection works so that the failure related problem could be handled effectively; (iv) investigation of indigenous knowledge on flow and erosion processes for sustainable erosion management.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

Before starting of the present research work, reconnaissance surveys were conducted. The objective of the reconnaissance surveys was to identify the field problem related to erosion and bank protection works. The rate of erosion along the right bank of the Jamuna River is higher than the left bank. So, this survey was carried out along the right bank of the Jamuna River. The first reconnaissance survey was performed from 18th September to 21st September during second flood in 2007. During reconnaissance survey I visited Kamarjani permeable groin site under Gaibandha district; Hasnapara spur 1 and 2, Titporal revetment, Kalitola groin, Sariakandi hardpoint, Mathurapara hardpoint, Debdanga revetment, Chandan Baisha groin, Kamalpur groin, Sharabari spur and Baniajan spur under Bogra district, Sirajganj hardpoint site and BRE near Khoksabri Union Parishad under Sirajganj district. During this reconnaissance survey different modes of failure and their maintenance activities were observed. The modes of failures were mainly: (i) the RCC part was detached from the earthen shank of the RCC spur; (ii) slip circle failure of the earthen shank of the groin; (iii) slide down of the shank of the groin and (iv) a part of the revetment was damaged etc. At some places the BRE is breached due to bank erosion. Another reconnaissance was performed on 8th December 2007 at Betil and Enayetpur spur sites. It was observed that the earthen shank of both spur was damaged. From the reconnaissance survey the visible field problems (i.e. erosion and failure of bank protection work) are identified. But we should identify what are the insight problems of the failure of the bank protection works. Among the above mentioned sites some sites were selected (at the mid-reach of the Jamuna River) to investigate the inherent problems of the failure of those structures. A brief discussion is given about the selected study sites in chapter four. In this chapter it is discussed that the methodology the present research work was carried out. The overall methodology of the present research work is shown in Fig. 3.1 through a schematic diagram. The details of the methodology are given in the subsequent section.

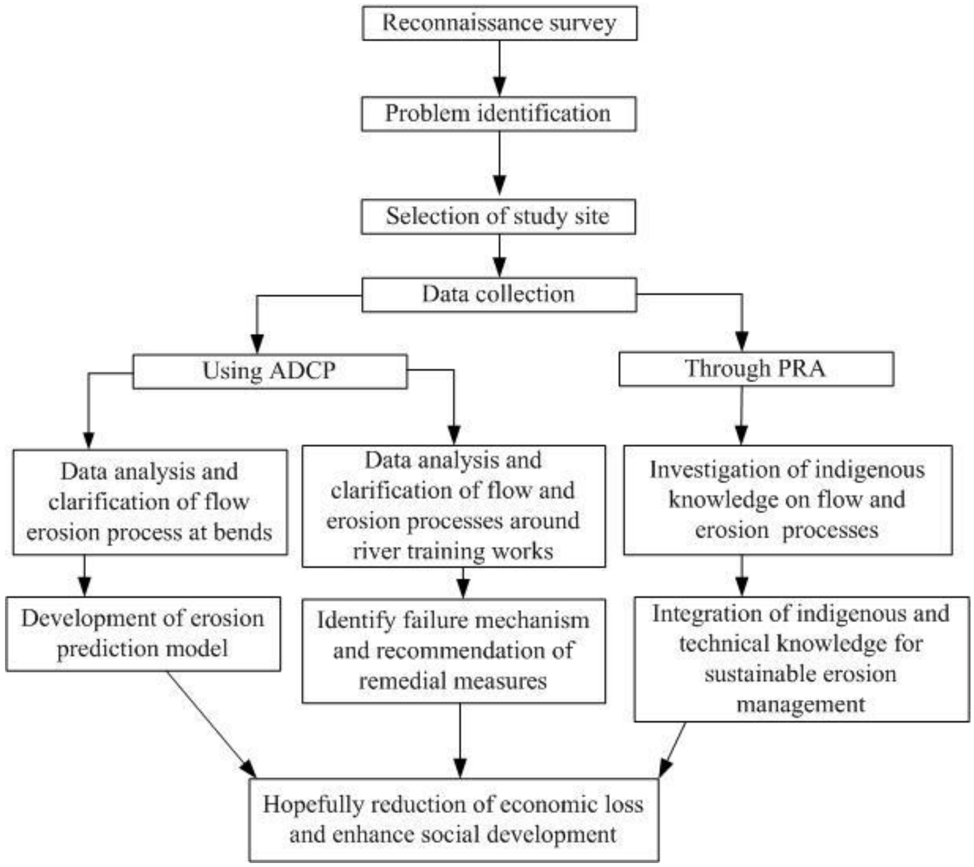


Figure 3.1: Schematic diagram of the methodology

3.2 Methodology of Data Collection and Analysis

3.2.1 Hydraulic data collection

To analyze the flow and erosion processes, 3-D flow and velocity and bed level were measured using Acoustic Doppler Current Profiler (ADCP: 1200 kHz: WH-ADCP Rio Grande by RD Instruments). The ADCP uses the Doppler effect (the change in observed sound pitch that result from relative motion) to measure velocity by transmitting sound at fixed frequency and listening to echoes returning from sound scatters such as suspended sediment in the water.

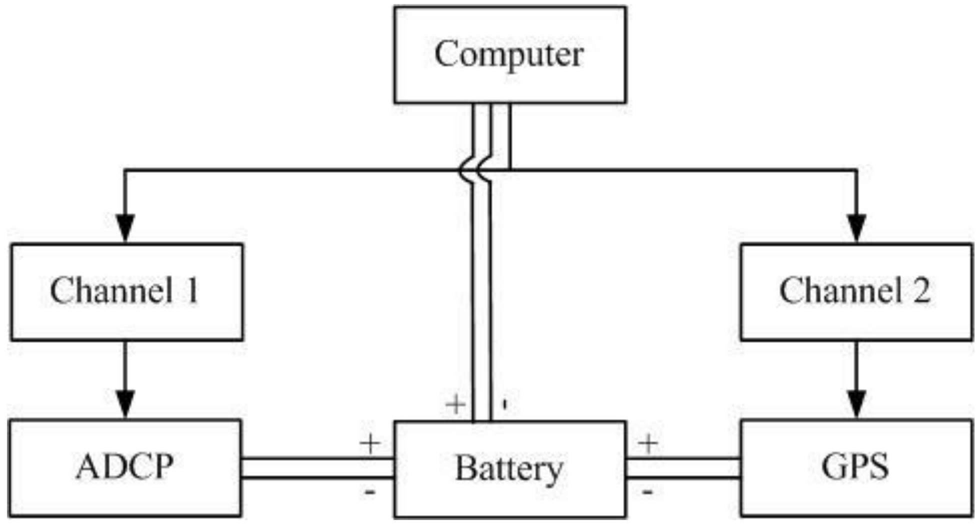
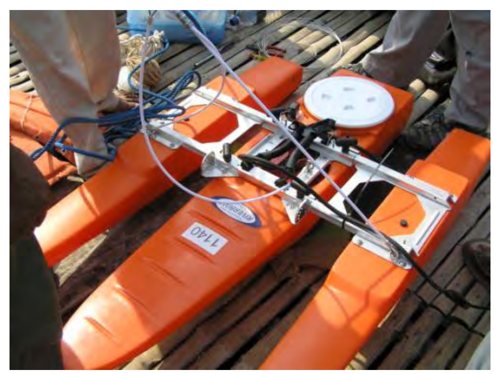


Figure 3.2: The schematic diagram of connecting ADCP and GPS with computer

(a) ADCP is being connected with plastic boat



(b) ADCP is prepared for data collection

(c) Data is being collected using ADCP

Figure 3.3: Data collection using ADCP

Global Positioning System (GPS) was used to locate the measuring point. The ADCP was connected mounting downward with a specially designed plastic boat. The plastic boat with ADCP was tied with the country boat by rope. The schematic diagram of connecting ADCP and GPS with computer is shown in Fig. 3.2. ADCP setting and the data collection technique are shown in Fig. 3.3. The entire system was connected with a laptop computer for data collection. During data collection it is important that the boat should be moved following the transect line (line taken from one bank to the other bank (or char) of the channel) along which the hydraulic data would be measured. The bow of the boat should keep pointing upstream direction. Otherwise, the boat movement line may deviate in the downstream direction from the pre-selected transect line. The WinRiver program with (ADCP) is used for data acquisition. 3D-velocity, discharge, depth of flow, global positions and other data were collected using ADCP. At a particular location the last velocity data was measured by ADCP at some distance above from the channel bottom. The collected raw data sets were usually recorded as ASCII text file which were processed afterward. The GPS data was usually recorded by ADCP in degree (latitude and longitude) which subsequently was converted in meter (easting and northing) with respect to a reference point by coordinate calculator software.

3.2.2 Data collection and analysis at Shuvogacha bend

The flow data from the entire Shuvogacha bend area was collected during the monsoon (16th July, 2008). Acoustic Doppler Current Profiler (ADCP) is used for data collection of the present study from the entire Shuvogacha bend area. The data collection technique has been discussed in sub-section 3.2.1. The processed 3D-velocity data is represented by velocity vector at different depth along the horizontal. The 3D-velocity data is also represented by velocity vector vertical plane along different cross-section. Measured data and available information from literature are used (Richardson and Thorne, 1998; Blanckaert et al., 2008; Islam et al., 1999; Islam et al., 2007; Islam et al., 2008) for investigating flow and erosion processes at a selected bend of the Jamuna River. The indigenous or local knowledge and technical knowledge regarding flow and erosion processes at a bend are compared. The methodology of investigation of indigenous knowledge on flow and erosion processes at a bend has been discussed in sub-section 3.2.5.

3.2.3 Data collection and analysis around different river training works

Three different types of structures have been selected for the present study. These are: (1) The Sirajgang hardpoint is selected as a revetment-like structure. (2) Betil and Enayetpur spurs are selected as groin-like structure. (3) Bandal-like structure, located at Randhunibari under Belkuchi Upazilla, implemented by River Research Institute (RRI) as pilot basis, is selected as traditional low cost structure. The same procedure is followed which has been discussed in sub-section 3.2.1 during data collection around the above bank protection structures.

Sirajgang hardpoint: In total three sets of hydraulic data were measured around Sirajganj hardpoint. Out of the three sets of data two sets of them were measured during the dry season and one data set was measured during the flood season. The dry season data were measured on 22nd and 23rd March, 2008 and 19th March, 2009. The flood season flow data was measured on 18th August, 2009.

The processed 3D-velocity data has been represented by velocity vector along horizontal and vertical planes. The velocity vectors along horizontal planes have been represented at different depth. The flow circulations along horizontal planes are discussed. The actual flow processes such as downflow, primary and secondary vortices, and the return current are investigated from the flow process analysis around the bank protection works extending from the bank line (Melville, 1975; Hjorth, 1975; Kandasamy, 1989; Rahman, 1998; Barbuiya and Dey, 2003; Dey and Barbuiya, 2005; Dey and Raikar, 2007). The mechanism of the development of scour whole around the Sirajgang hardpoint is clarified from the flow analysis. The recent failure (July, 2009) of the Sirajganj hardpoint has also been clarified using the field data. The failure event is clarified depending on the two years satellite images, different field measured data, oblique flow and flow attracted towards the hardpoint, dune movement and the lowering of a bed level.

Betil and Enayetpur spurs: The hydraulic data around Betil and Enayetpur spurs and from the approach channels of both spurs was measured during the monsoon (15th July, 2008). The failure mechanisms of the Betil and Enayetpur RCC spurs are clarified (BWDB, 2008; BWDB, 2006) from analysis of the hydraulic data. The processed 3D-velocity data is represented by velocity vector along horizontal and vertical planes. The actual flow phenomena around the bank protection works extending from the bank line is clarified from hydraulic data analysis (Melville, 1975; Hjorth, 1975; Kandasamy, 1989; Rahman, 1998; Barbuiya and Dey, 2003; Dey and Barbuiya, 2005; Dey and Raikar, 2007). The failure mechanism of both spurs is explained depending on the oblique flow, amplified parallel flow and flow circulation.

Bandal-like structure: The hydraulic data around bandal-like structures was also measured during the monsoon (17^{th} July, 2008). To clarify effectiveness the bandal structures, the flow velocity is measured very close (approximate 2m upstream and 2m downstream from the bandal structures) to the bandal structures and entire channel adjacent to the Randhunibari market area. The effectiveness of the bandal-likes structures as flow diversion structure (resulting bank protection) is investigated through field measurement.

Total discharge measuring site: BWDB has constructed huge bank protection works in different rivers in Bangladesh. Among them some of the structures have faced expected hydraulic load but a number of structures don't face such situations (JICA, 2010). The purpose of measuring in the dry season the total discharge of the Jamuna is to compare with the discharge passing through the channel near the study site. While selecting the discharge measuring site, it is kept in mind that wherever the total discharge is passing through a single channel. So, a discharge measuring site is selected about 7 km downstream from the Bangabandhu Bridge where all channels are joined together.

The methodology for investigation local knowledge on flow and erosion processes around bank protection structures have been discussed in sub-section **3.2.5**. The indigenous or local knowledge and scientific technical knowledge regarding the flow processes and failure mechanism of bank protection structures have been compared.

3.2.4 Development of an analytical erosion prediction model

Richardson (2002) has developed a simplified erosion prediction model to estimate the rate of erosion at a meander bend. As input data, the centerline radius of curvature and width of the meandering river are used in the model. A conversion factor is derived for shear stress at a bend based on the assumption that the ratio of outer bank velocity to section average velocity is equal to the ratio of channel centerline arc length to outer bank arc length. The ratio of outer bank shear stress to average shear stress is assumed to be directly proportional to the square of velocity. The rate of river bank erosion is related to the total sediment transport rate that can be estimated by Engelund and Hansen (1967) total sediment load transport formula. Due to the amplified flow velocity near the outer bank of a meandering channel, the sediment transport capacity near the outer bank increases as compared to the average sediment transport. To meet the near bank sediment transport capacity, extra sediment would be supplied through bank erosion. So, the volume of excess sediment transport is equal to the volume of bank erosion. Using the Richardson's relation and Engelund and Hansen total sediment load transport formula, an analytical erosion prediction model is developed. Satellite images of different years were used to determine the width and radius of curvature of bend channel. The satellite images were collected from Center for Environmental and Geographic Information Services (CEGIS). The indigenous knowledge is considered to estimate total effective erosion duration over the year. The developed model is verified with field and EGIS (2002) data.

3.2.5 Investigation of indigenous knowledge

Mainly Participatory Rural Appraisal (PRA) method was followed in the present study to investigate indigenous knowledge (local knowledge/indigenous technical knowledge (Schmuck, 2001; Neogi and Babul, 2004)) on flow and erosion processes, bank protection measures, failure mechanism of protection works, social acceptance of bank protection works and socio-economic development around bank protection works. The following tools have been used during PRA: Key Informant Interview (KII), Focus Group Discussion (FGD) and Informal Group Discussion. First, KII was conducted with local officers of BWDB, LGED, Ward Commissioners, UP Chairmen, UP Members, village leaders, religious leaders and other people who are well aware of the relevant issues for major information and group formation for FGD. A series of FGDs were conducted with different groups such as mainland and charland people, erosion affected people (farmers, fishermen, loom workers, day laborers, rickshaw and van pullers, boat owners and boatmen etc.) and non-affected people (rich people, middle class farmer, poor farmer, day laborers, loom owners, loom workers, etc.). The indigenous knowledge on flow and erosion processes, erosion protection measures and failure mechanism of protection works have been investigated through FGD. At the same time the social acceptance of the bank protection works and socio-economic development around bank protection works have also been investigated through this method.

Focus Group Discussion (FGD): During FGD we try to form a group including 6 to 12 (approximate) people. But sometimes the number of persons falls below the required limit due to the limited number of special groups of people available near the study area. For FGD an appropriate check list is prepared to collect required information (Appendix-B2 and B3). A team is formed for FGD including 2 to 3 persons. Among them one is facilitator, one is recorder and the other is organizer. The functions of the facilitator are as follows: to introduce the session, encourage discussion, encourage involvement, avoid being placed in the role of an expert, control the rhythm of the meeting but in an unobtrusive way, take time at the end of the meeting to summarize, check for agreement and thank the participants and listen for additional comments and spontaneous discussions which occur after the meeting has been closed. The recorder should keep the following items: date, time, place, names and characteristics of participants, general description of the group dynamics (level of participation, presence of a dominant participant, level of interest), opinions of participants, recorded as much as possible in their own words (especially for key statements), emotional aspects (e.g., reluctance, strong feelings attached to certain opinions), spontaneous relevant discussions during breaks or after the meeting has been closed, missed comments from participants and missed topics (the recorder should have a copy of the discussion guide during the FGD).

Questionnaire Survey: To assess the impact of erosion a questionnaire survey was conducted on the erosion affected people. For this purpose a semi-structured questionnaire was prepared including the following issues: the loss of livelihood, generated vulnerabilities, social destruction; the impact on agriculture, the impact on the environment; livelihood dependency on rivers, etc (Appendix-B1).

The questionnaire survey was performed on those people who are living near the bank protection works, near free eroding bend and on the charland. About thirty number of different types bank protection structures are constructed along both the banks of the Jamuna River. Out of this bank protection structures only four sites along the right bank of the Jamuna River have been selected for the questionnaire survey. The multi-stage sampling technique was applied to select study sites for the questionnaire survey. Three study areas were selected adjacent to three distinct bank protection structures such as revetment-like structures, groin-like structures and bandal-like structures. Several hardpoints were constructed along the right bank of the Jamuna River. Among the hardpoints the area adjacent to the Sirajganj hardpoint was selected for questionnaire survey. About fifteen number of RCC spurs were built along the right bank of the Jamuna River. About fifty percent of the RCC spurs were damaged. The rest of the RCC spurs are functioning now. The Betil and Enayetpur spurs are now functioning well. The area near the both spurs was selected for questionnaire survey. The area adjoining to the bandal-like structures (recurrent bank protection structures) at Randhunibari was selected for questionnaire survey. The fourth site was selected adjacent to a free eroding bend. Actually this bend is developed after damaging of two RCC spurs. The sample population was randomly selected from the selected study sites for the questionnaire survey.

3.3 Concluding Remarks

The visible problem is observed from the reconnaissance survey. ADCP is used to measure flow and velocity data to investigate inherent technical causes of the failure of bank protection works which is related to flow-velocity and morphology. The actual problem is identified by analyzing the measured data. The erosion prediction analytical model is developed using a simplified erosion prediction model and Engelund and Hansen (1967) total sediment load transport formula. PRA is capable of investigating the experienced based indigenous technical knowledge on flow and erosion processes. Comparisons are made among indigenous technical knowledge, field engineer's knowledge, field measured result and technical scientific knowledge. The indigenous knowledge on effective duration of erosion which was investigated through PRA is incorporated in the erosion prediction model. The indigenous knowledge on failure of the bank protection works have been investigated through PRA. The erosion management activity would be very effective if the indigenous knowledge is evaluated as like technical scientific knowledge. The present study has been successfully completed following the above mentioned methodologies.

CHAPTER FOUR

STUDY AREA

4.1 Introduction

The Jamuna River is very dynamic in nature. It always changes its course, and the sand bars gradually move towards downwards direction. The erosion problem is severe in the Jamuna River due to its dynamic characteristics. The rate of erosion along the right bank of the Jamuna River is higher than that of the left bank. The Brahmaputra Right Embankment (BRE) was built during the late 1950s and mid 1960s to protect the flood plain against flooding. On-going bank erosion has led to breaches of the BRE. Under FAP 24 (1996) project the detailed morphological characteristics are investigated. The FAP1 (1994) component was formulated to study on short-term and long-term protection along the right bank of the Jamuna river. Out of the 10 locations, 6 priority vulnerable locations were selected for bank protection measures. Under this component hardpoints were suggested to stabilize the boundaries of the braided belt. During 1998, hard points have been built at Sirajgang, Sariakandi and Mathurapara. The construction costs of the hardpoints were too high. Later on, BWDB introduced a new low cost RCC spur for bank protection. However, several types of protective works have been constructed along the Jamuna River. In some cases, combination of structures has been installed, which ranges from active measures to passive measures or combination of both. About 30 river training structures have been constructed along BRE mostly during the last decade. While relatively big flood comes to the Jamuna River, a number of structures are affected by the flood. At that time usually different types of failure event are observed. Different modes of failures have already been shown in Chapter One. The failure events were observed during the reconnaissance survey in 2007. The visible problem can be shown from the filed investigation only. So, it is essential to investigate the inherent causes of failure of the bank protection structures. There are a very few field-based investigations on flow and erosion processes especially, in a large sand bed braided river like the Jamuna. Several sites were selected: (i) to investigate flow and erosion processes at bends; (ii) to investigate flow and erosion processes around some selected bank protection works; and (iii) to study the intrinsic causes of failure of those selected structures. A brief discussion on the selected study sites has been given in the following section.

4.2 Description of the Study Area

To study on flow and erosion processes at bends and around river training works, Shuvogacha bend and three distinct characteristic bank protection structures have been selected within the middle reach of the Jamuna River. Shuvogacha and Sirajgang hardpoint are located about 20 km and 8 km upstream from the Bangabandhu Bridge, respectively. Randhunibari bandal site and Betil-Enayetpur spur sites are situated about 2 km and 15 km downstream from the Bangabandhu Bridge respectively. The four study sites are shown in Fig. 4.1. The brief description of these study sites is given in the following sub-sections.

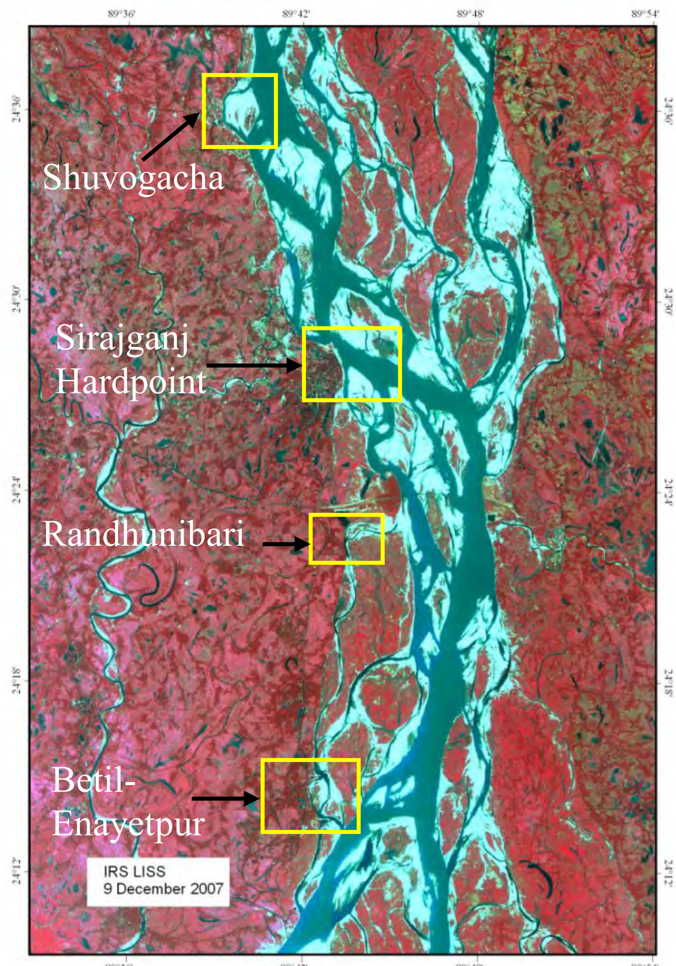


Figure 4.1: Selected study sites

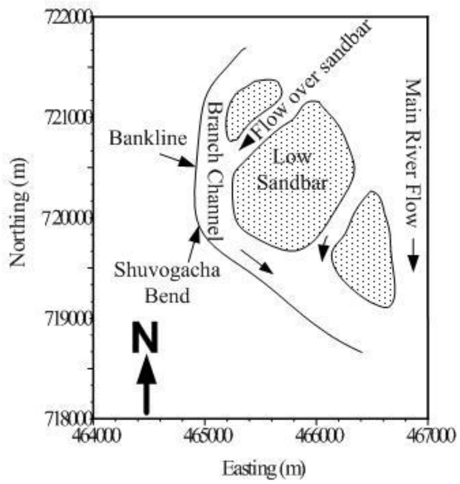


Figure 4.2: Shuvogacha branch channel

4.2.1 Impact of erosion on socio-economy

The impacts of erosion on livelihood, agriculture and environment have been investigated through questionnaire survey. The questionnaire survey was performed on those people who are living near the selected bank protection works, near free eroding bend and on the charland. The questionnaire survey results have been presented in Appendix-A. A huge number of people along the bankline of the Jamuna River are displaced every year. They become destitute overnight by losing their homestead, houses, cultivated land and other properties. Many of them migrate to the nearest town or big cities in search of work. A lot of farmers are compelled to change their occupation. They work as van drivers, rickshaw pullers, wage laborers, loom workers, boatmen, masons, vendors, etc. Their status of living is lowered. Before erosion they are recognized as mainland or *birland* people, but after erosion when they go back to their reemerged char they are recognized as *choura or chorer manush.* This *choura* term express its meaning as lower-grade people. The erosion-affected people densely build their houses along the BRE or very near the bank line. They cultivate ground nut, til, kaon or other low yielding varieties of crops on the sandy char during the dry season. Erosion greatly affects the agriculture and environment. The fertility of the cultivated land usually degrades. Their family relation is broken down. Their service network and social network are disrupted.

4.2.2 Shuvogacha

The present study is made on the secondary channel having meandering planform in the braided Jamuna River at Shuvogacha. Shuvogacha is situated under Kazipur Upazila of Sirajgang district in Bangladesh. The study area is shown in Fig. 4.2. Before developing the secondary channel the main channel was passing far away from the study site.

The prominent characteristic of the secondary channels is that they become dead during the dry season. But during the flood season they become live and erosion occurs by flow through these channels. During the period of 1985 to 1995 about 1500m was eroded at the study area. Two RCC spurs (consists of earthen shank with 150m RCC part) were built to protect the Shuvogacha area in 2000. Spur number one was damaged during the 2001 flood due to the construction problem and change in the bathymetry adjacent to the spurs. Now it has no existence. The earthen shank of spur number two has also been washed away in the same year. Only the RCC part is existed into the char. After failure of both spurs erosion was being continued at this area and subsequently a bend channel (meander channel) is developed. A char has been developed between the bend channel and the main river. At present erosion is being continued at this bend. The channel is as like a free eroding bend channel.

The study bend channel can be divided into two parts: upper part and lower part. The upper part of the channel is up to the first channel flowing over the sand bar. The lower part of the channel is from downstream of the first channel flowing over the sand bar up to the main river (Fig. 4.2). The meander channel at Shuvogacha carries a certain portion of discharge of the total discharge of the Jamuna River. The average discharge of the upper part of the channel and the lower part of the channel were about 800m^3/sec and 1075 m^3/sec respectively. Whereas the maximum recorded discharge is 100,000m^3/sec and the bank full discharge is 48,000m^3/sec in the Jamuna. The maximum depth of flow was 13.25m in the study channel during field measurement. The range of variation of braiding index of the Jamuna River is 4 to 6.

4.2.3 Sirajganj hardpoint

The Sirajgang is an old established town in Bangladesh. The urban and peri-urban development has been expanded close to the river bank. It is reported that one kilometer of right bank has already shifted in the westward direction since 1830 (Halcrow, 1994). To protect this town a massive hardpoint named Sirajgang hardpoint was constructed in 1998 under FAP 1 (1994). High Flood Level (HFL) and Low Water Level (LWL) are considered (+) 15.75mPWD and (+) 6.80mPWD respectively. Apron setting level and the deepest design scour levels are (-) 4.20mPWD and (-) 13.25mPWD respectively.

Table 4.1: Design parameter of the Sirajgang hardpoint

Section	**Depth (m)**	**Block size**	
		Upper slope	Lower Slope
Straight portion	29	55 cm cubic block (one layer)	55 cm cubic block (two layers)
Upstream Termination	33	55 cm cubic block (two layers)	85 cm cubic block (two layers)

The thickness of the launching apron is 1.93m. Design flow velocity is 3.7m/s. The length of the apron is 1.5 times the scour depth (below the apron setting level). The crest level is (+) 16.75mPWD, whereas approximate ground level is (+) 13.00mPWD. The side slope of the hardpoint is 1V:3.5H. Some design parameters of straight portion and upstream termination of Sirajgang hardpoint are shown in Table 4.1. The length of an apron on upstream termination and thickness are 19.5m and 3.83m respectively. The Sirajgang hardpoint faced the greatest flood in the history of the Jamuna in 1998 just after its construction. Due to unfavorable bathymetric development (common in the Jamuna) at the upstream of the Sirajganj hard point, the scouring rate at the upstream part of the structure was very quick.

Figure 4.3: Failure part of the Sirajgang hardpoint (March, 2008)

It was clarified that flow slides occurred due to excessive mica content in the soil on which falling/launching aprons were set. The apron material could not get sufficient time for its settlement on the quickly developed scour hole. After the 1998 flood, the structure was repaired and rehabilitated. Again, the upstream termination of the hard point was undermined during the 2007 flood. Moreover, during 2008 flood, a portion of the upstream termination of the hardpoint was damaged (Fig. 4.3).

4.2.4 Betil and Enayetpur spurs

Betil is located at about 25 km downstream of the Sirajgang town. Enayetpur is situated at 2.5 km downstream from Betil. Betil and Enayetpur are handloom enriched area. The bankline has shifted towards west by 5 km since 1914 (Halcrow, 1994). In this reach the bank moves towards west at an average rate of 100 m/y. To protect government and private land and property, two spurs have been constructed at Betil and Enayetpur areas. The total length of the Betil and Enayetpur spurs is 801m and 1050m respectively. The design of both spurs is basically the same, and represents a typical low-cost spur design of BWDB. The RCC-head replaces the normally used bell-mouth structure to save material. No model study was conducted before the construction of the Betil and Enayetpur spurs. Two physical model studies were carried out for RCC spur at Simla and Meghai along the right bank of the Jamuna River and the estimated net maximum scour depth was 18.5m and 17m respectively. The head of the RCC is built of in-situ casted, 500 mm diameter concrete piles and a vertical RCC-wall, with a walking path on the top. The pile is driven up to a depth of 24m (i.e. -16.5 mPWD) below the river bed. The design Highest Flood Level (HFL) is considered (+) 14mPWD. The crest level of the earthen shank is (+) 15.5mPWD. The slope of the earthen shank is 1V:2H at the upstream side and 1V:3H at the downstream side. The top width of the earthen shank is 6m. The top of the launching apron is (+) 9.5 mPWD with thickness ranging from 1 to 3 m, depending on the position of dumping. At the river end of the RCC wall a perpendicular wall is present which serves as a kind of energy diffuser to dissipate the strong turbulence at the end of the vertical wall. The RCC-part of the spur is protected from scour by dumping 90 m^3/m CC-blocks at the bell mouth and 3 m^3/m CC-blocks at both U/S and D/S side of the RCC (original design). The earthen shank in the original design is protected by 40cmx40cmx20cm CC-blocks and the toe by dumping 3 to 9 m^3/m CC-blocks. The connection between the RCC-wall and the earthen shank is in the form of a bell-mouth, in the original design with only a few meters overlap. The RCC-wall was constructed on the sandbar (local name *char*); therefore its bottom end is at the level of low water.

During the 2003 flood, a slip circle failure at the earthen shank over a length of 200 m occurred in Enayetpur. In Betil, a slip circle failure of the earthen bell-mouth occurred. The damaged part of the spur was repaired. The earthen bell-mouths and RCC-parts of both spurs were strengthened by the dumping of CC-blocks and geo-bags. Failure of the earthen shank or belmouth (connection of earthen shank and RCC) has occurred at both spurs during the monsoon since their construction. The earthen shank of both spurs was washed away during the flood of 2004. The disconnected RCC part of the Betil spur is shown in Fig. 4.4 (a). The RCC part of the Betil spur was opened and water started to flow beneath the RCC part of the spur. Since then it is working as a permeable spur or to some extent as bandal-like structure. A major rehabilitation programme was implemented in 2006. During rehabilitation work CC blocks were dumped as launching apron at the rate of 25 m^3/m at the RCC portion and at the rate of 20 to 50 m^3/m at the earthen shank and the belmouth. Almost every year a portion of the earthen shank is damaged and a huge amount of maintenance budget is required for repairing of the failure part. The failure of the earthen shank of the Enayetpur spur in 2008 is shown in Fig. 4.4 (b).

(a) Betil spurs, 2004 (b) Enayetpur spur, 2008

Figure 4.4: Failure of earthen shank of Betil and Enayetpur spurs

4.2.5 Randhunibari bandal site

Randhunibari is a handloom enriched area. A secondary channel of the Jamuna was passing nearby the Randhunibari market. The intake of this channel was closed by the western approach road of the Bangabandhu Bridge during its construction period. After the construction of the Bangabandhu Bridge the river morphology is affected by the Jamuna Bangabandhu Bridge and the river training works (BWDB and ADB, 2006). After initial adaptation, the morphology of the Jamuna was gradually adapted to the new situation. A large depositional zone has developed downstream of the bridge along the western bank of the Jamuna River.

The incoming flow from the old upstream branch channel towards Randhunibari has been stopped. But during the monsoon a portion of the discharge from the main channel (downstream of the Bangabandhu Bridge) comes towards the Randhunibari channel. Randhunibari market place is being eroded due to flow obliquely attacked to the market place. To protect Randhunibari area some bandal-like structures were constructed by River Research Institute (RRI) during 2007 and 2008 as pilot basis. The upstream and downstream sides of the bandal-like structure are shown in Fig. 4.5 (a-b). The length of the bandal-like structures was about 10m (extended towards the river from bankline) and makes an angle of 50^0-60^0 to the bank line. The spacing of the vertical bamboo piles was about 46 cm center to center along the longitudinal direction. The total length of the vertical bamboo piles was about 9m. Half of the total length of the vertical bamboo piles was driven into the river bed (but not less than 1.8m) and half of the total length remained above the river bed.

(a) Upstream side

(b) Downstream side

Figure 4.5: Bandal structures

The inclined bamboo piles were also driven to prevent the horizontal thrust on the bandal structures. The inclined bamboo piles make an angle of 45^0 with vertical bamboo piles. The spacing of the inclined bamboo piles was similar to vertical bamboo piles. Spacing between two bandal structures was about 32m. To increase the stability of the bandal structures cross bamboo was tied with the vertical bamboo piles at the rate of 75 cm center to center. The upper portion of the bandal was closed by bamboo thatched (local name *chatai*) and the lower portion of bandal was opened. Water flow beneath bamboo thatched. The ranges of diameter of the bamboos used for bandal structures were 6 to 9 cm.

4.3 Concluding Remarks

In this chapter a brief description has been given on the study areas selected for present research work and on the impact of erosion. The hydrological and morphological characteristics of the Shuvogacha channel have been described. The design parameters of the Sirajganj hardpoint, Betil and Enayetpur spurs and bandal structures at Randhunibari have also been discussed in this chapter.

CHAPTER FIVE

FLOW AND EROSION PROCESSES AT BENDS

5.1 Introduction

Riverbank erosion in the Jamuna River is one of the major problems in Bangladesh. Homestead, croplands, mosques, schools, hospitals etc are eroded into this mighty river. The erosion affected people migrate to cites and live in the urban slum areas (CEGIS, 2009; Mosselman, 2006; Schumuck-Widmann, 2001; Elahi, 1991; Halli, 1991; Elahi et al., 1991). Population displacement due to flood and river erosion is considered as one of the main contributors to landlessness and impoverishment of rural population (Ahmed, 1991). Different structural and non-structural measures are taken to reduce sufferings of the riparian population. The rate of erosion along the right bank is higher than the left bank. So, the most of the bank protection works have been constructed along the right bank of the Jamuna River. The structural measures are sometimes ineffective due to the morphological change of the river and rapid erosion upstream and downstream of the structure of non-cohesive bank materials. CEGIS prepared reports on predicting erosion vulnerability along the Jamuna, the Ganges and the Padma on a yearly basis to protect the existing structure and construct new ones. The erosion predicting tools used by CEGIS are purely based on the sedimentary features. A new erosion predicting tool has been developed based on physical parameters, hydraulic properties, bank materials properties and indigenous knowledge.

The embayment or bend is developed in the Jamuna River due to rapid erosion. The flow processes at bends also accelerates the erosion processes especially at bends. The flow processes in a single thread meandering channel are well known. The growth and decay of a secondary is flow phenomena in bend flow (Islam et al. 2007; Rozovskii 1957). The amplified flow velocities and shear stress are also play a role for erosion at the outer banks of a meander bends. These issues have clarified through the present filed research for a bend of the third order channel within a large scale braided river. The third order channels are present in the braided river (Williams and Rust, 1969; Bristow and Best, 1993 and Bridge, 1993).

5.2 Flow Processes at Bends

Flow passing through the meandering channel consists of the primary current and secondary current. The primary current plays an important role in determining the sediment load capacity. The secondary current transfers momentum to the outer bank in the upper part and to the inner bank in the lower part of the flow. This momentum transfer redistributes the primary flow, and consequently, the flow accelerates at the upstream of the inner bank and downstream of the outer bank and decelerates at the corresponding opposite bank. On the bottom of the channel, the secondary current directly transports bed load from the outer bank to the inner bank, whereas the surface flow converges to the outer bank. As a consequence, the outer banks in meandering channels suffer severe erosion (Duan and French, 2001). The flow patterns of a bend of the third order channel of the braided Jamuna River, where the erosion is active, are being discussed in the following section.

5.2.1 Flow processes along the horizontal plane

The Shuvogacha bend channel is originated from the main channel of the Jamuna River and flows in the western direction. It gradually turns in the southward direction and migrates as a straight channel about one kilometer in the southward direction. Finally it turns in the south-east direction and again meets with the main channel in the downstream direction. The velocity vectors along the bend channel at near surface and at a depth of 5 m from water surface are shown in Fig. 5.1 and Fig. 5.2. From the satellite images it seems that during the dry season, a single sand bar is present at the study bend. But during the flood season the sand bar gradually goes under water. Then it seems that the sand bar is divided into two or three parts. Some portion of the flow of the study channel is added through shallow channels which flow over the sandbar. At the starting point of the study bend, due to the shoaling of a flow over the sandbar, the flow is directed outwards e.g. towards the north-western bankline. The flow pattern is modified due to the development of a sand bar in a curved channel (Dietrich & Smith 1983). The flow patterns at a bend become more complex when a flow is added through the shallow channel over the sandbar as like in the present case. At the starting point of the bend channel the velocity magnitude is relatively high at the mid-channel. After that, the flow is impinged near the bank and directly attacks the bankline and due to higher boundary shear stress, bed and bank erosion occurs at this location. Then the flow turns in the southern direction and travels near about one kilometer as a straight channel. During field measurement (July 16, 2008), it has been observed that most of the bankline of the straight portion of the channel was submerged due to low bank height. After passing the straight portion of the channel, it gradually turns in the south-east direction. It has been investigated that the direction of outward migration of banks depends on the approach of the main flow towards the banks (Halcrow et al. 1993, EGIS 2002). Due to bank erosion, the bends migrate in downstream, lateral direction and also upstream direction in the Jamuna River (EGIS 2002). The banks must be eroded in those locations where the bed adjacent to them is eroded (da Silva 2006). The erosion deposition zone at a bend of meandering channel is dependent on the deflection angle (θ_0) of the meander flow (da Silva 2006, da Silva & Tahawy 2008). If θ_0 is small ($<30^0$), then meandering channel migrates downstream, while meandering channel expand laterally if θ_0 is large ($> 100^0$). In the case of the intermediate value (30^0-100^0) of θ_0, meandering channel exhibits the combination of downstream migration and lateral expansion (da Silva & Tahawy 2008). In the present case, the deflection angle (θ_0) of a flow is around 80^0 and the channel migrates both laterally and in downstream direction, which is quite similar to the laboratory findings. The most erosion prone locations are C and D (Fig 5.2). Erosion occurs at the locations where the thalweg is near the bankline (Fig. 5.2). From the starting of the bend channel the thalweg is near the bankline. At the end of the first sand bar, the thalweg is shifted towards the mid-channel from near bank. The thalweg is along the mid-channel in the straight portion of the channel. At the downstream bend of the channel the thalweg is very close to the bankline. After that the thalweg is shifted towards the mid-channel. The variation of depth along thalweg is shown in Fig. 5.3. It is observed that the severe erosion occurs at those locations where the depth of thalweg is more i.e. at C and D. The erosion at locations C and D is shown by Fig. 5.4 and Fig. 5.5 respectively. It is found that the bank profiles are nearly vertical. It is also found from data analysis that the outer bank velocity is amplified by 1.1 to 1.3 times as compared to the section averaged velocity.

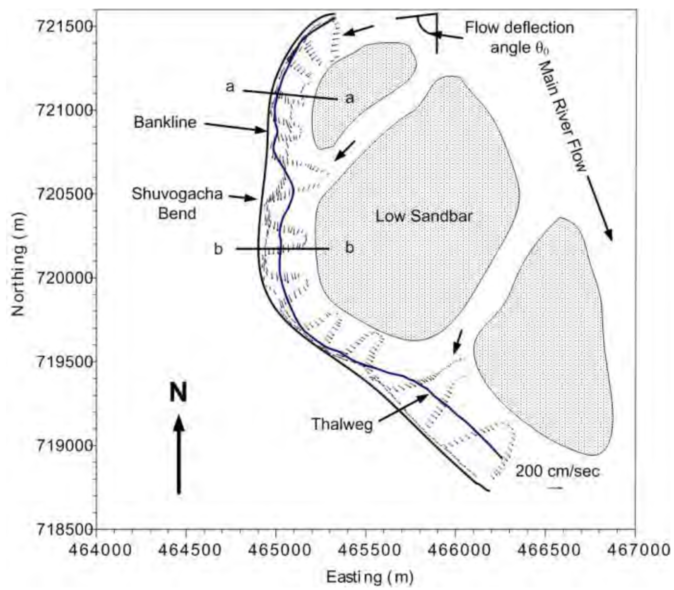


Figure 5.1: Near surface flow pattern along horizontal plane

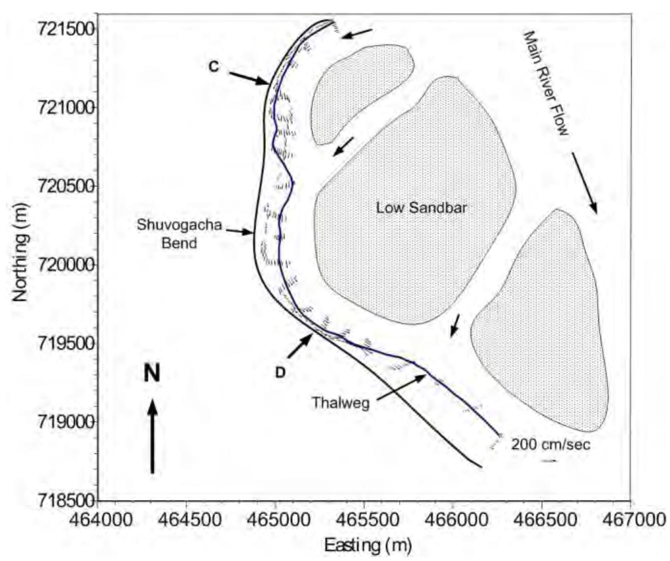


Figure 5.2: Flow pattern along horizontal plane at a depth of 5m

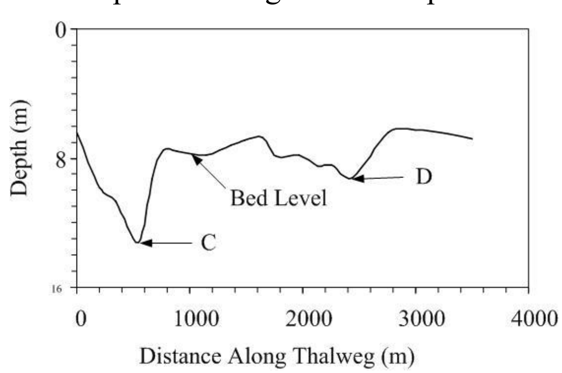


Figure 5.3: Variation of the depth along thalweg

Figure 5.4: Erosion at the upstream bend of the study area (C)

Figure 5.5: Erosion at the downstream bend of the study area (D)

5.2.2 Secondary current

Two vertical sections are taken along lines a-a and b-b (Fig. 5.1). The secondary current along line a-a and b-b are shown in Fig. 5.6 and Fig. 5.7 respectively. The secondary current in the deep thalweg driving fast close to the water surface towards the outer bank, erodes banks and bed and the inward flow takes sediment towards the bar (Chang 1987, Bathurst et al. 1979). Outer bank cells, generating flow convergence and plunging at some distance away from the banks, promotes basal scour and undercuts of the banks around the bank toe (Bathurst et al. 1979).

The secondary current is divided into multi-cell along vertical section c-d due to the additional effect by the flow coming through the shallow channel over the sand bar. The evolution and decay of the secondary current is a common feature in a river bend flow (Chang 1987, Islam et al. 1999). But it is not clear in the present analysis. Because some flow over the sand bar was also added to the bend channel flow, and a general pattern in the bend flow was modified.

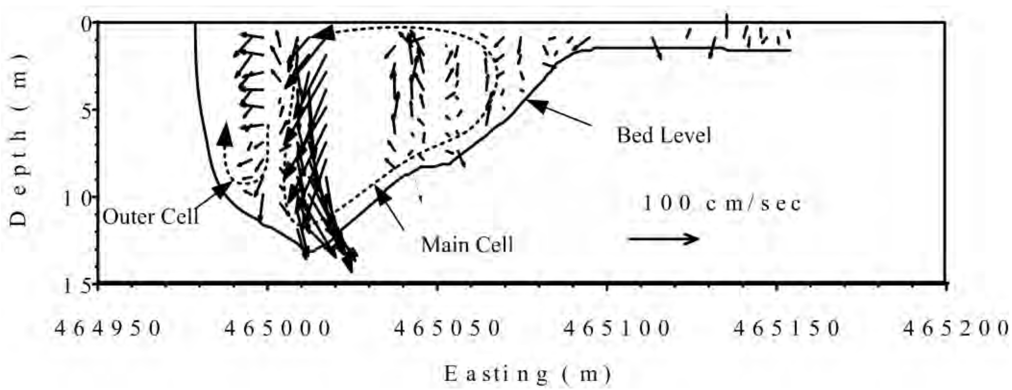


Figure 5.6: Secondary current at section a-a

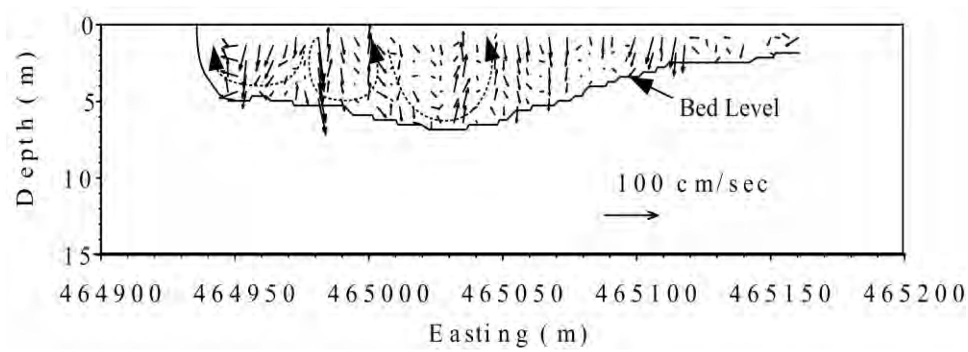


Figure 5.7: Secondary current is divided into multi-cell at section b-b

5.2.3 Shear velocity

If the shear velocity (u_*) is higher than the critical shear velocity (u_{*c}) the sediment particles go to motion. Two vertical sections have been taken along line c-c and d-d (Fig. 5.8) to investigate the ratio of shear velocity (i.e. u_*/u_{*c}). The variation of shear velocity along line c-c and d-d are shown in Fig. 5.9 and Fig. 5.10.

