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River training works for Padma multipurpose bridge, Bangladesh

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ABSTRACT: The paper describes principal characteristics of the Padma River as they affect the design of river training works, including design flood discharges, cross-sectional dimensions, and flow velocities, depths of scour, sediments and morphology. It then describes various alternatives leading to the selected layout of the proposed river training works. Proposed methods of erosion protection are discussed briefly, along with geotechnical aspects, construction procedures, and maintenance requirements.

1 INTRODUCTION

The Padma River in central Bangladesh (Figure 1) is approximately 100 km long and flows in a south-east direction from the confluence of the Jamuna (or Brahmaputra) and the Ganges to join the upper Meghna River, below which point it is known as the Lower Meghna. The Padma Multipurpose Bridge will be located at Mawa, about two-thirds of the way down the Padma and about 35 km southwest of the capital city Dhaka.

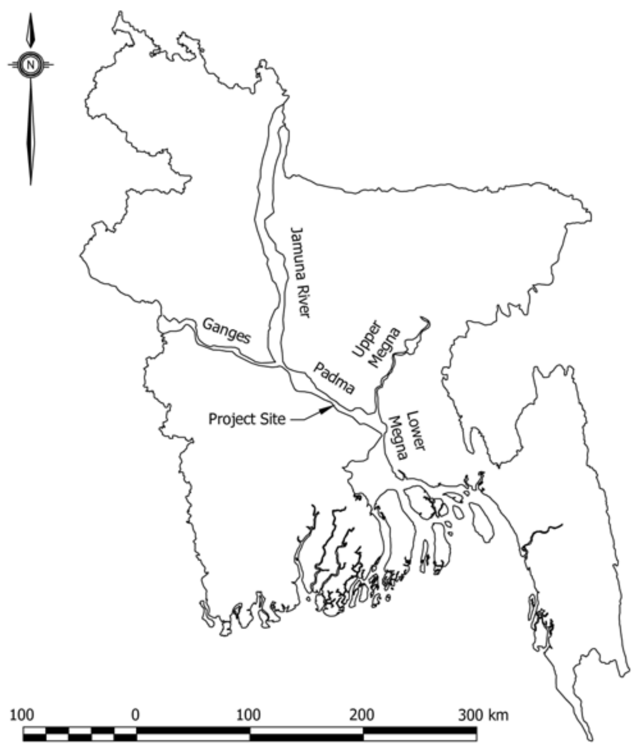

Figure 1 – Major river system of Bangladesh

The paper describes some characteristics of the river and key design features of river training works intended to maintain the river in a reasonably stable alignment as it approaches and passes under the bridge. Since the late 19th century such training works have been an essential feature of bridge design for the large alluvial rivers of the Indian sub-continent (Bell 1890, Spring 1903, Inglis 1949, Joglekar 1971).

Other recent large bridge projects in Bangladesh are the Jamuna Multipurpose Bridge (see for example Tappin et al. 1998), Paksey Bridge on the Ganges (see for example Mott MacDonald 1996), and the Bangladesh-UK Friendship Bridge on the Upper Meghna (see for example Collings et al. 2003). An older facility is Hardinge Bridge on the Ganges (Gales 1917, 1938). All those projects involved river training works of some type, and most have required periodic maintenance or upgrading.

2 PADMA RIVER CHARACTERISTICS

2.1 *Physical setting and flow variations*

The Padma River lies within a vast delta complex that has been growing for several million years and forms the greater part of present-day Bangladesh. Both major tributaries, Jamuna and Ganges, originate in the Himalaya and have been subject to major historical shifts associated with earthquakes and land-use changes. Of the present mean flow of around 30 000 m^3/s in the Padma, about two-thirds is derived from the Jamuna and one-third from the Ganges. The seasonal flow pattern through the year is of the monsoon type, with maxima in August-September and minima in February-March. Year-to-year variation is moderate.

