Laboratory Based Study Using Physical Modelling On River Bank Erosion Control Using Concrete Block Mats And Placed Concrete Blocks With Filter On The Arial Khan River Bank At Madaripur District

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1 INTRODUCTION

1.1 Background

In historical times, the Arial Khan river was originally a drainage khal of the Arial Beel located in the Dhaka and Munshiganj districts. This khal had its outfall in the Bhubaneswar river. After the great flood of 1787, morphological changes in the flow path of Jamuna and Kali (Buri) Ganga rivers led the combined flow pass through the Ganga river. But the Ganga river main course shifted its flow to the Padma river. This led to abandoning the Bhubaneswar course upstream. To the downstream, the Bhubaneswar channel became the Arial Khan river (M. Inamul Haque, 2008).

The Arial Khan river is a distributary of the Padma river. It is the abandoned course of the Padma river. Even five decades ago, the river used to have several off-takes. Presently, its main off-take is at Sadarpur upazilla of Faridpur district. After originating from the Padma river, it falls into the Tentulia (Barisal) River at the Mehendiganj upazilla of Barisal district. On its way, the Arial Khan river maintains its link with the Padma through a number of streams and canals or khals such as the Naria, Palang, Moynakata, Bhubaneshwar, Kumar Kailar and Nayabhangi. The river maintains a meander channel throughout its course and is erosional in nature. It is a sinuous river and its degree of sinuosity is very high. A number of settlements have already been destroyed due to severe river bank erosion of Arial Khan river and the process is continuing. BWDB has taken measures to save these areas.

The Arial Khan is a medium size tidal river all along its length. But its water is sweet round the year. This river is eroding in nature, all over its length. For this reason, major changes occurred through its course, leaving natural loops at many places. It has an important water level station at Madaripur.

Concrete block mats and placed concrete blocks with filter are the developments of conventional old loose concrete block placement and loose concrete block dumping. There is an existence of sister technology like articulated concrete mattress and geo-textile filter which support the effectiveness of newly proposed protective measure. In this case, one mathematical formula for the position of holes in concrete blocks has been considered which is helpful for the formation of concrete block mats and one hydrostatic force has been considered for the placement of rolled geo-textile linked with RCC cylinders/pipes under water up to the required depth. Here the effectiveness will be more and expenditure will be decreased.

Engr. Syed Imdadul Haque of Manob Hitoishi Sangstha started thinking about the requirement of new river bank protective measure in the year 1988 while he was doing job in one consulting firm named Project Management and Consultancy Services Ltd. for the project of Bangladesh Water Development Board (BWDB). Making contact with the concerned water resource specialists of different organizations in Bangladesh for the long time from 1989 to 2014 it is concluded that the proposed new river bank protective measure using concrete block mats and placed concrete blocks with filter can be applied to the bank of river after model test at RRI. The test can be done in the laboratory for a location along the bank of Major River in low, medium and high flow condition. But presently the test to be done for a medium type river. The workmanship will be clear after the field based study for river erosion control of upper and lower bank.

The technique of proposed new river bank protection work is based on concrete block mattress system where precast holed concrete blocks held together by steel wires and its placement on bank manually. From literature review we can find the articulated concrete block mattress has been used in Mississippi river of USA in different way where precast concrete blocks held together by steel rods or cables and its placement on bank mechanically.

Similar type of work has not done yet in Bangladesh and abroad. The idea and technique have been developed by Manob Hitoishi Sangstha (MHS). So, it is felt that there is a need for the development of economical and environment friendly approaches. From approximate technical and financial analyses, it is found that river bank erosion control using concrete block mats and placed concrete blocks with filter are the best effective substitute and much cheaper than the conventional loose concrete blocks placement and dumping for the control of river erosion. The technical and financial aspects of newly proposed protective measure through Physical Modelling to be explored by River Research Institute (RRI).

With a view to reproduce the new concrete block mat in the model, all dimensions will be scaled down as per selected scale ratio. The block hole and rod/wire tie will also be simulated with considered scale ratio as far as practicable. The geo-textile used underneath the block mat will also be simulated with appropriate materials in consultation with the client and concerned design engineer. Set up of the concrete block in the model is a challenging work. However, all major issues will be incorporated to reproduce the scour hole correctly in the model.

Under this backdrop, BWDB has duly taken up a study project entitled "Laboratory Based Study using Physical Modelling on River Bank Erosion Control using Concrete Block Mats and Placed Concrete Blocks with Filter on the Arial Khan River Bank at Madaripur District" and an agreement is signed between RRI & BWDB on 6th June, 2016 to conduct the aforementioned study with the guidance and funding of Bangladesh Water Development Board (BWDB).

The study area is at the bend of Arial Khan river at Ramarpole near Mollarhat bazar under Kalkini upazila of Madaripur district. Here the river is very dynamic and active. The river has a shifting tendency and devastating bank erosion occurs at the right side of it.

The surveyed area (6 km) has some protective works but modelling area (1km) has no protective works. About 1.0 km of river reach [0.5 km u/s & 0.5 km d/s of centre of bend (CS53)] of Arial Khan river is reproduced in the model which does not have any protective works. The location of study area is shown in **Figure 1.1.1.**

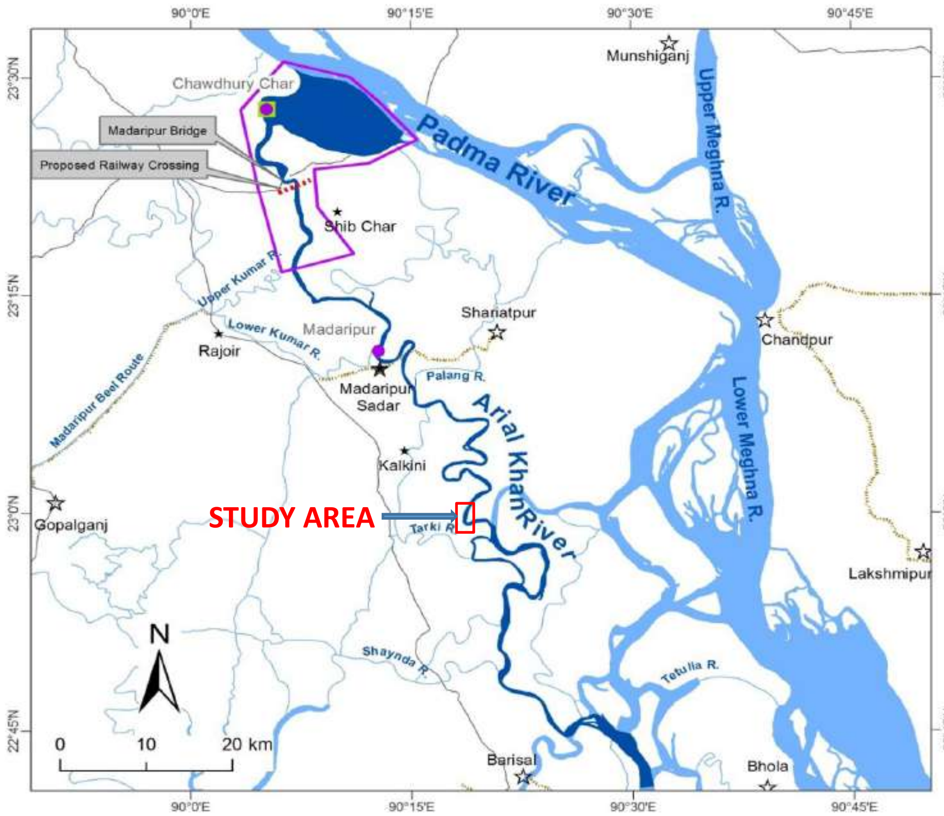


Figure 1.1.1: The location of the study area of Arial Khan river (Source: CEGIS, 2014)

1.2 Objectives of the Study

The overall objective of the study is to evaluate and determine the performance of concrete block mats and placed concrete blocks with filter in river bank erosion control compared to conventional methods.

The specific objectives of the project are:

- To verify the sustainability of protective measures using concrete block mats (wire tied) and placed concrete blocks (wire tied) in respect to the traditional case of technical and financial aspects.
- To construct a physical model of the Arial Khan River at the laboratory of RRI to investigate the effectiveness of protective structures with low, medium & high discharge conditions.
- To determine the design criteria for the proposed protective measures.
- To develop relationship/correlations among different parameters using the results of physical model study with different flow conditions.
- To identity the advantages and disadvantages of the proposed protective measures compared to conventional measures.
- To indicate construction methodology and monitoring method for the proposed measures of river bank protection works.

1.3 Literature Review

The traditional approach to combating river bank erosion is to use artificial devices to absorb the energy of the flow in the channel. Although vegetation has long been used to prevent erosion, both passively and actively, it has recently become an engineering tool. In this study, structural and mechanical stabilization techniques for concrete block mats has been explored.

Riprap blankets consist of concrete block is installed on the banks of a river to directly protect against erosion. Keown et al. (1977) describe the procedure for installing riprap. Usually, the bank is graded to an appropriate slope, the bank is lined with a bedding material to prevent leaching of the bank through the coarse riprap, and then riprap is placed on top of the bedding. An appropriately sized riprap must be chosen so that it does not erode under expected flow conditions. For best stability, elongated, angular stones are preferred to round, smooth stones, but design generally only specifies size of the stones used in the riprap. The riprap blanket should be about 1.5 or more median diameters in thickness, and must be properly tied into the bank at the upstream and downstream ends. Recommended maximum slopes are 2:1 (H:V) but 3:1 is more suitable. Riprap blankets are also sometimes referred to as longitudinal dikes or rock revetments. Riprap blankets can be expensive because of the large amount of material that may be required.

Maynord (1987) developed relations for appropriately sizing riprap. He used physical models to determine the diameter of riprap necessary to withstand hydraulic and gravitational erosive forces. Maynord provides relations for sizing riprap diameter for both straight and curved channels. Transverse dikes and weirs Dikes are commonly installed to protect banks from erosion. They also tend to increase the roughness on the edges of a channel, increasing depth and decreasing flow velocity. Three of the most commonly used types of dikes are longitudinal dikes, spur dikes, and vane dikes. Spur dikes (also called jetties or transverse dikes) are installed perpendicular to or at a slight incline to the flow (angled upstream into the flow), extending from the shoreline into the stream. Spur dikes greatly reduce near-shore water velocities, but also reduce the effective flow area of the channel. Sediment is deposited in low velocity areas behind spur dikes. Keown (1977) divides transverse dikes into: 1. permeable and 2. impermeable dikes. Permeable dikes are often constructed by driving timber piles into the bed at specific intervals. The dikes reduce flow along the outer bank and cause deposition between the dikes. Deposition increases the effectiveness of the dikes. Wire and timber fences have also been installed in the place of permeable dikes. The fences trap debris and encourage the deposition of sediment. Impermeable dikes are usually made of stone or concrete block that is dumped on the bed of the river and extend from the bank out into the flow. Impermeable dikes force all of the flow towards the center of the stream and can help deepen the channel.

Structural bank protection methods including (a) a longitudinal dike, (b) spur dikes, and (c) bend way weirs (after McCullah and Gray, 2005) Bend way weirs are submerged spur dikes that are built on the outside bank of a bend and are angled upstream. Bend way weirs are less costly than revetments and do not reduce effective flow area as much as spur dikes. Water flows over a bend way weir perpendicular to the weir. The angle of the weirs protects the outside bank by causing water to turn away from the bank. Vane dikes are installed to guide the direction of the flow. Vanes deflect the flow away from areas where erosion is undesirable. These dikes are also less costly than other types of dikes. If designed properly, vane dikes and bend way weirs can be relatively non-intrusive, and better for natural habitat than other forms of river training structures. All dikes impede stream flow by increasing bank roughness and/or reducing flow area.

Pavement and mattresses: Keown et al. (1977) list a variety of pavements and mattresses. Like riprap, pavement and mattresses are used to line the erodible outer banks of streams. Concrete pavement is cast in place and is very effective at preventing erosion. However, it is also very expensive. Articulated concrete mattress consists of blocks of concrete that are tied together with corrosion resistant wire. Concrete mattress is also expensive, but more flexible than pavement because it does not have to be cast in place. Interstices between the blocks of concrete can allow sediment behind the blocks to be eroded away over time, possibly leading to failure of the mattress. Both of these methods are limited to locations with good access to heavy machinery, and are not commonly used in small streams. Asphalt pavement and blocks have also been tried, but have not been particularly successful and in most cases were determined to be uneconomical. Mattresses can also be fascine mattresses (bundles of untreated tree stems) or timber and brush mattresses. These two types of mattresses are generally used when the material necessary to construct them is readily available. Their performance is not very good in terms of longevity because continual wetting and drying can lead to excessive rot.

Submerged vanes were first introduced to provide a low cost form of erosion control. The vanes are discussed in details by Odgaard and Kennedy (1983) and Odgaard and Mosconi (1987). The general idea was to make use of the energy of a small part of the flow to redirect a larger portion of the flow. By installing vanes on the bed of the river, secondary currents could be induced in the flow that would cause the entire flow to turn. Vanes are situated on the bed of a bend and affect the dominant circulation cell such that momentum on the outer bank is substantially reduced.

Other methods: An attempt has been made to cover the more commonly used structural erosion control techniques. However, there are many other techniques. For example, Keown et al. (1977) describe a variety of other mechanical methods, including the use of log revetments, jacks, tires, and even automobile bodies to protect against erosion. In addition to Keown et al. (1977), the report by McCullah and Gray (2005) and the handbook by Biedenharn et al. (1997) are good sources of information about structural and biotechnical streambank stabilization techniques.

The techniques of the proposed bank protection measures are the outcome of long time research by Engr. Syed Imdadul Haque. He started the research from 1988. Firstly, he developed the technique for the wide type mat formation by concrete holed blocks which is suitable to apply at upper bank of river. Later, he developed the technique for the strip mat formation by concrete holed blocks which is suitable to apply at lower bank of river. Here plantation is considered at gap of concrete block mats for upper bank of river.

1.4 Methodology

The model is investigated on a mobile bed. The hydraulic similarity is established in the model to an undistorted scale. The model is a Froude model and is studied over bathymetry of arch/2017. The model is constructed to an undistorted scale. The scale ratio is selected as 1:30. The model has been designed to fulfil both flow and sediment transport criterion simultaneously. It means the model velocity is higher than the critical flow velocity for the initiation of sediment motion. This is because for any velocity higher than the critical, the scour dimensions are only function of flow direction and structure geometry. The model will, therefore, reproduce the scour holes correctly.

An open air model bed of RRI has been selected for model development. It provides all kinds of facilities related to model study. Then layout of model is given by grid system. After setting reference grid points in the model, channel planform is given using these grid points and the bed & bank levels are fixed up by levelling instrument as per bathymetry using Rise & Fall method. This requires some cutting and filling of sand from the model bed.

In this physical model, various types of instrument and facilities are needed such as, a sharp-crested weir for measuring flow, point gauge for measuring water level, 3-D current meter for measuring velocity, high resolution camera for taking video and photographic view of model, stopwatch for taking instant time and plastic coloured balls (floats) for tracing flow path of flowing water.

The discharge in the model is measured using sharp-crested weir at the inflow section using Rebock's formula. Model velocity is quantified by current meter. Water slope can be found by analysing the water level measurements of different point gauges installed in the model. Flow lines of the stream can be identified by dropping coloured balls starting from calibration section and catching them at the end of the model. A stopwatch can be used to calculate surface velocity of the flow. In the physical model, model data requires to be analysed for interpretation of test results.

1.5 Stable Length for Under Water Slope Protection

Observed maximum depth of scour = Do
Safe protection depth against scour = Dp
Factor of safety = N
Length of applied protection = NDo
Safe angle of slope = 45^0

<u>Case-1</u>:

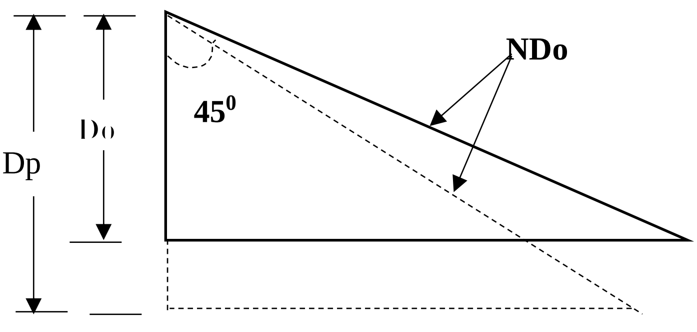
Do = 18m

N = 1.5

NDo = 1.5 x 18 = 27m

Then, Dp = Cos45^0 x 27 = 19m

Hence, Dp > Do by 1m (19 -18)



Case-2

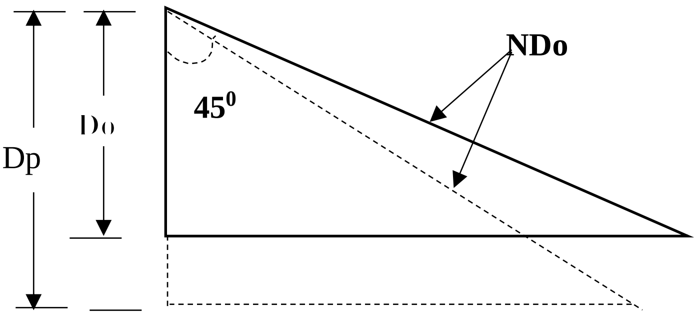
Do = 18m

N = 2

NDo = 2 x 18 = 36m

Then, Dp = Cos45^0 x 36 = 25m

Hence, Dp > Do by 7m (25 -18)



Case-3:

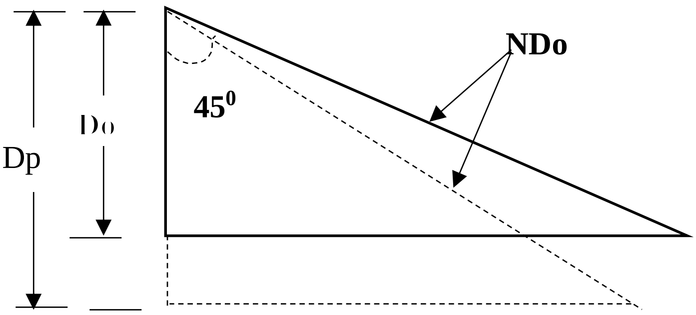
Do = 18m

N = 2.5

NDo = 2.5 x 18 = 45m

Then, Dp = Cos45^0 x 45 = 32m

Hence, Dp > Do by 14m (32 -18)



Now, it is shown that the consideration of 3 cases are safe.
For enough safety we have taken Case-2. So, length = 2 x 18 = 36m.

1.6 Structure of the Report

The Final Report presents the summary of test results of the proposed concrete block mat technology using physical model study conducted at RRI. The introduction, necessity and objectives of the model study are presented in Chapter 1. Chapter 2 describes the type of data used for model investigation. The aspects of the model scaling, design and setup are explained in Chapter 3. Chapter 4 discusses the test scenarios of the model. In Chapter 5, the calibration of the model is illustrated. Chapter 6 describes the application test runs and analysis of the test results. Finally, the conclusion and recommendation of the model study are discussed in Chapter 7.

2 PROTOTYPE DATA

2.1 General

Prototype data are required to simulate the existing hydro-morphological processes of the river in the physical model. For this purpose, bathymetric data, topographic data, hydrometric data, bed & bank material data, details design of the proposed structure, field observations etc. are required for model study. The details are described in the following sections.

2.2 Bathymetric Data

The bathymetric data of March 2017 are obtained by surveying the Arial Khan river at & around the study area. The length of river reach surveyed is about 6km. The survey is done for 0.5km u/s & 0.5km d/s centre of bend of the river @30m interval, after that 0.5km u/s & 0.5km d/s of the river @50m interval & next 2.0km u/s & 2.0km d/s of the river @100m interval. The base map is shown in **Figure 2.2.1.**

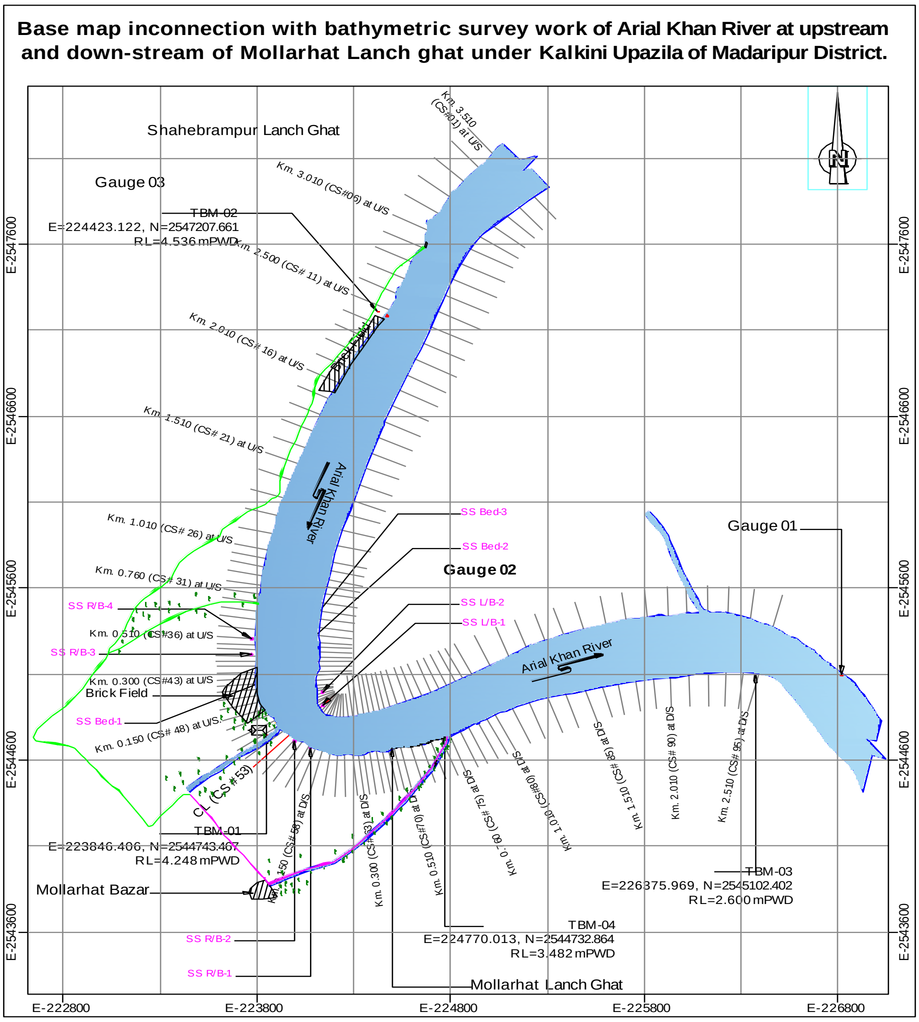


Figure 2.2.1: Base map for the study area of Arial Khan river at Ramarpole near Mollarhat bazar, Kalkini,

2.3 Hydrometric Data

The water level, discharge and velocities are measured at the location of proposed intervention (500m upstream of Mollarhat launch ghat bend. These data are analysed and used for design of the model.

2.4 Bed and Bank Material Data

9 (nine) nos. of bed & bank material samples of Arial Khan river are collected from different location of the study area at Ramarpole under Kalkini upazila of Madaripur district and these have been analysed in the Sediment Laboratory of RRI. These data have been used in the model study. The soil testing report is incorporated in this report as an **Appendix-A.**

2.5 Design of Proposed Protective Measure

Detail design & drawings of the proposed protective structure are collected from Manob Hitoishi Sangstha (MHS), Dhaka.

2.6 Field Visit

Field visits are made as per requirements of the model study.

2.7 Design WL and Discharge Data

In the present study, the low water level (LWL) considered is 0.24 mPWD which is found during survey of Aria Khan river from 16.03.2017 to 22.03.2017 by Survey & Data Consultants, Mirpur, Dhaka. The discharge corresponding to LWL is 1151 cumec. The medium & high water level considered as the water level of 2.33-yr & 100-year return period (RP).

Frequency analysis was done using 26 years of water level data at station: Offtake of Arial Khan river (SW-4A) using Generalized Extreme Value (GEV) and Extreme Value Type I (Gumbel) distribution.

The choice of a suitable standard frequency distribution is often controversial but the GEV distribution has obtained widespread acceptance as it considers the shape parameters. In the present study the General Extreme Value (GEV) distribution was considered.

The water level at this station corresponding to 2.33 & 100-year return period is 6.48 & 8.18 mPWD respectively. From slope analysis, the water level is 1.23 & 2.93 mPWD respectively at the study location corresponding to these return periods. The discharge corresponding to these water levels is calculated as 2156 & 3465 cumec respectively. The plots of the fitted GEV and EVI distributions together with 95% confidence limits for the EVI are **Figure 2.7.1**.

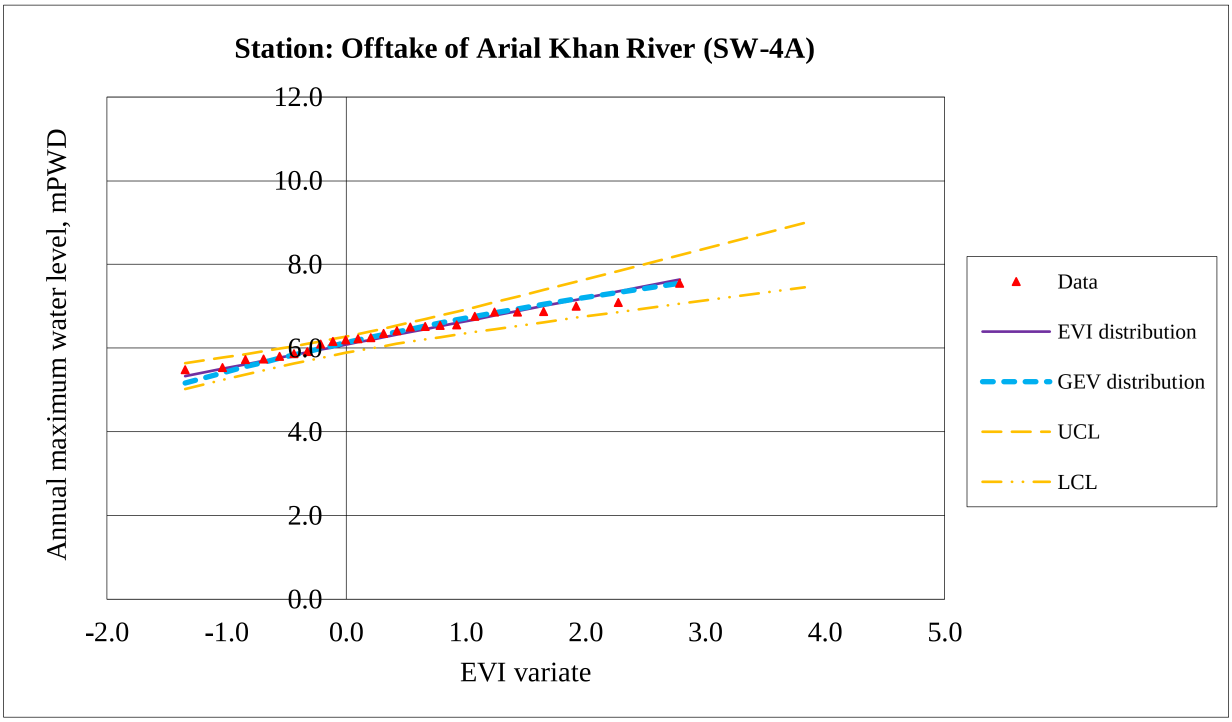


Figure 2.7.1: Fitted GEV and EVI distributions lying outside the 95% confidence limits for the EVI

3 MODEL SCALING, DESIGN AND SETUP

3.1 Modelling Approach and Scaling

Scaling of the model mainly depends on the objectives of the model studies and the available laboratory facilities. An open air model bed of RRI is used for setting up the model. The model has been designed based on the scale model laws and conditions used for scale /physical model of river. In this regard, recent development in the theories of the physical processes of the alluvial rivers has been considered during scaling and design of the model.

There is a close water circulation system in both the models controlled by discharge measurement weirs, tail gates for water level control, gate valve for water flow etc. Sediment transport condition is simulated as per requirements of the model comparing with field condition. The performance of each model test runs are analysed and evaluated and accordingly the next test run is planned/finalized after discussing with the client to achieve an acceptable solution.

3.2 Concrete Block Mat (CBM) Model

About 1.0 km length (0.5 km upstream and 0.5 km downstream of centre line of bend, C/S-53) with partial width of the Arial Khan river is reproduced in the model. It is an undistorted model having horizontal and vertical scale 1: 30. Model bed and bank are composed of fine sand having D_{50} about 0.16mm. Ebb discharge corresponding to LWL, 2.33-yr WL & 100-yr WL is taken into account to investigate the model. Two different discharge conditions, one is Froudian discharge and the other is scour discharge. Froudian discharge provides flow pattern & velocity field as a whole and the scour discharge focuses on the scour simulation and sediment transport. Each test of the model continues until a dynamic equilibrium condition is reached and Froudian discharge is run for 12 hrs. Considering the above issues the model scale is selected ensuring the following model requirements.

- The model scale is undistorted
- The model scale is selected to ensure sufficient water depth for measurement of velocity
- The model fulfilled flow as well as sediment transport condition simultaneously
- The geometric scale should be such that it allows the model to be fitted within the available laboratory space at RRI
- The discharge requirement in the model should be within RRI pumping capacity

The need for reliable field data on the flow and sediment transport processes is of immense importance in the scaling process. The previous information and present surveyed data are taken in to consideration for calculating different parameters. The design processes of the models have been described in the following sub-sections:

3.2.1 Similarity Condition of CBM Model

The CBM model has been designed so that the scale conditions for simulation of flow field, sediment transport and local scour are satisfied. The scale conditions are described below:

- ***Geometric Condition***

The detail models should be undistorted: $L_r = h_r$

Where, L_r = horizontal scale and h_r = vertical scale

- ***Roughness Condition***

In the model the following roughness condition is required in order to reproduce the flow field properly. But in this model some deviation is occurred as the model is rougher.

$C_r^2 = L_r / h_r = 1$ Where, Cr = roughness scale

- ***Froude Condition***

The Froude condition is fulfilled which holds when: $V_r = h_r^{0.5}$

- ***Sediment Transport Condition***

In the movable bed model following scale condition for sediment transport should be satisfied:

$V_m > V_{crm}$

Where, V_m is velocity in the model.

The critical velocity in the model, V_{crm} can be calculated using the following formula:

$V_{cr} = 0.19(d_{50})^{0.1} \log(12h/3d_{90})$ for $0.0001m \le d_{50} \le 0.0005m$

Where, d_{50}= Median particle diameter (m) and d_{90} = 90% particle diameter (m)

The critical velocity for sediment transport can also be calculated from the critical Shields value. The critical velocity in the model has been calculated from the following equations (Van Rijn, 1982):

$$D_* = d_{50}\{(s-1)\, g/\nu^2\}^{1/3}$$

$$\theta_{cr} = 0.14D_*\text{^}(-0.64) \text{ for } 4<D_*<=10$$

$$\theta_{cr} = 0.24D_*\text{^}(-1) \text{ for } 1<D_*<=4$$

$$V_{cr} = \{\theta_{cr}(s-1)d_{50}C^2\}^{1/2}$$

In which, D_* = Particle parameter, d_{50} = Median grain size, s = Relative density of the sediment ν = Kinematic viscosity, C = Chezy co-efficient and θ_{cr} = Critical shields parameter.

The critical flow velocity for median particle diameter of model bed sand (0.16mm) has been determined from the above equations. The investigation is aimed at the equilibrium scour depth with continuous sediment transport. A requirement in this type of model is that in the model sediment transport has to be occurred at all locations as it occurs in prototype. In order to fulfil this condition an increase in the model velocity has been considered to ensure the sediment transport upstream and downstream of the proposed bridge. In this situation the scour hole characteristics are not influenced by the size of the bed material or approach flow velocity. But, like on the prototype, it is influenced only by the flow pattern, the geometry of the structure and cross-section. Thus, live bed scour condition is ensured in the model at which equilibrium scour depth is reached when, over a period of time, the eroded material equals the supplied material from upstream.

On the basis of the above considerations the following scale factors for the prototype and model have been obtained for different parameters for test T0-1 (**Table 3.2.1.1**) using average discharge data corresponding to 2.33-year return period water level and test T0-2 (**Table 3.2.1.2**) using field /observed data.

Table 3.2.1.1: Hydro-morphological parameters for CBM model (T0-1)

Description	Unit	Prototype	Model	Scale
Water level	mPWD	1.23	-	30
Length, L	m	1000	33	30
Top width at C/S-39	m	112.81	3.76	30
Avg. water depth, h	m	6.12	0.20	30
Water surface slope, i	-	0.00005	0.00005	1.00
Average velocity, v	m/s	1.50	0.274	5.48
Cross-sectional area, A	m^2	871.79	0.9687	900.00
Roughness height (K_s)	m	-	0.02500	-
Critical velocity by van Rijn, v_{cr}	m/s	-	0.158	-
Chezy roughness co-efficient, C	$m^{1/2}/s$	70	30	-
2.33-yr discharge, Q	m^3/s	1309	0.265	4929.50
Scour discharge, Q_s	m^3/s	1309	0.402	4279.22
Median particle diameter, D_{50}	m	0.00012	0.00016	-
Dimensionless particle diameter, D*	-	2.688	3.584	-
Shields parameter, Θ	-	1.547	0.039	-
Critical Shields parameter, Θ_{cr}	-	0.089	0.067	-
Froude number, Fr	-	0.194	0.194	1.00
Shear velocity, v*	m/s	0.055	0.010	-
Critical shear velocity, $v*_{cr}$	m/s	0.01317	0.01317	-
Particle Reynolds number, Re*	-	1.317	1.756	-
Reynolds number, Re	-	7661865	46629	-
Sediment Transport by Enguland-Hansen	m^3/hr	441.07	0.23	1945.87
Critical velocity by Sheilds, v_{cr}	m/s	0.294	0.126	-
Fall velocity, w	m/s	0.01079	0.01918	-

Table 3.2.1.2: Hydro-morphological parameters for CBM model (T0-2)

Description	Unit	Prototype	Model	Scale
Water level	mPWD	0.73	-	30
Length, L	m	1000	33	30
Top width at C/S-36	m	105.00	3.50	30
Avg. water depth, h	m	6.56	0.22	30
Water surface slope, i	-	0.00005	0.00005	1.00
Average velocity, v	m/s	0.41	0.074	5.48
Cross-sectional area, A	m^2	835.75	0.9286	900.00
Roughness height (K_s)	m	-	0.02500	-
Critical velocity by van Rijn, v_{cr}	m/s	-	0.160	-
Chezy roughness co-efficient, C	$m^{1/2}/s$	70	30	-
Discharge, Q	m^3/s	340	0.07	4929.50
Scour discharge, Q_s	m^3/s	340	0.402	846.47
Median particle diameter, D_{50}	m	0.00012	0.00016	-
Dimensionless particle diameter, D*	-	2.688	3.584	-
Shields parameter, Ɵ	-	1.656	0.041	-
Critical Shields parameter, Ɵcr	-	0.089	0.067	-
Froude number, Fr	-	0.051	0.051	1.00
Shear velocity, v*	m/s	0.057	0.010	-
Critical shear velocity, $v*_{cr}$	m/s	0.01317	0.01317	-
Particle Reynolds number, Re*	-	1.317	1.756	-
Reynolds number, Re	-	2223127	13530	-
Sediment Transport by Enguland-Hansen	m^3/hr	0.60	0.26	2.32
Critical velocity by Sheilds, v_{cr}	m/s	0.294	0.126	-
Fall velocity, w	m/s	0.01079	0.01918	-

3.3 Model Setup

The model is setup in the outdoor model bed (60mX40m) of RRI using the available facilities. The river reach reproduced in the model is about 1.0 km including length of protective structure. On the basis of topographic, bankline and bathymetric survey of March 2017, the model bed is constructed. The layout of the model is shown in **Figure 3.3.1.** After calibration of the model, application tests are conducted with the discharges corresponding to LWL, 2.33-year WL & 100-year WL. These data are used to measure flow velocity, scour depth and float tracking. Model setup consists of model bed preparation & construction, water circulation system, stilling pond construction, installation of point gauges, measurement of water level, discharge & velocity and outflow condition in the model are briefly described in the following section.

Model Bed Preparation & Construction

Model bed preparation & construction is done based on the bathymetry of March 2017 of the Arial Khan river is used in the model. The bed material in the model is composed of fine sand (d_{50} = 0.16mm) in the movable portion of model bed. Some portion of the bed is fixed by cement-plastering at the inflow and outflow section of the model. The prototype cross-sectional data of surveyed sections are converted to model to prepare the model bed.

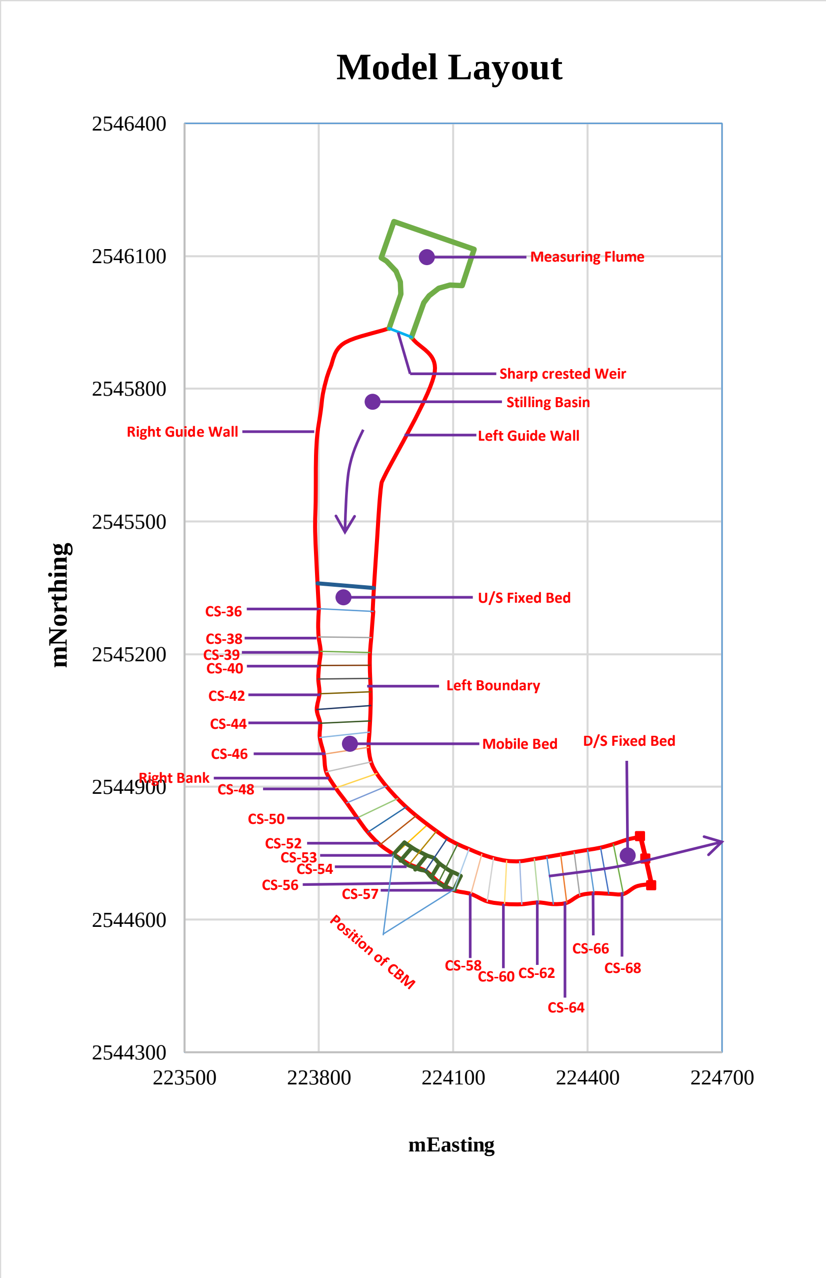


Figure 3.3.1: Layout of the Concrete Block Mats (CBM) Model

Water Circulation System

The channel network of the model area is a gravitational type. The available head difference between the supply and drainage sump is about 1.3m. In the water circulation system, the supply sump is connected with the pump having capacity of 0.400 m^3/s. The supply sump and the measuring flume are interconnected by gate valves. The water enters the model through these gate valves, flows over rectangular sharp crested weir and falls into the stilling pond where energy is dissipated for maintaining uniform flow at the u/s of the model boundary. At the d/s of the model area, 2-tailgates have been provided to allow water for draining into the drainage sump. The drainage sump is linked with the suction reservoir of pump house.

Construction of Stilling Pond

At the u/s end of the model, stilling pond is constructed in order to facilitate energy dissipation so that steady uniform flow is ensured.

Installation of Point Gauges and Measurement of Water Level

4-point-gauges are installed inside the model bed. The purpose of these gauges is to measure water surface level & slope.

Measurement of Discharge

The discharge was determined from the measured water level upstream of sharp crested weir. In the model the discharge is measured with sharp crested weir (length1.8 m and height 0.40m) installed at the measuring flume using Rehbock's formula as given below:

$$Q=(0.403 + 053h_w/p)(2g)^{0.5}b\,[(h_w + u_w^2/2g)^{1.5} – (u_w^2/2g)^{1.5}]$$

Where, Q = discharge in m^3/s, h_w= head over the weir in m, p = height of the crest of the weir in m g = acceleration due to gravity in m/s^2, b = length of the weir in m, u_w= velocity of approach in m/s

Measurement of Velocity

The flow velocities are measured with A-Ott type current meter. The average velocity is obtained by taking the velocity at 0.6 times the depth from the water surface.

Outflow Condition

In order to control the water level in the model three numbers of tailgates are installed at the end of the model. In all tests, desired water level is maintained by operating the tailgates.

3.4 Design of Protective Measures

The size of the holed block considered in the model study is 400mm×400mm×100mm. This block size should be scaled down to make it usable in the model for bank protection. It appears that making of model sized blocks is a cumbersome and time consuming task. **Figure 3.4.1** shows the typical holed block of CBM. The typical plan of erosion control measure by CBM at Arial Khan river bank is shown in **Figure 3.4.2. Figure 3.4.3 (a&b)** is typical section of erosion control measure by CBM at Arial Khan river bank. The typical displacement of deformative CBM under water due to scour can be seen in **Figure 3.4.4**. **Figure 3.4.5** shows rope fixation on pipe and placement of holed blocks by pusher.