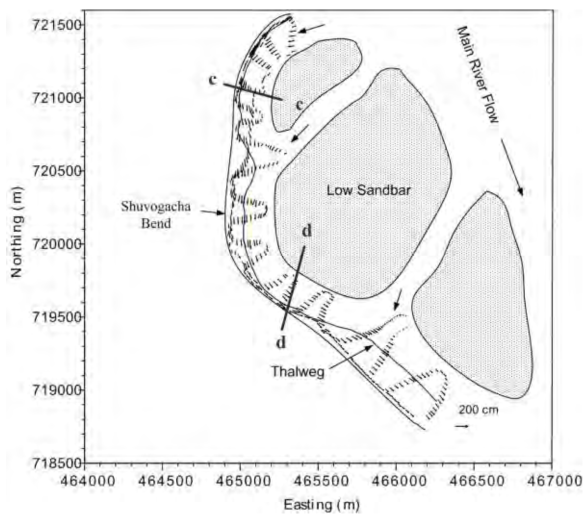


Figure 5.8: Shuvogacha bend

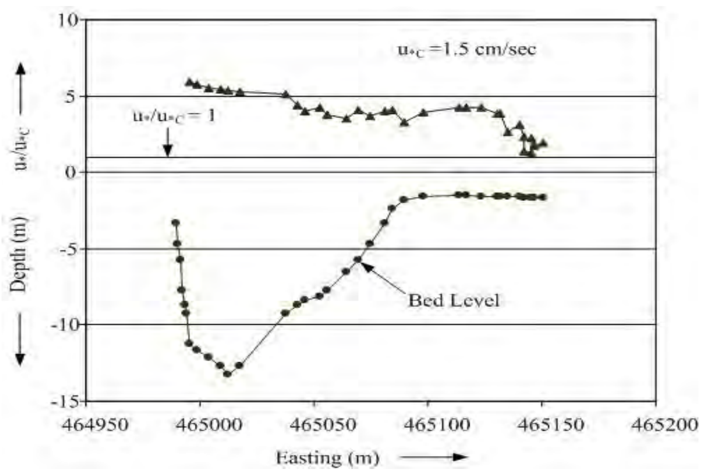


Figure 5.9: Shear velocity along line c-c

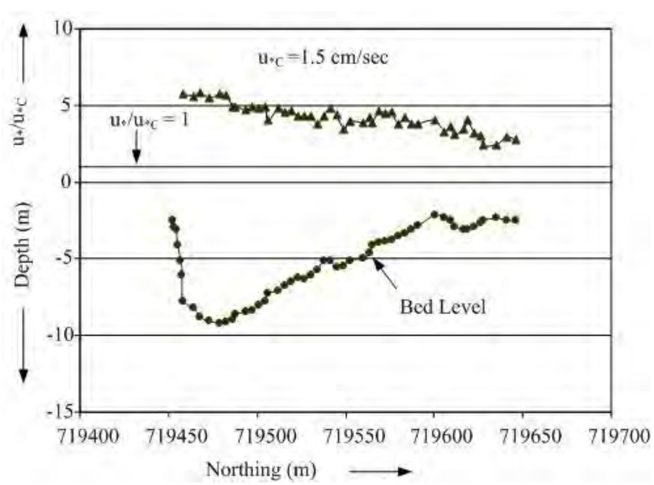


Figure 5.10: Shear velocity along line d-d

It is observed that the ratio of shear velocity near the bankline is 6 times higher than the critical shear velocity. It is an indication that the flow near the bankline has capacity of carrying excess amount of sediment. If the sediment supplied from the upstream is less than the sediment carrying capacity of the flow. The sediment would be supplied from the bank or bed to the flow through erosion. It is also evident that the slope of the bankline is very steep.

5.2.4 Summary

The secondary current transports bed load from the outer bank towards the sandbar. The secondary current in a third order bend channel within a braided river is similar to that of the single thread meandering channel. But the secondary cell is divided into multi-cell due to flow over the sandbar. Depending on the deflection angle (θ_0) of the meander flow the bend migrates towards downstream, lateral direction and also upstream direction which is similar to the laboratory investigation. The maximum rate of erosion is observed at the upstream and downstream sides of the bend. At these two locations the shear velocity is 6 times higher than critical shear velocity and the thalweg is also near the bankline.

5.3 Development of Erosion Prediction Model

5.3.1 Model development

Different models for the prediction of bank erosion have been developed by researchers (Duan 2005, Duan & French 2001, Rodríguez & García 2000). Richardson (2002) has developed a simplified model to estimate the rate of erosion at a meander bend. As input data the centerline radius of curvature and width of the meandering river are used in his model. A conversion factor (K) for shear stress is derived based on the assumption that the ratio of outer bank velocity to section averaged velocity is related to the ratio of channel centreline arc length to outer bank arc length. Shear stresses are assumed to be directly proportional to the square of velocity. Equation (5.1) describes the subsequent relationship.

$$K = \frac{\tau_{toe}}{\tau_{avg}} = \left(\frac{V_{toe}}{V_{avg}}\right)^2 = \left(\frac{B}{2R} + 1\right)^2 \qquad 5.1$$

where K = conversion factor; τ_{toe} = shear stress at outer bank (N/m^2); τ_{avg} = one-dimensional average shear stress (N/m^2); V_{toe}= depth-average velocity at outer bank (m/s); V_{avg}= one-dimensional section-average velocity (m/s); R = channel centerline radius of curvature (m); and B = channel width (m).

Using the above relationship a simplified model is developed to estimate the rate of erosion at a meander bend. The rate of river bank erosion is related to the total sediment transport rate that can be estimated by Engelund-Hansen (1967) total sediment load transport formula as below:

$$q_t = MV_{avg}{}^5 \qquad 5.2$$

where M is coefficient defined as:

$$M = \frac{0.05}{(S-1)^2 g^{0.5} d_{50} C^3} \qquad 5.3$$

q_t = volumetric total load transport (m^2/s); S = specific gravity; d_{50} = median particle size of bed material (m); C = Chezy's coefficient; V_{avg} = depth-average velocity (m/s).

$$C = \frac{V_{avg}}{\sqrt{hI}} \qquad 5.4$$

where h = average depth of flow (m), I = longitudinal slope of the channel. From (4.3) and (5.4)

$$M = \frac{0.05h^{1.5}I^{1.5}}{(S-1)^2 g^{0.5} d_{50} V_{avg}{}^3} \qquad 5.5$$

Due to the amplified flow velocity near the outer bank of a meandering channel, the sediment transport capacity near the outer bank increases as compared with the average sediment transport. To meet the near bank sediment transport capacity, sediment would be supplied through bank erosion. Therefore, the volume of excess sediment transport is equal to the volume of bank erosion that can be expressed as:

$$Ev = (q_{toe} - q_{avg}) \times b \qquad 5.6$$

where E_v = Erosion volume; q_{toe} = outer bank sediment discharge (m^2/s); q_{avg} = average sediment discharge (m^2/s); b = outer bank erosion width (m) assumed equal to bank height, h (measured from top to bottom) (Fig. 5.11). Such assumption also made by Richardson (2002) for developing simplified model (for assessing meander bend migration rate). It is also clarified from the present study that the amplified shear velocity is observed at the zone of outer bank erosion (Fig. 5.9 and Fig. 5.10).

It is already stated that the excess sediment flow through width b would be supplied from the bank. The bank profile may be either steep slope or mild slope. The height of the bank h would be equal to L if the bank profile is steep. Otherwise h would be less than L. The subsequent erosion volume (E_v) is then translated to a bank erosion rate (E_r) by dividing the erosion volume by bank height.

$$Er = Ev / h = \left(q_{toe} - q_{avg}\right) \qquad 5.7$$

From (5.2) and (5.7)

$$Er = M * V_{toe}^{5}\left\{1-\left(\frac{V_{avg}}{V_{toe}}\right)^{5}\right\} \qquad 5.8$$

where E_r = Rate of erosion (m/s).

From (5.1)

$$V_{toe} = \left(\frac{B}{2R}+1\right) * V_{avg} \qquad 5.9$$

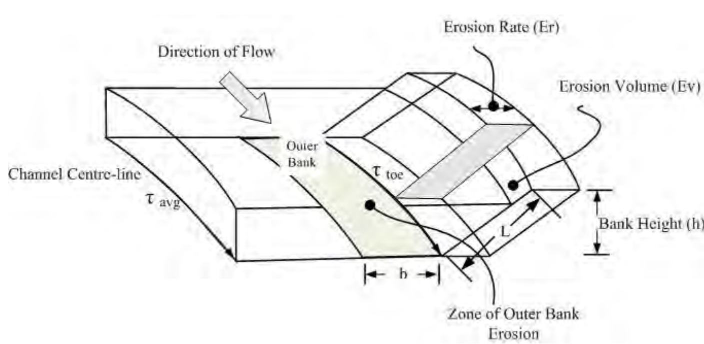


Figure 5.11: Relationship between erosion volume E_v and erosion rate E_r (Courtesy: Richardson, 2002)

From (5.8) and (5.9) the following expression is obtained.

$$Er = M\left(\frac{B}{2R}+1\right)^5 * V_{avg}{}^5 * \left[1-\left(\frac{B}{2R}+1\right)^{-5}\right] \quad 5.10$$

From (5.5) and (5.10)

$$Er = \frac{0.05h^{1.5}I^{1.5}}{(S-1)^2 g^{0.5} d_{50}} * V_{avg}{}^2 * \left[\left(\frac{B}{2R}+1\right)^5 - 1\right] \quad 5.11$$

Using the equation (5.11) the rate of erosion can be estimated of a particular bend.

5.3.2 Model application

The developed model is applied for the Shuvogacha bend to estimate the rate of erosion. Finally, the estimated rate of erosion is compared with the observed rate of erosion and data available for other bends along the Jamuna River. A study was made by EGIS (2002) for different bends of the entire Jamuna River. The observed rate of erosion is calculated from the Landsat TM images for the period of 1998-2006 used for the comparison of model prediction. To estimate the rate of erosion using the developed model, the centerline radius and width of the Shuvogacha bend are determined from the dry season satellite image for the period of 1998-2006. The bank lines of different years are shown in Fig. 5.12. The arrow shows that the outer bank line is migrating towards the lateral and longitudinal direction. The outer bank velocity and section average velocity are determined from the data collected using ADCP.

For the study area considering the following values: d_{50} = 0.20 mm, h= 6.25 m, I =$7.6*10^{-5}$, V_{avg} = 0.8 m/s. The equation (5.11) is reduced to

$$Er = 1.94*10^{-4} * \left[\left(\frac{B}{2R}+1\right)^5 - 1\right] \quad 5.12$$

From the hydrological view point the effective erosion occurs for three weeks. One week during the rising period of the flood and another two weeks during the falling period of the flood. So, the equation (5.12) further can be written in the following form:

$$Er_{(m/y)} = 352 * \left[\left(\frac{B}{2R} + 1 \right)^5 - 1 \right] \qquad 5.13a$$

here, $E_{(m/y)}$ = rate of erosion per year.

The predicted rate of erosion is compared with the observed data and EGIS (2002) data as shown in Fig. 5.13. It is found that if the ratio of R/B is greater than or equal to 3, then the developed model i.e. equation (5.13a) fits as an envelope curve with the observed data and with the EGIS (2002) data. The rate of erosion is gradually decreasing with the increasing value of R/B ratio. One of the limitations of this model is that it does not fit if R/B ratio is less than 3. By several trials it is found the following equation i.e. equation (5.13b) fits to estimate the rate of erosion if R/B ratio is less than 3.

$$Er_{(m/y)} = 50 * \left(\frac{B}{2R} \right)^{-1.2} \qquad 5.13b$$

Hickin and Nanson (1975) type equations i.e. equations (5.14a) and (5.14b) are also used to predict the rate of erosion as shown in Fig. 5.13 and found very close to the predicted lines by equations (5.13a) and (5.13b).

$$Er_{(m/y)} = 1100 * \left(\frac{R}{B} \right)^{-0.9} \qquad \text{If } R/B \geq 3 \qquad 5.14a$$

$$Er_{(m/y)} = 47 * \left(\frac{R}{B} \right)^{2} \qquad \text{If } R/B < 3 \qquad 5.14b$$

5.3.3 Discussion

It is found from Fig. 5.13 that the developed model covers 87% of observed data and 78% of EGIS data. The Hickin and Nanson type equations cover 91% of observed data and 84% of EGIS data. The Hickin and Nanson type equations consider only planform of the channel such as the radius of curvature and width of the river bend. But the developed model considers hydraulic parameter such as V_{avg} together with planform parameters such as the radius of curvature and width of the channel. To predict the rate of erosion for the Jamuna River using Hickin and Nanson type equations the coefficient of equations (5.14a) and (5.14b) is much larger than that used for the Beatton River. The larger coefficient value indicates higher erodibility of the Jamuna River as compared with the Beatton River.

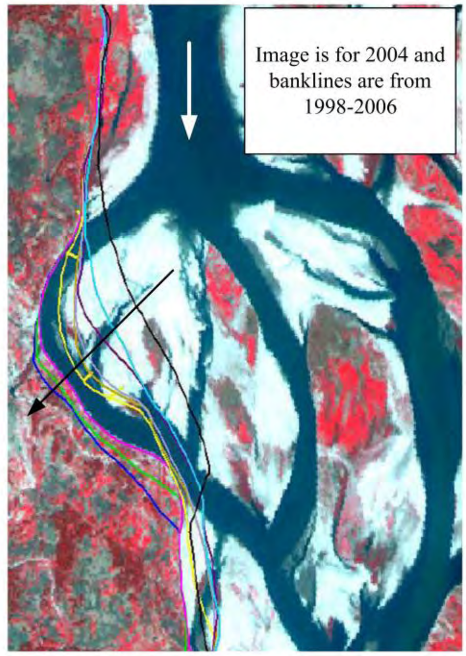


Figure 5.12: Outer bankline in different years (1998-2006) along the Shuvogacha bend (Uddin 2007).

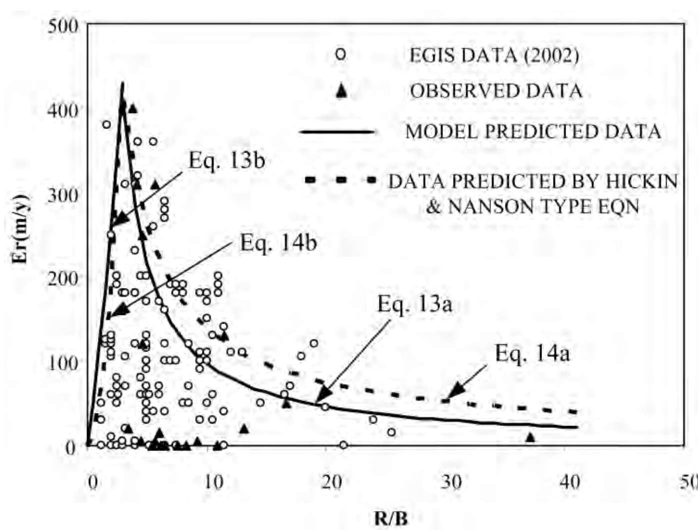


Figure 5.13: Comparison of rate of erosion with relative radius of curvature

Different bank erosion prediction models are available in literature. The flow parameters, planform parameters and properties of bank materials are used in the existing models for predicting the rate of erosion. But in the present developed model the flow parameters, planform parameters properties of bank materials and the indigenous knowledge are used to estimate the rate of erosion. Using those above mentioned information in the developed model, the field engineers could estimate the rate of erosion for the secondary channel which is similar to the present study channel.

5.4 Concluding Remarks

The flow processes at a bend of a third order channel of a large scale braided river is similar to the simply meander bend. But the flow pattern is greatly affected by the flow over the sand bar. The amplified shear velocity is responsible for the bank erosion. The bend may migrate along lateral, downstream and upstream direction. The flow parameters, planform parameters, properties of bank materials and indigenous knowledge are used in the developed model. The developed model is capable to predict the rate and extent of erosion along the third order channel of the braided river.

CHAPTER SIX

FLOW AND EROSION PROCESSES AROUND BANK PROTECTION WORKS

6.1 Introduction

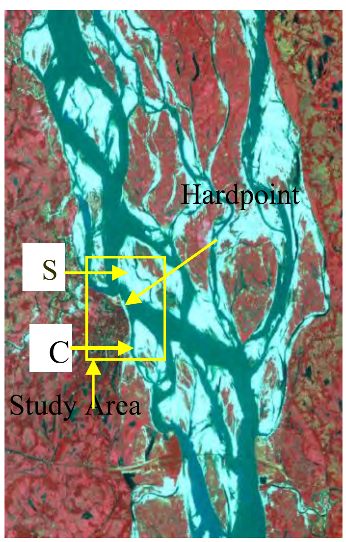
River bank erosion is a big problem in Bangladesh, especially along the braided Jamuna River. Thousands of hectares of land are eroded each year by the mighty Jamuna River. Social and economical problems are created in consequence of erosion. To protect banks from erosion different types of protection measures have been implemented along the braided Jamuna River. These are revetment-like (in this case hardpoint) structures, groin-like structures and bandal-like structures. The physical configuration and alignment of these structures are completely different. A revetment-like structure is constructed along the bankline without imposing significant disturbance on the flow. The groin-like structure (permeable and impermeable) is constructed normal to the bankline towards the main channel to divert the flow away from the bank. The bandal structures are aligned at an angle with a bankline in the downstream direction. The bandal-like structures have been recently being used as bank protection along the secondary channel of the Jamuna River on a pilot basis. The bandal-like structures, which are made of bamboo, are a very weak structure. It was usually used to increase flow depth in the navigational channel along different rivers in Bangladesh for a long time. The previous studies concentrated on exploring the flow and scouring on a laboratory scale around bandal-like structures (Rahman et al., 2003; Rahman et al., 2005; Rahman et al., 2006). Under FAP 21/22 (1997) a detailed study was made on bandal (fixed surface screen) as soft or recurrent measures in a prototype scale along the Jamuna River. The detailed working principle of the surface screen is described by Rahman et al. (2007).

The construction costs of a hardpoint, the RCC spur and bandal structures along the Jamuna River are 21,000 US$, 950 US$ and 9 US$ respectively to protect one linear meter of the bank. The construction years of the Sirajgang hardpoint, Betil and Enayetpur RCC spurs, and the bandal like structures are 1998, 2001 and 2008 respectively. The RCC spur has two parts: the first part is an earthen shank starting from the bank line or flood embankment and the last part is made of RCC (150m). The Sirajganj hardpoint, and Betil and Enayetpur spurs are facing the problem of failure during the flood period since their construction due to an unusual flow pattern and development of the local scour hole around the structures. So it is essential to identify the causes of such problems. The complex flow around the structure is one of the important factors for such failure. The extensive studies on a flow field around groin-like structures and abutments have been investigated by Rajaratnam and Nwachukwu (1983), Kandasamy (1989), Ahmed and Rajaratnam (2000), Barbhuiya and Dey (2003), Dey and Barbhuiya (2005), Kwan and Melville (1994), Kuhnle et al. (2008), Zhang et al. (2006) and many others at a laboratory level or by using the numerical model. The results of these studies are usually extrapolated in the field. There are a very few field-based investigations on flow processes, especially in a large scale sand bed braided river like the Jamuna. The 3-D flow and erosion processes have been investigated through the present study around the Sirajganj hardpoint, Betil and Enayetpur spurs so that the failure-related events could be handled effectively. At the same time, the effectiveness of the bandal-likes structures has been investigated as bank protection measures.

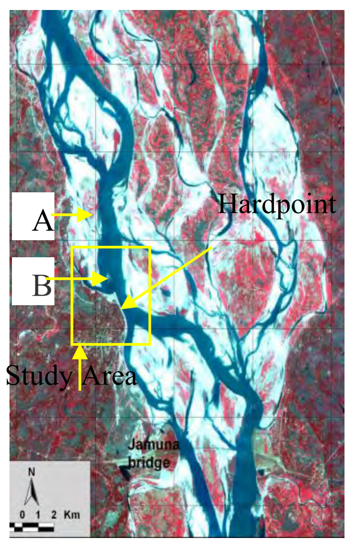
6.2 Revetment-Like Structure

6.2.1 Change of morphology

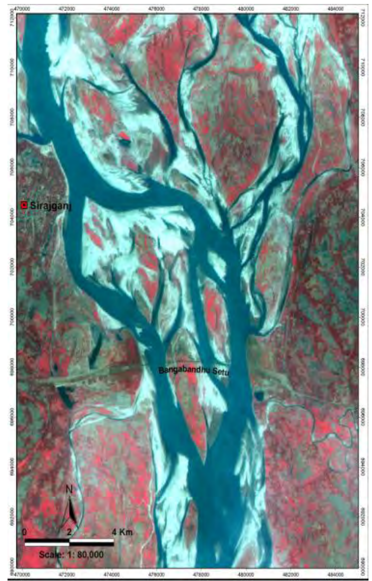
It is formerly stated that the Jamuna is a dynamic river. Some of the bed forms of height about 15m move at a rate about 600m/day in the downstream direction (Coleman, 1969). Satellite images after 2007 and 2008 flood seasons are shown in Fig. 1.1(a) and Fig. 1.1(b). A major morphological change was observed between two years. In 2007 the confluence of the curved and the straight approach channel was just upstream of the upstream termination of the hardpoint. It was seen in the satellite image of 2009 that the upstream of the curved channel has been dried up at “A” due to siltation at the upstream intake of the curved channel. One important characteristic, usually observed in the case of the secondary curved channel of the Jamuna, is that it is abandoned in 7 to 10 years cycle. It also varies according to the reach and type of the channel. In the present study reach, the upstream curved channel is also about to be abandoned though it is only active during the flood season. Significant change has occurred in the straight approach channel during the 2008 flood season. The western part of the parallelogram shaped "S" sand bar (local name *char*) as shown in Fig. 6.1 (a) has been washed away. This sand bar has moved about 300m towards the downstream direction. The width of the straight approach channel has been enlarged. A low sand bar "B" as shown in Fig. 6.1 (b) is formed just upstream of the termination of the hardpoint. A channel "C" adjacent to the eastern part of the hardpoint image is in the developing stage in the 2007. Though, it had no flow during the dry season. This channel has been fully developed after the 2008 flood season. It was found that water was flowing through this channel (March, 2009) with about 5m depth of the flow. About 70% of the total discharge was passing through Sirajganj channel on 23rd March, 2008. But due to the morphological change, the total flow (i.e. 100% of the flow) was passing near the Sirajganj channel on 19th March, 2009 (Table 6.1). It is found form the satellite image of 2010 that this channel is also further developed (Fig. 6.1(c)). No doubt a significant amount flow (i.e. about 50% of total flow) is passing through this channel in 2010.



(a) Satellite image (Dec 9, 2007)
WL: 8.37 mPWD



(b) Satellite image (Feb 13, 2009)
WL: 6.67 mPWD



(c) Satellite image (Jan, 2010)

WL: 6.92 mPWD

Figure 6.1: Changes of river morphology in the study sites

Table 6.1: Dry season discharge passing through the Sirajganj channel

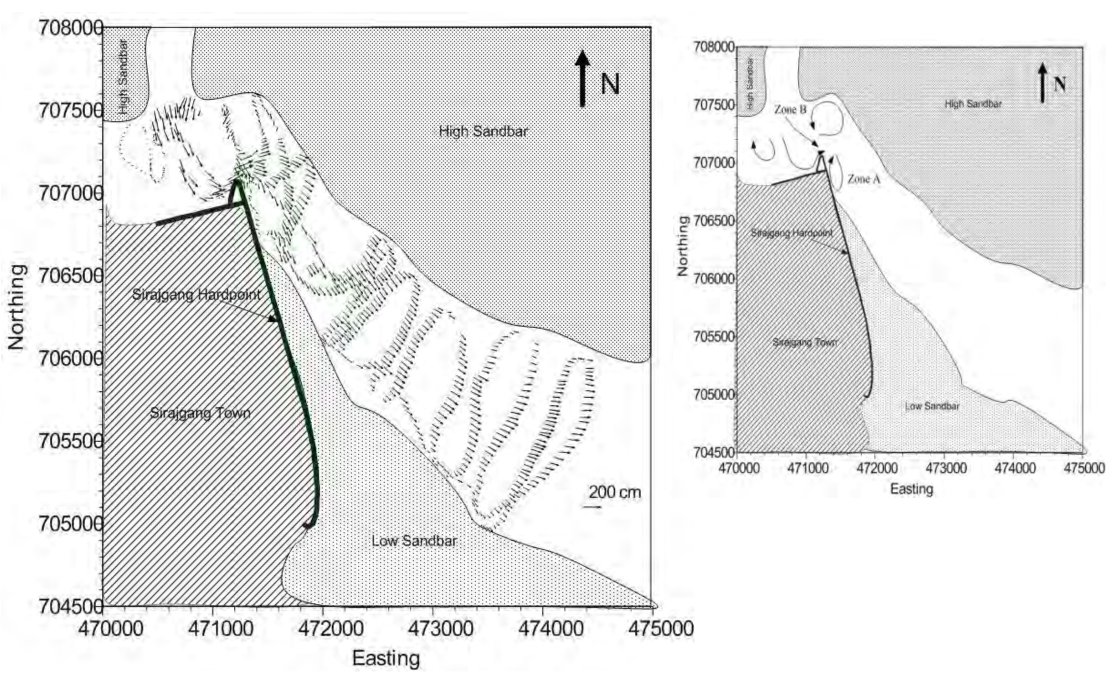
Year	Total Discharge	Discharge Passing
23rd March, 2008	4800 m^3/sec	3300 m^3/sec (70%)
19th March, 2009	4150 m^3/sec	4150 m^3/sec (100%)

6.2.2 Flow around the Sirajganj hardpoint

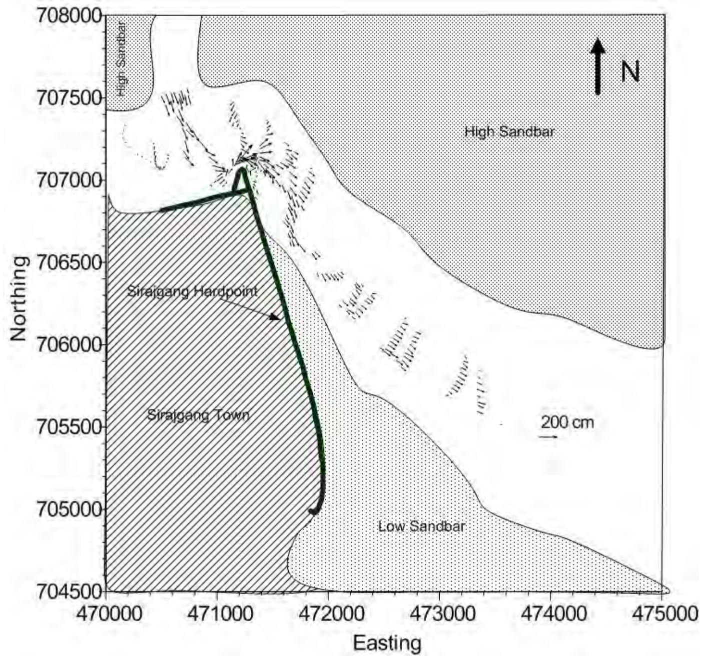
Flow along the horizontal plane:

Flow along the horizontal plane in March, 2008:

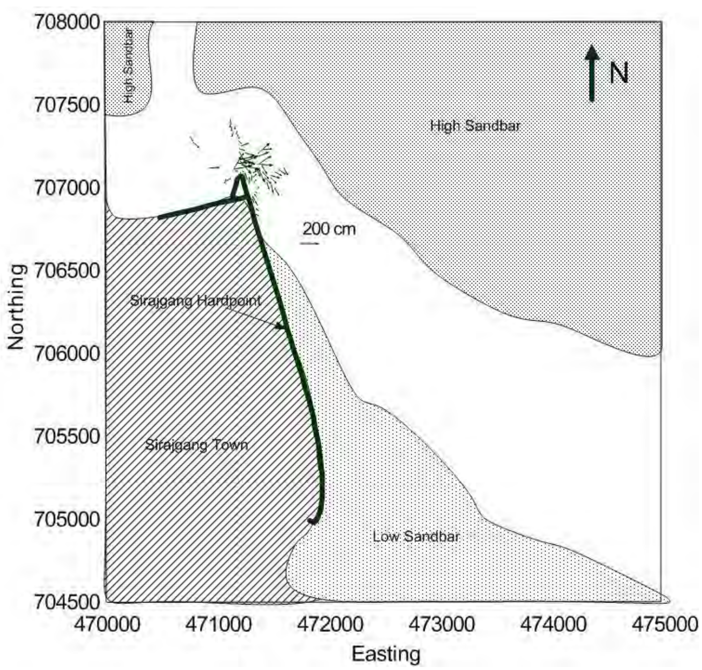
The flow pattern around bank protection structures in the braided Jamuna River continuously changes due to changing morphology of the approach channel, bathymetry, presence of sand bars, roughness and the configuration of the bank protection structure (Uddin et al., 2010). The flow patterns along six horizontal planes at every five meter depth interval are shown in Fig. 6.2 (a-f) around the Sirajgang hardpoint. The horizontal planes are taken at a depth of 1m, 5m, 10m, 15m, 20m and 25m. The direction of the approach flow from the north approach channel is more or less southward. From the velocity vectors, it is clearly evident that a part of the flow smoothly turns in the south-east direction. The remaining part of the flow in the western side of the termination then turns north-east direction when passes the termination, and again the flow changes its direction in the south-east direction. Two dominant flow circulation zones (zones A and B) are observed in Fig. 6.2(a) around the Sirajgang hardpoint. Zone „A‟ is just downstream of the upstream termination and Zone „B‟ is adjacent to the sandbar which is located at opposite side of the termination. The flow circulation Zone B is relatively stronger than Zone A. But Zone A exists up to 20 m deep. The flow is concentrated into the scour hole. It was found from the field observation during the monsoon that flow circulation or return current (Zone A) near the hardpoint becomes very much stronger than that of the dry season. Zone B doesn‟t exist during the flood season because sandbar goes under water flow. The magnitude of flow velocity is relatively high in the mid-channel of the study area on March, 2008. The velocity adjacent to the hardpoint is amplified up to 2 times than that of the approach average flow velocity. It is also evident that the deep scour hole is located near the upstream termination.



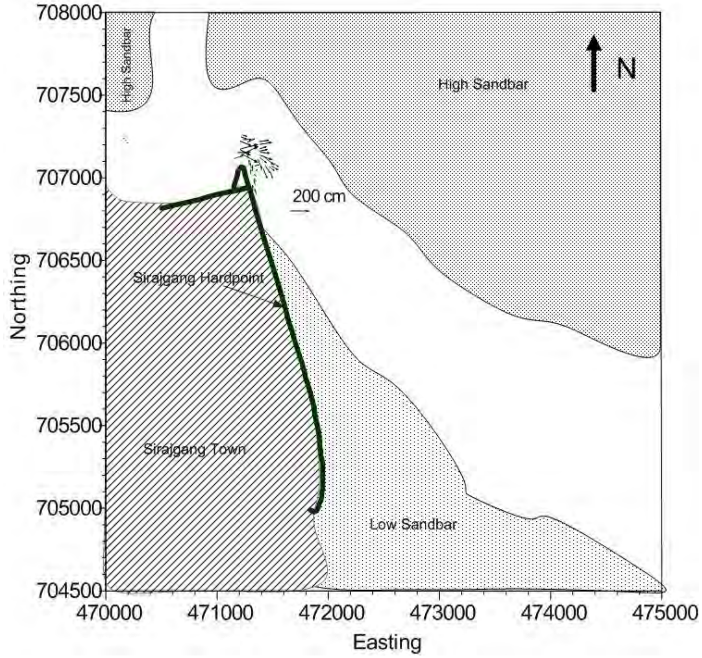
(a) Velocity vectors at a depth of 1m (March, 2008)



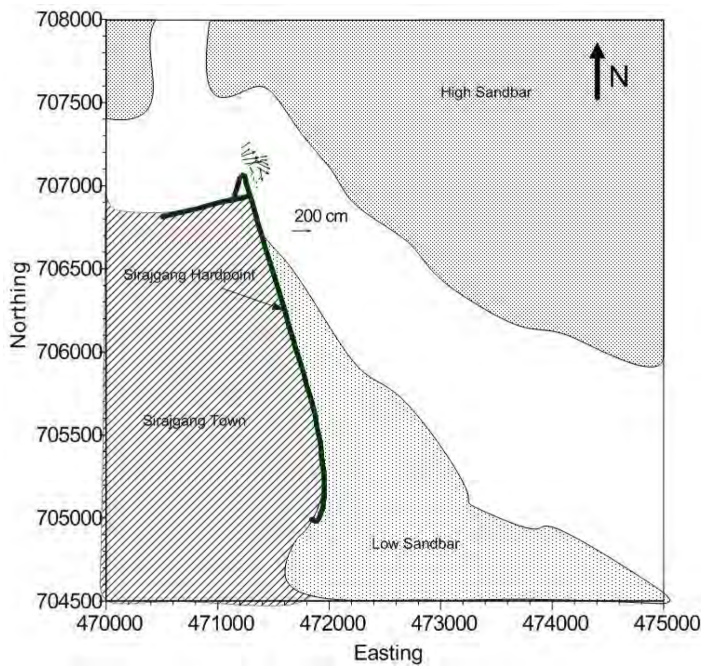
(b) Velocity vectors at a depth of 5m (March, 2008)



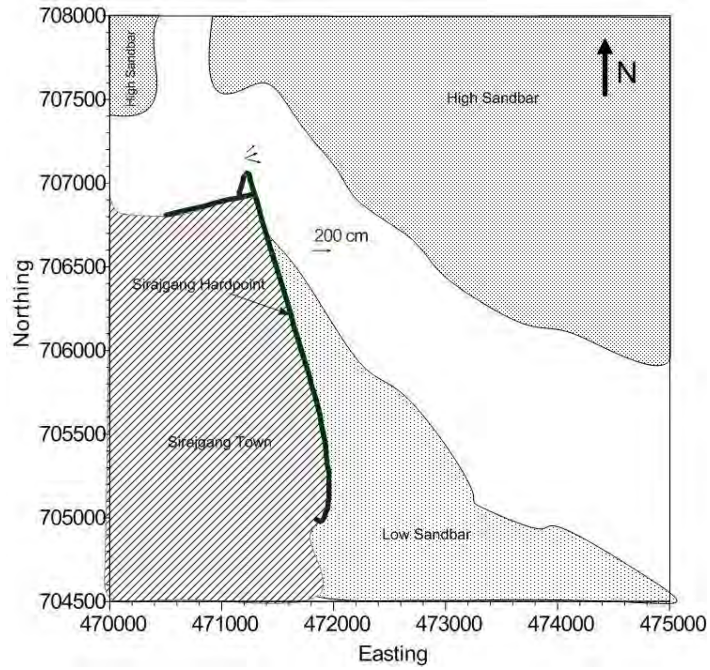
(c) Velocity vectors at a depth of 10 m (March, 2008)



(d) Velocity vectors at a depth of 15 m (March, 2008)



(e) Velocity vectors at a depth of 20 m (March, 2008)



(f) Velocity vectors at a depth of 25 m (March, 2008)

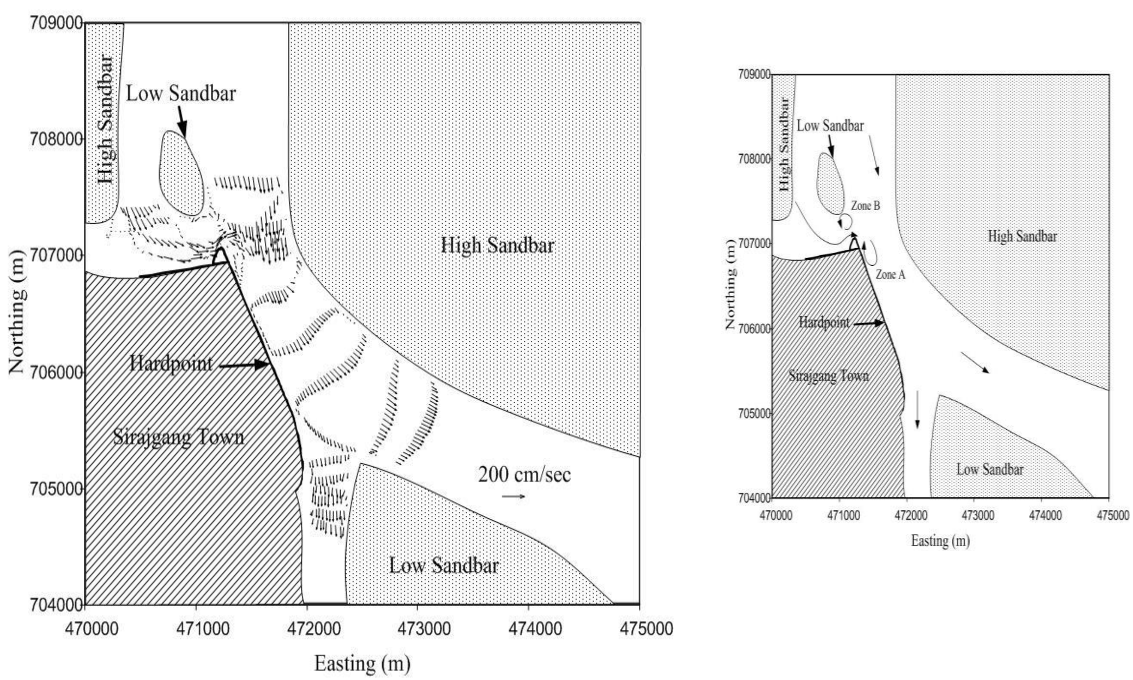
Figure 6.2: 2-D velocity vectors around Sirajganj hardpoint at different depths (March, 2008)

Flow along the horizontal plane in March, 2009:

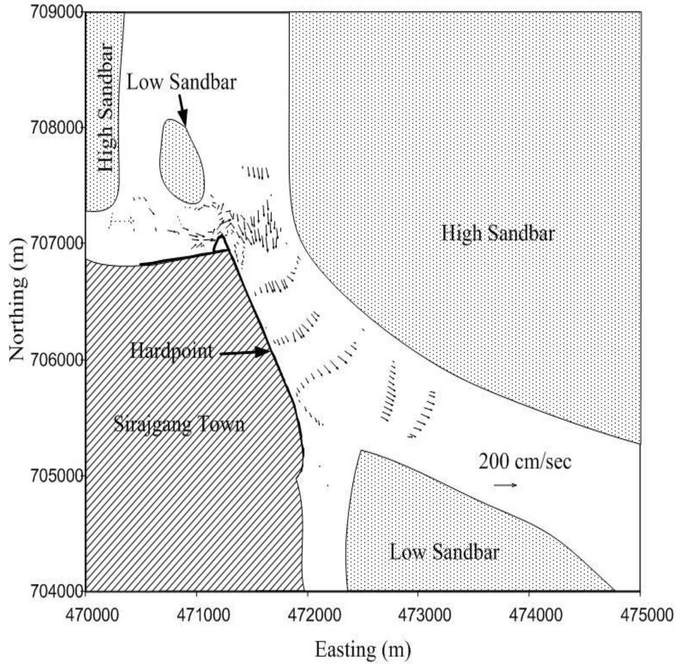
The magnitude and direction of velocities along six horizontal planes are shown with velocity vectors in Fig. 6.3 (a-f). The surface velocity along the horizontal plane is considered at a depth of 1m from the surface. Another five horizontal planes are measured at the depth of 5m, 10m, 15m, 20m and 25m. Due to the formation of sandbar, the approach flow was divided into two channels in 2009. The western approach channel is silted up and only 25% of the total discharge flows through this channel (Fig. 6.3f). About 75% of the total discharge is carried by the eastern approach channel. The maximum velocity in the eastern approach channel was 1.5m/sec. Again two approach channels meet together near the upstream termination of the hardpoint. One important issue is that the approach flow is guided by the sandbar. The oblique flow which is generated by the sandbar hits the eastern part of the hardpoint. The channel is again divided into two channels after some distance downstream. About 25% of the total discharge flows through the channel passing by the hardpoint and the depth of flow of this channel is about 5m. The remaining 75% of the total discharge flows through the second channel. Two flow circulation zones (zone A and B) are observed in Fig. 6.3(a). The flow circulation zone „A‟ is existed just downstream of the upstream termination. The flow circulation zone „B‟ is existed in between two approach channels and downstream of the low sandbar. The periphery of flow circulation zone B is larger than zone A. Since the low sandbar goes under water and water starts to flow over the low sandbar, the flow circulation zone B doesn‟t exist during the flood season. The flow circulation zone A exists up to 20m deep.

Comparison between the flow along the horizontal planes in March of 2008 and 2009:

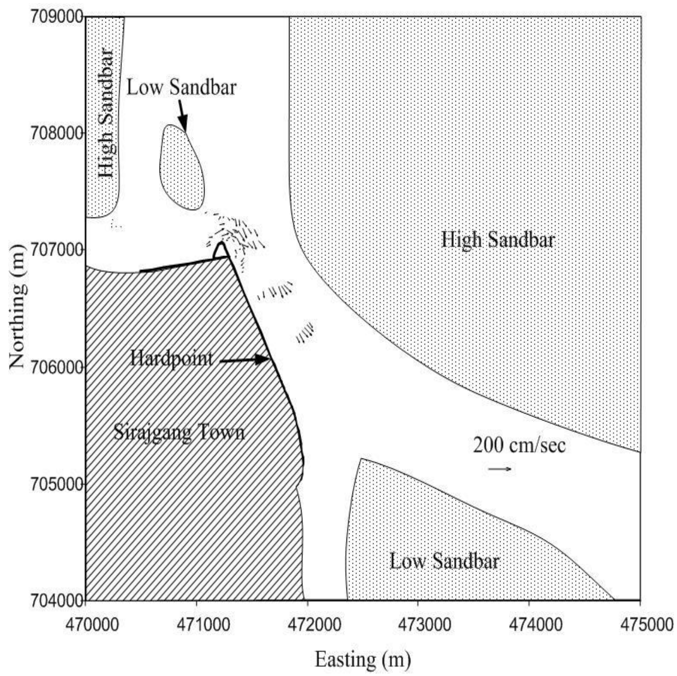
The maximum velocity near the upstream termination was 2m/sec in the year 2008. But the maximum velocity near the upstream termination was 1.4m/sec in the year 2009. Only one approach channel was existed in 2008. But the approach channel was divided into two channels in 2009. The flow was diverted by the hardpoint towards the south-east direction in 2008. The flow guided by the sandbar towards the eastern part of the hardpoint in 2009. Two flow circulations were observed in 2008 and 2009. The location of zone B was in between two approach channels due to morphological change. The flow circulation zone A was present up to 25m and 20m deep in 2008 and 2009 respectively.



