Review of BWDB designs for river bank erosion management in Polder 29, Khulna, Bangladesh

Deltares

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River bank erosion, bank protection, river morphology, groynes

Summary
This report reviews design documents prepared by the Bangladesh Water Development Board for groynes along the right bank of the Lower Bhadra River at Chandgar in Polder 29, Khulna, Bangladesh. Additionally, it gives suggestions for emergency measures to be taken before the monsoon of 2017.

A report of the April 2017 mission to Dhaka in the framework of this project has been added in Annex C.

References
Contract agreement between Euroconsult Mott MacDonald and Deltares for review of BWDB designs for bank protection along the Lower Bhadra River at Chandghar, February 2017, including the "Addendum to proposal of Lower Bhadra bank erosion control at Polder 29" dated 5 April 2017.

Version	Date	Author	Initials	Review	Initials	Approval	Initials
1.0	Mar. 2017	Erik Mosselman		Mohamed Yossef		Johan Boon	
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Contents

1 Introduction

Blue Gold is a collaboration programme between the Government of the Netherlands and the Government of Bangladesh. Its overall objective is to reduce poverty for 150,000 households living in 160,000 ha of selected coastal polders in Khulna, Satkhira and Patuakhali by creating a healthy living environment and a sustainable socio-economic development.

One of these coastal polders, Polder 29, has been experiencing bank erosion problems for a long time. The embankment was retired several times due to severe erosion along the right bank of the Lower Bhadra river near Chandgar and Baroaria. Blue Gold engaged the Institute of Water Modelling for a study to (i) identify the underlying causes of erosion; (ii) find the extent of erosion in order to control the erosion by providing mitigation and protective measures; and (iii) develop a comprehensive, ecologically sustainable and innovative adaptive approach for the planning, design and implementation of the erosion protection work on the proposed site. In this context, the Embassy of the Kingdom of the Netherlands requested the Institute of Water Modelling to select a solution based on low-cost permeable groynes made of natural materials with an oblique orientation to the bankline. The institute then prepared a preparatory study report (IWM, 2015).

Figure 1.1 Project area: Polder 29 and Lower Bhadra River.

Blue Gold subsequently engaged Deltares to review this IWM report. The resulting document (Mosselman, 2016) pointed out that erosion could be expected over a longer part of the bank, not only at Chandgar but also at Jaliakhali or even Baroaria. Furthermore, it recommended setting up the project from a wider perspective that includes economic underpinning and structural design issues in a more thorough manner.

It also suggested considering a Building-with-Nature type of low-cost intervention in the wide river area at Chandgar. It might be possible to dredge the dying bend of this area and to dump the dredged material in the channel along the actively eroding bank.

After adjustment of the IWM report (IWM, 2016), a meeting was held in the Director General BWDB's conference room on 23 June 2016 (BWDB, 2016). Mr. Motaher Hossain (SE, Design Circle-6) advised the use of pre-cast concrete piles instead of bamboo and bullah piles because of the risk of loss due to scour and theft. Mr. Braza Mohan Nath (Chief Engineer, Hydrology) noted that the proposed battery of groynes over 500 m might be too short because model computations indicated an erosion length of 1.83 km. Mr. Erik Mosselman recommended paying particular care, in design and in monitoring, to bed scour at the heads of individual groynes as well as to bed scour and bank erosion at the upstream and downstream terminations of the battery of groynes. The meeting concluded by approving implementation of the bank protection works.

The Bangladesh Water Development Board prepared design documents for permeable groynes with pre-cast concrete piles. Blue Gold requested Deltares to review the designs, identifying observations and concerns (Jones, 2017a). In an additional email, Blue Gold asked Deltares to include advice on emergency measures to be taken before the 2017 monsoon, because the embankment, although repaired, is severely weakened and feared not to survive the next monsoon. Blue Gold aims at providing some form of protection from high discharges in the Lower Bhadra during the 2017 monsoon, for the sake of the communities across the 2,000 ha that were flooded from end-August 2015 to May 2016 (Jones, 2017b).

The present report addresses Blue Gold’s requests. Observations and concerns regarding the designs are given in Chapter 2; suggestions for emergency measures are given in Chapter 3.

2 BWDB designs

2.1 Length of protected bank

Figure 2.1 shows the 1.63 km long bank protection proposed by IWM (2016). Mosselman (2016) argued that bank erosion might even extend further downstream. Figure 2.2, however, shows that the planned extent of bank protection is more limited in the designs of BWDB. This was also noted by Mr. Braza Mohan Nath who argued at the meeting on 23 June 2016 that protection over a length of 500 m might be too short (BWDB, 2016). Banks upstream and downstream of the battery of four groynes can hence be expected to erode, so that the structure will not protect the embankment from breaching. If the purpose of the structure merely consists of testing a new type of groyne battery, it remains worth noting that bank erosion upstream and downstream of the battery will change the direction of attack at the upstream and downstream terminations. The structure has not been conceived for this and might fail as a result, putting an untimely end to the corresponding monitoring programme.