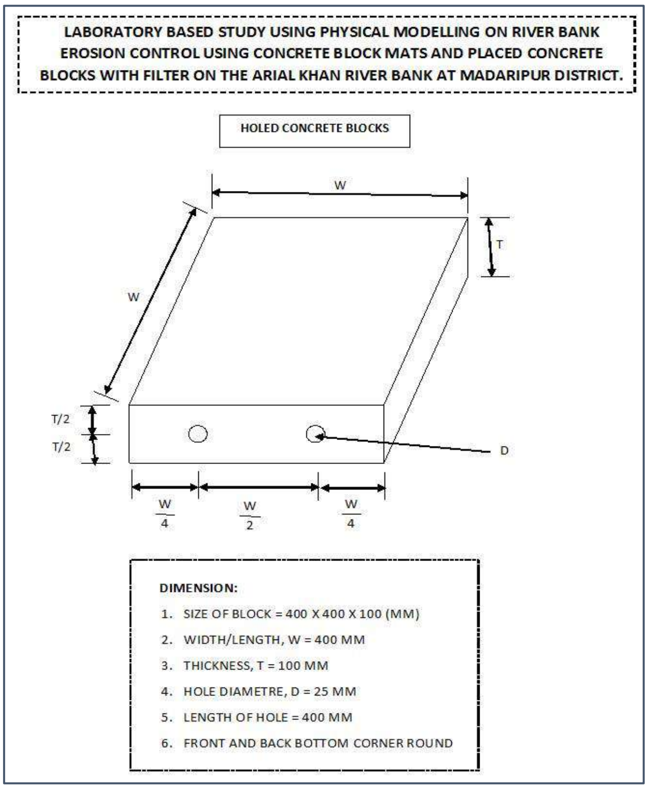


Figure 3.4.1: Typical holed block of CBM

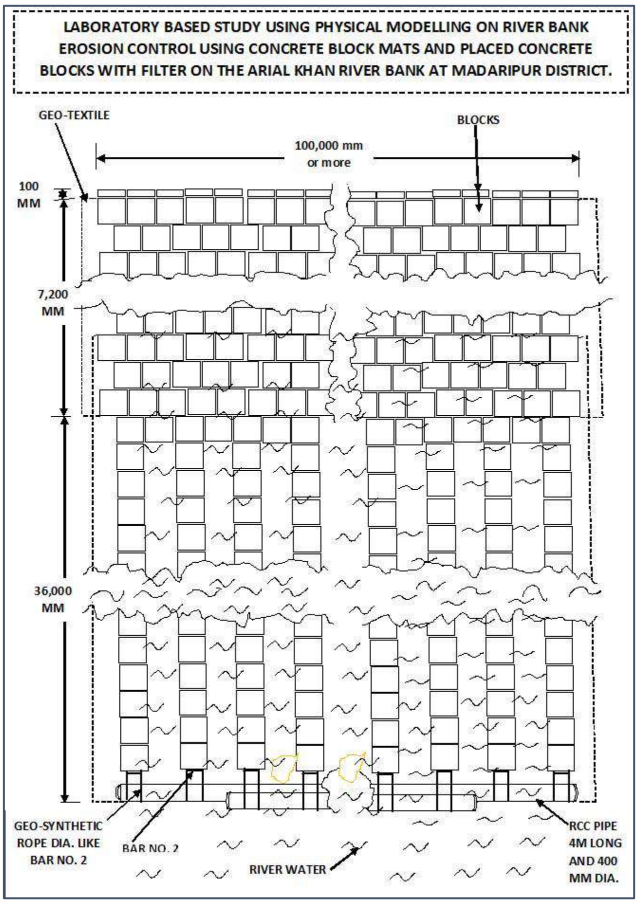


Figure 3.4.2: Typical plan of erosion control measure by CBM at Arial Khan River bank

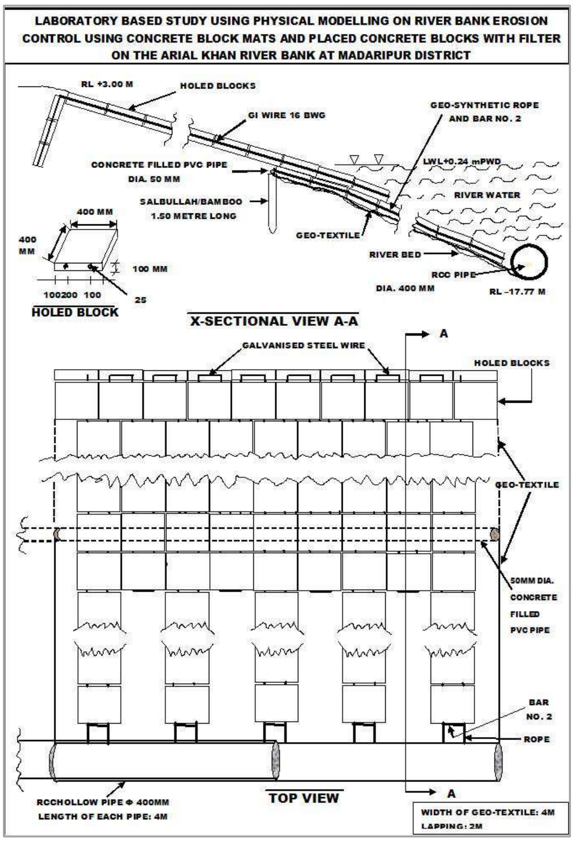


Figure 3.4.3 (a): Typical section (A-A) of erosion control measure by CBM at Arial Khan River bank

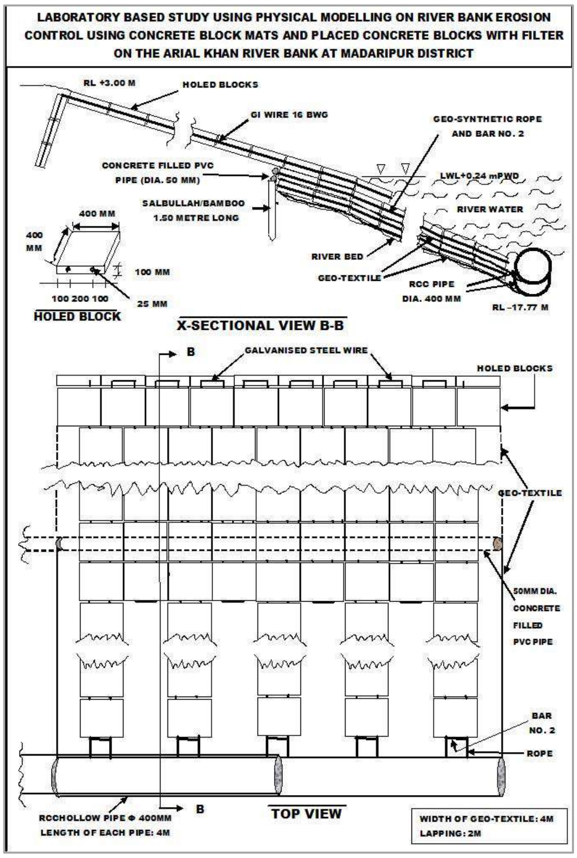


Figure 3.4.3 (b): Typical section (B-B) of erosion control measure by CBM at Arial Khan River bank

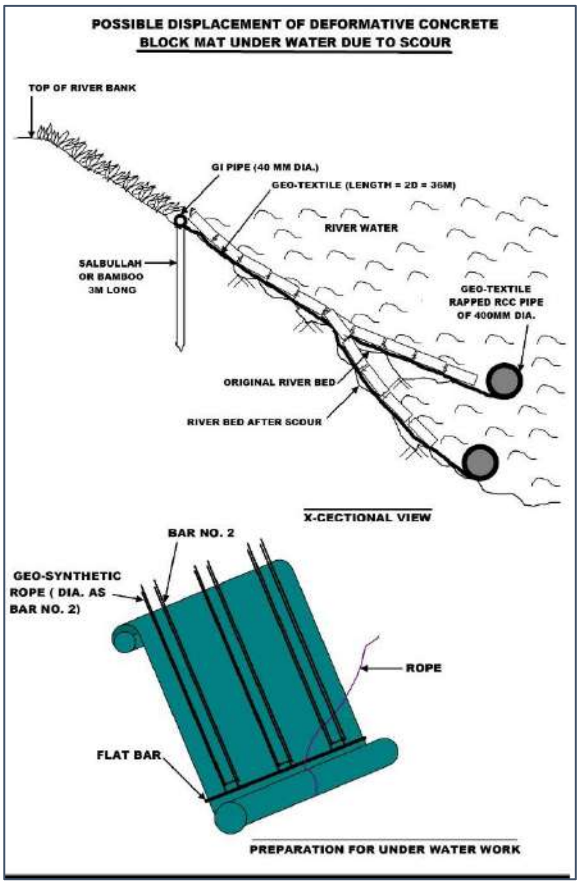


Figure 3.4.4: Typical displacement of deformative CBM under water due to scour

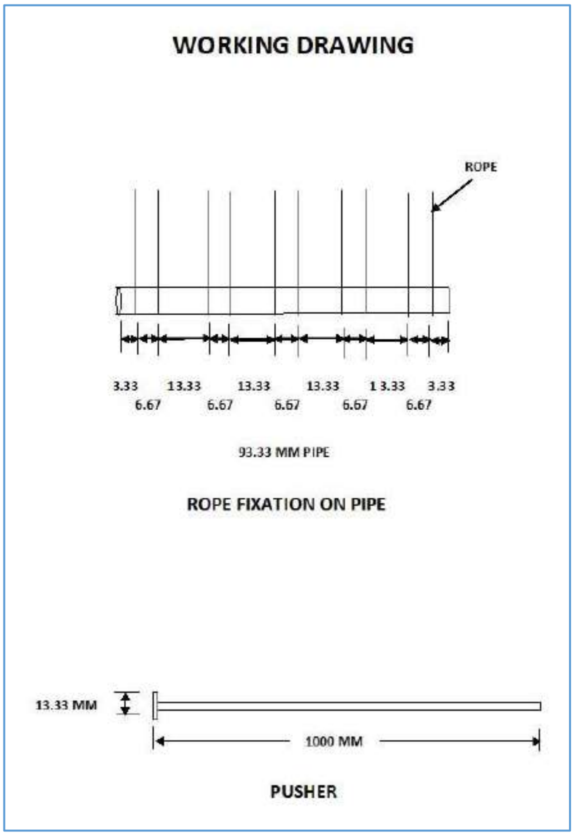


Figure 3.4.5: Rope fixation on pipe and placement of holed blocks by pusher

3.5 Design Consideration

Concrete Block Mats are designed for maximum erosion control. It is possible to install concrete blocks manually on a non-woven filter fabric that promotes proper drainage and allows for natural vegetative growth, adding lasting benefits to the property. The interconnected blocks enable easy, economical installation in areas prohibitive of heavy equipment due to site constraints, remote access and huge cost. By design, concrete block mats can be installed on filter at upper bank as well as lower bank in stages as a project progresses or as a budget allows.

Here, two type mats can be applied for the erosion control of Arial Khan river bank. One is wide mat suitable for upper bank and other one is strip mat suitable for lower bank. The width of wide mat is fixed to 4 metre due to availability of geo-textile width and the length is ascertained from the slope (1:2) length of bank. On the other hand, the width of strip mat is fixed to the width of one block and the length is ascertained from two times of maximum scour depth.

The square size block for the mat formation is ascertained from the comparative analysis of conventional individual block uses for river bank erosion control in Bangladesh, block of articulated concrete mattress uses for river bank erosion control in USA, pave uses for pavement works and tile uses on floor. Depending on this idea the size of each holed concrete block was fixed to 400mm x 400mm x 100 mm. For physical modeling the size of each block was ascertained to 13.33mm x 13.33mm x 3.33 mm.

For the proposed new concrete block mats there should remain at least one pair hole in each block. Here, one pair hole is considered and diameter of each hole should be t/4 or 25mm. The position of hole should be located at one-fourth distance of block dimension from end and distance between two holes is half of the dimension. The length of hole should be equal to the dimension of block. The size of hot dip galvanised wire for passing through the hole of blocks should be 12 BWG for wide mat of upper bank. The bar no. 2 will be used for the strip mat of lower bank The tensile strength of the wire should be in the range of 300 to 550 Mpa.

Observing the behaviour of new protective measure in physical modelling the decision for appropriate block size, hole diameter and wire size has been finalised. After the final run of model, the design has been finalized. In the final model run oblique flow was applied and found the satisfactory result for the protective measure.

The hydraulic forces which are considered in the design of erosion control projects using this technology are hydraulic lift, drag, and impact. Concrete block mats have demonstrated the ability to resist high velocity flows in excess of 25 ft./s (7.6 m/s), usually associated with drainage channels, water control structures, dam spillways, and fast flowing rivers. While many of the forces created by water can be readily calculated, particularly uplift and drag, each project application has separate design considerations. Concrete block mats are not designed to add structural strength to the slopes. The protected slope must be geotechnical stable prior to placement of surface protection. Known as "flexible revetments," Concrete block mats installations should not be placed on slopes which are steeper than the natural angle of repose of the soil. This is a different technology than retaining walls which resist lateral earth pressures. Protruding height variances between adjacent blocks should be minimized and must be in accordance with the design value utilized. Grading beneath the block and fabric is critical to establishing an acceptable finished profile of the Concrete block mats. Filter layers should always be placed under the Concrete block mats. The function of the filter is critical, as it must retain the soil. The filter layer must remain in intimate contact with the block and the soil to preclude soil particles from being transported down the slope beneath the geotextile. The key design points to consider in the filter selection are:

- Only woven monofilament or nonwoven needle punched geotextiles should be considered for filter applications.

- The filter layer must have a long-term permeability capable of handling the required volume of water through a restricted surface area equal to the joint area of the connected concrete block.

- The permeability of the filter layer must always be equal to or greater than the permeability of the protected soil unless a special bedding layer is provided.

- The filter layer needs only to retain the majority of particles beneath it, thus creating a filter bridge.

Care should be taken in the specification of the underlying geotextile filter layer. Appropriate ASTM test methods are available to characterize soil properties and should be done to develop the retention criteria and proper permeability. The geotextile must possess adequate strength and endurance properties to survive the process of installation and any long-term forces applied to it. ASTM D6684, Standard Specification for Materials provides strength requirements for geotextiles.

In most of these designs, the executing agency like Bangladesh Water Development Board should rely upon the engineering expertise of Innovator Engr. Syed Imdadul Haque to select the appropriate block type, filter layer, soil compaction, and design parameters. Proper material selection and construction practices are required and should be checked during installation. In course of time, the design procedure will be acquired by the Design Engineers of Bangladesh Water Development Board.

The formula for the design of concrete block mats may be reviewed with the cooperation of academic expert of water resource engineering department of engineering university. Here, velocity of flow is considered as design factor. The thickness of holed blocks is considered as 75mm for the velocity of flow up to 1.50m/sec. and 100mm for the velocity of flow more than 1.50m/sec.

As maximum velocity of flow of Arial Khan river is more than 1.50m/sec the thickness of block is considered as 100mm. The size of block becomes 400mm x 400mm x 100mm. The hole diameter (25mm) is one-fourth of thickness (100mm).

3.6 Construction Methodology

The explored new protective measure can be applied at different places of river bank with some equipment i.e. channel, pusher and barge etc. as per direction of Innovator or Consultant (Engr. Syed Imdadul Haque). In some places only wide type concrete mat will be required to apply as per design. In some places only strip type concrete mat will be required to apply as per design. In some places both type mats will be required to apply as per design. Concrete block mats can be installed by small construction crews with a modest amount of equipment. Installations are fast and are easy to inspect due to the visibility of all components.

At work place all workers including divers as well swimmers and supervisors will be oriented to the construction technique for execution by the Innovator or Consultant at the beginning stage of work. After this the Innovator or Consultant will guide the workers and supervisors very closely during construction for the appropriate execution of work as per design.

Subgrade preparation includes excavation, earth fill, installation of bedding or filter material, and geotextile installation. Prepare the subgrade in accordance with ASTM D6884, Standard Practice for Installation of Concrete Block Mat Systems. Compact the subgrade to the density as per direction of the engineer or consultant. Earth fill necessary to prepare the subgrade must be of the type and class standard. Compact bedding or filter material to the standard density. Compaction control and accurate shaping and fine grading of the subgrade is needed so that the components (i.e. geotextile, crushed stone or gravel where applicable, geogrid where applicable, and concrete blocks) remain in intimate contact with each other. Thus, a high degree of quality control is required. Do not place Concrete Block Mats, bedding, or geotextiles until the subgrade preparation is completed and inspected by the engineer or consultant.

The required number of holed concrete blocks will be casted by steel mould box. Mould boxes will be prepared by steel sheet and angle as per shape and size of blocks. Before casting the blocks two pieces of plastic pipe will be placed in the box as per requirement of the blocks. The plastic pipe will remain in the concrete blocks. The proportion of concrete for the holed block to be 1:2:4 and strength 3500 psi.

Where wide type concrete block mat will be required to apply for erosion control the bank should be prepared first as per 1:2 ratio. After the preparation of bank slope geo-textile filter will be placed on the bank earth slope. After the placement of geo-textile the holed blocks will be placed one by one passing steel wire and synthetic rope through the hole with the help of steel channel. At the top end of mat three blocks will be placed in earth forming 90^0 angle to the mat.

Where strip type concrete block mat will be required to apply for erosion control the salbullah or borak bamboo will be drived first at the bank earth near to the lowest water level. After driving the salbullah or borak bamboo one concrete filled PVC Pipe will be tied on the end of salbullah or borak bamboo. There after required geo-textile of 36m length and 4m wide will be cut from the roll and it will be rolled on the RCC pipe. At the time of rolling two flexible rope of same length to geo-textile piece will be kept inside the geo-textile. After completion of rolling the geo-textile end will be fixed on the concrete filled PVC pipe. After the fixation of geo-textile end the roll of geo-textile will be opened pulling the flexible rope by barge. Steel channels will also be placed under water for passing the blocks. The help of diver and swimmer will be taken for the placement confirmation about geo-textile and channels under water. The holed concrete block will be placed passing the steel wire and rope through the block hole. For major rivers, under water block placement is also possible if suitable instruments are utilised and capable Construction Company is engaged.

Concrete block mats to be installed on top of a filter layer over a prepared subgrade. The filter acts to protect and hold the subgrade in place while allowing bidirectional water penetration. Final subgrade elevation should be 0 to + ½ in. (12.7 mm) under a 10 ft. (3.05 m) straight edge. After the Concrete block mat installation is complete, the open cell voids or joints between the Concrete block mat units are filled with granular material or soil. Unit to unit vertical offset should be limited to the value utilized in the design. If vegetation is required, hydraulic seeding or mulching provides a low cost and highly effective method of establishing commonly used grasses and plants.

For the placement of wide type concrete block mats on upper bank slope geo-textile will be placed at first. Geo-textile will be placed one by one giving 50% lap. Wide type concrete block mats will be prepared by holed concrete blocks passing even numbers block one after odd numbers block. In suitable position one block gap will remain for plantation. After plantation the gap will be filled up by stone or brick chips.

3.7 Monitoring Method

Since river bank protection work by concrete block mats is long durable measure there will be needed easy monitoring. After the completion of whole construction work it should be monitored by the concerned field office and head office. Here, important observation for attack of river erosion at the nearby places should be carefully noted. If, any threat appears it should be checked applying appropriate measure in time. All concerned should remain alert against the miscreant’s intentional damage to the work.

The riverbank stability monitoring method includes: building monitoring leads based on a riverbed topographic map and a monitoring data acquisition network for riverbed underwater slope analysis sections; using the river-channel riverbed topographic map as basic information to digitally process the part of the topographic map of river-channel riverbed where the scour-and-fill monitoring lead is located, and digitally processing the part of the topographic map of the river-channel riverbed where the underwater slope monitoring start lead, the underwater slope monitoring end lead and an intersection of the scour-and-fill monitoring lead and the monitoring analysis section are located; according to obtained data, drawing a riverbed elevation change relation diagram of the scour-and-fill monitoring lead along the flow path, drawing a relation diagram about change of riverbed underwater slope ratio and underwater inner footing slope ratio, and calculating an average of sections; and scoring grading detailed rules of classification grade characteristic items for the segments according to the obtained data and technical parameters such as riverbank geological boundary conditions and the like, calculating and assessing comprehensive scores, and assessing bank slope stability risk levels of the corresponding sections.

The present invention relates to the field of hydraulic engineering technology, in particular to a riverbank stability monitoring methods, is a form of river bank collapse evolution, commonly found in alluvial plain river, bankline impact is not just related to the collapse of the bank area was gradually "eroded" disappears, is particularly important to build on the bank of the ground threatening bank collapse. The dike underlying security, thus threatening people's lives and property safety of the dike protected areas, affecting the normal use of river bankline resources development and utilization of water conservancy facilities, river sides, as well as the normal development of social and economic dike protected areas. River bank protection work to maintain or control the river bankline stabilization is an effective measure, is widely used in the alluvial plain river training works, as with all construction projects, river bank protection works not once, but also their natural life, especially underwater protection engineering, water damage is a major factor in the destruction of river bank protection works affect the natural life, loss of bank protection works to protect the slope from the bank collapse occurred the day is not far away.

The present process is basically the banks of stable risk management after the bank collapse, it is difficult to achieve a hedge against unburned, the result is a loss, difficulty and size of bank collapse focused governance required maintenance than conventional reinforcement. The collapse of shoreline or riverbank instability is stability risks continue to accumulate in the process, the general risks generated through riparian steady accumulation of development, the time course of the emergence of the phenomenon of bank collapse, which will have a riverbank stability risks predictable opportunities. Major accidents precautionary unburned timely risk of riverbank stabilization governance, maintenance of stability of the banks of the role of significant flood control can prevent occurrence.

3.8 Cost Comparison

The concerned field office of Bangladesh Water Development Board at Madaripur was requested to extend their cooperation to analyse the cost of protection measure applying loose concrete blocks and proposed concrete block mats for a same location. The location is selected at Ramarpole neat Mollarhat under Kalkini upazila of Madaripur district along the bank of Arial Khan River. Physical modelling was done referring to this location.

Cost for 314m length protection by **Conventional Loose Concrete Blocks**	Cost for 314m length protection by **Proposed Concrete Block Mats**
Taka 5,05,19,318.00	**Taka 3,58,65,859.00**

From the above comparison it is found that the protection measure applying new measure of concrete block mats is about 30% less than the cost of protection measure applying conventional measure of loose concrete blocks.

The detail cost estimate using conventional loose concrete blocks method & proposed concrete block mats method is shown in **Table 3.8.1** & **3.8.2** respectively.

The plan & section of design of the 314m length protection at Ramarpole under Kalkini upazila by using conventional Loose Concrete Blocks method are shown in **Figure 3.8.1 (a)** & **(b)** respectively.

Table 3.8.1: The detail cost estimate for 314m length protection by conventional measure

Abstract cost of estimate for Protection of Mollar Hat Bazar (Ramarpol & Alimabad) area from the erosion of Arial Khan River due to Climate Change in Upazila: Kalkini under Madaripur from km. 0.00 to km. 0.314 = 314.00 m. at Righ bank during the year 2013-14

Sl. No.	Description of items	Quantity	Unit	Rate (Tk)	Amount (Tk)
1 04-180	Site preparation by manually removing all miscellaneous objectional materials from entire site and removing soil up to 15cm depth including uprooting stumps, jungle clearing, leveling dressing etc. complete as per direction of Engineer in charge.	30,000.00	Sqm	30.08	9,02,400.00
2 40-900	Earth work in cutting and filling of eroded bank of river, channel etc. to design slope, including leveling, dressing and compacting the earth in 150mm layers and preparation of the base for bank protection work as per direction of Engineer in charge.	980.09	Cum	155.34	1,52,247.18
3 40-650 40-650-30	Supplying and laying sand as filter layers as per specific size ranges and gradation including preparation of surface, compacting in layer etc. complete with supply of all materials and as per direction of engineer in charge. FM : 1.00 to 1.50	225.14	Cum	938.75	2,11,350.18
4 40-600 40-600-40	Supplying and placing non-woven needle punched type geo-textile fabric as filter materials of elongation >=40%, horizontal and vertical permeability (under 2 kn/m^2 pressure) = > 2x10E-3 m/sec. for effective erosion protection in hydraulic structures/river training works including local handling, placing in position, providing machine seamed joints (with 100% polypropylene or nylon thread) or 35cm lap in dry condition or minimum 100cm lap under water including protecting the geo-textile material from UV ray and from any other damages including supply of all materials, labours, equipments etc. complete as per direction of Engineer in charge. (Geo-textile delivered at site should be certified by ISO and clearly labelled with brand name and grade printed at regular intervals across the body of the fabric. Mass => 350 gm/m^2, thickness (under 2 kpa pressure) =>3.00mm, EoS<=0.08mm, strip tensile strength =>23kn/m, grab strength =>1500N, CBR puncture resistance =>3800N	2747.50	Sqm	221.47	6,08,488.82
5 40-610	Supplying and laying dry 1st class or pick jhama chips as filter in two layers (top and bottom) as per specific size, range and gradation, including breaking chips, grading, preparation of surface, compacting each layer etc. complete with supply of all materials and as per direction of Engineer in charge.				
40-610-20	Well graded between 40mm to 20mm size	112.569	Cum	3956.32	4,45358.986
40-610-30	Well graded between 20mm to 5mm size	112.569	Cum	4329.00	4,87,311.20
6 40-140	Manufacturing and supplying C.C. blocks in leanest mix. 1:3:6, with cement, sand (FM>=1.5) and stone chips (40mm down graded), to attain a minimum 28 days cylinder strength of 9.0 N/mm^2 including grading, washing stone chips, mixing, laying in forms, consolidation, curing for at least 21 days, including preparation of platform, shuttering and stacking in measurable stacks etc. complete including supply of all materials (steel shutter to be used) as per direction of Engineer in charge.				
40-140-40	Block size: 40cmx40cmx20cm	14113	Each	367.82	51,91,043.66
40-140-35	Block size: 40cmx40cmx40cm	14719	Each	714.52	1,05,17,019.88
40-140-50	Block size: 30cmx30cmx30cm	23259	Each	305.65	71,09,113.35
7 40-485	Supplying of geo-textile bags (empty) of different sizes and capacity (fill volume and weight whene filled with dry sand) at project/work site including fabrication and supply of Geo-textile fabric (mass>=400gm/m2) and sewing in accordance with the detail drawing and technical specifications including in the tender document and schedule of Rates of BWDB, protecting the geo-textile bags from UV ray or any other damage, including cost of all materials, labours, Taxs, incidental charges etc complete as per direction of the Engineer-in charge.				
40-485-20	Geo-bag size : 1050mm x 800mm, Geo-fabrics thickness => 3.00mm, Fill Vol: 0.1160cum, wt. = 175kg	43310	Each	255.79	1,10,78,264.90

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Table 3.8.1 (Contd.)

Sl. No.	Description of items	Quantity	Unit	Rate (Tk)	Amount (Tk)
8 40-490	Filling of empty geo-bags of different sizes with sand (dry) of FM>=1.0, sewing along one transverse (top) side after filling sand, stacking in measurable/countable stacks including protecting the geo-textile bags from UV ray or any other damage, including cost of all materials, labours, Taxs, incidental charges but excluding cost of geo bags (item 10-485) as per design, technical specifications and detailed drawing including in the tender documents etc. complete as per direction of Engineer in charge.				
40-490-20	Geo-bag (1050mm x 800mm): Geo-fabrics th => 3.00mm, Vol: 0.1164cum, wt. = 175kg	43310	Each	104.19	45,12,468.90
9 40-487	Dumping of sand filled geo-bags from properly positioned and anchored flat top barge/pontoon over an area specified by the bathymetric survey for uniform area coverage along the bank line up to the designed length towards river, making a provisional falling apron at the river end of areal coverage, recording the position of dumping barge by a total station etc. complete including loading unloading, sequential piling of geo-bags on the dumping edge of pontoon/barge, carrying geo-bags from stack yard to dumping place by head load and power driven flat top country boat ect. complete including hair charge and mobilization of all equipments, materials, labours, taxes, incidental charges but excluding cost of sand filled geo bags (item 10-490) as per technical specifications, approved design, and direction of Engineer in charge.				
40-487-20	Geo-bag (1050mm x 800mm): Geo-fabrics th => 3.00mm, Vol: 0.1164cum wt. = 175kg	43310	Each	116.06	50,26,558.60
10 40-220	Labour charge for protective works in laying C.C. blocks of different sizes including preparation of base, watering and ramming of base etc. Complete as per direction of Engineer in charge.				
40-220-10	Within- 200m	451.616	Cum	1239.66	5,59,850.29
11 40-320	Labour charge for dumping in position Hard rock/stone/ boulders/C.C blocks/brick blocks/ sand cement blocks of different sizes on river bed/slope beyond 1.00m depth of water by boat or any other means as per direction of Engineer in charge.				
40-320-10	Within 200m	1570.00	Cum	1426.54	22,39,667.80
12 40-440	Supplying and filling empty gunny/ synthetic bags as approved in design and drawing with sand/earth available at site sewing the end with sutly, including carrying and placing in position within the site with supply of all materials as per direction of Engineer in charge.				
40-440-60	Capacity : 75 kg (New synthetic bags)	46001	Nos.	31.40	14,44,431.40
13 28-120	Cement concrete work in leanest mix. 1:3:6 with sand of FM>=1.5, in foundation or floor including breaking, screening, grading and washing aggregates with clear water, mixing, laying in position, consolidation to levels, curing, including supply of all materials, excluding the cost of form works etc. complete as per direction of Engineer in charge.				
28-120-20	With 25mm down graded stone chips	3.14	Cum	10,746.15	33,742.91
				Total =	5,05,19,318.00

(In word: Five Corer Five Six Lack Nineteen Thousand Three Hundred Eighteen Taka & Zero Paisa only)

পার্থ প্রতিম সাহা
নির্বাহী প্রকৌশলী
মাদারীপুর পওর বিভাগ
বাপাউবো, মাদারীপুর।

(মোঃ সাইদুর রহমান)
উপ-বিভাগীয় প্রকৌশলী (অঃ দাঃ)
মাদারীপুর পওর উপ-বিভাগ-২
বাপাউবো মাদারীপুর।

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Table 3.8.2: The detail cost estimate for 314m length protection by proposed new measure

Abstract cost of estimate for Protection of Mollar Hat Bazar (Ramarpol & Alimabad) area from the erosion of Arial Khan River due to Climate Change in Upazila: Kalkini under Madaripur from km. 0.00 to km. 0.314 = 314.00 m. at Righ bank during the year 2013-14

Sl. No.	Description of items	Quantity	Unit	Rate (Tk)	Amount (Tk)
1 04-180	Site preparation by manually removing all miscellaneous objectional materials from entire site and removing soil upto 15cm depth including uprooting stumps, jungle clearing, levelling dressing etc. complete as per direction of Engineer in charge.	30000.00	sqm	30.08	902400.00
2 40-900	Earth work in cutting and filling of eroded bank of river, channel etc. to design slope, including leveling, dressing and compacting the earth in 150mm layers and preparation of the base for bank protection work as per direction of Engineer in charge.	980.09	cum	155.34	152247.18
3 28-150	Reinforced cement concrete work in leanest mix. 1:2:4 with 25mm downgraded coarse aggregates and sand of FM>1.8 to FM<=2.5, to attain a minimum 28 day cylinder strength of 18.0 N/mm², including breaking, screening, grading and washing aggregates with clear water, mixing, laying in forms, consolidation to levels, curing, including supply of all materials, excluding cost of M.S. work for reinforcements and formworks etc. complete and as per direction of Engineer in charge.				
28-150-20	With stone chips.	1394.00	cum	11476.94	15998854.36
4 40-600	Supplying and placing non-woven needle punched type geo-textile fabric as filter materials of elongation >=40%, horizontal and vertical permeability (under 2 kn/m² pressure) = > 2x10E-3 m/sec. for effective erosion protection in hydraulic structures/river training works including local handling, placing in position, providing machine seamed joints (with 100% polypropylene or nylon thread) or 35cm lap in dry condition or minimum 100cm lap under water including protecting the geo-textile material from UV ray and from any other damages including supply of all materials, labours, equipments etc. complete as per direction of Engineer in charge. (Geo-textile delivered at site should be certified by ISO and clearly labelled with brand name and grade printed at regular intervals across the body of the fabric.				
40-600-40	Mass => 350 gm/m2, thickness (under 2 kpa pressure) =>3.00mm, EoS<=0.08mm, strip tensile strength =>23kn/m, grab strength =>1500N, CBR puncture resistance =>3800N	27946.00	cum	221.47	6189200.62
5 40-540	Supplying, sizing and placing of barrack bamboo pins and stays of diameter >= 8.0 cm in position etc. complete as per direction of Engineer in charge.				
40-540-20	Length: >= 2.0 m to < 4.5 m.	158.00	no	138.00	21804.00
6 50-442	Pipe, PVC., 50mm dia	628.00	m	120	75360.00
7 28-120	Cement concrete work in leanest mix. 1:3:6 with sand of FM>=1.5, in foundation or floor including breaking, screening, grading and washing aggregates with clear water, mixing, laying in position, consolidation to levels, curing, including supply of all materials, excluding the cost of form works etc. complete as per direction of Engineer in charge.				
28-120-20	With 25mm down graded stone chips	5.00	cum	10746.15	53730.75

Table 3.8.2 (Contd.)

8 60-260	Manufacturing and Supplying Standard machine made RCC pipe of different diameter, length and thickness in construction of Drain/ Sluice/ Culvert/ Outlet and any other works in leanest mix. 1:1.5:3 with12mm/20mm down graded stone chips, sand of FM>=2.0 and admixture (water reducing plasticiser) @ 1.5 litre per cubic meter of concrete to attain a minimum 28 days cylinder strength of 25 N/mm² including breaking, screening, grading and washing aggregates with clear water, mixing, laying in forms, consolidating, curing including the cost of 6mm dia M.S. work for reinforcement and form works as per approved drawing and specification including tools, plants, testing, stacking in measurable stack etc. complate as per direction of Engineer in charge.				
60-260-25	RCC Pipe : 450mm dia, wall thickness not less than 50mm, circular reinforcement 100mm c/c and longitudinal reinforcement 225mm c/c.	628.00	m	2135.27	1340949.56
9 76-100	M.S. Work for reinforcement with plain M.S. bar, fy=276 N/mm², (made from billet) in RCC works, including local handling, cutting, forging, bending, cleaning and fabrication with supply of plain round M.S. bar in different sizes and binding with 22 to 18 gages G.I. wire etc. complete including the cost of all materials as per direction of Engineer in charge.				
76-100-10	6mm dia.	13056.12	kg	82.02	1070862.96
10 40-760	Manufacturing and supplying 100mm size hexagonal mesh wire netting crates of 12 SWG galvanised wire, filling the same with boulders/bricks/brick bats (not smaller than half brick) and stitching with 12 SWG galvanised wire, tying the same and laying in position under water in bed or slope of canal/river, with supply of all materials etc. complete and as per direction of Engineer in charge:	623.00	kg	90.00	56070.00
11 26-556	Rope, Nylon : 6mm dia	1000.00	kg	180.00	180000.00
12 76-170	M.S. Work in plates, angles, channels, flat bars, Tees etc. including fabricating, machining, cutting, bending, welding, forging, drilling, revetting, embedding anchor bars, staging and fitting, fixing, local handling etc. comlpete with energy consumption and supply of labours including the cost of materials as per design, specification and direction of Engineer in charge.				
(a)	MS Angel	9231.60	kg	150.61	1390371.28
(b)	GI Pipe	126.00	m	345.00	43470.00
13 50-410	20 set pusher of 39m long by 19mm dia .GI pipe i/c manufacturing	2512.00	m	160.00	401920.00
14 50-407	One qualifed Guide who has sound knowledge on concrete block mats including support staff for himand	6.00	month	500000.00	3000000.00
15	labour Charge for installation	1394.00	cum	1239.66	1728086.04
	Sub-Total =				32605326.75
16	Incidental Expenditure		%	10	3260532.67
	Total=				35865859.42

06/06/18
(Partha Protim Saha)
Executive Engineer
Madaripur O & M Division
BWDB, Madaripur

06/06/18
(Md. Syedure Rahaman)
Sub-Divisional Engineer A.C
Madaripur O&M Sub-Divitional-2
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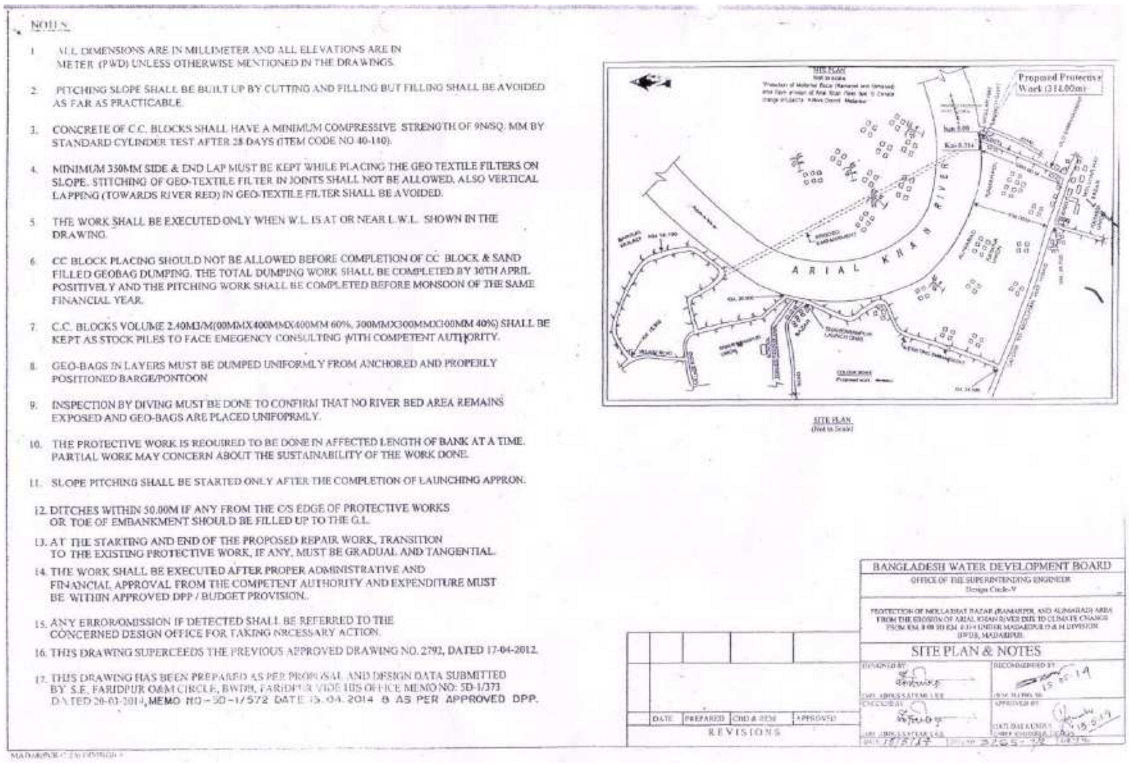


Figure 3.8.1(a): The plan of design of the 314m length protection at Ramarpole (Conventional method)

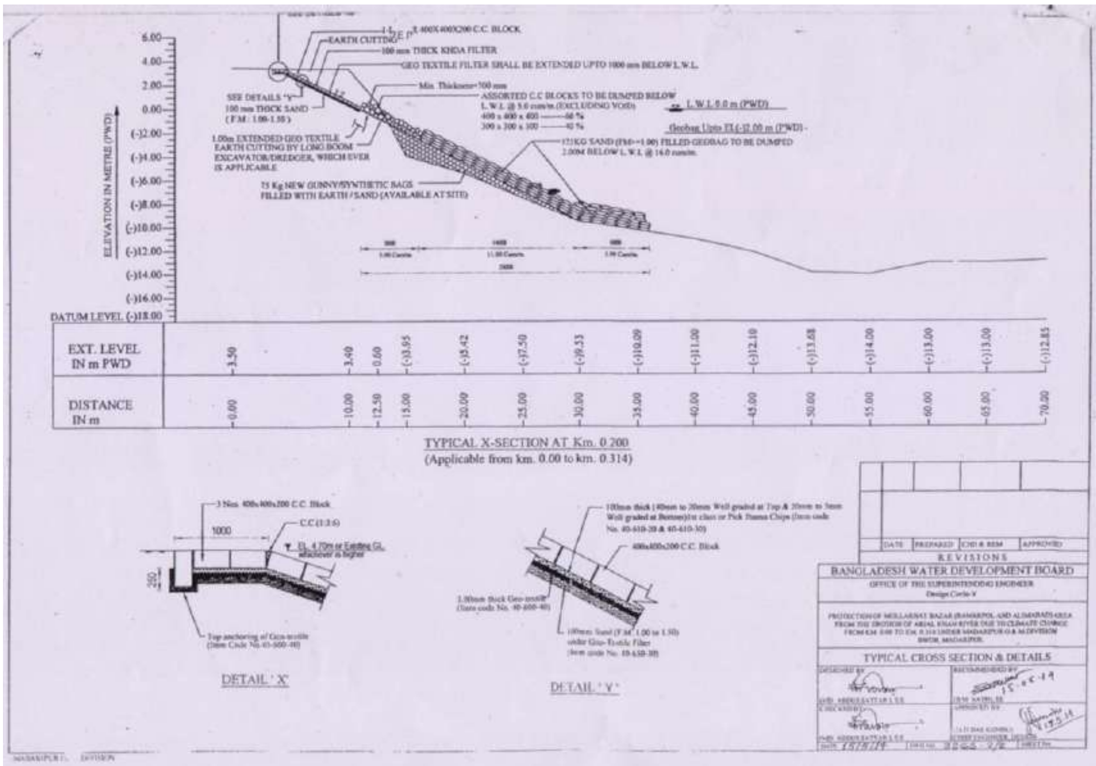


Figure 3.8.1(b): The section of design of the 314m length protection at Ramarpole (Conventional method)

3.9 Model Construction

After a long analysis the size 400mm x 400mm x 100mm of holed concrete block was fixed for the preparation of concrete block mats suitable to control the bank erosion of Arial Khan River. The reference location was selected with the cooperation of Madaripur O and M Division under Bangladesh Water Development Board. In model 1:30 scale ratio was taken.