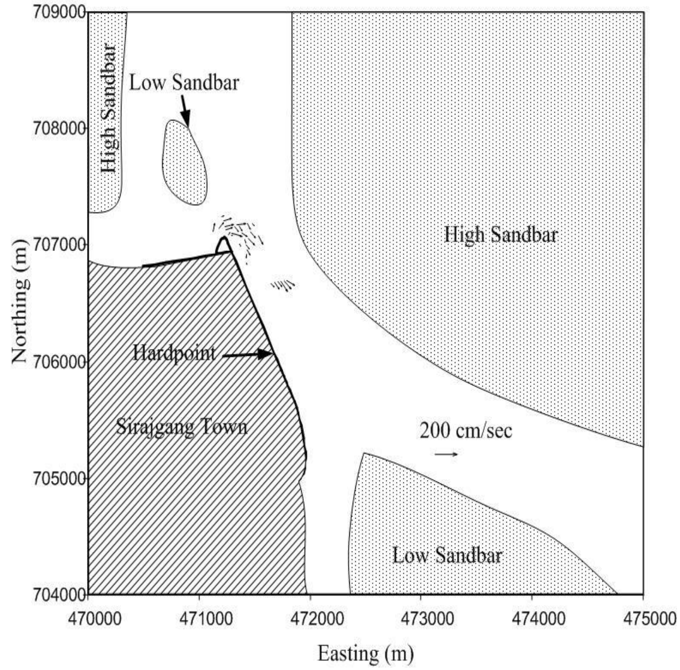
(a) Velocity vectors at a depth of 1 m (March, 2009)



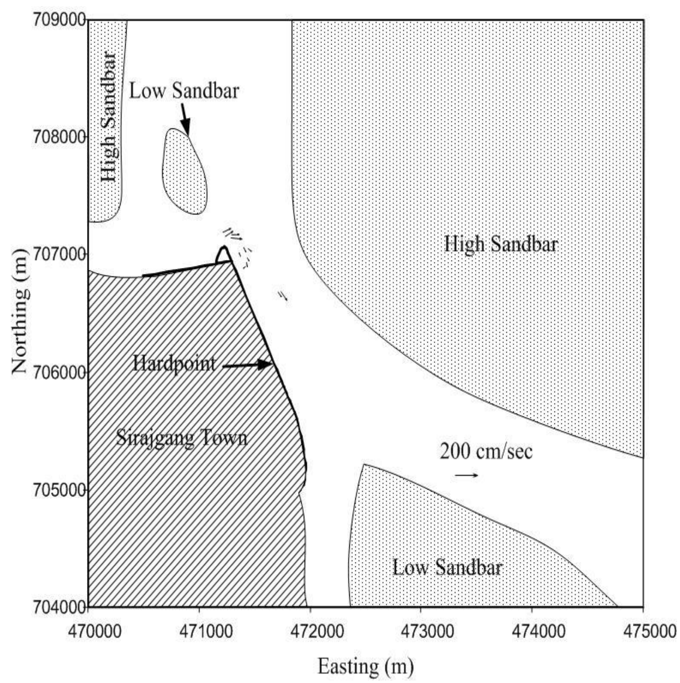
(b) Velocity vectors at a depth of 5 m (March, 2009)



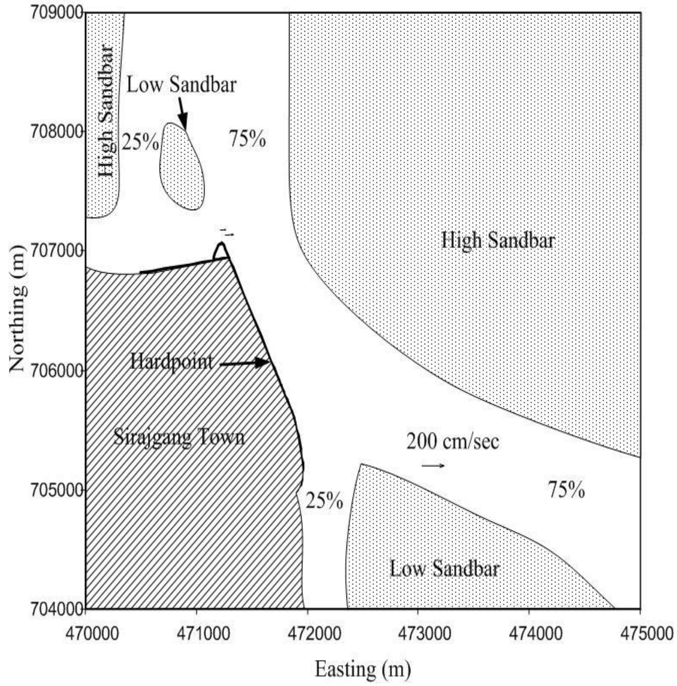
(c) Velocity vectors at a depth of 10 m (March, 2009)



(d) Velocity vectors at a depth of 15 m (March, 2009)



(e) Velocity vectors at a depth of 20 m (March, 2009)

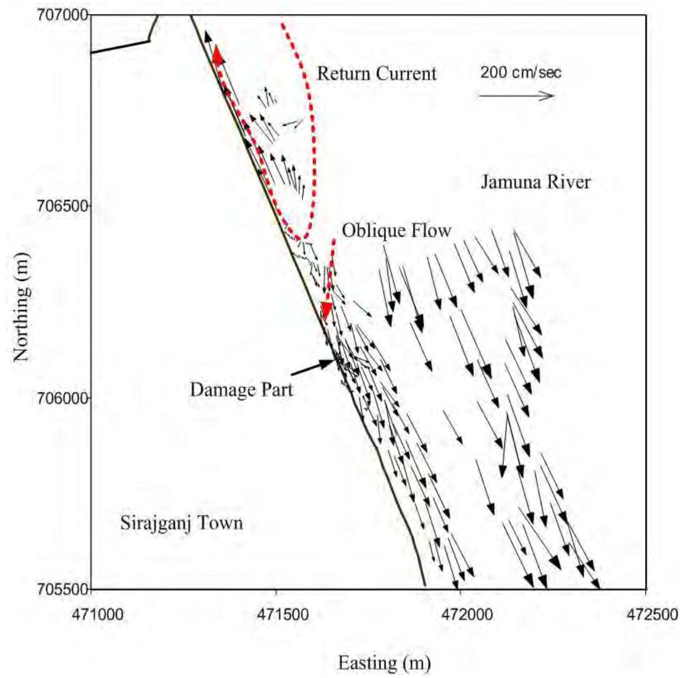


(f) Velocity vectors at a depth of 24 m (March, 2009)

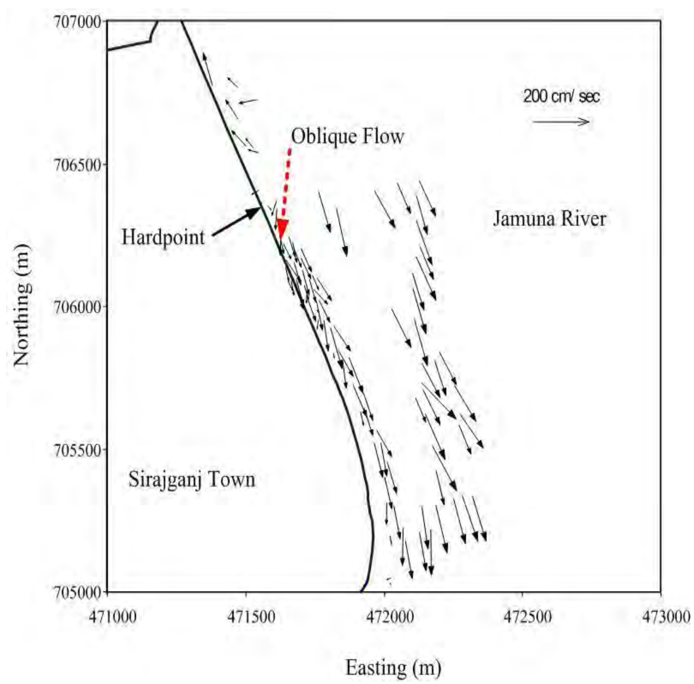
Figure 6.3: 2-D velocity vectors around Sirajganj hardpoint at different depths (March, 2009)

Flow along the horizontal plane in August, 2009:

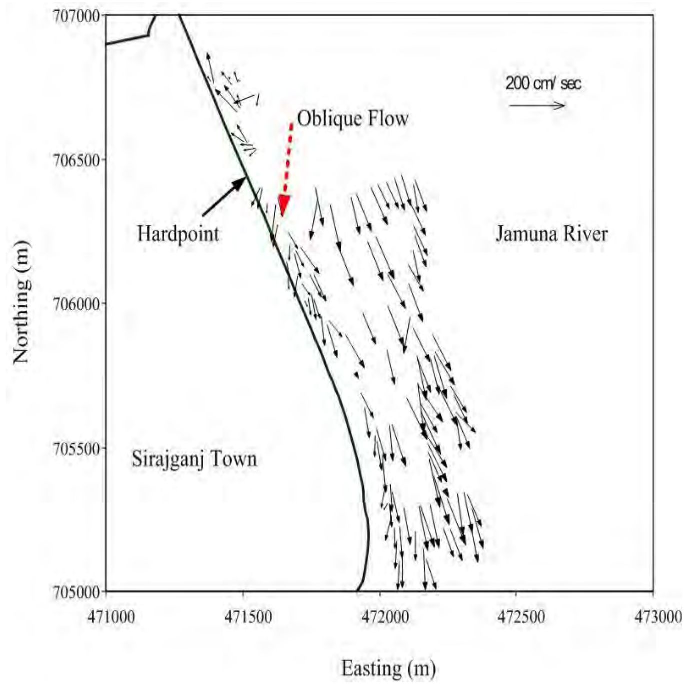
The flow data could be measured by using the present ADCP up to 25m. So, the flow data was measured at the downstream reach of the upstream termination of the hardpoint. The flow patterns along horizontal planes are shown in Fig. 6.4 (a-d). At every 5m interval four horizontal planes are taken at a depth of 1m, 5m, 10m and 15m. The influence of the return current (zone A) was extended up to more than 600m in August of 2009. But the influence of the return current was observed 250m to 300m in March of 2008 and 2009. Zone A was existed up to 15m depth in August 2009. The flow obliquely hits the hardpoint just downstream of the influence of the return current. The oblique flow is observed up to 15m deep. The hydraulic data was recorded by ADCP in the region adjacent to the hardpoint and up to 300m distance away from the hardpoint. The ADCP could not record the hydraulic data where the flow was highly turbulent.



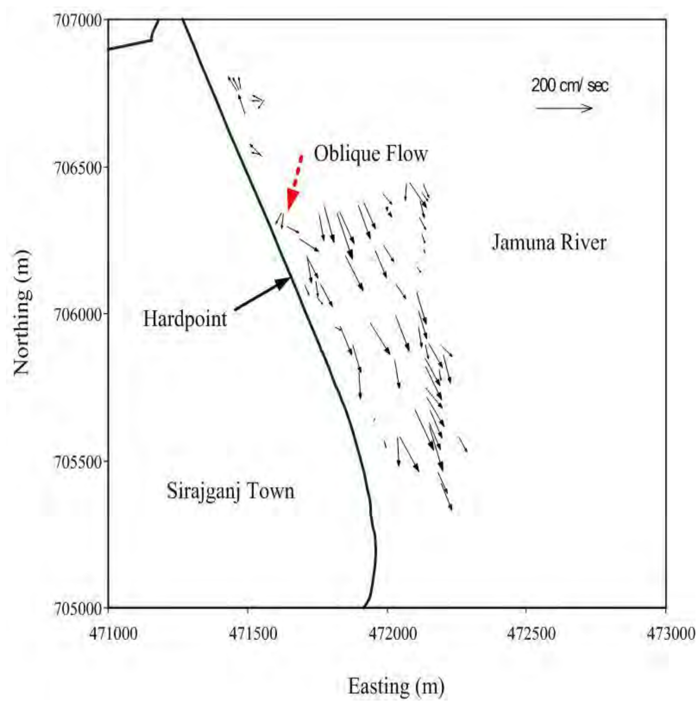
(a) Velocity vectors at a depth of 1m (August, 2009)



(b) Velocity vectors at a depth of 5m (August, 2009)



(c) Velocity vectors at a depth of 10m (August, 2009)



(d) Velocity vectors at a depth of 15m (August, 2009)

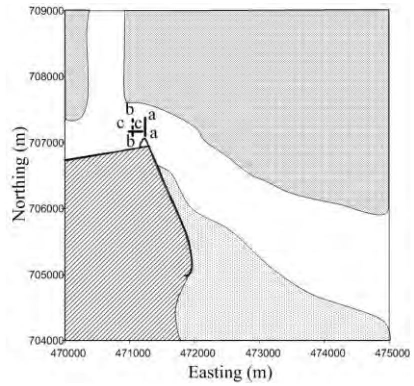
Figure 6.4: 2-D velocity vectors around Sirajganj hardpoint at different depths (August, 2009)

Flow along the vertical plane:

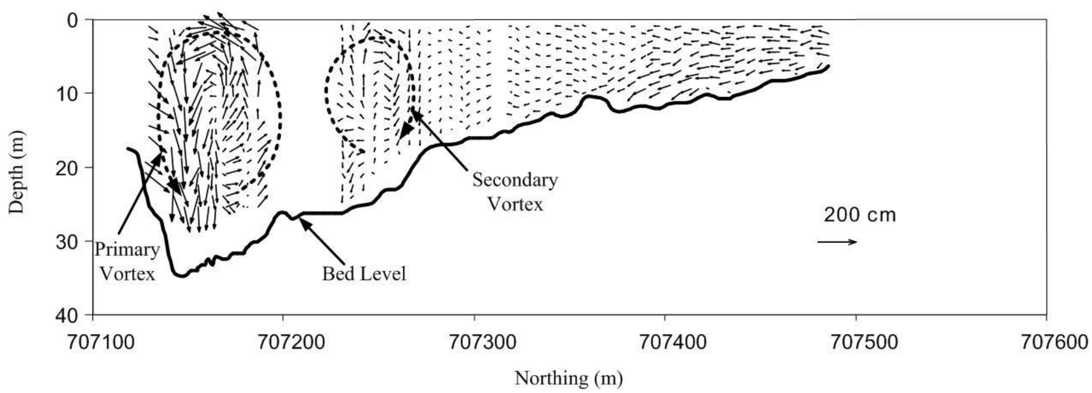
Flow along the vertical plane in March, 2008:

Many researchers have investigated that the downflow and primary vortex are responsible for the development scour hole around a structure (Kandasamy, 1989; Kwan and Melville, 1994; Barbhuiya and Dey, 2003). To investigate flow phenomena a vertical section was taken along line a-a (from the upstream termination of the hardpoint towards sandbar) through the scour hole (Fig. 6.5(a)). The primary and secondary vortices are found in Fig. 6.5(b). The scouring potential depends on the downward flow component of the primary vortex. In the present case, the strong primary vortex is formed into the deep scour hole. The primary vortex rotates in the anti-clockwise direction. At the same time a secondary vortex is also developed. The secondary vortex rotates in the clockwise direction. The magnitude of velocity is higher in the upper and lower regions of the primary vortex. The slope of the bed level is steeper from northing 707100m to 707150m due to the development of the deep scour hole. The magnitude of velocity into the scour hole is relatively higher than that of other locations along the vertical plane. We can easily understand the gradually development of the primary vortex from Fig 6.5 (b) and Fig. 6.5 (c). The vertical section taken along line b-b is upstream from the vertical section taken along line a-a. It is found that the primary vortex along line b-b is in developing stage while the primary vortex is fully developed along line a-a.

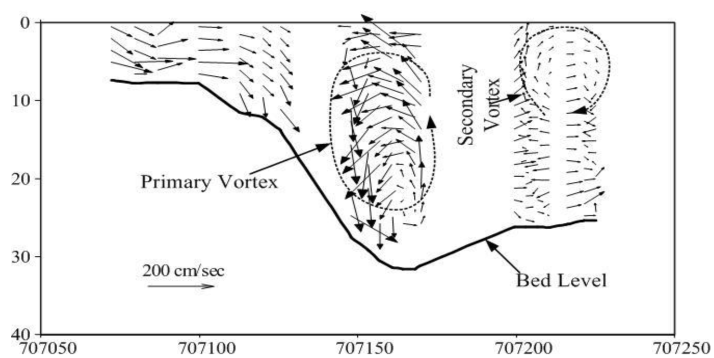
A vertical is taken along line c-c. This line is passed through the scour hole. The velocity vectors along line c-c are shown in Fig. 6.5(d). It is observed that the velocity vectors along line c-c are downward direction. It is an indication that the water is flowing towards the deep scour hole. The approach flow dives downward into the scour hole; similar findings are obtained by different researcher (Kwan and Melville, 1994; Barbhuiya and Dey, 2003 and Dey and Barbhuiya 2005) in laboratory experiment**.** The deeper scour hole is developed due to such complex flow processes adjacent to the upstream termination. The bed materials are washed away by the strong primary vortex. As a result, the launching materials are dislocated. Finally, the upstream termination of the hardpoint is damaged in September 2008.



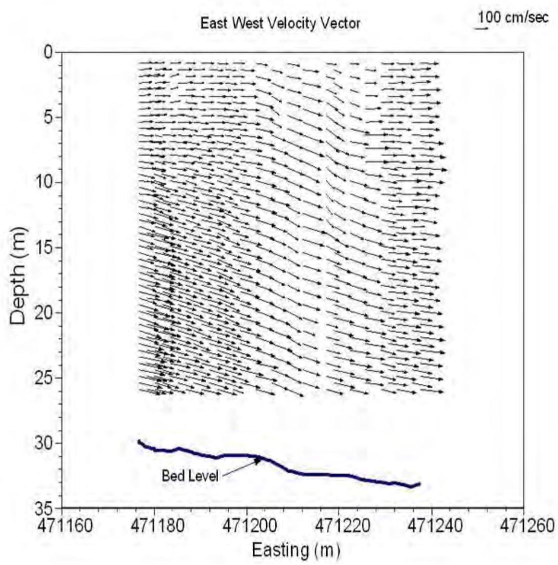
(a) Vertical sections



(b) Velocity vectors along line a-a (March, 2008)



(c) Velocity vectors along line b-b (March, 2008)

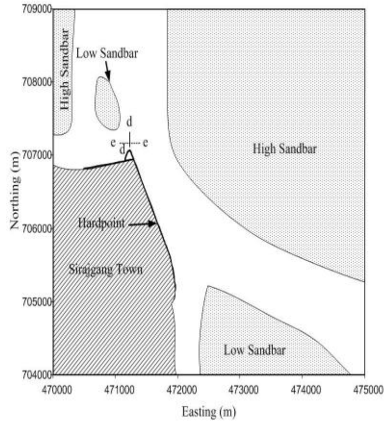


(d) Velocity vectors along line c-c (March, 2008)

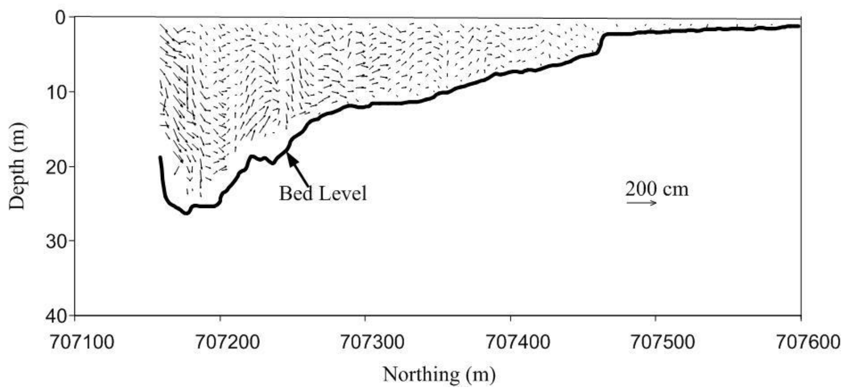
Figure 6.5: 2-D velocity vectors around Sirajganj hardpoint at different vertical sections (March, 2008)

Flow along the vertical plane in March, 2009:

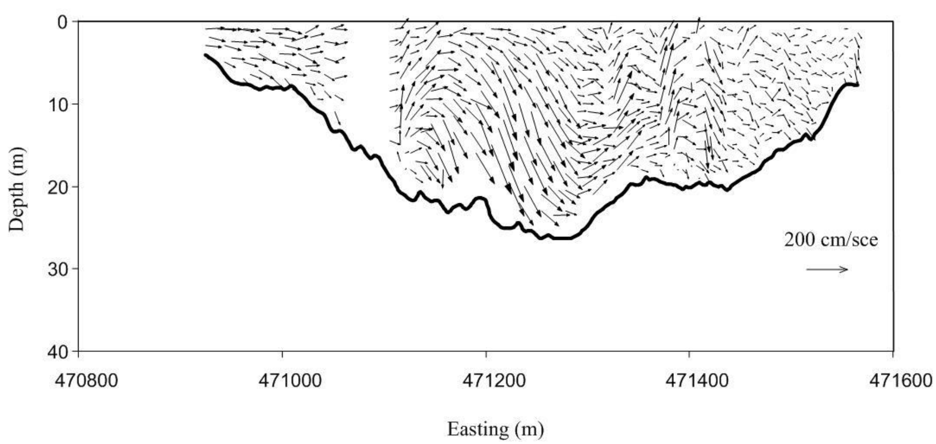
Two vertical sections are taken along line d-d and e-e (Fig. 6.6 a) to investigate the flow processes in vertical planes. The velocity vectors in the vertical plane through the scour hole along line d-d and e-e are shown in Fig 6.6(b) and Fig. 6.6(c). It is observed from the velocity vectors along line d-d that the weak primary vortex exists and the significant secondary vortex does not exist. Due to a decrease in the scouring potentiality in March of 2009, the maximum depth into the scour hole was 25m. A vertical section is taken along line e-e through the scour hole. Unusual velocity vectors are observed along this vertical section**.** From easting 470900m to 471020m the direction of velocity vectors is downward. After that the flow is highly turbulent. From easting 471100m the flow velocity is in the upward direction. Then the flow is in the downward direction into the scour hole. It is considered that this type of flow phenomena is originated due to the heaping of CC blocks which were dumped after damaging of the upstream termination of the hardpoint in September 2008.



(a) Vertical sections (March, 2009)



(b) Velocity vectors along the vertical plane along line d-d (March, 2009)



(c) Velocity vectors along the vertical plane along line e-e (March, 2009)

Figure 6.6: 2-D velocity vectors around Sirajganj hardpoint at different vertical sections (March, 2009)

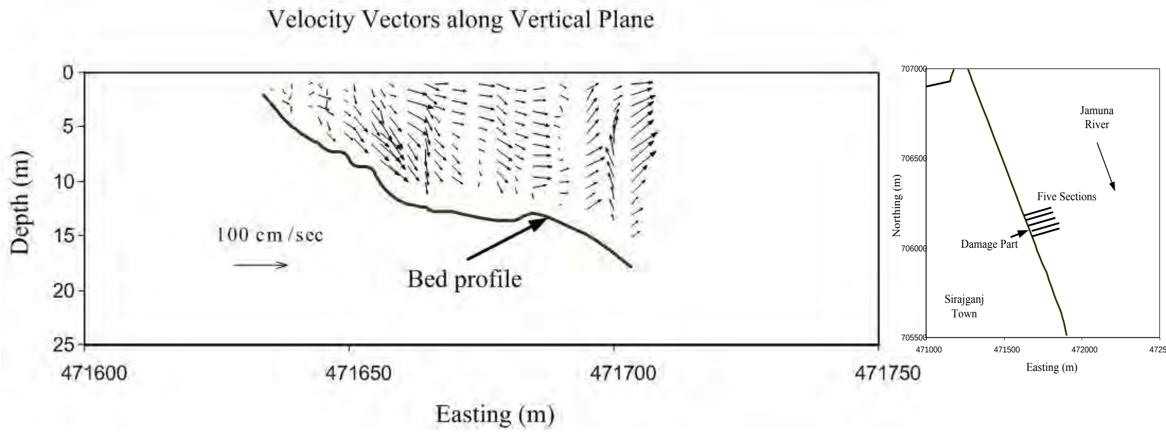
Comparison between flow along the vertical planes in March of 2008 and 2009:

Considerable changes of flow phenomena along vertical planes were observed in March of 2008 and 2009. The main cause of the changes of the flow phenomenon is the morphological change of the approach channel upstream of the upstream termination of the hardpoint. The primary vortex was very strong and velocity vectors in the scour hole were really downward direction in 2008.

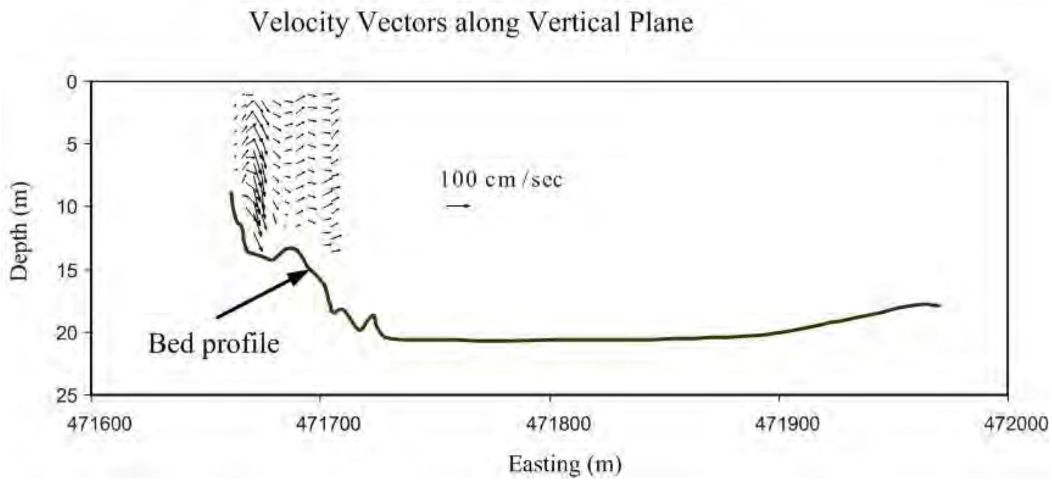
But the primary vortex was relatively weak in 2009 than 2008. The magnitude of the velocity is relatively smaller in 2009 than 2008. Typical velocity distribution in a flume experimental or in a river is usually increased from bed to the water surface. But in the present study a complex flow structure is visualized around the upstream termination due to upstream channel geometry, bathymetry and the configuration of the hardpoint itself in both cases (Uddin and Rahman, 2009).

Flow along the vertical plane in August, 2009:

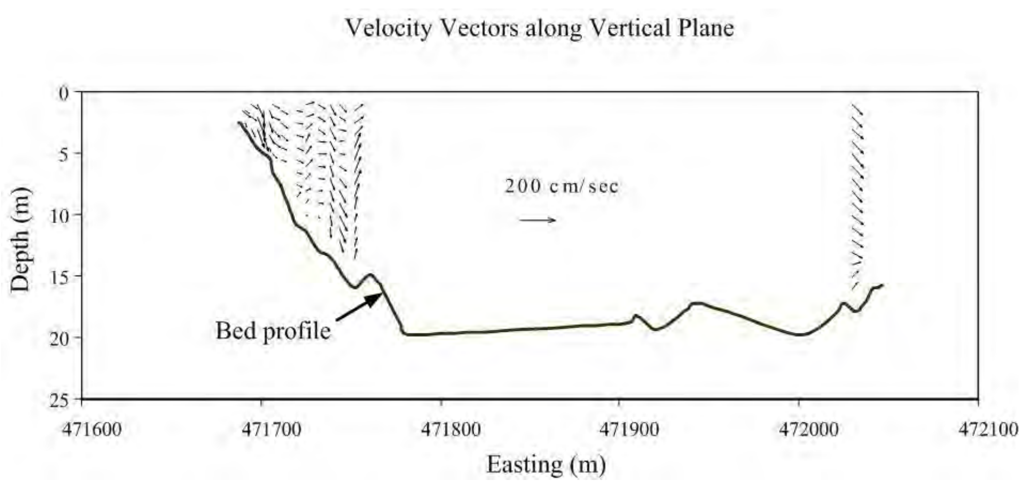
The hardpoint was damaged at two locations about one kilometer downstream of the upstream termination of the hardpoint in July, 2009. The first damage event occurred on 10th of July 2009 and the second damage event occurred on 17th of July in 2009. The hydraulic data were measured about one month later of the failure event when hydraulic condition was similar to the failure period of the hardpoint. The hydraulic data has been analyzed to investigate the flow phenomena around the damaged part. Five vertical sections have been taken normal to the hardpoint. The flow velocity along these five vertical sections is shown in Fig. 6.7(a-e). It is found along all vertical sections that the direction of flow velocity is outward from the hardpoint. In most of the cases the direction flow velocities are in the downward. The average velocity at a distance 75m from the sloping side of the hardpoint is about 1.55m/sec. Considering the median bed materials size d_{50} is 0.2mm. The critical shear velocity u_{*C} is 1.5 cm/sec. The sediment particle goes under motion if the ratio of u_*/u_{*C} is 1. The actual shear velocity u_* is 14.5 cm/sec about 60m away from the hardpoint (Fig. 6.8). The ratio of u_* /u_{*C} is 10 which is much more than 1. If any portion of the launching apron is exposed the bed materials underlying toe of the hardpoint may be washed away very quickly by the flow. This type flow is very dangerous for the structural stability of the hardpoint.


Velocity Vectors along Vertical Plane
0
5
10
15
20
25
Depth (m)
100 cm /sec
Bed profile
471600
471650
471700
471750
Easting (m)
707000
706500
706000
705500
Northing (m)
471000
471500
472000
472500
Easting (m)
Jamuna River
Five Sections
Damage Part
Sirajganj Town

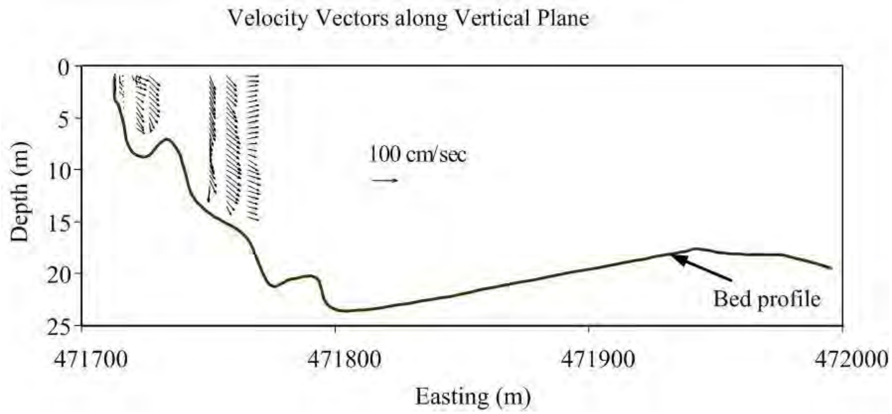
(a)


Velocity Vectors along Vertical Plane
0
5
10
15
20
25
Depth (m)
100 cm /sec
Bed profile
471600
471700
471800
471900
472000
Easting (m)

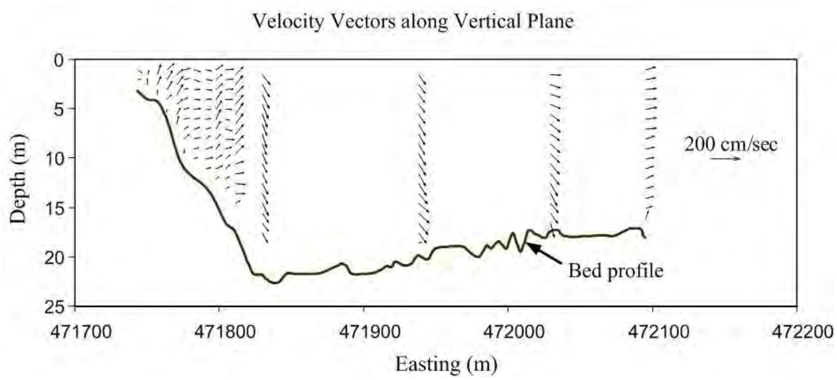
(b)


Velocity Vectors along Vertical Plane
0
5
10
15
20
25
Depth (m)
200 cm/sec
Bed profile
471600
471700
471800
471900
472000
472100
Easting (m)

(c)



(d)



(e)

Figure 6.7: Flow along the vertical section taking through the scour hole

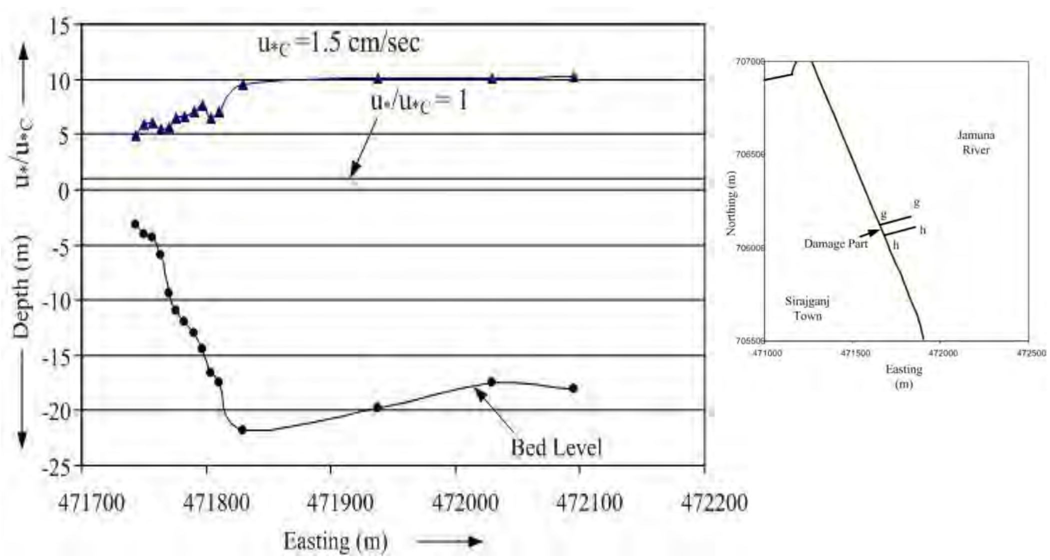


Figure 6.8: Variation of ratio of the shear velocity along vertical section h-h

A vertical section along line f-f (Fig. 6.9), which is parallel to the hardpoint, is taken through the scour hole adjoining the damage part of the hardpoint. How water is flowing through the scour hole is shown by arrows. Water enters into the scour hole in the downward direction. Water goes away from the scour hole in the upward direction. Similar type flow condition is existed into the both scour holes (Fig. 6.9). This type of flow phenomena plays an active role for removing the soil particle from the scour hole. Deeper scour hole is developed due to removing soil particle from the scour hole. The average flow velocity into the scour hole is about 0.7m/sec. The median bed materials size d_{50} is considered 0.2mm. The critical shear velocity u_{*C} is 1.5 cm/sec. The actual shear velocity u_* is 5 cm/sec. The sediment particle goes under motion if the ratio of u_*/u_{*C} is 1. The ratio of u_*/u_{*C} is 3 which is much more than 1. The soil particle from the scour hole is continuously washed away. It is found from Fig. 6.9 that a small part of the hardpoint is undamaged in between two scour holes.

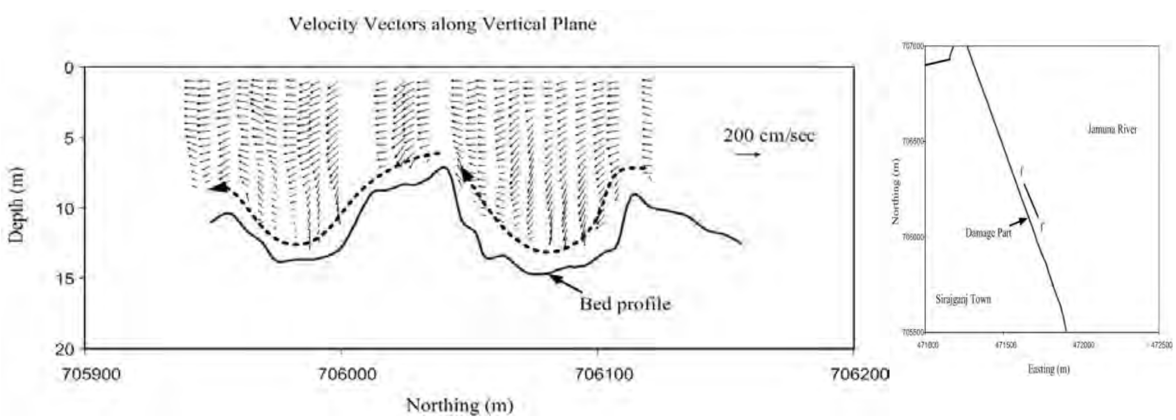


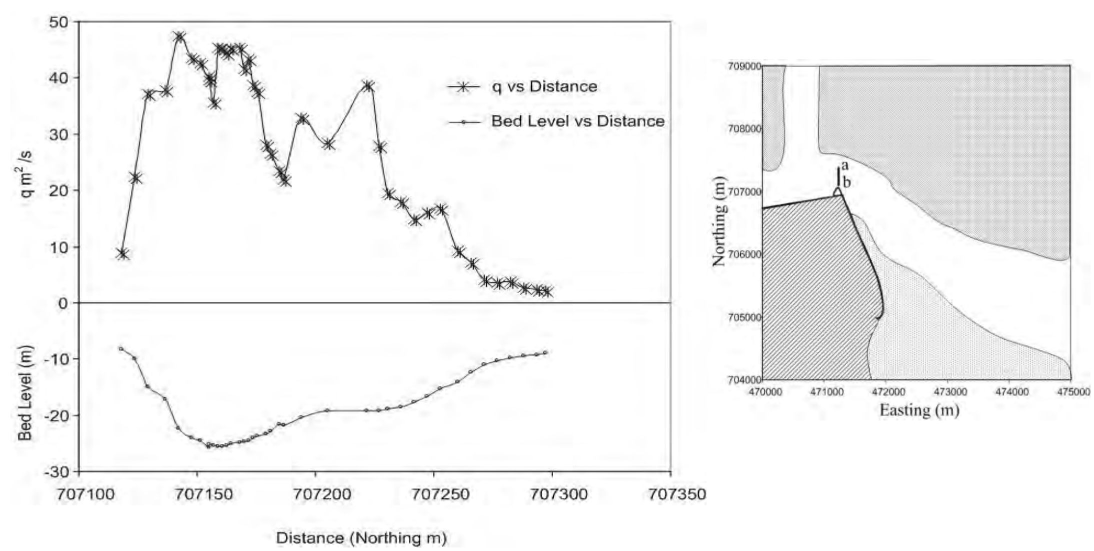
Figure 6.9: Flow velocity along line f-f through the scour hole

6.2.3 Change of discharge intensity

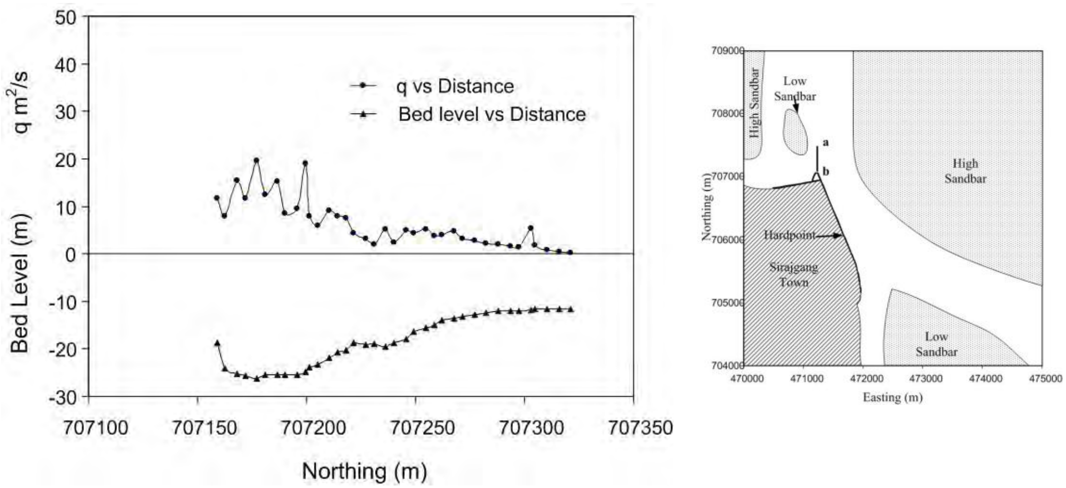
It was earlier stated that about 70% and 100% of the total flow was passing near the Sirajganj channel in March 2008 and March 2009 respectively (Table 6.1). The variation of discharge intensity along line a-b in March 2008 is shown in Fig. 6.10 (a). The maximum discharge intensity is at some distance from the termination of the hardpoint which is similar to the experimental result (Rahman, 1998). The variation of discharge intensity along line a-b in March 2009 is shown in Fig. 6.10 (b). Due to the upstream morphological change, discharge intensity significantly reduces in March 2009. The maximum discharge intensity near the upstream termination was 47m^2/s/m (Table 6.2) in March 2008. But maximum discharge intensity was 20m^2/s/m (Table 6.2) at some distance from the upstream termination in March 2009. As a result, the scouring potentiality decreased and the maximum depth in the scour hole was 25m in March 2009. Whereas the maximum scour depth was 36.5m in March 2008 due to a strong primary vortex in the scour hole (Table 6.2).

Table 6.2: Comparison of different parameters between two years near the upstream termination

Year	**March, 2008**	**March, 2009**
Maximum depth of scour (m)	36.5	25.0
Maximum velocity (m/sec)	2.0	1.4
Maximum discharge intensity (m^2/s/m)	47	20



(a) Discharge intensity along the line a-b (2008)



(b) Discharge intensity along the line a-b (2009)

Figure 6.10: Discharge intensity

6.2.4 Change of flow velocity

The variations of velocity and bed level along line a-b in March 2008 are shown in Fig. 6.11 (a). This vertical line is taken from hardpoint towards the sandbar. It is found that the variation depth-averaged-velocity in the scour hole adjacent to the upstream termination of the hardpoint is similar pattern which is investigated by Kwan and Melville (1994) in laboratory experiment Fig. 6.11 (c). Two peaks of velocity distribution are seen in this figure. The first velocity peak is observed near the upstream termination of the hardpoint, which is amplified by 1.7 times as compared with the approach velocity. The second peak velocity is found at some distance of the termination, which is also amplified by 1.5 times as compared with the approach velocity. The variation of discharge flux and bed-level variation are shown in Fig. 6.10 (a). The variation of velocity variation follows a similar pattern to the discharge flux. It is evident that the flow is concentrated in the deep scour hole. Two peaks for velocity and discharge are due to the following reasons. It is stated earlier that the two parts of the flow pass near the hardpoint. The first part of the flow turns smoothly in the south-east direction, which is the cause of a second peak of velocity and discharge flux. The second part of the flow turns following the configuration of the upstream termination, and the first peak of the velocity and discharge flux is found near the termination. In between the two parts of the flow, a strong vortex (Fig. 6.5 b) is formed. As a result, relatively lower velocity and discharge flux are observed.

The variation of depth average velocity along line a-b is shown in Fig. 6.11 (b) in March 2009. The maximum depth averaged velocity is reduced significantly in March 2009 than 2008. The maximum depth average velocity in March 2008 was 1.7 m/sec but the maximum depth average velocity in March 2009 was 0.8 m/sec.

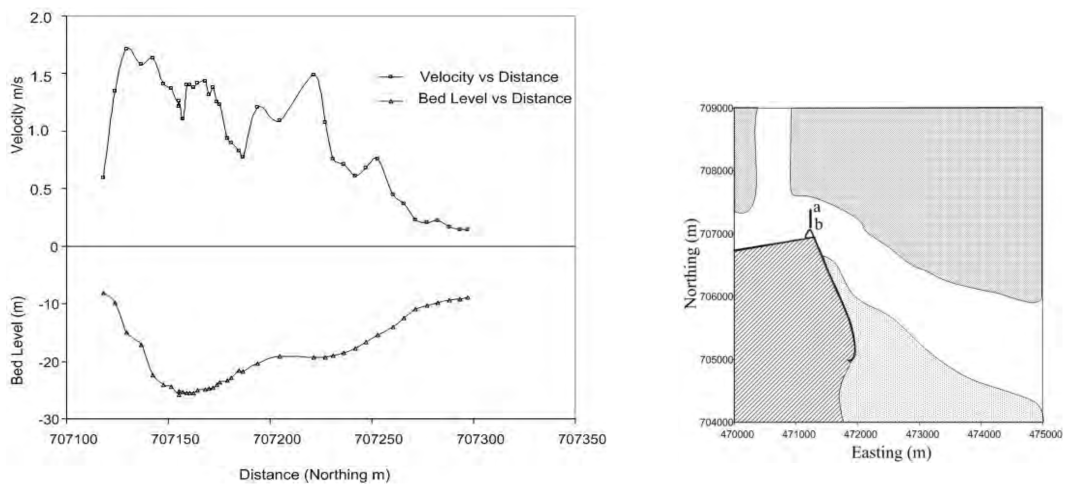


Figure 6.11(a): Velocity along line a-b (March, 2008)

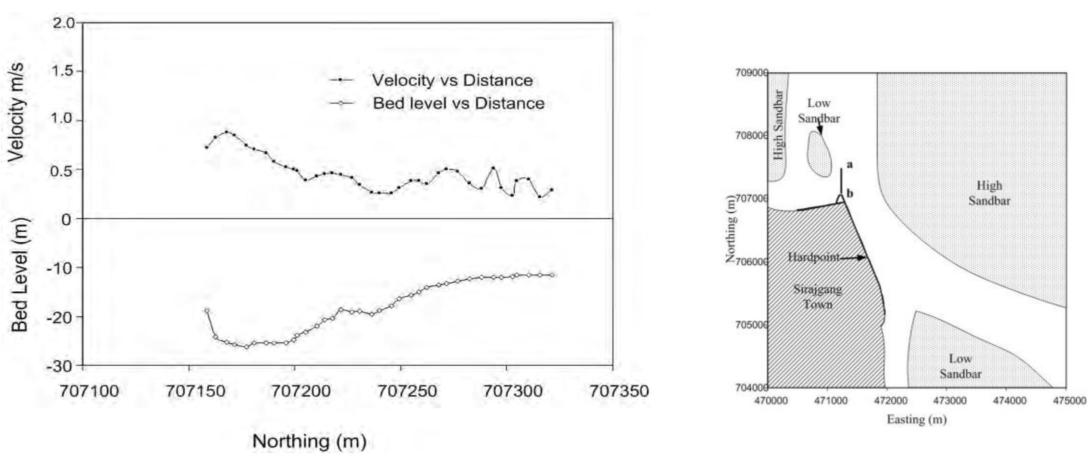


Figure 6.11(b): Velocity along line a-b (March, 2009)

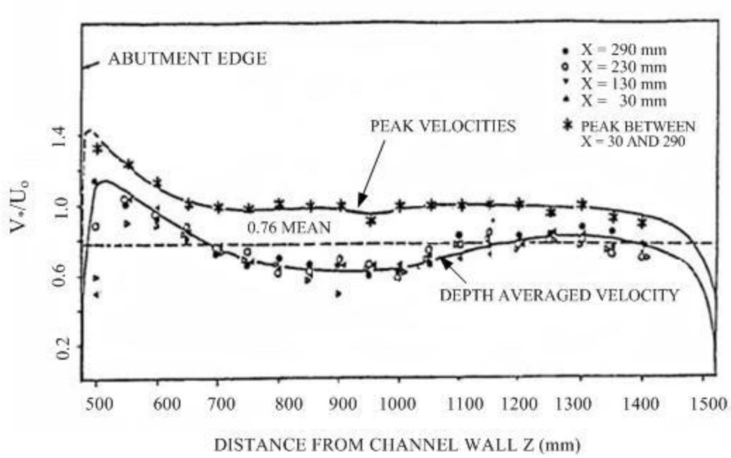


Figure 6.11(c): Lateral distribution of the depth average and peak resultant velocities at and near the scour hole around wing wall abutment (Courtesy: Kwan and Melville, 1994)

6.2.5 Variation of scour depth

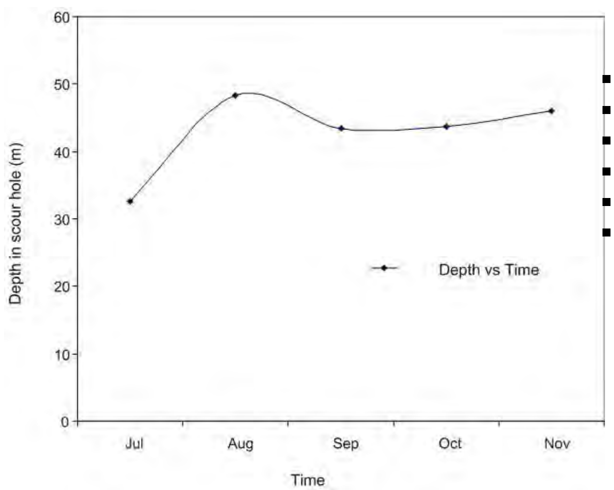
It is found that the bathymetry around the hardpoint changes year by year from the previously analyzed data measured by BWDB. Even the bathymetry changes in different months within a year. The variation of maximum water depth in the scour hole in 2007 is shown in Fig. 6.12. It is found that the depth of a scour hole rapidly increases from July to August and gradually decreases in September. Again the scour depth gradually increases up to November. This curve follows like the classic live-bed scour condition (Uddin and Rahman, 2009; Melville and Chiew, 1999; Rahman, 1998, Melville, 1975).