2.2 *Hydrologic deign parameters*

Hydrologic parameters related to bridge design include low and high water levels and 100-year and 500-year flood discharges. Analyses were also conducted of wind speeds, wave heights and wave run-up. Maximum discharges of 100- and 500-year return periods are referred to as Design Flood and Check Flood, amounting to approximately 128 000 and 138 000 m^3/s based on the historical record. Effects of climate change on hydrologic parameters were investigated on the basis of a severe IPCC scenario, resulting in potential 100- and 500-year discharges of 148 000 and 160 000 m^3/s within the design life of the bridge. Although there are tidal effects at lower discharges, high water levels at the site are not significantly affected by potential rises in ocean level.

A 14-year record of water level versus discharge at the bridge site, 1994-2008, shows considerable variability. For example, at bankfull stage the discharge has varied from about 60 000 to 90 000 m^3/s with an average of about 75 000 m^3/s. This variability is mainly due to the shifting morphology of the river channel.

2.3 River mrphology

The present general location of the Padma River dates from about 1826. The planform is mostly of the partly multi-channel or anastomosing type, although a central reach including the bridge site has been most frequently single-channel. Aerial and satellite images from 1967 to date show that whereas the bridge site has remained relatively stable over the period, a reach extending about 20 km upstream has migrated back and forth from a near-straight alignment to a pronounced meander loop with a period of around 30 years (Figure 2). At present the main approach to the bridge is fairly straight, but it is likely to resume the meander alignment several times during the bridge life. In this alignment the main flow will approach the bridge from the southwest at a skew angle of about 45 degrees, and will tend to erode floodplain land on the right bank, towards the proposed south approach road.

The bed and bank materials of the Padma are generally fine sands that can be mobilized by quite low river flows, except at a few "nodal points" where cohesive outcrops in the banks more or less fix the channel location. The north or left bank near the bridge site is somewhat erosion-resistant along substantial lengths due to clay soils, but the south or right bank consists generally of unconsolidated, non-cohesive, fine-grained soils and has exhibited major erosional and depositional changes within periods of a few years.

The overall width of the Padma between tops of banks is typically 5 to 10 km. Average width increased after 1930 and particularly after 1990, allegedly due to sediment inputs from a major 1950 earthquake with landslides far upstream in Assam. Bankfull cross-sections are typically irregular, with a main deep channel and a wide shallower part (Figure 3). Average bankfull depths are around 10 m, but maximum depths at certain points in time and space can be 40 m or more.