Prototype			**Model**		
Size (mm)	Volume (mm^3)	Weight	Size (mm)	Volume (mm^3)	Weight
400x400x100	1,60,00,000	38.40kg	13.33x13.33x3.33	592.59	1.42gm (Unit wt. of concrete = 2405 kg/m^3)

In model the size of block 13.33mmx13.33mmx3.33mm was taken as per ratio 1:30. This type of small two holed block preparation was very difficult. Firstly, it was tried to cast by a wooden mould box, but it was failed. Secondly, it was tried to cast by a steel sheet box, but it was also failed. Lastly, the blocks were prepared by 133.33mm x 133.33mm x 3.33mm size steel sheet frame, stainless steel spoke and knife. About 100 blocks were prepared by cutting 133.33mm x 133.33m size one block. The hole was kept by stainless steel wire during casting.

Hessian cloth was used in physical modelling against geo-textile for prototype work. This was applied at upper bank and lower bank as per design.

GI wire of 24BWG was applied during mat formation against bar no.2 for prototype work. On the other hand, 0.5mm synthetic thread was used for mat formation against 6mm geo- synthetic rope.

Two type mats were prepared. One was wide mat and other one was strip mat. Wide mat was selected for upper bank and strip mat was selected for lower bank. Size of wide mat was prepared to the size 333.25mm x 93.31mm. Length of strip mat was selected to 1.50m, 1.20m and 1.00m to check the suitability. Finally, it is observed that the strip mat of 1.20m length is enough suitable for lower bank protection.

There was no difficulty to prepare the wide mat manually for upper bank but there was some difficulty to prepare the strip mat for lower bank. The problem was overcome applying some instruments to form the strip mat under water. The instruments were channel and pusher.

Soil filled geo-bags were used to create oblique flow and the effectiveness of protective measure by concrete block mats were justified.

3.10 Scale Effects

The scaling of the model has been carefully determined in order to prevent scale effects in the phenomenon of interest (scour development and flow velocity) as much as possible. In principle, scour models are not affected by serious scale effects. A correct prediction of the scour hole dimension can be obtained when the model is undistorted. This is the case when the length and height scales are equal. In this way a geometrical similarity is obtained between the prototype and the model. For flow velocities above the critical flow velocity the scouring only depends on the geometry of the structure and the flow conditions. The dimensions of the scour hole increase linearly with the dimensions of the structure in a geometrically similar situation. For the development of the scour hole the sediment transport needs to be enough so that the maximum equilibrium scour dimensions can be reached within one working day. In this way possible error in the adjustment of the boundary conditions for each day filling and emptying of the model can be prevented. For the measurements related to the flow field in a relatively small area around the structure, the model boundary conditions have been adjusted so that the Froude condition is fulfilled.

4 TEST SCENARIOS OF THE MODEL RUNS

4.1 Test Scenarios

In the model, 2 (two) calibration tests (T0-1 & T0-2) with existing conditions and 17 (seventeen) application test runs (T1-T17) with proposed interventions have been conducted. 6 (six) different designs have been tested in the application runs with various flow conditions changing velocity & water level as mentioned in **Table 4.1.** These designs have been applied in tests T1, T2, T5, T8, T11 & T12.

Table 4.1: Test Scenarios of the model

Test No.	Test Scenarios & WL/Q Conditions
Calibration Test (T0-1)	• Test with existing conditions & 2.33-year RP water level • WL= 1.23 mPWD • $Q_{sectional}$ =1309 cumec (C/S39)
Calibration Test (T0-2)	• Test with existing conditions & using field data • WL= 0.73 mPWD • $Q_{sectional}$ = 340 cumec (C/S36)
1st application test (T1)	• Design supplied by Senior Design Engineer of MHS • Lower bank protection works applying strip type concrete block mats on filter • Upper bank protection works applying wide type concrete block mats on filter • Low flow WL= 0.24 mPWD • $Q_{sectional}$ =808 cumec
2nd application test(T2)	• Modification of design based on test T1 • Low flow WL= 0.24 mPWD • $Q_{sectional}$ =808 cumec
3rd application test(T3)	• Same design as in test T2 • Medium flow WL= 1.23 mPWD • $Q_{sectional}$ =1381 cumec **(C/S36)**
4th application test(T4)	• Same design as in test T2 • High flow WL=2.93 mPWD • $Q_{sectional}$ = 1967 cumec
5th application test (T5)	• New design supplied by Senior Design Engineer of MHS • Lower bank protection works applying loosely placed concrete block mats on filter • Upper bank protection works applying closely placed concrete block mats with some gaps on filter • Low flow WL= 0.24 mPWD • $Q_{sectional}$ =808 cumec
6th application test (T6)	• Same design as in test T5 • Medium flow WL= 1.23 mPWD • $Q_{sectional}$ =1381 cumec
7th application test (T7)	• Same design as in test T5 • High flow WL=2.93 mPWD • $Q_{sectional}$ = 1967 cumec
8th application test (T8)	• Modification of new design based on test T5 • Low flow WL= 0.24 mPWD • $Q_{sectional}$ =808 cumec

Test No.	Test Scenarios & WL/Q Conditions
9th application test (T9)	• Same design as in test T8 • Medium flow WL= 1.23 mPWD • $Q_{sectional}$ =1381 cumec
10th application test (T10)	• Same design as in test T8 • High flow WL=2.93 mPWD • $Q_{sectional}$ = 1967 cumec
11th application test (T11)	• Different design supplied by Senior Design Engineer of MHS • Low flow WL= 0.24 mPWD • $Q_{sectional}$ =808 cumec
12th application test (T12)	• Final design supplied by Senior Design Engineer of MHS • Low flow WL= 0.24 mPWD • $Q_{sectional}$ =808 cumec
13th application test (T13)	• Same design as in test T12 • Medium flow WL= 1.23 mPWD • $Q_{sectional}$ =1381 cumec
14th application test (T14)	• Same design as in test T12 • High flow WL= 2.93 mPWD • $Q_{sectional}$ =1967 cumec
15th application test (T15)	• Same design as in test T12 with introduction of oblique flow • Low flow WL=0.24 mPWD • $Q_{sectional}$ = 808 cumec
16th application test (T16)	• Same design as in test T12 with introduction of oblique flow • Medium flow WL= 1.23 mPWD • $Q_{sectional}$ =1381 cumec
17th application test (T17)	• Same design as in test T12 with introduction of oblique flow • High flow WL= 2.93 mPWD • $Q_{sectional}$ =1967 cumec

5 CALIBRATION OF THE MODEL

5.1 Model Calibration

Model calibration is the simulation of the model condition with field condition i.e. to make the agreement of model data with the measured prototype data. In order to reproduce the flow field in the model it is important to set the boundary conditions, those are obtained from the field measurements.

Two boundary conditions, discharge distribution at the upstream end and water level at the proposed bridge have been maintained to simulate the water surface slope, required velocity, bed resistance, unit discharge etc. in the model.

At the calibration stage, the model aims at adjusting the incoming prototype flow distribution at the approach section and water level at the downstream section and also the morphological development in the model. Calibration of the model is concerned on the following points:

- Flow distribution at the upstream
- Water level at the downstream
- Sediment transport

5.1.1 Test T0

Test T0 is conducted to calibrate the model i.e. to simulate the model with the prototype condition. The model bed is prepared according to the bathymetric survey of March 2017. Two tests for model calibration are conducted:

(a) T0-1: Calibration test with 2.33-year return period WL 1.23 mPWD and the corresponding computed discharge 1381 cumec.

(b) T0-2: Calibration test with observed WL 0.73 mPWD (Ebbing) at a station which is 500m upstream of Mollarhat Lanchghat bend (C/S36) on the Arial Khan river and the corresponding measured discharge is 340 cumec.

(a) Flow Distribution in test T0-1

Flow velocity at the upstream boundary (C/S-39) is measured in the model and is compared with the calculated values corresponding to 2.33 year RP water level. A comparison between calculated and model velocity is done in the model as shown in **Figure 5.1.1.1**. From this figure it is evident that the velocities observed in the model are close to the calculated values**.**

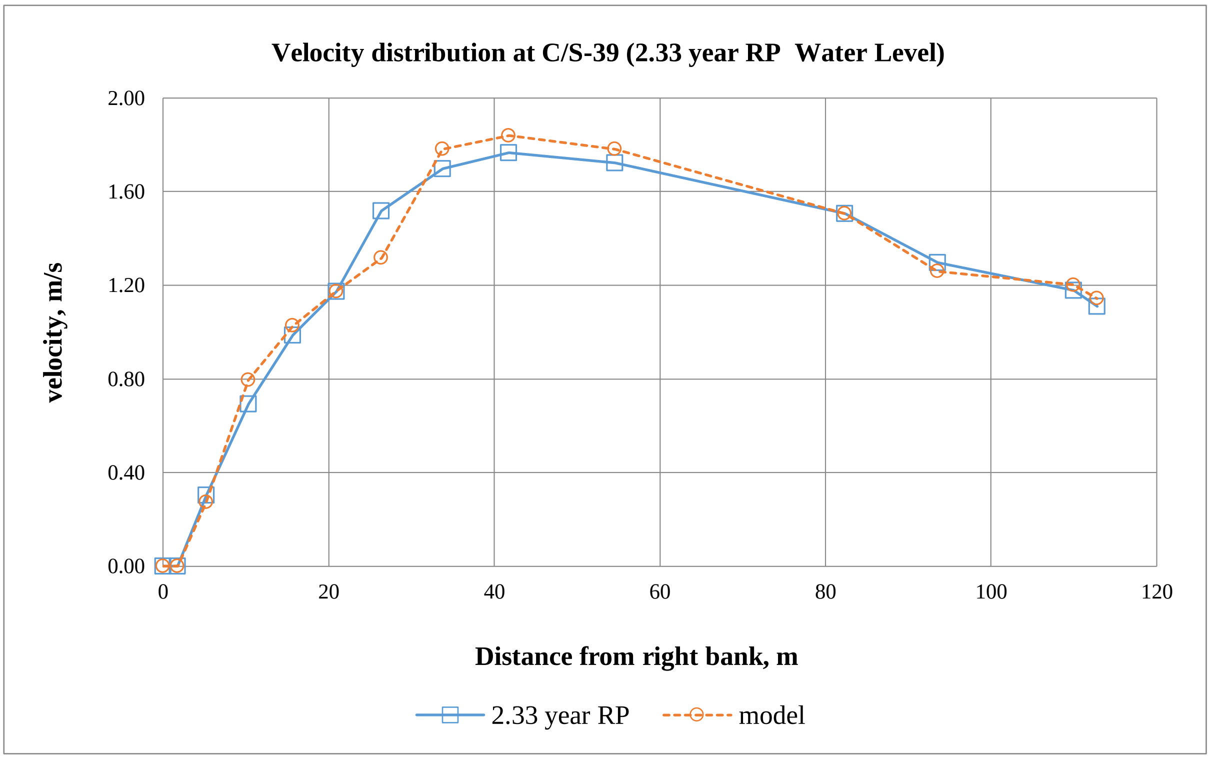


Figure 5.1.1.1: Comparison of velocity at C/S-39 in test T0-1

Sediment Transport

Sediment transport is calculated using Enguland-Hansen formula as 0.23 m^3/hr. During calibration test, sediment is manually fed at the inflow section of the model as 0.30 m^3/hr which is required to maintain the constant bed level (neither scouring nor deposition) at the model entrance.

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 5.1.1.2.** It is seen that flow lines are passing through the different cross-sections of the river reproduced in the model. Flows are concentrated near the right bank of river reach which indicates river bank protection is needed to combat erosion at this region.

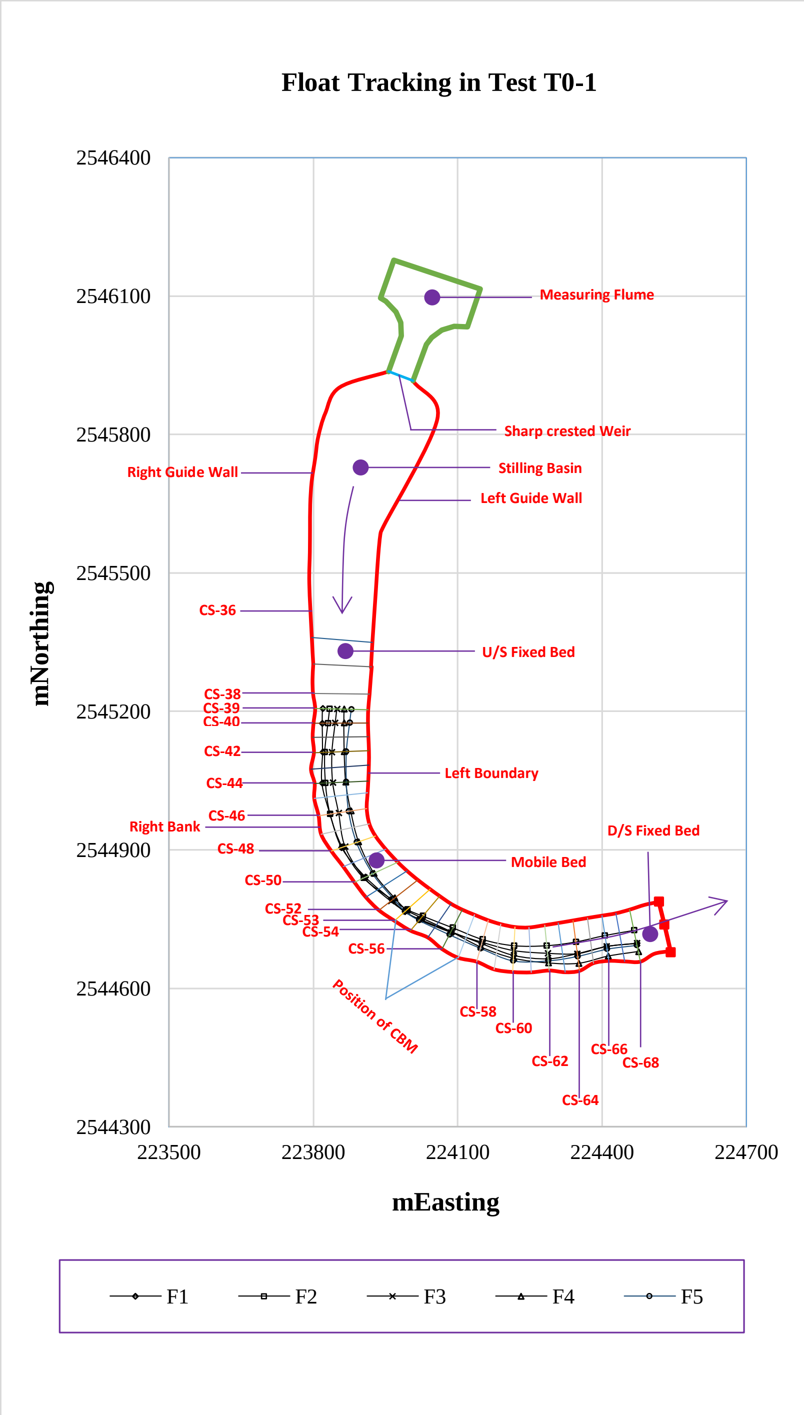


Figure 5.1.1.2: Flow lines recorded in test T0-1

Velocity Measurement

The depth averaged velocities measured in test T0-1 along different cross-sections of the river reproduced in the model are shown in **Table 5.1.1.1.** The maximum cross-sectional velocity is 2.13 m/s. Some photos of the calibration test (T0-1) for CBM model can be seen in **Photo 5.1.1.1-5.1.1.3.**

Table: 5.1.1.1: Velocity along different cross-sections of river model in test T0-1

Sl. No.	C/S No.	C/S Velocity (m/s) in test T0-1									
		Distance from Right Bank (m)									
		0	15	30	45	60	75	90	105	120	135
1	**C/S -40**	0.33	0.91	1.26	2.13	1.43	1.43	1.14	1.2		
2	**C/S -42**	0.68	1.14	1.38	1.55	1.43	1.2	1.14	1.14		
3	**C/S -44**	0.45	0.68	1.2	1.49	1.38	1.14	1.09	1.03		
4	**C/S -46**	0	0.85	1.38	1.43	1.43	1.32	1.32			
5	**C/S -48**	0.33	0.91	1.43	1.67	1.55	1.26	1.43			
6	**C/S -50**	0	0.85	1.61	1.84	1.49	1.49	1.2			
7	**C/S -52**	0.56	0.62	0.91	1.49	1.2	1.14	1.03	0.74		
8	**C/S -53**	0	0.39	1.14	1.32	1.26	1.14	0.97			
9	**C/S -54**	0.68	0.91	1.14	1.09	1.14	0.97	0.97	0.74		
10	**C/S -56**	1.03	1.09	1.49	1.55	1.43	1.26	1.14			
11	**C/S -58**	0.85	1.2	1.38	1.38	1.32	1.2	1.26			
12	**C/S -60**	0.21	0.8	1.2	1.26	1.26	1.14	1.2			
13	**C/S -62**	0.91	1.2	1.26	1.32	1.32	1.09	1.14			
14	**C/S -64**	0.21	0.8	1.14	1.26	1.26	1.14	1.14	0.91		
15	**C/S -66**	1.2	1.43	1.61	1.43	1.26	1.26	1.03			
16	**C/S -68**	0	0.74	1.14	1.49	1.38	1.43	1.26	1.09		

Photo 5.1.1.1: Initial model bed as per bathymetry before calibration test run (T0-1)

Photo 5.1.1.2: Model during calibration test run (T0-1)

Photo 5.1.1.3: Model bed after calibration test run (T0-1)

(b) Flow Distribution in test T0-2

The velocity at 500m upstream of Mollarhat Lanchghat bend (C/S-36) is measured in the model and is compared with the field measurement using bathymetry data of March/2017. A comparison between prototype and model velocity is done after calibration of the model as shown in **Figure 5.1.1.3**. From this figure it is evident that the model values observed in the model are very close to the prototype value**.**

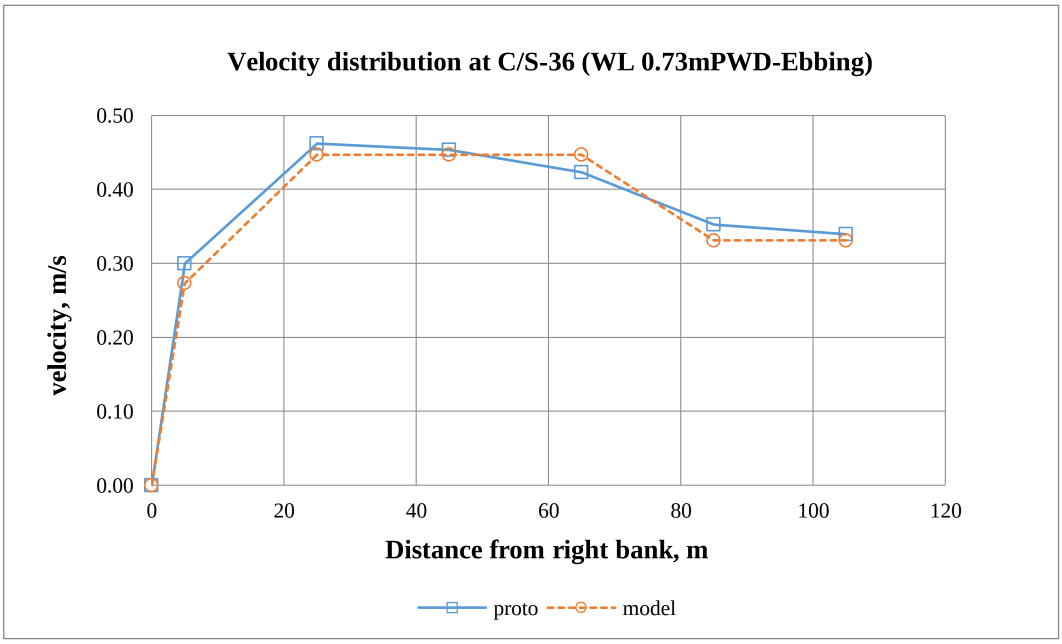


Figure 5.1.1.3: Comparison of velocity at C/S-36 in test T0-2

Sediment Transport

Sediment transport is calculated using Enguland-Hansen formula as 0.26m^3/hr. During calibration test, sediment is manually fed at the inflow section of the model as 0.30 m^3/hr which is required to maintain the constant bed level (neither scouring nor deposition) at the model entrance.

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 5.1.1.4.** It is seen that flow lines are close to the right bank of river reach and these are passing through the different cross-sections of the river reproduced in the model. Therefore, it has been planned to protect the river bank erosion at the extreme bend portion of the stretch *i.e.* from C/S53 to C/S57 covering a length about 168m.

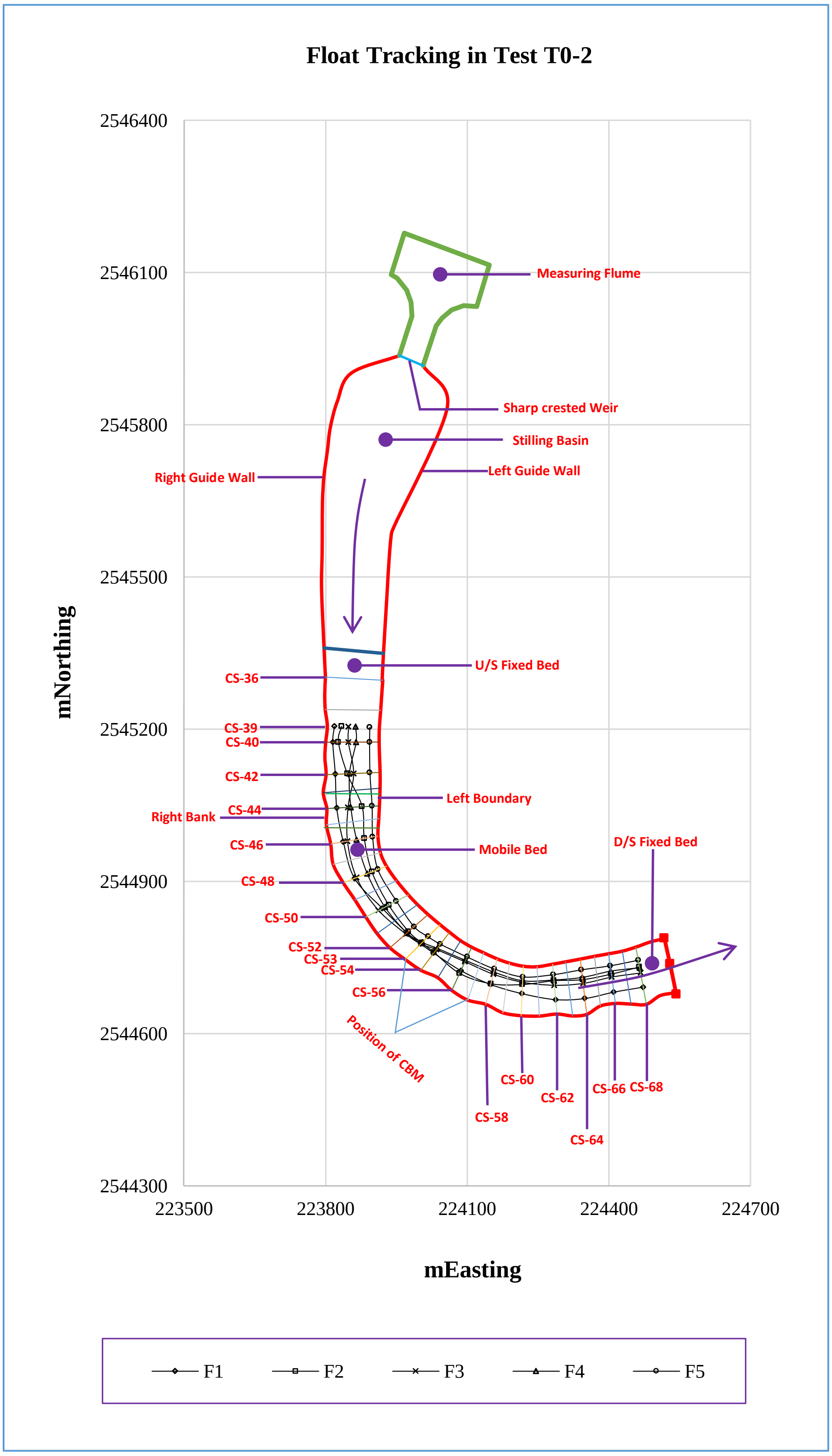


Figure 5.1.1.4: Flow lines recorded in test T0-2

Velocity Measurement

The average velocities measured in test T0-2 along different cross-sections of the river reproduced in the model are shown in **Table 5.1.1.2.** The maximum cross-sectional velocity is 0.51 m/s.

Table: 5.1.1.2: Velocity along different cross-sections of river model in test T0-2

Sl. No.	C/S No.	C/S Velocity (m/s) in test T0-2									
		Distance from Right Bank (m)									
		0	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**
1	**C/S-40**	0	0.33	0.39	0.45	0.39	0.45	0.27	0.21		
2	**C/S-42**	0	0.39	0.45	0.45	0.39	0.45	0.21	0.21		
3	**C/S-44**	0.21	0.39	0.45	0.39	0.45	0.45	0.33	0		
4	**C/S-46**	0	0.27	0.45	0.39	0.45	0.39	0.33			
5	**C/S-48**	0	0.27	0.45	0.45	0.51	0.33	0.39			
6	**C/S-50**	0	0.33	0.45	0.45	0.45	0.45	0.33			
7	**C/S-52**	0	0	0.45	0.39	0.39	0.39	0.33			
8	**C/S-53**	0	0	0.39	0.45	0.39	0.33	0.27			
9	**C/S-54**	0	0	0.39	0.33	0.33	0.27	0.27			
10	**C/S-56**	0	0.27	0.45	0.45	0.39	0.39	0.33			
11	**C/S-58**	0	0.33	0.5	0.51	0.45	0.39	0.33			
12	**C/S-60**	0	0	0.39	0.45	0.39	0.39	0.39			
13	**C/S-62**	0	0	0.21	0.33	0.39	0.39	0.39	0.33		
14	**C/S-64**	0	0	0.33	0.39	0.33	0.39	0.27	0.27	0.27	
15	**C/S-66**	0.39	0.39	0.45	0.45	0.39	0.39	0.33			
16	**C/S-68**	0	0.33	0.45	0.5	0.5	0.45	0.39	0.33		

Scour Measurement

Scour was measured at each cross-section within the lateral boundary of model. Maximum scour is 10.26m (-13.21mPWD) which is 22.50m away from R/B along C/S-48 in calibration test run T0-2.

The development of maximum scour with time at C/S-48 in test T0-2 is shown in **Figure 5.1.1.5.** It is seen from the figure that it takes around 13-15 hours to reach dynamic equilibrium condition for maximum scour development at C/S-48. The variation of bed level with time to reach the maximum scour is shown in **Figure 5.1.1.6.** Non-dimensional plot is shown in **Figure 5.1.1.7.**

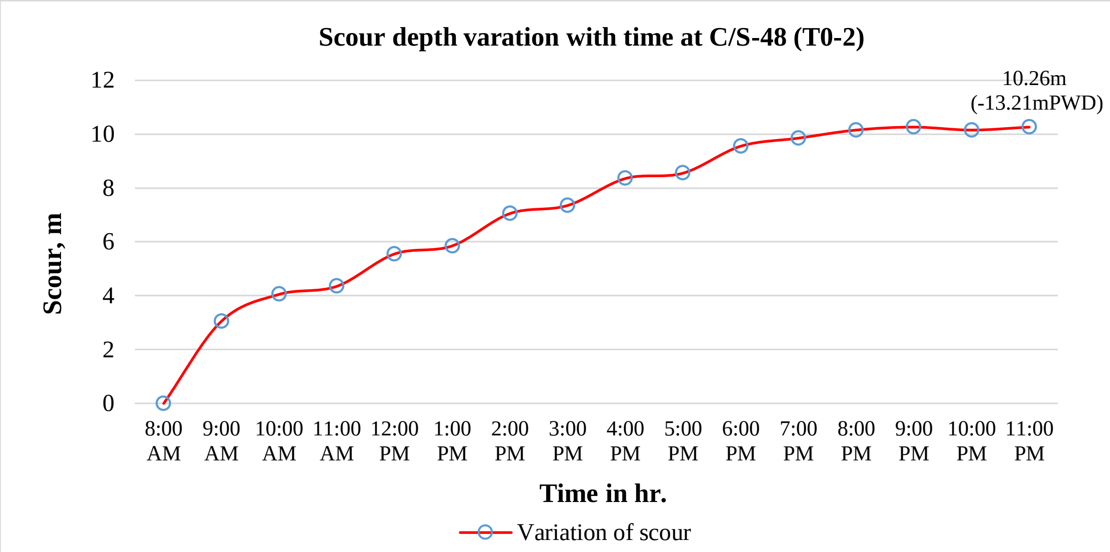


Figure 5.1.1.5: Development of maximum scour with time (T0-2)

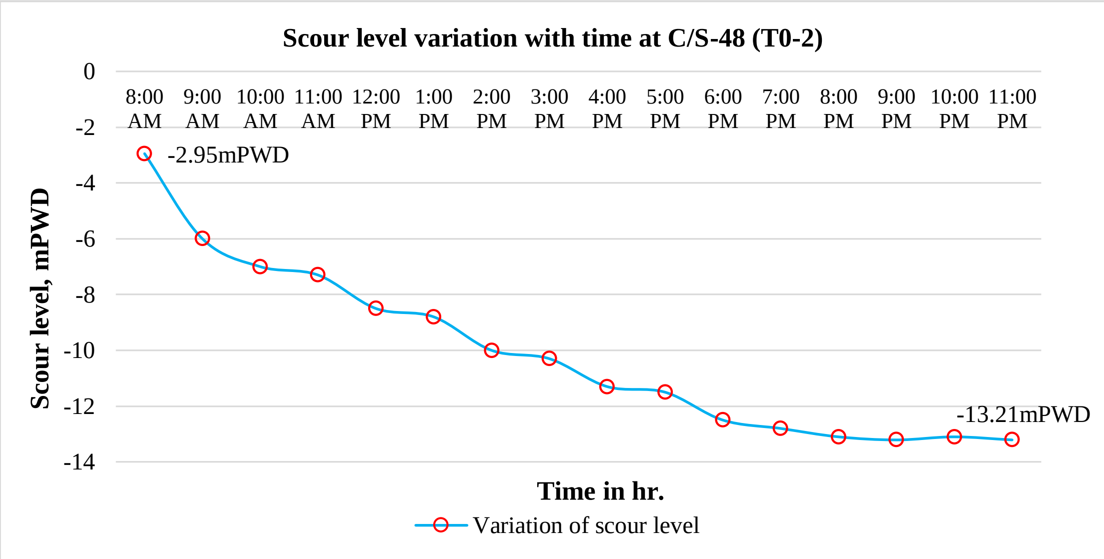


Figure 5.1.1.6: Variation of bed level with time to reach the maximum scour (T0-2)

Non-dimensional plot in log paper (hs /h0) vs. (t/t1) for maximum scour at C/S-56 is as follows. Here hs= scour depth, h0 = initial average water depth, t = time in hours required for scour development and t1= equivalent time defined as the time at which hs= h0.

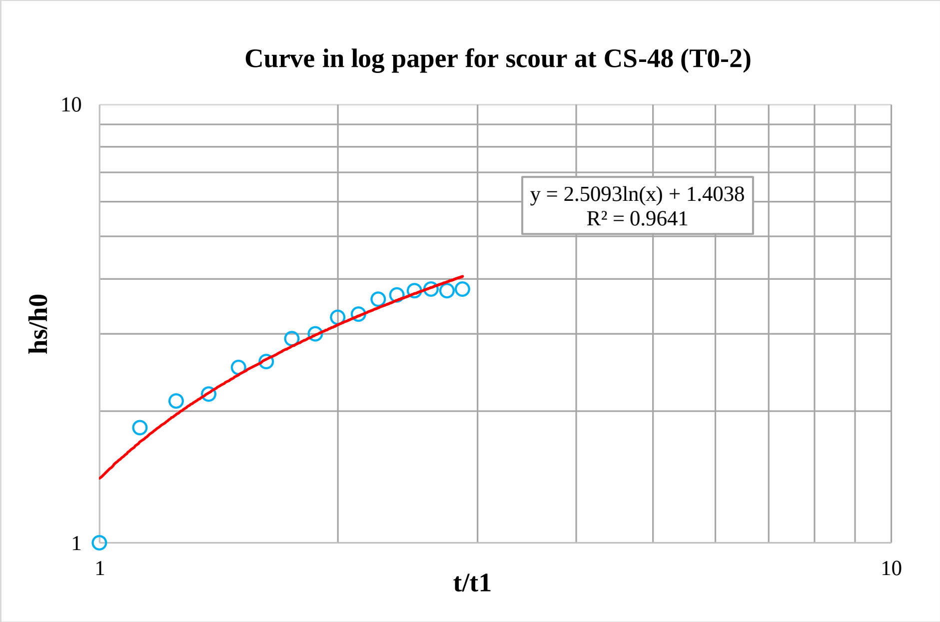
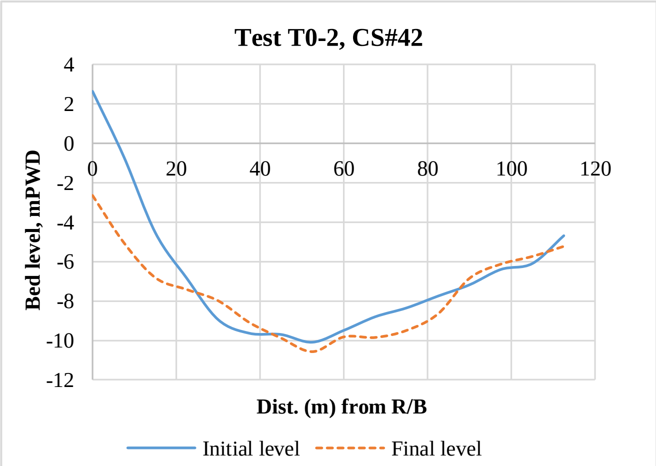
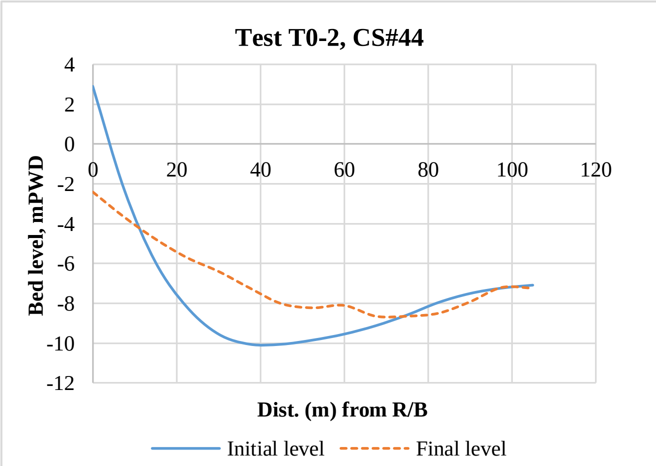


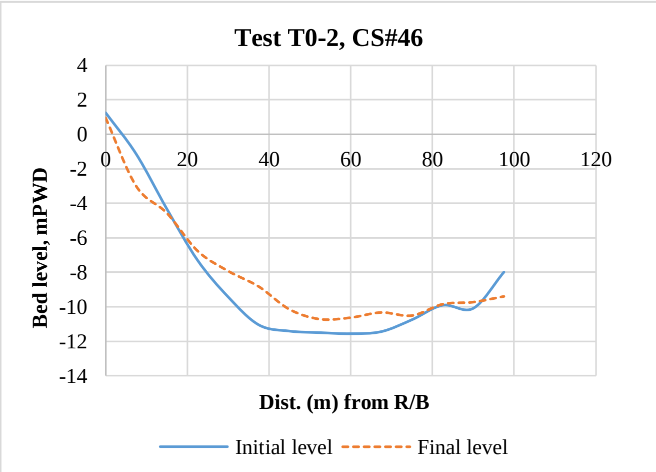
Figure 5.1.1.7: Non-dimensional plot of (hs /h0) vs. (t/t1) in log paper for scour (T-02)

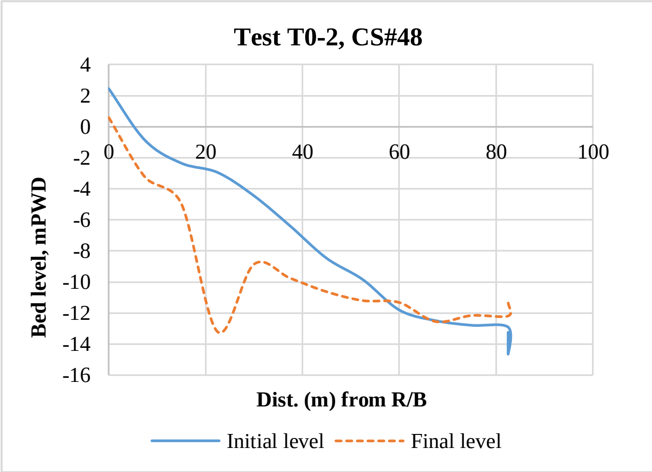
Bed Level

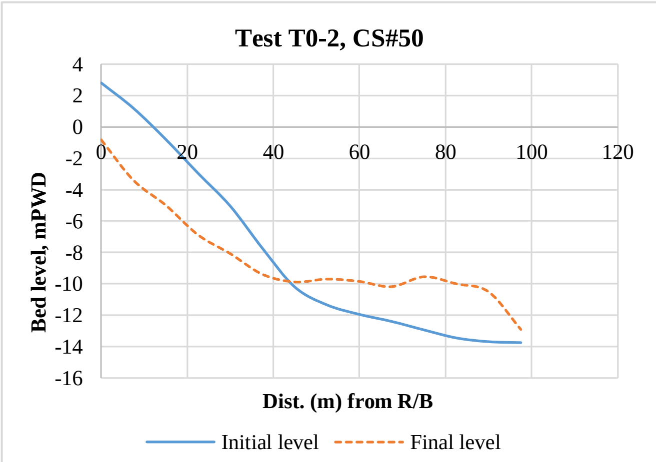
The bed level before and after test run was measured for each cross-section within the model boundary using levelling staff. Thus the initial & final bed level have been obtained and these are superimposed to have an idea about scour or deposition. Some of the superimposed cross-sections through and around the protective structure (C/S42-C/S66) are shown below.