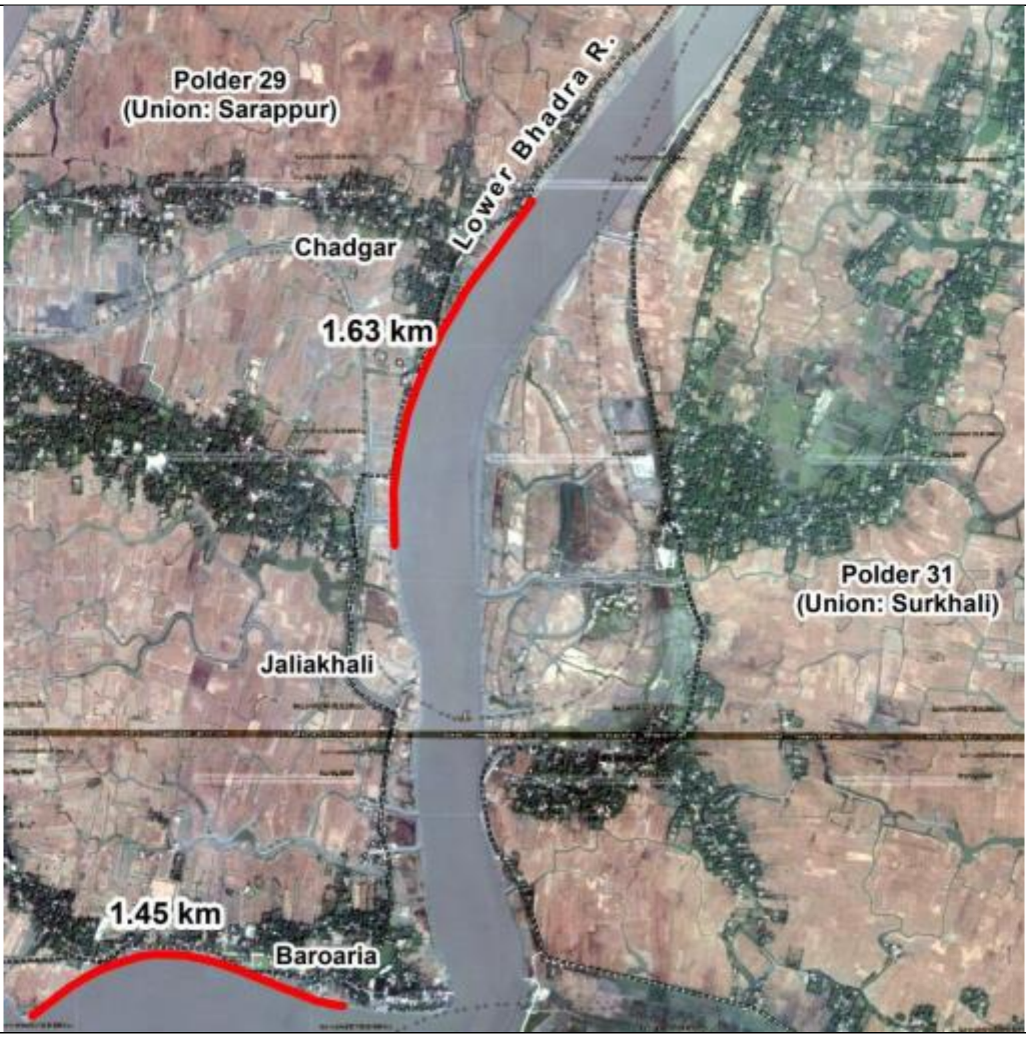

Figure 2.1 Originally proposed extent of bank protection (IWM, 2016).