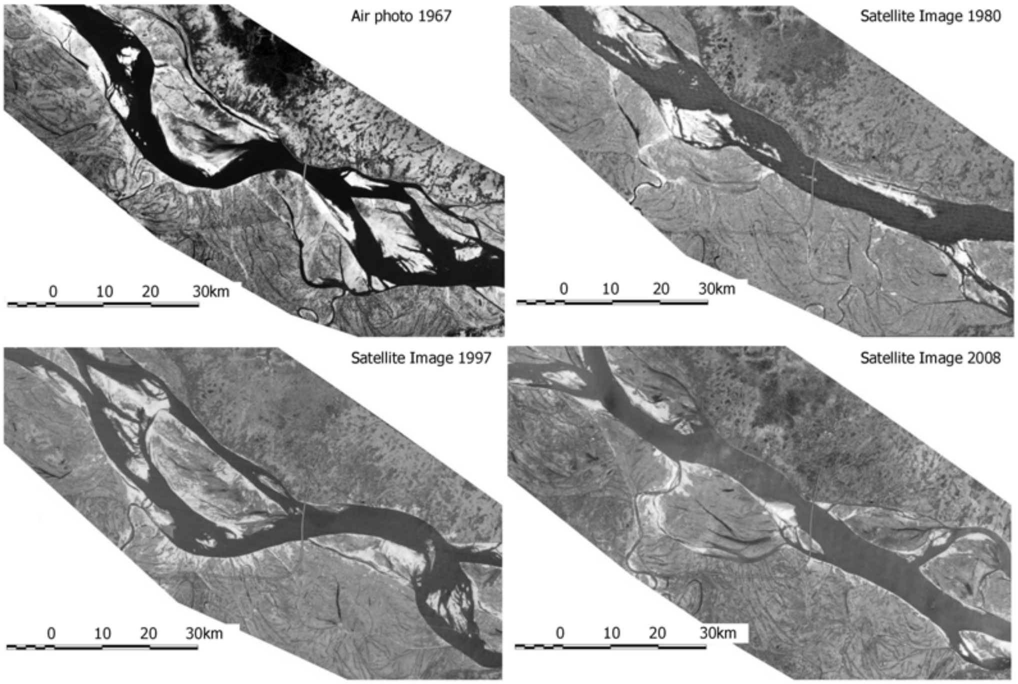

Figure 2 – Recent alternating alignments of main channel near bridge site

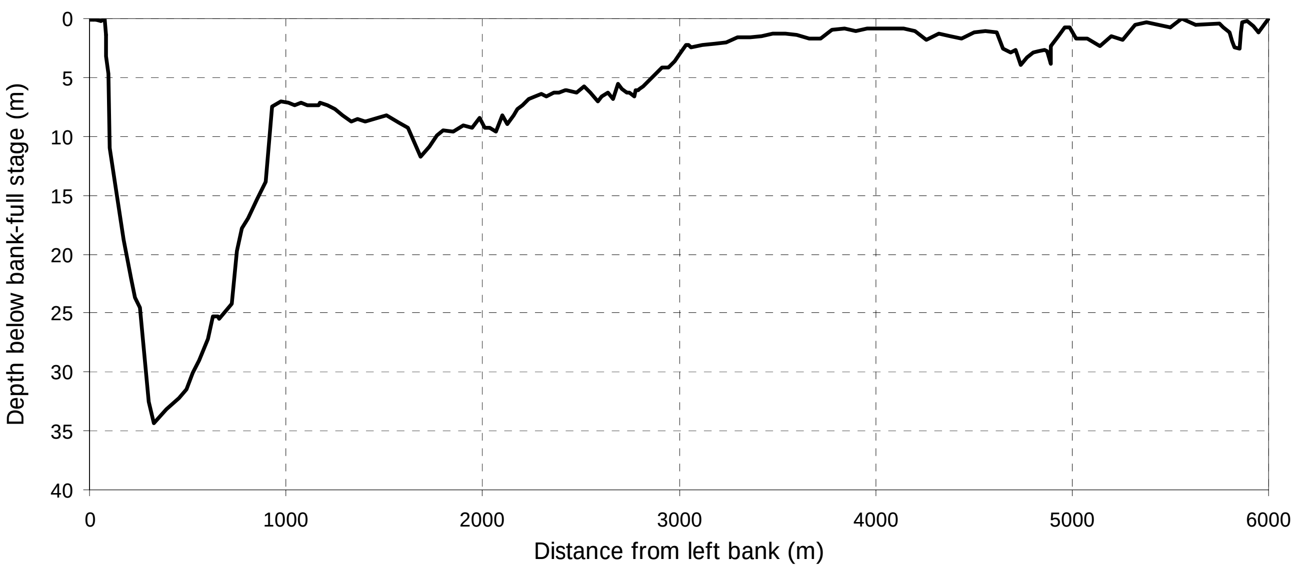

Figure 3 – Typical river cross-section

2.4 *River bathymetry and hydraulics*

A bathymetric survey of the 100-km Padma River was conducted as part of the bridge design project in August-October 2008. A length of 14 km near the bridge site was re-surveyed in August 2009. Velocities and discharges were measured at eight transects using an Acoustic Doppler Current Profiler.

The average slope of the river upstream of the bridge site is around 5 cm per km (0.00005). The overall hydraulic roughness (Manning n) decreases from about 0.040 at the lowest discharges to a minimum of about 0.013 at a bankfull discharge of around 75 000 m^3/s, and increasing somewhat at overbank discharges. A tentative explanation supported by limited field profiling is that prominent bed-forms at low discharges flatten with increasing discharges to reach a plane-bed condition under high flows. The fine sand of the bed is easily mobilized for both bed and suspended transport.