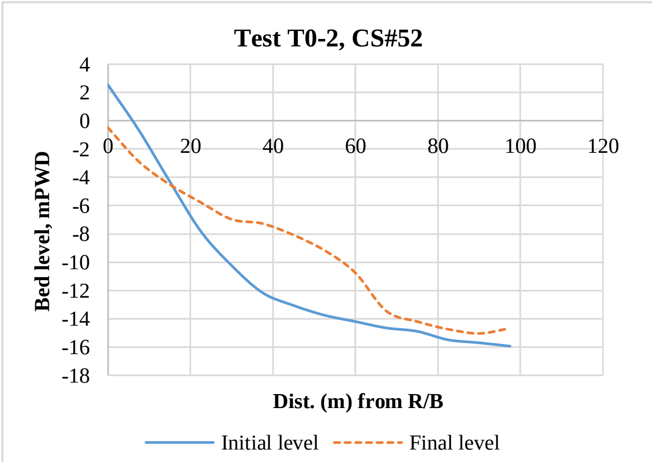


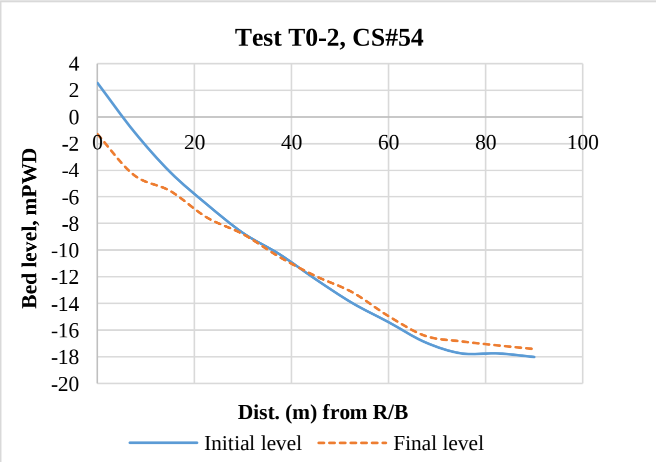


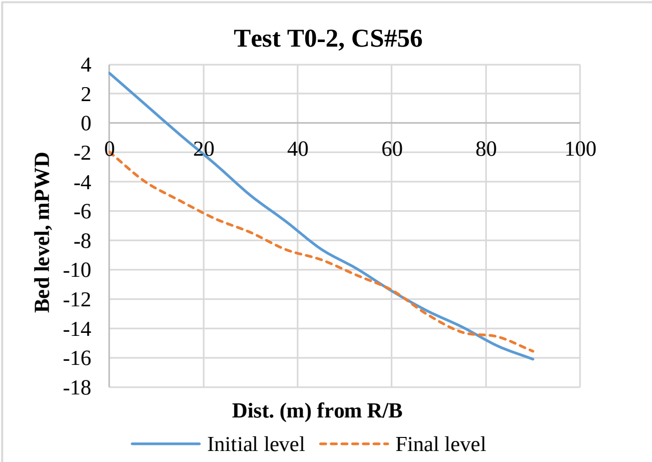

Test T0-2, CS#46
Bed level, mPWD
Dist. (m) from R/B
Initial level
Final level


Test T0-2, CS#48
Bed level, mPWD
Dist. (m) from R/B
Initial level
Final level


Test T0-2, CS#50
Bed level, mPWD
Dist. (m) from R/B
Initial level
Final level


Test T0-2, CS#52
Bed level, mPWD
Dist. (m) from R/B
Initial level
Final level


Test T0-2, CS#54
Bed level, mPWD
Dist. (m) from R/B
Initial level
Final level


Test T0-2, CS#56
Bed level, mPWD
Dist. (m) from R/B
Initial level
Final level

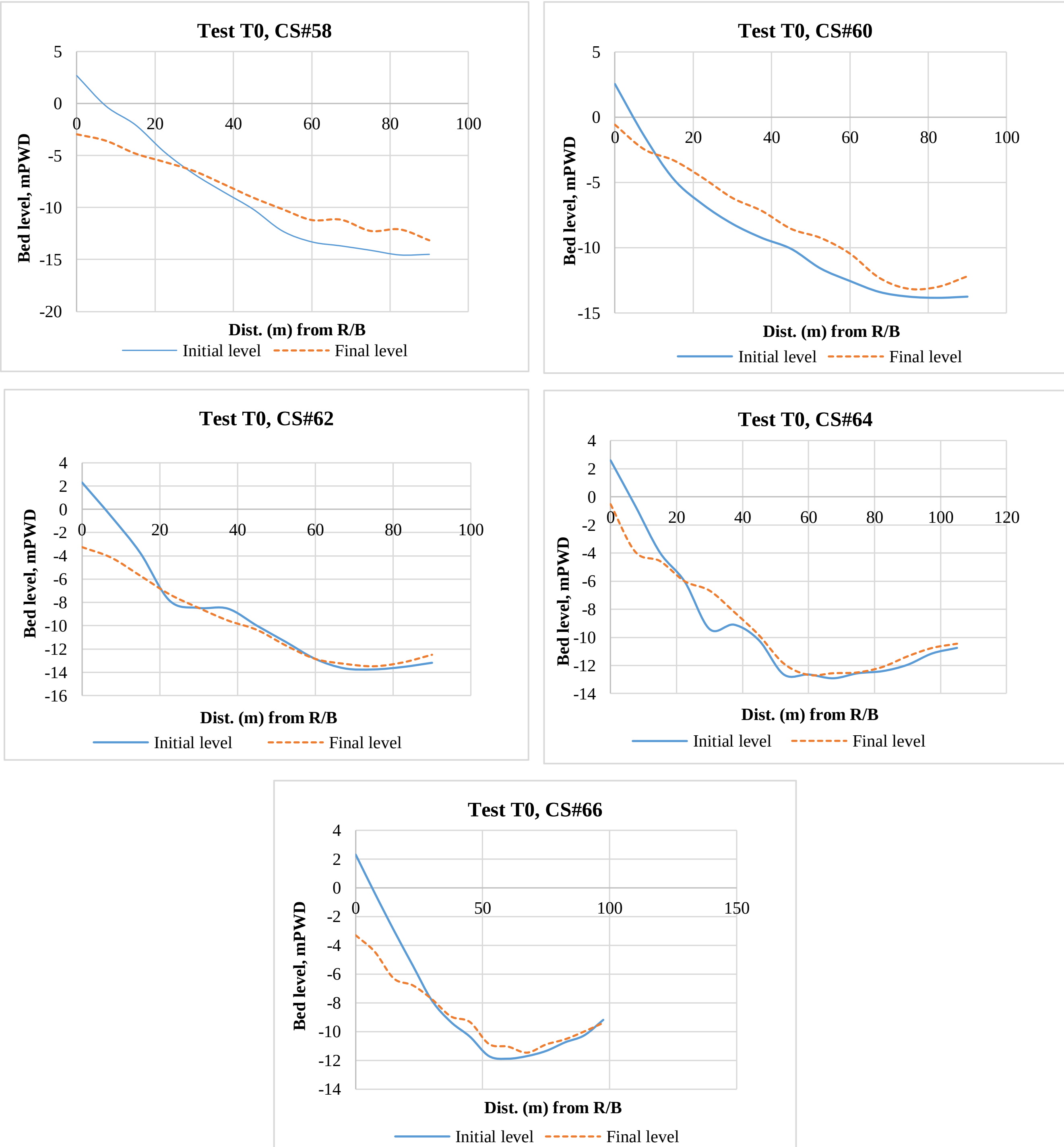


Figure 5.1.1.8: Superimposed initial and final bed level for C/S42-C/S66 in test T-02 of CBM model

Bank Erosion

The tentative river bank erosion after the calibration test is measured at different cross-sections along the right bank of Arial Khan river and is shown in **Table 5.1.1.3.** It is seen from the table that maximum bank erosion is 10.8m at C/S-55**.** Some photos of the calibration test (T0-2) for CBM model can be seen in **Photo 5.1.1.4-5.1.1.5.**

Table 5.1.1.3: Tentative bank erosion after the calibration test (T0-2)

Sl. No.	C/S No.	Tentative bank erosion, m
1	**C/S-41**	3
2	**C/S-42**	7.2
3	**C/S- 43**	0
4	**C/S- 44**	9
5	**C/S- 45**	0
6	**C/S- 46**	1.8
7	**C/S- 47**	0
8	**C/S- 48**	0
9	**C/S-49**	6.3
10	**C/S-50**	4.5
11	**C/S-51**	0
12	**C/S-52**	0
13	**C/S-53**	0
14	**C/S-54**	2.4
15	**C/S-55**	10.8
16	**C/S-56**	2.4
17	**C/S-57**	3.3
18	**C/S-58**	6.3
19	**C/S-59**	0
20	**C/S-60**	0
21	**C/S-61**	4.8
22	**C/S-62**	5.7
23	**C/S-63**	0
24	**C/S-64**	0
25	**C/S-65**	10.7
26	**C/S-66**	10.2

Photo 5.1.1.4: Model at running condition during calibration test (T0-2)

Photo 5.1.1.5: Model bed after calibration test run (T0-2)

6 APPLICATION TEST RUNS AND ANALYSIS OF TEST RESULTS

Total 17 (seventeen) nos. of application test runs (T1-T17) have been conducted in the model with different test scenarios, discharge and WL conditions as mentioned in **Table 4.1.** 6 (six) different designs provided by Senior Design Engineer Syed Imdadul Haque have been tested in different application runs. These designs have been applied in tests T1, T2, T5, T8, T11 & T12.

Velocities at different cross-sections, velocity around the proposed protective structure called concrete block mat (CBM), bed levels, and flow lines are measured at different tests in the model. Moreover, a brief description of different test results is mentioned in the following articles. Block preparation, placing of concrete mats and its effectiveness are shown in **Photo 6.1.1** to **6.1.5**.

6.1 Test T1

This is the first application test using low flow as per design supplied by Senior Design Engineer of MHS which is carried out with proposed concrete block mats (CBM). In test T1, the lower bank & upper bank (slope pitching) is protected by applying strip & wide type concrete block mats respectively on filter during low flow as shown in **Photo 6.1.3**. Here the number of CC blocks in each strip in lower bank protection is 100 nos (the details are below). In CBM, holed CC blocks having dimension 40cm X 40cm X 10cm are used. These blocks have been made manually at RRI Lab which is a cumbersome and time consuming task as shown in **Photo 6.1.1-6.1.2.**

The sectional discharge ($Q_{sectional}$) corresponding to low water level is 808 cumec. The model bed is prepared according to the bathymetric survey of March 2017. Scour discharge is run until equilibrium condition is reached and Froudian discharge is run for 12 hrs. The design details of proposed concrete block mats (CBM) are as follows:

- River bank level: 3.0mPWD
- Low water level: 0.24mPWD
- Block type: Holed concrete block
- Block size used in the model: 13.33mmX13.33mmX3.33mm (40cmX40cmX10cm in proto)
- Length of river reach to be protected: 5.6m (168m in proto)
- Length of upper bank protection: 0.22m (6.6m in proto)
- Length of lower bank protection: 1m (30m in proto)
- Length of RCC pipe: 4 inch (120 inch in proto)
- Diameter of RCC pipe: 0.5 inch (15 inch in proto)
- Width of filter: 4 inch (120 inch in proto)
- Consecutive filters are overlapped one over another by 50% along the river
- Nos. of columns on each 2 inch (60 inch in proto) wide overlapped filter in lower bank: 2
- Nos. of blocks: 50+50=100 (each column containing 50 blocks)

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 6.1.1** It is seen that flow lines are close to the right bank and passing through the different cross-sections of the river reproduced in the model. Flow enters at the u/s junction of CBM protection with river bank causing bank caving as well as erosion occurs.

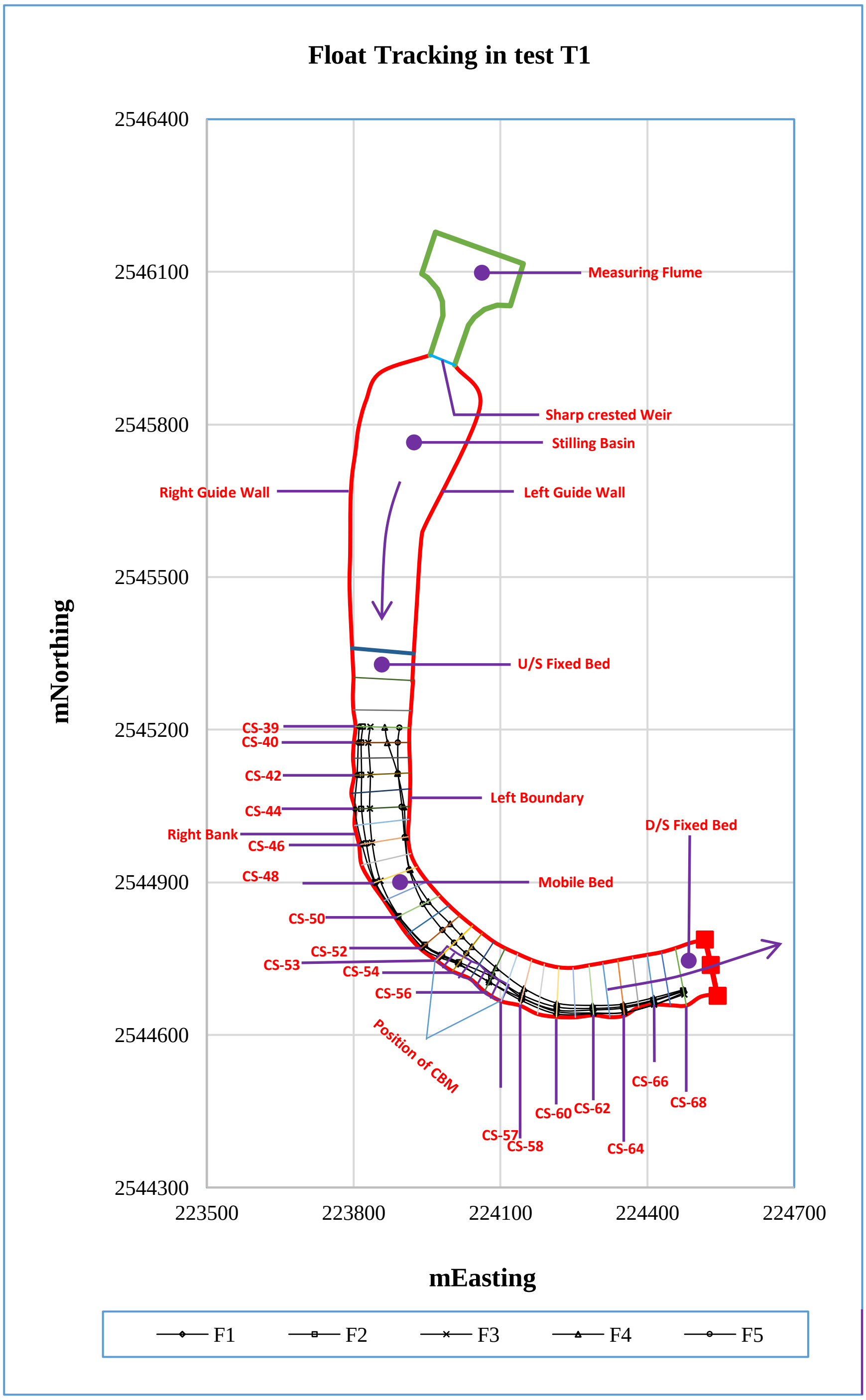


Figure 6.1.1: Flow lines recorded in test T1

Velocity Measurement

The average velocities measured in this test along different cross-sections of the river reproduced in the model are shown in **Table 6.1.1.** The maximum cross-sectional velocity is 2.65 m/s.

Table: 6.1.1: Velocity along different cross-sections of river model in test T1

Sl. No.	C/S No.	C/S Velocity (m/s) in test T1									
		Distance From Right Bank (m)									
		0	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**
1	**C/S-36**	0.00	1.78	1.61	1.72	1.78	2.13	0.62	1.20	1.09	
2	**C/S-38**	0.00	1.55	1.67	1.78	1.72	1.67	0.62	0.68		
3	**C/S-40**	0.00	1.26	1.55	1.67	1.72	1.49	0.74	0.74		
4	**C/S-42**	1.14	1.43	1.84	1.43	1.55	1.61	1.26	0.80		
5	**C/S-44**	0.00	0.62	1.32	1.67	1.61	1.84	1.49	1.26		
6	**C/S-46**	0.00	1.26	1.72	1.49	1.84	1.72	1.55			
7	**C/S-48**	0.00	1.03	2.65	1.49	1.49	1.32	0.91			
8	**C/S-50**	0.00	0.74	1.49	1.55	1.67	1.20	1.38	1.14		
9	**C/S-52**	0.00	1.43	1.61	1.55	1.49	1.38	1.20			
10	**C/S-53**	0.00	1.78	1.55	1.38	1.20	1.20	0.91			
11	**C/S-54**	0.00	0.91	1.49	1.32	1.20	1.03	0.62			
12	**C/S-56**	0.00	0.97	1.55	1.32	1.14	1.09	0.85			
13	**C/S-58**	0.00	1.43	1.38	1.32	1.20	1.14	0.97			
14	**C/S-60**	0.91	1.43	1.38	1.43	1.32	1.20	1.14			
15	**C/S-62**	1.43	1.49	1.38	1.32	1.20	1.20	1.09			
16	**C/S-64**	0.85	1.55	1.38	1.49	1.43	1.26	1.20			
17	**C/S-66**	1.09	1.43	1.38	1.43	1.32	1.32	1.09			
18	**C/S-67**	0.00	1.49	1.55	1.49	1.32	1.26	1.26			

Velocity is also measured at the top of concrete block mats (CBM) @ 7.5m interval along the right bank from upstream to downstream as shown in **Table 6.1.2**. From this table it is seen that maximum velocity is 1.38 m/s.

Table: 6.1.2: Velocity around the top of CBM along right bank u/s to d/s in test T1

Sl. No.	Dist. from start of CBM (m) from u/s	Velocity (m/s)
1	0.0	0.97
2	7.5	1.38
3	15.0	0.85
4	22.5	0.27
5	30.0	0.45
6	37.5	0.27
7	45.0	0.27
8	52.5	0.33
9	60.0	0.39
10	67.5	0.62
11	75.0	1.14
12	82.5	1.20
13	90.0	1.09
14	97.5	0.56
15	105.0	0.68
16	112.5	0.62
17	120.0	0.51
18	127.5	0.51
19	135.0	0.68
20	142.5	0.45
21	150.0	0.51
22	157.5	0.51

Observation

- Some concrete block columns of CBM for lower bank protection have been detached from the u/s end of protection during model run under low flow condition**.**
- The RCC pipes have also been slightly moved d/s by the flow velocity due to its less weight.
- Bank caving occurs at the start of protection as there is no provision of termination.

Some photos of test (T1) for CBM model can be seen in **Photo 6.1.1-6.1.5.**

Photo 6.1.1: Making of holed CC blocks at the laboratory at RRI

Photo 6.1.2: Making of CBM strip at RRI Lab

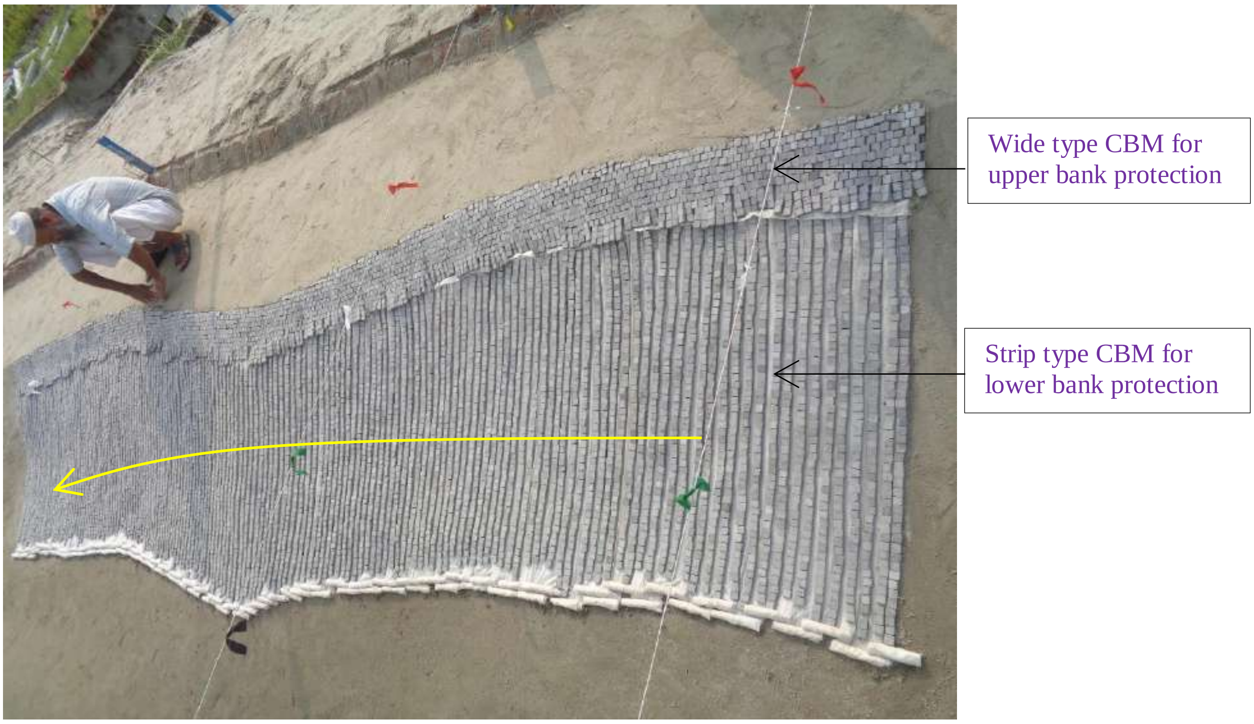


Photo 6.1.3: Placement of CC blocks in the CBM to protect river bank erosion before test run (T1)

Photo 6.1.4: Model is under running condition (T1) with CBM

Photo 6.1.5: Detachment of CC block columns after test run (T1) in the model

6.2 Test T2

This test is same as test T1 using low flow but conducted with some design modification based on test T1. Here the number of CC blocks in each strip is 82 nos (details are given below). Moreover, termination is provided at the u/s & d/s end of CBM. The placement of CC blocks in the CBM model is shown in **Photo 6.2.1.**

The sectional discharge ($Q_{sectional}$) corresponding to low water level is 808 cumec. The model bed is prepared according to the bathymetric survey of March 2017. Scour discharge is run until equilibrium condition is reached and Froudian discharge is run for 12 hrs. The design details of proposed concrete block mats (CBM) are as follows:

- River bank level: 3.0mPWD
- Low water level: 0.24mPWD
- Block type: Holed concrete block
- Block size used in the model: 13.33mmX13.33mmX3.33mm (40cmX40cmX10cm in proto)
- Length of river reach to be protected: 5.6m (168m in proto)
- Length of upper bank protection: 0.22m (6.6m in proto)
- Length of lower bank protection: 0.8m (24m in proto)
- Length of RCC pipe: 4 inch (120 inch in proto)
- Diameter of RCC pipe: 0.75 inch (22.5 inch in proto)
- Width of filter: 4 inch (120 inch in proto)
- Consecutive filters are overlapped one over another by 50%
- Nos. of columns on each 2 inch (60 inch in proto) wide overlapped filter in lower bank: 2
- Nos. of blocks: 40+40+2=82 (Each column containing 40 blocks+2 additional blocks, one at left side & another right side of 2 column blocks totaling 4 blocks at the end row). These 4 blocks are attached with RCC pipe by rolling filter around it to increase its weight.
- Length of u/s termination 0.50 m (15m in proto) & d/s termination 0.50 m (15m in proto)

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 6.2.1** It is seen that flow lines are close to the right bank and passing through the different cross-sections of the river reproduced in the model. Flow still attack the bank upstream and downstream of protection by CBM.

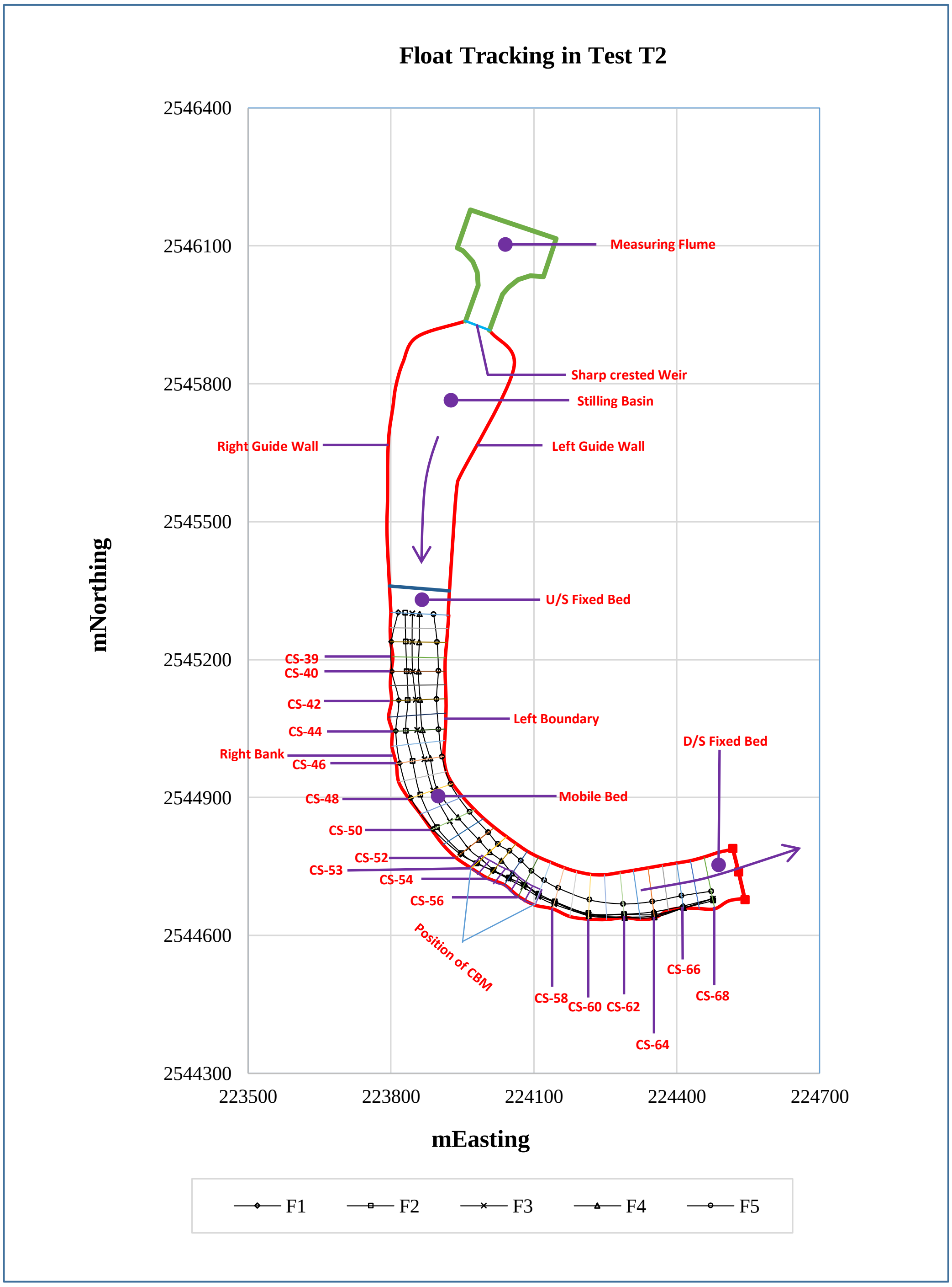


Figure 6.2.1: Flow lines recorded in test T2

Velocity Measurement

The average velocities measured in this test along different cross-sections of the river reproduced in the model are shown in **Table 6.2.1.** The maximum cross-sectional velocity is 2.01m/s.

Table: 6.2.1: Velocity along different cross-sections of river model in test T2

Sl. No.	C/S No.	C/S in Velocity (m/s) in test T2									
		Distance from Right Bank (m)									
		0	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**
1	**C/S-36**	0.0	1.72	1.72	1.67	1.72	**2.01**	0.68	1.09	1.03	
2	**C/S-38**	0.0	1.20	1.32	1.49	1.49	1.55	0.62	0.80	0.62	
3	**C/S-40**	1.49	1.38	1.32	1.38	1.49	0.91	0.74	0.39		
4	**C/S-42**	0.62	1.26	1.20	1.32	1.14	1.09	0.80	0.51		
5	**C/S-44**	1.14	1.43	1.26	1.55	1.49	1.20	0.97	0.68		
6	**C/S-46**	0.45	1.09	0.97	1.14	1.20	1.20	1.09			
7	**C/S-48**	0.62	0.62	0.97	0.91	1.03	1.09	0.80			
8	**C/S-50**	0.74	0.97	1.03	0.91	0.85	0.91	0.85	0.80		
9	**C/S-52**	0.62	0.97	1.20	1.14	1.14	1.03	0.80			
10	**C/S-53**	0.0	1.32	1.20	1.09	0.91	0.74	0.68			
11	**C/S-54**	0.0	0.45	1.14	1.03	0.91	0.91	0.68			
12	**C/S-56**	0.0	0.00	1.26	1.09	0.85	0.85	0.74			
13	**C/S-58**	0.56	1.14	1.03	0.97	0.91	0.91	0.80			
14	**C/S-60**	0.80	0.97	1.03	1.03	0.91	0.80	0.80			
15	**C/S-62**	0.85	0.97	0.91	0.91	0.85	0.80	0.80			
16	**C/S-64**	0.85	0.97	0.91	1.03	1.03	0.91	0.91			
17	**C/S-66**	0.97	1.03	0.97	1.09	1.03	0.97	0.85			
18	**C/S-68**	0.0	0.51	1.32	1.26	1.26	1.14	1.09			

Velocity is also measured at the top of concrete block mats (CBM) @ 7.5m interval along the right bank from upstream to downstream as shown in **Table 6.2.2**. From this table it is seen that maximum velocity is 0.97 m/s.

Table: 6.2.2: Velocity around the top of CBM along right bank u/s to d/s in test T2

Sl. No.	Dist. from start of CBM (m) from u/s	Velocity (m/s)
1	0.0	0.68
2	7.5	0.51
3	15.0	0.68
4	22.5	0.62
5	30.0	0.51
6	37.5	0.33
7	45.0	0.45
8	52.5	0.33
9	60.0	0.56
10	67.5	0.68
11	75.0	0.91
12	82.5	0.97
13	90.0	0.74
14	97.5	0.56
15	105.0	0.45
16	112.5	0.56
17	120.0	0.39
18	127.5	0.27
19	135.0	0.51
20	142.5	0.33
21	150.0	0.51
22	157.5	0.68
23	65.0	0.68

Observation

- CBM protection worked better than test T1 during low flow condition.

Some photos of test (T2) for CBM model can be seen in **Photo 6.2.1-6.2.3.**

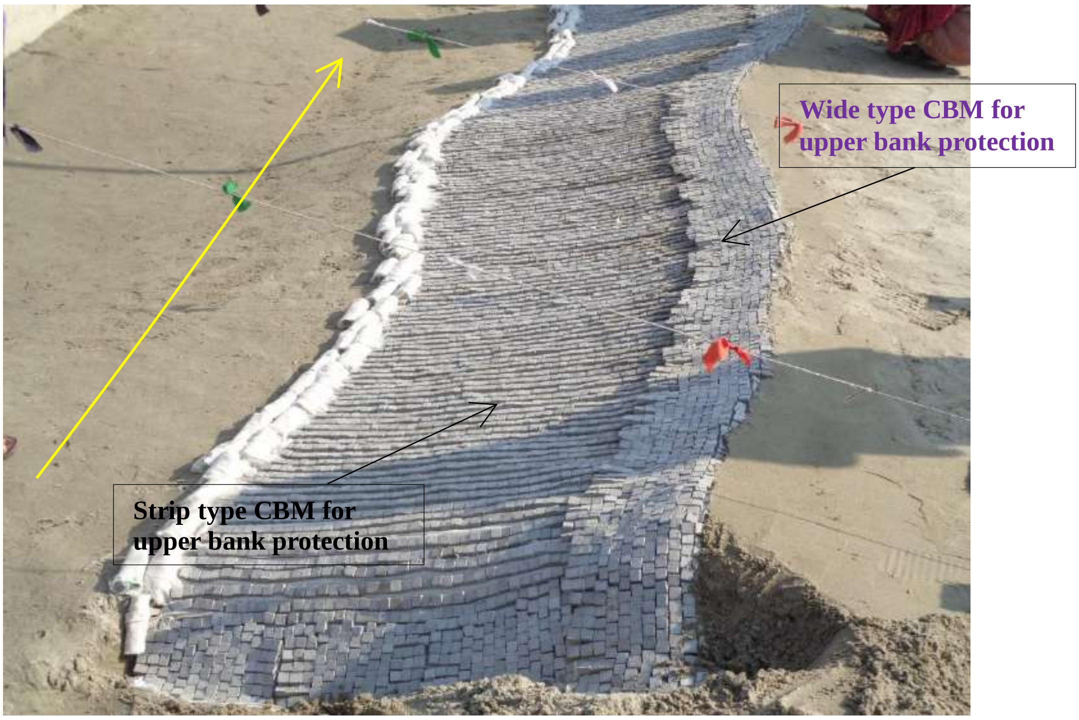


Photo 6.2.1: Placement of CC blocks in the CBM to protect river bank erosion before test run (T2)

Photo 6.2.2: Model is under running condition (T2) with CBM

Photo 6.2.3: CBM after test run (T2) in the model

6.3 Test T3

This test is conducted with the same design as in test T2 but using medium flow. Here the number of CC blocks in each strip is 82 nos (details are given below). Termination is also provided at the u/s & d/s end of CBM to prevent bank caving.

The sectional discharge ($Q_{sectional}$) corresponding to medium water level is 1381 cumec. The model bed is prepared according to the bathymetric survey of March 2017. Scour discharge is run until equilibrium condition is reached and Froudian discharge is run for 12 hrs. The design details of proposed concrete block mats (CBM) are as follows:

- River bank level: 3.0mPWD
- Medium water level: 1.23mPWD
- Block type: Holed concrete block
- Block size used in the model: 13.33mmX13.33mmX3.33mm (40cmX40cmX10cm in proto)
- Length of river reach to be protected: 5.6m (168m in proto)
- Length of upper bank protection: 0.22m (6.6m in proto)
- Length of lower bank protection: 0.8m (24m in proto)
- Length of RCC pipe: 4 inch (120 inch in proto)
- Diameter of RCC pipe: 0.75 inch (22.5 inch in proto)
- Width of filter: 4 inch (120 inch in proto)
- Consecutive filters are overlapped one over another by 50%
- Nos. of columns on each 2 inch (60 inch in proto) wide overlapped filter in lower bank: 2
- Nos. of blocks: 40+40+2=82 (Each column containing 40 blocks+2 additional blocks, one at left side & another right side of 2 column blocks totalling 4 blocks at the end row). These 4 blocks are attached with RCC pipe by rolling filter around it to increase its weight.
- Length of u/s termination 0.50 m (15m in proto) & d/s termination 0.50 m (15m in proto)

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 6.3.1** It is seen that flow lines are close to the right bank and passing through the different cross-sections of the river reproduced in the model. Bank erosion occurs at upstream & downstream of protective work (CBM) due to flow velocity.

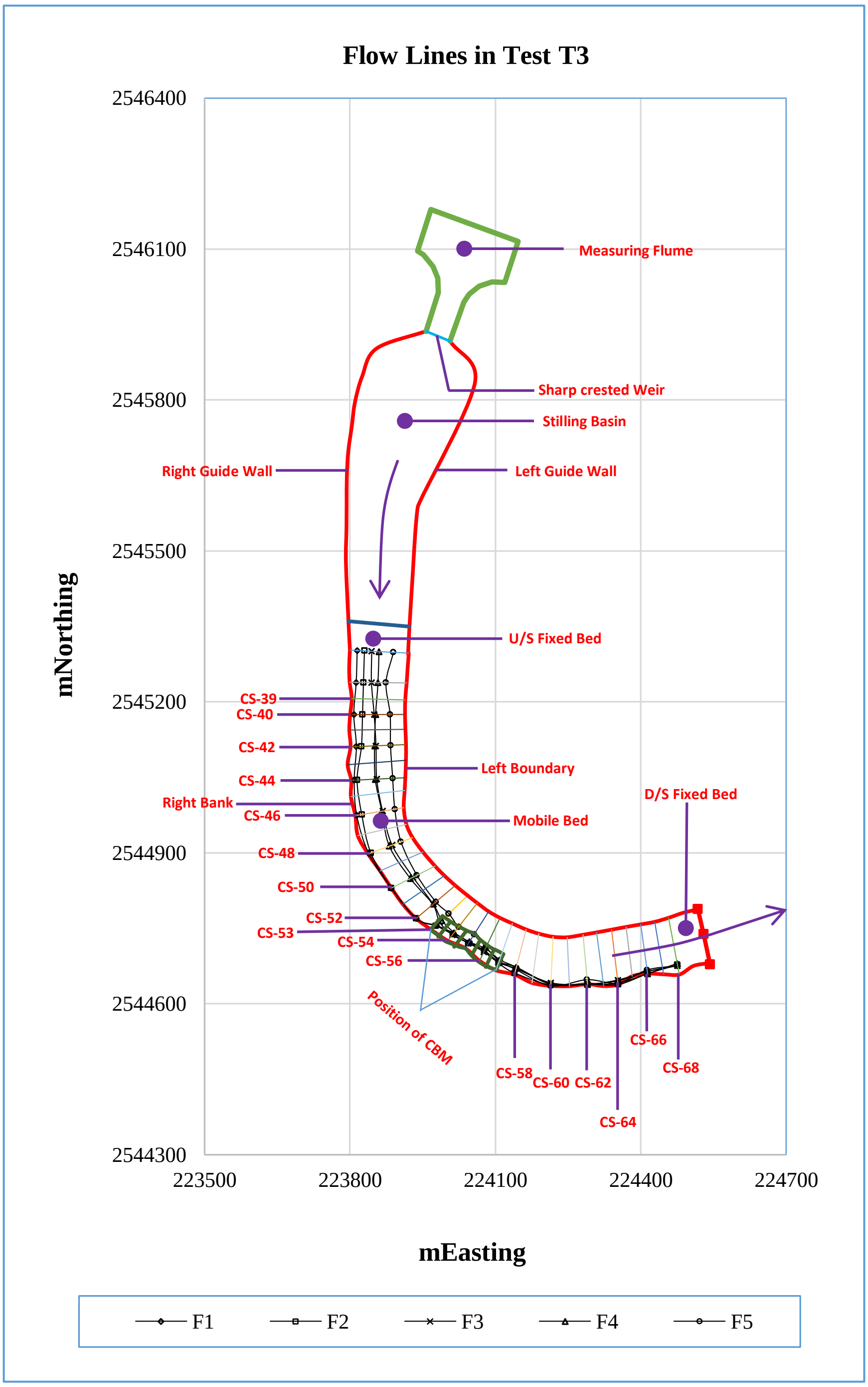


Figure 6.3.1: Flow lines recorded in test T3

Velocity Measurement

The average velocities measured in this test along different cross-sections of the river reproduced in the model are shown in **Table 6.3.1.** The maximum cross-sectional velocity is 2.54 m/s.

Table: 6.3.1: Velocity along different cross-sections of river model in test T3

Sl. No.	C/S No.	C/S Velocity (m/s) in test T3									
		Distance from Right Bank (m)									
		0	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**
1	**C/S-36**	0.00	2.25	2.13	2.13	2.42	2.54	1.09	1.84	1.72	
2	**C/S-38**	0.00	2.19	2.01	2.25	2.36	1.90	0.80	1.32	1.61	
3	**C/S-40**	0.00	2.07	1.96	2.42	2.30	1.43	0.91	1.61		
4	**C/S-42**	0.97	2.01	1.72	1.96	2.07	1.55	0.85	1.26		
5	**C/S-44**	1.78	2.01	2.01	2.30	2.42	1.72	1.43	1.32		
6	**C/S-46**	1.43	1.96	2.07	2.13	2.30	1.90	1.84	1.78		
7	**C/S-48**	1.26	2.07	1.90	2.19	2.25	1.96	1.90			
8	**C/S-50**	1.72	1.90	2.01	1.96	1.84	1.67	1.49	1.26		
9	**C/S-52**	1.67	1.78	2.01	2.01	1.96	1.78	1.55	1.26		
10	**C/S-53**	0.00	2.25	2.36	1.96	1.78	1.67	1.26	1.14		
11	**C/S-54**	0.00	1.67	2.19	1.84	1.72	1.61	1.14			
12	**C/S-55**	0.00	2.54	2.19	1.96	1.67	1.49				
13	**C/S-56**	0.00	0.33	2.30	2.07	1.90	1.67	1.43	1.20		
14	**C/S-57**	0.68	2.19	2.01	1.67	1.49	1.32	1.26			
15	**C/S-58**	0.91	1.84	1.90	1.84	1.90	1.72	1.49			
16	**C/S-60**	1.67	2.01	1.96	1.90	1.67	1.55	1.43			
17	**C/S-62**	2.13	1.78	1.84	1.84	1.84	1.72	1.55	1.32		
18	**C/S-64**	1.61	2.19	1.90	1.96	2.01	1.09	1.67	1.55	1.72	
19	**C/S-66**	1.43	2.19	1.96	2.07	1.78	1.72	1.84	1.61		
20	**C/S-68**	0.00	1.20	2.54	2.36	2.25	2.01	1.90	1.84		

Velocity is also measured at the top of concrete block mats (CBM) @ 7.5m interval along the right bank from upstream to downstream as shown in **Table 6.3.2**. From this table it is seen that maximum velocity is 1.61 m/s.

Table: 6.3.2: Velocity at top of CBM along right bank u/s to d/s in test T3

Sl. No.	Dist. from start of CBM (m) from u/s	Velocity (m/s)
1	0.0	1.03
2	7.5	1.61
3	15.0	0.39
4	22.5	0.56
5	30.0	0.27
6	37.5	0.45
7	45.0	0.51
8	52.5	0.51
9	60.0	0.80
10	67.5	0.85
11	75.0	1.38
12	82.5	1.38
13	90.0	0.56
14	97.5	0.51
15	105.0	0.80
16	112.5	0.56
17	120.0	0.51
18	127.5	0.56
19	135.0	0.33
20	142.5	1.03
21	150.0	0.62
22	157.5	0.62
23	165.0	1.14

Observation

- Few concrete block columns along with filter materials of CBM for lower bank protection have been detached and lower bank is exposed during model run under medium flow condition.
- The RCC pipes were found to work better.

Some photos of test (T3) for CBM model can be seen in **Photo 6.3.1-6.3.3.**

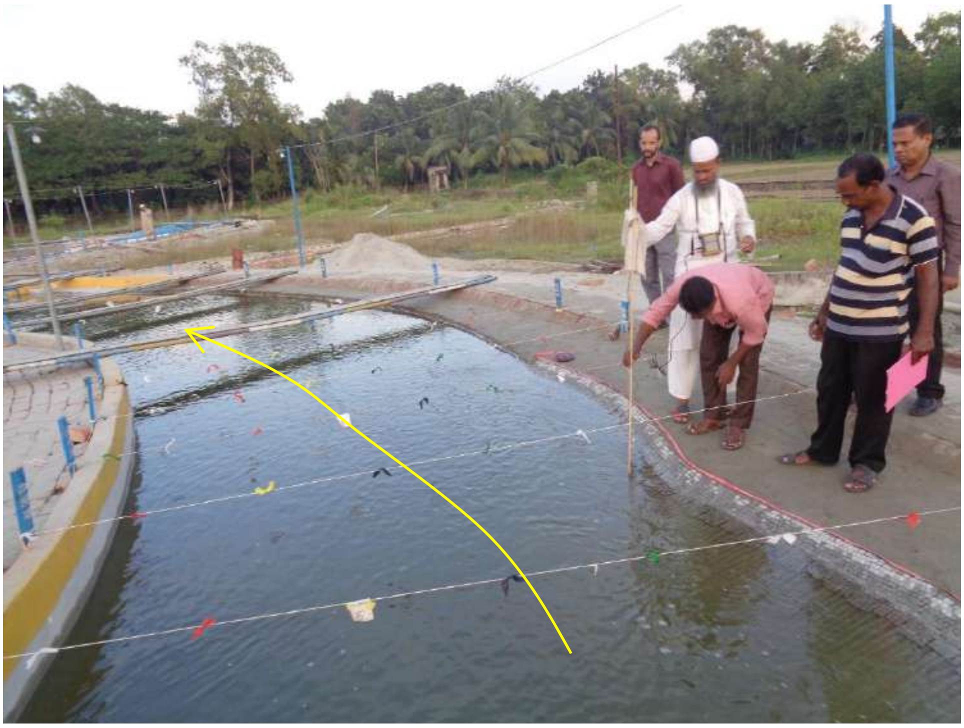


Photo 6.3.1: CBM to protect river bank erosion during test run (T3)

Photo 6.3.2: CBM after test run (T3) in the model

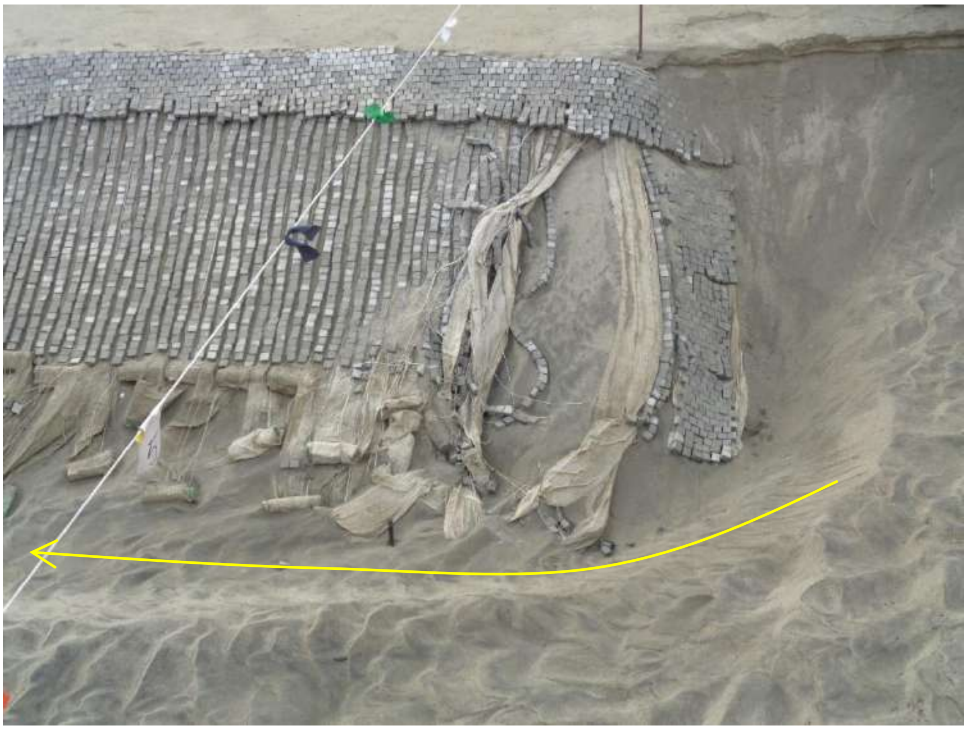


Photo 6.3.3: Detachment of CBM after test run (T3) in the model

6.4 Test T4

This test is conducted with the same design as in test T2 but using high flow. Here the number of CC blocks in each strip is 82 nos. Moreover, termination is provided at the u/s & d/s end of CBM.