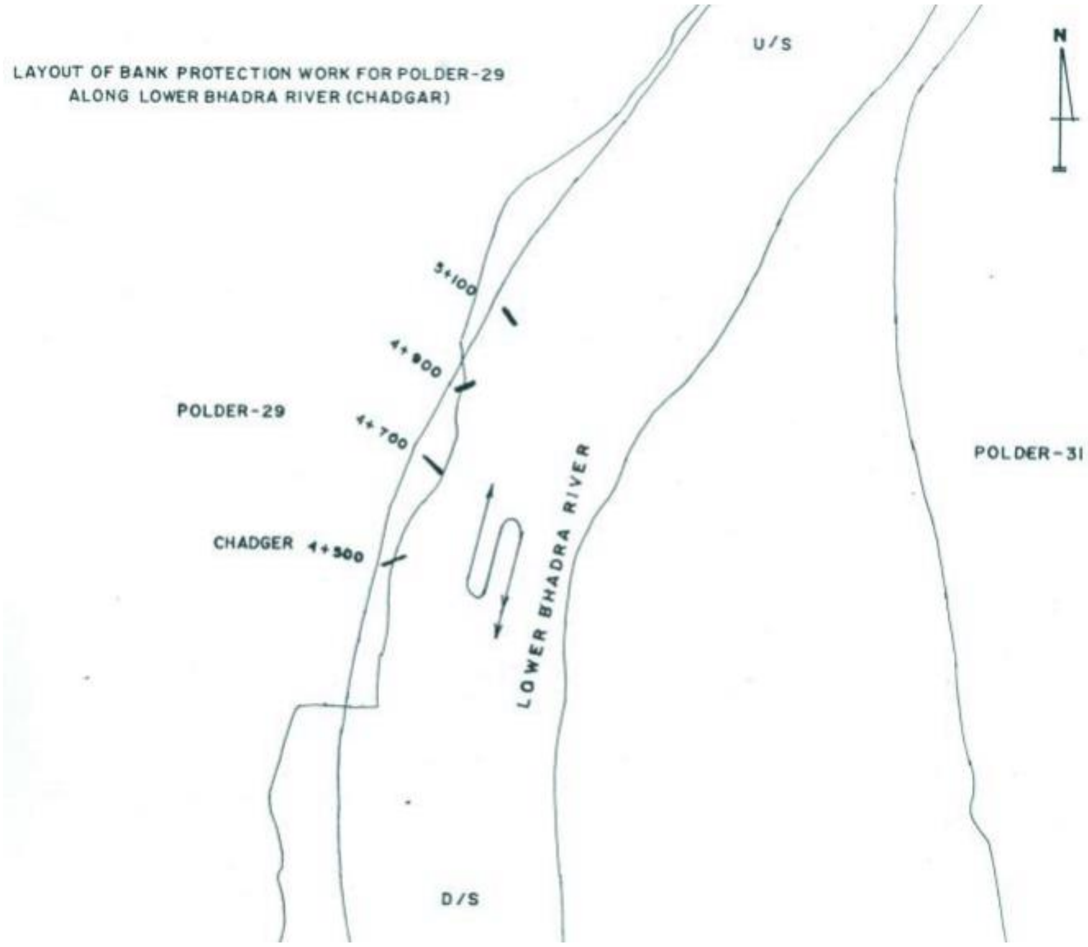

Figure 2.2 Battery of groynes between km 4,500 and 5,100 according to BWDB designs. "Chadger" stands for Chandgar.

2.2 Type of structure

Blue Gold expressed concern that the penetration of piles at the river end of the groynes will not be sufficient to provide structural resistance to horizontal loads, or to withstand further scour at the toe of the groynes (Jones, 2016c). Concerns are justified. This is not just a matter of scour depth around the pile of the river end, but of scour depth around all piles. Piles of the most upstream groyne in particular might be attacked from another direction after bank erosion, exposing the landward pile to the severest attack. This pile has been rightly designed with the same length as the pile of the river end, but scour around this pile may lead to outflanking, i.e. bank erosion behind the groyne.

Moreover, groynes are not necessarily the best solution to bank erosion. Trends in the science of river training move away from groynes, since longitudinal structures are often more favourable (Annex A).

2.3 Layout of groynes

The Embassy requested applying groynes with an oblique orientation to the bankline. Whether this yields more favourable conditions than groynes perpendicular to the bankline depends on flow stage and channel width-to-depth ratio. There is no ground for a general preference for oblique groynes. Perpendicular groynes then have the advantage of requiring the least amount of construction material.

In the particular case of the designs for the Lower Bhadra River, the oblique orientation of the most upstream groyne makes the structure more vulnerable to outflanking in case of upstream bank erosion than would be the case for a perpendicular orientation (Figure 2.3). The same holds for the oblique orientation of the most downstream groyne if the tide reverses the flow direction on the river. The differences are marginal though, because the landward side is vulnerable in both cases.

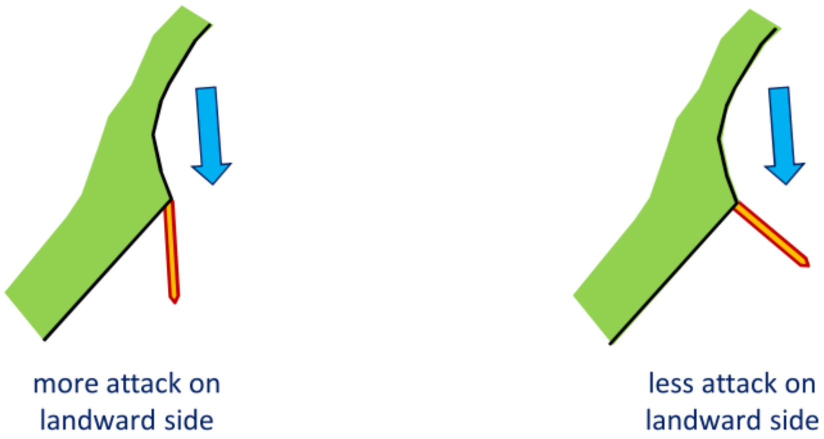

Figure 2.3 Vulnerability of landward side of most upstream groyne (km 5,100).

A design rule for batteries of groynes is that the ratio of spacing, S, to projected groyne length, L, is kept smaller than 3 to 5 in order to keep the main current away from the bank: $S/L \leq 3 \text{ to } 5$. For instance, the spacing-length ratio of the permeable groynes along the Jamuna River at Kamarjani, still standing after 20 years (cf. Annex A.3), varies between 1.8 and 3.7. Figure 2.4, where $S = 250\text{ m}$ and $L = 50\text{ m}$, shows that the ratio is equal to 5 in the present BWDB designs. The design rule is thus stretched to the limit and it might be wise to reduce the spacing. Moreover, the overall groyne alignment is not favourable for a stable flow circulation between the groynes that helps in keeping the main flow away from the bank.