It is found from Table 6.3 that the water level rises from 4th July to 26th August by 81cm, but the bed level lowers by 15m. Though the water level was the same on 26th August and 6th September, but the bed level rose by 5m on 6th September. The fluctuation of the scour depth most probably due to the dune wave passes through the scour hole in the live-bed condition. It can be mentioned here that the first flood peak passed on 1st August with water level +14.95 mPWD and the second peak passed on 13th September with flood peak +14.72 mPWD. During the second peak the depth in the scour hole was reduced as compared to the first peak. The design scour depth 33m was assumed for the upstream termination and the corresponding design bed level was -17.25 mPWD. The design bed level is much lower than the measured bed level (-36 mPWD) during the monsoon. Even the dry season bed level (-30 mPWD, measured on 23rd March 2008) was lower than the design bed level.

Table 6.3: Water level, bed level and maximum depth of water in scour hole near Sirajgang hardpoint during the year 2007

Date	Water level (mPWD)	Bed level (mPWD)	Maximum water depth in scour hole (m)
04-07-07	12.54	-20	32.54
26-08-07	13.35	-35	48.35
06-09-07	13.35	-30	43.35
03-10-07	11.67	-32	43.67
13-11-07	10.00(approx)	-36	46.00

(Data Source: BWDB)



- Crest level of hardpoint +16.75 mPWD
- Design Highest flood level +15.75 mPWD
- Recorded highest flood level +15.12 mPWD
- Design Low water level +6.80 mPWD
- Apron setting level -4.20 mPWD
- Design deepest scour level -13.25 mPWD

Figure 6.12: Depth into the scour hole near the Sirajgang hardpoint in 2007 (Source: BWDB)

6.2.6 Characteristics of dune

A comprehensive study has been conducted by Coleman (1969) on the Jamuna River. Two areas (Sirajganj and Aricha) were selected on the Jamuna River to investigate bed form characteristics. About 3 km longitudinal profile was taken at Aricha and about 6.5 km longitudinal profile was taken at Sirajganj during the flood season. During the period of investigation the following characteristics were measured as wave height, wave length, foreset slope, ripple index and rate of movement. The characteristics of the bed forms are shown in Table 6.4. During the study period no structural intervention was present in the Jamuna River.

Table 6.4: Characteristics of bedforms in the Jamuna River (Coleman, 1969)

	Ripples	Mega ripples	Dunes	Sand waves
Range in wave height (WH)	up to 0.3m	0.3m-1.5m	1.5m-7.5m	7.5m-15m
Range in wave length (WL)	up to 1.5m	3m -150m	40m-490m	180m-915m
Range in ripple index (WH/WL)	1:5-1:20	1:6-1:100	1:30-1:60	1:25-1:100
Maximum amount of movement in 24hour period	-	250m	160m	640m
Average amount of movement per 24-hour period	3m	120m	70m	200m
Depth of water	up to 30m	up to 30m	3m-30m	10m-35m
Water turbulence pattern	small surface eddies in shallow water	small surface boils in shallow water	large surface boils	large surface boils
Plan view of crestline	linguloid	straight, linguloid and lunate	irregular in shallow water, straight or gently curved in deep water	straight but commonly curved down-stream

A study was conducted on August, 2009 near the Sirajganj hardpoint to investigate the flow over dune, dune height and dune movement. This study was performed just one month after the failure of the hardpoint. The hydraulic constitutions were more or less similar during the failure of the hardpoint and the study period. There is a difference between the Coleman‟s investigation and the present study. The present study was conducted at a reach where the structure induced effect was significant on flow, morphology and bedform. But the structure induced effect was absent on flow, morphology and bedform in the study performed by Coleman (1969. During the present study the longitudinal bed profile data was collected along 2.5 km length. The section, along which bed profile data was collected, was parallel to the hardpoint. The flow features over bed form and the characteristics of the bed form have been analyzed from the collected data. The flow features over dune is shown in Fig. 6.13(a). The flow data was not acquired by ADCP up to the bed level due to instrumental limitation. A general feature of dune type bed form is leeside flow separation, resulting in a strong eddy motion of the dune crest.

This type of flow phenomenon is found in Fig. 6.13(a). A recirculation zone is observed downstream of the dune crest. Reattachment and acceleration of the flow does occur on the stoss side of the dune (van Rijn, 1993; Chang, 1988). The dune height is shown in Fig. 6.13 (b). The range of the height of the dune is from 1m to 5m.The observed maximum dune height is about 5m. Coleman reported that the range of the dune height is from 1.5m to 7.5m. The length of the dune varies over a range 20m to 30 m. This length of dune is quite different from Coleman‟s (1969) finding, i.e. 40m to 490m. This difference is due to the structural effect on the flow processes. The range in ripple index in the present study is 1:7 to 1:20 which is far different from Colman‟s finding, i.e. 1:30 to 1:60. The relation between the dune wave length to average depth of water is $\lambda = 1.5h$. If approximately 5m height dune moves over the launching apron there may be the possibility of the embedment failure of launching apron which ultimately affect the stability of the sloping face of the hardpoint. An attempt was taken to determine the rate of dune movement along line j-j in Fig. 6.13 (c). Two sets of data were measured after 5 hours‟ interval. It is very difficult to trace out the rate of movement of a dune. It is observed that the bed level after 5 hours is lowered down than the previous one.

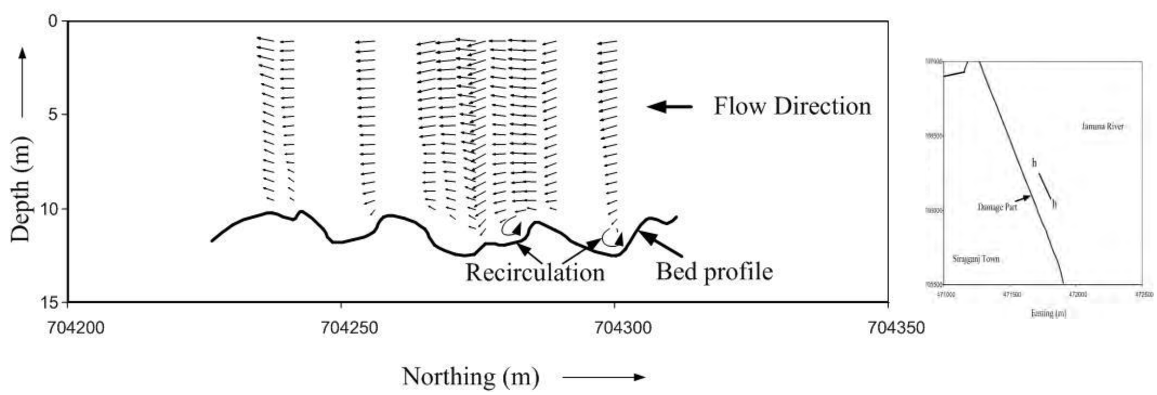


Figure 6.13 (a): Flow features over dune

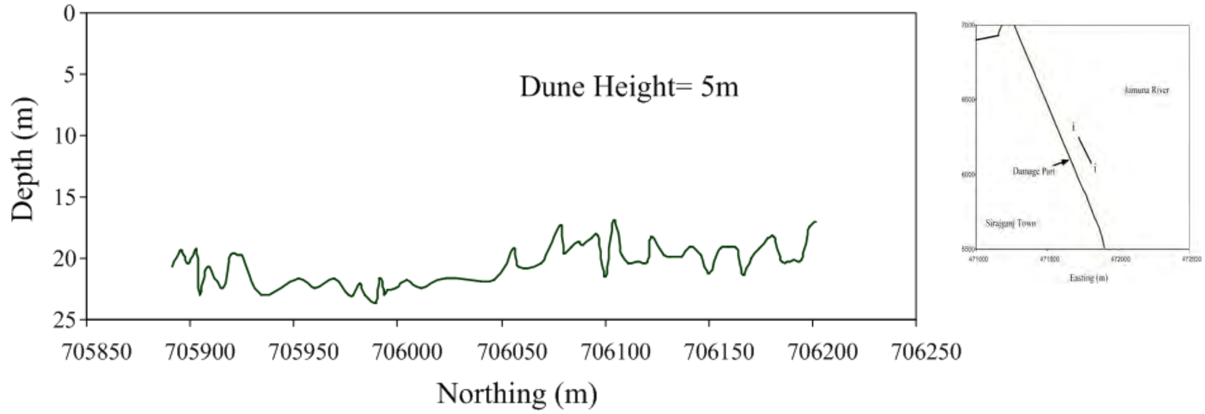


Figure 6.13(b): Dune height

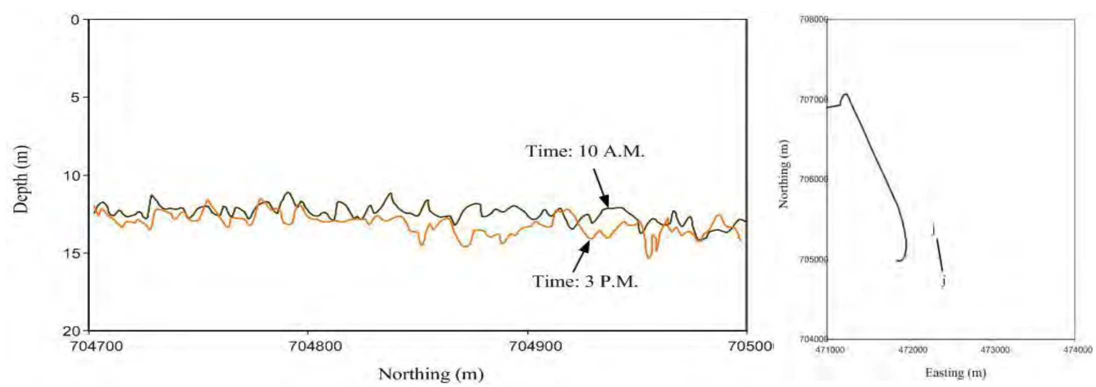


Figure 6.13(c): Dune movement

6.2.7 Causes of failure of the hardpoint

Different causes of the failure of bank protection works are discussed in section 2.3.7 of Chapter Two. The causes which may lead to damage or failure may be environmental and nature, construction, and human factors. Especially, the revetment failure may be due to: (i) instability of the cover-layer caused by external loads (current, waves etc.) or internal loads (e.g. due to pore water pressure); (ii) insufficient toe protection and instability or improper launching or falling behavior of the apron materials; (iii) the sliding of the cover layer over the intermediate layer, and (iv) different micro-and macro-instability arising from geotechnical characteristics of soil and changed boundary conditions, e.g. due to rapid scour development or water level changes (BWDB, 2008).

It is found from Fig. 6.1(a) that the confluence of two approach channels was near to the upstream termination. The western approach channel had no flow in the dry season. But during the flood season water usually starts to flow through both channels. The flow processes during the dry season have already been discussed in section 6.2.2. Usually, the strength of the primary vortex increases during the flood season. A deeper scour hole is developed due to a stronger vortex flow. It is evident from the previous studies that due to the development of the scour hole, flow slides could be occur formed in any direction of the scour hole (Halcrow and Hasconing, 1999). It may be considered that part of the upstream termination was damaged in September 2008 due to the development of vortex-induced scour hole and flow slides from the revetment side. The damaged part is shown in Fig. 1.5 (e) in Chapter One.

The oblique flow is generated by the sand bar due to morphological changes, which is already discussed in section 6.2.2. It attacks the eastern straight portion of the hardpoint. The temporal variation of the bed level from 4th February to 11th July, 2009 at a particular point near the failure part of the hardpoint is shown in Fig. 6.14. It is found that no significant variation of the bed level has occurred from 4th February to 28th April. The bed level slightly rises within the period 28th April to 14th May. No bed level variation is observed from 14th May to 12th June. After that the bed level is rapidly lowered from 12th June up to failure of the hardpoint, i.e. 11th July. The variation of bed profile from 4th February to 11th July is shown in Fig. 6.15 (section is taken at failure part along line k-k normal to the hardpoint). The bed profile is rapidly lowered from 12th June up to the failure of the hardpoint. The deepest bed level is -11mPWD which was just after one day of the failure of the hardpoint. Although the apron setting level and the deepest design scour level along the straight portion of the hardpoint is at -4.2mPWD and -13.25mPWD respectively. In the Jamuna River the maximum rate of scouring is 5 to 6m per day, 12m in 10 days and 20m in less than one month. The rate of deposition is 3.5m per day, 11m in 3 days and 25m in 50 days (BWDB, 2008; Uddin, 2007). On October 21, 2003, the maximum scour depth in the Jamuna was observed 56.75m near Sailbari Groin. It is easily considered that the developed deepest scour depth before failure of the hardpoint was higher than -11mPWD. The flow slide is occurred from the revetment side. As a result the hardpoint is failed. The scour hole is filled up by the sliding materials. The catastrophic failure of the hardpoint on 10th July, 2009 is shown in Fig. 1.5(f).

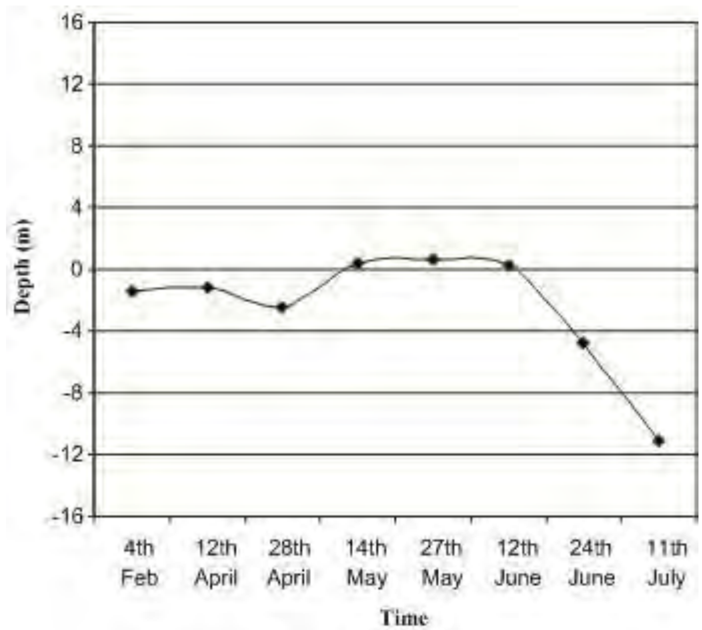


Figure 6.14: Temporal variation of the bed level near the damaged part of the hardpoint

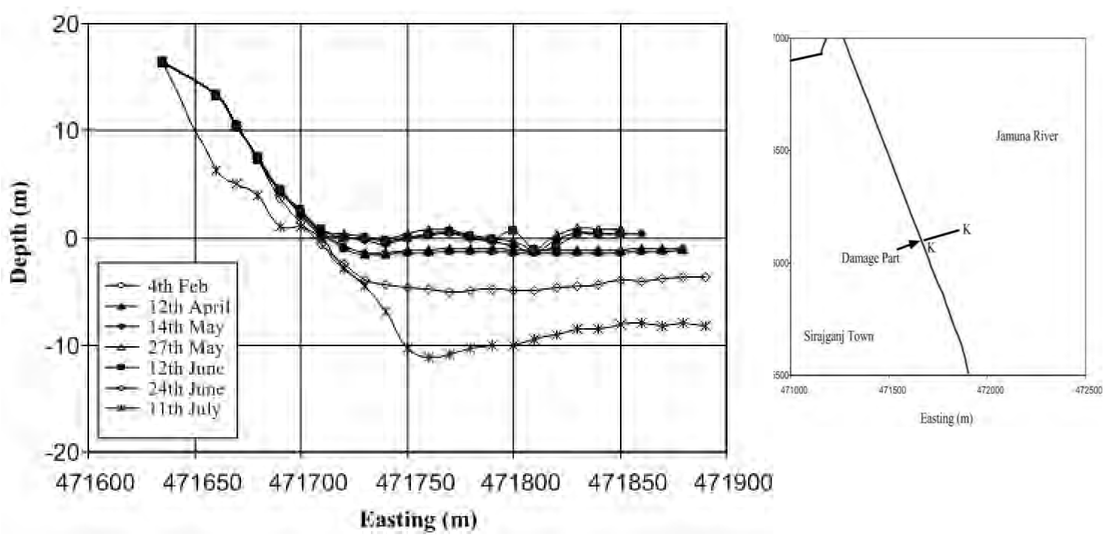


Figure 6.15: Change of bed profile near the damaged part of the hardpoint

One important aspect has been investigated from the field measured data (August, 2009) that about 5m high dune was passing through the channel adjacent to the hardpoint. It is found from the previous study that the rate of movement of dune is 100m-160m/d. It is already discussed that the length of the dune varies from 20m to 30 m near the hardpoint. So, the dune would pass 3 to 4 times per day through a particular point. If the dune would repeatedly move over the riprap it would be undermined into the bed materials. The effect of dune movement on the riprap failure has been discussed in section 2.3.7 of chapter two.

The main causes of failure of hardpoint are summarized as follows:

- ❖ Change in upstream and local river morphology
  - Oblique flow generation and attacking to the straight part of the hardpoint
  - Washed away sand bar and channel development adjacent to the hardpoint
  - Thalweg is shifted towards the hardpoint
- ❖ Repeatedly dune movement through the developed channel (3 to 4 times per day at a particular point)
  - Undermine the riprap into the trough of the dune
  - Due to the failure of riprap the scour hole is developed.
- ❖ Flow slides from the revetment side due to rapid development of the scour hole
- ❖ Ultimately the hardpoint is collapsed.

Diversion of oblique flow

The oblique flow plays a vital role in the damaging activity of bank protection works. We should adopt some additional measures so that the oblique flow may be diverted. We know about the function of bandal-like structures. This type of structure effectively diverts the flow towards mid-channel. Therefore, bandal-like structures should be constructed at a certain angle with revetment (Fig. 6.16). The materials should be durable enough. So, we should select suitable materials for bandal structures.

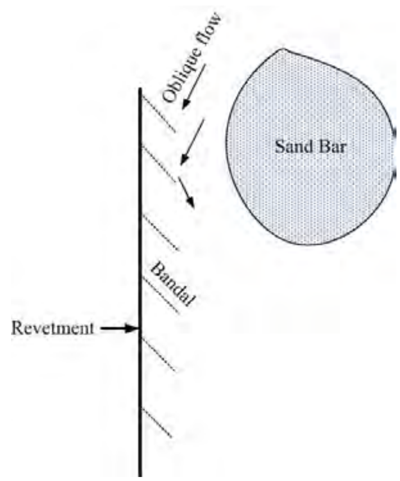


Figure 6.16: Diversion of the oblique flow developed by a sand bar

6.2.8 Social response

Failure of the hardpoint and social response

About 7.5 km long revetment was constructed along the curved channel upstream of Sirajganj hardpoint in 2008-2009. Instead of this revetment along the curved channel, the erosion affected people strongly claimed for dredging and filling of the curved channel (bend channel or embayment upstream of the hardpoint) and they proposed for construction of straight revetment (hardpoint) from the upstream termination of Sirajganj hardpoint up to Shailabari Groyne (Ziar Mohr). It has been revealed during FGD that local knowledge could help in failure management program. The opinion of the local people should be considered positively during the construction of a bank protection structure.

The intensity of socio-economic developments in the Sirajganj town was increased after the construction of a hardpoint in 1998. But after the damaging of the upstream termination of the hardpoint in 2008, the local people were confused regarding the stability of this structure. The degree of confusion also increased after failure of the straight part of the hardpoint in July, 2009. Severe panic was created among the people living near the damaged part of the hardpoint. A huge number of males, females and children were around the structure and they were making shouts, sounds, hue and crying during the failure event. They were extremely afraid of losing all of their belongings by the failure of the hardpoint.

Thousands of people were gathered at the failure spot. They tried heart and soul to protect the structure from failure through dumping the CC blocks. Many inhabitant of the Sirajganj town took part in the dumping activity of C. C. blocks. They believe that the hardpoint is their own property. They had strong faith that "Saving the hardpoint means saving themselves".

Failure of the hardpoint and development activities

The inhabitant of the Sirajganj town had strong faith on the structural stability of the hardpoint. But after failure of the hardpoint they are confused regarding the stability of the hardpoint. So, they are worried about their financial investment on a wide scale. The rate of development activities has been reduced a lot due to decrease of investment in various sectors like health, housing, industry, hotels, business, etc. The investment plans of the local people as well as people from other localities have been changed. It is assumed that the impact of failure of the hardpoint would be far reaching for the area. Perhaps, no major investment in construction of multi-storied building, massive industry, and hospital would be realized in future. As per local people‟s opinion they would not go for any construction of their building very close to the hardpoint.

6.2.9 Summary

The morphological change in the Jamuna River is very rapid. The flow processes in this river also change due to its morphological change. It is investigated from the present study that as a result of sand bar movement oblique flow is generated. The oblique hit the straight portion of the hardpoint. It is considered that oblique is main factor for the structural failure of the hardpoint. Other factors also accelerated the failure event. Those are washed away of sandbar adjacent to the hardpoint, shifting of thalweg at the vicinity of the hardpoint, movement of dune through the channel passing near the hardpoint, failure of riprap as a consequence of repeatedly passing of dune, due to failure of riprap scour hole is developed, flow slide is occurred from the hardpoint side, resulting the hardpoint was damaged. Flow and morphological change in the Jamuna River is inevitable. Therefore, some additional measures should be taken to divert oblique flow away from bank hardpoint towards the mid-channel. A substantial amount of riprap should also be dumped to avoid its failure. The local people could play a vital role in the management program especially during the emergency situation. So, the societal involvement is necessary for the effective management activity.

6.3 Groin-Like Structure

6.3.1 Change of morphology around Betil and Enayetpur spurs

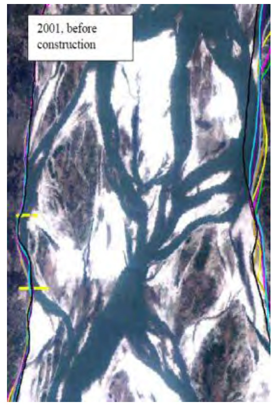
The morphological change around Betil and Enayetpur are shown through satellite images (Fig. 6.17). A series of satellite images from 2000 to 2008 are shown. Before construction of spur a branch channel was passing near Betil and Enayetpur area in 2000. The channel became relatively wider in 2001. Betil and Enayetpur spurs were constructed in 2001-2002. After construction of the spurs a small sandbar is formed just downstream of the Betil spur. The sandbar became larger in 2003. A channel is developed parallel to the Enayetpur spur. The earthen shanks of the both spurs were washed away during 2004 flood season. The channel in between Betil and Enayetpur spurs turned into larger. But after major rehabilitation programme the morphology around both spur are stable. Though, almost every year failure of the earthen shank occurs.

6.3.2 Flow around Betil and Enayetpur spurs

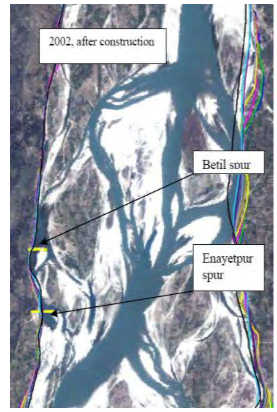
Flow along horizontal plane

As stated above, the flow pattern around bank protection structures depends on different parameters. The flow patterns along the horizontal plane around Betil and Enayetpur spurs at a depth of 1m, 5m, 10m, 15m, 20m and 24m are shown in Fig. 6.18 (a-f). It is found that the confluence of two secondary channels is just upstream of Betil spurs. The oblique flow hits the earthen shank of the Betil spurs. It is considered that the strong parallel flow is generated upstream of both spurs due to a relatively long spur as compared to the recommended one. The approach average flow velocity is 0.7 m/s. The parallel flow velocity is amplified up to 1.75 times than approach average flow velocity adjacent to the Betil spur. Usually, a return current is generated downstream of a spur due to flow separation. Some RCC spurs along the Jamuna River have been damaged due to a strong return current (Uddin, 2007). The Betil spur is functioning as a bandal-like structure. The hydraulic functions of bandal-like structures have been discussed in section 6.4.

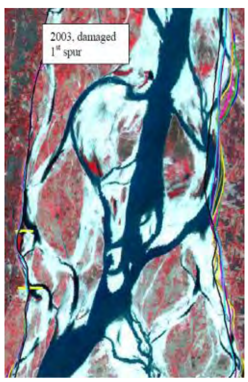
(a) 2000



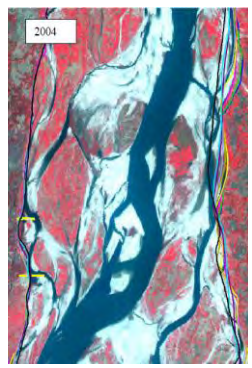
(b) 2001



(c) 2002



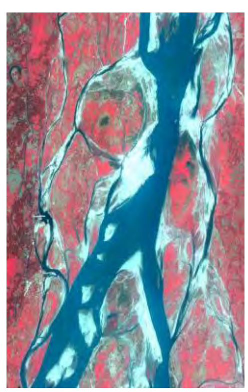
(d) 2003



(e) 2004

(f) 2005

(g) 2006



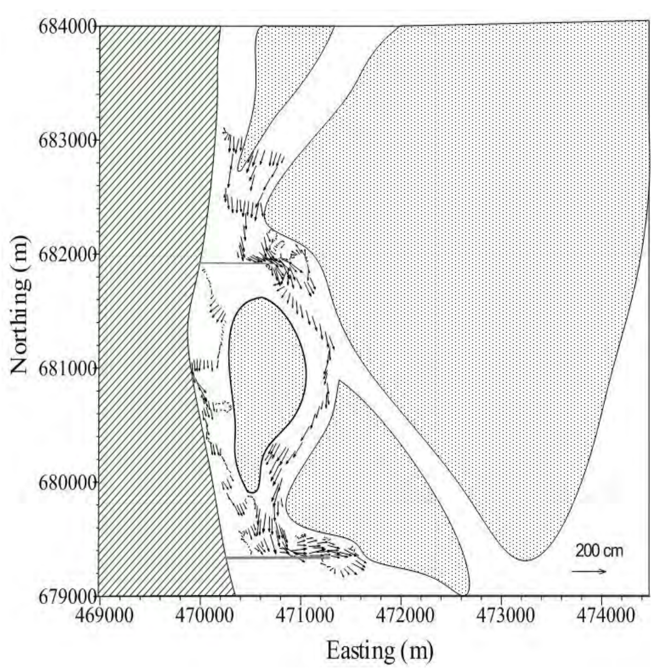
(h) 2007

(i) 2008

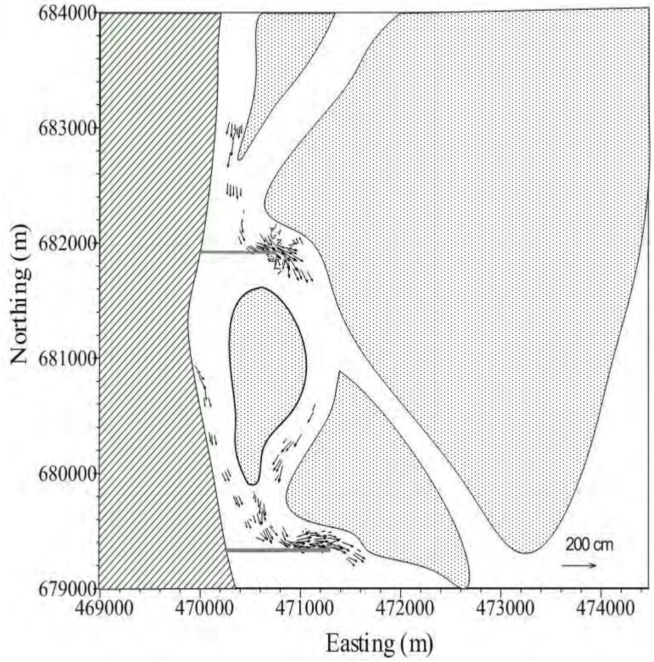
Figure 6.17: Change in morphology around Betil and Enayetpur spurs

It is clearly found in Fig. 6.19 (a-c) that the return current is counter-balanced by the flow passing beneath the RCC part of the Betil spur. The flow downstream of the RCC part of the Betil spur is divided into three parts and flows through three separate channels. A reverse circulation of the flow is found adjacent to the bar is located opposite to the nose of the RCC part.

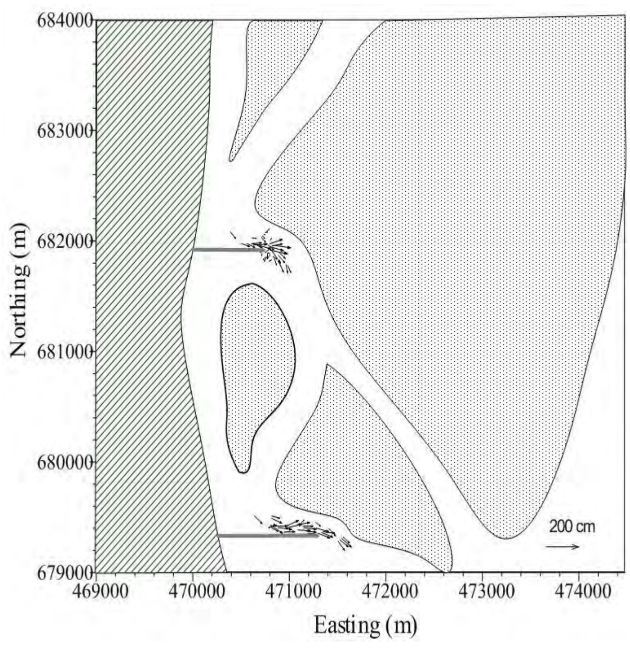
The flow patterns along the horizontal plane around the Enayetpur spur at a depth of 1m, 5m, 10m and 15m are also shown in Fig. 6.20 (a-d). The oblique flow hits the earthen shank of the Enayetpur spur. A strong parallel flow is generated upstream of the Enayetpur spur which is similar to the Betil spur. The approach average flow velocity is 0.5 m/s. But the parallel flow velocity is amplified adjacent to the Enayetpur spur up to 2.3 times than approach flow velocity. Though, the approach average flow velocity of the Enayetpur spur is less than that of Betil spur. But the amplification higher in the case of Enayetpur spur than the Betil spur.



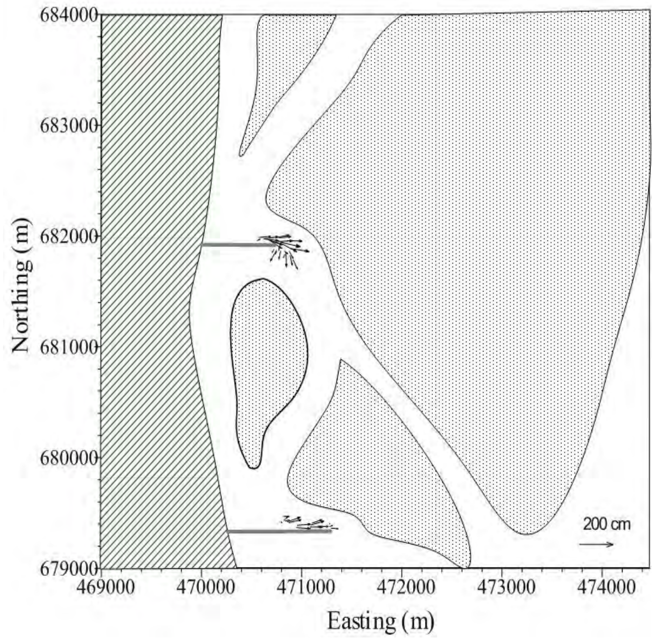
(a) Velocity vectors at a depth of 1m (July, 2008)



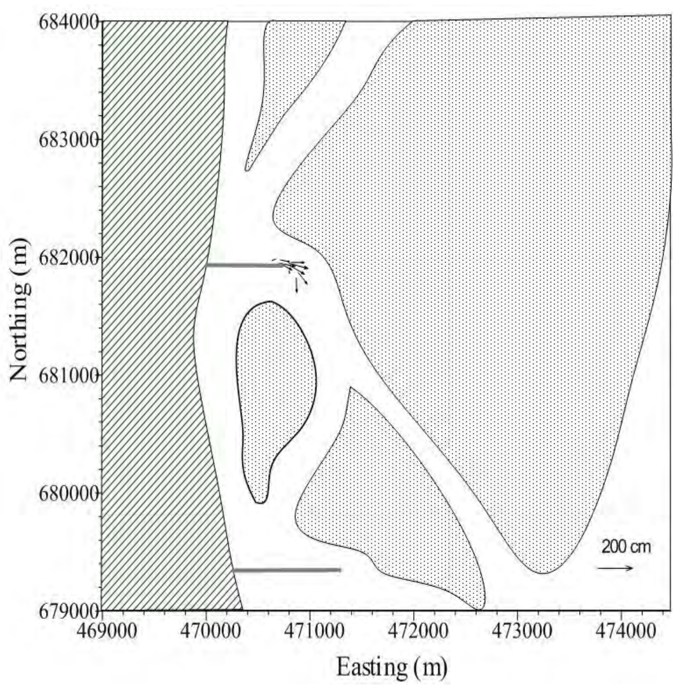
(b) Velocity vectors at a depth of 5m (July, 2008)



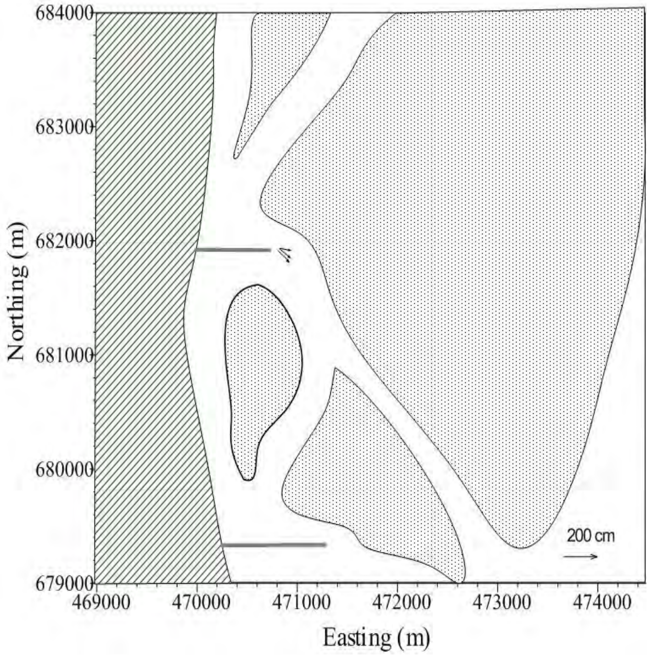
(c) Velocity vectors at a depth of 10m (July, 2008)



(d) Velocity vectors at a depth of 15m (July, 2008)

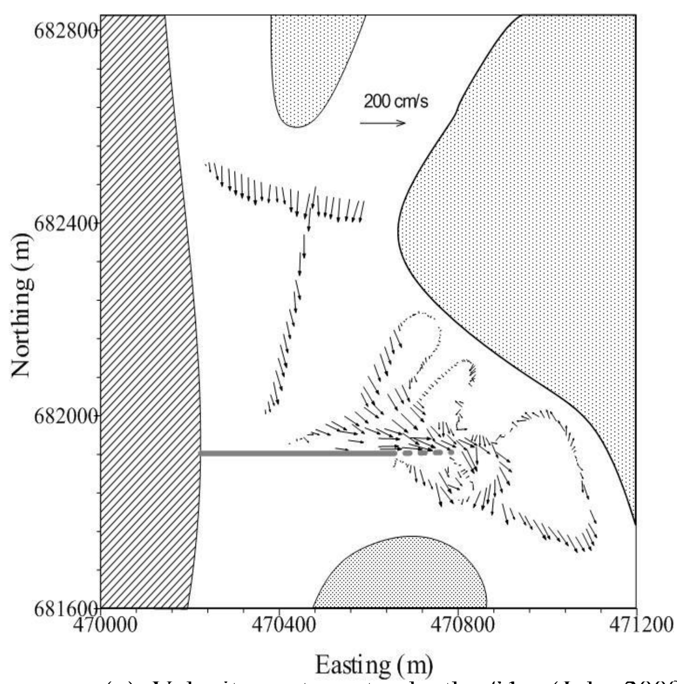


(e) Velocity vectors at a depth of 20m (July, 2008)

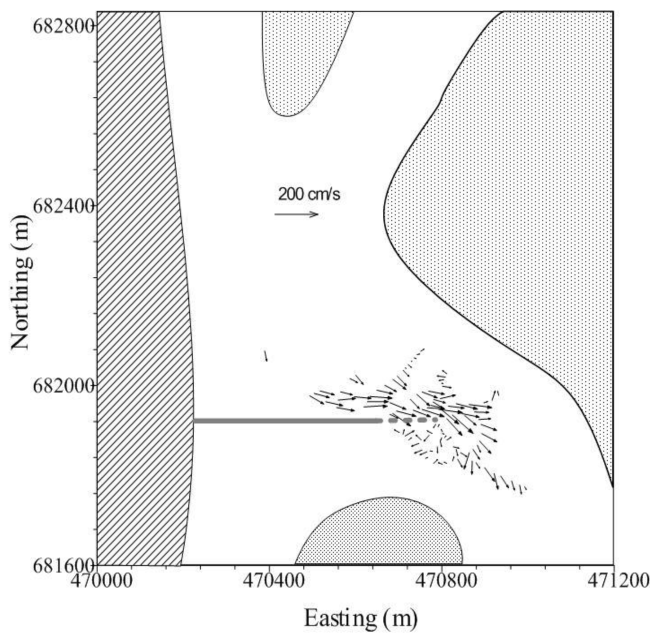


(f) Velocity vectors at a depth of 24m (July, 2008)

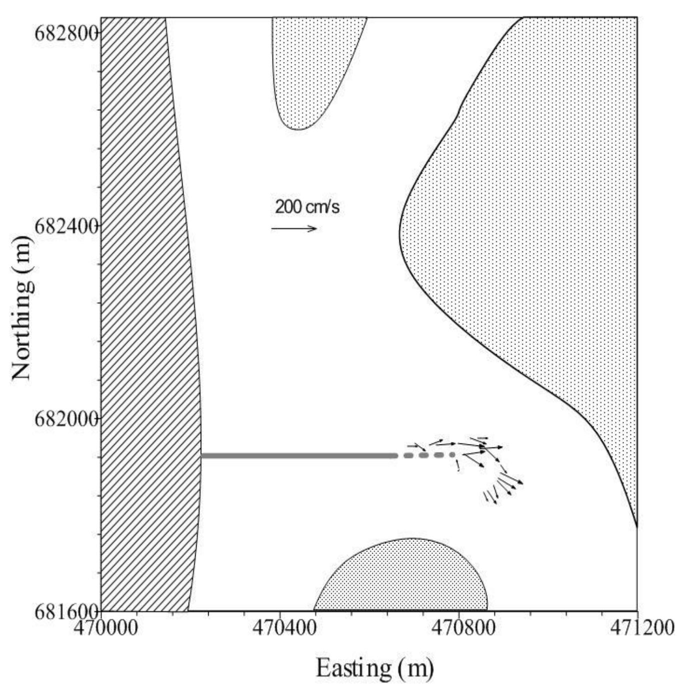
Figure 6.18: 2-D velocity vectors around Betil and Enayetpur spurs at different depths (July, 2008)



(a) Velocity vectors at a depth of 1m (July, 2008)

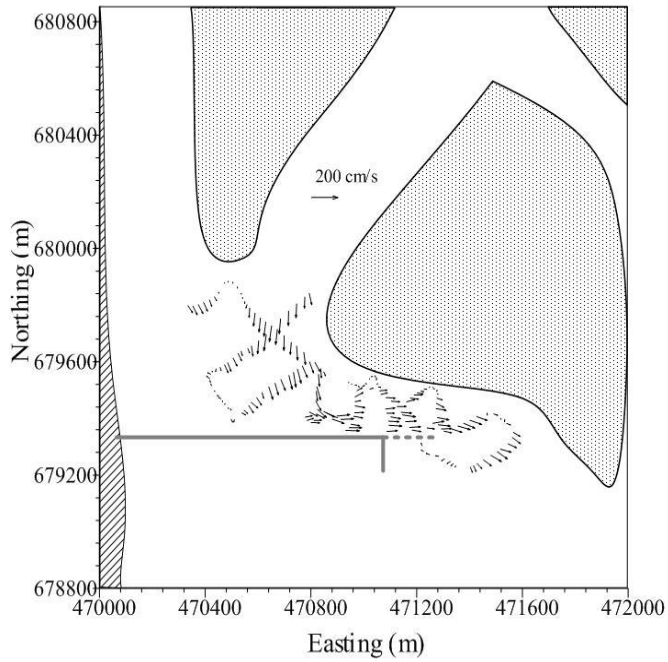


(b) Velocity vectors at a depth of 10m (July, 2008)

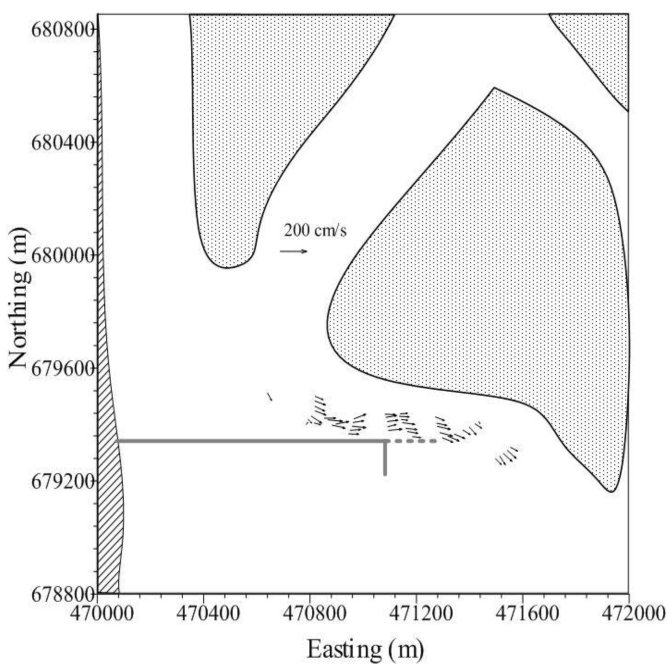


(b) Velocity vectors at a depth of 22m (July, 2008)

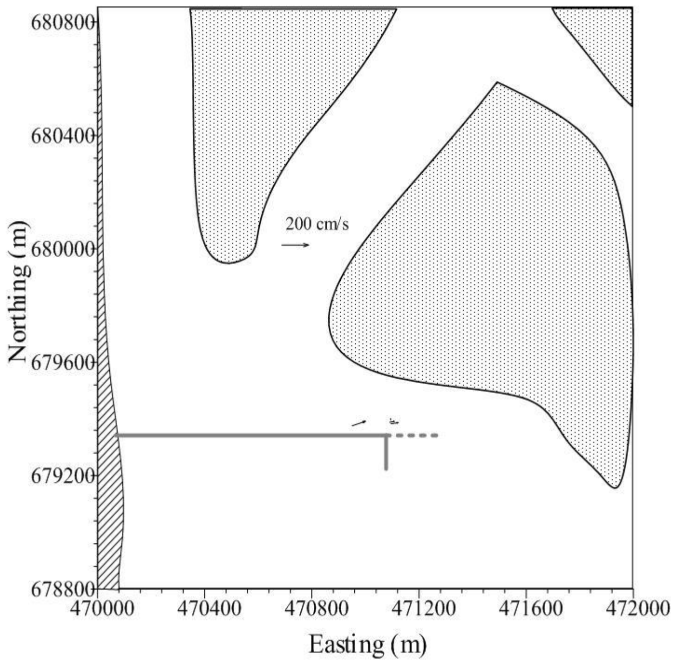
Figure 6.19: 2-D Velocity vectors around Betil spur at different depths (July, 2008)



(a) Velocity vectors at a depth of 1m (July, 2008)



(b) Velocity vectors at a depth of 10m (July, 2008)



(c) Velocity vectors at a depth of 18m (July, 2008)

Figure 6.20: 2-D Velocity vectors around Enayetpur spur at different depths (July, 2008)

An earthen cross dam, normal to the earthen shank of the Enayetpur spur, has been built by the local people to protect the return current. Due to this cross dam, a weak return current is found at the backside of the RCC part of the Enayetpur spur. If the elevated land is existed downstream side of a RCC spur it will be very effective for the stability of the spur. The measured maximum scour depths around the Betil and Enayetpur spurs on 17July 2008 is 28m and 18m respectively. The maximum scour depth around Betil spur is 10m higher than that of the Enayetpur spur. One important thing is that the magnitude of the parallel flow velocity is amplified to approach velocity up to 1.75 times upstream of the Betil spur and up to 2.3 times upstream of the Enayetpur spur respectively. The Enayetpur spur is 250m longer than the Betil spur. It can be concluded that the amplification of flow velocity upstream of the Enayetpur is higher due to longer spur.

Flow along the vertical plane

The Betil spur

To identify the flow patterns along vertical planes, some vertical sections have been selected around the Betil and Enayetpur spurs. The flow patterns along these vertical planes have been discussed here. A vertical section is taken along line a-a, normal to the RCC part of the Betil spur. The primary and secondary vortices are observed along this section (Fig. 6.21). Velocity vectors along line b-b parallel to the Betil spur are shown in Fig. 6.22. The water is flowing towards the deepest scour hole which is near the tip of the RCC spur. Another vertical section is taken along line **c-c** from tip of the RCC part towards the sandbar. The velocity vectors along this line are shown in Fig. 6.23. The velocity magnitude is higher in lower layer than upper layer along this section.