Cross-sectional average velocity at a bankfull discharge is only about 1.6 m/s, but the greater part of the flow is carried in a minor part of the width where maximum vertically-averaged velocities are up to nearly 3 m/s. Under 100-year design flood and 500-year check flood conditions, maximum vertically-averaged velocities are estimated as around 4.5 and 5 m/s.

2.5 *Maximum Scoured Depths*

Extensive bathymetric data in the general vicinity of the bridge site were collected by two government agencies from the mid-1960s to date. Generally, the greatest depths occur close to the relatively erosion-resistant north or left bank. Frequency analysis yields 100- and 500-year maximum scoured depths of about 52 and 60 m below top of banks. If data near the north bank are excluded, these values reduce to about 40 and 45 m.

These maximum natural scoured depths do not allow for local scour due to bridge piers and river training works. Physical model testing on bridge pier foundations indicate a potential additional depth of as much as 15 m below the ambient bed for the preferred design involving 8 raked tubular piles of 3 m diameter. Near the proposed river training works, total scoured depths below top of banks may range from about 60 to 70 m depending on flood frequency and location. (Although those depths are very large in relation to general river experience, they amount to only about 1% of the 6-km river width.)

2.6 *Geotechnical Aspects*

Principal geotechnical issues affecting the river training works are: 1) the maximum allowable steepness of underwater slopes to resist static failure due to river action, scour and construction operations; and 2) potential liquefaction of constructed works under dynamic loading due to earthquake action. Flow slides in over-steepened river banks are not uncommon in Bangladesh and were experienced during construction of Jamuna Bridge in the 1990s. Earthquake tremors are also fairly common.

Test hole drilling for the river training works was conducted during the 2009 monsoon and following dry season. Geotechnical assessment for common static load cases is based on deriving safety factors using generalized data for various soil strata, accounting for the effect of mica content on the loose, fine, and poorly graded sands and silts. Potential failure in locally weaker zones is also assessed, using shear parameters obtained from triaxial extension tests.

General conclusions regarding static stability are that underwater slopes should be no steeper than 1 vertical to 6 horizontal down to the lower limit of dredging at about 30 m below top of banks, where a wide apron will be placed to allow for deeper scour. An inner berm should be retained at that level after the outer part of the apron launches to cover the lower slope exposed by scour – see also Section 3.4 below.

With respect to earthquakes, it is concluded that the uppermost 10 m or so of south bank soils are susceptible to liquefaction under 50- to 100-year earthquake conditions. The relatively steep slope of a launched apron is also vulnerable, but the combined risk of critical earthquake action concurrent with deep scour and an exposed launched apron is considered to be low.

3 RIVER TRAINING WORKS

3.1 *Definitions*

The following terms are used to describe elements of river training works:
Revetment – erosion protection placed directly on a river bank or exposed slope.
Embankment – a dike or similar feature extending above high water level to contain or exclude water; it may form an upward extension of a revetment.
Guide Bund (or Guide Bank) – a dike or embankment more or less at right angles to bridge, intended to guide river flow smoothly into the bridge waterway opening; it may be constructed on the floodplain or in the river channel.
Hard point - a local erosion-resistant feature constructed on a river bank or projecting out into the river.

3.2 *Layouts Proposed in Previous Studies*

The current Padma Bridge design study was preceded by a Pre-feasibility Report (RPT et al. 2000) and a Feasibility Study (Nippon Koei 2004). The Pre-feasibility Report showed no river training works on the north bank, and only a relatively short (3 km) guide bund on the south bank. The Feasibility Study showed a 6-km length of revetment on the north bank, plus a 10-km length of continuous embankment and revetment on the south bank, extending far into the present minor south channel (Figure 4).