The sectional discharge ($Q_{sectional}$) corresponding to high water level is 1967 cumec. The model bed is prepared according to the bathymetric survey of March 2017. Scour discharge is run until equilibrium condition is reached and Froudian discharge is run for 12 hrs. The design details of proposed concrete block mats (CBM) are as follows:

- River bank level: 3.0mPWD
- High water level: 2.93mPWD
- Block type: Holed concrete block
- Block size used in the model: 13.33mmX13.33mmX3.33mm (40cmX40cmX10cm in proto)
- Length of river reach to be protected: 5.6m (168m in proto)
- Length of upper bank protection: 0.22m (6.6m in proto)
- Length of lower bank protection: 0.8m (24m in proto)
- Length of RCC pipe: 4 inch (120 inch in proto)
- Diameter of RCC pipe: 0.75 inch (22.5 inch in proto)
- Width of filter: 4 inch (120 inch in proto)
- Consecutive filters are overlapped one over another by 50%
- Nos. of columns on each 2 inch (60 inch in proto) wide overlapped filter in lower bank: 2
- Nos. of blocks: 40+40+2=82 (Each column containing 40 blocks+2 additional blocks, one at left side & another right side of 2 column blocks totaling 4 blocks at the end row). These 4 blocks are attached with RCC pipe by rolling filter around it to increase its weight.
- Length of u/s termination= 0.50 m (15m in proto) & d/s termination= 0.50 m (15m in proto)

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 6.4.1** It is seen that flow lines are close to the right bank and passing through the different cross-sections of the river reproduced in the model. Severe bank erosion occurs at upstream & downstream of CBM protection due to high velocity of flow.

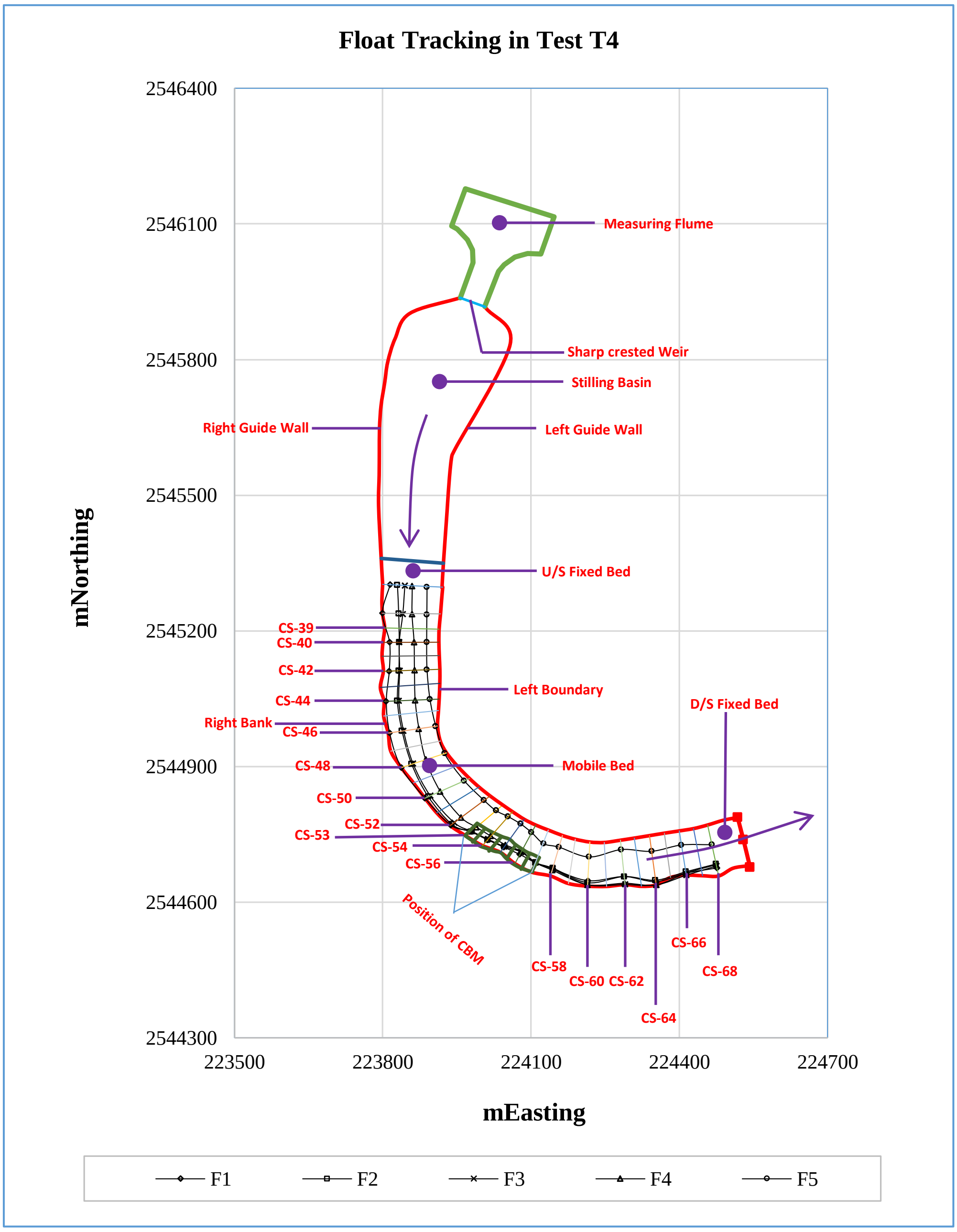


Figure 6.4.1: Flow lines recorded in test T4

Velocity Measurement

The average velocities measured in this test along different cross-sections of the river reproduced in the model are shown in **Table 6.4.1.** The maximum cross-sectional velocity is 3.18 m/s.

Table: 6.4.1: Velocity along different cross-sections of river model in test T4

Sl. No.	C/S No.	C/S Velocity (m/s) in test T4									
		Distance from Right Bank (m)									
		0	15	30	45	60	75	90	105	120	**135**
1	**C/S-36**	0	3	2.42	2.77	2.94	3.12	0.91	2.48	2.19	
2	**C/S-38**	0	2.89	2.48	2.6	2.94	2.3	0.85	1.78	2.19	
3	**C/S-40**	0	2.71	2.54	2.6	2.83	1.61	1.2	1.84		
4	**C/S-42**	1.61	2.36	2.48	2.6	2.54	1.9	1.03	1.32		
5	**C/S-44**	2.25	2.6	2.42	2.42	2.42	2.07	1.43	1.43		
6	**C/S-46**	2.25	2.6	2.77	2.71	3.06	2.6	2.07			
7	**C/S-48**	2.6	2.48	2.77	2.77	2.71	2.54	2.6			
8	**C/S-50**	2.48	2.6	2.77	2.71	2.42	2.48	1.72			
9	**C/S-52**	2.19	2.48	2.65	2.54	2.48	2.07	1.9	1.96		
10	**C/S-53**	0	2.89	2.36	2.65	2.36	2.36	1.61	1.55		
11	**C/S-54**	0	2.65	2.77	2.6	2.36	2.01	1.49			
12	**C/S-55**	0	3.18	2.77	2.36	2.3	1.78				
13	**C/S-56**	0	1.32	3.06	2.3	2.25	1.9	1.72			
14	**C/S-57**	0	1.32	2.83	2.25	2.07	1.67	1.55			
15	**C/S-58**	0.97	2.65	2.13	2.07	2.3	2.01	1.67			
16	**C/S -60**	1.84	2.07	2.19	2.25	2.07	1.9	1.84			
17	**C/S -62**	2.25	2.3	2.13	2.25	2.07	2.19	1.9	1.67		
18	**C/S-64**	2.25	2.13	2.36	2.25	2.19	2.13	2.01	1.49		
19	**C/S-66**	1.9	2.25	2.25	2.42	2.36	2.25	2.01	1.72		
20	**C/S-68**	0	1.14	3.00	2.94	2.71	2.54	2.36	2.13		

Velocity is also measured at the top of concrete block mats (CBM) @ 7.5m interval along the right bank from upstream to downstream as shown in **Table 6.4.2**. From this table it is seen that maximum velocity is 2.19 m/s.

Table: 6.4.2: Velocity at top of CBM along right bank u/s to d/s in test T4

Sl. No.	Dist. from start of CBM (m) from u/s	Velocity (m/s)
1	0.0	1.90
2	7.5	2.07
3	15.0	2.19
4	22.5	1.90
5	30.0	1.20
6	37.5	1.49
7	45.0	1.03
8	52.5	1.43
9	60.0	1.32
10	67.5	1.20
11	75.0	1.49
12	82.5	2.01
13	90.0	2.13
14	97.5	1.84
15	105.0	1.55
16	112.5	1.03
17	120.0	0.80
18	127.5	0.45
19	135.0	0.51
20	142.5	1.14
21	150.0	0.85
22	157.5	0.74
23	165.0	1.14

Scour Measurement

Scour was measured around the protective work (CBM). Maximum local scour around CBM structure is 3.69m (-14.89mPWD) which is 45.00m away from R/B along C/S-56 in test run T4.

The development of maximum scour with time at C/S-56 in test T4 is shown in **Figure 6.4.2**. It is seen from the figure that it takes around 13-15 hours to reach dynamic equilibrium condition for maximum scour development at C/S-56. The variation of bed level with time to reach the maximum scour is shown in **Figure 6.4.3.** Non-dimensional plot is shown in **Figure 6.4.4.**

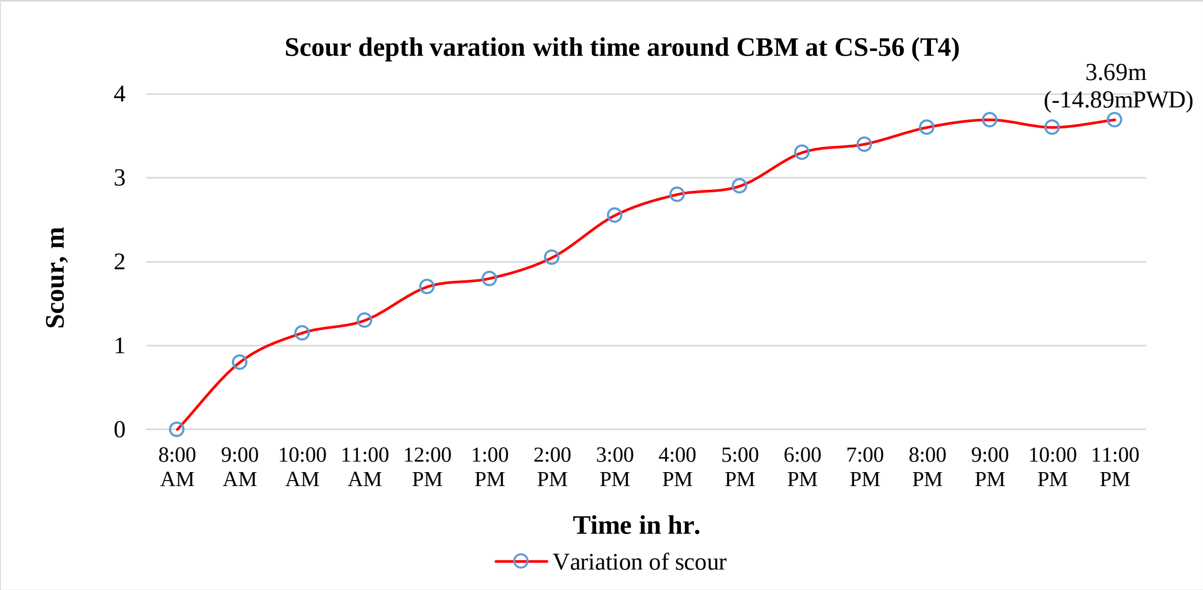


Figure 6.4.2: Development of maximum scour with time around CBM (T4)

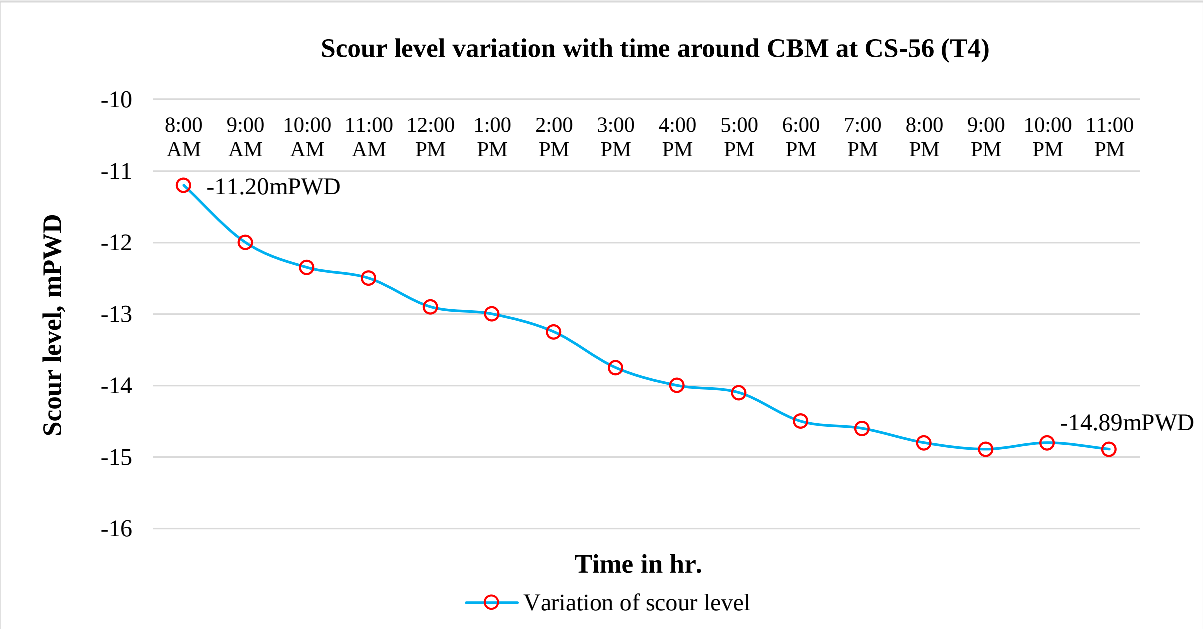


Figure 6.4.3: Variation of bed level with time to reach the maximum scour around CBM (T4)

Non-dimensional plot in log paper (hs /h0) vs. (t/t1) for maximum scour at C/S-56 is as follows. Here hs= scour depth, h0 = initial average water depth, t = time in hours required for scour development and t1= equivalent time defined as the time at which hs= h0.

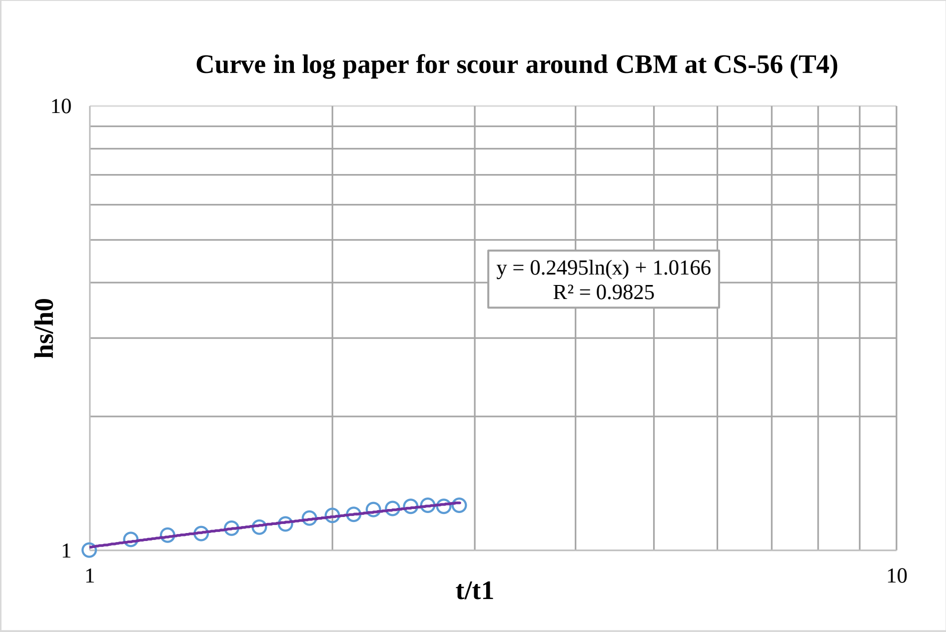
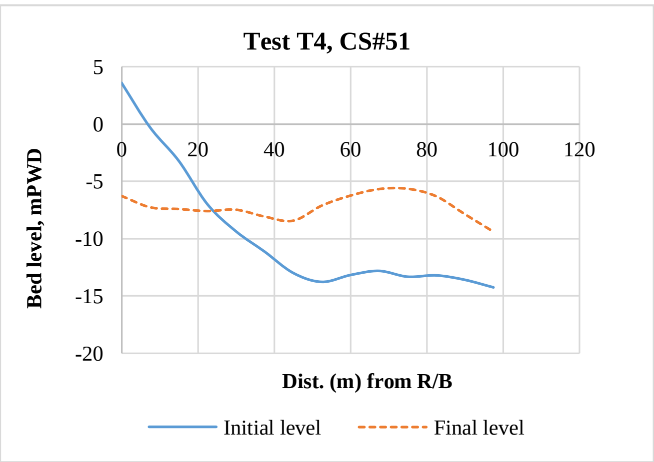
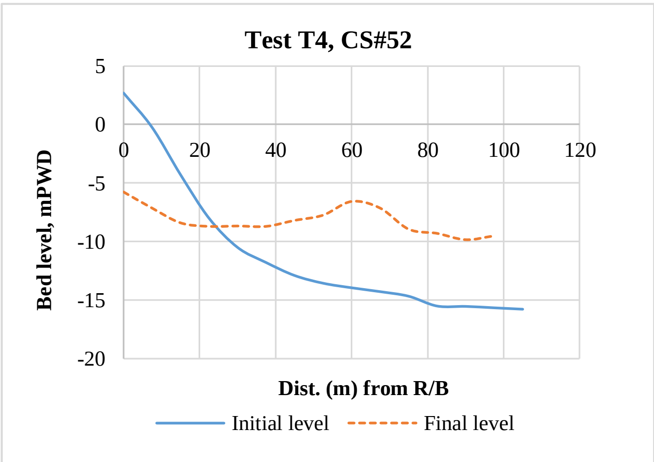


Figure 6.4.4: Non-dimensional plot of (hs /h0) vs. (t/t1) in log paper for scour around CBM (T4)

Bed Level

The bed level before and after test run was measured for each cross-section within the model boundary using levelling staff. Thus the initial & final bed level have been obtained and these are superimposed to have an idea about scour or deposition. Some of the superimposed cross-sections through and around the protective structure (C/S51-C/S58) are shown below.





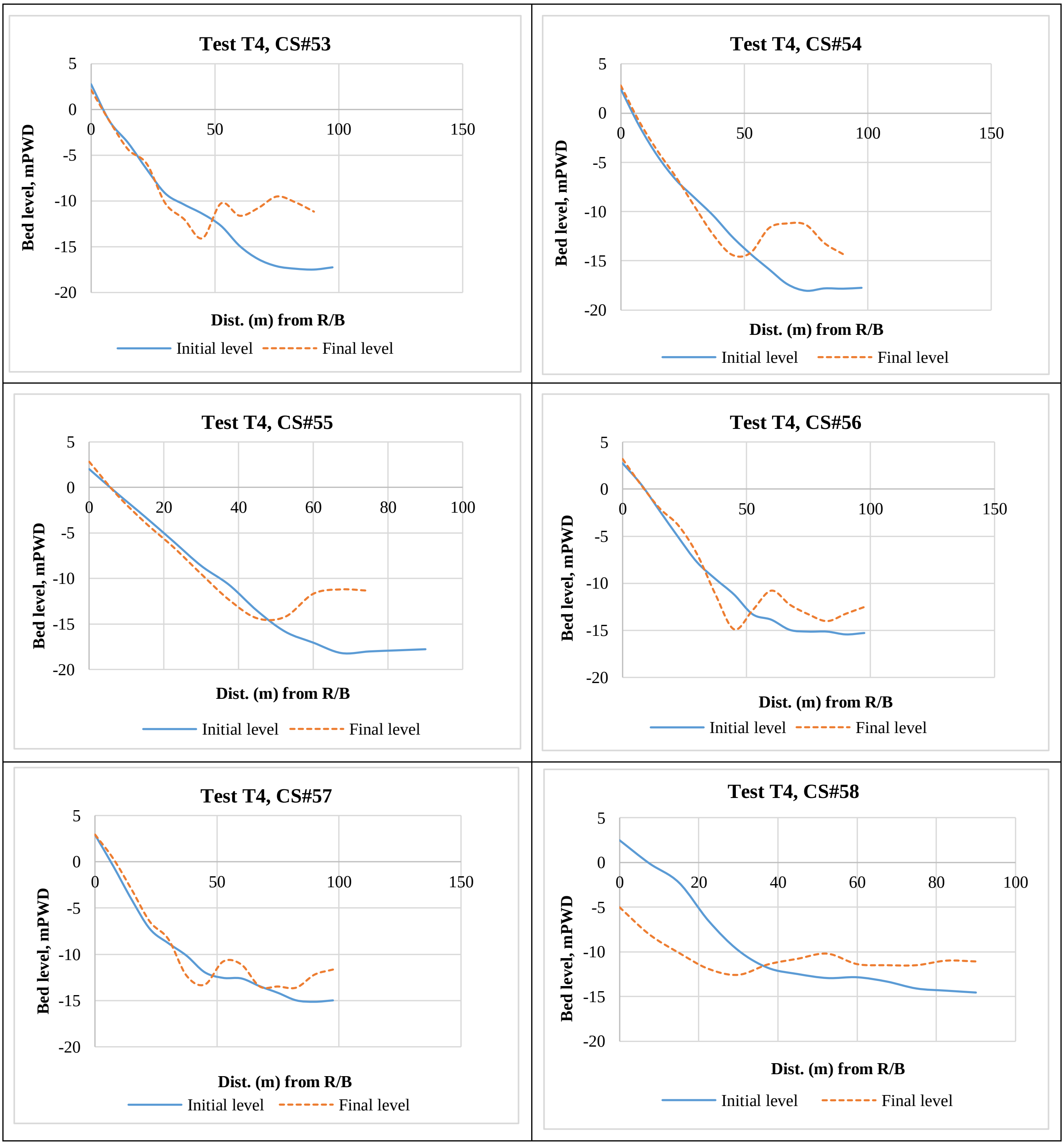


Figure 6.4.5: Superimposed initial and final bed level for C/S51-C/S58 in test T4 of CBM model

Bank Erosion

The tentative river bank erosion after the application test T4 is measured at different cross-sections along the right bank of Arial Khan river and is shown in **Table 6.4.3.** It is seen from the table that maximum bank erosion is 25.2 m at C/S-44.

Table 6.4.3: Tentative bank erosion after the application test T4

Sl. No.	C/S No.	Tentative bank erosion, m in test T4
1	**C/S-41**	13.8
2	**C/S-42**	15.6
3	**C/S-43**	15
4	**C/S-44**	25.2
5	**C/S-45**	22.2
6	**C/S-46**	23.4
7	**C/S-47**	19.5
8	**C/S-48**	21
9	**C/S-49**	17.1
10	**C/S-50**	23.1
11	**C/S-51**	23.1
12	**C/S-52**	16.8
13	**C/S-53**	0
14	**C/S-54**	0
15	**C/S-55**	0
16	**C/S-56**	0
17	**C/S-57**	0
18	**C/S-58**	7.2
19	**C/S-59**	12
20	**C/S-60**	19.8
21	**C/S-61**	21
22	**C/S-62**	17.1
23	**C/S-3**	22.2
24	**C/S-64**	24
25	**C/S-65**	20.4
26	**C/S-66**	18

Observation

- Some concrete block columns and filter materials of CBM protection work for lower bank protection have been displaced & lower bank is exposed.
- At the start of protection work, some portion of CBM including u/s termination have been collapsed due to severe bank erosion during model run under high flow condition.

Some photos of test (T4) for CBM model can be seen in **Photo 6.4.1-6.4.3.**

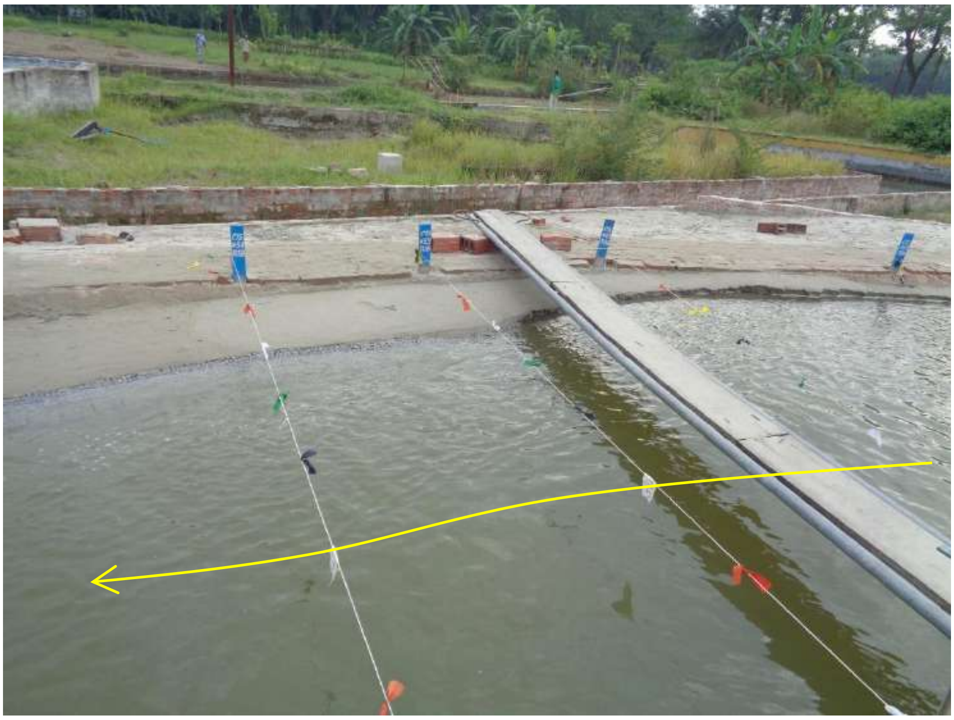


Photo 6.4.1: CBM to protect river bank erosion during test run (T4)

Photo 6.4.2: CBM after test run (T4) in the model

Photo 6.4.3: Detachment of CBM after test run (T4) in the model

6.5 Test T5

This test is conducted with new design supplied by Senior Design Engineer of MHS using low flow. Here lower bank protection work is done applying loosely placed concrete block mats on filter and upper bank protection work is done applying closely placed concrete block mats with some gaps on filter. Here the gaps in the upper bank protection on filter have been provided for plantation.

The CC blocks in a strip of CBM are arranged in twenty rows / lines which are parallel to each other and river bank. Moreover, termination provided at the u/s end of CBM has been increased & d/s termination is kept same with respect to design in test T2. The placement of CC blocks in the CBM is shown in **Photo 6.5.1.**

The sectional discharge ($Q_{sectional}$) corresponding to low water level is 808 cumec. The model bed is prepared according to the bathymetric survey of March 2017. Scour discharge is run until equilibrium condition is reached and Froudian discharge is run for 12 hrs. The design details of proposed concrete block mats (CBM) are as follows:

- River bank level: 3.0mPWD
- Low water level: 0.24mPWD
- Block type: Holed concrete block
- Block size used in the model: 13.33mmX13.33mmX3.33mm (40cmX40cmX10cm in proto)
- Length of river reach to be protected: 5.6m (168m in proto)
- Length of upper bank protection: 0.22m (6.6m in proto)
- Length of lower bank protection: 1m (30m in proto)
- Length of RCC pipe: 7 inch (210 inch in proto)
- Diameter of RCC pipe: 0.5 inch (15 inch in proto)
- Width of filter: 7 inch (210 inch in proto) [4 inch (120 inch in proto) + 4 inch (120 inch in proto)], overlapping 1.0 inch (30 inch in proto)
- Nos. of blocks on 3.5 inch (105 inch in proto) wide overlapped filter in lower bank: 20+20+20+20+10=90 (4 column blocks, each column containing 20 blocks & additional 10 blocks at 10 alternate rows of each strip). In each strip, the top 6 rows of blocks are placed with no gaps, other 14 rows of blocks are placed with some gaps
- Length of u/s termination 0.75 m (22.5m in proto) & d/s termination 0.50 m (15m in proto)

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 6.5.1** It is seen that flow lines are close to the right bank and passing through the different cross-sections of the river reproduced in the model. Flow hits the middle portion of the CBM protection work which causes detachment of some portion of CBM from the lower bank protection.

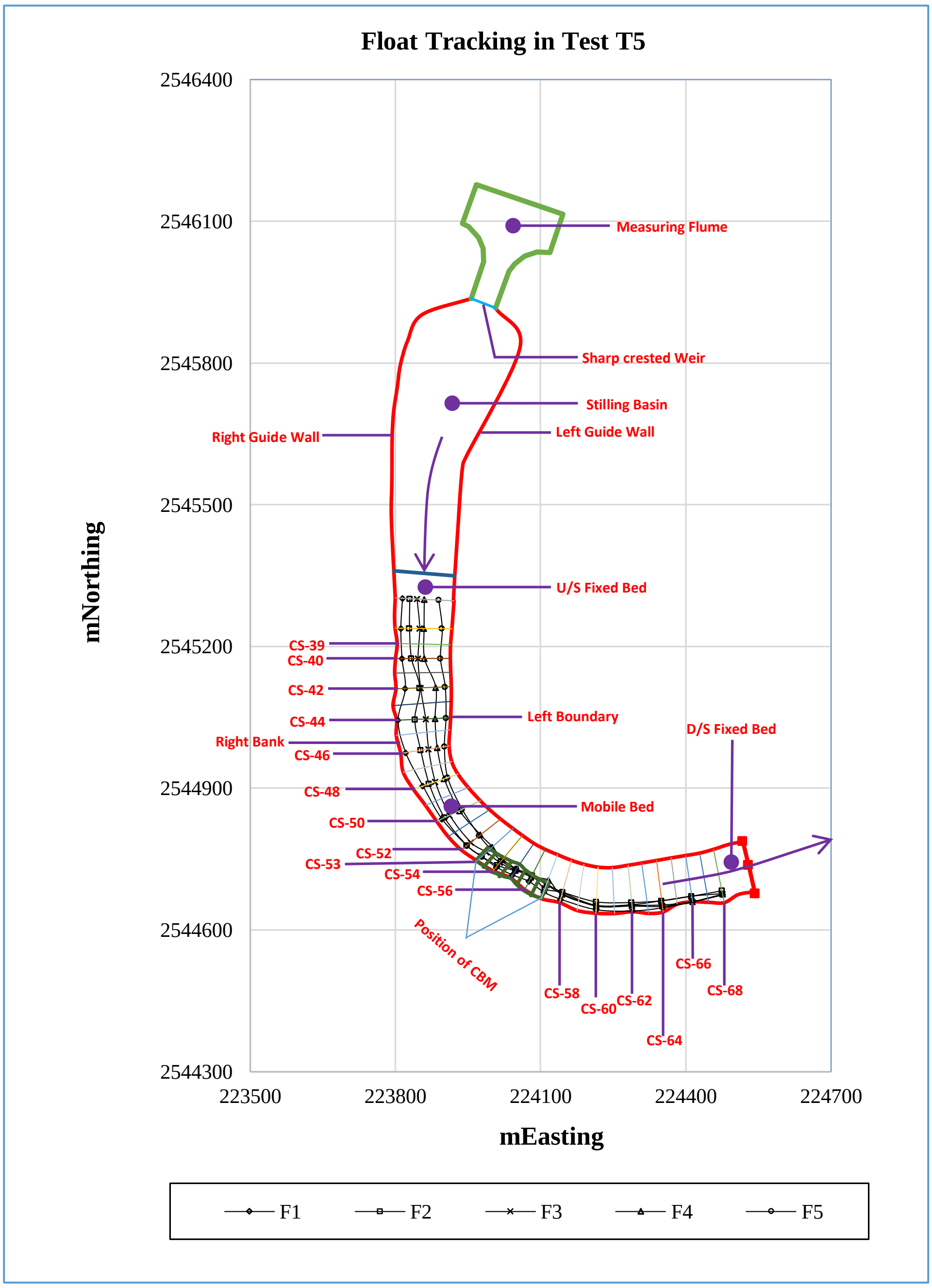


Figure 6.5.1: Flow lines recorded in test T5

Velocity Measurement

The average velocities measured in this test along different cross-sections of the river reproduced in the model are shown in **Table 6.5.1.** The maximum cross-sectional velocity is 1.49 m/s.

Table: 6.5.1: Velocity along different cross-sections of river model in test T5

Sl. No.	C/S No.	C/S Velocity (m/s) in test T5									
		Distance from Right Bank (m)									
		0	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**
1	**C/S-36**	0.00	**1.49**	1.32	1.32	1.26	1.38	0.62	0.85	0.27	
2	**C/S-38**	0.00	1.14	1.09	1.09	1.09	1.14	0.56	0.33	0.27	
3	**C/S-40**	0.00	1.14	1.09	1.03	1.09	1.20	0.62	0.62		
4	**C/S-42**	0.74	1.20	1.32	1.43	1.20	1.32	1.03	0.62	0.68	
5	**C/S-44**	0.68	1.14	1.03	1.26	1.49	1.14	1.09	0.85		
6	**C/S-46**	0.80	1.09	1.20	1.32	1.32	1.26	1.20			
7	**C/S-48**	0.00	0.62	0.56	1.03	1.09	1.09	1.03			
8	**C/S-50**	0.00	0.91	0.97	1.03	1.14	1.03	0.68			
9	**C/S-52**	0.00	0.68	0.80	0.91	0.91	0.68	0.56	0.51		
10	**C/S-53**	0.00	0.85	0.91	0.97	0.80	0.51	0.56	0.39		
11	**C/S-54**	0.00	0.51	1.09	0.97	0.68	0.56	0.33			
12	**C/S-55**	0.00	0.97	1.14	0.80	0.51	0.51	0.51			
13	**C/S-56**	0.00	0.00	1.14	0.91	0.62	0.62	0.45			
14	**C/S-57**	0.00	0.00	1.09	0.85	0.68	0.56	0.62			
15	**C/S-58**	0.00	0.68	0.91	0.85	0.68	0.68	0.56			
16	**C/S-60**	0.00	0.80	0.85	0.91	0.85	0.62	0.74			
17	**C/S-62**	0.68	1.09	0.97	0.85	0.85	0.74	0.56	0.39		
18	**C/S-64**	0.00	0.62	1.03	0.80	0.91	0.68	0.56	0.56		
19	**C/S-66**	0.62	0.74	1.03	0.97	0.91	0.91	0.68			
20	**C/S-68**	0.00	0.97	0.68	1.20	1.14	1.09	0.91	0.91		

Velocity is also measured at the top of concrete block mats (CBM) @ 15m interval along the right bank from upstream to downstream as shown in **Table 6.5.2**. From this table it is seen that maximum velocity is 0.85 m/s.

Table: 6.5.2: Velocity around the top of CBM along right bank u/s to d/s in test T5

Sl. No.	Dist. from start of CBM (m) from u/s	Velocity (m/s)
1	0	0.45
2	15	0.51
3	30	0.56
4	45	0.68
5	60	0.62
6	75	0.62
7	90	0.85
8	105	0.00
9	120	0.00
10	135	0.00
11	150	0.00
12	165	0.00
13	180	0.00

Observation

- Few **c**oncrete block columns and filter material of CBM protection work during lower bank protection have been detached from the middle portion & lower bank is exposed**.**
- Some mats are placed over the exposed bank during run to protect it.
- Flow hits the right bank at upstream & downstream of CBM protection causing bank erosion.

Some photos of test (T5) for CBM model can be seen in **Photo 6.5.1-6.5.4.**

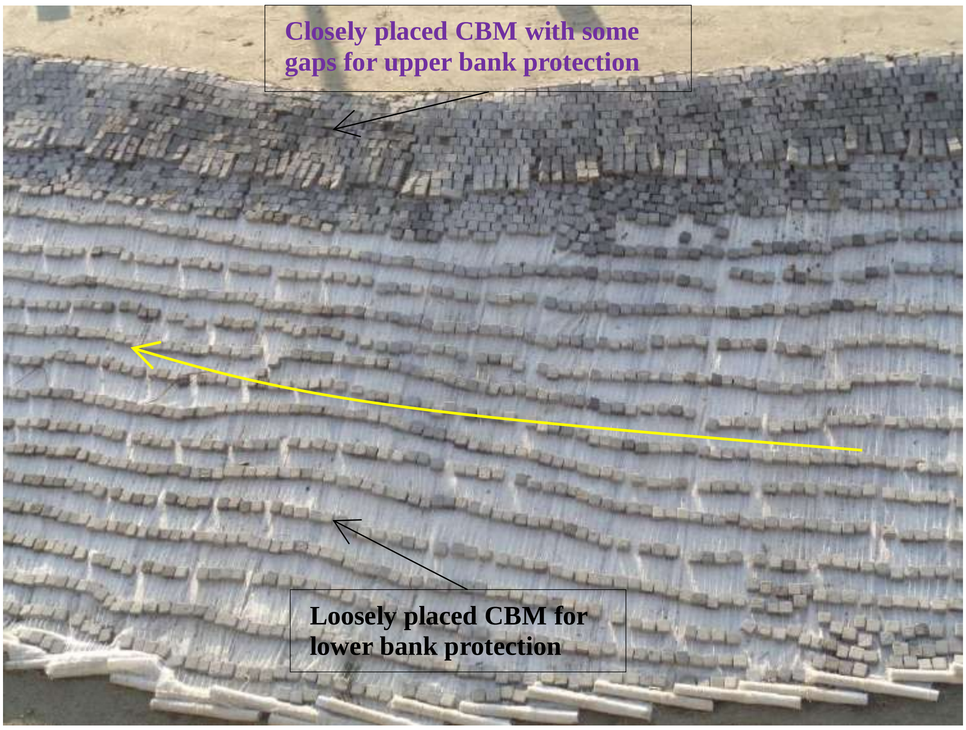


Photo 6.5.1: Placement CC blocks in the CBM to protect river bank erosion before test run (T5)

Photo 6.5.2: Model is under running condition (T5) with CBM

Photo 6.5.3: Detachment of filter from CBM during test run (T5)

Photo 6.5.4: CBM after test run (T5) in the model

6.6 Test T6

This test is conducted with the same design as in test T5 but using medium flow. Here lower bank protection work is done applying loosely placed concrete block mats on filter and upper bank protection work is done applying closely placed concrete block mats with some gaps on filter using medium flow. Here the gaps in the upper bank protection on filter are filled with plantation.

The sectional discharge ($Q_{sectional}$) corresponding to medium water level is 1381 cumec. The model bed is prepared according to the bathymetric survey of March 2017. Scour discharge is run until equilibrium condition is reached and Froudian discharge is run for 12 hrs. The design details of proposed concrete block mats (CBM) are as follows:

- River bank level: 3.0mPWD
- Medium water level: 1.23mPWD
- Block type: Holed concrete block
- Block size used in the model: 13.33mmX13.33mmX3.33mm (40cmX40cmX10cm in proto)
- Length of river reach to be protected: 5.6m (168m in proto)
- Length of upper bank protection: 0.22m (6.6m in proto)
- Length of lower bank protection: 1m (30m in proto)
- Length of RCC pipe: 7 inch (210 inch in proto)
- Diameter of RCC pipe: 0.5 inch (15 inch in proto)
- Width of filter: 7 inch (210 inch in proto) [4 inch (120 inch in proto) + 4 inch (120 inch in proto)], overlapping 1.0 inch (30 inch in proto)
- Nos. of blocks on 3.5 inch (105 inch in proto) wide overlapped filter in lower bank: 20+20+20+20+10=90 (4 column blocks, each column containing 20 blocks & additional 10 blocks at 10 alternate rows of each strip). In each strip, the top 6 rows of blocks are placed with no gaps, other 14 rows of blocks are placed with some gaps.
- Length of u/s termination 0.75 m (22.5m in proto) & d/s termination 0.50 m (15m in proto)

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 6.6.1** It is seen that flow lines are close to the right bank and passing through the different cross-sections of the river reproduced in the model. Flow hits the middle portion of CBM protection work which causes detachment of concrete block columns.