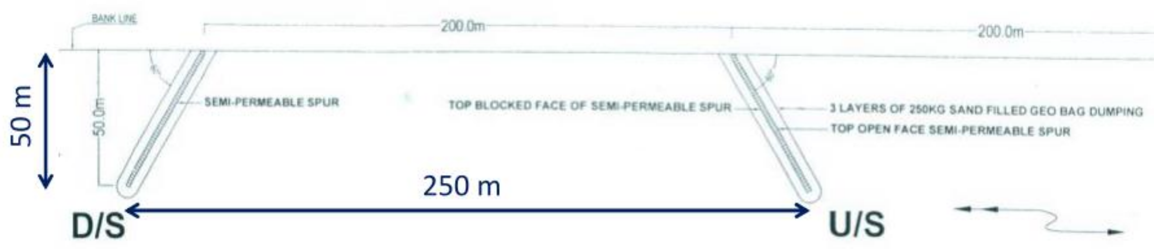

Figure 2.4 Proposed layout of groynes.

2.4 Structural design of groynes

Mr. Motaher Hossain advised the use of pre-cast concrete piles instead of bamboo and bullah piles because of the risk of loss due to scour and theft (BWDB, 2016). This is a good advice. Nature-based solutions making use of natural materials may work in low-energy environments and areas with flat-bed slopes, but they are less suitable for eroding river banks with severe hydraulic loads and scouring. Theft is a serious problem too, even in case of low-cost materials.

For instance, the local community of Porabari (Tangail) had to provide guards 24 hours per day to watch the bamboo and bullah piles for bottom vanes in the Elanjani River, designed by the same Mr. Motaher Hossain.

2.5 Conclusion and recommendations

The current design gives rise to several reservations. It is doubtful whether the project should go ahead in the present form. It is therefore recommended to reconsider the project before taking further steps.

3 Emergency measures

Blue Gold asked advice on emergency measures to be taken before the 2017 monsoon, fearing the embankment will not survive the next monsoon. The groynes according to the current design will only influence a limited length of the bank exposed to erosion. Moreover, the present design without additional structures at the upstream and downstream ends carries the risk of outflanking. Once outflanking occurs, bank erosion at the locations of the groynes becomes more intense than when groynes would have been absent (Die Moran et al, 2013). Groynes hence cannot play a role in the emergency measures.

The most appropriate measure for emergency bank protection is a revetment. Revetments based on geobags have been shown to be successful at other locations in Bangladesh (cf. Annex A.3). It is recommended to consult Dr. Knut Oberhagemann, based on his experience, for a solution based on geobags, to see what can be achieved in the short time remaining before the monsoon. Annex B provides a scope of work for emergency survey.

An auxiliary measure could be to dredge sediments from the recently accreted land on the opposite side of the river and to dump this along the bank at Chandgar (Mosselman, 2016). This would be a truly nature-based solution according to the philosophy of Building with Nature (Figure 3.1). However, as the new land has been developed into usage immediately, this option may not be feasible for social and political reasons. Ideally this type of solutions would be anticipated earlier, allowing timely administrative arrangements. In general, adaptive approaches may be technically sound, but they require monitoring, early anticipation and planning of a timely response. The range of options diminishes if adaptive measures are only emergency-driven. If this solution could be tried, it is recommended to dump the sediments at the turn of the tide when flow velocities are smallest. The effectiveness may be limited if the sediments are too fine.

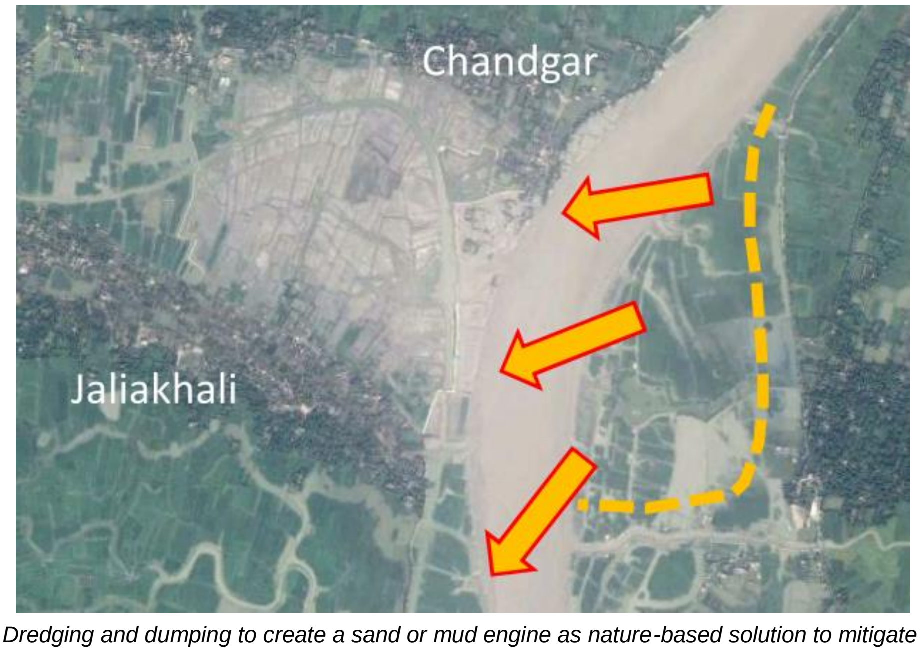

Figure 3.1 Dredging and dumping to create a sand or mud engine as nature-based solution to mitigate bank erosion.