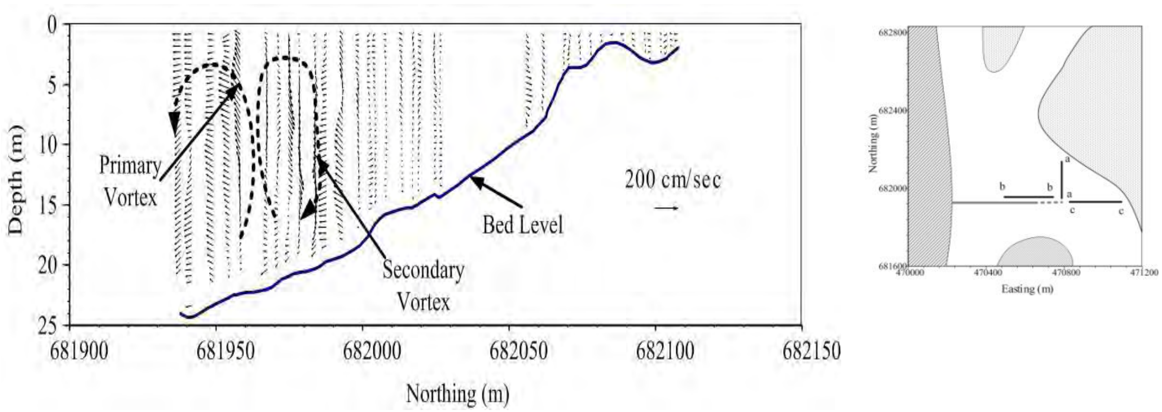


Figure 6.21: The primary vortex and secondary vortex around the Betil spur along line a-a

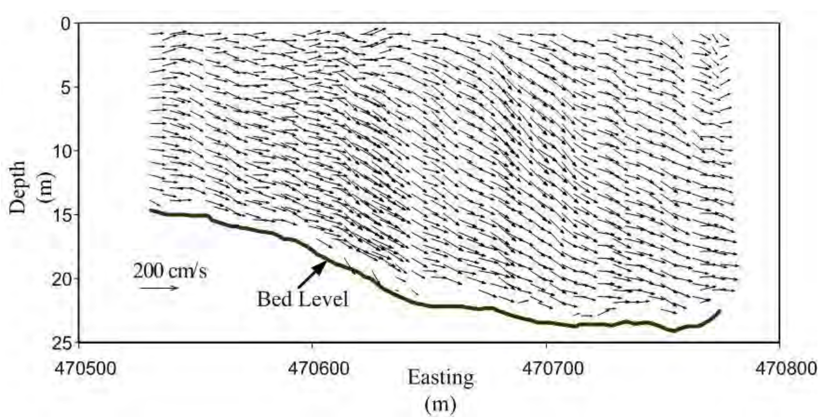


Figure 6.22: Velocity vectors in the vertical plane around the Betil spur along line b-b

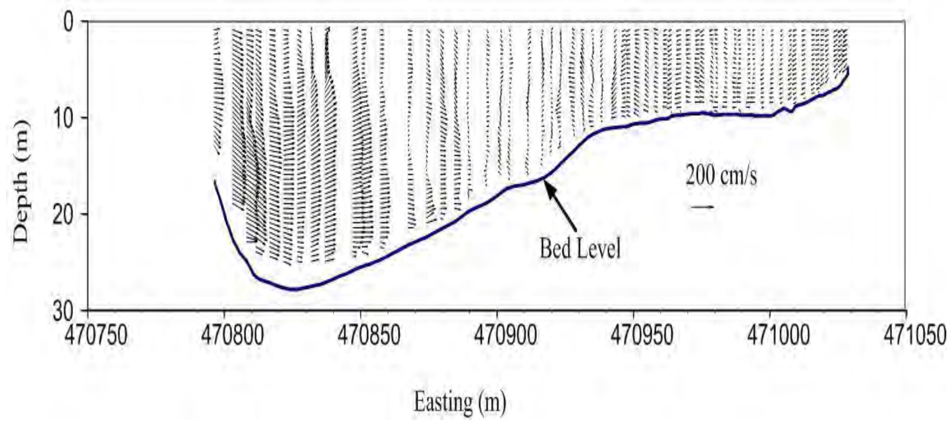


Figure 6.23: Velocity vectors in the vertical plane around the Betil spur along line c-c

Enayetpur spur

It is found in (14th July, 2008) field measurement that the earthen shank of the Enayetpur spur has been damaged. A vertical section is taken along line d-d**,** normal to the earthen shank to identify the flow phenomena adjacent to the failure portion of the earthen shank. The direction of the upper portion flow is in the earthen shank. But the direction of near bed level flow is outward from the earthen shank (Fig. 6.24). The sediment particles are washed away by the outward near-bed-level flow. As a result, the lunching materials are dislocated and a create gap between RCC blocks. The soil particles from the gap of RCC blocks are washed out. If this process continues, a deeper channel is developed. While the driving force exceeds the resisting force, the upper part of the earthen shank slides down. Usually, slip circle failure is found. The failure of the earthen shank, which is shown in Fig. 1.5 (f), is due to the above type of flow phenomena (Fig. 6.24). Another vertical section, normal to the Enayetpur spur (adjacent to the belmouth), is taken along line e-e. The flow circulation is observed along this vertical section (Fig. 6.25). This type of flow patterns (similar to secondary current) is usually observed at the bend of a channel. Considering the median bed materials size d_{50} is 0.2mm. The variation of the ratio of the shear velocity along line e-e is shown in Fig. 6.26. The critical shear velocity u_{*c} is 1.5 cm/sec. The ratio of u_* / u_{*C} is 5 near the belmouth of the RCC spur which is much more than 1. So, the sediment particles are transported from near the earthen shank of the RCC spur towards the sandbar by the flow circulation. As a result, deep channel is developed near the spur which is a big threat to the structural stability of the spur.

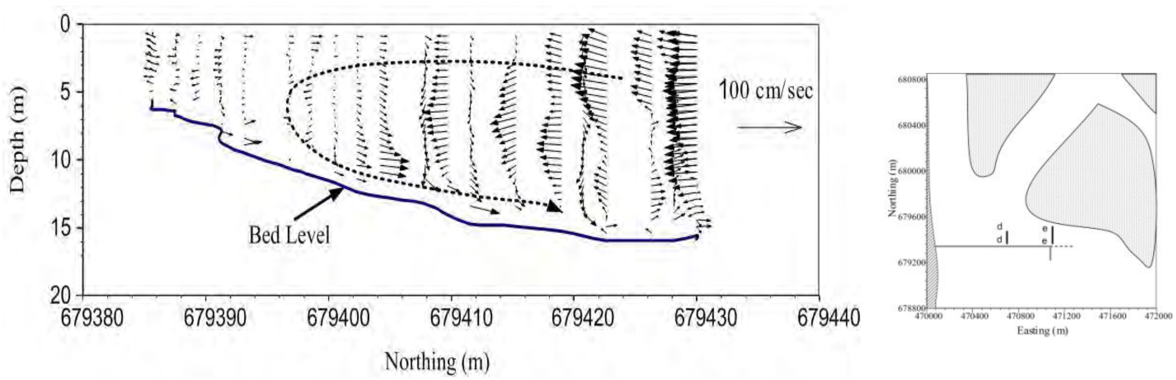


Figure 6.24: Flow circulation around the Enayetpur spur along line d-d

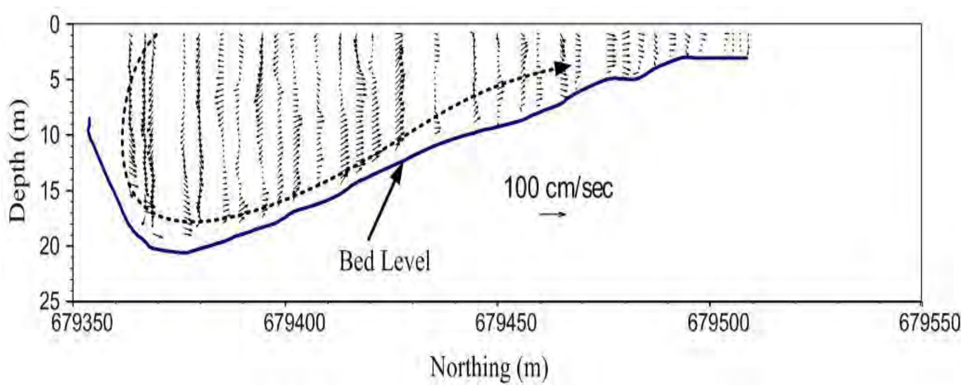


Figure 6.25: Flow circulation around the Enayetpur spur along line e-e

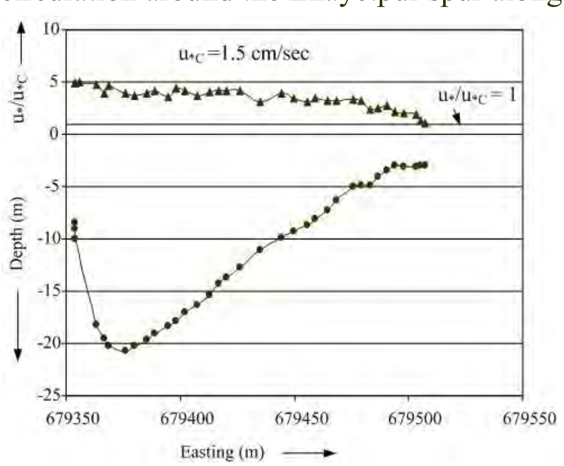


Figure 6.26: The variation of the ratio of the shear velocity along line e-e

6.3.3 Causes of failure of spurs

It is considered that the main causes of the failure of the earthen shank of the Betil and Enayetpur spurs are (Fig. 6.27): (i) the striking of flow obliquely to the earthen shank, (ii) the generating of a strong parallel flow upstream of the earthen shank and RCC part of the spur, (iii) flow circulation normal to the earthen shank and the belmouth, and (iv) development of a deeper channel upstream of both spurs by the higher sediment carrying capacity parallel flow. The deeper channel near the earthen shank affects the structural stability of the earthen shank. As a result, the earthen shank of the spurs frequently failed. Rahman et al. (2007) proposed a conceptual model as shown in Fig. 6.28, to protect the bank using bandal-like structures in between spurs or earthen shank of the spur, from the oblique flow. One of the big challenges for the bandal-like structures is that the selections of durable materials during its construction in reality in a large scale river like the Jamuna.

6.3.4 Social response

At present, mainland people around Betil and Enayetpur spur sites are satisfied with the effectiveness of spurs. The mainland is free from river erosion. Only some repair and maintenance works are required each year to keep the structures safe. After the construction of spurs, a large land area has been reclaimed downstream of the Enayetpur spur. A lot of people are settled in the Dhuliabari char and Enayetpur char.

Figure 6.27: Failure of the earthen shank of the Enayetpur spur in July, 2008

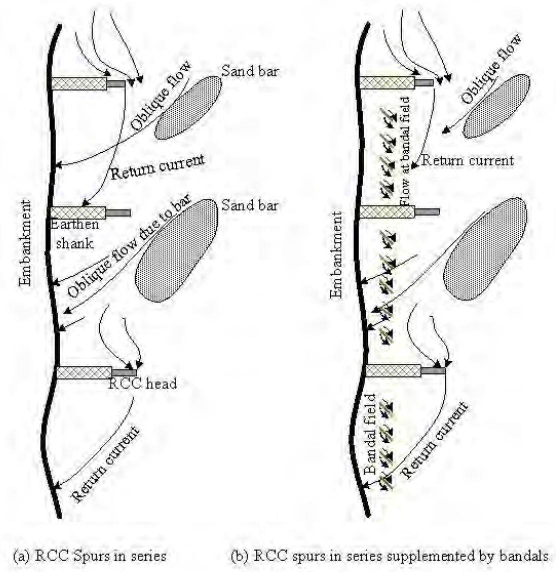


Figure 6.28: Conceptual model of bandal-like structures in between RCC spurs

They are also satisfied on the function of the spurs, though some erosion occurrs at the western part of the Enayetpur char. The people of the Dhuliabari char demand that a revetment be constructed along the edge of the Dhuliabari char where the main channel is flowing.

After the construction of the spurs, the mainland gets free from river erosion. The intensity of development activities at Enayetpur has been increased manifold and the Khaza Yunus Medical College and Hospital is constructed close to the spur. At present, several 2 to 4 storied buildings are under construction along the bank line near the Enayetpur spur. The value of land also has been increased manifold after the construction of the spur.

6.3.5 Summary

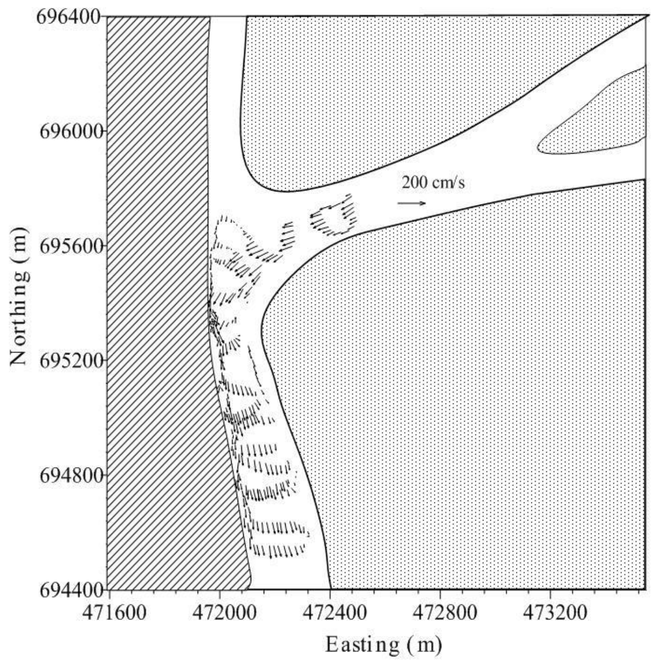
The structural stability is affected by river morphology, length of the spur, amount of riprap and flow processes around the RCC spur. Mainly, the upstream morphology is the main driving force for the failure of the Betil and Enayetpur spur. Other factors also speed up the failure event. Those are the oblique flow, parallel flow and flow circulation normal to the spur. As a result of flow circulation deep channel is generated near the earthen shank or the belmouth of the spur. The structure becomes unstable due to the development of deep channel very near the RCC spur. Additional measures should be taken in between and upstream of the spurs to avoid failure problem.

6.4 Bandal-Like Structure

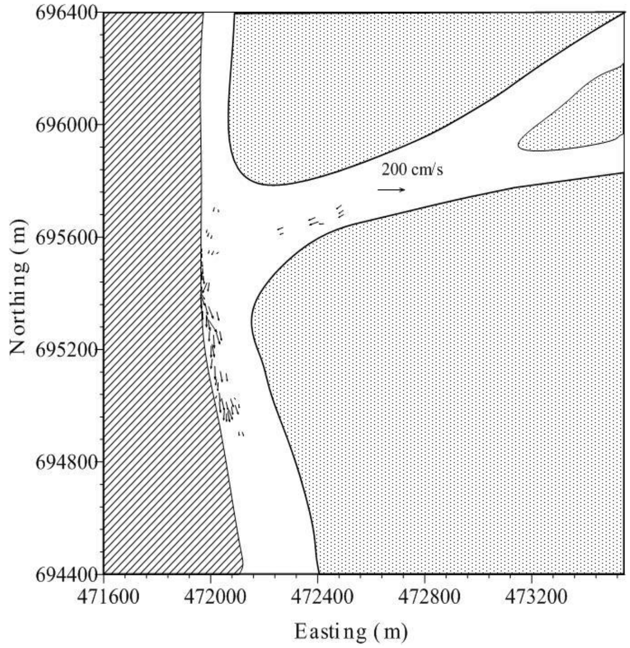
6.4.1 Flow around Bandal-like structures at Randhunibari

Flow along the horizontal plane

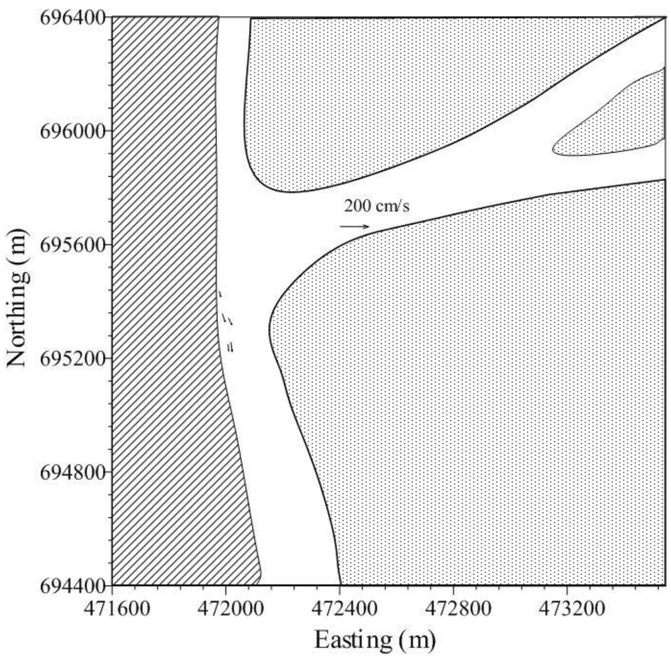
The flow patterns at a depth of 1m, 4m and 8m along the horizontal plane around the Randhunibari bandal site are shown in Fig. 6.29. The flow is mildly diverted by the bandal-like structures towards the main channel (Fig. 6.30). It is seen from a field visit that erosion is prevented by the bandal-like structures. Sometimes the flow diversion by this types of structures (constructed normal to the bankline) attacks the opposite bank of a channel. But in the present case, the flow diversion by the bandal-like structures does not attack the opposite bank (i.e. homestead bar). The bandal-like structures have no such adverse effect.



(a) Velocity vectors at a depth of 1m (July, 2008)



(b) Velocity vectors at a depth of 4m (July, 2008)



(c) Velocity vectors at a depth of 8m (July, 2008)

Figure 6.29: 2-D Velocity vectors around the Randhunibari at different depths (July, 2008)

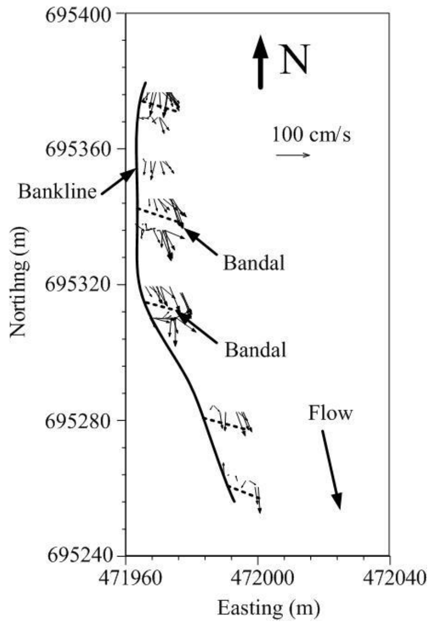


Figure 6.30: Flow diversion by the bandal-like structures (July, 2008)

Flow along the vertical plane

To study on flow phenomena along the vertical plane around the bandal-like structures, the velocity is measured about 2m upstream and 2m downstream of the bandal-like structures. It is found in Fig. 6.31 (2m upstream of a bandal) that the flow is diverted by the bandal structure towards the main channel. It is also observed in Fig. 6.32 (2m downstream of a bandal) that the flow passed under the bandal is directed towards the main channel upstream of bandal-like structures. The return current is counter balance by the flow passing beneath the bamboo thatch. Flow diversion by the bandal structures constructed in natural river is similar to the experimental results investigated by Rahman et al. (2004). The velocity vectors in vertical planes along line o-p are shown in Fig. 6.33. Though, the channel turns about 90^0 and it should act as a bend. But the flow is smoothly diverted towards the sandbar by the bandal-like structures. The bandal-like structures effectively protect the bank. But this type of structure can withstand only one or two seasons.

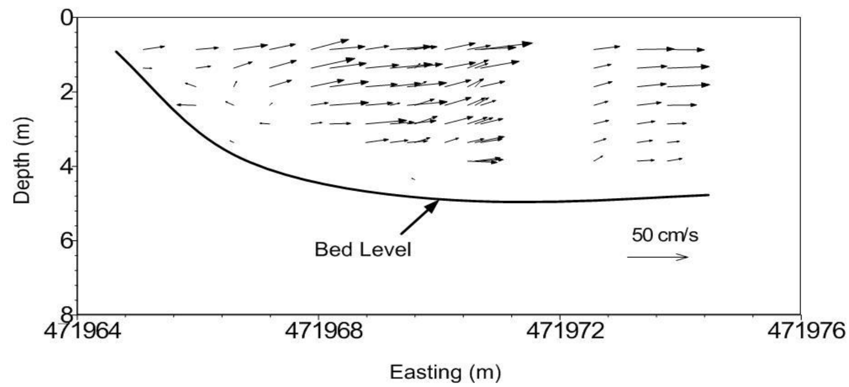


Figure 6.31: Flow pattern upstream of a bandal structure (July, 2008)

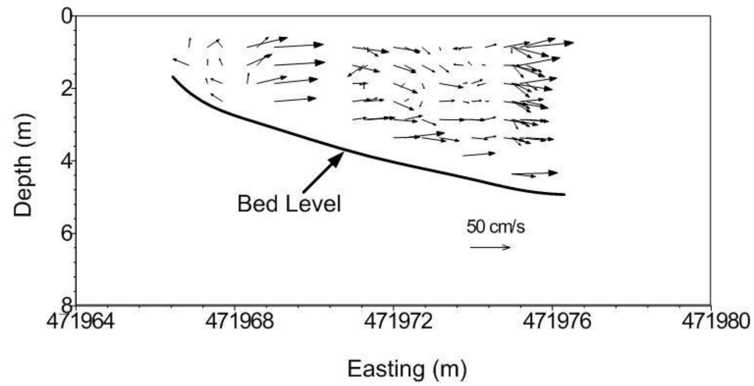


Figure 6.32: Flow pattern downstream of a bandal structure

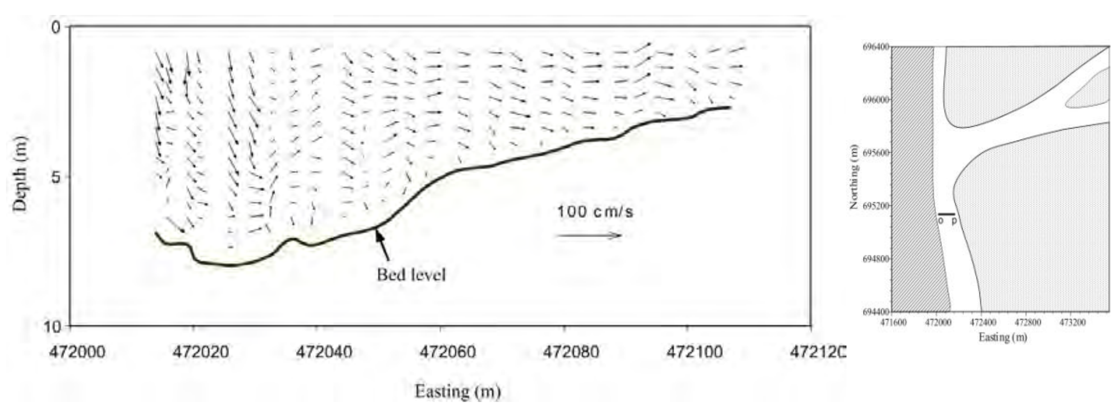


Figure 6.33: Velocity vectors along the vertical planes along line o-p

(a) Randhunibari (b) Upstream east guide of Bangabandhu Bridge

Figure 6.34: Bandal-like structures

Effectiveness of the bandal-like structures

River Research Institute (RRI) has constructed some bandal-like structures as erosion management technique on a pilot basis (Fig. 6.34). The bank erosion has been mitigated to some extent after the construction of bandal-like structures. The local people informed that the bed level of the Randhunibari channel is raised about 0.8 m downstream of bandal-like structures. It was also observed during the field visit that sediment deposition occurred at some locations downstream of the bandal-like structures. The elevation of the deposited sediment is almost at the same level as that of the original ground. So, it may be concluded that effectiveness of the bandal-like structures is very high in the context of our country.

6.4.2 Social response

Acceptability of the bandal-like structures by the local people is an important issue. Most of the people opined during FGDs that it would be possible to prevent river bank erosion to some extent using bandal-like structures. The bandal-like structures function well during the period of the rising water level, i.e. bamboo thatch getting submerged. Sediment is deposited downstream of the bandal-like structures. But deposited sediment again wash away during the recession period when water flow below the bamboo thatch. Sometimes the river bank is also eroded in such conditions. So, the local people demand a permanent structure such as the revetment-like structure above which good transport facilities should be ensured.

6.4.3 Summary

The bandal-like structure has high potentiality to accelerate sedimentation. It also drives the flow away from the bankline. It protects the bank from erosion. But its acceptability is a big question at that place where the business centre or economic centre is present. Especially at a place where is a great possibility of economic losses if a small extent of erosion is allowed.

6.5 Concluding Remarks

The morphological change of the sand-bed braided river like the Jamuna River is a great challenge for the structural stability of river training works. The flow processes around a river training works is guided the morphology around the river training works. The flow processes is changed with morphological change. The oblique flow a prime factor for the failure of the river training works. Other factors also accelerate the failure of the river training works. The following are reasons of the failure of the Sirajganj hardpoint such as: (i) oblique flow generated by sandbar attacked the hardpoint; (ii) washed away of sandbar adjacent to the hardpoint; (iii) thalweg shifting at the vicinity of the hardpoint; (iv) riprap failure due to movement of dune through the channel passing adjacent to the hardpoint; (v) development of scour hole because of riprap failure, and (vi) flow slides from the hardpoint side.

The causes of failure of the Betil and Enayetpur spurs are as follows: (i) oblique flow is generated as a result of upstream morphology of both spurs; (ii) strong parallel flow upstream of both spurs; and (iii) development of deep channel due to flow circulation normal to the spurs. The oblique flow may be drive away from river training works towards mid-channel by adopting supplementary measures. But the nature and quality of the construction materials of the supplementary measures is a great issue. Bandal-like structure is very effective as a flow diversion and sediment deposition measure. But site selection for implementing of such structures is major factor.

CHAPTER SEVEN

INDIGENOUS KNOWLEDGE ON FLOW AND EROSION PROCESSES

7.1 Introduction

To investigate the indigenous knowledge about flow and erosion processes around bank protection works, a series of Focus Group Discussion (FGD) was conducted at different places along the braided Jamuna River where the bank protection works exist. Since the erosion is a major problem along the Jamuna River; the riparian populations are fighting against the flood and erosion for a long time. So, the erosion-affected people or people along the bankline are already cognizant of about the bank erosion process. More than thirty bank protection structures are constructed along both the banks of the Jamuna River to protect BRE. The response of these structures to the river is different. The people in the neighborhood of these structures have already gained experience-based knowledge. So, the main objectives of conducting FGD are to investigate experience-based indigenous knowledge on flow and erosion. Finally, comparisons are made among the indigenous technical knowledge, field engineer's knowledge, field measure result and result obtained from laboratory experiment. All the relevant hands sketching by local people during FGD are attached in Appendix-C. The hands sketching have been further reproduced by the author and these are added in the present Chapter. Some photographs of FGD are attached in Appendix-D.

7.2 Indigenous Knowledge on Morphology and Erosion Processes

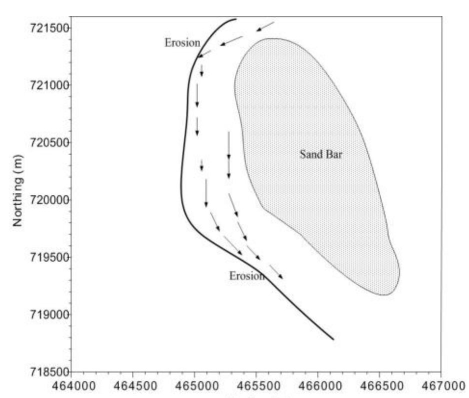
7.2.1 Morphological change

Some aged people gave descriptions about the morphological change of the Jamuna River. The river was flowing in the downstream direction smoothly up to the early 1960s. During the flood season the incoming flow into the Jamuna River spread over the entire flood plain through the distributaries and numerous canals connected with the Jamuna River. All the canals were active before the construction of BRE. The water level both in the river and in flood plain gradually was raised prior to the construction of BRE. The flood level was existed at the same level inside the main river and in the flood plain. Brahmaputra Right Embankment (BRE) was built in the mid-sixties to protect the flood plain from flooding. According to the local people after construction of the BRE the river become aggressive. The causes of becoming aggressive of the river are as follows: (i) the outflow from the main channel towards the flood plain is blocked; (ii) the water level into the main river is increased; and (iii) the velocity in the main river is increased. As a result, the rate of erosion is increased along the bankline. They also gave information that in 1950 a lot of floating wood, trees and its branches, dead body of livestock were washed away. They stated that after the starting of severe bank erosion simultaneously sand bars were formed into the main river. When a sand bar is formed, the flow is divided by the sand bar (Ferguson, 1993). The deflected flow attacks the bank line, and the resulting rate of erosion increases (CEGIS, 2007). Now there are numerous sand bars in the Jamuna River. It is found from different FGD's that the depth of the Jamuna River is significantly reduced than the previous one which was existed forty years back. They believe that the reasons decreasing the depth of the Jamuna River are: (i) formation of the sand bars, and (ii) gradually widening of the river.

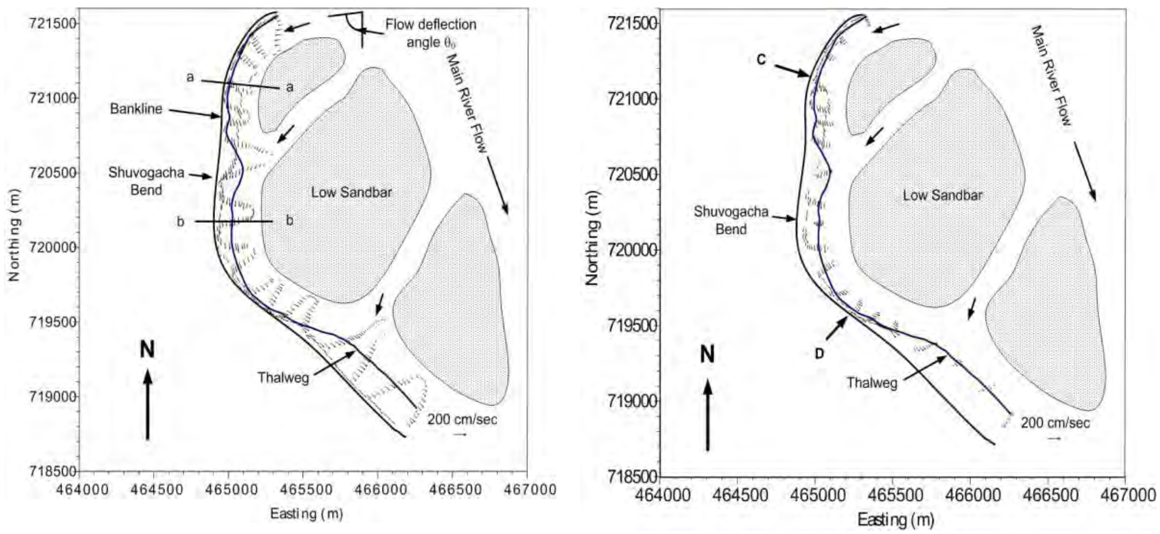
After the construction of the Bangabandhu Bridge, the river training works as part of the bridge construction affect the river morphology. The width of the Jamuna River was contracted to 4.8 km from a greater width. The morphology of the Jamuna River was adapted by the Bangabandhu Bridge to a new situation (BWDB and ADB, 2006; Uddin and Rahman, 2010). A large sandbar is formed downstream of the Bangabandhu Bridge along the west bank of the Jamuna River. At present, thousands of previously displaced people are living on that sandbar. As reported by the local people about 18 villages have been washed away within one month after construction of the Bangabandhu Bridge (Schmuck-Widmann, 2001). As a result, a huge number of people became homeless, landless and ultimately displaced in an emergency situation. Most of them took shelter at different places in the Sirajgang town. It is clear from their story that how the river morphology is radically changed by a structure.

7.2.2 Flow and erosion processes at bends

The flow and erosion processes at bends have been investigated through FGD and KII. During FGD, the participants either sketched or gave verbal description on the flow and erosion processes at bends. The rate of erosion depends on the river course whether it is straight or bends. If a river is straight the rate of erosion becomes less. The rate of erosion starts to increase when a river turns from a straight channel to a bend channel. River erosion also depends on the flow pattern. Rate of erosion is higher at that place where the main river passes close to the bankline. Usually, a part of the main channel flow diverted by a sandbar enters into the bend channel. This flow directly attacks at the upstream part of the bend. The rate of erosion is relatively higher at the place where the flow attacks the bankline and the flow changes its direction. The typical flow processes at bends as per local people's hand sketching is shown in Fig. 7.1(a). They also explained that the rate of erosion is higher at upstream part as well as at downstream part of the bend. The local people gave explanation the mechanism of sand bar formation. They observe that the bank is eroded at a bend and at the same time a certain portion of eroded materials are deposited into the channel. As a result, a sandbar is formed into the channel. A per local peoples's explanation the sand bar which is formed through bank erosion is shown in Fig. 7.2. The rest of the bank eroded materials move in the downstream direction and form another sand bar or add to another sandbar. The flow and erosion processes sketched by the local people are similar to filed measured result as shown in Fig 7.1 (b). It is evident that the local people have clear understanding about the flow and erosion processes at bends.



(a) Flow processes at bends (Reproduced from the hand sketching of the local people: see Fig C6 in Appendix C)



(b) Measured flow phenomena at bends

Figure 7.1: Flow processes at bends

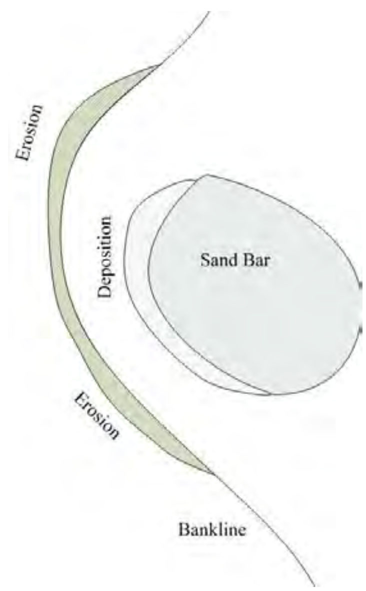


Figure 7.2: Erosion and deposition processes at bends (Reproduced from the hand sketching of the local people: see Fig C7 in Appendix C)

7.2.3 Flow and erosion processes along straight bankline

The local people are acquainted with the sandbar induced erosion processes. They explained the erosion processes through sketching during FGD. The flow is diverted by the sandbar and obliquely attacks the bankline as shown in Fig. 7.3. The bank materials are highly erodable and easily washed away by the flowing water (FAP 24, Annex-5, pp 5-5). Usually, a flow circulation zone is formed just upstream of the eroded bankline (Fig. 7.3). Sometimes, they observe a reverse flow is generated near the bankline at the straight reach while severe bank erosion occurs (Fig. 7.4). They consider something is going to be happened observing the air bubble bustling out from the river bed. At that time they can guess that the riverbed is quickly lowered down, and at any time the bank may be collapsed. Bank failure is a consecutive process. While a part of the bank is collapsed over the river bed then the bank materials are gradually washed away by the river flow. The collapsed bank materials are usually unsaturated. Entrapped air is existed into the bank materials. So, when the collapsed bank materials are washed away the entrapped air is released as bubble form from the collapsed bank materials.

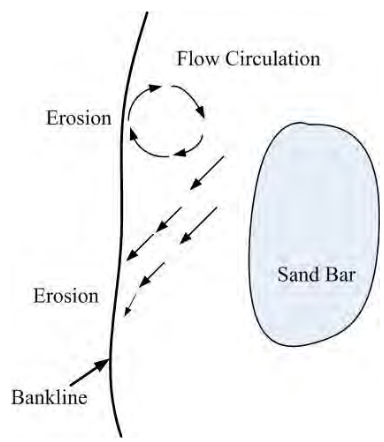


Figure 7.3: Flow and erosion processes due to the sandbar (Reproduced from hand sketching of the local people: see Fig C8 in Appendix C)

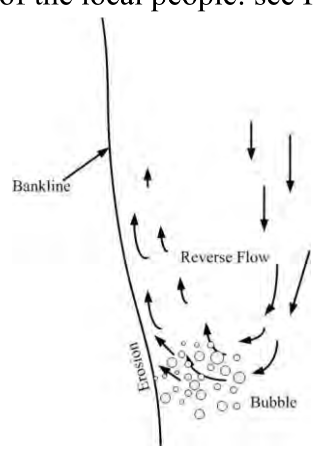


Figure 7.4: Erosion processes along bankline (Reproduced from hand sketching of the local people: see Fig C9 in Appendix C)

7.2.4 Rate of erosion

Erosion-hazard map:

The literate and illiterate both groups could recall the real situation of erosion but their means of expression are different. Both the groups are expert on this issue. The literate people of the study area could draw the erosion hazard map on paper but illiterate people could give excellent verbal description about the rate of erosion of different years. Anybody can guess the similarity of the hazard maps between the two groups. The erosion hazard map at the Shuvogacha bend which is drawn by some literate local people is shown in Fig. 7.5. Though it is a qualitative map but there are indications of variation of the rate of erosion in different years. The similarities are also existed between two hazard maps prepared by the local people and the technical personnel (Fig. 7.5 and Fig. 7.6). The rate of erosion is higher in between 2002-2003 and 2003-2004. Similar information is given by the local people and technical personnel.

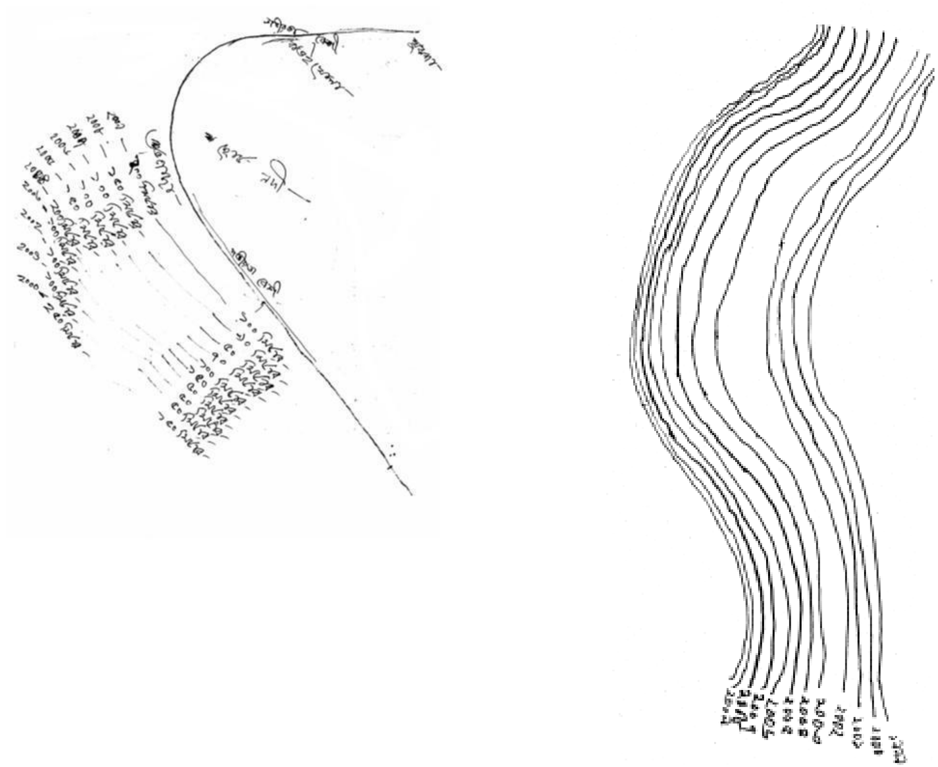


Figure 7.5: Erosion hazard map prepared by the local people

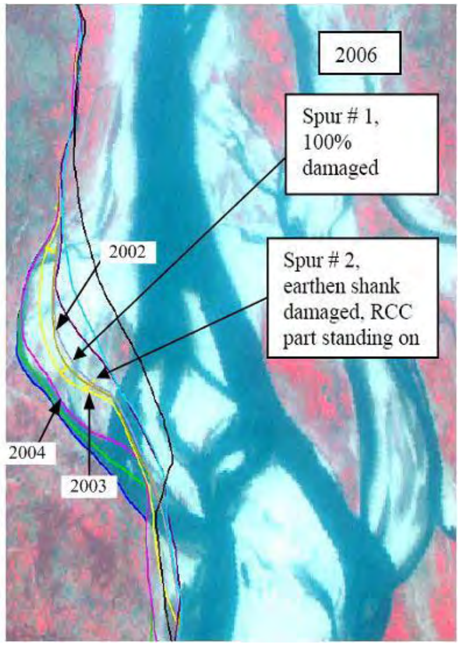


Figure 7.6: Erosion hazard map prepared by the technical persons using satellite images

Analysis of erosion trend:

During FGD with farmers and fishermen, they gave information verbally about the rate of erosion as yearly basis. But during KII, the literate people gave clear information through drawing on paper about the rate of erosion. They can easily draw the qualitative graph of the rate of erosion up to 10 to 12 years. The trend of the rate of erosion from 1999 to 2009 prepared by one Key Informant is shown in Fig. 7.7. They sketched that the rate of erosion higher in 2002 to 2003 and 2003 to 2004.

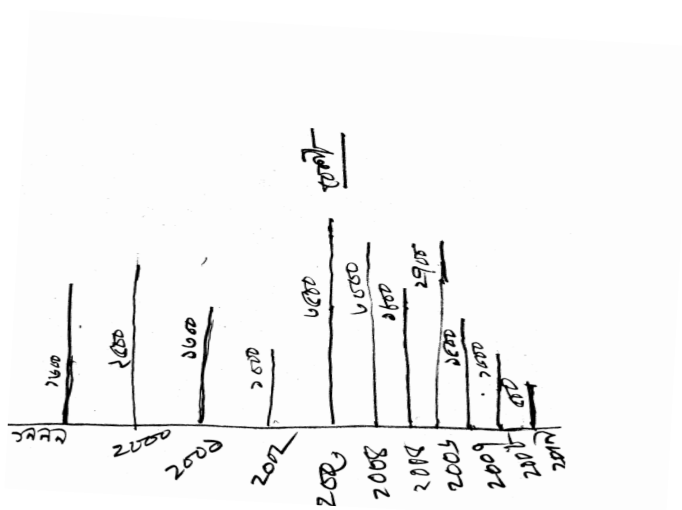


Figure 7.7: Erosion trend prepared by the local people

Effective period of erosion:

The effective erosion period varies depending on the type of the channels (e.g. main channel or branch channel) and location of the bank line. The effective erosion period along the bank line of the main channel is stated from the months of Ashar, Srabon, Vhadro and Ashwin according to Bangla calendar (i.e. June, July, August and September). But in the branch channel, the effective period of erosion is relatively shorter. The rate of erosion is usually relatively higher during the rising or falling period (Schumuck-Widmann, 2001). The rate of erosion reduces when the bank line goes submerged condition. During FGD, it is investigated that the intensive erosion occurs 2 to 3 weeks in the branch or secondary channel of the Jamuna River (including rising and falling period). The rate of erosion also depends on the flood frequency. The effective duration of erosion along the secondary channel obtained from FGD is used in the erosion prediction model developed in chapter 5. The indigenous knowledge regarding effective period of erosion has been integrated in the erosion prediction model.

Comparison between indigenous and technical knowledge:

There are strong similarities between erosion hazard maps prepared by the local people based on their real field observation and the erosion hazard map prepared by the technical personnel based on the satellite images and sediment features. Again, there is also similarity between the trend of the rate of erosion sketch by the local people (Fig. 7.7) and the one prepared by technical persons using satellite images (Fig. 7.6). Both groups of the people shows that the rate of erosion higher in between 2002 to 2003 and 2003 to 2004.

7.2.5 Bend development

During KII with Mr. Abdul Matin Hawlader, a retired employee of UNICEF, expressed his opinion on the bend development process in an erosion prone area. When erosion continues at a straight reach along the Jamuna River, gradually a straight channel reach is turned into a bend channel from its straight condition. At this time bar and bend are formed simultaneously at the channel reach. A bend channel gradually moves towards the main land through bank erosion. This process is continued up to 10 to 12 years. Afterwards, the development of the bend channel becomes weak, and the flow is diverted towards the main channel. Most of the local people gave their opinion that the bend development process is continued up to 3 to 5 years. After that the erosion processes, i.e. the bend development process is reduced. During KII with Mr Anwar Hossain, Sub-Divisional Engineer (SDE) of BWDB gives his opinion that the bend development process is continued up to 7 to 8 years. Afterwards, the bend channel is abandoned, and the flow is diverted towards the main channel. However, the duration of bend development also varies along reach to reach according to other local people. From the series of satellite images it is evident that the Shuvogacha bend developed within 7 to 8 years, i.e. from 1999 to 2006. Afterwards the bend is abandoned through deposition occurred at the mouth of the upstream inflow channel. The duration of bend development process is confirmed from the study performed by CEGIS in 2007 using satellite images. It is investigated from this study that the duration of embayment or bend development varies reach to reach. There is similarity among local people's knowledge, field engineer's knowledge and information from satellite image based study performed by CEGIS.

7.2.6 Indigenous knowledge on erosion protection and adaptation

It is investigated during FGD that sometimes the local people took initiative to protect their homestead and cultivated land for their own interest. They drove bamboo poles close to the bank line and placed a lot of branches of trees to divert the flow. Finally, they dumped sandbag into the driven bamboo poles. They became successful because the energy of the flow was relatively weak due to the narrow branch channel. But they failed in their attempts when the main channel came close to their homestead. They couldn't protect their holdings from erosion causes by the main channel. They opined that local attempt is not enough to protect from erosion when a main channel came close to bankline.

Still people use indigenous techniques to protect their homestead and cultivated land from erosion in the branch channel or secondary channel of the Jamuna River. The people living in between the Betil and Enayetpur spurs use local material such as bamboo piles, tin, sand filling sacks etc. to protect their homestead and cultivated land. Some businessmen of the Randhunibari area personally took initiative to protect their shops from erosion.

Figure 7.8: Planted nalkhagra to reduce hydraulic impact on the bankline at Randhunibari

They drove bamboo piles and dumped sand filling sacks as erosion protection measures. At some places (such as at Randhunibari) they have planted nalkhagra (one type of vegetation) to reduce the hydraulic impact on the bankline so that the bank is to be protected (Fig. 7.8).

The people living near the bankline could easily determine where erosion would occur under the present flow condition. So, they gradually take preparations for shifting their property. First of all, they cut their big trees. They wait for adverse situations (i.e. severe erosion along bankline). They quickly shift their house building materials to a safer place. They temporarily live on BRE or relative's houses. Later, they migrate to other places, permanent char, city or town for living and earning. Sometimes they buy a piece of land and build hut for living. They wait year after year for accreted land as sand bar. When they get their land on the sand bar, they make houses on the sand bar. They start to live there and produce different types of crops which are suitable to grow on the sand bar. It was investigated during FGD (August, 2009), that the erosion affected people in the Shuvogacha village were waiting to make houses on the sand bar (adjacent to the bankline). They gave their opinion that if government takes initiative to raise homestead and settlement on the sandbar they are ready to settle on the sandbar. If a very few people live on the sandbar there is a possibility of robbery. Especially the sandbar is located at remote place into the river. Some people have already built their houses on that sand bar in April 2010. There are a lot of opportunities for livestock to graze on the sandbar.

7.2.7 Summary

The local people could easily give information about historical changes of the morphology of the Jamuna River, flow and erosion processes at bends, erosion processes at the straight bankline, the trend of the rate of erosion, effective period of erosion through out the year. There are strong similarities among information given by the local people, information prepared by technical personnel and field measured result. So, we should evaluate the information provided by the local people.

7.3 Indigenous and Scientific Knowledge on Bank Protection Works

To investigate flow and erosion processes around the Sirajganj hardpoint a series of FGD's were conducted with different group of people such as: erosion affected people, fishermen, boatmen and boat owners, etc. A number of KII's were also conducted with Sub-Divisional Engineers (SDE of BRE specialized Division, BWDB), Section Officers (SO) of BRE, Work Assistants (WA) of BWDB, Ward Commissioner of Sirajganj Pourashava, Chairman of Shuvogacha Union Parishad, Members of Shuvogacha Union Parishad, Member of the Saudia Chandpur Union of Chowhali Upazilla and other persons who well known about the Jamuna River and the bank protection works. Several group discussions were also conducted with different classes of people. The information collected through FGD and KII on flow and erosion processes around different kinds of bank structures has been summarized in the following section.