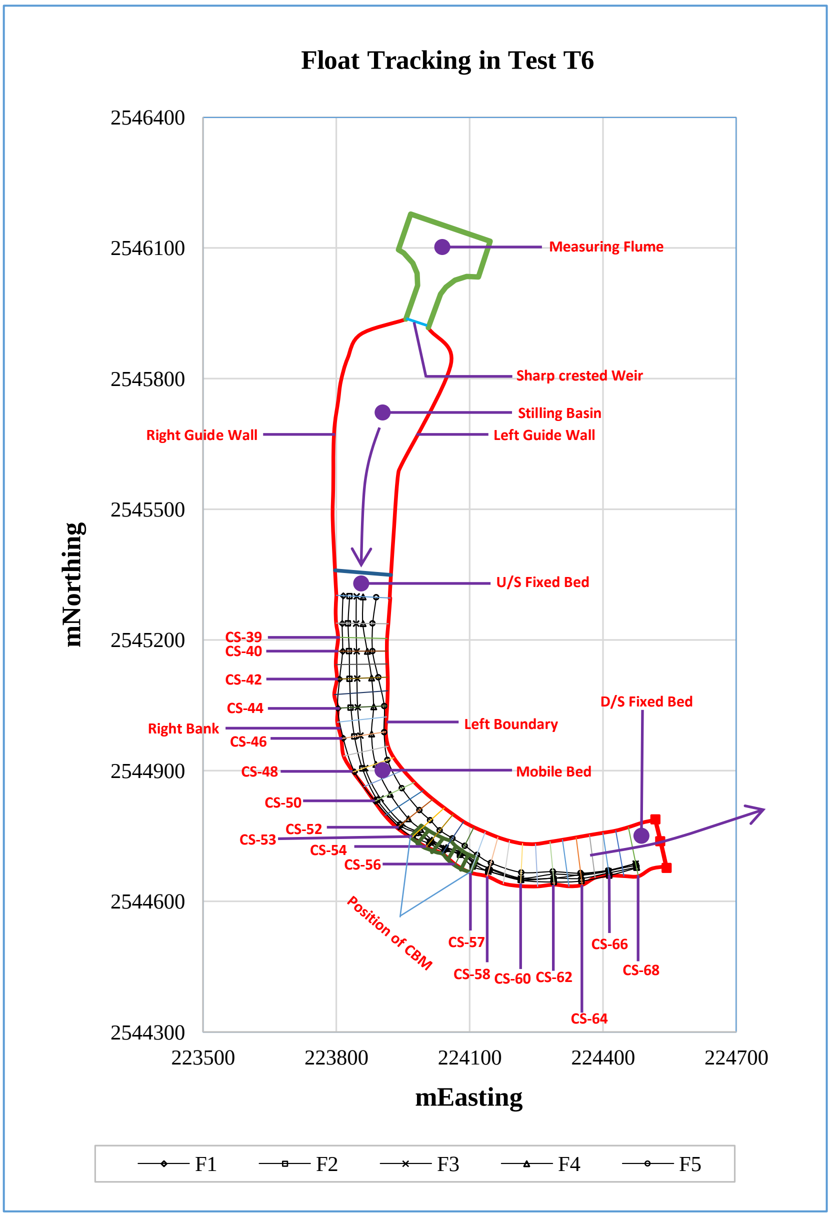


Figure 6.6.1: Flow lines recorded in test T6

Velocity Measurement

The average velocities measured in this test along different cross-sections of the river reproduced in the model are shown in **Table 6.6.1.** The maximum cross-sectional velocity is 2.48 m/s.

Table: 6.6.1: Velocity along different cross-sections of river model in test T6

Sl. No.	C/S No.	C/S Velocity (m/s) in test T6									
		Distance from Right Bank (m)									
		0	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**
1	**C/S -36**	0.00	2.30	1.78	1.90	2.13	2.25	0.62	1.38	1.38	
2	**C/S -38**	0.00	2.13	1.90	2.01	2.01	1.38	0.56	1.14	2.19	
3	**C/S -40**	2.07	1.96	1.90	1.96	2.19	1.55	1.26	1.32		
4	**C/S -42**	1.49	2.19	2.19	2.13	2.01	1.90	1.20	1.32		
5	**C/S -44**	1.38	2.42	2.36	2.48	2.42	2.13	2.07	1.55		
6	**C/S -46**	0.00	2.01	2.13	2.36	2.36	2.13	1.90	1.84		
7	**C/S -48**	0.00	1.32	1.43	2.13	2.07	1.96	1.78	1.03		
8	**C/S -50**	1.20	1.78	1.90	1.84	2.01	1.61	1.09			
9	**C/S -52**	0.00	1.61	1.90	1.84	1.61	1.43	2.13	1.14	1.09	
10	**C/S -53**	0.00	1.84	1.90	1.67	1.67	1.03	0.91	0.91		
11	**C/S -54**	0.00	1.78	1.72	1.78	1.49	1.09	0.97			
12	**C/S-55**	0.00	2.25	1.84	1.67	1.09	1.09	0.91			
13	**C/S -56**	0.00	0.00	2.07	1.90	1.32	1.32	1.14	0.91		
14	**C/S-57**	0.00	0.45	1.84	1.49	1.49	1.38	1.14			
15	**C/S -58**	0.00	1.61	1.49	1.38	1.32	1.38	1.26			
16	**C/S -60**	0.00	1.90	1.61	1.72	1.55	1.32	1.61			
17	**C/S -62**	1.20	1.90	1.78	1.55	1.26	1.38	1.20			
18	**C/S -64**	0.00	1.78	1.84	1.78	1.61	1.55	1.38	1.26		
19	**C/S -66**	1.67	2.07	1.96	1.84	1.67	1.55	1.49			
20	**C/S -68**	0.00	1.90	2.19	2.07	1.84	1.78	1.67	1.49		

Velocity is also measured at the top of concrete block mats (CBM) @ 7.5m interval along the right bank from upstream to downstream as shown in **Table 6.6.2**. From this table it is seen that maximum velocity is **1.61** m/s.

Table: 6.6.2: Velocity around the top of CBM along right bank u/s to d/s in test T6

Sl. No.	Dist. from start of CBM (m) from u/s	Velocity (m/s)
1	0.0	0.80
2	7.5	1.14
3	15.0	1.09
4	22.5	1.20
5	30.0	1.20
6	37.5	0.91
7	45.0	0.74
8	52.5	0.51
9	60.0	0.74
10	67.5	0.80
11	75.0	0.85
12	82.5	1.09
13	90.0	1.61
14	97.5	0.68
15	105.0	0.00
16	112.5	0.00
17	120.0	-0.42
18	127.5	-0.31
19	135.0	-0.54
20	142.5	-0.37
21	150.0	-0.13
22	157.5	-0.08
23	165.0	-0.08
24	172.5	0.00
25	180.0	0.56

Observation

- Some concrete block columns and filter materials of CBM for the lower bank protection have been detached from the middle portion & lower bank is exposed.

- To prevent exposure, extra CBM have been placed on it.

Some photos of test (T6) for CBM model can be seen in **Photo 6.6.1-6.6.3.**

Photo 6.6.1: Model is under running condition (T6) with CBM

Photo 6.6.2: Displacement of CC blocks in the CBM after test run (T6) in the model

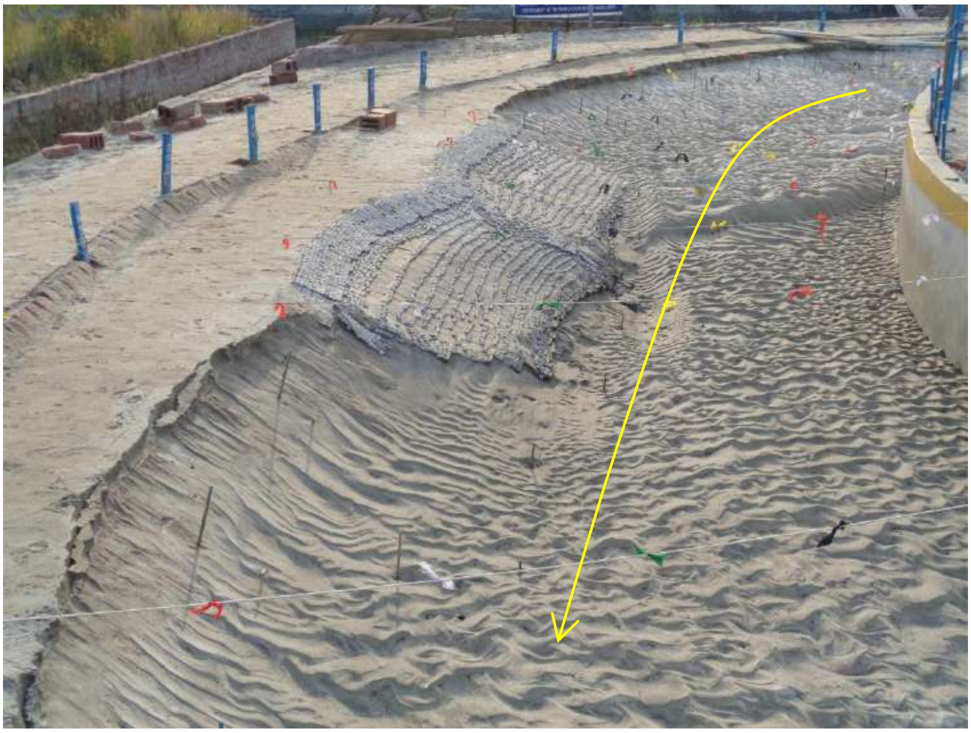


Photo 6.6.3: Bed level around CBM after test run (T6) in the model

6.7 Test T7

This test is conducted with the same design as in test T5 but using high flow. Here lower bank protection work is done applying loosely placed concrete block mats on filter and upper bank protection work is done applying closely placed concrete block mats with some gaps on filter using high flow. Here the small gaps in the upper bank protection on filter have been provided for plantation.

The sectional discharge ($Q_{sectional}$) corresponding to high water level is 1967 cumec. The model bed is prepared according to the bathymetric survey of March 2017. Scour discharge is run until equilibrium condition is reached and Froudian discharge is run for 12 hrs. The design details of proposed concrete block mats (CBM) are as follows:

- River bank level: 3.0mPWD
- High water level: 2.93mPWD
- Block type: Holed concrete block
- Block size used in the model: 13.33mmX13.33mmX3.33mm (40cmX40cmX10cm in proto)
- Length of river reach to be protected: 5.6m (168m in proto)
- Length of upper bank protection: 0.22m (6.6m in proto)
- Length of lower bank protection: 1m (30m in proto)
- Length of RCC pipe: 7 inch (210 inch in proto)
- Diameter of RCC pipe: 0.5 inch (15 inch in proto)
- Width of filter: 7 inch (210 inch in proto) [4 inch (120 inch in proto) + 4 inch (120 inch in proto)], overlapping 1.0 inch (30 inch in proto)
- Nos. of blocks on 3.5 inch (105 inch in proto) wide overlapped filter in lower bank: 20+20+20+20+10=90 (4 column blocks, each column containing 20 blocks & additional 10 blocks at 10 alternate rows of each strip). In each strip, the top 6 rows of blocks are placed with no gaps, other 14 rows of blocks are placed with some gaps.
- Length of u/s termination 0.75 m (22.5m in proto) & d/s termination 0.50 m (15m in proto)

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 6.7.1** It is seen that flow lines are close to the right bank and passing through the different cross-sections of the river reproduced in the model. Flow attacks the middle portion of CBM protection work resulting detachment of some protection work occurs.

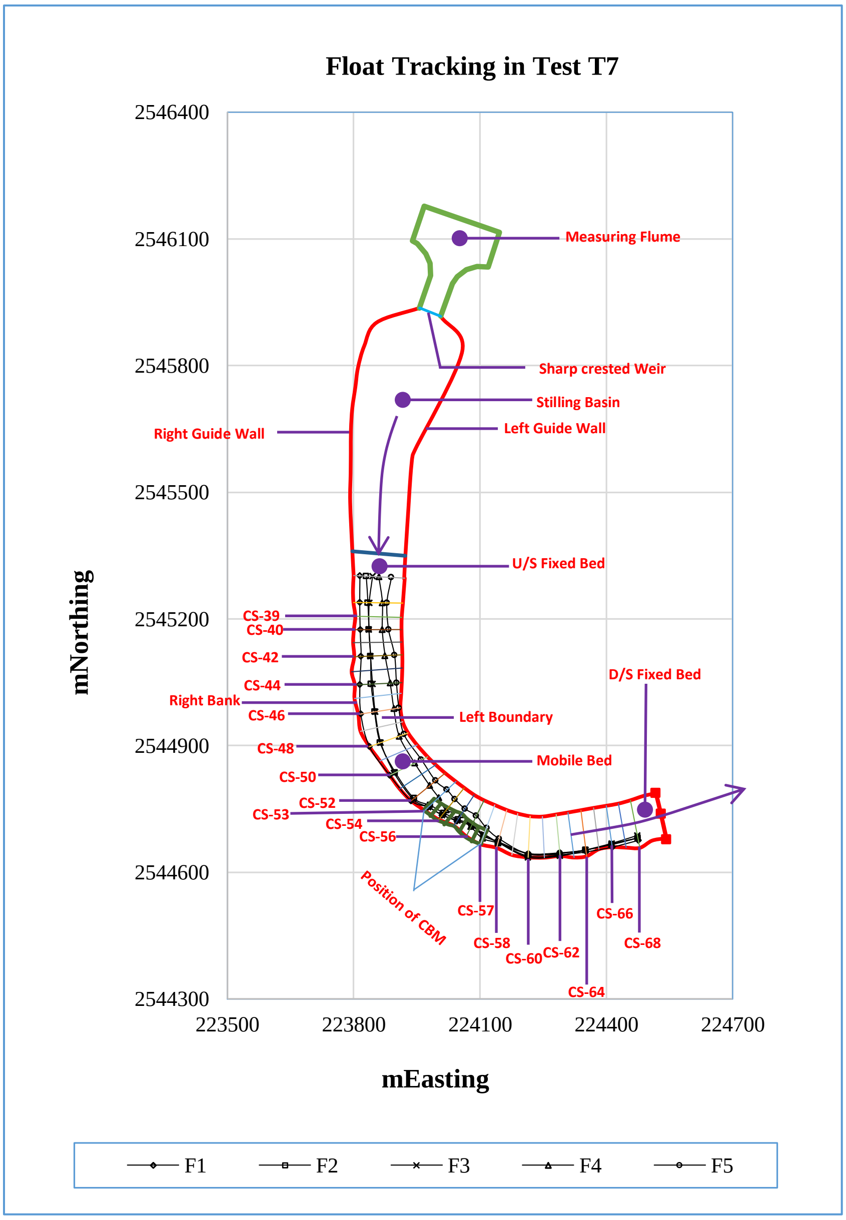


Figure 6.7.1: Flow lines recorded in test T7

Velocity Measurement

The average velocities measured in this test along different cross-sections of the river reproduced in the model are shown in **Table 6.7.1.** The maximum cross-sectional velocity is 3.93 m/s.

Table: 6.7.1: Velocity along different cross-sections of river model in test T7

Sl. No.	C/S No.	C/S Velocity (m/s) in test T7									
		Distance from Right Bank (m)									
		0	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**
1	**C/S -36**	0.00	3.06	2.83	2.83	3.06	2.94	1.20	2.07	0.91	
2	**C/S -38**	3.93	2.83	2.65	2.77	2.65	2.25	1.26	1.72		
3	**C/S -40**	1.61	2.71	2.65	2.48	2.54	2.42	1.61	1.84		
4	**C/S -42**	2.48	2.89	2.89	2.71	2.48	2.13	1.61	1.84		
5	**C/S -44**	2.71	2.77	3.06	2.94	2.71	2.77	2.48	2.07		
6	**C/S -46**	2.77	2.94	3.12	3.06	2.89	2.71	2.71	2.65		
7	**C/S -48**	2.65	2.83	2.94	2.71	2.60	3.12	3.00			
8	**C/S -50**	2.65	3.00	2.83	2.94	2.77	2.77	2.30	1.84		
9	**C/S -52**	2.07	2.54	2.89	3.00	2.77	2.65	2.42	1.67		
10	**C/S -53**	0.00	3.41	3.41	3.06	2.89	2.54	2.01	1.49		
11	**C/S -54**	0.00	3.18	3.18	2.65	2.48	2.07	1.43			
12	**C/S-55**	0.00	3.47	2.94	2.65	2.30	1.78				
13	**C/S -56**	0.00	3.29	2.71	2.54	2.13	1.61				
14	**C/S-57**	0.00	1.72	3.00	2.60	2.48	2.13	1.55			
15	**C/S -58**	0.91	2.48	2.30	2.60	2.30	2.07	1.55			
16	**C/S -60**	2.36	2.48	2.36	2.65	2.42	2.13	1.78			
17	**C/S -62**	2.54	2.48	2.60	2.60	2.42	2.13	1.84	1.26		
18	**C/S -64**	2.36	2.83	2.71	2.71	2.30	2.25	2.01	1.61		
19	**C/S -66**	2.19	2.77	2.83	2.77	2.60	2.30	2.07			
20	**C/S -68**	0.00	2.89	3.18	2.94	2.83	2.60	2.30	2.13		

Velocity is also measured at the top of concrete block mats (CBM) @ 7.5m interval along the right bank from upstream to downstream as shown in **Table 6.7.2**. From this table it is seen that maximum velocity is 2.36 m/s.

Table: 6.7.2: Velocity around the top of CBM along right bank u/s to d/s in test T7

Sl. No.	Dist. from start of CBM (m) from u/s	Velocity (m/s)
1	0.0	2.36
2	7.5	2.07
3	15.0	1.38
4	22.5	1.72
5	30.0	1.96
6	37.5	1.26
7	45.0	1.61
8	52.5	1.20
9	60.0	1.43
10	67.5	1.14
11	75.0	1.32
12	82.5	1.14
13	90.0	2.07
14	97.5	2.13
15	105.0	1.09
16	112.5	-0.25
17	120.0	-0.37
18	127.5	-0.37
19	135.0	-0.54
20	142.5	-0.54
21	150.0	-0.31
22	157.5	-0.02
23	165.0	0.00
24	172.5	0.68
25	180.0	0.51

Scour Measurement

Scour was measured around the protective structure (CBM). Maximum local scour around CBM structure is 3.6m (-14.2mPWD) which is 37.50 m away from R/B along C/S-56 in test run T7.

The development of maximum scour with time at C/S-56 in test T7 is shown in **Figure 6.7.2**. It is seen from the figure that it takes around 13-15 hours to reach dynamic equilibrium condition for maximum scour development at C/S-56. The variation of bed level with time to reach the maximum scour is shown in **Figure 6.7.3.** Non-dimensional plot is shown in **Figure 6.7.4.**

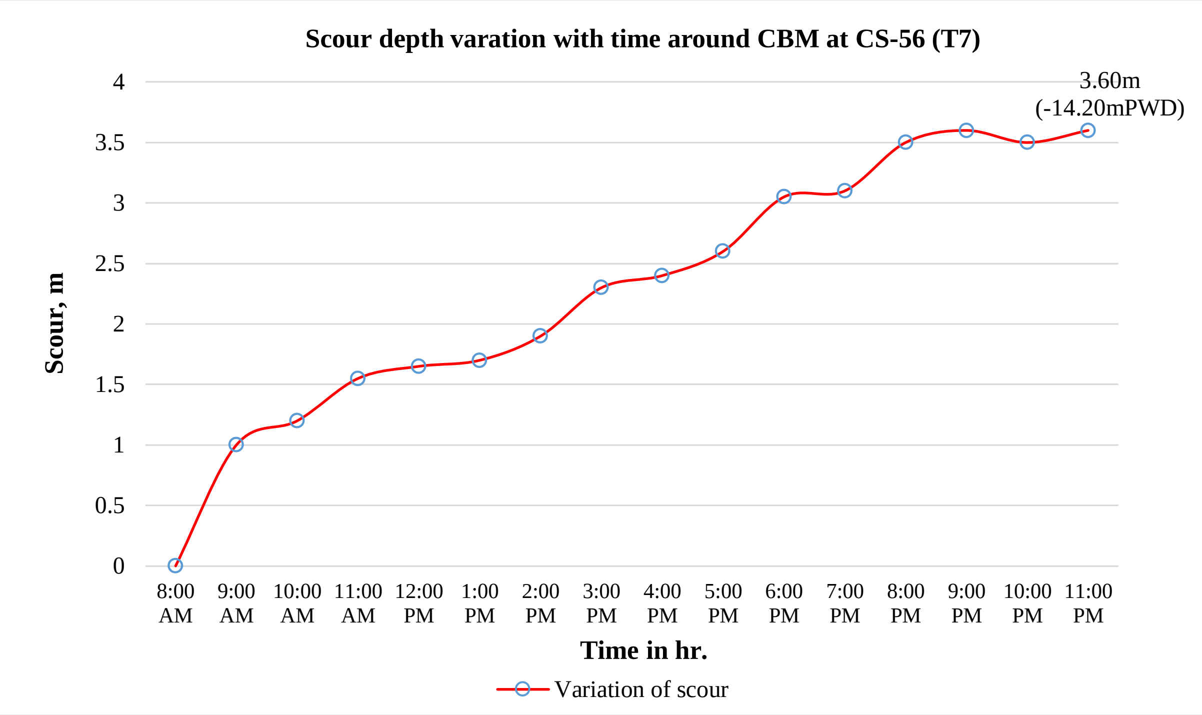


Figure 6.7.2: Development of maximum scour with time around CBM (T7)

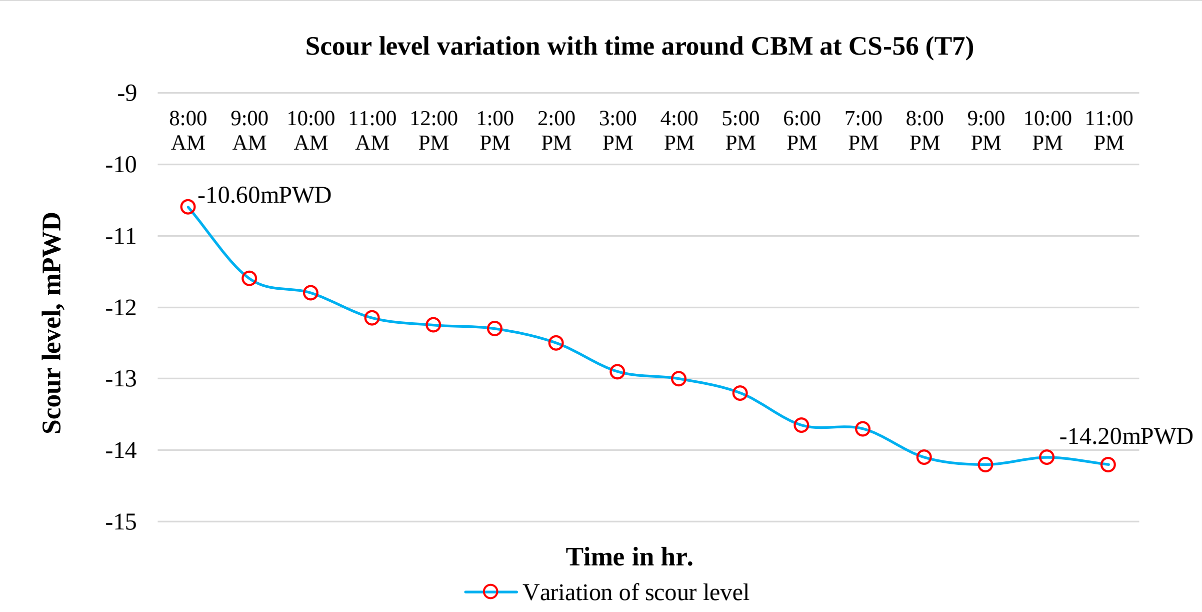


Figure 6.7.3: Variation of bed level with time to reach the maximum scour around CBM (T7)

Non-dimensional plot in log paper (hs /h0) vs. (t/t1) for maximum scour at C/S-56 is as follows. Here hs= scour depth, h0 = initial average water depth, t = time in hours required for scour development and t1= equivalent time defined as the time at which hs= h0.

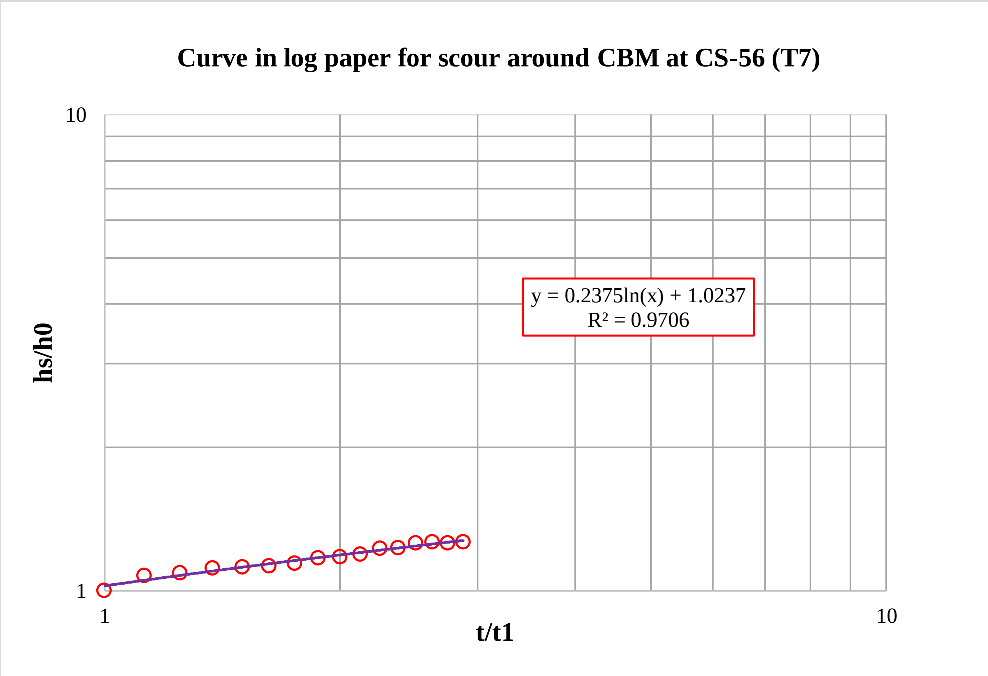
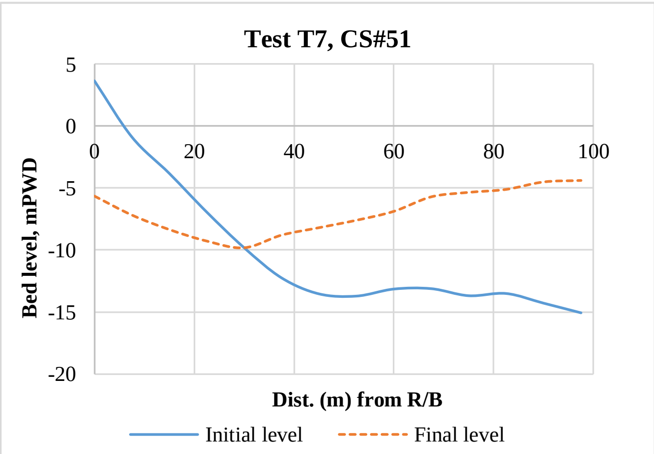
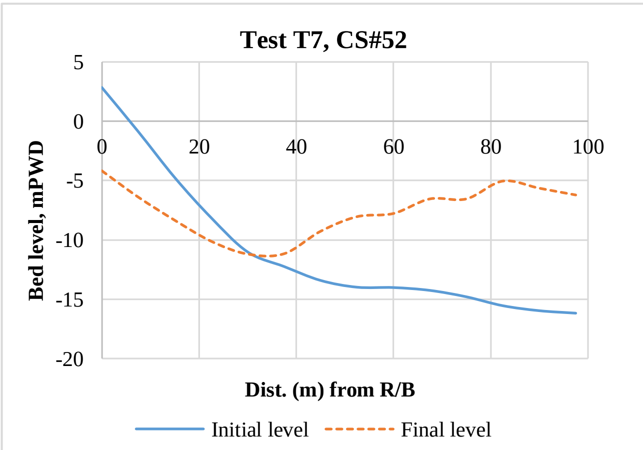


Figure 6.7.4: Non-dimensional plot of (hs /h0) vs. (t/t1) in log paper for scour around CBM (T7)

Bed Level

The bed level before and after test run was measured for each cross-section within the model boundary using levelling staff. Thus the initial & final bed level have been obtained and these are superimposed to have an idea of scour or deposition. Some of the superimposed cross-sections through and around the protective structure (C/S51-C/S58) are shown below.





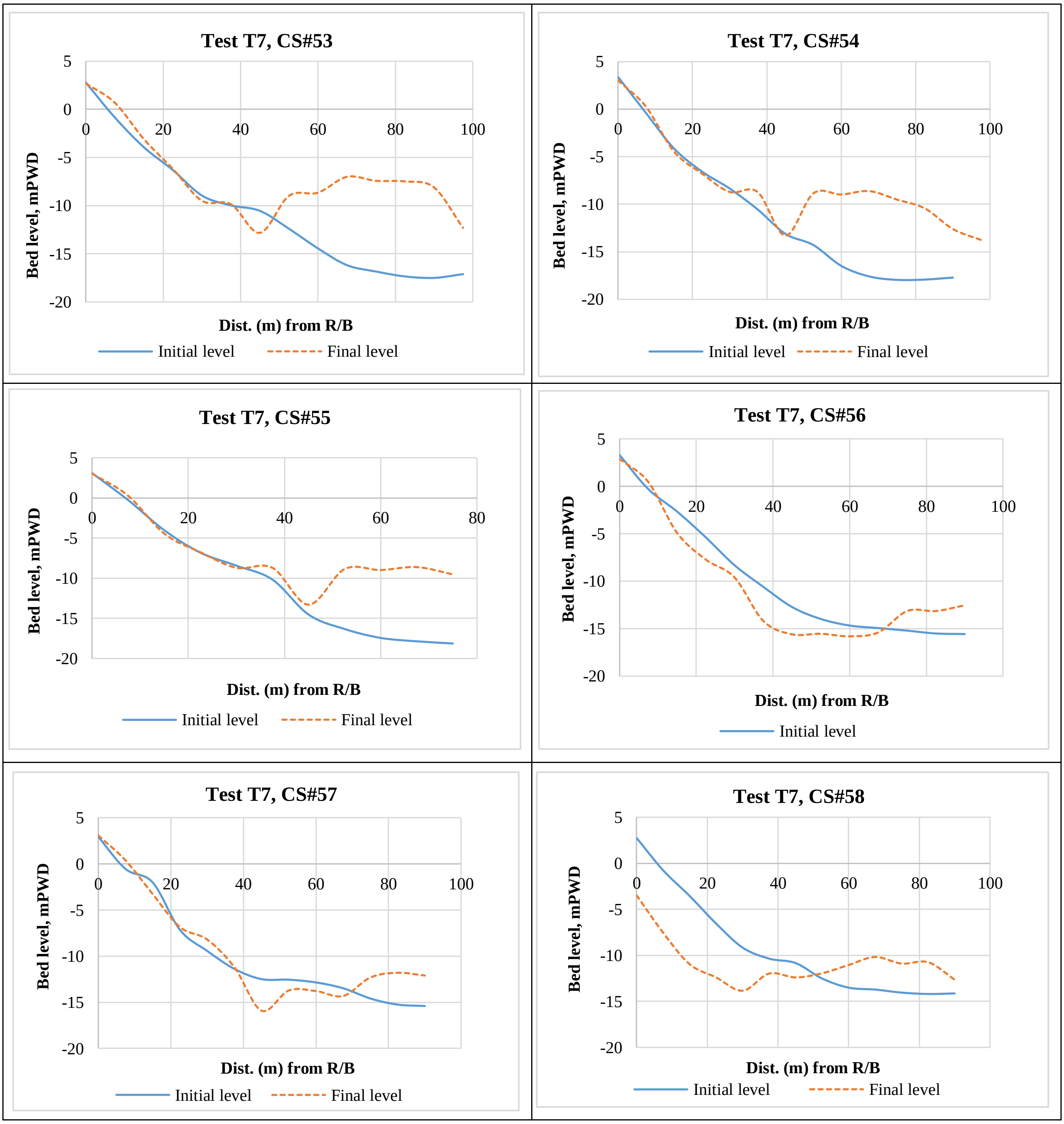


Figure 6.7.5: Superimposed initial and final bed level for C/S51-C/S58 in test T7 of CBM model

Bank Erosion

The tentative river bank erosion after the application test T7 is measured along the right bank of Arial Khan river and is shown in **Table 6.7.3.** It is seen from the table that maximum bank erosion is **28.2** m at C/S-44/45.

Table 6.7.3: Tentative bank erosion after the application test T7

Sl. No.	C/S No.	Tentative bank erosion, m in test T7
1	**C/S-41**	13.5
2	**C/S-42**	21.3
3	**C/S-43**	22.5
4	**C/S-44**	28.2
5	**C/S-45**	28.2
6	**C/S-46**	27.6
7	**C/S-47**	23.4
8	**C/S-48**	25.2
9	**C/S-49**	22.5
10	**C/S-50**	17.7
11	**C/S-51**	25.2
12	**C/S-52**	14.4
13	**C/S-53**	0
14	**C/S-54**	0
15	**C/S-55**	0
16	**C/S-56**	0
17	**C/S-57**	0
18	**C/S-58**	9.3
19	**C/S-59**	13.2
20	**C/S-60**	21
21	**C/S-61**	25.8
22	**C/S-62**	29.7
23	**C/S-63**	27
24	**C/S-64**	25.8
25	**C/S-65**	33.9
26	**C/S-66**	28.2

Observation

- Observation is almost similar to test T6

Some photos of test (T7) for CBM model can be seen in **Photo 6.7.1-6.7.3.**

Photo 6.7.1: Model is under running condition (T7) with CBM

Photo 6.7.2: CBM after test run (T7) in the model

Photo 6.7.3: Model bed after test run (T7) with CBM

6.8 Test T8

This test is same as test T5 using low flow but conducted with some design modification based on test T5. Here the CC blocks of all strips in a CBM are arranged in such a way that the rows of CC blocks in a strip are placed in between the rows of consecutive strips. The rows of CC blocks of all strips are not in the same lines / rows horizontally but in a scattered way.

The CC blocks in a strip of CBM are arranged in twenty rows / lines which are parallel to each other and river bank. In this case, the lower bank protection work is done applying loosely placed concrete block mats on filter and upper bank protection work is done applying closely placed concrete block mats with some gaps on filter. Here the gaps in the upper bank protection on filter are filled with small grasses. The placement of CC blocks in the CBM on the river bank is shown in **Photo 6.23.** Here the length of termination at u/s & d/s end is same as that provided in test T5.

The sectional discharge ($Q_{sectional}$) corresponding to low water level is 808 cumec. The model bed is prepared according to the bathymetric survey of March 2017. Scour discharge is run until equilibrium condition is reached and Froudian discharge is run for 12 hrs. The design details of proposed concrete block mats (CBM) are as follows:

- River bank level: 3.0mPWD
- Low water level: 0.24mPWD
- Block type: Holed concrete block
- Block size used in the model: 13.33mmX13.33mmX3.33mm (40cmX40cmX10cm in proto)
- Length of river reach to be protected: 5.6 m (168 m in proto)
- Length of upper bank protection: 0.22 m (6.6 m in proto)
- Length of lower bank protection: 1m (30 m in proto)
- Length of RCC pipe: 7 inch (210 inch in proto)
- Diameter of RCC pipe: 0.5 inch (15 inch in proto)
- Width of filter: 7 inch (210 inch in proto) [4 inch (120 inch in proto) + 4 inch (120 inch in proto)], overlapping 1.0 inch (30 inch in proto)
- Nos. of blocks on each 3.5 inch (105 inch in proto) wide overlapped filter in lower bank: 20+20+20+20+10=90 (4 column blocks, each column containing 20 blocks & additional 10 blocks at 10 alternate rows of each strip). In each strip, the top 3 rows of blocks are placed with no gaps, other 17 rows of blocks are placed with some gaps
- Length of u/s termination 0.75 m (22.5 m in proto) & d/s termination 0.50 m (15 m in proto)

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 6.8.1** It is seen that flow lines are close to the right bank and passing through the different cross-sections of the river reproduced in the model.

Flow attacks the CBM protection work at its start and middle portion causing detachment of protection occurs.

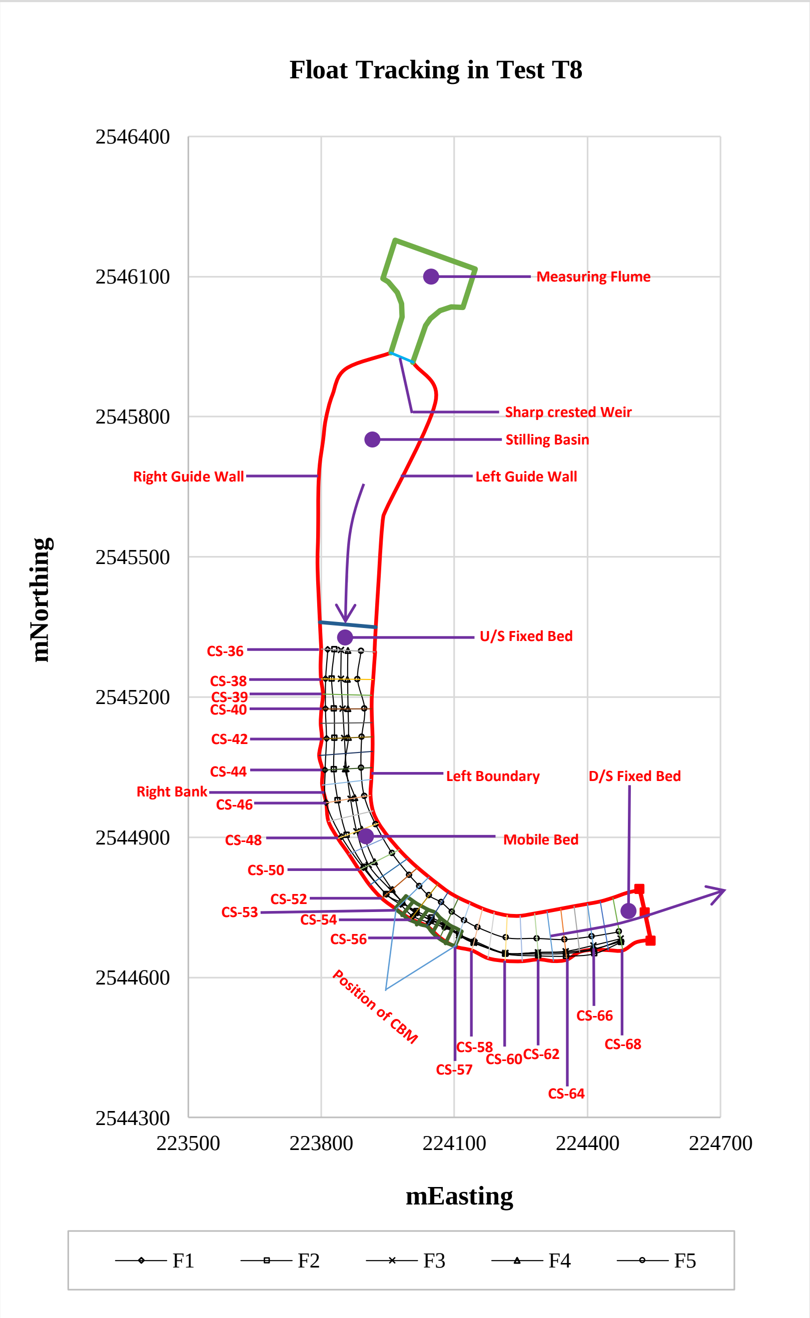


Figure 6.8.1: Flow lines recorded in test T8

Velocity Measurement

The average velocities measured in this test along different cross-sections of the river reproduced in the model are shown in **Table 6.8.1.** The maximum cross-sectional velocity is 1.67 m/s.

Table: 6.8.1: Velocity along different cross-sections of river model in test T8

Sl. No.	C/S No.	C/S Velocity (m/s) in test T8									
		Distance from Right Bank (m)									
		0	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**
1	**C/S-38**	0.00	1.32	1.38	1.32	1.38	1.26	0.39	0.68		
2	**C/S-39**	0.00	1.61	1.43	1.26	1.26	1.20	0.51	0.74		
3	**C/S-40**	0.00	1.09	1.32	1.32	1.26	1.14	1.03	0.80	0.68	
4	**C/S-42**	1.03	1.26	1.38	1.32	1.26	1.38	0.91	0.68		
5	**C/S-44**	1.32	1.49	1.55	1.55	1.49	1.67	1.09	1.14		
6	**C/S-46**	0.97	1.38	1.49	1.55	1.67	1.61	1.43	1.38		
7	**C/S-48**	0.00	0.91	1.26	1.38	1.32	1.14	1.38			
8	**C/S-50**	0.68	1.14	1.43	1.32	1.32	1.43	1.09			
9	**C/S-52**	0.00	1.14	1.09	1.32	1.38	1.26	0.97	0.68		
10	**C/S-53**	0.00	1.03	1.26	1.09	0.97	1.03	0.80			
11	**C/S-54**	0.00	1.03	1.32	1.20	1.03	0.80	0.56			
12	**C/S-55**	0.00	1.14	1.38	1.14	1.03	0.80	0.68			
13	**C/S-56**	0.00	0.00	1.43	1.26	1.09	0.97	0.80			
14	**C/S-57**	0.00	0.00	1.26	1.26	1.14	1.09	0.97			
15	**C/S-58**	0.00	1.26	1.20	1.26	1.09	0.91	0.91			
16	**C/S-60**	0.00	1.14	1.26	1.26	1.09	1.09	0.97			
17	**C/S-62**	0.00	0.91	1.20	1.14	1.14	1.03	0.97	0.80		
18	**C/S-64**	0.00	0.97	1.14	1.03	1.09	1.03	1.03	0.85		
19	**C/S-66**	0.00	0.91	1.26	1.38	1.32	1.20	1.14	1.03		

Velocity is also measured at the top of concrete block mats (CBM) @ 7.5m interval along the right bank from upstream to downstream as shown in **Table 6.8.2**. From this table it is seen that maximum velocity is 0.97 m/s.

Table: 6.8.2: Velocity around the top of CBM along right bank u/s to d/s in test T8

Sl. No.	Dist. from start of CBM (m) from u/s	Velocity (m/s)
1	0.0	0.39
2	7.5	0.51
3	15.0	0.62
4	22.5	0.62
5	30.0	0.68
6	37.5	0.68
7	45.0	0.39
8	52.5	0.51
9	60.0	0.39
10	67.5	0.33
11	75.0	0.51
12	82.5	0.62
13	90.0	0.74
14	97.5	0.97
15	105.0	0.91
16	112.5	0.00
17	120.0	0.00
18	127.5	0.00
19	135.0	-0.08
20	142.5	-0.02
21	150.0	-0.25
22	157.5	-0.02
23	165.0	0.04
24	172.5	0.00
25	180.0	0.00

Observation

- For the lower bank protection using CBM technique, some CC block columns including filter materials of CBM have been detached from the start & middle portion of it.
- As a result lower bank is exposed and additional block mats have been used to prevent.
- Flow hits the right bank upstream & downstream of CBM protection causing bank erosion occurs at these regions.