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A Historical notes on development of bank protection and river training

A.1 The Netherlands

The first groynes for bank protection in the Netherlands were built by Romans almost 2000 years ago (Figure A.1). This remained a practice among riparian landowners for many centuries. As local groynes often had negative effects on other parts of the river, a law was introduced in 1715 that prohibited the implementation of this type of structures by individual landowners. From that moment onwards, river training became a task of the government. Hundreds of groynes (cf. Figure A.2) were implemented along the Dutch Rhine branches between 1850 and 1880 to establish a uniform width, because locally wider sections with bars and islands gave rise to ice jams in winter, a major cause of dike breaches and flooding. The width was reduced further in the next 35 years by making the groynes longer, this time to improve navigability. Recognizing, after 2000, the adverse effects of river training on a long term, longitudinal training dams were developed as an alternative with similar performance but less harmful side effects (Figure A.3). Innovation in river training in the Netherlands thus follows a trend towards longitudinal rather than transverse training structures.

Figure A.1 Archeological reconstruction of a Roman groyne at De Meern near Utrecht, the Netherlands. The groyne was made of basalt stone and wood. Its purpose was to protect a road against bank erosion.

Figure A.2 Normalized river in the Netherlands with groynes to establish a uniform width.

Figure A.3 Longitudinal training dams on the river Waal in the Netherlands.

A.2 Indo-Gangetic Plains

British engineers faced challenges in the 19th century when training the unstable rivers of the Indo-Gangetic Plains. Their main question was how to constrict meander or braid belts to limit the span of bridges across the rivers. By trial and error, they developed structures to lead deep channels properly under the bridge without upstream channel migration to erode the abutments. They started with transverse structures, but eventually found longitudinal guiding structures to provide the best solution (Figure A.4). These structures, called guide banks or Bell's bunds, consist of an upstream curved head, a straight shank, and a downstream curved head (Spring, 1924; Gales, 1938). Innovation thus moved from transverse to longitudinal training structures. Guide banks became a standard solution for bridges worldwide. Examples in Bangladesh include the Hardinge Bridge on the Ganges (Gales, 1938) and the Bangabandhu Bridge on the Jamuna.

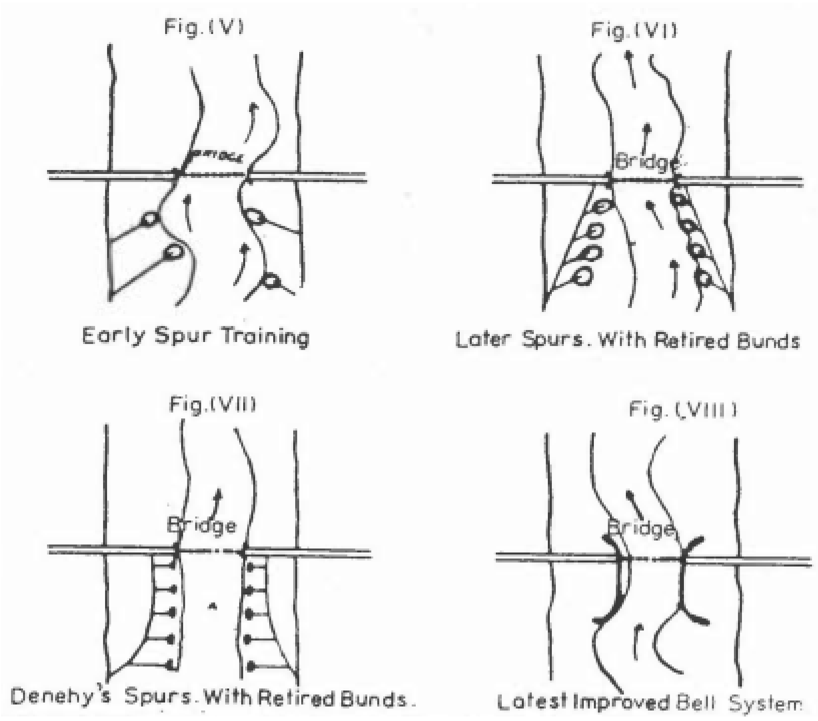

Figure A.4 Development of river training for bridge crossings on the rivers of the Indo-Gangetic Plains (Varma et al, 1989).