7.3.1 Flow and erosion processes around the Sirajgang hardpoint

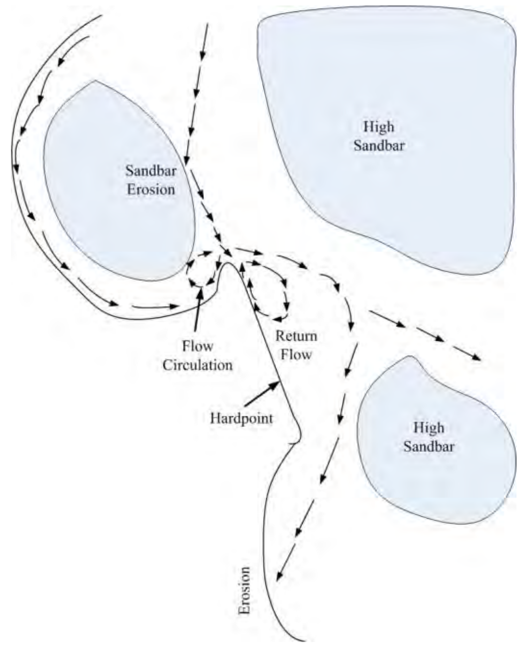
Flow and erosion processes:

The flow and erosion processes around Sirajganj hardpoint have been investigated through FGD. During FGD several sketches on flow and erosion processes have been prepared as per opinions of fishermen, boatmen and boat owners and erosion affected people. It is found that they have clear idea on the flow processes around the hardpoint and surrounding area. The flow and erosion processes around the Sirajganj hardpoint are shown in Fig. 7.9(a). This figure is reproduced from the local people's hand sketching. The flow is coming from upstream towards the hard point. First of all the flow obliquely attacks the eastern side of the sandbar. As a result the eastern part of the sandbar is gradually being eroded. After that the flow directly hits the upstream termination of the hardpoint. A strong flow circulation along horizontal plain is formed in the western direction of upstream termination of the hardpoint. The local people gave their opinion that the bed material is being washed away due to this type of flow circulation. The upstream curved channel dries up during the dry season and the flow starts through this channel when the water level rises in the main channel. During FGD it is found that a strong return current (*local term ulta aoor*) existed adjacent to the eastern part of the upstream termination. The strong return current is also found in the field measured result. The return current observed from field measured result is shown in Fig. 7.9(c). The strength of the return current becomes stronger when high magnitude flow attacks to the hardpoint. The strength of the return current becomes weaker and the reattached length becomes shorter when flow magnitude is low. They provided information that the flow velocity changes with time. The flow passes in the downstream direction and attacks the upstream part of the sandbar. As a result, the sandbar is being eroded. Then the flow is separated into two parts. First part of flow is going towards the south-east direction and second part flow is going towards the south-west direction. According to the local people the second part of the flow attacks the bankline where severe erosion is occurring. This location is downstream of the Sirajganj town. This issue is confirmed from another field-based research performed by Rahman at el. (2011).

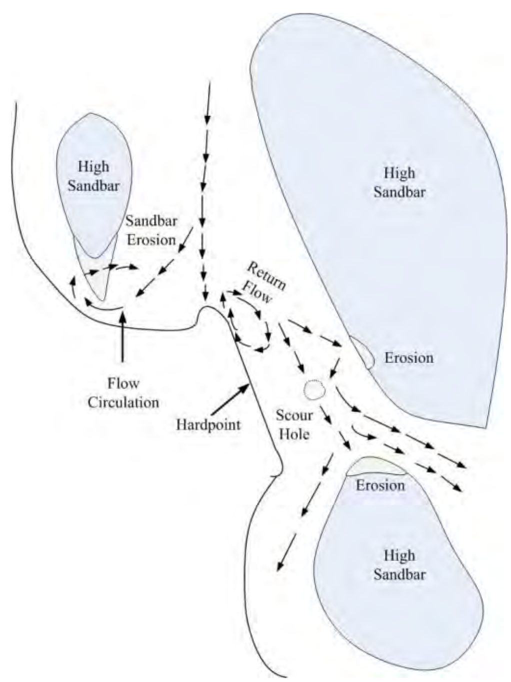
One question was asked to the local people that what is the reason of development deep scour hole. They gave answer that the vortex flow (*local term vhorka*) is the main reason of the development of deep scour hole. The explained that the vortex flow (vhorka) is usually existed near the upstream termination as a result the bed materials are washed away (*local term mati kete uthe jai*). Their observation is similar to the experimental investigation (Melville, 1975; Kandasamy, 1989).

The flow and erosion processes around the Sirajganj hardpoint are also sketched by the Sub-Divisional Engineer of BWDB (23.04.2010), which is shown in Fig. 7.9(b). His hand sketching is moderately similar to hand sketching prepared by the local people during FGD. In his hand sketching he showed that the incoming flow directly attacks the upstream termination and two flow circulation zones are visualized. The first one is just in the western direction of the upstream termination. The second one is adjacent to the eastern part of the upstream termination. The flow is diverted by the upstream termination of the hardpoint. Later on, this flow is obliquely attacking the eastern sandbar. As a result, the western part of this sandbar is being washed away. In his hand sketching he also showed that the flow reflected by the sandbar. This reflected is joined with the direct flow and a flow circulation is formed just in front of the damaged part of the hardpoint. After that the joined flow goes in the southern direction and attacks the sandbar. As a result, the sandbar is being gradually washed away.

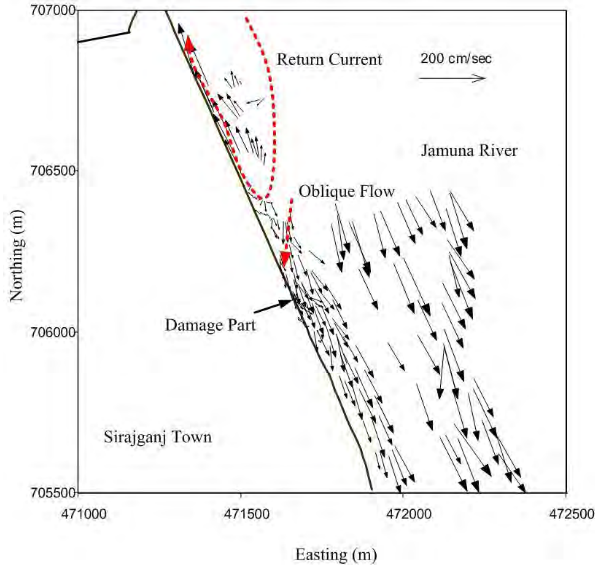
From the above discussion, it is obviously clear that the local people possess a good idea about the flow processes. They could give information about the historical changes of the flow processes. One important issue is that the fishermen and boatmen could give more accurate information about flow and erosion processes than other group of people of the riparian population. They gave information that the *katal* (thalweg) is shifted in the western direction at present time (24.04.2010). The thalweg moves in an irregular and sudden fashion during the rising and falling stages of the river (Coleman, 1969). Actually, the boatmen and fishermen are experts on river, flow and erosion processes among the riparian population. Without any hesitation, we could give the boatmen and fishermen designation as *Indigenous knowledge-based river experts* (Schmuck-Widmann, 2001). They always drive their boat into the river. Continuously they observe the changing phenomenon of the river. Therefore, they could easily realize when, how and in which direction the thalweg or deep channel is being shifted.



(a) Flow and erosion processes around the Sirajganj hardpoint (reproduced from hand sketching of the local people: see Fig C2-C5 in Appendix C)



(b) Flow and erosion processes around the Sirajganj hardpoint (reproduced from hand sketching of SDE of BRE specialized division: see Fig C1 in Appendix C)



(c) Flow process on 19th August, 2009

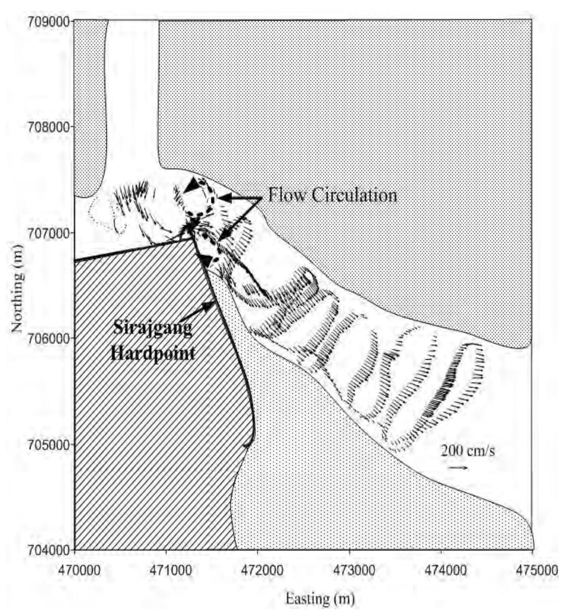
Figure 7.9: Flow and erosion processes around the Sirajganj Hardpoint

The causes of failure of these bank protection structures:

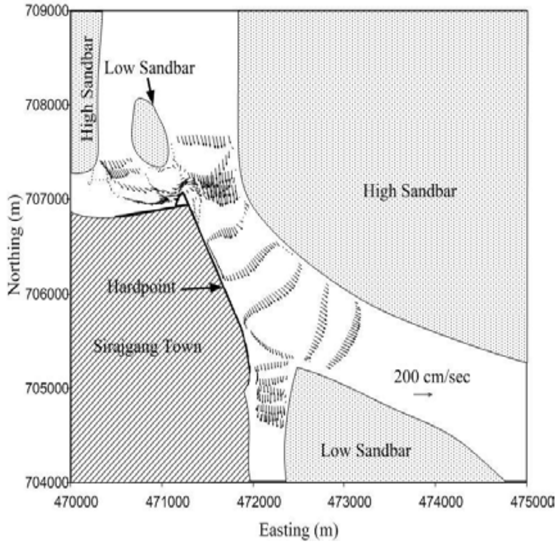
The causes of failure of the bank protection structures along the right bank of the Jamuna River as per BWDB officials are as follows: (i) one of the main factors for the failure of the bank protection structures is the shortage of funds (ii) timely, properly and as per design implementation of bank protection structures is not possible using insufficient fund ; (iii) starting of the construction work too late as a result the construction work could not be completed before the flood season; (iv) the original design is followed but cut back; (v) inadequate design assumptions for scour depth, resulting insufficient falling apron; (vi) lack of fund for maintenance work; (vii) irregular monitoring of the existing structures especially during flood period, especially bathymetry survey is required frequently for the prediction of scoured depth for the protection work.

Causes of structural failure of Sirajganj hardpoint:

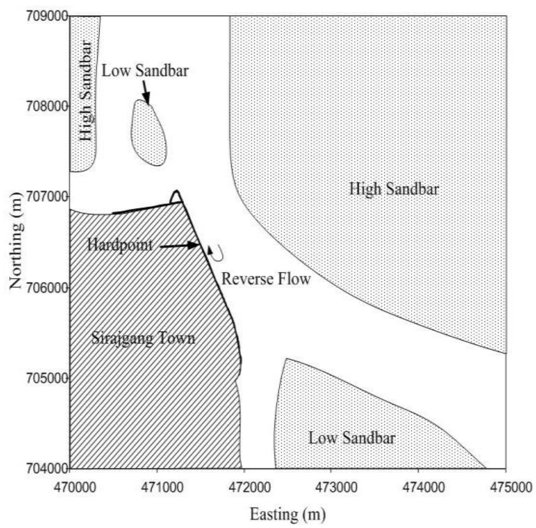
The upstream termination was damaged in 2008. They explained causes of failure of the hardpoint: "the flow directly hits upstream termination". Their explanation is similar to the field measured findings shown in Fig. 7.10 (a). The main hydraulic thrust was on the upstream termination of the hardpoint. Again they explained the causes of failure of the hardpoint in 2009. A sandbar was formed adjacent to the straight portion of the hardpoint in 2006. Their information is verified by satellite images collected from CEGIS. The local people's information is exactly similar to the satellite image. But during the 2008 flood season the sandbar adjacent to the hardpoint was gradually washed away. A channel was developed adjoining the hardpoint. The issue is verified from the satellite images of 2006 and 2009 as shown in Fig. 7.11. The thalweg (*local term katal*) was very close to the upstream termination in 2009 flood season. The straight portion of the hardpoint was damaged on 10th and 17th July in 2009. The field measured findings in March 2009 is shown in Fig. 7.10(b). The flow is guided by the sandbar towards eastern part of the hardpoint. Their explanations are summarized here: (i) washed away of the sandbar during the 2008 flood season and, (ii) development of deep channel very near to the eastern straight part of the hardpoint (Unger and Hager, 2006; Lauchlan and Melville, 2001; Chiwe and Lim, 2000). They made a hand sketching showing reverse flow which was observed in front of the damaged part (Fig. 7.10c). The scientific explanation may be the flow separation zone is formed due to the development of the scour hole.



(a) Flow and morphology on 23rd March, 2008

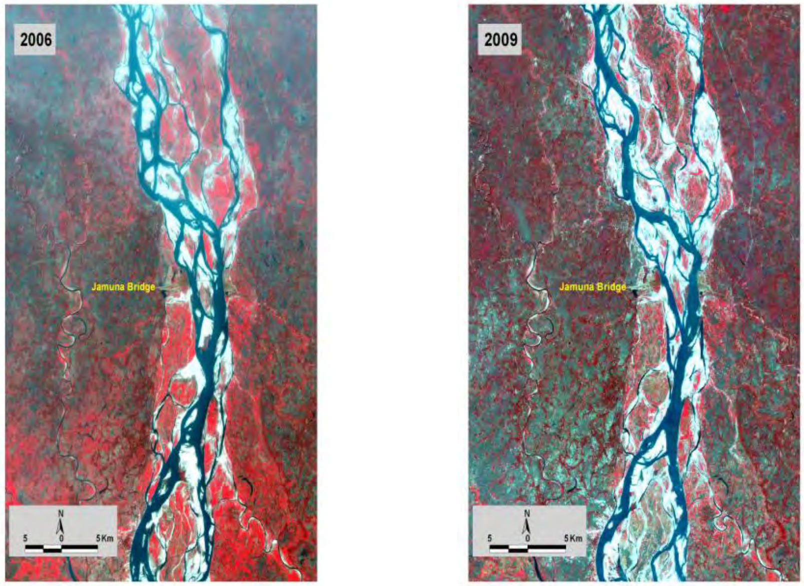


(b) Flow and morphology on 19th March, 2009



(c) Reverse flow near the damaged part on 19th August, 2009

Figure 7.10: Flow and morphology around the Sirajganj hardpoint



(a) 2006 (b) 2009

Figure 7.11: Morphological change between 2006 and 2009

During FGD one question was asked to the local people (12th July, 2009) just after the failure of the hardpoint: "how can they presume before the failure of the hardpoint". They gave interesting answers that they have clear knowledge about the sequence of construction of the hardpoint. The CC blocks were dumped as lunching apron. Bamboo grids were formed for properly placement of the CC block during construction of the hardpoint. Geo-textile was placed under the side slope CC block. When the local people observed that air bubbles were bustling out from the river bed, bamboo and geo-textile were coming out to the water surface, something is going to be happened very soon. They transmit this information to the BWDB personnel to take necessary steps. BWDB personnel immediately arrived at the spot. They were measuring the depth of water at that location. The local people requested the BWDB personnel for dumping CC block immediately to the place where an unusual situation is being observed. But the BWDB personnel delayed for taking decision for dumping CC blocks at desired location. Ultimately, the hardpoint was damaged on 10th July 2009. One question was asked to the local people that "What are the signs of the failure of the hardpoint?" Their answers have been summarized here: (i) bustling out of bubbles (Fig. 7.12); (ii) vortex flow or reverse flow close to the damage part; (iii) floating out bamboo and geo-textile to water surface,; and (iv) flowing turbid water very close to the failure part.

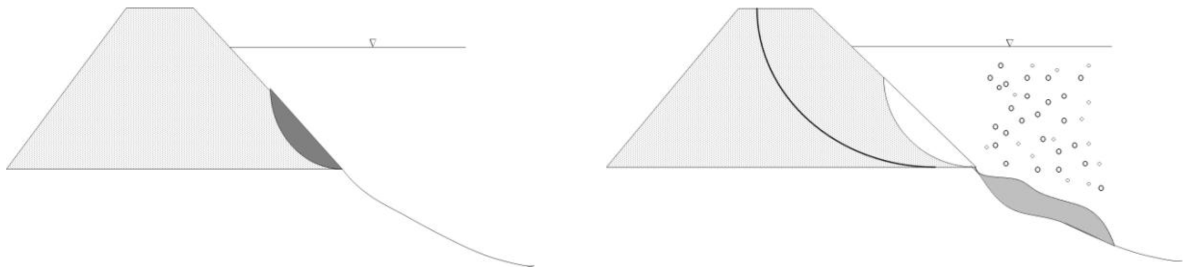
What are the reasons of bustling out of bubble and flowing turbid water? Regarding this issue several Key Informant Interview (KII) have been conducted with Sub-divisional Engineer (SDE), Section Officers (SO), and Work Assistance of BWDB. They have given the following explanations:

(1) After failure of the lower portion of the bank protection works the unsaturated materials are clean out very quickly (Fig. 7.12). At that time the air entrapped into unsaturated materials is released as bubble form.

(2) The CC blocks or other materials from the sloping side of the revetment are collapsed over the river bed. The air entrapped into the bed material, which is produced by decomposing of the organic matter, is released as bubble form.

(3) The bed material is mainly consisted of mica and it is as like as ash. This mica content bed material is very quickly clean out and mixed with water. As a result, the flowing water becomes turbid.

There are strong similarities between the experience-based indigenous knowledge and knowledge of the field engineers. The indigenous knowledge could play an important role in the management activity during the emergency situation. Therefore, we should evaluate the indigenous knowledge for the emergency management activity. So, the management program should be formulated including the local people. The local people would provide information on the basis of experience-based indigenous knowledge as quickly as possible accordingly the management activity could be started immediately.



(a) (b)

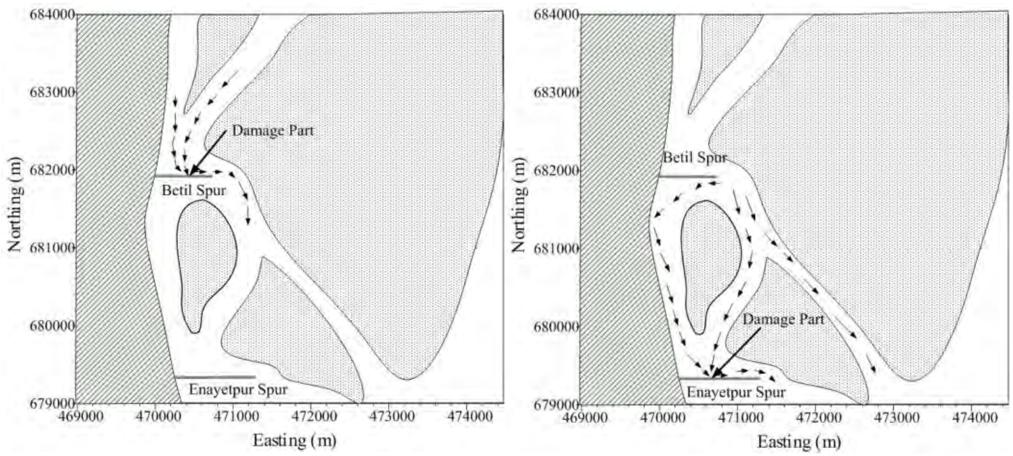
Figure 6.12: Indigenous knowledge as indication of structural failure

7.3.2 Flow and erosion processes around Betil and Enayetpur spurs

Flow and erosion processes:

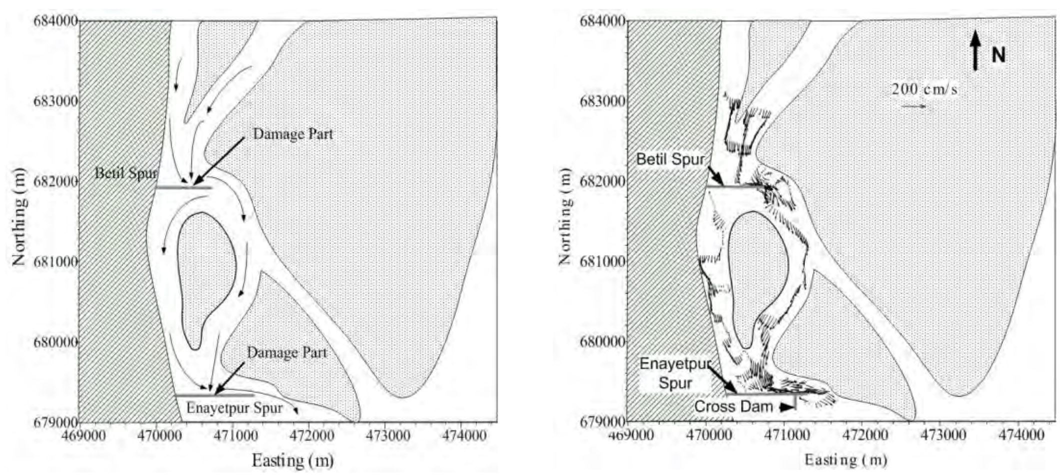
A series of FGDs were conducted with different groups of people to investigate flow and erosion processes around Betil and Enayetpur spurs. The homogeneous groups were of erosion-affected people, charland people, mainland people, loom workers and loom owners, day laborers, etc. The local people always observe the flow processes around Betil and Enayetpur spurs. So, they have clear understanding on the flow and erosion processes around both spurs. They sketched the flow processes around the Betil and Enayetpur spurs . The upstream morphology of both spurs is quite similar. The confluence of approach channels is just upstream of the spurs. They explained that the flow obliquely hits to the earthen shank of the both spurs as shown in Fig. 7.13(a-b). The local people's hand sketches are reproduced in Fig. 7.13(a-b). The earthen shank of both spurs fails due to this type of flow phenomenon. In between Betil and Enayetpur spurs minor erosion occurs. Though the rate of erosion is negligible but the valuable hand loom industry is affected by erosion. So, the local people are very aware about the flow and erosion processes.

The hand sketching prepared by Sub-Divisional Engineer (SDE) of BWDB (22.04.2010) on the flow processes around Betil and Enayetpur spurs is shown in Fig. 7.13 (c). The both groups explained that the oblique flow is dangerous for both spurs. From the field measured result it is also confirmed that the flow obliquely attacks the earthen shank as shown in Fig. 7.13(d). Due to oblique flow the earthen shank or belmouth is damaged almost every year. It is evident from the above discussion that the local people have clear perception on flow and erosion processes as BWDB personnel and filed measured result. The reason of frequent failure of the belmouth of the betil spur is explained by SDE responsible for Betil spur. The reason is that after the rehabilitation of the Betil spur a depositional zone is developed covering most of the length of the earthen shank. So, a relatively shorter length of the Betil spur is exposed to the flow. The flow obliquely hits at exposed part of the Betil (i.e. at the belmouth). As a result, the belmouth of the RCC spur is damaged.



(a) Flow processes around Betil spur (b) Flow processes around Enayetpur spur

(Reproduced from hand sketching of the local people: see Fig C22 and C23 in Appendix C)



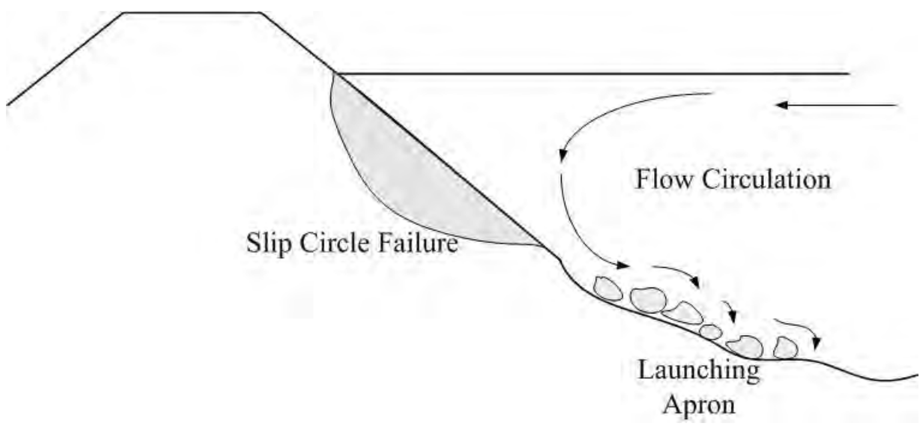
(c) Flow processes around Betil spur sketch (d) Flow processes around Enayetpur spur

(Fig c is reproduced from hand sketching of SDE BWDB: see Fig C16 in Appendix C)

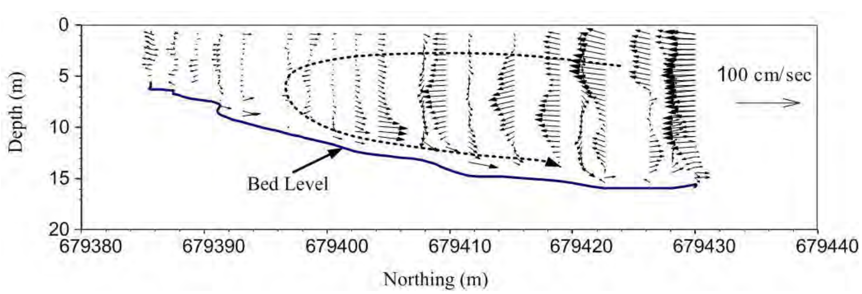
Figure 7.13: Flow and erosion processes around Betil and Enayetpur spurs

Structural failure:

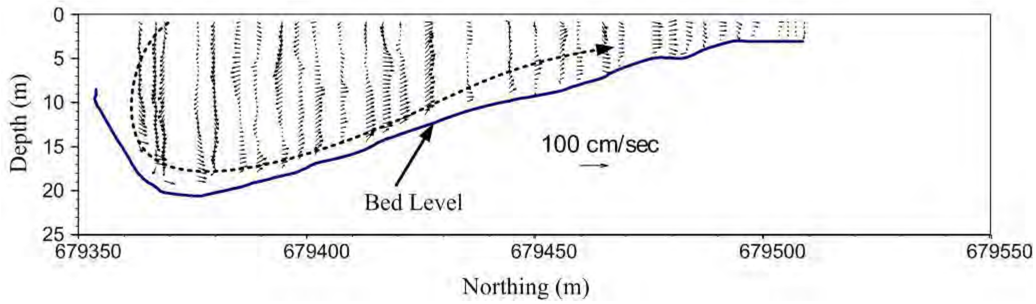
The local people gave information that the flow of both approach channels jointly attack at the earthen shank. The attacking of combined flow on the spur is responsible for the structural failure. There are some hidden causes which are explained by Sub-Divisional Engineer (SDE) as shown in Fig. 7.14(a). It is true that the oblique flow attacks to the earthen shank. At the same time, flow circulation is occurred and the bed materials are removed below from the launching apron. Consequently, the launching apron is displaced and slip circle failure is occurred. The flow phenomenon along the vertical plane sketched by SDE is further clarified through the field measured results. The flow circulation normal to the earthen shank of the Enayetpur is shown in Fig. 7.14(b). The flow circulation normal to the belmouth of the Enayetpur is shown in Fig. 7.14(c). The bed materials are clean out by the circulating flow. A deep channel is developed close to the earthen shank of the spur. For this reason the slip circle failure is occurred. This issue is clarified in section 6.3.2 of chapter six.



(a) Flow circulation (Reproduced from hand sketching of SDE: see Fig C17 in Appendix C)



(b) Flow circulation normal to the earthen shank of the Enayetpur spur



(c) Flow circulation near belmouth of the Enayetpur spur

Figure 7.14: Flow circulation normal to the earthen shank

7.3.3 Flow and erosion processes around Shuvogacha spur

Flow and erosion processes:

During FGD, the local people gave information that the rate of erosion is increased after the failure of the RCC spurs located at Shuvogacha. They provided information that one of the main causes of the failure of the RCC spurs is the alignment of the RCC spurs. During FGD local people informed that before construction of the RCC spur they gave their opinion to BWDB personnel about the alignment of spurs. Their opinion about orientation of the RCC was that the spur should be constructed pointing downstream direction so that the flow could pass smoothly in the downstream direction. Their proposed alignment is shown in Fig. 7.15. But the BWDB official strongly refused the local people's proposed orientation of the RCC spurs. The spurs were constructed pointing upstream direction as per BWDB personnel decision. As a result, the flow is strongly obstructed by the spurs. The floating debris such as banana trees, grasses, etc. were accumulated upstream of the spurs. The vortex or reverse flow was formed near the earthen shank of the spur as shown in Fig. 7.16. The local people showed through hand sketching that the flow passing the spur again attacked the bank line after some distance downstream of the Shuvogacha spur. Severe erosion is occurred at that location. The erosion process is continued upstream and downstream sides of the earthen shank.

The flow phenomenon as shown in Fig. 7.16 is sketched by the local people after 10 years of the failure of the RCC spurs. The flow phenomena also sketched by the BWDB personnel during the failure of the RCC spur (Fig. 7.17). A similar type flow phenomenon is found from the hand sketching of both groups. The BWDB personnel showed that a reverse flow was developed adjacent to the earthen shank. A strong return current was also generated downstream side of the spur. Interesting information found from the flow processes sketched by local people as shown in Fig. 7.16 is that the flow processes around a spur is quite similar to which is usually found in the laboratory investigation (Fig. 7.18). We can confidently state that local people's experienced based knowledge on flow and erosion processes are no less than that of the technical persons working in the field and knowledge acquired from the laboratory investigation.

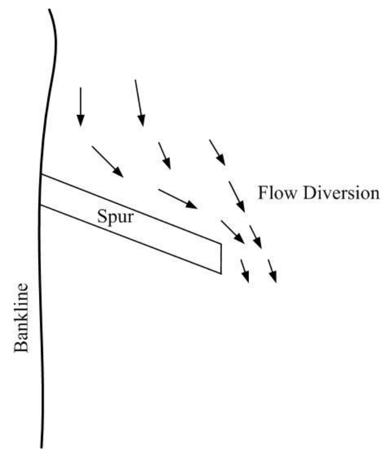


Figure 7.15: Alignment of RCC spur proposed by the local people pointing downstream direction (Reproduced from hand sketching of the local people: see Fig C10 in Appendix C)

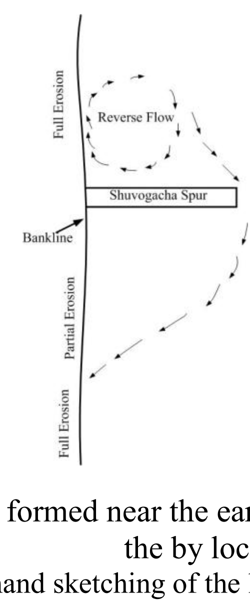


Figure 7.16: Reverse flow formed near the earthen shank of the Shuvogacha spur (observed the by local people)
(Reproduced from hand sketching of the local people: see Fig C11 in Appendix C)

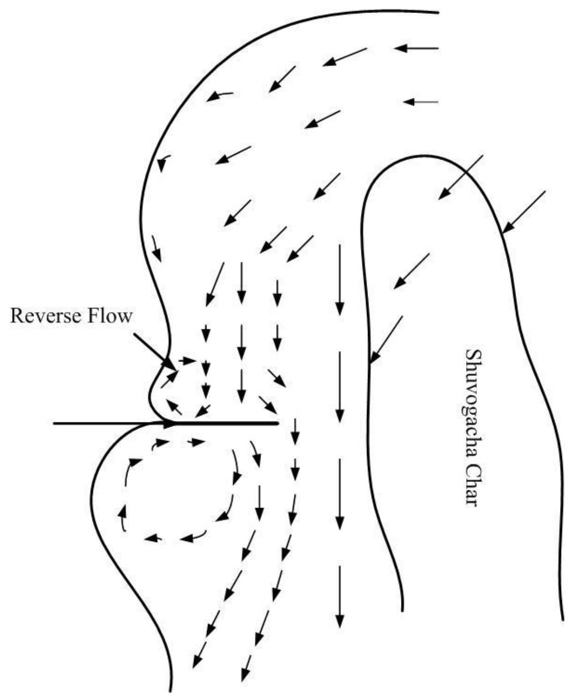


Figure 7.17: Actual flow phenomena observed during the failure of the Shuvogacha RCC spur (Reproduced from hand sketching of the BWDB personnel: see Fig C13 in Appendix C)

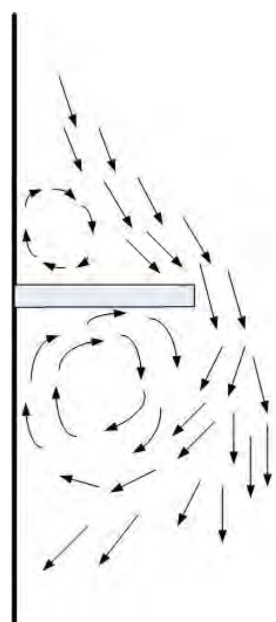


Figure 7.18: Typical flow phenomena usually observed in the laboratory study

Structural failure:

The flow processes around the Shuvogacha spur is already discussed. The local people could give clear explanations about the causes of failure of the Shuvogacha spurs. They explained that the erosion is accelerated along the bank line just upstream of the earthen shank due to reverse flow (*local term ulta aoor or vhorka*). The scour hole is developed adjoining the earthen shank and bank line due to this reverse flow. Finally, the earthen shank of the spur is collapsed. Water started to flow through space in between the RCC part of the spur and the bankline. It is found from a sketch prepared by the local people (Fig. 7.19) that a deep scour hole is developed near the nose of the RCC part. They believe that after failure of the Shuvogacha spur the rate of erosion is increased towards the mainland.

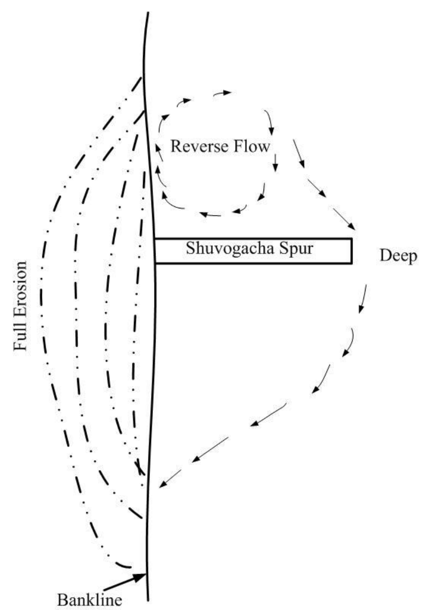


Figure 7.19: Erosion processes after failure of the earthen shank of the Shuvogacha spur
(Reproduced from hand sketching of the local people: see Fig C12 in Appendix C)

7.3.4 Flow and erosion processes around bandal structures

Flow and erosion processes:

The local people sketched of the flow processes around Randhunibari bandal site as shown in Fig. 7.20. They explained that the flow entered into the Randhunibari channel from the main channel of the Jamuna River. The flow obliquely attacks the Randhunibari market place. Then the flow changes its direction towards the south-east direction. After that the flow attacks the Char Konabari. Again, water flows towards the Mukimpur groin. It is also evident from the field measured result (Fig. 7.21) that the flow entered into the Randhunibari channel from the main channel of the Jamuna River. The flow obliquely attacks at Randhunibari market place. Then the flow changes its direction towards the Char Konabari. It is clear that the local people's perception is exactly similar to the filed measured result.

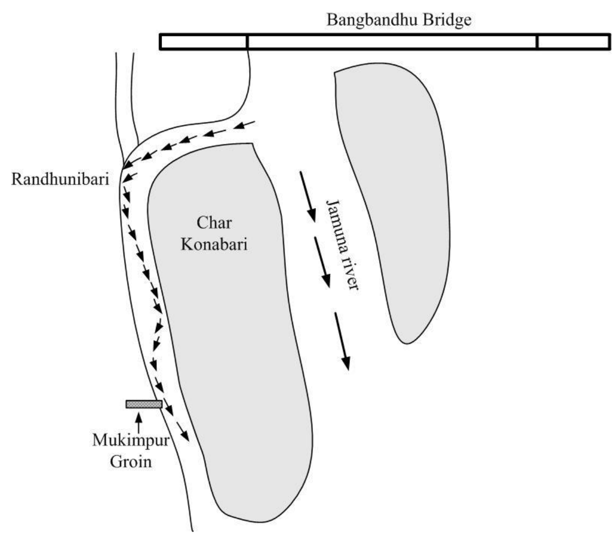


Figure 7.20: Flow processes around Randhunibari bandal site observed by the local people
(Reproduced from hand sketching of the local people: see Fig C24 in Appendix C)

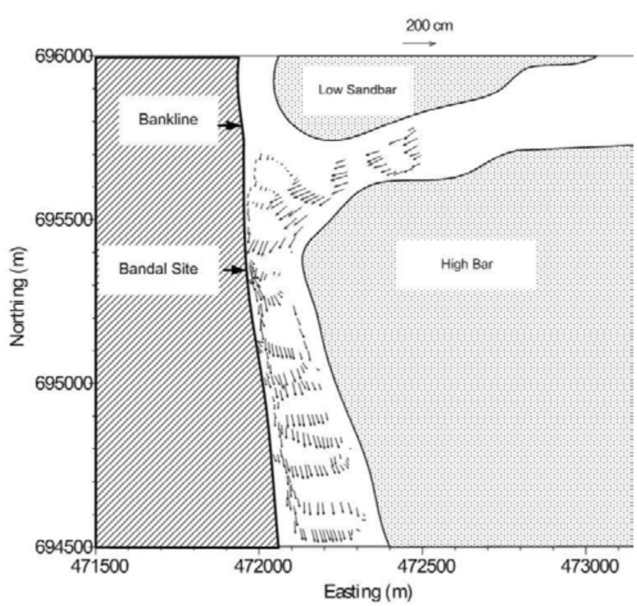


Figure 7.21: Flow processes around Randhunibari bandal site (field measured)

7.3.5 Summary

It is found from this section that there are similarities among indigenous knowledge, field engineer's knowledge, field measured result and laboratory based technical or scientific knowledge. There are close relationships of knowledge on flow and erosion processes around different types of bank protection works. First of all, the local gather knowledge through visual observation. Later on they could explain their experienced based knowledge. The local people minutely observe the flow and failure mechanism of the bank protection structures. One important issue has been investigated from the present study that the local people can guess before failure of the bank protection work observing some indications. The indications are bustling out of air bubble, floating bamboo and geo-textile and turbid water. The field engineers are agreed with the above indications. The field engineers also explained the reasons of such indications in the technical view point. If the field engineers, who are involved in the management activity of the bank protection works, take help from the local people's experienced knowledge regarding the failure event. Accordingly, taking management program the failure event may be avoided or the degree of damage may be reduced. There is scope of integration of indigenous knowledge on failure event with technical knowledge regarding management activity.

It is evident that among different groups of the riparian population, the fishermen and boatmen are well aware of the changes of the river morphology and flow processes. We can get latest information without any technical measurement on flow and erosion processes at a particular region where they always move. Although they can give gross idea but we can guess actual field situation on the basis of their given information.

7.4 Concluding Remarks

The local people are well acquainted with the flow and erosion processes. They have knowledge on flow and erosion processes around different bank protection works, flow and erosion processes at bends, erosion processes at the straight bankline, historical morphological change, bend development, the trend of the rate of erosion, effective duration of erosion. It is evident from the study that there are strong similarities among information given by the local people, information prepared by technical personnel, field measured result and laboratory based scientific knowledge. It is also found that all groups of people have knowledge on flow and erosion processes. But the erosion-affected people and people living near the bank line know about the bank erosion processes. The fishermen and boatmen have clear idea of flow and erosion processes around the bank protection works. They can give more accurate information on flow phenomena because they always move in the river from one place to other place. During moving in the river by boat they observe the flow phenomena and morphology of the river and they gather knowledge through visual observation. It has been investigated from the present study that the information obtained from local people on flow and erosion processes are very close to the field situation. This information on flow and erosion processes may be received from the local people's without any scientific measurement. It is found from the present study that the local people could guess the bank protection structure is going to be failed observing some indications (i.e. bustling out of air bubble, floating bamboo and geo-textile and turbid water). Immediately, they convey this message to the BWDB personnel for management activity. Such indigenous knowledge would be very useful for the management activity. The degree of damage may be reduced through integrating indigenous knowledge on failure event with technical knowledge regarding management activity. So, we should evaluate the indigenous knowledge especially during the emergency situation.

CHAPTER EIGHT

CONCLUSION AND RECOMMENDATION

8.1 Conclusions

The main outcomes of the present research work are as follows:

8.1.1 Flow and erosion processes at bends:

In the present study it is found that the secondary current in a bend channel of a third order channel of a braided river is similar to that of the single thread meandering channel. But the secondary cell is divided into multi-cell due to flow over the sandbar. It is found from the present study that the bend channel migrate downstream, lateral direction and also upstream direction. The maximum rate of erosion is observed at the upstream and downstream sides of the bend. At these two locations the shear velocity is six times higher than critical shear velocity and the thalweg is also near the bankline.

8.1.2 Failure mechanism of the river training works:

Sirajganj hardpoint: It is evident that the rapid morphological change in a sand-bed braided river is a great challenge for the structural stability of river training works. The flow processes around a river training works is guided by the morphology especially the sandbar around the river training works. The flow processes around a bank protection work is changed with morphological change. It is investigated that the oblique flow a prime factor for the failure of the river training works. Other factors also accelerate the failure of the river training works. From the analysis of flow processes and morphology around the Sirajganj hardpoint it is clarified that the following are reasons of the failure of the Sirajganj hardpoint such as: (i) generation of oblique flow by sandbar and attacked the hardpoint; (ii) washed away of sandbar adjacent to the hardpoint; (iii) thalweg shifting at the vicinity of the hardpoint; (iv) failure of due to movement of 5m high dune through the channel passing adjacent to the hardpoint (v) development of scour hole because of riprap failure ; (vi) flow slides from the hardpoint side.

Failure of the Betil and Enayetpur spurs: The causes of failure of the Betil and Enayetpur spurs have been investigated from the present study. The causes are as follows: (i) generation of oblique flow as a result of upstream morphology of both spurs; (ii) strong parallel flow upstream of both spurs; and (iii) development of deep channel due to flow circulation normal to the spurs. The oblique flow may be drive away from the river training works towards mid-channel by adopting supplementary measures. But the nature and quality of the construction materials of the supplementary measures is a great issue. It is also found from field measured data analysis that the bandal-like structure is very effective as flow diversion and sediment deposition measure. But selection of site for implementing of such structures is a major factor in a large scale sand bed braided river.

8.1.3 Development of erosion prediction model:

An analytical erosion prediction model has been developed for the third order channel of a sand bed braided river. In the developed model the flow parameters, planform parameters, properties of bank materials and the indigenous knowledge have been used to estimate the rate of erosion. The indigenous knowledge regarding effective period of erosion has been integrated during developing the erosion prediction model. The model basically produces an envelope curve. The envelope curve covers eighty seven percent of the observed data and seventy eight percent of EGIS data. Using the above mentioned information in the developed model, the field engineers could estimate the rate of erosion for the third order channel of a sand braided river.

8.1.4 Indigenous knowledge on flow and erosion processes:

It is evident from the present study that the riparian people are enriched with indigenous knowledge on flow and erosion processes around different bank protection works, flow and erosion processes at bends, erosion processes at the straight bankline, historical morphological change, bend development, the trend of the rate of erosion, effective duration of erosion. Most of the indigenous knowledge is based on experience. It is clarified from the present study that there are strong similarities among experience-based indigenous knowledge, field engineer’s knowledge, field measured result and laboratory based scientific knowledge. Interesting outcome of the present study is that the local people can guess the bank protection structure is going to be failed observing some signs (i.e.

bustling out of air bubble, floating bamboo and geo-textile and turbid water). Observing such signs, the local people convey message of probable failure of the bank protection works to the BWDB personnel for taking necessary steps to avoid failure event. By taking necessary steps immediately the failure event may be avoided. Therefore, the indigenous knowledge should be considered positively for management activity during emergency situation.

The outcome of the present research work on flow and erosion processes at bends of the third order channel of a sand bed braided river, the failure mechanism of the river training works with rapid changing flow and morphology, erosion prediction model for third order channel of sand bed braided river and indigenous knowledge on flow and erosion processes would be the part of the permanent literature.

8.2 Recommendations

The recommendations for the further research are as follows:

- The erosion prediction model is applicable for the secondary channel of a sand bed braided river. The present erosion prediction model is developed based on one set of velocity and depth of water data. But these two parameters always change with time. Therefore, the value of these two parameters should be used of different time and different reaches of the river.

- Additional flow diversion is proposed to divert oblique flow away from the revetment-like and groin-like structures in the present study. The effectiveness of additional flow diversion structure should be confirmed through experiment in laboratory before implementation in the field level as pilot basis.

- Failure of the bank protection structures along the Jamuna River is a very common event. So, it is essential to identify the insight problem of each structure; and accordingly appropriate measures should be implemented to overcome the problem.

- It is investigated from the present study that the local people have a lot of knowledge on flow and erosion processes. Their knowledge stock also varies from place to place. The indigenous knowledge is very helpful for the management activity. Hence, further study should be conducted to investigate additional indigenous knowledge. So that flow and erosion related problems may overcome effectively.

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APPENDIX: A

Socio-Economic Impact of Erosion

1. Introduction

Riverbank erosion has long-term and short-term impacts. It has an impact on livelihood, agriculture, environment and other sectors. In this section the socio-economic impact of erosion would be discussed. Though Shuvogacha is the most vulnerable location during the discussion, Shuvogacha is lightly highlighted here. The socio-economic impact on another three locations, i.e. Sirajgang, Betil-Enayetpur and Randhunibari, are also discussed. The data was collected through the semi-structured questionnaire survey. The informations on the following issues are collected during the questionnaire survey such as: losses of livelihoods, generated vulnerabilities, social destruction, impacts on agriculture, impacts on environment, relief and benefit for erosion victims and livelihood dependency on the river.

2. Shuvogacha

Shuvogacha under Kazipur Upazila of Sirajganj district is one of the erosion prone areas along the right bank of the Jamuna River. Shuvogacha is located in between Sirajganj town and Kazipur Upazila. The river was very aggressive at Shuvogacha before the construction of two spurs. The bazaar, homestead and valuable agricultural land were being eroded continuously. Two RCC spurs were constructed in the year 1999-2000 under the project "*Protection of Meghai Bazar, Shuvogacha and Simla area from erosion of the Jamuna River*". The RCC spur number one located at Shuvogacha was damaged in June during the 2001 flood. A portion of RCC part of the spur number two was also damaged on 18th September 2000 during its construction. It was rebuilt in the year 2000-2001. The earthen shank was washed away in the monsoon of the same year of 2001. The failure event occurred so quickly that there was a little chance to perform repair works without some emergency works. The RCC part is now standing in the char detached from the earthen shank. The main channel had started to flow near the right bank since 2001. As a result, the rate of bank erosion increased sharply. The situation became worse from 2003-2005. The main flow of the Jamuna River directly attacked the right bank in 2006. At that time, it was observed that the tendency of the main channel of the Jamuna River was gradually shifting its course towards the west.