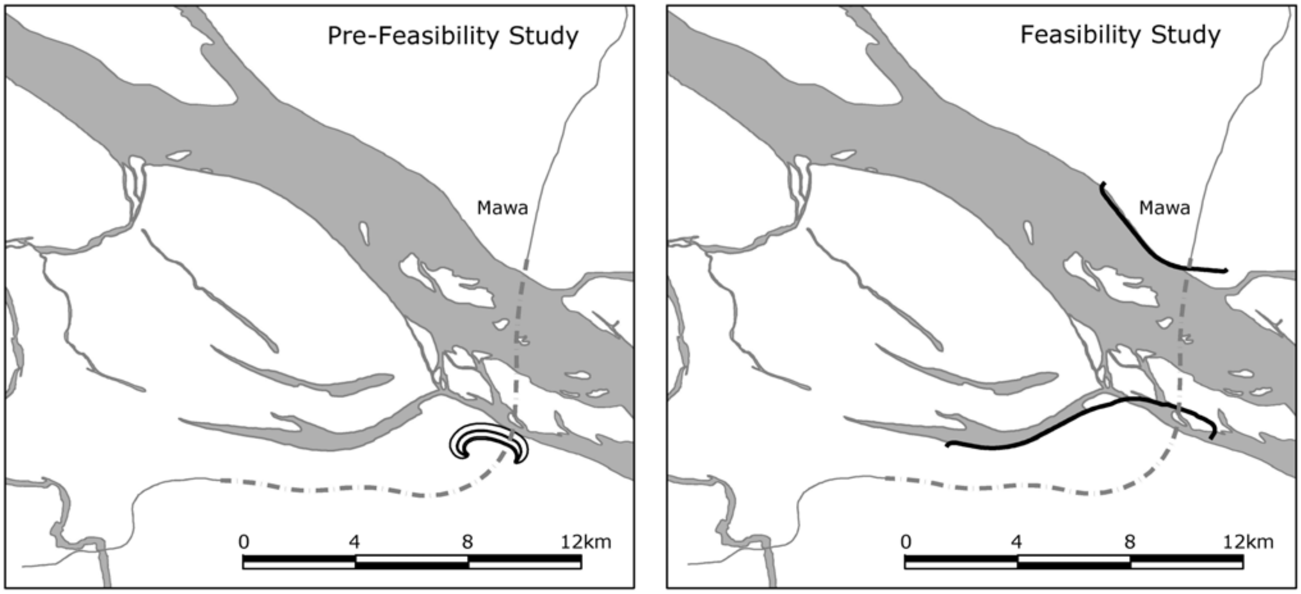

Figure 4 – Conceptual river training layouts from Pre-feasibility and Feasibility studies

3.3 *Considered Alternative Layouts*

The following three layout alternatives (Figure 5) were presented in an inception report of April 2009:
Alternative 1 - a modified Feasibility Study layout, recognizing that the south bank at the bridge alignment receded by about 500 m between 2004 and 2009.
Alternative 2 - a north bank revetment as in the Feasibility Study, plus an 8-km long guide bund on the south bank extending mainly upstream of bridge centreline and curving into the present minor south channel.
Alternative 3 - continuous revetments or embankments on both sides of the river for 20 km or more upstream of the bridge, intended to maintain the present favorable alignment through the life of the bridge.