A.3 Bangladesh

The FAP 21 project implemented and tested a full range of innovative bank protection structures along the Jamuna River in the 1990s: permeable groynes at Kamarjani (Figure A.5) and revetments with falling and launching aprons at Bahadurabad / Kulkandi and Ghutail (Figure A.6). These structures still stand in place after 20 years (Figure A.7 and Figure A.8). The experiences were documented and translated into design guidelines that still constitute a solid state of the art (Jamuna Test Works Consultants (2001a,b). One of the river engineers of the FAP21 project, Dr. Knut Oberhagemann, realized in subsequent projects that bank protection using geobags often provides the best combination of technical performance and cost-effectiveness (Figure A.9). Bank protection structures using geobags do require monitoring, adjustments and repairs, but so do traditional bank protection structures with concrete and stone. Dr. Oberhagemann prefers revetments over groynes because they produce less scour. Subsequent innovations in Bangladesh thus moved towards longitudinal structures.

Figure A.5 Permeable groynes along Jamuna River at Kamarjani.

Figure A.6 Revetment along Jamuna River at Ghutail.

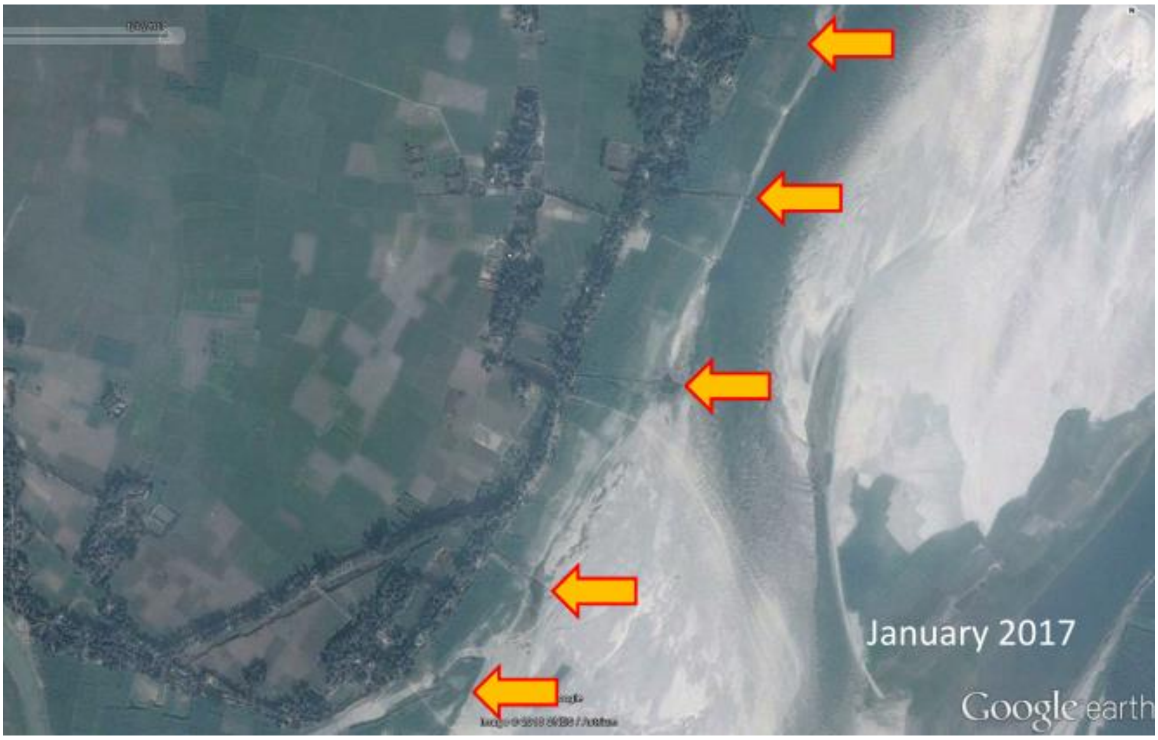

Figure A.7 Permeable groynes along Jamuna River at Kamarjani intact after 20 years (source: Google Earth).

Figure A.8 Revetments at Bahadurabad / Kulkandi and Ghutail along Jamuna River intact after 20 years (source: Google Earth).

Figure A.9 Geobag bank protection along Jamuna River at Chauhali.

B Scope of work for emergency survey

B.1 Rationale

The emergency measures of Chapter 3 require a rapid survey of the local conditions. The present appendix specifies its scope of work.

B.2 Survey dates

Flow measurements (ADCP, float tracks) are to be executed at spring tide. Possible dates:

- April 27-28 (related to new moon on April 26)
- May 12-13 (related to full moon on May 11)
- May 27-28 (related to new moon on May 26)

Bathymetric surveys can be conducted on preceding days. Water levels are read throughout the entire period of the measurement campaign. Dates of drilling and sediment sampling do not depend on the tide.

B.3 Riverbed topography survey

Thompson & Oberhagemann (2017) give appropriate specifications of the survey for riverbed topography in their Section 5.1.1:

The bathymetric survey should be conducted along the river with 100 m line spacing along the 5.8 km long reach indicated in Figure B.1. The survey should be conducted using a dual-frequency, single-beam echosounder (Echotrac CVM or similar), with a recording frequency of 0.1 s. For georeferencing of the survey boat, an RTK unit with base station, or similar, should be used. In total about 59 cross-sections of the river are to be surveyed.