Brahmaputra Right Embankment (BRE) was at a distance about 400m from the bankline of the Shuvogacha bend in 2008. Some portions of the bank get inundated during the flood season. At that time the river flow directly attacked the BRE. But according to the early practice, the BRE was protected from wind wave action by erecting bamboo as shown in Fig. A1(a). Later, the river side of the BRE was protected by geo-textile with cc blocks as shown in Fig. A1(b) in 2009. The homesteads and crop lands are being eroded into a secondary channel (Shuvogacha branch channel). Bank erosion and char formation are the regular phenomena at the Shuvogacha bend.

Three-fourths of the Shuvogacha Union is now inside the Jamuna River. There were about 2900 hectares of land in the Shuvogacha Union before erosion, while at present only about 450 hectares of land remain (Table A1). One of the Union Parishad (UP) members of Shuvogacha said that during the 2001 national election, total number of voters of the Shuvogacha union was 16,500, but during the 2008 national election it was 7,565. From this information anybody can guess how many people have been affected by erosion. The number of educational institutions and mosques before erosion was 30 and 60 respectively. After erosion, the number of educational institutions and mosques is 15 and 40 respectively. The capable people have migrated to towns. Only poor people are living in the char or slope of the BRE. About 67 % of the total families are poor and ultra-poor (Table A2).

(a) In 2008 (b) In 2009

Figure A1: BRE is protected by erecting bamboo or geotextile with concrete block at Shuvogacha

Table A1: Some important information of the Shuvogacha union

Sl. No	Before Erosion	After Erosion
Mouza	9	9*
Number of voter	16,500 (2001)	7,565 (2008)
Land	2900 hectares	450 hectares
Educational Institution	30	15
Mosque	60	40
Graveyard	20	17
Pucca road	-	1 km
Kaccha road	-	45 km
Literacy rate	-	65 %
Post office	3	2
Registered club	5	2

Source: UP Member
*Most of the mouza (land plots) inside the river

Table A2: Classes of family depending on the property of the Shuvogacha union

Class	No of Family	Percent (%)
Rich	321	12
Middle class	553	21
Poor	966	37
Ultra-Poor	797	30
Total	2637	100

Source: Proposed budget for 2007-2008 fiscal year of Number 4 Shuvogacha Union Council.

3. Losses of Livelihood

River erosion seriously affects the livelihood of the riparian population. Due to riverbank erosion, many farmers become poor overnight. They lose homestead, houses, cultivable land and trees and all other properties. It is found that at all places cent percent of the respondents have lost their homestead and living houses (Table A3). About 90%, 84%, 87% and 100% of the respondents of Shuvogacha, Sirajgang, Betil-Enayetpur and Randhunibari areas had cultivable land respectively. But during erosion they lost their cultivable land. Many of the erosion-affected people live near their eroded place for reemergence of the land. In Char Konabari near the Randhunibari about 50% of the respondents go back to their reemerged land. They built houses several years back; at present they are living there. Some respondents of the Randhunibari area lost their loom factory due to erosion. Before erosion when they can guess that there is a possibility of erosion of their homestead. They follow a strategy that first they cut the big trees. They keep small tress and wait for erosion. Some respondents have also lost their pond, dug well, tube well and latrine.

Table A4 provides the information about eroded cultivated land area. Most of the erosion affected people had cultivated land up to 2 ha. On an average one fourth of the victims had cultivated land ranging from 2 to 4 ha. A few of the respondents were land owners more than 4 ha. Though this percentage is very few but they become poor overnight by losing everything (Schumuck-Widmann, 2001). The cultivated land is the main source of income of most of the rural people. The heart of anybody is affected seeing their distressed situation.

A famous song in Bangla is:

"Nadir Ekul Bhange Okul Gore Eito Nadir Khela.
Sakal Bela Amir Re Bhai Fakir Sandhabela."

One bank of a river is eroded and another bank is formed,
It is the game of a river.
Due to this game a man is wealthy in the morning,
But in the evening he is turned into a beggar.

Table A3: Losses of livelihoods

Sl. No.	**Item**	**Shuvogacha**	**Sirajganj**	**Betil-Enayetpur**	**Randhunibari**
		(%)	(%)	(%)	(%)
1.	Homestead	100	100	100	100
2.	Houses	100	100	100	100
3.	Cultivable land	90	84	87	100
4.	Pond	35	32	13	10
5.	Dug well	25	16	7	10
6.	Tube well	15	12	20	-
7.	Trees	90	72	67	70
8.	Latrine	30	20	27	60
9.	Factories (loom)	-	-	-	50

Table A4: Losses of cultivated land

Sl. No.	Cultivated land (ha)	Shuvogacha N=20	Sirajganj N=25	Betil-Enayetpur N=15	Randhunibari N=10
		%	%	%	%
1.	0-2	70	60	53	80
2.	2-4	25	28	33	20
3.	4-6	5	12	13	-
4.	6>	-	4	-	-

4. Generated Vulnerabilities

Different types of vulnerabilities are generated as a result of erosion (Table A5). They become homeless by losing their original homestead and houses. Temporarily they built huts on the side of BRE or they purchase a piece of land and build houses for living. Sometimes relatives or other people also give a piece of land to build huts. Many of the victims migrated to the nearest town or big city like Dhaka. Hossian (1991) mentioned that the displacees move to one of the several places: (i) to nearly rural areas, (ii) to the flood protection embankment, (iii) to emerged charland, and (iv) to nearly urban area. In the present study about cent percent of the respondents of Sirajganj town migrated as a result of erosion. On an average, about 40% of the respondents have changed their occupation. In the Shuvogacha area, a number of respondents are van drivers or wage laborers but before they cultivate their own land. In the Sirajgang town, a number of respondents are now doing small business on roadside or others are working as masons or boatmen. In the Betil and Enayetpur areas most of the respondents are working in the hand loom industry or as wage laborers. In the Randhunibari area, a number of respondents are working in the hand loom industry and also work as wage laborers. Some people run up debts due to erosion. There is also evidence of school dropouts and child marriage.

5. Social Destruction

The social damage created as a result of bank erosion is shown in Table A6. Highest percent (95%) of the respondents of the Shuvogacha area opined that social bondage and family relation are broken down due to erosion. As a consequence of erosion, many people are compelled to change their occupation. It is already discussed that many people migrate to urban areas in search of shelter, employment and food.

Table A5: Generated vulnerabilities

Sl. No.	Item	Shuvogacha	Sirajganj	Betil-Enayetpur	Randhunibari
		(%)	(%)	(%)	(%)
1.	Homeless	90	72	73	30
2.	Landless	90	76	93	50
3.	Displacement	100	100	73	30
4.	Indebted	10	16	22	10
5.	Unemployed	-	12	11	-
6.	School drop out	10	16	33	-
7.	Child marriage	5	-	22	10
8.	Change of occupation	40	32	53	50
10.	Asset selling	-	-	-	20

Table A6: Social destruction as a result of bank erosion

Sl. No.	Item	Shuvogacha	Sirajganj	Betil-Enayetpur	Randhunibari
		(%)	(%)	(%)	(%)
1.	Broken social bondage	95	80	53	87
2.	Broken family relation	95	72	27	33
3.	Occupational change	25	56	67	50
4.	Migration to city	50	56	-	-
5.	Disruption to social services	10	12	60	100
6.	Broken social network	65	44	47	75
7.	Degradation of social status	55	33	33	53
8.	Ruin of peace	35	28	27	53
9.	Increase of social injustice of the poor by the power and rich group	-	8	-	13

A good number of respondents said that social services and social network are broken down as a result of erosion. The people who are living on charland are deprived of medical services in the emergency situation. During an emergency situation it is very difficult for them to arrange transport like boat or other vehicle. The mainland people called the charland people as *choura* (Schumuck-Widmann, 2001, Zaman, 1991). They express its meaning as inferior status of the char people. Some people made known that their peaceful life was shattered completely.

6. Impact on Agriculture

Riverbank erosion has a great impact on agriculture (Schumuck-Widmann, 2001). The impact on agriculture as a result of erosion is shown in Table A7. On an average, seventy percent of the respondents opined that the cropping pattern is changed as a result of bank erosion. It also affects the crop diversity. Rice growing fertile cultivable land becomes unsuitable for rice cultivation. Though the fertility of the land reduces as a result of the yield of the land decline, they grow on the newly formed charland maize, dal, til, groundnut, etc. There is a change in the crop diversity. Not all the emerged land is suitable for crop growing so there is also change in the crop intensity. About seventy percent of the respondents said the crop was severely damaged due to erosion.

7. Impact on Environment

The impact on the environment due to bank erosion is shown in Table A8. On an average, sixty five percent of the respondents express their view that crop land is affected by sand deposition. As a result, it disrupts the crop production. Erosion and char formation are continuing in the Jamuna River. The depth of the river is decreasing gradually. The channel near the bankline dried up so fish are usually unavailable in this channel. Only 36% of the respondents give information that now fish are available during the dry season. About 70% of respondents have expressed their opinion that they have access to safe drinking water. About seventy five percent of the respondents believed that shallowness of the Jamuna River is one of the main causes of erosion. About 40% and 75% of the respondent at Betil-Enayetpur and Randhunibari areas respectively express their opinion that the river is polluted by waste water discharged from the handloom industry.

8. Relief and Benefit for Erosion

The relief and benefit received by the bank erosion victims are presented in Table A9. It is found from this Table that only one fifth of the respondents received relief during the emergency situation. At present some NGOs are working on the char. They are helping the charland people in raising their homestead to be safe from high flood. Erosion and deposition are the synchronized process. Therefore, erosion is caused at one place and deposition or char formation occurs at another places.

They get their original land through the formation of a new char. Thus, sometimes they indirectly are benefited from bank erosion.

Table A7: Impact on agriculture as a result of bank erosion

Sl. No.	Item	Shuvogacha	Sirajganj	Betil-Enayetpur	Randhunibari
		(%)	(%)	(%)	(%)
1.	Impact on agriculture	90	84	73	100
2.	Changed cropping pattern	70	80	60	80
3.	Decline of production	65	72	67	60
4.	Change in crop diversity	50	64	53	50
5.	Impact on cropping intensity	75	52	60	60
6.	Damage of crop	65	76	67	80

Table A8: Impact on environment as a result of bank erosion

Sl. No.	Item	Shuvogacha	Sirajganj	Betil-Enayetpur	Randhunibari
		(%)	(%)	(%)	(%)
1.	Cropland affected by sand deposition	75	72	67	60
2.	Fish available in dry season	35	32	47	10
3.	Water quality	35(not affected)	40 (not affected)	40 (affected)	75(affected)
4.	Access to safe drinking water	75	76	65	70
5.	Erosion due to low channel depth	75	80	73	80

9. Livelihood Dependency on River

At almost all the sides, a number of the respondents are dependent on the Jamuna River for different purposes as washing, bathing, cleaning, fishing, crop cultivation, transportation, recreation and livestock. Table A10 provides the livelihood dependency of the erosion affected people on the river. About 84% of the respondents of Sirajganj town are dependent on the river for washing, bathing and cleaning. About 60% of the respondents use river for fishing. At Betil, Enayetpur and Randhunibari about 70% of the respondents are dependent on the river for transportation purposes. Especially those people who live on the charland are solely dependent on boat as transport to go to the mainland. About 25% of the respondents of the Randhunibari area use river water for crop cultivation. About 75 % of the respondents of the Betil, Enayetpur and Randhunibari areas use the river for livestock purposes.

Table A9: Relief and benefit of erosion victims

Sl. No.	Item	Shuvogacha	Sirajganj	Betil-Enayetpur	Randhunibari
		(%)	(%)	(%)	(%)
1.	Received relief service	20	20	33	-
2.	Shelter on embankment	20	16	-	-
3.	Development services from NGOs	10	-	33	25
4.	Land from accreted char	5	8	33	100
5.	Aid in raising homestead	-	-	33	50

Table A10: Livelihood dependency on river

Sl. No.	Item	Shuvogacha	Sirajganj	Betil-Enayetpur	Randhunibari
		(%)	**(%)**	**(%)**	**(%)**
1.	Washing, bathing, cleaning	45	84	80	70
2.	Fishing	45	60	67	60
3.	Transportation	20	24	67	75
4.	Cultivation of crop	-	4	-	25
5.	Recreation	10	12	20	10
6.	Livestock	15	16	73	80

10. Summary

From the above discussion it is clear that the erosion has a great impact on the livelihoods of riparian population, agriculture, and environment. As a consequence of erosion, different types of vulnerabilities are generated. Family relation and social bondage are broken down, and social status is degraded. Social services and social networks are disrupted. Therefore, structural measures and at the same time non-structural measures should be adopted. Though a number of bank protection works are constructed along the Jamuna River and erosion is stopped locally with the aid of the construction of the bank protection works. It is essential for the prediction of erosion and the forecasting of the predicted results. CEGIS is performing this work on a routine basis depending on the sedimentary feature. A new prediction model should be developed including hydraulic parameters. In the next section a discussion would be followed up regarding erosion prediction.

APPENDIX: B1

Social Survey on River Bank Erosion under DelPHE project

Questionnaire

Name of respondent:
Age:
Occupation:
Education:
Address:
Village:
Union:
Upazila:
District:
No. of family members:
No. earning members:
Name of neighboring river(s):
Distance of residence/home from neighboring river:

A. Impact of river erosion:

1. How many times your household been victimized by the river erosion?
2. What were the consequences?

Losses of livelihoods assets:

Item	Number	Item	Number
- cropland (how much)		- van	
- homestead		- boat	
- pond		- bicycle	
- dug well		- tractor	
-commercial land (market/factories		- pump machine	
- shop		- cow	
- houses (kachcha/pacca)		- goat	
- trees (timber/fruits):		- chicken	
- tube well:		- duck	
- latrine:		- any other assets:	
- rickshaws			

What vulnerabilities been generated?

- Homeless	- children's drop out from school
- landless	- illness
- migration	- child marriage
- unemployed	- asset selling
- indebted	- change of occupation
- separation/divorce	

What kinds of social destruction caused by river erosion in your life world?

- Broken social bondage
- Broken family relation
- Compelled in changing occupation
- Migration to city
- Closed access to social services
- Broken the social networks
- Lowered social status
- Destroyed peace, love and happiness in family and social life
- Generated oppressions for women by men and poor by rich

Impact on agriculture:

- How the river erosion impacts agriculture?
  Sand deposition/reduce fertility of land/other
- Does the cropping pattern get changed? Yes/no
- What happens to cropping intensity? Yes/no
- Does the production go high or decline? High / Decline
- Does it affect crop diversity? Yes/no
- Does it affect irrigation? Yes/no
- Crop damage: yes/no

Impact on environment:

- Does the cropland get affected by sand deposition? Yes/no
- How is the availability of water in dry season? Yes/no
- Is fish available in dry season? Yes/no
- Water quality: good/bad
- Access to safe drinking water: yes/no

Access to relief and rehabilitation services:

- Received relief services: yes/no
-Received rehabilitation services: house building, agriculture inputs, loan, etc
- Got job/work
- Raising homestead

Indirect benefits:

- Land from accredited chars
- Shelter on embankment
- Development services from NGOs

B. Knowledgeability:

Causes of erosion:

- What are the causes of river erosion? Natural/Man made)
- How do you predict about river erosion?
- What risks do you face by river erosion?
- How do you survive (adaptability) after river erosion?
- What do you do (preparedness) to face future hit by river erosion?

Protection from river bank erosion:

-What kind of measures to take to protect the village from river erosion you think?
- Should it be only local knowledge based; what are those?
- Who initiate those and who manages?
- What type of materials are used?
- Should there be heavy engineering intervention; what types?
- Who and how to manage those?
- Do you think river dredging minimize erosion?
- Do you think river dredging minimize abstraction of navigation, restoration of waterways?
- How to keep river flow undisturbed?
- What is your opinion about results of interventions of the past?

C. Relationship of villagers' day-to-day life with river(livelihoods dependency):

How river serves your day-to-day life:

- drinking water	- recreation
- washing/bathing/cleaning	- health
- fishing	- livestock
- growing crops/food grains	- base flow of water
- irrigation	- bio-diversity
- transportation	

D. Villagers' dealing strategy with river bank erosion:

- How do you predict about river erosion?
- How many times you had to move in your life time for river erosion (mention the intervals)?
- At what situation you move?
- Where do you move and how?
- How do you survive in post displaced period?
    - migration
    - access to relief
    - occupation change
    - selling of assets
    - borrowing/loan taking
    - *Dadon* (loan from village moneylenders with high rate of interest)
- How do you resettle – how long it took to be resettled?
- What type conflicts arise?
- How do you deal with conflicts?
- Do you receive any emergency relief, from home and how long?
- Do you receive rehabilitation supports, from whom and what types?
- How do you cope with a new community (where you have resettled)?

E. General comments and opinion:

Name in interviewer:
Date:

APPENDIX: B2

Interview with Local Concerned Officials

Checklist

Name of respondent:

Age:

Designation:

Location of the Structure:

Type of the Structure:

1. Main goal of the protection work in this area:
2. Number with types of damages after construction:
3. What are the reasons of structural failure?
4. Is any indication usually observed before failure of a structure?
5. How such failure event may overcome?
6. Flow process around this particular bank protection work?
7. What type of structure is appropriate for effective bank protection?
8. How morphological changes affect the bank protection structure?
9. What is your opinion about soft structure (e.g. bandal) as sediment management technique?
10. What is the effective period of erosion?
11. When bank is eroded mostly: During high, low, rising or falling water levels?
12. How do the social acceptability of this structure?
13. Do you think dredging minimize erosion?
14. Do you think dredging minimize abstraction of navigation, restoration of waterways?
15. How branch channel is abandoned? Is any idea about channel development and abandoned cycle?
16. Is proposed technique is suitable for sediment acceleration?

Name in interviewer:

Date:

APPENDIX: B3

Checklist for FGD at Community Level

A. General Information:

1. Address of the study location/site

   Mouza/Village/Ward no: Union:

   Upazila/Pourashava: District:

2. Name of neighboring river(s):
3. Distance of locality from neighboring river:
4. Is the river main channel or branch channel?

B. Knowledge:

(a) Flow, erosion and morphology:

1. Do you know about the history of the morphological change of the Jamuna River?
2. What are the causes of river erosion?

   (i) natural (ii) man made

3. How do you predict about river erosion?
4. How flow attacks the river bank?
5. How do you feel that one place will erode?
6. Draw the erosion hazard map.
7. Trend analysis of rate of erosion of previous 10 years.
8. What are usual flow processes in the river?
9. How morphological changes affect the flow processes?
10. Is the adjacent charland affected due to structure or vice versa; how much?
11. Is new land accreted in your area as a result of protection works; what amount?
12. How the flow processes are modified after construction of a bank protection works?
13. What is the effective period of erosion?
14. When the bank is eroded mostly: During high, low, rising or falling water levels?
15. What is the period of channel development cycle?

(b) Bank protection works:

1. Which type of measures you took to protect your village from river erosion?
2. Is it only local knowledge based and what are these measures?
3. Who did initiate and who managed?
4. What type of materials is used?
5. Should there be heavy engineering intervention? What kind of structures?
   Hardpoint/Revetment/RCC spur/Groin
6. If any bank protection works is present there how does its social acceptability?
7. Do you think dredging will reduce erosion?
8. Do you think river dredging minimize abstraction of navigation, restoration of waterways?
9. What is your opinion about the results of interventions of the past?
10. Do you believe that the present bank protection structure is stable or not? If not. Why? Which type measures should be taken to stabilize the structure?
11. What are the reasons of structural failure?
12. How will you guess the bank protection structure fail?
13. While a bank protection structure (e.g. hardpoint, RCC spur etc) is failed? What is your opinion how this failure event may possibly overcome?
14. Usually what type of scene is created nearby the bank protection structures while it damages?
15. Do you play any role during failure of structures? Which type?

(c) Social impact:

1. Do you believe is there socio-economic changes have been occurred after construction of the bank protection structure?
2. What type of development has been accelerated?
   Construction of multi-storied building/Market/Factory/Other economic activities/Increases land value

(d) Acceptability of the proposed erosion management technique:

C. General Comments and Opinion:

Name in interviewer:

Date:

APPENDIX: C

Hand Sketching on Flow and Erosion Processes

<u>Sirajganj</u>

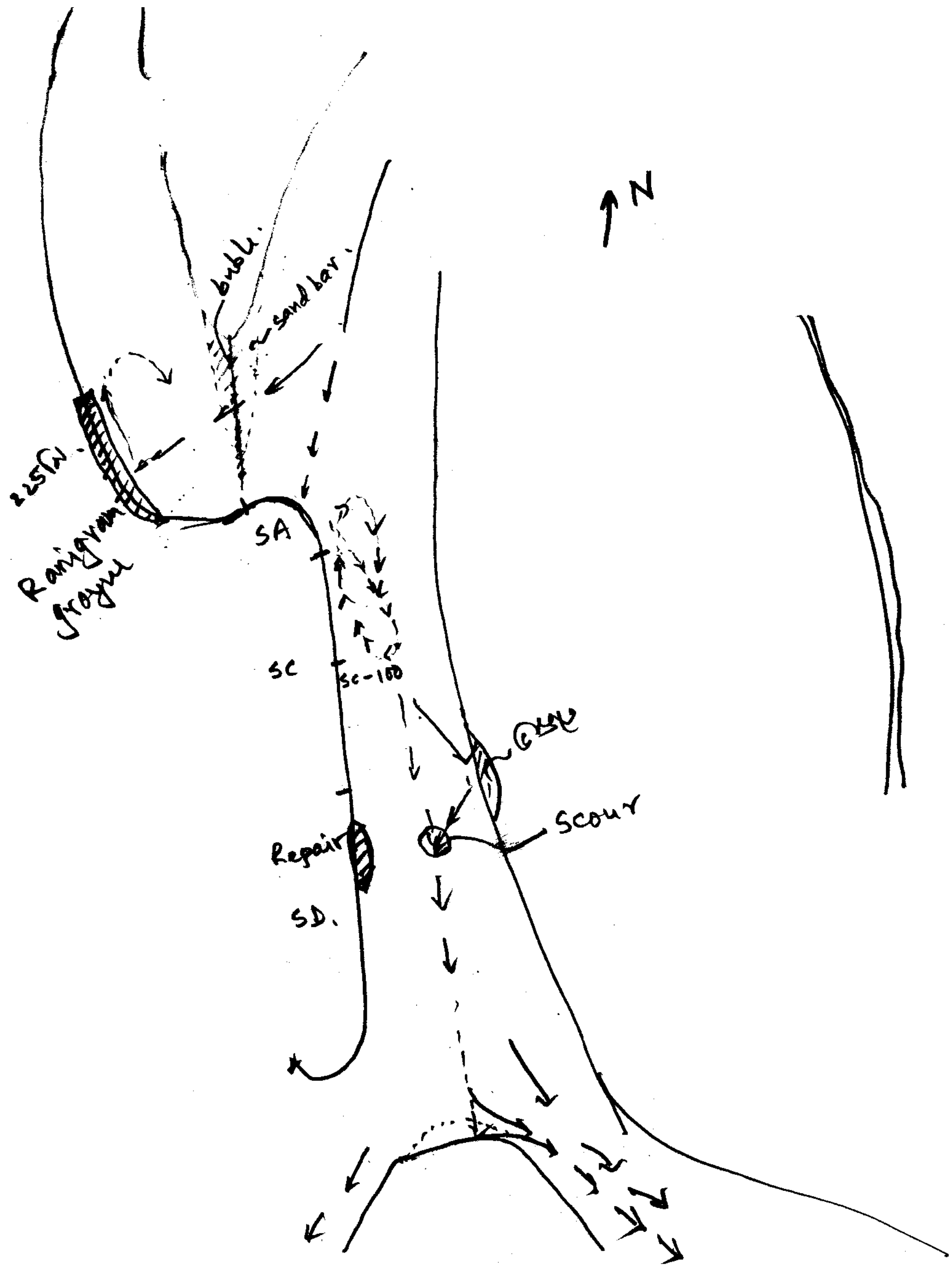

Figure C1: Flow processes around Sirajganj hardpoint (Sketched by SDE of BRE specialized division)

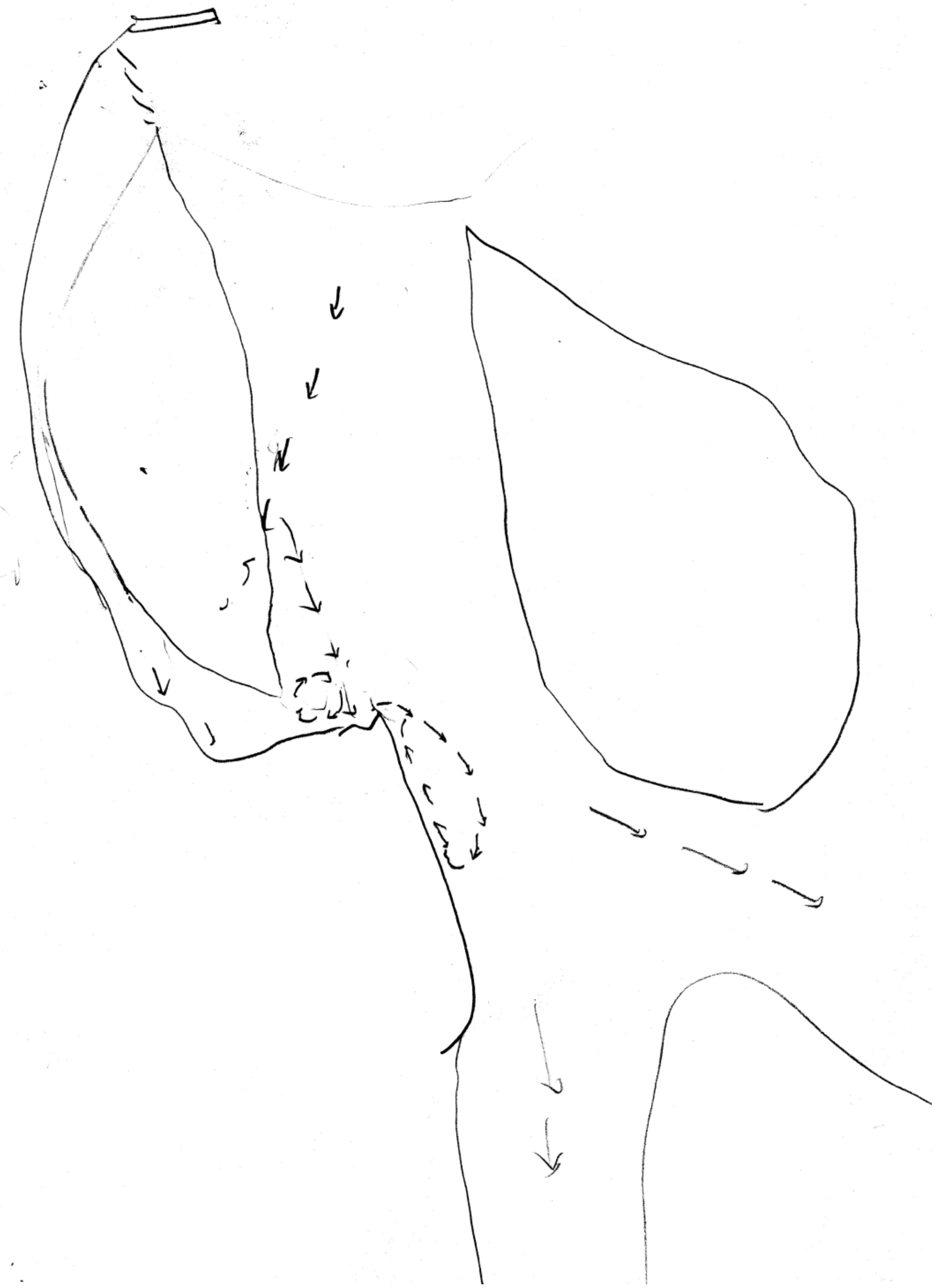

Figure C2: Flow processes around Sirajganj hardpoint (Sketched as per fisherman's opinion)

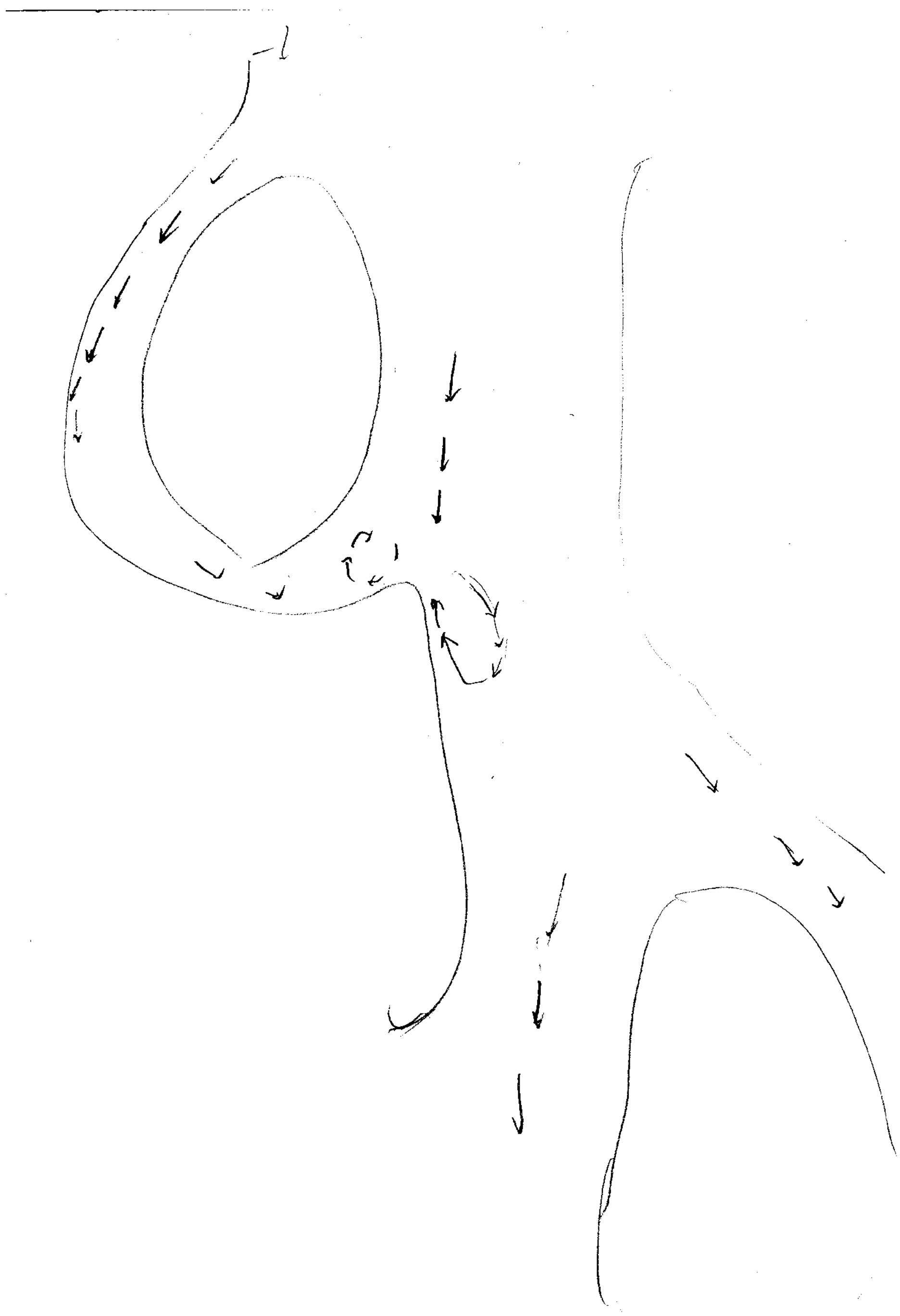

Figure C3: Flow processes around Sirajganj hardpoint (Sketched as per opinion of local people)

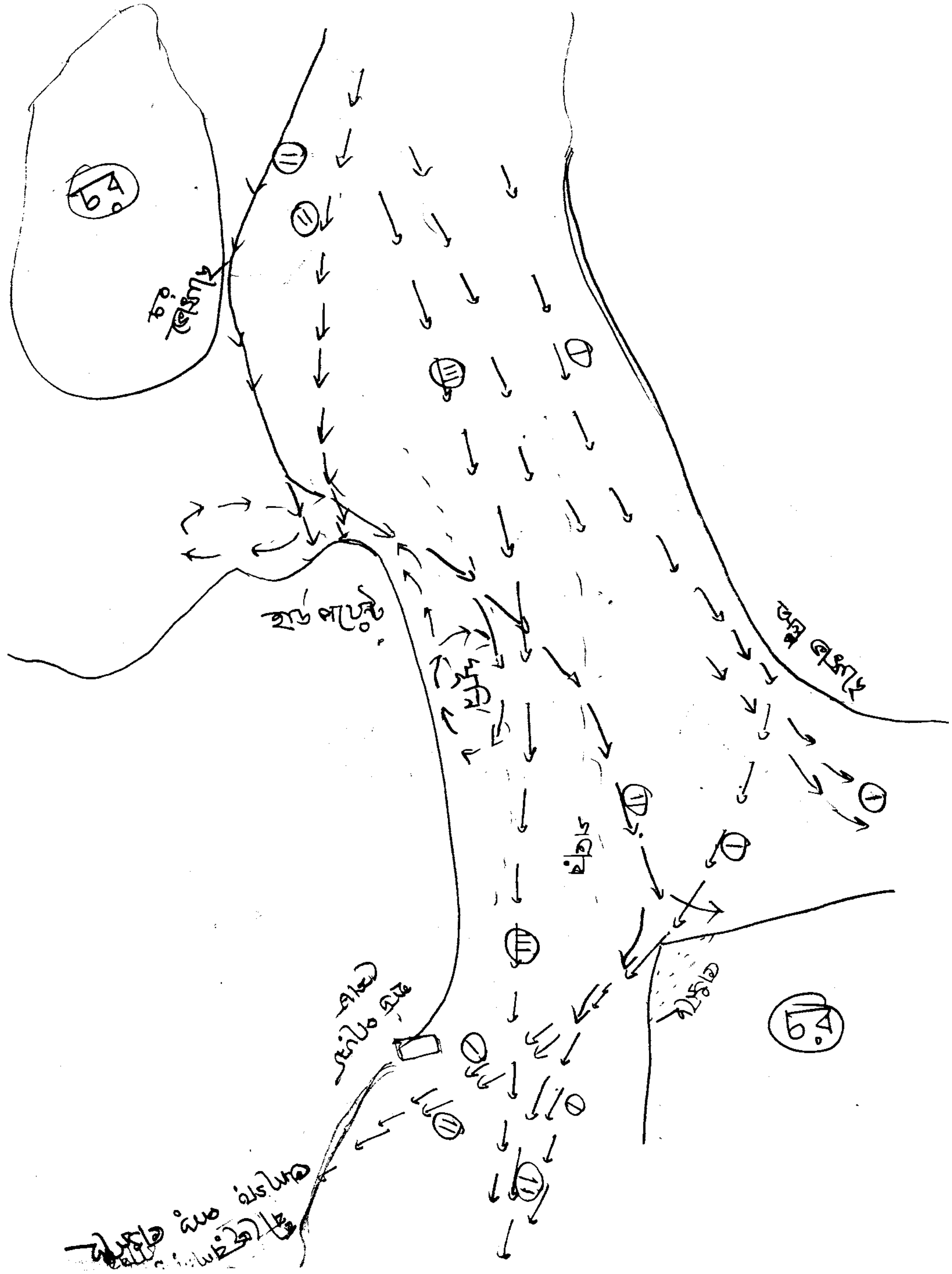

Figure C4: Flow processes around Sirajganj hardpoint (Sketched as per opinion of boatman)

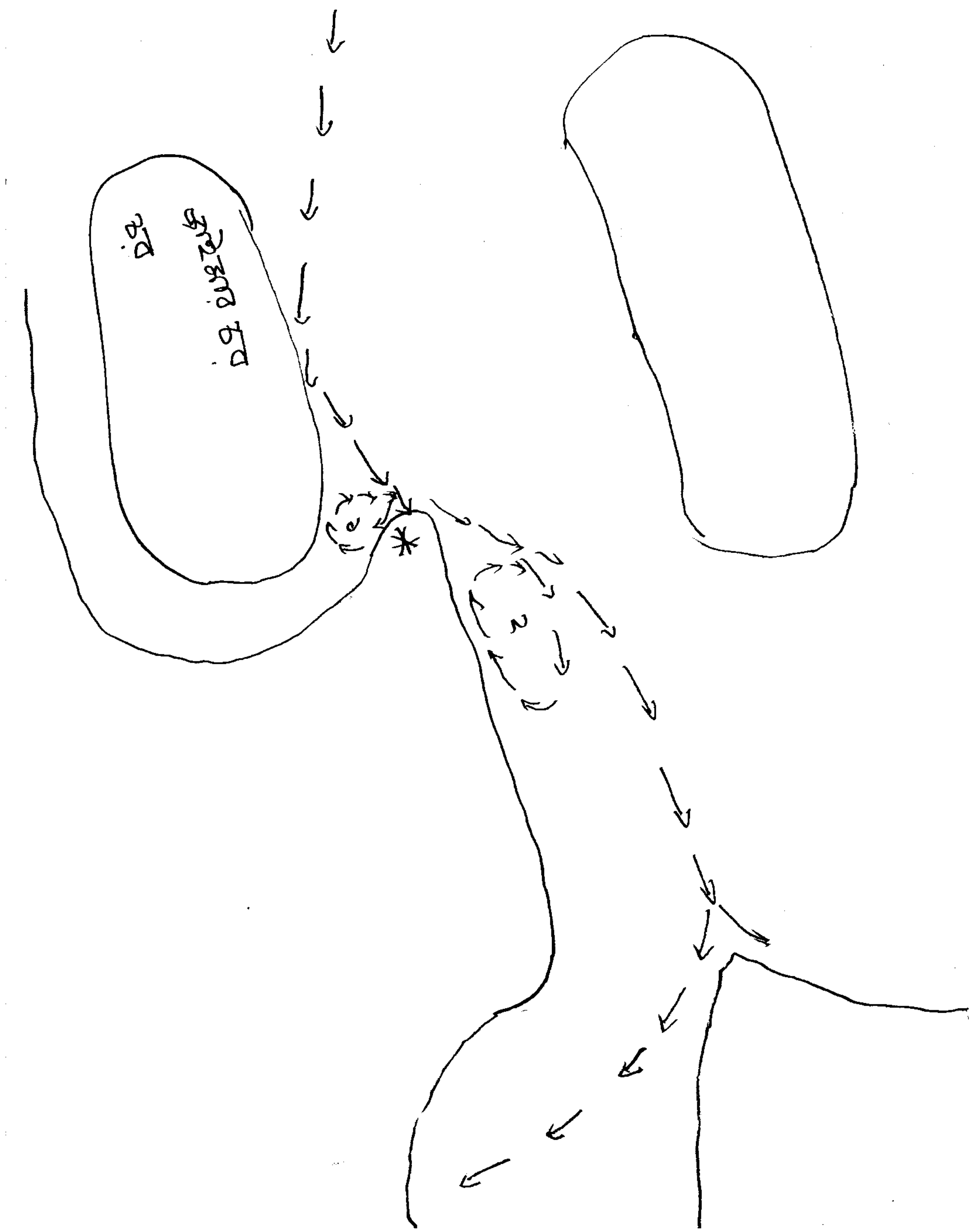

Figure C5: Flow processes around Sirajganj hardpoint (Sketched as per opinion of boatman)

Shuvogacha

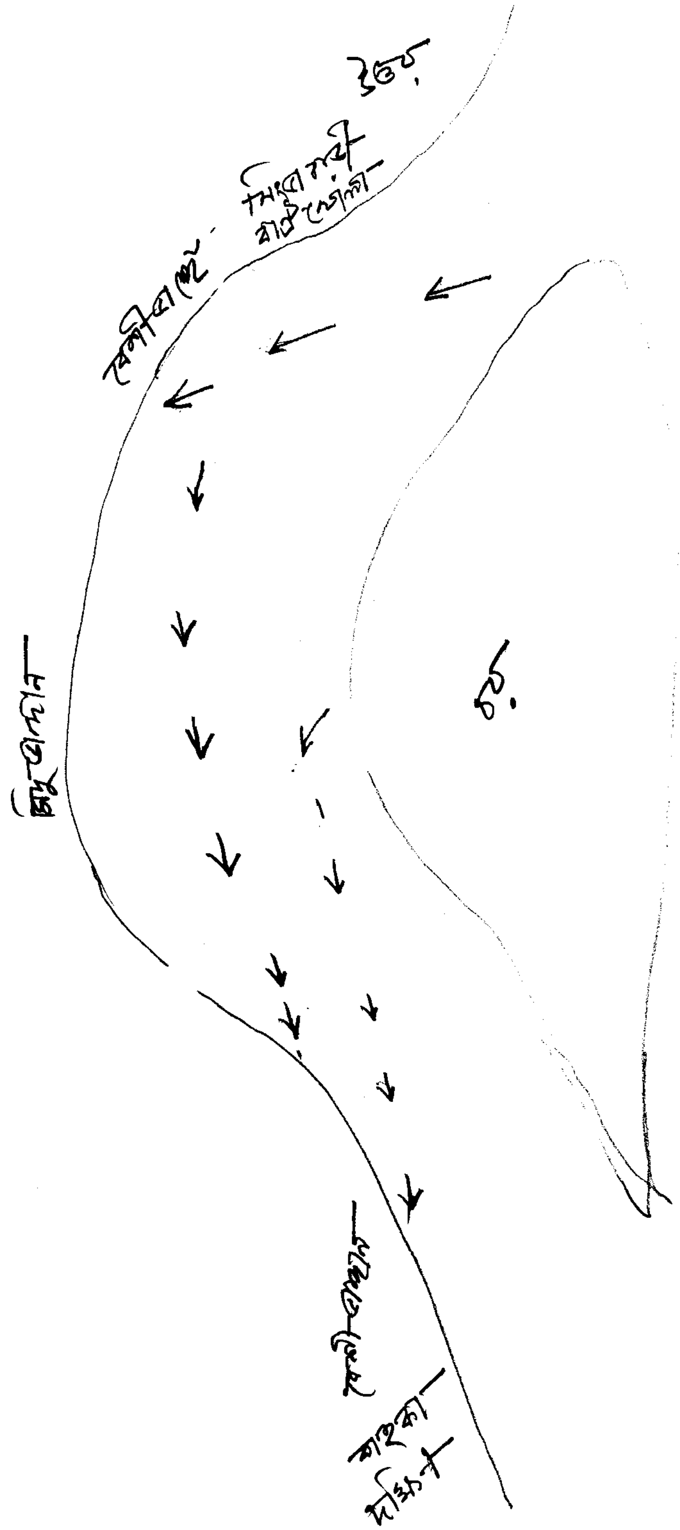

Figure C6: Flow and erosion processes at Shuvogacha (Sketched during KII)

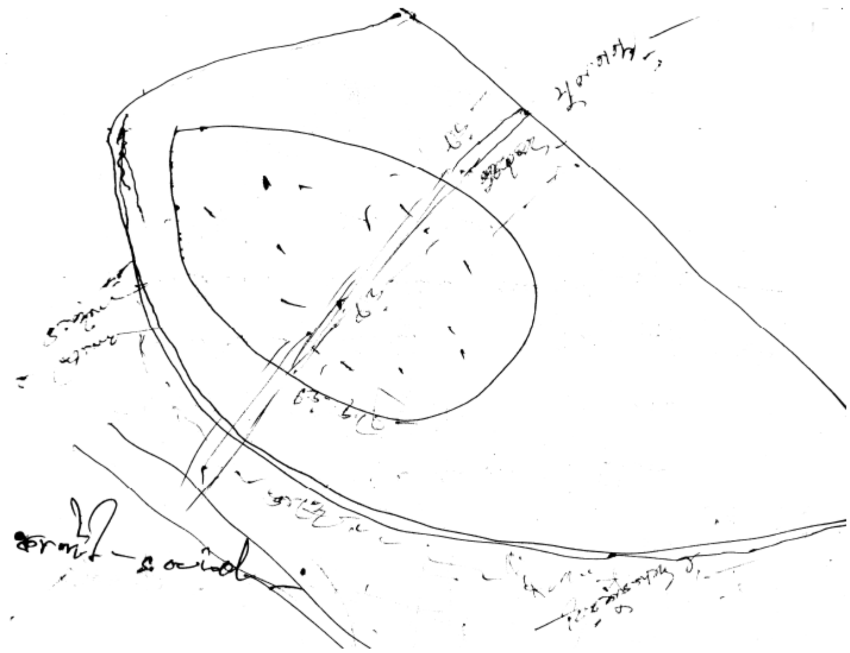

Figure C7: Flow and erosion processes at Shuvogacha (Sketched during FGD)