Some photos of test (T8) for CBM model can be seen in **Photo 6.8.1-6.8.3.**

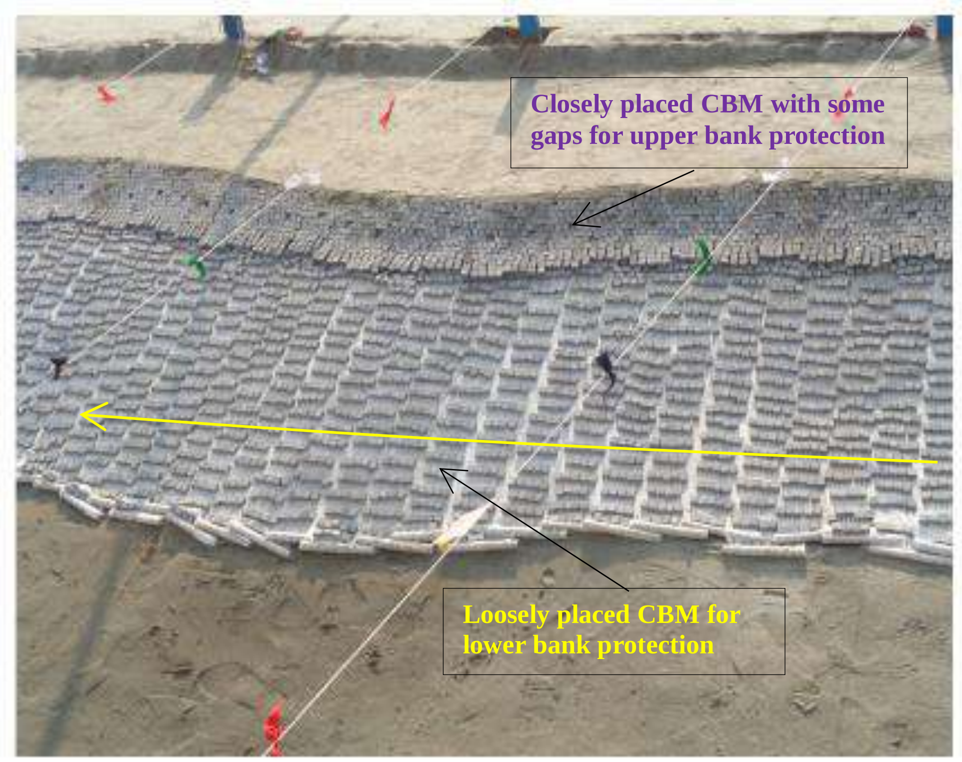


Photo 6.8.1: Placement of CC blocks in the CBM to protect river bank erosion before test run (T8)

Photo 6.8.2: Mode is under running condition (T8) with CBM

Photo 6.8.3: Model bed after test run (T8) with CBM

6.9 Test T9

This test is conducted with the same design as in test T8 but using medium flow. Here lower bank protection work is done applying loosely placed concrete block mats on filter and upper bank protection work is done applying closely placed concrete block mats with some gaps on filter using medium flow. Here the gaps in the upper bank protection on filter are filled with small grasses.

The sectional discharge ($Q_{sectional}$) corresponding to medium water level is 1381 cumec. The model bed is prepared according to the bathymetric survey of March 2017. Scour discharge is run until equilibrium condition is reached and Froudian discharge is run for 12 hrs. The design details of proposed concrete block mats (CBM) are as follows:

- River bank level: 3.0mPWD
- Medium water level: 1.23mPWD
- Block type: Holed concrete block
- Block size used in the model: 13.33mmX13.33mmX3.33mm (40cmX40cmX10cm in proto)
- Length of river reach to be protected: 5.6 m (168 m in proto)
- Length of upper bank protection: 0.22 m (6.6 m in proto)
- Length of lower bank protection: 1m (30 m in proto)
- Length of RCC pipe: 7 inch (210 inch in proto)
- Diameter of RCC pipe: 0.5 inch (15 inch in proto)
- Width of filter: 7 inch (210 inch in proto) [4 inch (120 inch in proto) + 4 inch (120 inch in proto)], overlapping 1.0 inch (30 inch in proto)
- Nos. of blocks on each 3.5 inch (105 inch in proto) wide overlapped filter in lower bank: 20+20+20+20+10=90 (4 column blocks, each column containing 20 blocks & additional 10 blocks at 10 alternate rows of each strip). In each strip, the top 3 rows of blocks are placed with no gaps, other 17 rows of blocks are placed with some gaps
- Length of u/s termination 0.75 m (22.5 m in proto) & d/s termination 0.50 m (15 m in proto)

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 6.9.1** It is seen that flow lines are close to the right bank and passing through the different cross-sections of the river reproduced in the model. Flow hits at the start and middle portion of the CBM protection which causes detachment of protection.

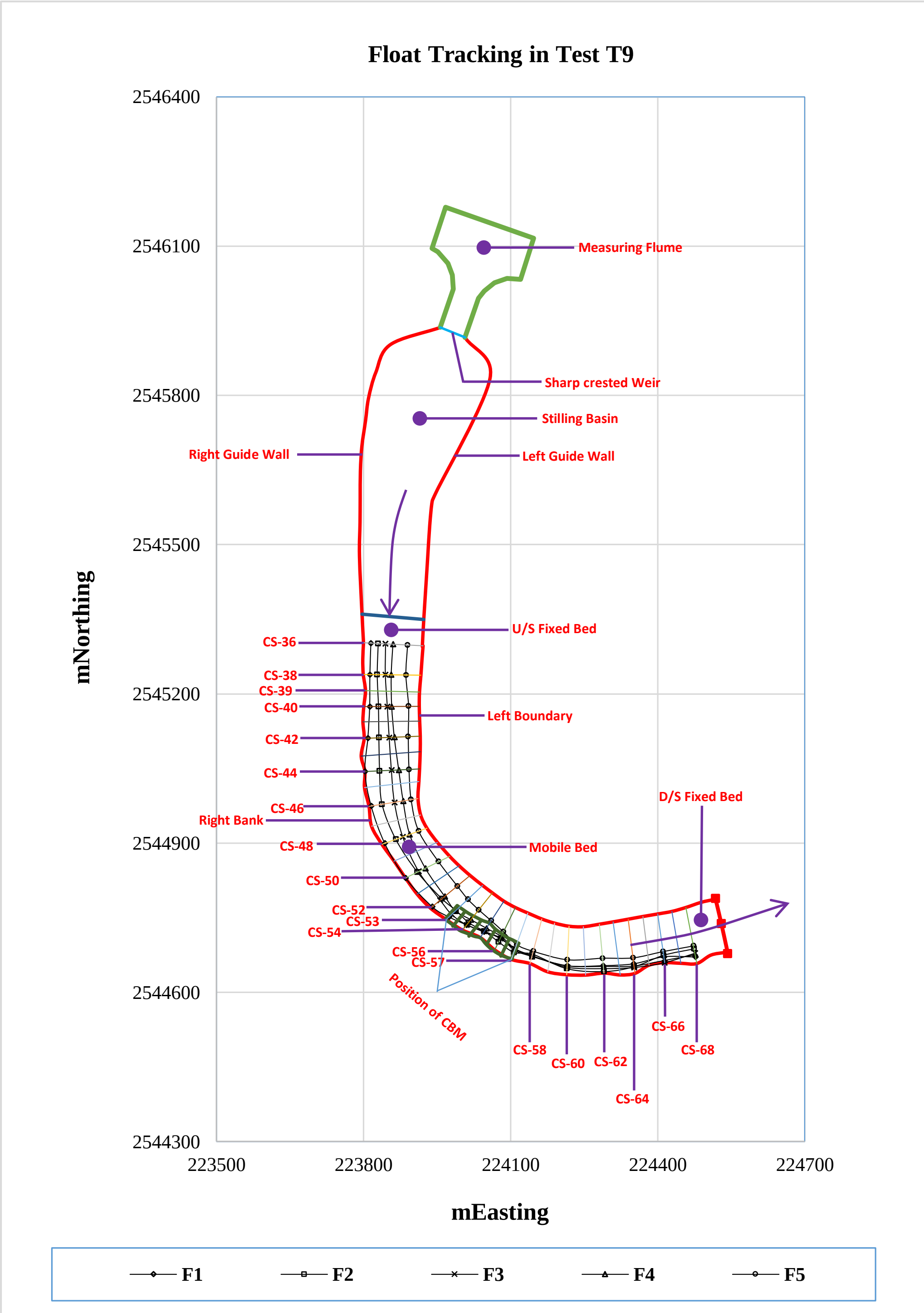


Figure 6.9.1: Flow lines recorded in test T9

Velocity Measurement

The average velocities measured in this test along different cross-sections of the river reproduced in the model are shown in **Table 6.9.1.** The maximum cross-sectional velocity is 3.12 m/s.

Table: 6.9.1: Velocity along different cross-sections of river model in test T9

Sl. No.	C/S No.	C/S Velocity (m/s) in test T9									
		Distance from Right Bank (m)									
		0	15	30	45	60	75	90	105	120	135
1	**C/S-36**	2.94	2.48	2.19	2.60	2.94	0.85	1.72	2.07		
2	**C/S-38**	0.00	2.65	2.25	2.36	2.65	2.01	0.68	1.49		
3	**C/S-39**	0.00	3.12	2.48	2.36	2.60	1.96	1.14	1.49		
4	**C/S-40**	2.13	2.71	2.30	2.25	2.48	1.96	1.26	1.72		
5	**C/S-42**	2.30	2.54	2.54	2.36	2.77	2.60	1.78	1.67		
6	**C/S-44**	2.25	2.77	2.60	2.60	3.00	2.77	2.30	1.96		
7	**C/S-46**	2.01	2.48	2.60	2.42	2.89	2.89	2.65			
8	**C/S-48**	0.00	1.55	2.19	2.30	2.48	2.19	1.78			
9	**C/S-50**	1.61	2.42	2.54	2.25	2.30	2.42	1.49			
10	**C/S-52**	0.00	2.01	2.60	2.48	2.19	1.67	1.26	1.03		
11	**C/S-53**	0.00	2.30	2.48	2.25	1.90	1.49	1.09			
12	**C/S-54**	0.00	1.61	2.30	2.13	1.84	1.67	1.03			
13	**C/S-55**	0.00	2.94	2.48	1.96	1.49	1.26	1.14			
14	**C/S-56**	0.00	0.33	2.60	2.07	1.72	1.43	1.20			
15	**C/S-57**	0.00	0.97	2.54	2.19	1.96	1.72	1.43			
16	**C/S-58**	0.80	2.54	2.13	2.42	1.78	1.67	1.49			
17	**C/S-60**	1.49	2.36	2.36	2.30	1.90	2.01	1.84			
18	**C/S-62**	1.72	2.36	2.30	2.01	1.90	1.67	1.49			
19	**C/S-64**	1.09	2.19	2.25	2.07	2.01	1.84	1.67	1.38		
20	**C/S-66**	1.96	2.36	2.42	2.30	2.13	1.96	1.67			

Velocity is also measured at the top of concrete block mats (CBM) @ 7.5m interval along the right bank from upstream to downstream as shown in **Table 6.9.2**. From this table it is seen that maximum velocity is 2.36 m/s.

Table: 6.9.2: Velocity around the top of CBM along right bank u/s to d/s in test T9

Sl. No.	Dist. from start of CBM (m) from u/s	Velocity (m/s)
1	0.0	1.43
2	7.5	1.49
3	15.0	1.67
4	22.5	1.96
5	30.0	2.01
6	37.5	1.67
7	45.0	1.38
8	52.5	1.26
9	60.0	1.26
10	67.5	1.20
11	75.0	1.32
12	82.5	1.49
13	90.0	2.01
14	97.5	2.25
15	105.0	2.36
16	112.5	0.00
17	120.0	0.00
18	127.5	-0.31
19	135.0	-0.42
20	142.5	-0.66
21	150.0	-0.54
22	157.5	-0.60
23	165.0	-0.37
24	172.5	-0.08
25	180.0	0.00

Observation

- For the protection of the lower bank using CBM technique, some portion of CBM protection work have been detached from the start & middle portion and therefore lower bank is bared.
- To stop this, additional block mats have been placed over it**.**
- Flow attacks the bank at upstream & downstream of CBM protection causing severe bank erosion occurs at these regions.

Some photos of test (T9) for CBM model can be seen in **Photo 6.9.1-6.9.3.**

Photo 6.9.1: Model is under running condition (T9) with CBM

Photo 6.9.2: CBM after test run (T9) in the model

Photo 6.9.3: Model bed after test run (T9) with CBM

6.10 Test T10

This test is conducted with the same design as in test T8 but using high flow. The lower bank protection work is done applying loosely placed concrete block mats on filter and upper bank protection work is done applying closely placed concrete block mats with some gaps on filter using high flow. Here the gaps in the upper bank protection on filter are filled with small grasses.

The sectional discharge ($Q_{sectional}$) corresponding to high water level is 1967 cumec. The model bed is prepared according to the bathymetric survey of March 2017. Scour discharge is run until equilibrium condition is reached and Froudian discharge is run for 12 hrs. The design details of proposed concrete block mats (CBM) are as follows:

- River bank level: 3.0mPWD
- High water level: 2.93mPWD
- Block type: Holed concrete block
- Block size used in the model: 13.33mmX13.33mmX3.33mm (40cmX40cmX10cm in proto)
- Length of river reach to be protected: 5.6 m (168 m in proto)
- Length of upper bank protection: 0.22 m (6.6 m in proto)
- Length of lower bank protection: 1m (30 m in proto)
- Length of RCC pipe: 7 inch (210 inch in proto)
- Diameter of RCC pipe: 0.5 inch (15 inch in proto)
- Width of filter: 7 inch (210 inch in proto) [4 inch (120 inch in proto) + 4 inch (120 inch in proto)], overlapping 1.0 inch (30 inch in proto)
- Nos. of blocks on each 3.5 inch (105 inch in proto) wide overlapped filter in lower bank: 20+20+20+20+10=90 (4 column blocks, each column containing 20 blocks & additional 10 blocks at 10 alternate rows of each strip). In each strip, the top 3 rows of blocks are placed with no gaps, other 17 rows of blocks are placed with some gaps
- Length of u/s termination 0.75 m (22.5 m in proto) & d/s termination 0.50 m (15 m in proto)

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 6.10.1** It is seen that flow lines are close to the right bank and passing through the different cross-sections of the river reproduced in the model. Flow hits the CBM protection work at its start & middle portion causing detachment of protection from the river bank.

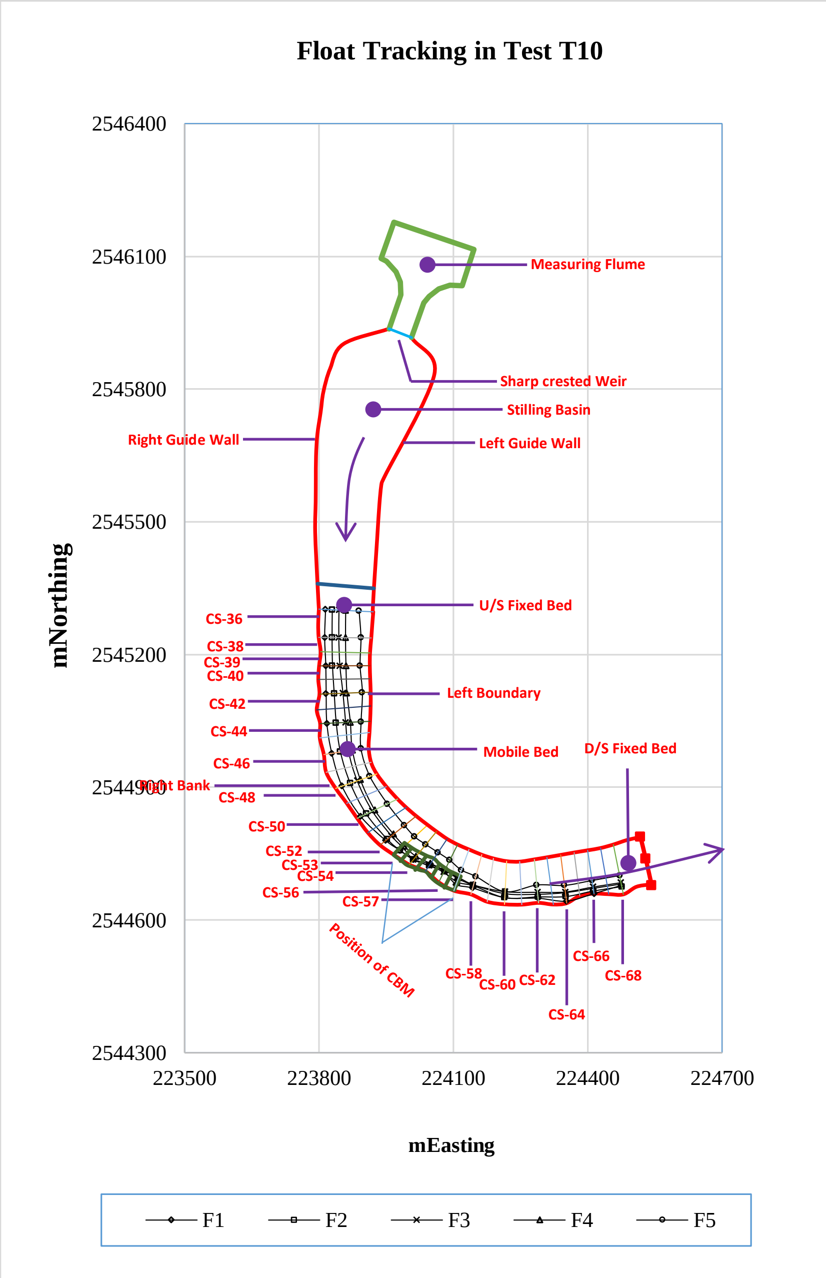


Figure 6.10.1: Flow lines recorded in test T10

Velocity Measurement

The average velocities measured in this test along different cross-sections of the river reproduced in the model are shown in **Table 6.10.1.** The maximum cross-sectional velocity is 3.64 m/s.

Table: 6.10.1: Velocity along different cross-sections of river model in test T10

Sl. No.	C/S No.	C/S Velocity (m/s) in test T0									
		Distance from Right Bank (m)									
		0	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**
1	**C/S-36**	0.00	3.41	2.94	2.77	2.54	3.29	3.23	1.49	2.71	
2	**C/S-38**	0.00	3.00	2.71	3.00	3.18	2.48	1.03	1.96		
3	**C/S-39**	0.00	3.52	2.94	2.77	3.00	2.54	1.38	2.01		
4	**C/S-40**	2.71	3.00	2.65	2.25	2.94	2.25	1.61	2.07		
5	**C/S-42**	2.94	3.06	2.89	2.94	2.94	2.77	2.19	1.78		
6	**C/S-44**	2.89	3.12	3.35	3.47	3.35	3.41	2.60	2.54		
7	**C/S-46**	2.83	3.06	3.23	3.23	3.41	3.41	3.23			
8	**C/S-48**	0.74	2.65	2.89	3.06	3.18	3.00	2.07			
9	**C/S-50**	2.48	3.00	2.83	2.83	2.89	2.83	1.72			
10	**C/S-52**	1.72	2.94	3.18	3.18	2.89	2.13	1.90			
11	**C/S-53**	0.00	2.94	3.00	2.77	2.42	1.67	1.67			
12	**C/S-54**	0.00	2.89	3.00	2.77	2.25	1.78	1.38			
13	**C/S-55**	0.00	3.64	3.23	2.77	2.25	1.84	1.43			
14	**C/S-56**	0.00	0.45	3.41	2.71	2.25	1.96	1.67			
15	**C/S-57**	0.00	1.55	3.00	2.36	2.36	2.07	1.67			
16	**C/S-58**	1.67	2.89	2.65	2.42	2.48	2.13	2.01			
17	**C/S-60**	1.96	2.77	2.77	2.65	2.48	2.48	2.13			
18	**C/S-62**	2.60	2.83	2.71	2.48	2.36	2.25	1.78			
19	**C/S-64**	2.13	2.83	2.83	2.71	2.48	2.30	2.25	1.78		
20	**C/S-66**	2.60	2.60	2.83	2.83	2.65	2.42	2.19			

Velocity is also measured at the top of concrete block mats (CBM) @ 7.5m interval along the right bank from upstream to downstream as shown in **Table 6.10.2**. From this table it is seen that maximum velocity is 2.89 m/s.

Table: 6.10.2: Velocity around the top of CBM along right bank u/s to d/s in test T10

Sl. No.	Dist. from start of CBM (m) from u/s	Velocity (m/s)
1	0.0	2.54
2	7.5	2.83
3	15.0	2.77
4	22.5	2.65
5	30.0	2.65
6	37.5	0.62
7	45.0	1.03
8	52.5	1.43
9	60.0	1.20
10	67.5	0.97
11	75.0	1.38
12	82.5	1.67
13	90.0	2.42
14	97.5	2.48
15	105.0	2.89
16	112.5	0.33
17	120.0	-0.19
18	127.5	-0.25
19	135.0	-0.60
20	142.5	-0.54
21	150.0	-0.60
22	157.5	-0.71
23	165.0	-0.13
24	172.5	-0.02
25	180.0	0.00

Scour Measurement

Scour was measured around the protective structure (CBM). Maximum local scour around CBM structure is 7.29m (-14.89mPWD) which is 30.00 m away from R/B along C/S-55 in test run T10.

The development of maximum scour with time at C/S-55 in test T10 is shown in **Figure 6.10.2**. It is seen from the figure that it takes around 13-15 hours to reach dynamic equilibrium condition for maximum scour development at C/S-55. The variation of bed level with time to reach the maximum scour is shown in **Figure 6.10.3.** Non-dimensional plot is shown in **Figure 6.10.4.**

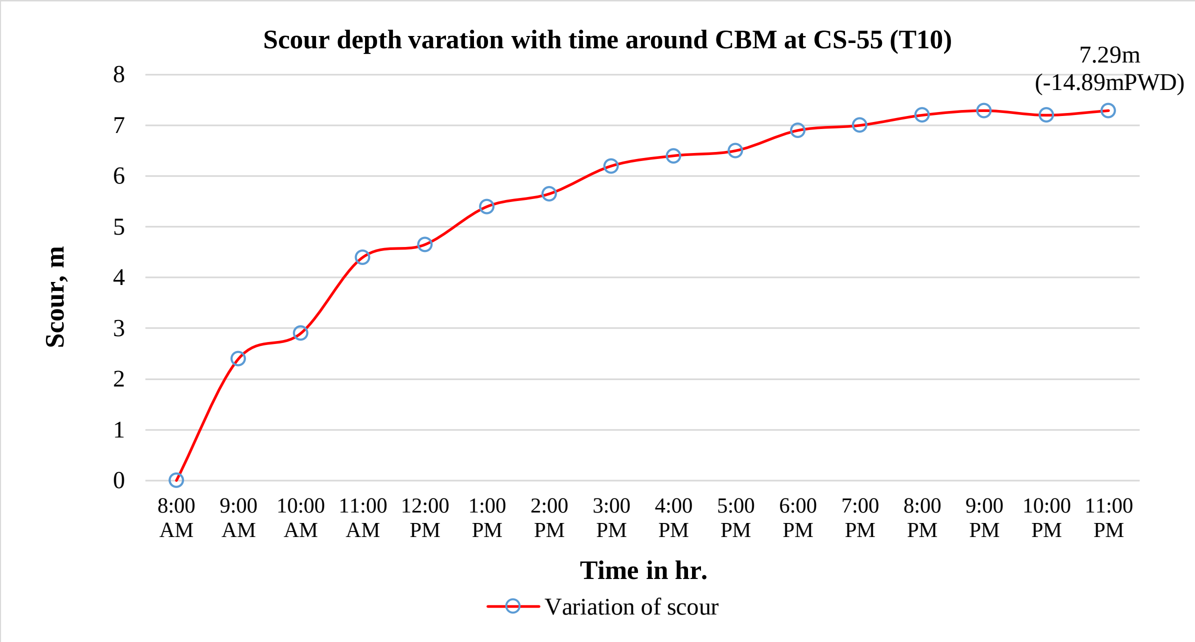


Figure 6.10.2: Development of maximum scour with time around CBM (T10)

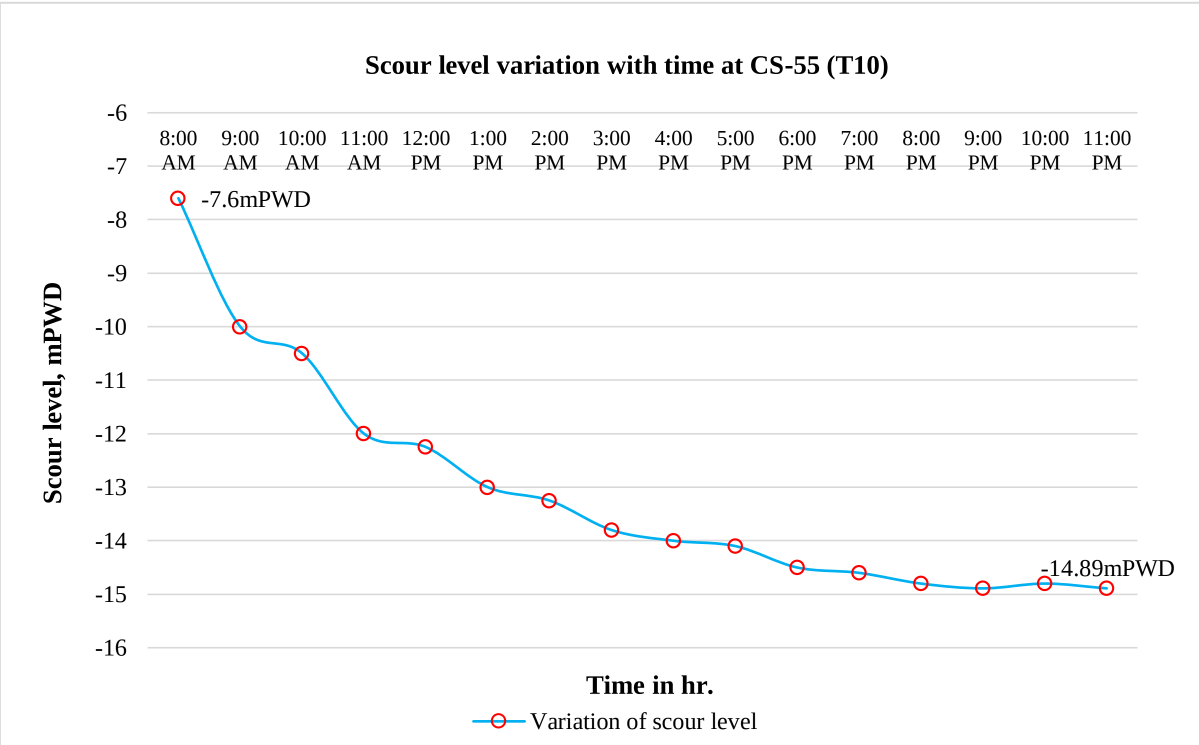


Figure 6.10.3: Variation of bed level with time to reach the maximum scour around CBM (T10)

Non-dimensional plot in log paper (hs /h0) vs. (t/t1) for maximum scour at C/S-55 is as follows. Here hs= scour depth, h0 = initial average water depth, t = time in hours required for scour development and t1= equivalent time defined as the time at which hs= h0.

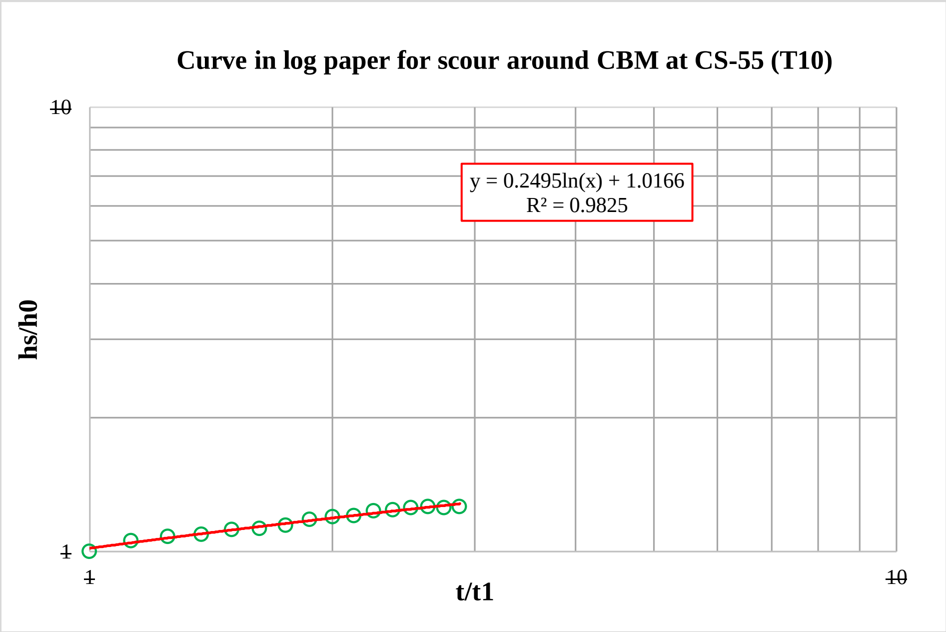
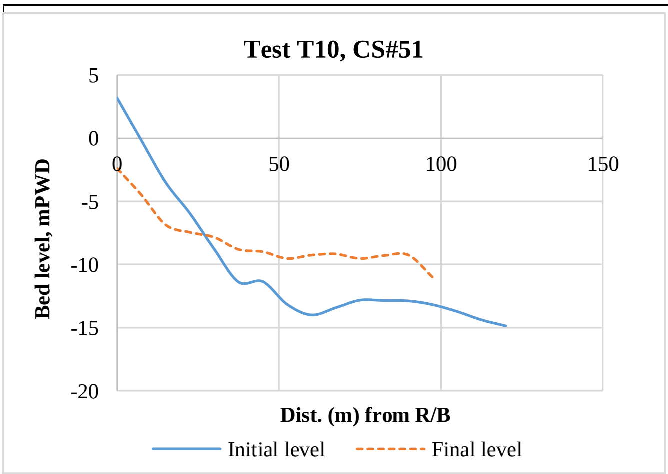
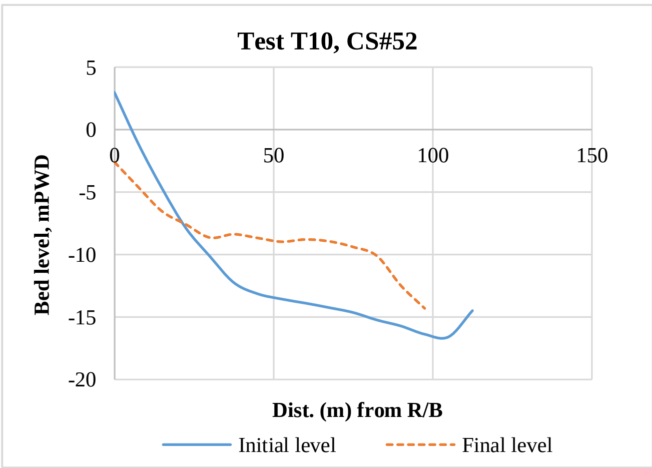


Figure 6.10.4: Non-dimensional plot of (hs /h0) vs. (t/t1) in log paper for scour around CBM (T10)

Bed Level

The bed level before and after test run was measured for each cross-section within the model boundary using levelling staff. Thus the initial & final bed level have been obtained and these are superimposed to have an idea about scour or deposition. Some of the superimposed cross-sections through and around the protective structure (C/S51-C/S58) are shown below.





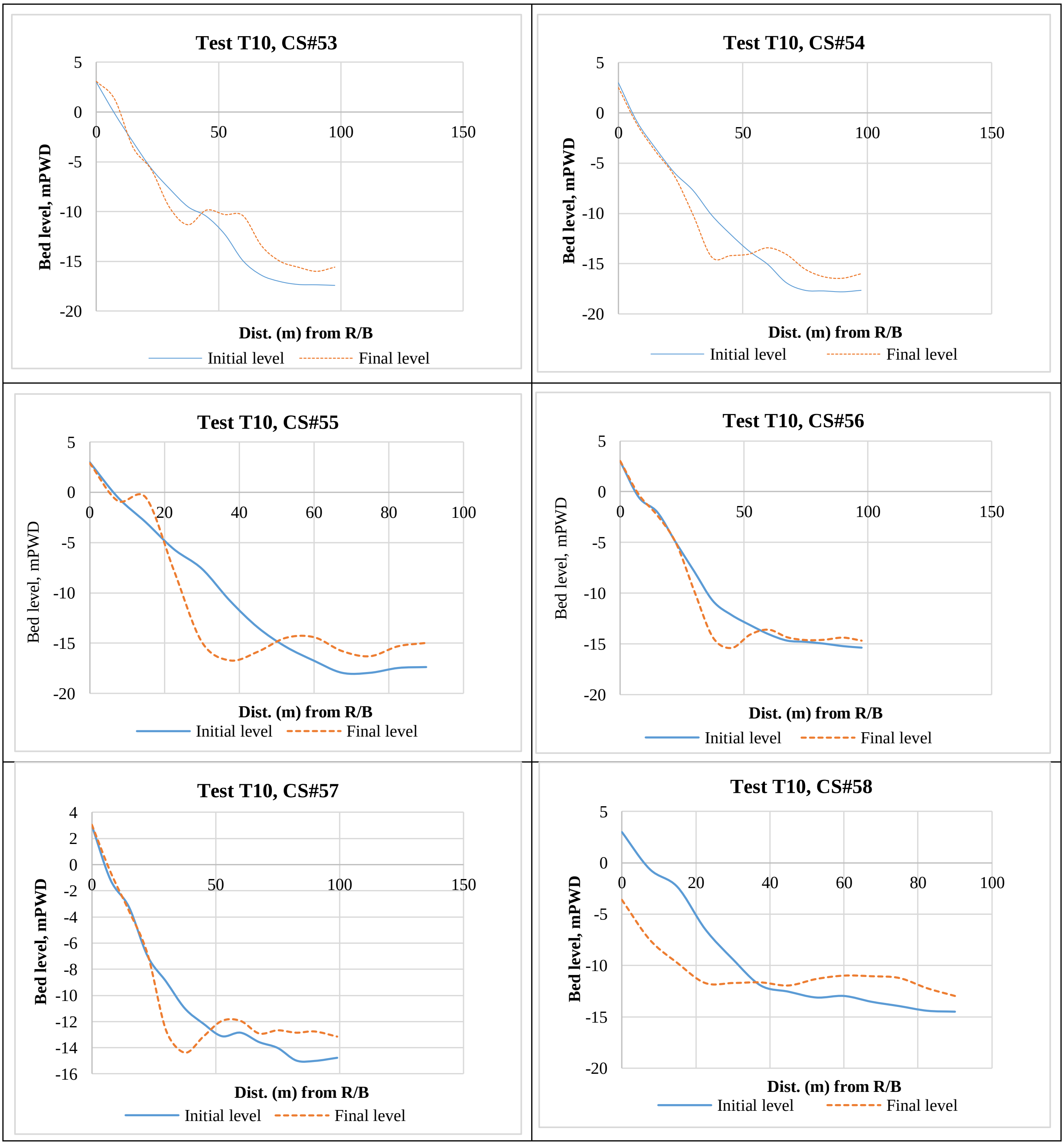


Figure 6.10.5: Superimposed initial and final bed level for C/S51-C/S58 in test T10 of CBM model

Bank Erosion

The tentative river bank erosion after the application test T10 is measured along the right bank of Arial Khan river and is shown in **Table 6.10.3.** It is seen from the table that maximum bank erosion is 28.5 m at C/S-44.

Table 6.10.3: Tentative bank erosion after the application test T10

Sl. No.	C/S No.	Tentative bank erosion, m in test T10
1	**C/S-41**	13.5
2	**C/S-42**	21.0
3	**C/S-43**	19.5
4	**C/S-44**	28.5
5	**C/S-45**	21.0
6	**C/S-46**	19.5
7	**C/S-47**	10.5
8	**C/S-48**	12.0
9	**C/S-49**	12.0
10	**C/S-50**	13.8
11	**C/S-51**	12.0
12	**C/S-52**	8.1
13	**C/S-53**	0.0
14	**C/S-54**	0.0
15	**C/S-55**	0.0
16	**C/S-56**	0.0
17	**C/S-57**	0.0
18	**C/S-58**	0.0
19	**C/S-59**	9.6
20	**C/S-60**	13.2
21	**C/S-61**	13.2
22	**C/S-62**	17.4
23	**C/S-63**	10.8
24	**C/S-64**	9.3
25	**C/S-65**	19.8
26	**C/S-66**	18.0

Observation

- For lower bank protection by CBM, some portion of CBM have been detached from the start & middle portion of protection work & therefore the lower bank is exposed.
- To prevent it, extra block mats have been placed over it.

Some photos of test (T9) for CBM model can be seen in **Photo 6.10.1-6.10.3.**

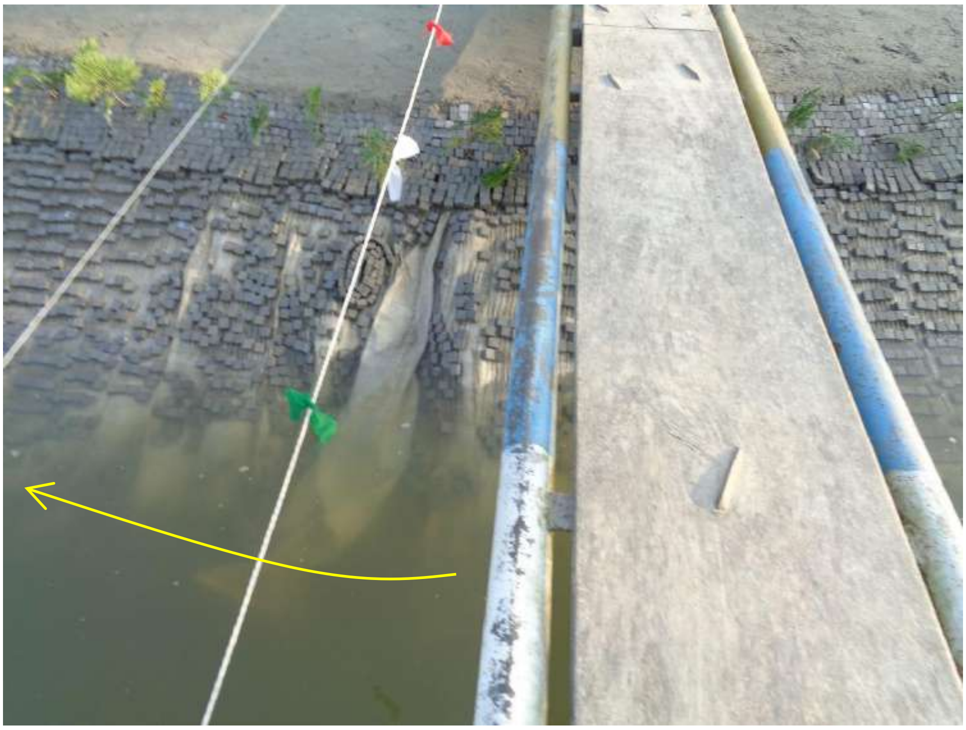


Photo 6.10.1: Detachment of filter during running model (T10) with CBM

Photo 6.10.2: CBM after test run (T10) in the model

Photo 6.10.3: Model bed after test run (T10) with CBM

6.11 Test T11

This test is conducted with different design supplied by Senior Design Engineer of MHS using low flow. The lower bank protection work is done applying loosely placed concrete block mats on filter and upper bank protection work is done applying closely placed concrete block mats with some gaps on filter using low flow. Here the gaps in the upper bank protection on filter are filled with small grasses. Here the successive 12 inch (360 inch in proto) wide filters are overlapped by 50%. Moreover, termination provided at the u/s & d/s end of CBM is kept same as that in test T5/T8.

The sectional discharge ($Q_{sectional}$) corresponding to low water level is 808 cumec. The model bed is prepared according to the bathymetric survey of March 2017. Scour discharge is run until equilibrium condition is reached and Froudian discharge is run for 12 hrs. The design details of proposed concrete block mats (CBM) are as follows:

- River bank level: 3.0mPWD
- Low water level: 0.24mPWD
- Block type: Holed concrete block
- Block size used in the model: 13.33mmX13.33mmX3.33mm (40cmX40cmX10cm in proto)
- Length of river reach to be protected: 5.6 m (168 m in proto)
- Length of upper bank protection: 0.22 m (6.6 m in proto)
- Length of lower bank protection: 1.42 m (42.6 m in proto)
- Length of RCC pipe: 12 inch (360 inch in proto)
- Diameter of RCC pipe: 0.5 inch (15 inch in proto)
- Width of filter: 12 inch (360 inch in proto)
- Nos. of blocks on each 6 inch (180 inch in proto) wide overlapped filter: 70X4=280 (4 column blocks, each column containing 70 blocks). Here 1 layer of CC blocks is placed over 2 layers of filter.
- Length of u/s termination 0.75 m (22.5 m in proto) & d/s termination 0.50 m (15 m in proto)

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 6.11.1** It is seen that flow lines are close to the right bank and passing through the different cross-sections of the river reproduced in the model. Flow hits the river bank causing detachment of some CBM protection work occurs.

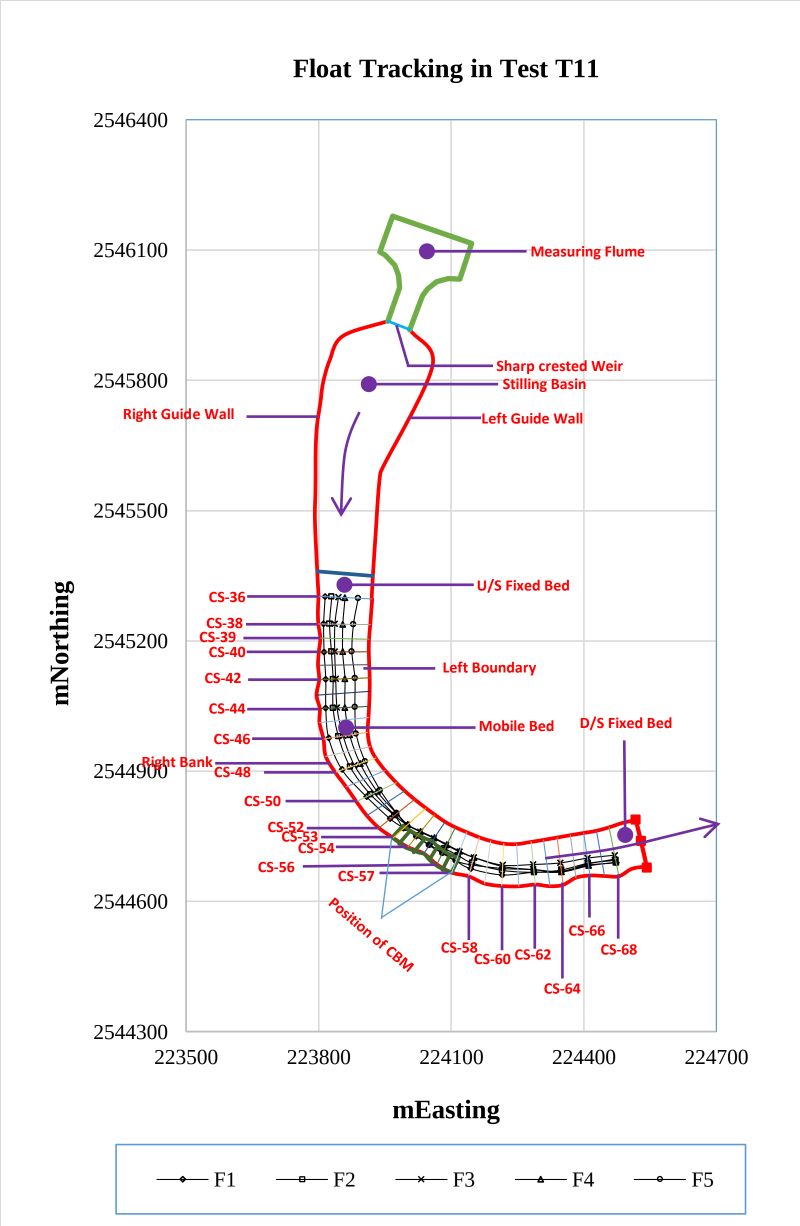


Figure 6.11.1: Flow lines recorded in test T11

Velocity Measurement

The average velocities measured in this test along different cross-sections of the river reproduced in the model are shown in **Table 6.11.1.** The maximum cross-sectional velocity is 1.49 m/s.