Water levels should be recorded every hour in order to translate bathymetry data (= water depths) into bed topography data (= bed elevations above a horizontal datum, suitable as input for models).

Figure B.1. River reach of bathymetrical survey.

B.4 ADCP measurements

Thompson & Oberhagemann (2017) give appropriate specifications of the ADCP measurements in their Section 5.1.2:

Flow velocities and discharges should be measured with an ADCP (Riogrande 620 or similar) along the four transects indicated in Figure B.2. The instrument location should be geo-referenced by an RTK unit with base station, or similar. The base station should be set one hour before the start of the survey. The ADCP measurements should be conducted repeatedly within one day, between 5:30 am and 7 pm, for a minimum of 13 hours.

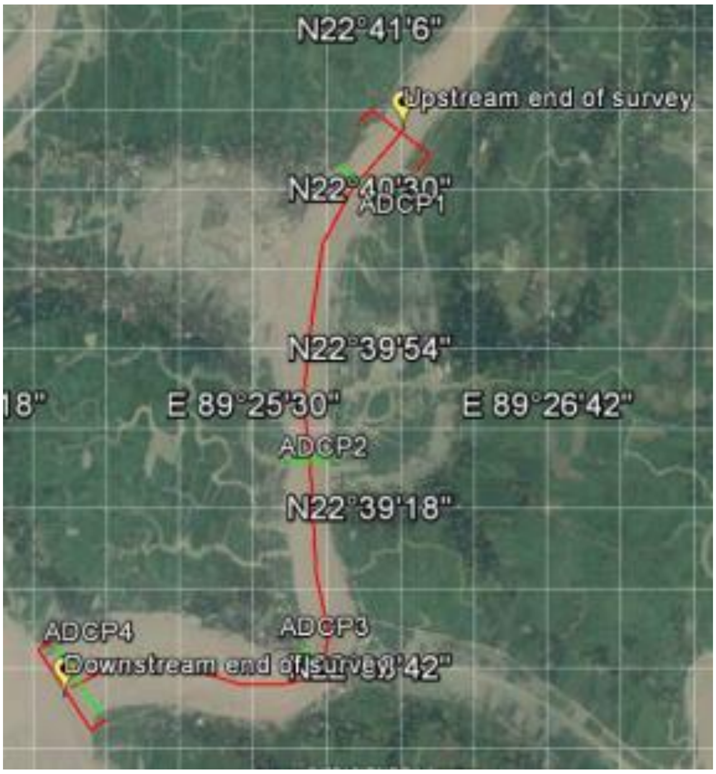

Figure B.2. Four transects for ADCP surveys (green).

B.5 Float tracking

Thompson & Oberhagemann (2017) give appropriate specifications of float tracking in their Section 5.1.3:

Float tracks should be recorded by tracking floats with a frequency of 3 seconds. The floats should have a fin of a minimum of 0.5 m depth. Their locations should be taken with a handheld GPS system. The floats should be started every hour between 6 am and 7 pm from the upstream boundary during the receding tide and from the downstream boundary during the incoming tide.

B.6 Water level gauging

Thompson & Oberhagemann (2017) give appropriate specifications of water level gauging in their Section 5.1.4:

A total of three water level gauges, connected to known benchmarks in the area, should be installed at the locations indicated in Figure B.3. The water level gauges shall be set up on the day before the first survey and read and noted at least twice daily, during high and low tide, until the day after the last survey.

Hourly readings of water levels are needed during the execution of the bathymetric survey. This will allow accurate translation of bathymetry data (= water depths) into bed topography data (= bed elevations above a horizontal datum, suitable as input for models).

Figure B.3. Locations of water level gauges.

B.7 Sediment sampling

Bed material samples are to be collected from the thalweg at the ADCP transects in Figure B.2 using a Van Veen sediment grabber (Figure B.4), or similar. This is the area where the most intense bedload transport and the coarsest sediment will be found. Given the time constraints of the emergency measures, the sediment is analyzed using a sediment ruler (Figure B.5). Sieving in a laboratory is not needed for a general impression of the type of sediment transport in the river.

B.8 Drilling

Drilling tests will provide information on geotechnical properties of the subsoil. Specifications are to be given by a geotechnical expert.

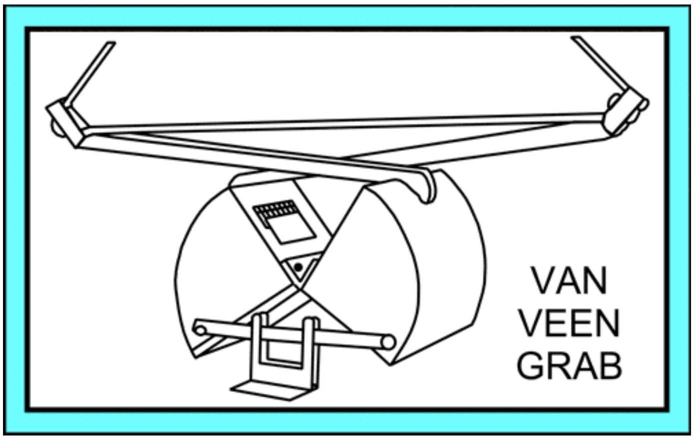

Figure B.4. Van Veen sediment grab.