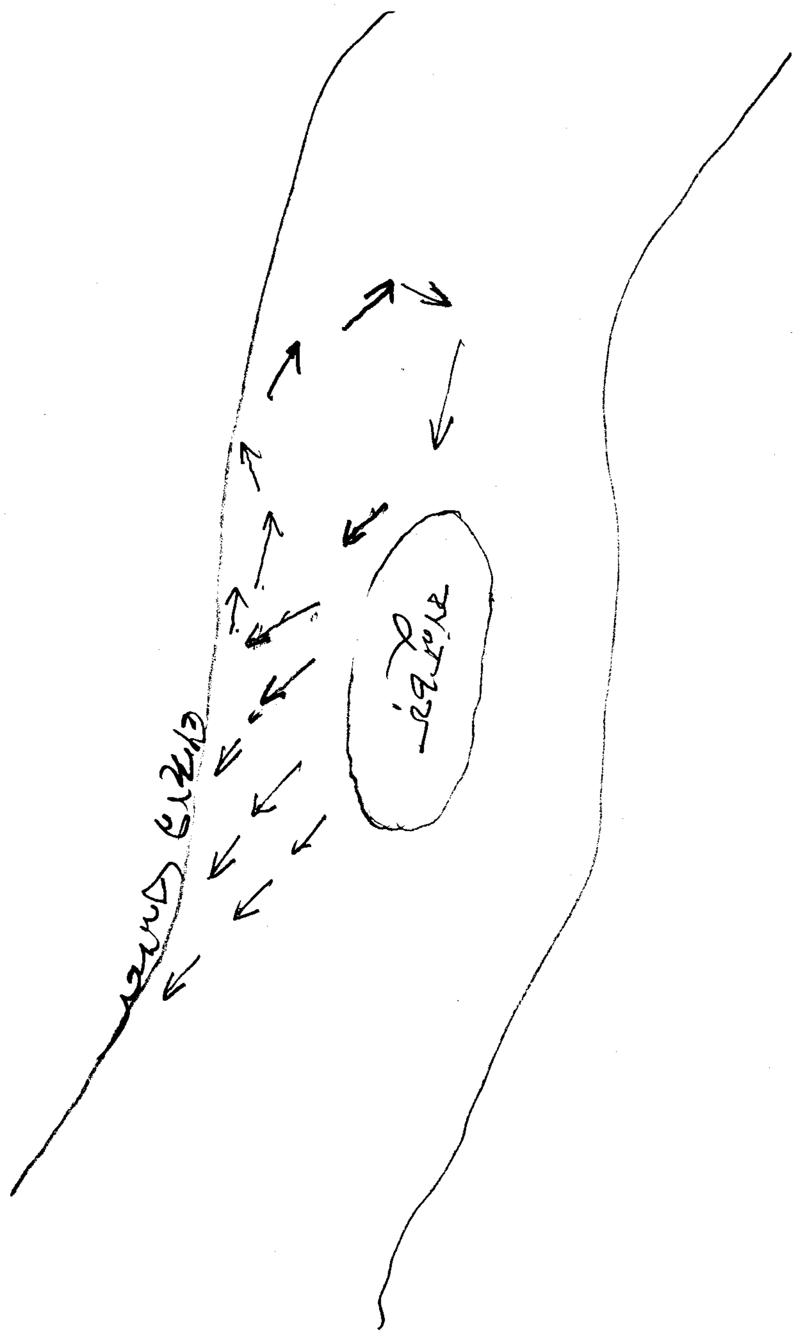

Figure C8: Bank erosion processes due to bar formation (Sketched during KII)

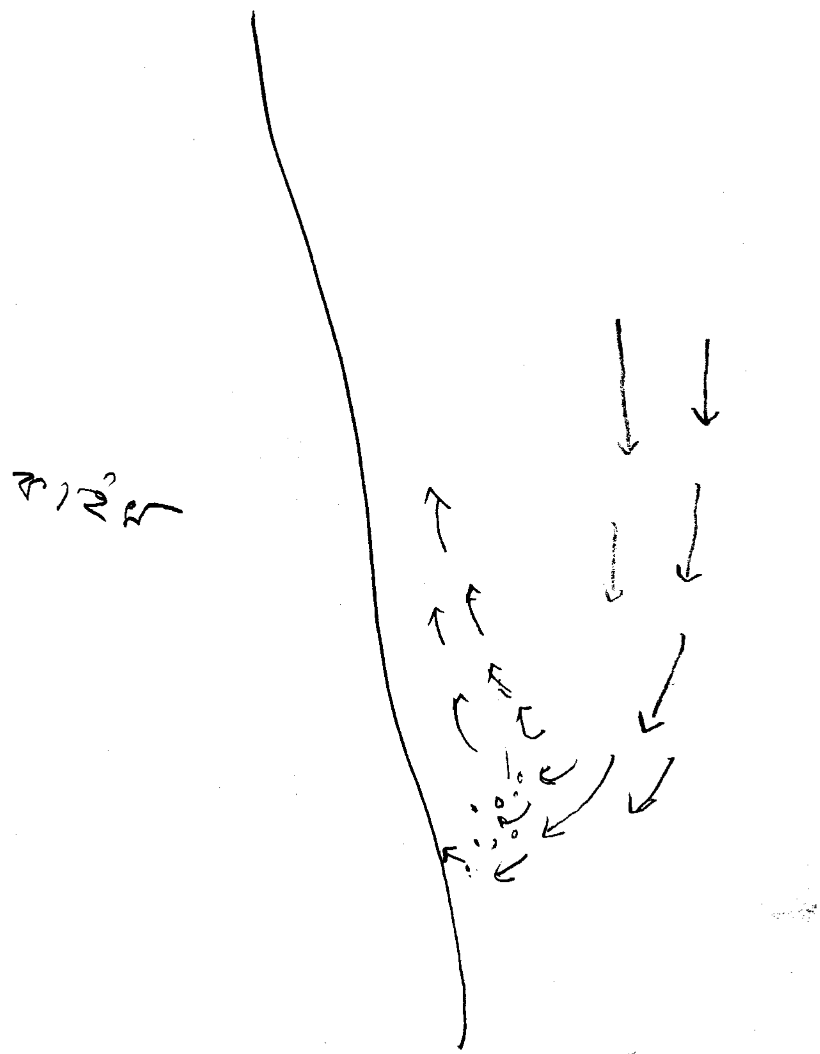

Figure C9: Bank erosion process for the period of normal flow (Sketched during KII)

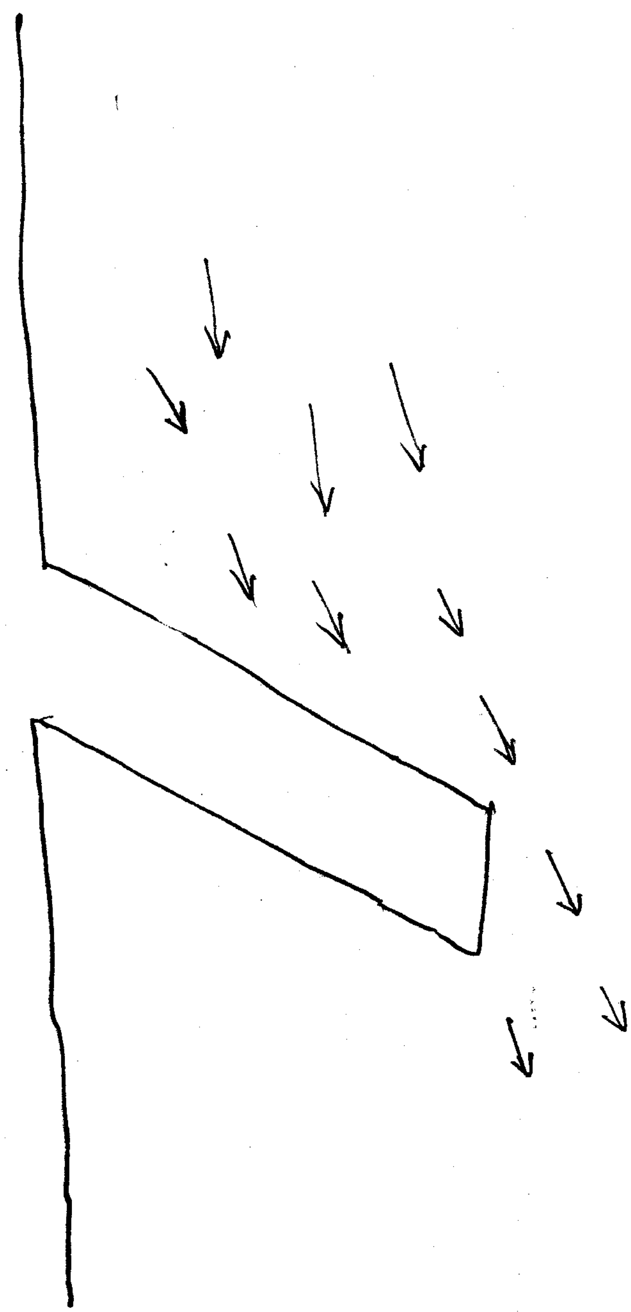

Figure C10: Orientation of the RCC spur as per local people (Sketched during KII)

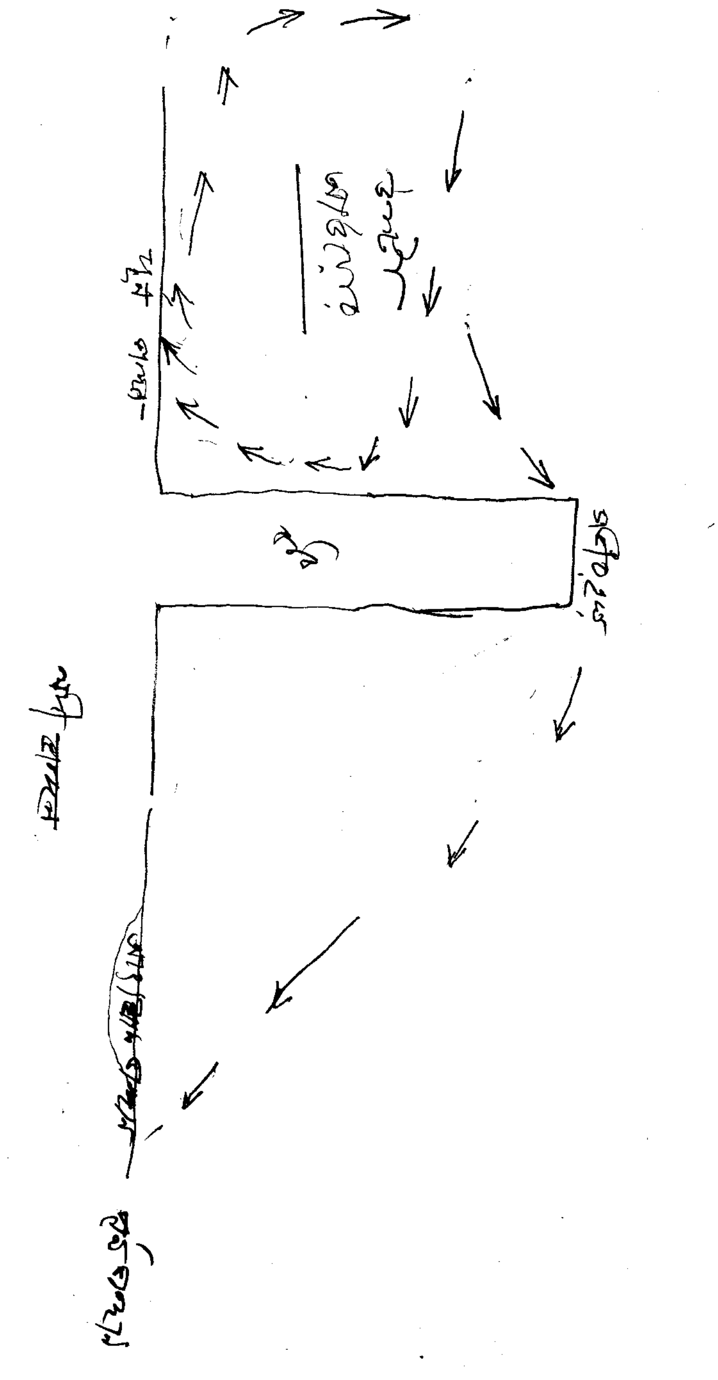

Figure C11: Flow and failure processes of Shuvogacha spur (Sketched during KII)

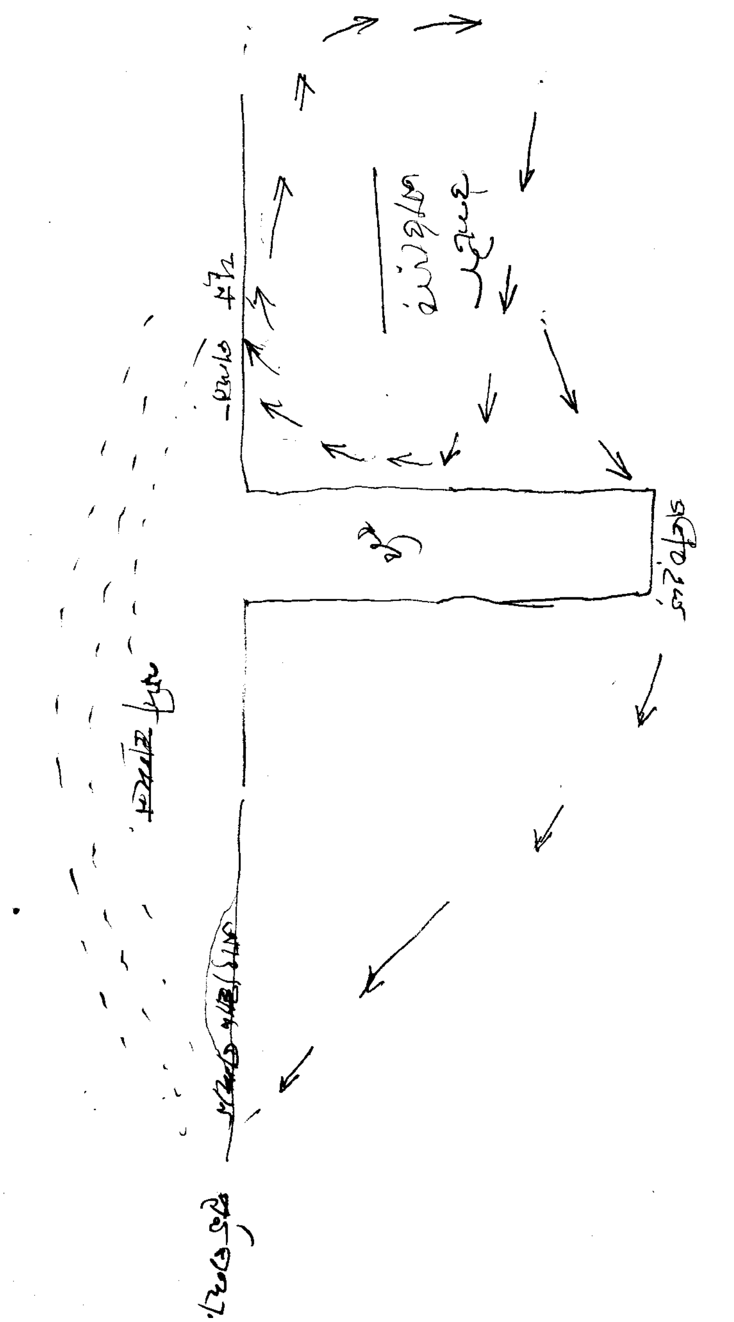

Figure C12: Development of bend after failure of the RCC spurs (Sketched during KII)

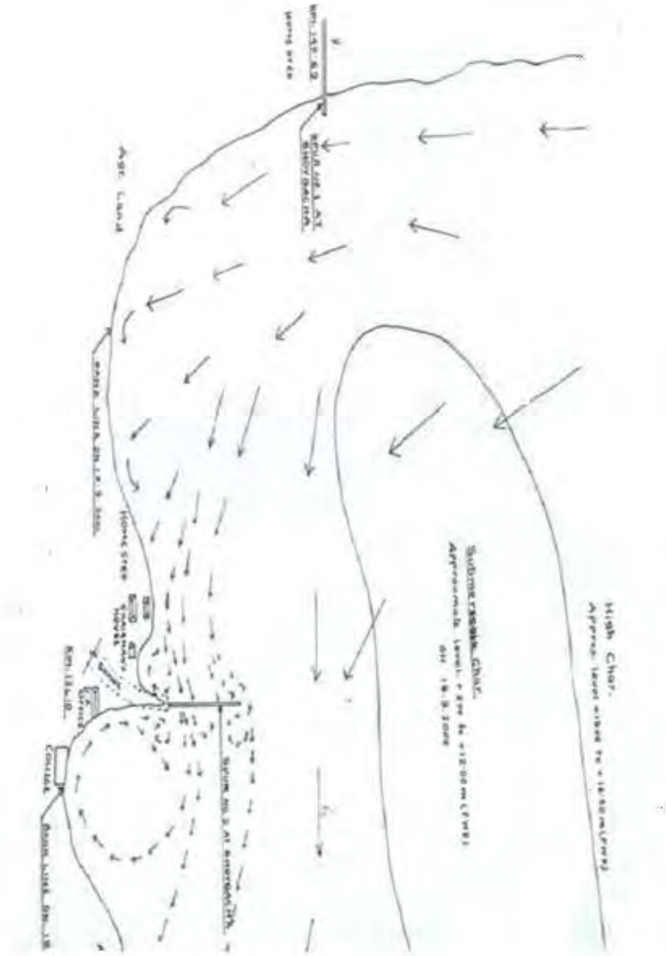

Figure C13: Actual flow phenomena during the failure of the spur sketched by the BWDB personnel

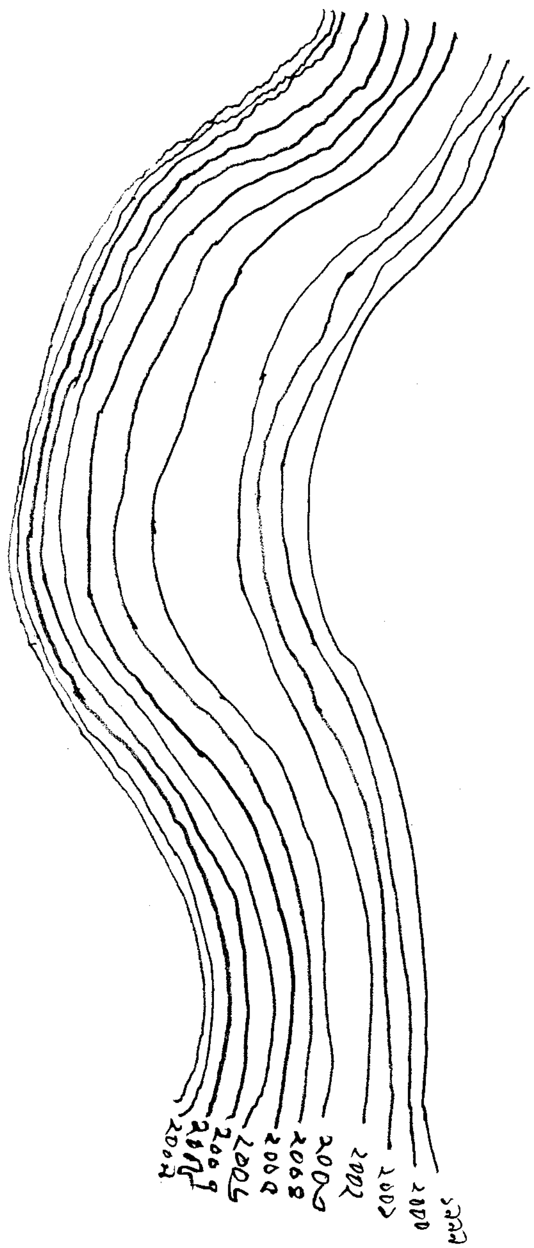

Figure C14: Deformation of the bend (Sketched during KII)

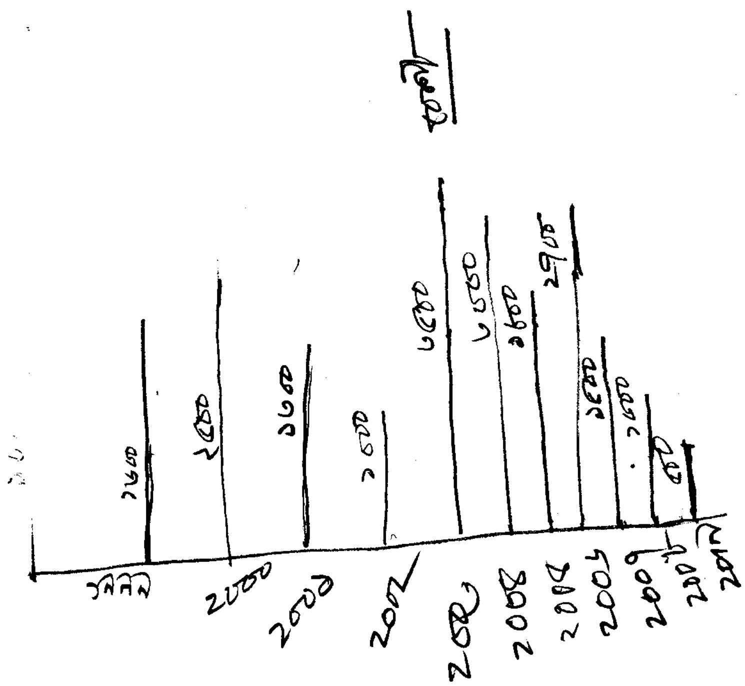

Figure C15: Rate of erosion according to local people (Sketched during KII)

Betil and Enayetpur

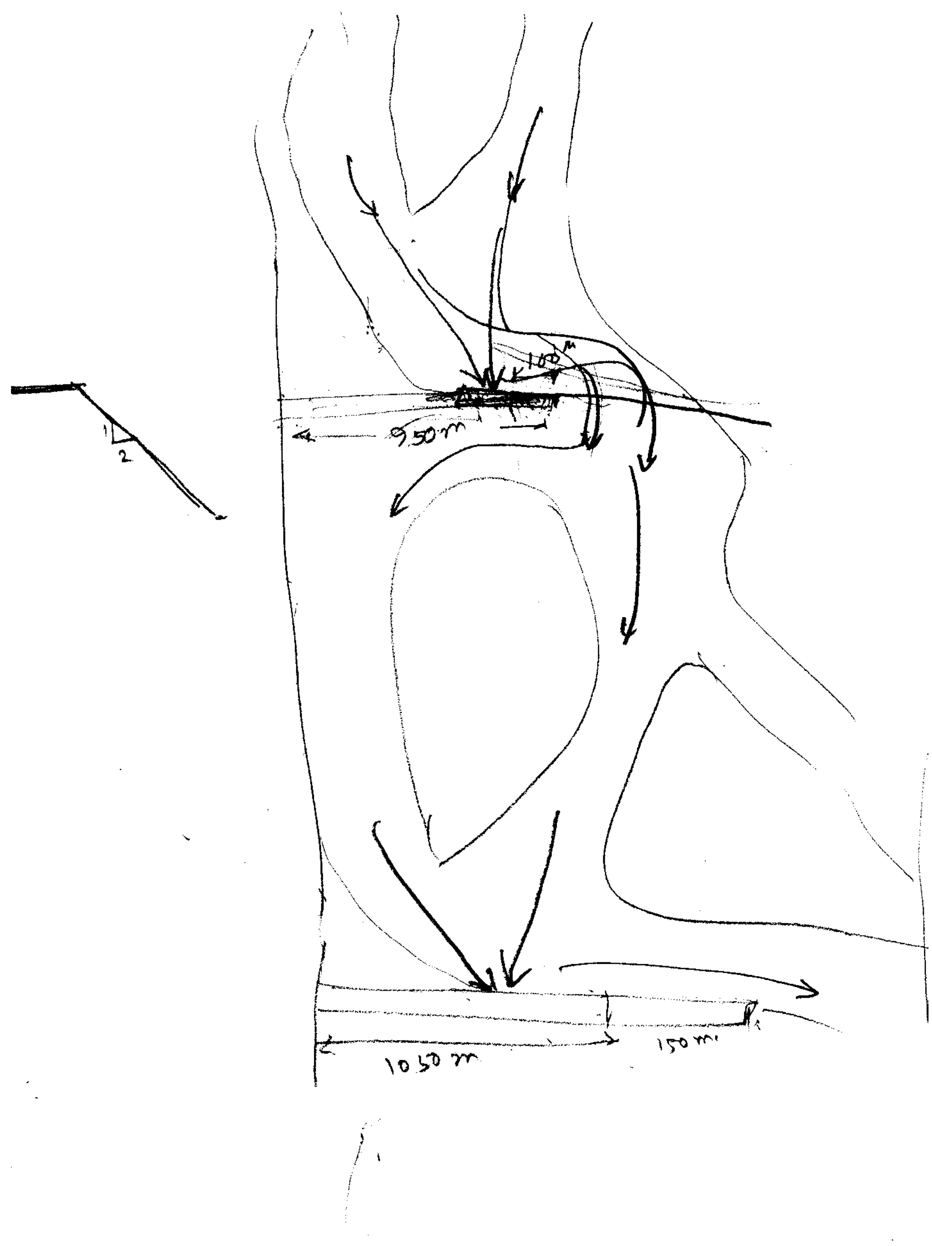

Figure C16: Flow and erosion process around Betil and Enayetpur spurs (Sketched by SDE Sirajganj during KII)

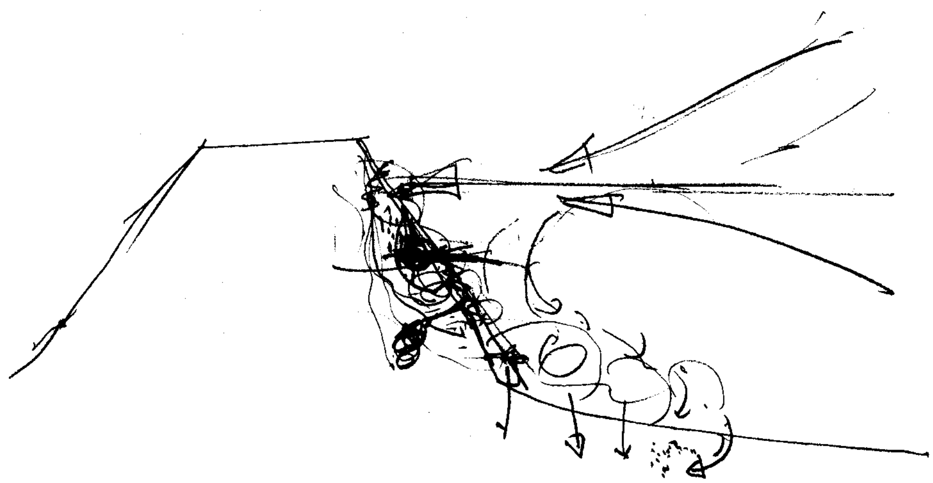

Figure C17: Flow and failure mechanism of Betil and Enayetpur spurs (Sketched by SDE Sirajganj during KII)

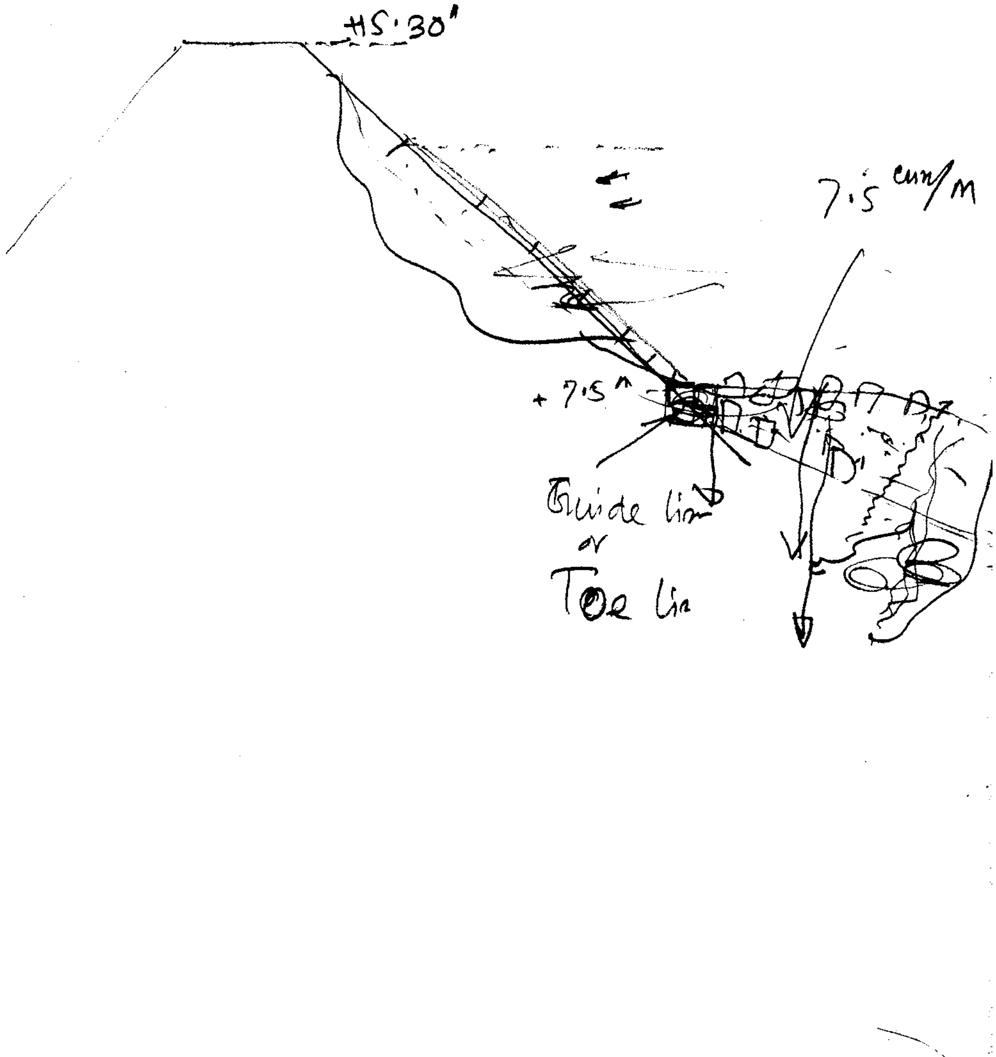

Figure C18: Failure mechanism of Betil and Enayetpur spurs (Sketched by SDE Sirajganj during KII)

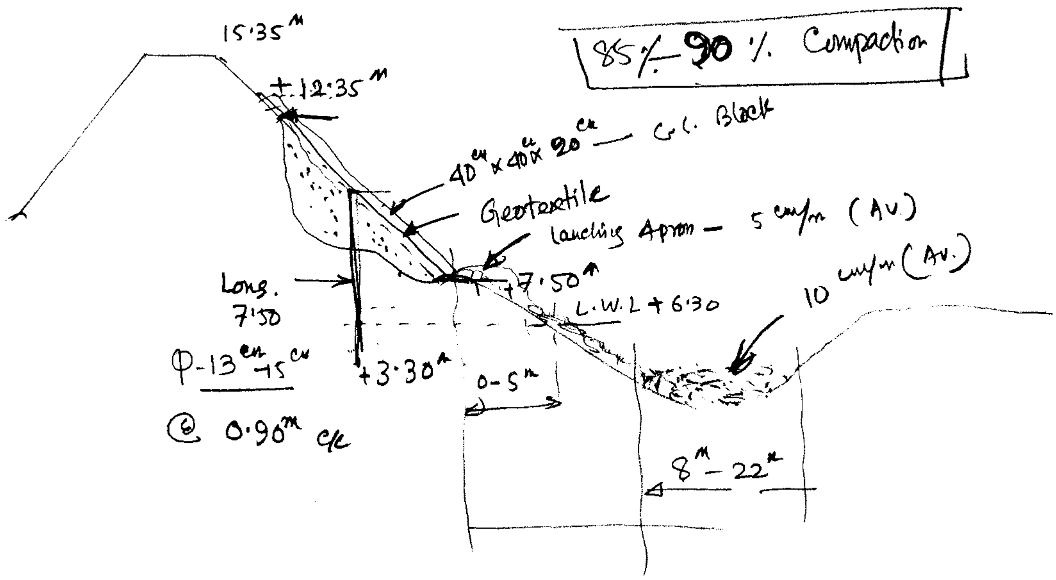

Figure C19: Maintenance of Betil spur (Sketched by SDE Sirajganj during KII)

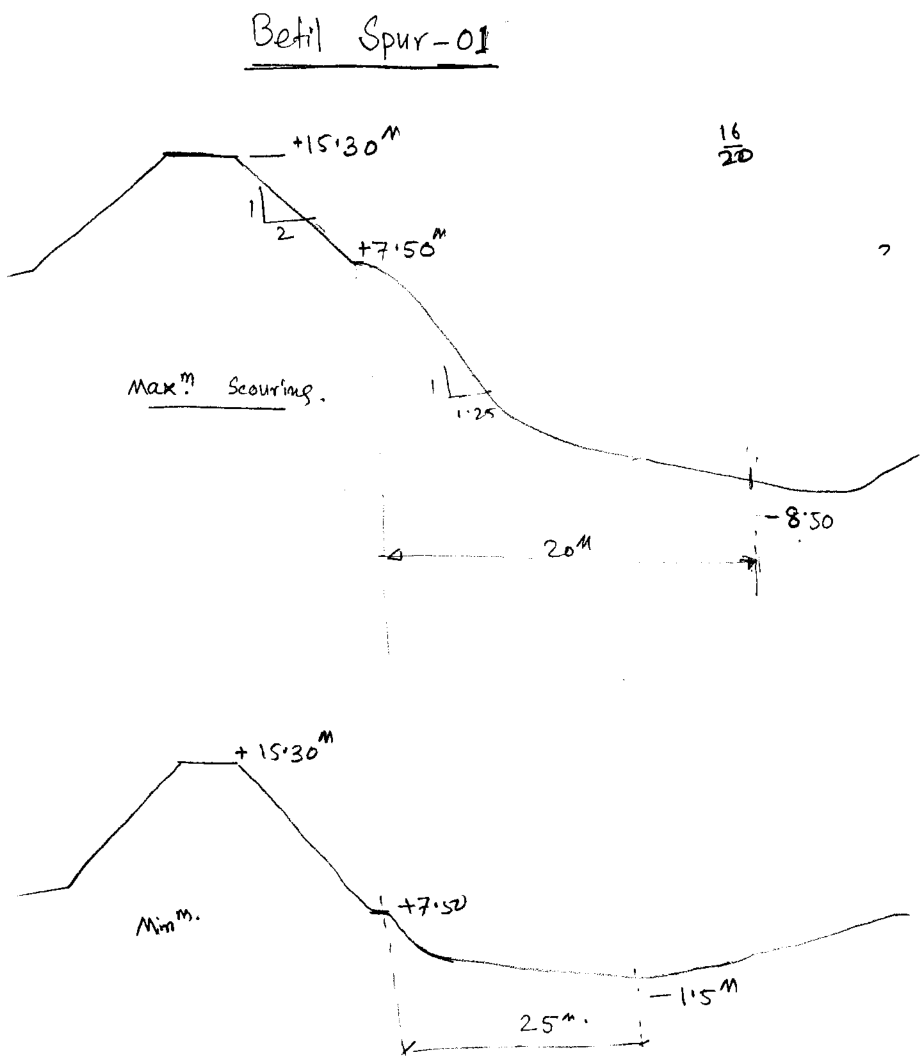

Figure C20: Channel cross sections upstream of Betil spur (Sketched by SDE Sirajganj during KII)

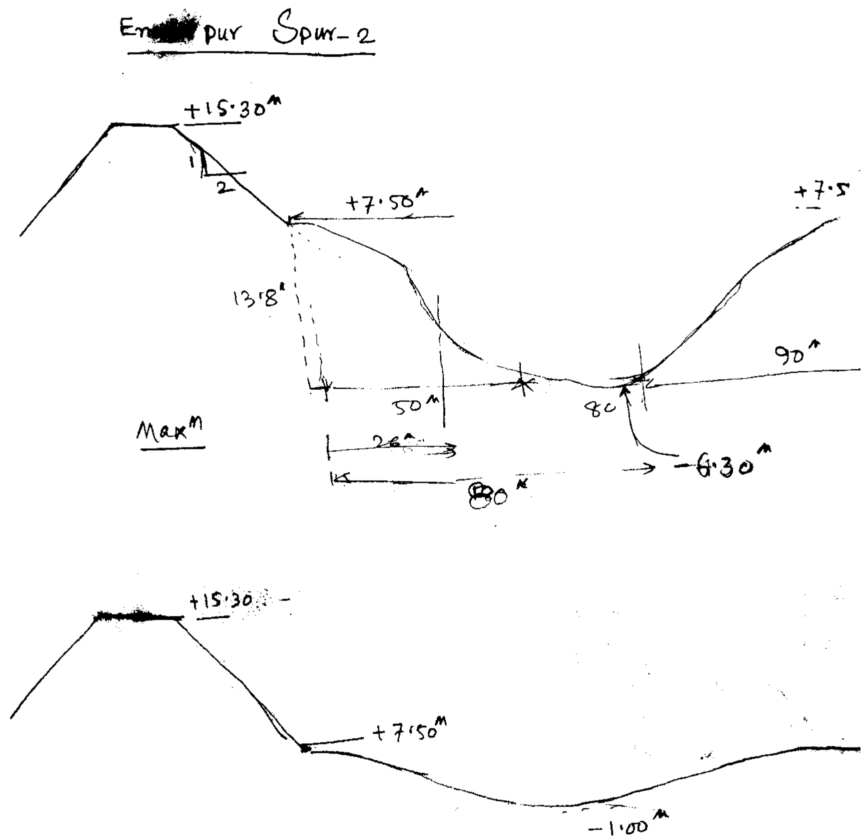

Figure C21: Channel cross sections upstream of Enayetpur spur (Sketched by SDE Sirajganj during KII)

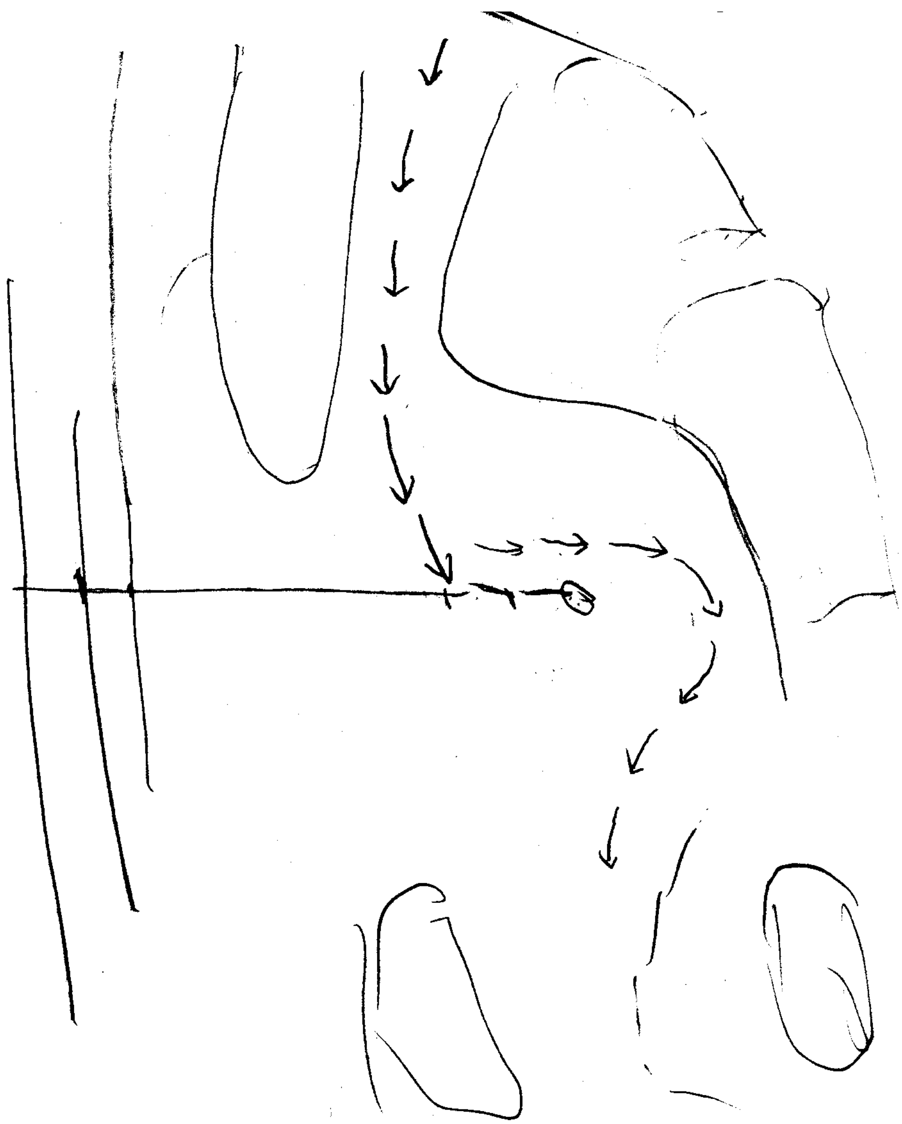

Figure C22: Flow processes upstream around Betil spur (Sketched by local people during FGD)

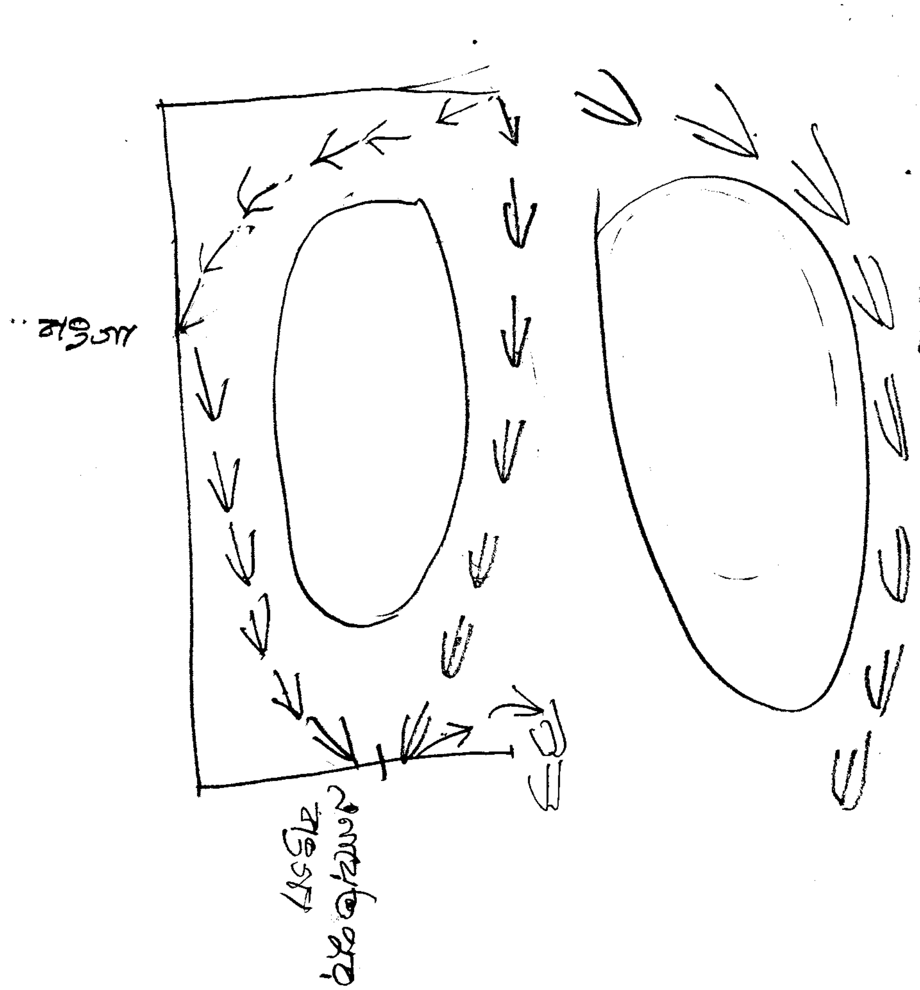

Figure C23: Flow processes upstream around Enayetpur spur (Sketched by local people during FGD)

Randhunibari

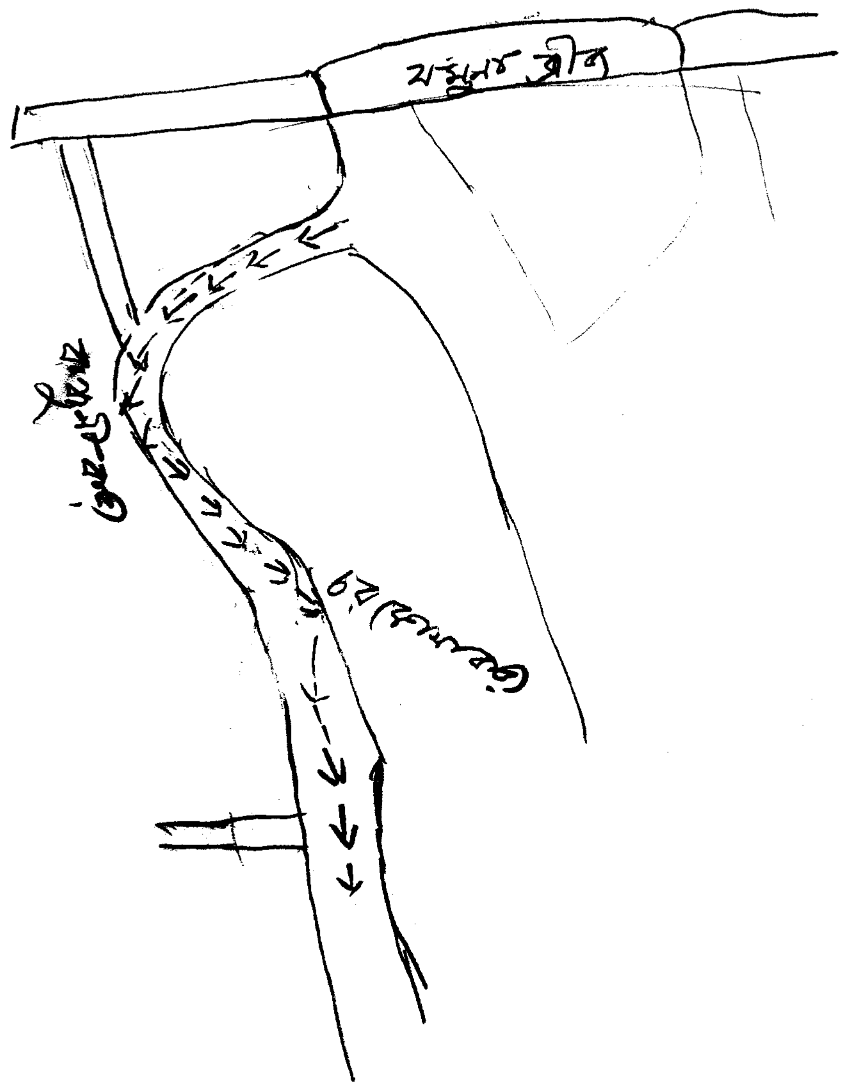

Figure C24: Flow processes around bandal structure (Sketched by local people during FGD)

APPENDIX D: Photograph

Shuvogacha

(a) Shuvogacha union parishad member with local people on BRE

(b) Local people is preparing hazard map at Bir Shuvogacha

(c) Focused group discussion at Shuvogacha South Para

(d) Erosion prone Shuvogacha bend

(e) Focus group discussion at Baikhola

(f) Focus group discussion on Shuvogacha char

(g) Focus group discussion on Shuvogacha char

Sirajganj

(a) Focus group discussion with religious people

(b) Discussion with headmaster of Gandayene High School, Sirajganj

(c) Focus group discussion with people adjacent to the hardpoint

(d) Focus group discussion at Ranigram

Betil and Enayetpur

(a) Focus group discussion with people of Char Enayetpur

(b) Focus group discussion into dhonche field

(c) Focus group discussion with local people of Char Dhuliabari

(d) Focus group discussion with local people of Char Dhuliabari

(e) Focus group discussion in Enayetpur market

(f) Focus group discussion with daily labor

(g) Discussion with BWDB personnel on Betil spur (h) Focus group discussion in Enayetpur market

Randhunibari

(a) Focus group discussion at Randhunibari market (b) Focus group discussion at Randhunibari market

(c)Focus group discussion at Char Konabari (d) Focus group discussion at Char Konabari