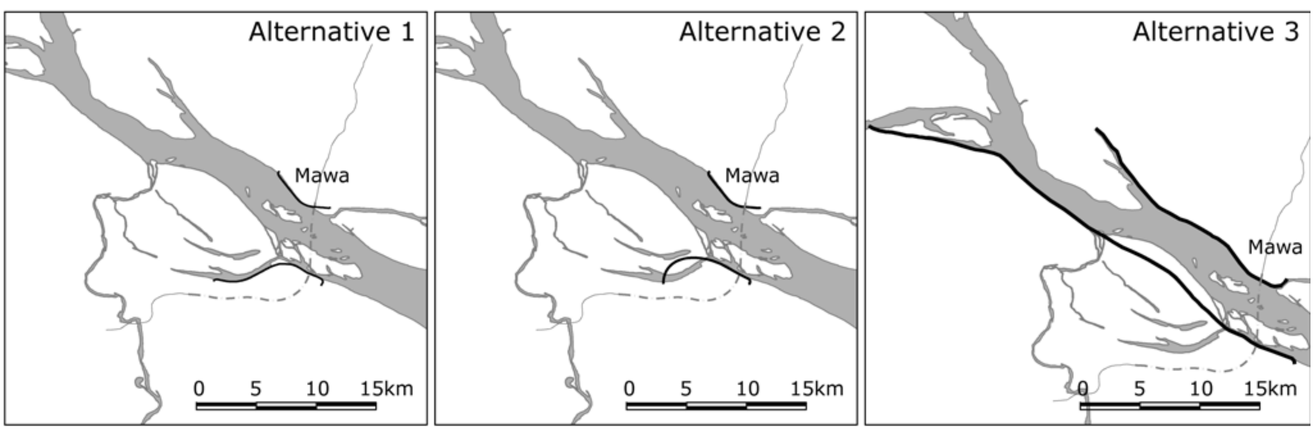

Figure 5 – Alternative training work layouts from Inception Report of 2009

Alternative 3 was rejected as impractical due to construction time, cost, and uncertainties over maintenance. Alternative 2 would have required a substantial part of the south guide bund to be placed on loose char deposits and would have afforded only limited protection for the south approach road. Alternative 1 was therefore preferred.

For the erosion-resistant north bank, further studies mainly involved shorter lengths of revetment than in the Feasibility Study. For the south bank the following three additional options, partly based on suggestions by the project's Panel of Experts, were studied (Figure 6):

In Option 1 the protection on the present main south bank was modified into the shape of a guide bund, and the continuous revetment in the present minor south channel was replaced with two or more hard points shaped like short guide bunds.

In Option 2 the south guide bund was shifted offshore onto a char, enabling a shorter length of main bridge.

In Option 3 a second guide bund was located some 10 km upstream, with a view to keeping the river in its present alignment.

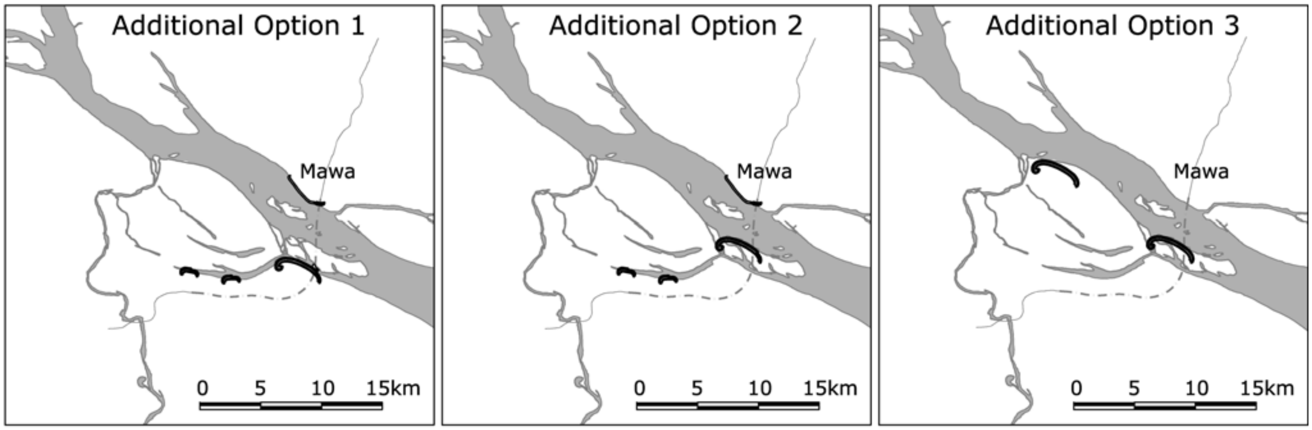

Figure 6 – Additional layouts studied in Scheme Design phase

The potential impacts on river flows and erosion patterns of all considered layouts were examined using morphological studies, numerical modelling, and physical modelling using both natural and low-density sediments. Morphological studies involved selecting "worst case" historical meander loops from elsewhere on the Padma River and superimposing them on the training works layouts. Numerical modelling involved examining velocity magnitudes and directions near the training works during flood flows, in both near-straight and meandering configurations of the river, using bathymetries surveyed in 2009 and 1996. Physical modelling included a comprehensive, vertically distorted model, a limited-area "sectional" model, and a flume model to examine bridge pier scour. These studies, together with multi-criteria assessments, generally confirmed that Alternative 1 (modified Feasibility Study layout) was likely to be the most constructable, durable and effective in the long run, given appropriate materials for erosion protection. As a result of physical model testing, the plan geometry of the south side work was further modified to soften the curvature.