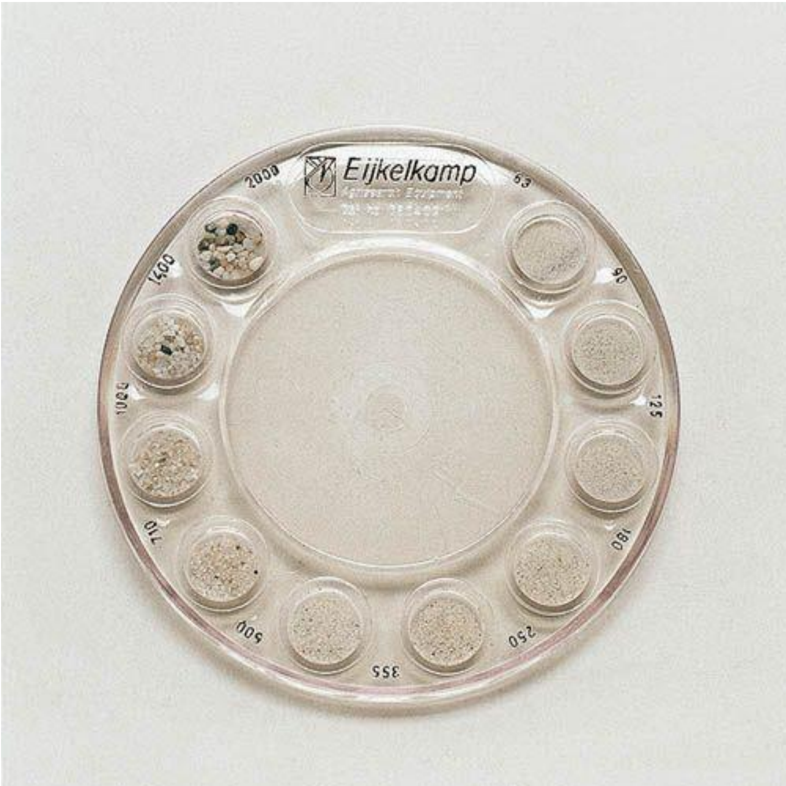

Figure B.5. Sand ruler.

C Mission report 23-25 April 2017

The author carried out a mission to Dhaka from April 23 to April 25, presenting the findings of this report at the “Workshop on Review the Innovative Design for the Polder 29 Bank Protection Works under Blue Gold Program”, held at BWDB in the WAPDA Building in Motijheel, Dhaka, on April 24. Subsequently he participated in meetings at the Embassy of the Royal Kingdom of the Netherlands and in Hotel Lake Castle on April 25.

The mission gives rise to the following notes:

The proposed top-blocked permeable groynes combine properties of permeable groynes and bandals. Two arguments have become entangled: emergency bank protection (by permeable groynes) and innovative research (on bandal-type structures).

In the role of groynes, the proposed structures cannot provide a solution for the present bank erosion emergency, because:

- The battery of groynes does not cover a sufficiently long part of the bank prone to erosion;
- The spacing between individual groynes is too large;
- Bank erosion will be enhanced at upstream and downstream terminations, risking outflanking at the upstream termination.

For the research on bandal-type structures, the following observations apply:

- Bandal-type structures are suitable as auxiliary or temporary structures, not as a primary line of defence;
- The effects of bandal-type structures on flow and morphology are known qualitatively, not quantitatively. This makes them suitable for research, not for emergency bank protection;
- Proper functioning of bandal-type structures requires well-defined unidirectional flow. Tides cancel out the effects from flow in one direction, similar to earlier experiences with bidirectional flow over bottom vanes (Asmerom & Jörissen, 2003). If groynes are placed in pairs with points close to one another, they may give rise to sedimentation between the two groynes (favourable), at the cost, however, of leaving upstream and downstream parts of the bank more exposed (unfavourable).

A longitudinal protection based on proven technology is recommended for the present bank erosion emergency. The innovative structures will thus be tested along a bankline that is stable anyway. This is favourable for systematic research under controlled conditions and takes away the utility of testing a battery of groynes.

It is recommended to limit the testing to two top-blocked permeable groynes only, one pointing upstream and one pointing downstream. Additional groynes would be superfluous. The focus shall be on details of flow, sediment transport and morphology around individual groynes rather than on the large-scale effect around a battery of groynes. These details could be modelled with CFD software, assessing the effects on depth-averaged flow field, secondary flows and turbulence.

It is recommended to try different arrangements in the research, with adjustable bamboo mats instead of a concrete closed top. An advantage of steel piles over concrete piles is that steel piles can be recycled.

Representatives of BWDB, the embassy, Blue Gold and FRERMIP held a meeting in Hotel Lake Castle on April 25. Here it was decided to implement a longer battery of top-blocked permeable groynes along the stabilized bank of the Lower Bhadra, combining funds of Blue Gold and piloting under FRERMIP.