3.4 *Training works cross-section and erosion protection*

Information provided here is basically for the preferred Alternative 1 layout (modified Feasibility Study). Details are partly novel and partly based on previous Bangladesh practice as at Jamuna Bridge. The basic components of embankment and revetment protection (Figure 7) are as follows:

Upper slope wave protection mainly above low water level, consisting of side-by-side concrete blocks underlain by a geotextile filter. The lower end of this component takes the form of a 5 m wide horizontal berm.

Lower (underwater) slope protection on a dredged slope of 1 vertical to 6 horizontal, consisting of rock riprap resting on several layers of sand-filled geotextile bags (geobags) acting as a filter. The toe level of this slope is variable but cannot be below the practical dredging limit at about 30 m below top of bank. The median rock size is tentatively about 450 mm. Consideration is being given to replacing the rock over part of the revetment length by geobags, which utilize local materials and labor, are less expensive than imported rock, and permit faster construction.

Toe apron consisting of several layers of rock or geobags placed horizontally at the toe of the lower slope. The outer part is designed to "launch" on a slope of 1 vertical to 2 horizontal as the lower slope is undermined by scour, leaving behind the inner part as a horizontal berm. Geotechnical stability considerations indicate that in areas subject to deep scour, apron placement and launching should be a multi-stage process whereby a new apron is placed once scour and launching have proceeded to a certain depth. As the timing of such a process is indefinite, this concept has important implications for monitoring and maintenance.

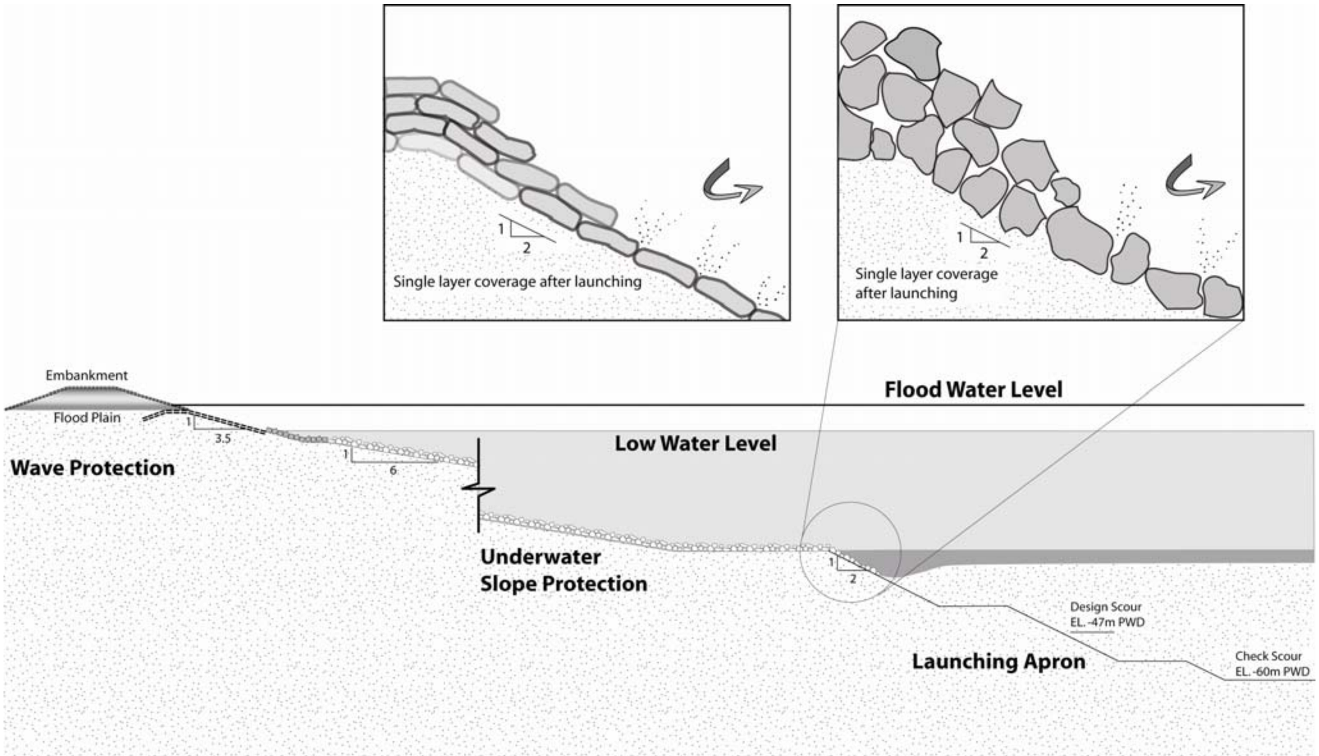

Figure 7 – Typical cross-section of training works slope with erosion protection (showing geobag and rock alternatives for launching apron)

Where required to prevent outflanking of the bridge ends by overbank flow, the training works will be raised to above maximum flood levels (*embankment).* Elsewhere, they will terminate at the top of the natural bank (*revetment)*. Special features including minor bridges will be required in order to maintain access to existing south bank distributaries and floodplain channels used for local navigation.

3.5 *Construction and Maintenance*

As for Jamuna Bridge, excavation and fill for construction of the training works and erosion protection will be done using cutter suction dredgers. Construction will proceed upstream from the downstream end of the works. The estimated total volume of dredged sand is in the order of 50 million m^3, probably requiring three construction seasons with three dredgers. Dredged material not required for embankment construction will be used for local fill and to form temporary chars in the river.

For such extensive training works in a shifting river environment, monitoring and maintenance will need to be kept up throughout the life of the bridge. A multi-step process is envisaged, consisting of regular monitoring, evaluation, adaptation and maintenance. Monitoring and evaluation involve the application and interpretation of general and local surveys plus diving and instrumental inspections. Adaptation involves mainly the upgrading of launched aprons on scoured slopes. Maintenance involves repair of damage and of gradual degradation.

4 CONCLUSIONS

The design of river training works for the Padma Bridge poses severe problems in river engineering, similar in nature but probably greater in severity than have been faced in other large bridge projects in Bangladesh. These problems include the very large scale and the periodic shifting of the river, the extremely fine non-cohesive boundary materials, the great potential depths of scour, potential geotechnical instability, and the high cost of traditional erosion protection materials such as rock riprap that have to be imported from abroad.

After analyzing a series of alternative layouts using various techniques including morphologic analysis and numerical and physical modelling, a layout fairly similar to that proposed in the Feasibility Study of 2004 has been adopted. Rather than attempting to maintain the river in its present fairly straight alignment towards the bridge, this layout allows the main river to re-occupy the present minor south channel from time to time, permits the south bank training works to be constructed on top of the slightly more consolidated sediments of the present river bank, and leaves room for the river to adjust to possible future developments like climate change.

Those works then consist of a continuous embankment and revetment that starts downstream of the bridge and continues upstream for a length of about 10 km, turning into the right bank of the south channel. This extension is designed to prevent outflanking of the south bridge abutment and eroding of floodplain land towards the south approach road. The work on the relatively stable north bank will consist of a relatively short length of embankment and revetment.

The typical embankment or revetment cross-section has three main components: upper-slope wave protection using concrete blocks, a dredged underwater slope with erosion protection using rock riprap and geobags, and a launching apron at the toe of this slope using rock riprap or geobags. Because potential maximum scoured depths far exceed the feasible maximum depth of the dredged underwater slope, the launching apron is critical for long-term stability and new ones may need to be placed at lower levels as scour deepens. This will require a long-term capability for in-river operations that goes beyond the common understanding of maintenance requirements.

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