Table: 6.11.1: Velocity along different cross-sections of river model in test T11

Sl. No.	C/S No.	C/S Velocity (m/s) in test T11									
		Distance from Right Bank (m)									
		0	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**
1	**C/S-36**	0.00	1.43	1.43	1.26	1.32	1.49	0.68	0.85		
2	**C/S-38**	0.00	1.38	1.20	0.97	1.14	0.91	0.74	0.00	0.00	
3	**C/S-39**	0.00	1.26	1.20	0.91	1.14	0.85	0.56			
4	**C/S-40**	0.00	1.09	1.03	0.91	1.03	0.62	0.27	0.00		
5	**C/S-42**	0.00	1.09	1.14	0.97	1.14	1.09	0.62	0.00		
6	**C/S-44**	0.00	0.74	0.97	0.80	0.97	0.97	0.56	0.45		
7	**C/S-46**	0.00	0.62	0.91	0.80	0.91	0.91	0.39			
8	**C/S-48**	0.00	0.62	0.91	0.80	0.85	0.74	0.56	0.00		
9	**C/S-50**	0.00	0.00	1.03	1.03	1.03	0.85	0.68			
10	**C/S-52**	0.00	0.00	0.62	0.97	0.85	0.62	0.45			
11	**C/S-53**	0.00	0.00	0.74	0.85	0.97	0.56	0.51			
12	**C/S-54**	0.00	0.00	0.56	0.80	0.68	0.51	0.51			
13	**C/S-55**	0.00	0.68	0.97	0.97	0.68	0.56	0.45			
14	**C/S-56**	0.00	0.00	0.80	0.85	0.80	0.68	0.56			
15	**C/S-57**	0.00	0.00	0.91	0.85	0.62	0.56	0.56			
16	**C/S-58**	0.00	0.45	0.85	0.80	0.68	0.56	0.68			
17	**C/S-60**	0.00	0.00	0.68	0.74	0.74	0.68	0.74			
18	**C/S-62**	0.00	0.68	0.91	0.91	0.74	0.74	0.56			
19	**C/S-64**	0.00	0.45	0.74	0.80	0.74	0.56	0.74	0.56		
20	**C/S-66**	0.00	0.80	1.03	0.85	0.85	0.74	0.68			

Velocity is also measured at the top of concrete block mats (CBM) @ 7.5m interval along the right bank from upstream to downstream as shown in **Table 6.10.2**. From this table it is seen that maximum velocity is 0.80 m/s.

Table: 6.11.2: Velocity around the top of CBM along right bank u/s to d/s in test T11

Sl. No.	Dist. from start of CBM (m) from u/s	Velocity (m/s)
1	0.0	0.00
2	7.5	0.00
3	15.0	0.33
4	22.5	0.39
5	30.0	0.33
6	37.5	0.45
7	45.0	0.62
8	52.5	0.56
9	60.0	0.45
10	67.5	0.56
11	75.0	0.62
12	82.5	0.80
13	90.0	0.33
14	97.5	0.00
15	105.0	0.00
16	112.5	0.00
17	120.0	0.00
18	127.5	0.00
19	135.0	0.00
20	142.5	0.00
21	150.0	0.00
22	157.5	0.00
23	0.0	0.00
24	7.5	0.00
25	15.0	0.33

Observation

- For the lower bank protection by CBM, some concrete block columns including filter materials of CBM have been detached due to high velocity of flow. As a result some portion of lower bank is exposed**.**

- To prevent it, extra block mats have been placed over it.

Some photos in this test can be as seen in **Photo 6.11.1-6.11.3.**

Photo 6.11.1: Placement of CC blocks under water in the model (T11)

Photo 6.11.2: Exposure of filter due to velocity of flow in the model (T11)

6.12 Test T12

This test is conducted with final design supplied by Senior Design Engineer of MHS using low flow. The lower bank protection work is done applying loosely placed concrete block mats on filter and upper bank protection work is done applying closely placed concrete block mats with some gaps on filter using low flow. Here the gaps in the upper bank protection on filter have been provided for plantation.

The sectional discharge ($Q_{sectional}$) corresponding to low water level is 808 cumec. The model bed is prepared according to the bathymetric survey of March 2017. Scour discharge is run until equilibrium condition is reached and Froudian discharge is run for 12 hrs. The design details of proposed concrete block mats (CBM) are as follows:

- River bank level: 3.0mPWD
- Low water level: 0.24mPWD
- Block type: Holed concrete block
- Block size used in the model: 13.33mmX13.33mmX3.33mm (40cmX40cmX10cm in proto)
- Length of river reach to be protected: 5.6m (168m in proto)
- Length of upper bank protection: 0.22m (6.6m in proto)
- Length of lower bank protection: 1.15m (34.5m in proto)
- Length of RCC pipe: 12 inch (360 inch in proto)
- Diameter of RCC pipe: 0.5 inch (15 inch in proto)
- Width of filter: 12 inch (360 inch in proto)
- Total nos. of CC blocks in each 12 inch (360 inch in proto) wide strip at top & bottom layer in lower bank: 58x5+58x5=580
- Here each 12 inch (360 inch in proto) wide strip contains 5 column of CC blocks at the top layer & 5 column of CC blocks at the bottom layer. Each column containing 58 blocks. These strips are overlapped by 50 % over each other. The top 5 column of CC blocks have been placed over the spaces among CC block columns at the bottom layer. Here 2 layers of CC blocks & 2 layers of filter in each strip.
- Length of u/s termination 0.75 m (22.5 m in proto) & d/s termination 0.50 m (15 m in proto)

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 6.12.1** It is seen that flow lines are close to the right bank and passing through the different cross-sections of the river reproduced in the model. Flow attacks the right bank of river causing erosion at u/s & d/s of CBM protection work.

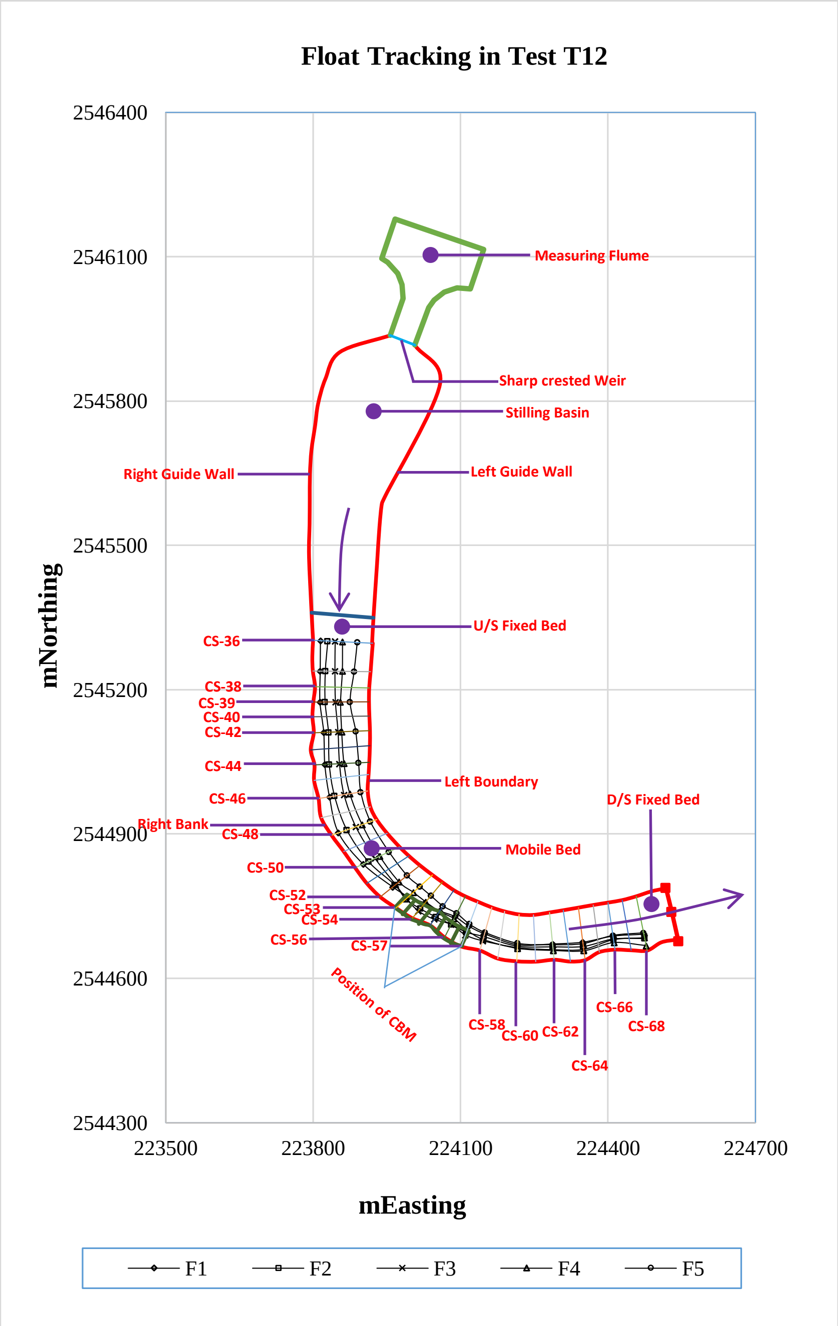


Figure 6.12.1: Flow lines recorded in test T12

Velocity Measurement

The average velocities measured in this test along different cross-sections of the river reproduced in the model are shown in **Table 6.12.1.** The maximum cross-sectional velocity is 1.49 m/s.

Table: 6.12.1: Velocity along different cross-sections of river model in test T12

Sl. No.	C/S No.	C/S Velocity (m/s) in test T12									
		Distance from Right Bank (m)									
		0	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**
1	**C/S-36**	0.00	1.43	1.38	1.20	1.20	**1.49**	0.56	0.85	0.00	
2	**C/S-38**	0.00	1.20	1.14	1.03	1.09	0.85	0.45	0.33		
3	**C/S-39**	0.00	1.20	1.14	1.03	1.03	0.85	0.45	0.45		
4	**C/S-40**	0.00	1.20	1.03	0.97	0.91	0.56	0.33	0.39		
5	**C/S-42**	0.00	1.20	1.14	1.03	0.97	0.97	0.68	0.45		
6	**C/S-44**	0.00	1.03	1.03	0.97	0.97	0.85	0.45	0.51		
7	**C/S-46**	0.00	0.74	0.91	0.74	0.85	0.80	0.56			
8	**C/S-48**	0.00	0.62	0.85	0.85	0.85	0.85	0.51			
9	**C/S-50**	0.00	1.14	1.03	1.03	0.91	0.74	0.62			
10	**C/S-52**	0.00	0.00	0.56	0.91	0.85	0.62	0.45			
11	**C/S-53**	0.00	0.39	0.51	0.97	0.85	0.68	0.39			
12	**C/S-54**	0.00	0.56	0.62	0.85	0.80	0.51	0.45			
13	**C/S-55**	0.00	0.68	1.03	0.97	0.74	0.62				
14	**C/S-56**	0.00	0.00	0.62	0.80	0.85	0.74	0.62			
15	**C/S-57**	0.00	0.00	0.56	0.85	0.80	0.62	0.62			
16	**C/S-58**	0.00	0.74	0.80	0.80	0.80	0.74	0.62			
17	**C/S-60**	0.00	0.33	0.80	0.80	0.74	0.74	0.85			
18	**C/S-62**	0.00	0.62	1.03	0.97	0.68	0.68	0.62			
19	**C/S-64**	0.00	0.51	0.80	0.74	0.80	0.80	0.80	0.51		
20	**C/S-66**	0.00	0.68	1.03	0.97	0.91	0.85	0.74			

Velocity is also measured at the top of concrete block mats (CBM) @ 7.5m interval along the right bank from upstream to downstream as shown in **Table 6.12.2**. From this table it is seen that maximum velocity is 0.91 m/s.

Table: 6.12.2: Velocity around the top of CBM along right bank u/s to d/s in test T12

Sl. No.	Dist. from start of CBM (m) from u/s	Velocity (m/s)
1	0.00	0.33
2	7.50	0.27
3	15.00	0.00
4	22.50	0.00
5	30.00	0.00
6	37.50	0.45
7	45.00	0.33
8	52.50	0.45
9	60.00	0.62
10	67.50	0.68
11	75.00	0.80
12	82.50	0.91
13	90.00	0.68
14	97.50	0.00
15	105.00	0.00
16	112.50	0.00
17	120.00	0.00
18	127.50	0.00
19	135.00	0.00
20	142.50	0.00
21	150.00	0.00
22	157.50	0.00
23	165.00	0.00

Observation

- For the lower bank protection by CBM, few CC block columns from top layer have been slightly detached (there is another bottom layer of CC block columns below it) under low flow but filter materials are still in position.

- The lower bank is not exposed and CBM works well because here protection consists of 2 layers of filter materials & 2 layers of CC block columns.

- RCC pipes have been moved no more in the downstream by flow velocity as its length has been increased.

Some photos of test (T12) for CBM model can be seen in **Photo 6.12.1-6.12.4.**

Photo 6.12.1: Placement of CC blocks during low flow in the model (T12)

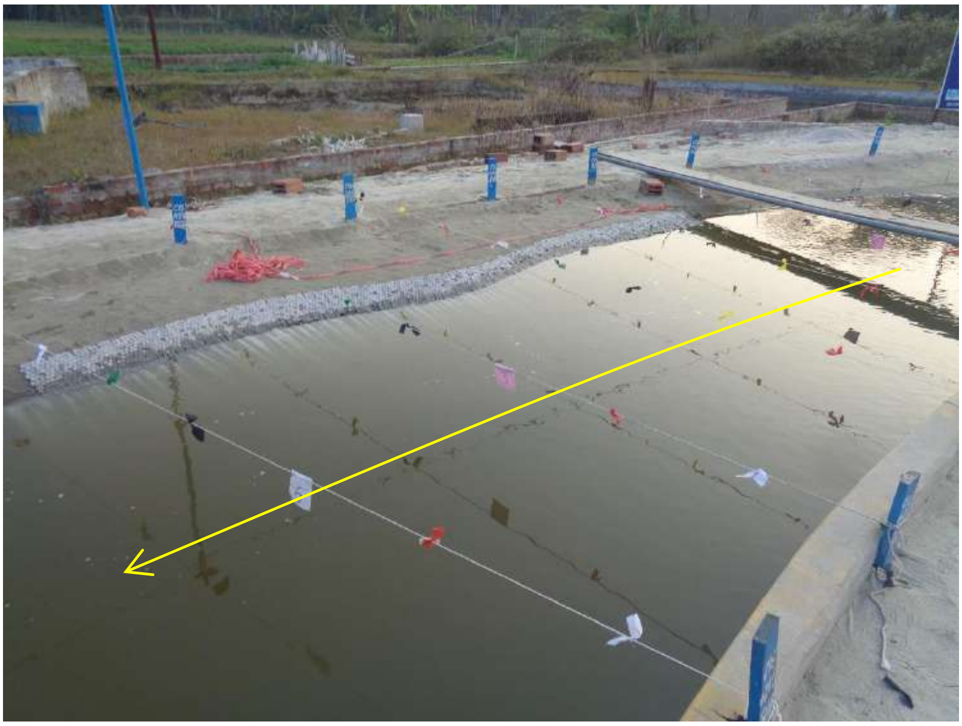


Photo 6.12.2: Model is under running condition (T12) with CBM

Photo 6.12.3: CBM after test run (T12) in the model

Photo 6.12.4: A view of the model bed after test run (T12) with CBM

6.13 Test T13

This test is conducted with the same design as in test T12 but using medium flow. The lower bank protection work is done applying loosely placed concrete block mats on filter and upper bank protection work is done applying closely placed concrete block mats with some gaps on filter using medium flow. Here the gaps in the upper bank protection on filter are filled with small grasses.

The sectional discharge ($Q_{sectional}$) corresponding to medium water level is 1381 cumec. The model bed is prepared according to the bathymetric survey of March 2017. Scour discharge is run until equilibrium condition is reached and Froudian discharge is run for 12 hrs. The design details of proposed concrete block mats (CBM) are as follows:

- River bank level: 3.0mPWD
- Medium water level: 1.23mPWD
- Block type: Holed concrete block
- Block size used in the model: 13.33mmX13.33mmX3.33mm (40cmX40cmX10cm in proto)
- Length of river reach to be protected: 5.6m (168m in proto)
- Length of upper bank protection: 0.22m (6.6m in proto)
- Length of lower bank protection: 1.15m (34.5m in proto)
- Length of RCC pipe: 12 inch (360 inch in proto)
- Diameter of RCC pipe: 0.5 inch (15 inch in proto)
- Width of filter: 12 inch (360 inch in proto)
- Total nos. of CC blocks in each 12 inch (360 inch in proto) wide strip at top & bottom layer in lower bank: 58x5+58x5=580
- Here each 12 inch (360 inch in proto) wide strip contains 5 column of CC blocks at the top layer & 5 column of CC blocks at the bottom layer. Each column containing 58 blocks. These strips are overlapped by 50 % over each other. The top 5 column of CC blocks have been placed over the spaces among CC block columns at the bottom layer. Here 2 layers of CC blocks & 2 layers of filter in each strip.
- Length of u/s termination 0.75 m (22.5 m in proto) & d/s termination 0.50 m (15 m in proto)

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 6.13.1** It is seen that flow lines are close to the right bank and passing through the different cross-sections of the river reproduced in the model. The right bank of river is attacked by the flow velocity causing severe erosion at u/s & d/s of CBM protection work.

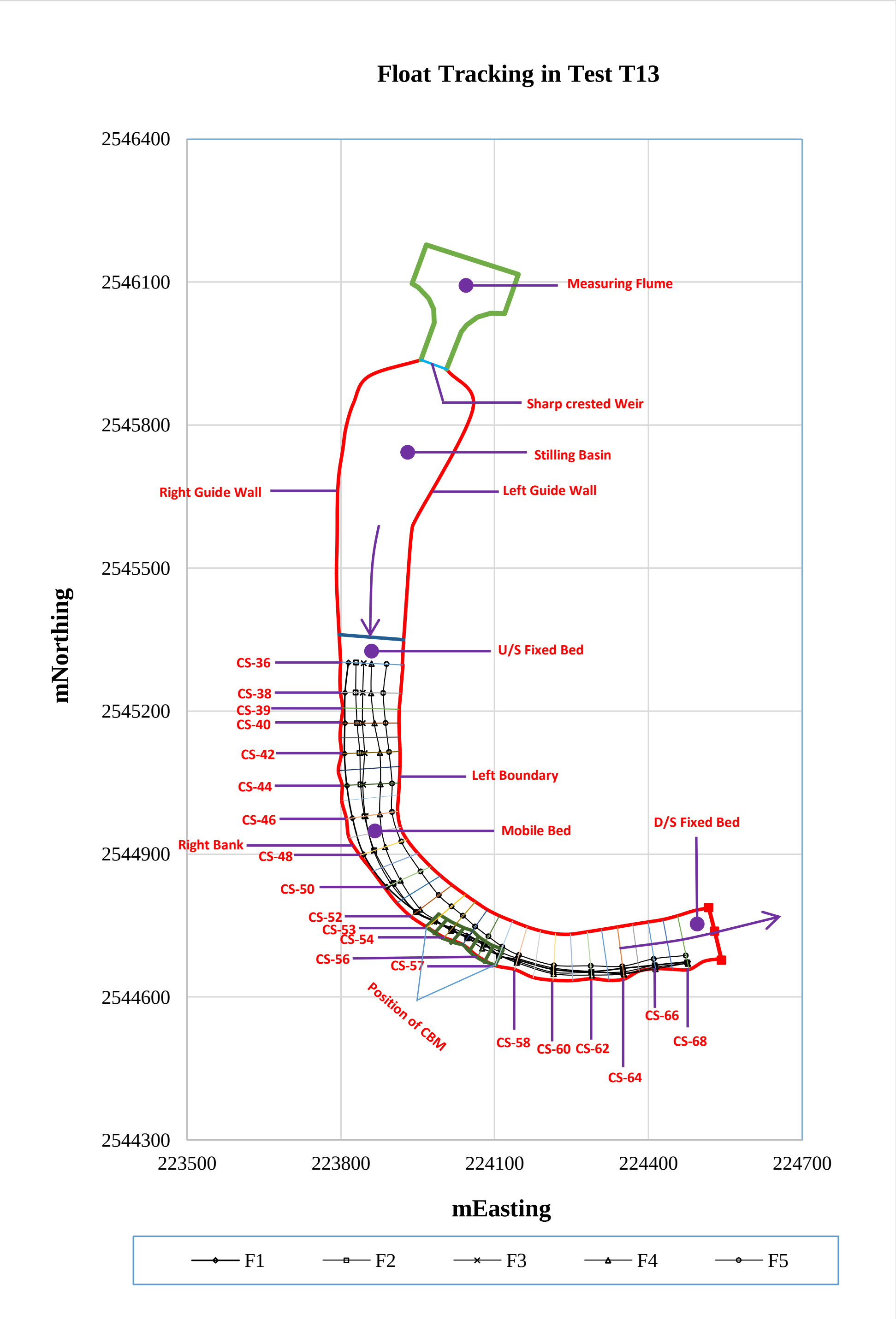


Figure 6.13.1: Flow lines recorded in test T13

Velocity Measurement

The average velocities measured in this test along different cross-sections of the river reproduced in the model are shown in **Table 6.13.1.** The maximum cross-sectional velocity is 2.54 m/s.

Table: 6.13.1: Velocity along different cross-sections of river model in test T13

Sl. No.	C/S No.	C/S Velocity (m/s) in test T13									
		Distance from Right Bank (m)									
		0	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**
1	**C/S-36**	0.00	**2.54**	2.01	1.84	2.13	2.30	1.09	1.55	2.30	
2	**C/S-38**	0.00	1.96	1.72	1.96	1.90	1.32	1.03	0.85		
3	**C/S-39**	0.00	2.01	1.20	1.90	1.84	1.38	0.97	1.03		
4	**C/S-40**	0.00	1.84	1.84	1.90	1.84	1.78	1.03	1.14		
5	**C/S-42**	1.55	2.01	2.30	2.01	2.13	1.96	1.20	1.26		
6	**C/S-44**	0.91	1.61	2.01	2.07	2.01	1.90	1.32	1.26		
7	**C/S-46**	0.00	1.55	1.84	1.90	1.84	1.78	1.55			
8	**C/S-48**	0.00	1.43	1.78	1.96	1.90	1.61	1.26			
9	**C/S-50**	0.00	2.01	2.13	2.07	1.90	1.43	1.14			
10	**C/S-52**	0.00	1.38	1.67	1.55	1.32	0.97	0.80			
11	**C/S-53**	0.00	1.49	1.90	1.61	1.43	1.03	0.97			
12	**C/S-54**	0.00	0.97	1.67	1.43	1.32	0.97	0.62			
13	**C/S-55**	0.00	1.78	2.01	2.25	1.26	0.97				
14	**C/S-56**	0.00	0.00	1.84	1.72	1.43	1.20	1.09			
15	**C/S-57**	0.00	0.00	1.96	1.61	1.14	1.09	1.32			
16	**C/S-58**	0.00	0.00	1.72	1.61	1.32	1.78	1.09	1.03		
17	**C/S-60**	0.00	1.38	1.67	1.55	1.38	1.26	1.38			
18	**C/S-62**	0.00	1.55	1.43	1.49	1.26	1.20	1.09			
19	**C/S-64**	0.00	1.67	1.49	1.55	1.26	1.32	1.14	1.09		
20	**C/S-66**	0.00	1.49	1.96	1.84	1.72	1.67	1.49	1.26		

Velocity is also measured at the top of concrete block mats (CBM) @ 7.5m interval along the right bank from upstream to downstream as shown in **Table 6.13.2**. From this table it is seen that maximum velocity is 1.43 m/s.

Table: 6.13.2: Velocity around the top of CBM along right bank u/s to d/s in test T13

Sl. No.	Dist. from start of CBM (m) from u/s	Velocity (m/s)
1	0.00	0.56
2	7.50	1.09
3	15.00	1.32
4	22.50	1.09
5	30.00	0.97
6	37.50	0.62
7	45.00	0.80
8	52.50	0.85
9	60.00	0.68
10	67.50	0.80
11	75.00	1.20
12	82.50	1.43
13	90.00	1.26
14	97.50	1.32
15	105.00	0.00
16	112.50	-0.08
17	120.00	-0.31
18	127.50	-0.31
19	135.00	-0.19
20	142.50	-0.08
21	150.00	-0.08
22	157.50	-0.02
23	165.00	0.10

Observation

- During lower bank protection by CBM, some CC block columns from top layer have been detached (there is another bottom layer of CC block columns below it) under medium flow but filter materials are still in position. Therefore the lower bank is not exposed and CBM works well. This is because here protection consists of 2 layers of filter materials & 2 layers of CC block columns.

- Filter bars have been moved no more in the downstream by flow velocity as its length is more (12 inch).

Some photos of test (T13) for CBM model can be seen in **Photo 6.13.1-6.13.4.**

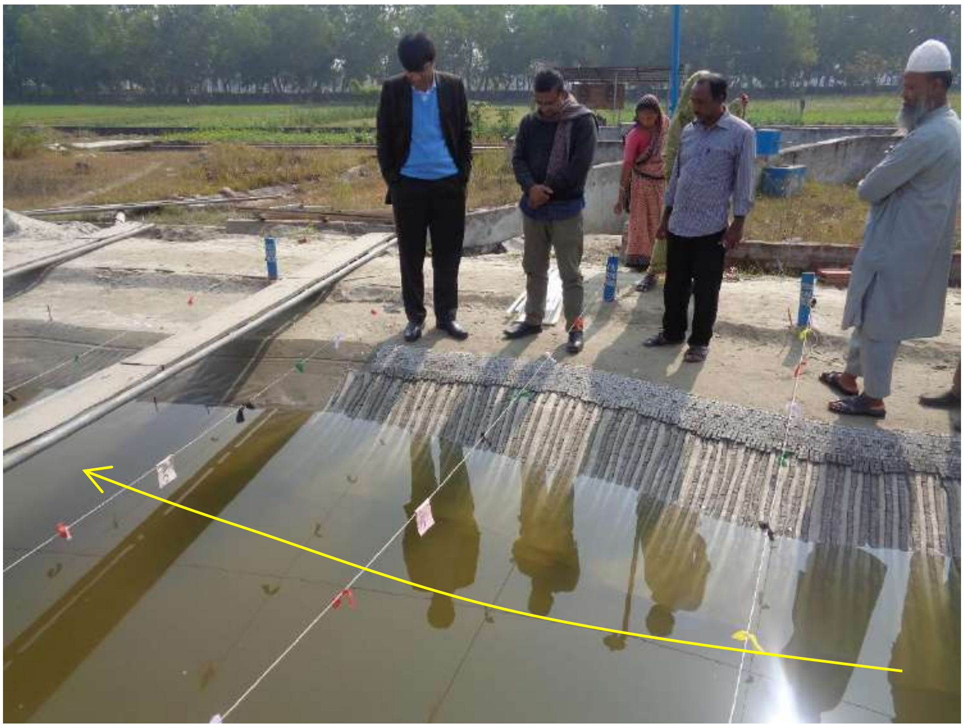


Photo 6.13.1: The XEN of Madaripur O&M division, BWDB visiting the model (T13)

Photo 6.13.2: Model is under running condition (T13) with CBM

Photo 6.13.3: CBM after test run (T13) in the model

Photo 6.13.4: Scour pattern u/s & d/s of CBM after test run (T13)

6.14 Test T14

This test is conducted with the same design as in test T12 but using high flow. The lower bank protection work is done applying loosely placed concrete block mats on filter and upper bank protection work is done applying closely placed concrete block mats with some gaps on filter using high flow. Here the gaps on filter are filled with small grasses.

The sectional discharge ($Q_{sectional}$) corresponding to high water level is 1967 cumec. The model bed is prepared according to the bathymetric survey of March 2017. Scour discharge is run until equilibrium condition is reached and Froudian discharge is run for 12 hrs. The design details of proposed concrete block mats (CBM) are as follows:

- River bank level: 3.0mPWD
- High water level: 2.93mPWD
- Block type: Holed concrete block
- Block size used in the model: 13.33mmX13.33mmX3.33mm (40cmX40cmX10cm in proto)
- Length of river reach to be protected: 5.6m (168m in proto)
- Length of upper bank protection: 0.22m (6.6m in proto)
- Length of lower bank protection: 1.15m (34.5m in proto)
- Length of RCC pipe: 12 inch (360 inch in proto)
- Diameter of RCC pipe: 0.5 inch (15 inch in proto)
- Width of filter: 12 inch (360 inch in proto)
- Total nos. of CC blocks in each 12 inch (360 inch in proto) wide strip at top & bottom layer in lower bank: 58x5+58x5=580
- Here each 12 inch (360 inch in proto) wide strip contains 5 column of CC blocks at the top layer & 5 column of CC blocks at the bottom layer. Each column containing 58 blocks. These strips are overlapped by 50 % over each other. The top 5 column of CC blocks have been placed over the spaces among CC block columns at the bottom layer. Here 2 layers of CC blocks & 2 layers of filter in each strip.
- Length of u/s termination 0.75 m (22.5 m in proto) & d/s termination 0.50 m (15 m in proto)

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 6.14.1** It is seen that flow lines are close to the right bank and passing through the different cross-sections of the river width reproduced in the model. Flow attacks the right bank of river causing severe erosion at u/s & d/s of CBM protection work.

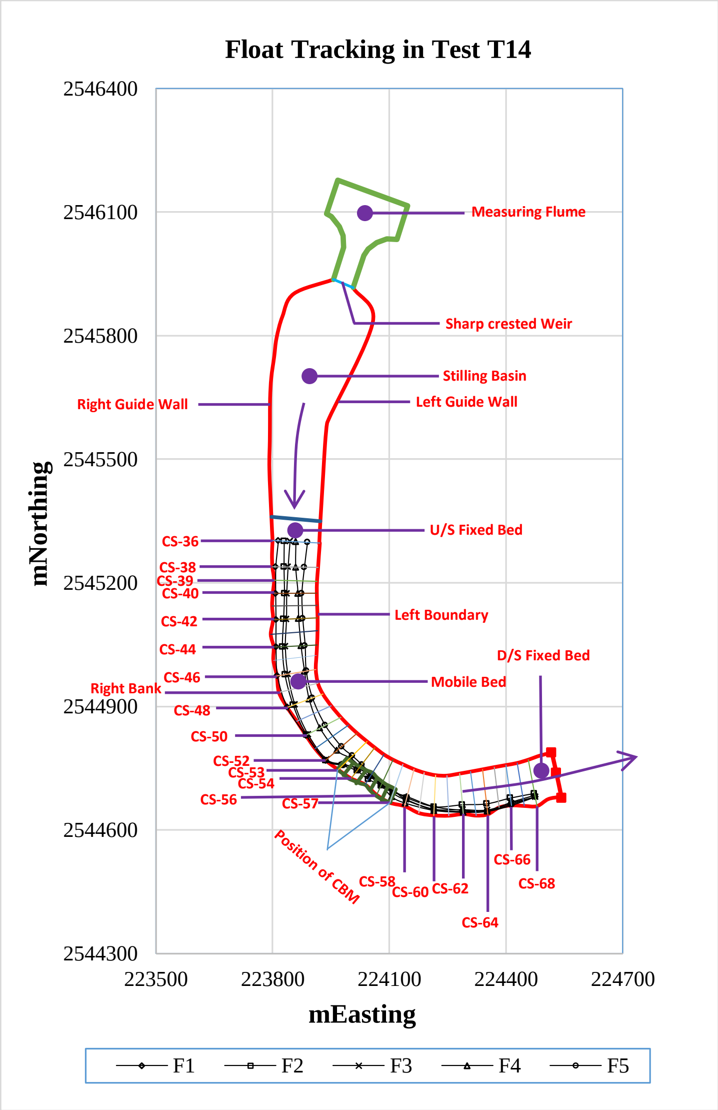


Figure 6.14.1: Flow lines recorded in test T14

Velocity Measurement

The average velocities measured in this test along different cross-sections of the river reproduced in the model are shown in **Table 6.14.1.** The maximum cross-sectional velocity is 3.23 m/s.

Table: 6.14.1: Velocity along different cross-sections of river model in test T14

Sl. No.	C/S No.	C/S Velocity (m/s) in test T14									
		Distance from Right Bank (m)									
		0	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**
1	**C/S-36**	0.00	3.18	2.77	2.71	2.36	2.71	1.72	0.85	1.96	
2	**C/S-38**	0.00	2.71	2.30	2.60	2.65	2.19	1.67	1.61		
3	**C/S-39**	0.00	2.83	2.42	2.60	2.42	1.49	1.32	2.07		
4	**C/S-40**	0.00	2.60	2.25	2.42	2.25	1.67	1.38	1.61		
5	**C/S-42**	2.01	2.54	2.30	2.48	2.54	2.25	1.55	1.67		
6	**C/S-44**	1.96	2.60	2.65	2.71	2.77	2.36	1.84	2.01		
7	**C/S-46**	2.36	2.71	2.83	3.06	3.06	2.89	2.54			
8	**C/S-48**	2.07	2.54	2.77	2.83	2.60	2.54	1.72			
9	**C/S-50**	2.30	2.77	2.83	2.77	2.54	2.30	1.61			
10	**C/S-52**	2.30	2.71	2.71	2.71	2.42	2.01	1.55			
11	**C/S-53**	0.00	2.89	2.83	2.54	2.30	1.90	1.49			
12	**C/S-54**	0.00	1.38	2.65	2.42	2.25	1.38	1.14			
13	**C/S-55**	0.00	3.23	2.83	2.36	1.84	1.55				
14	**C/S-56**	0.00	2.42	2.71	2.19	1.96	1.78	1.20			
15	**C/S-57**	0.00	2.01	2.77	2.13	1.96	2.01	1.55			
16	**C/S-58**	1.55	2.25	1.90	1.84	2.25	2.01	1.96			
17	**C/S-60**	1.84	2.36	2.36	2.30	2.07	2.36	1.96			
18	**C/S-62**	2.60	2.30	2.36	2.30	2.25	1.96	1.55			
19	**C/S-64**	2.30	2.36	2.42	2.30	2.30	2.07	1.96	1.49		
20	**C/S-66**	2.30	2.42	2.42	2.36	2.36	2.07	1.67			

Velocity is also measured at the top of concrete block mats (CBM) @ 7.5m interval along the right bank from upstream to downstream as shown in **Table 6.14.2**. From this table it is seen that maximum velocity is **2.30** m/s.

Table: 6.14.2: Velocity around the top of CBM along right bank u/s to d/s in test T14

Sl. No.	Dist. from start of CBM (m) from u/s	Velocity (m/s)
1	0.00	1.84
2	7.50	1.84
3	15.00	1.26
4	22.50	0.00
5	30.00	-0.60
6	37.50	-0.48
7	45.00	-0.60
8	52.50	-0.71
9	60.00	-0.48
10	67.50	-0.02
11	75.00	0.91
12	82.50	1.43
13	90.00	2.30
14	97.50	1.90
15	105.00	0.00
16	112.50	-0.08
17	120.00	0.00
18	127.50	0.00
19	135.00	0.00
20	142.50	0.00
21	150.00	0.74
22	157.50	0.62
23	165.00	0.91

Scour Measurement

Scour was measured around the protective work (CBM). Maximum local scour around CBM structure is 7.65m (-17.53mPWD) which is m away from R/B along C/S-55 in test run T14.

The development of maximum scour with time at C/S-55 in test T14 is shown in **Figure 6.14.2**. It is seen from the figure that it takes around 13-15 hours to reach dynamic equilibrium condition for maximum scour development at C/S-55. The variation of bed level with time to reach the maximum scour is shown in **Figure 6.14.3.** Non-dimensional plot is shown in **Figure 6.14.4.**

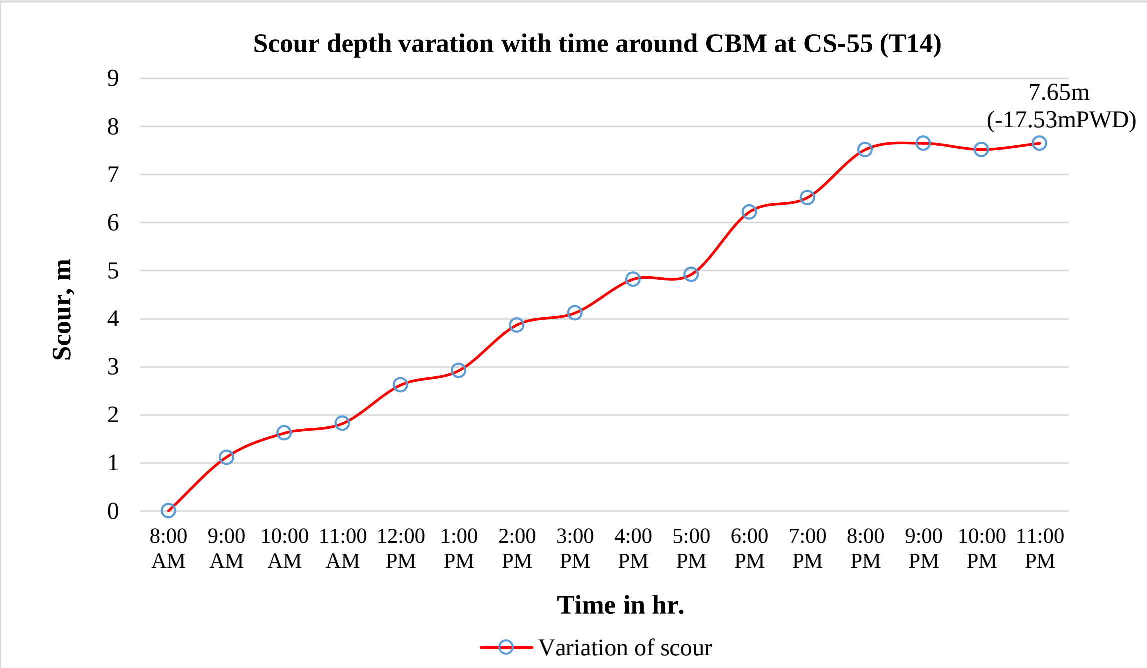


Figure 6.14.2: Development of maximum scour with time around CBM (T14)

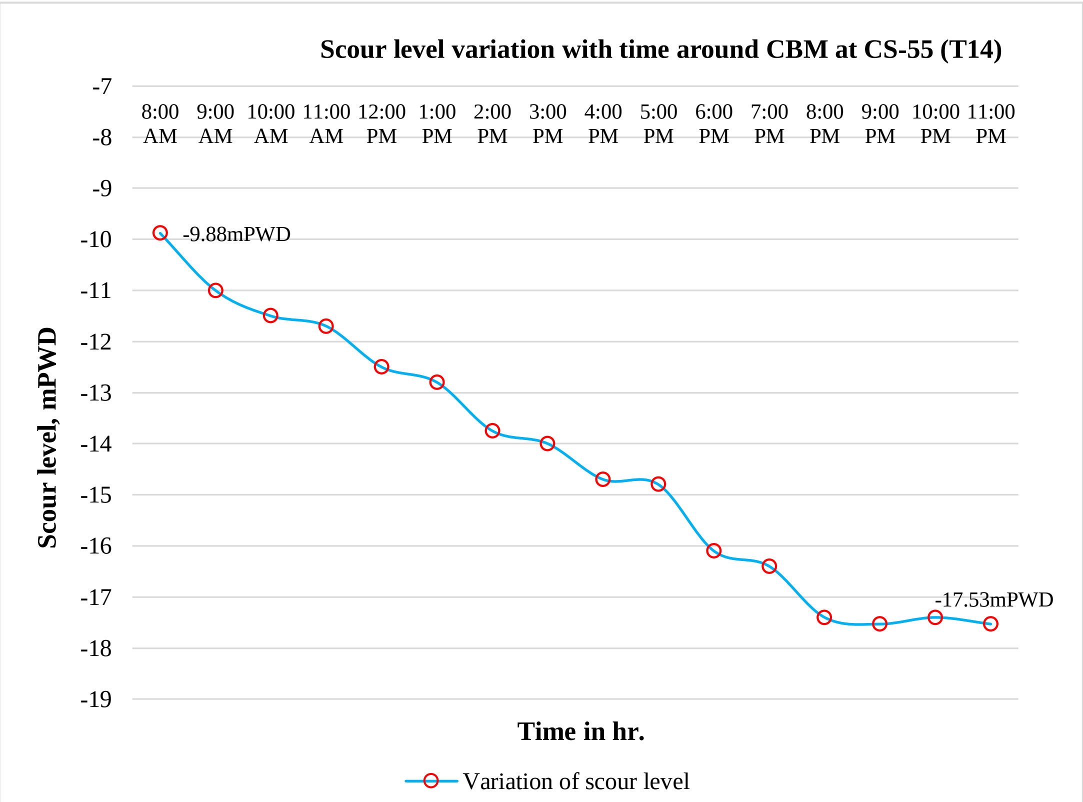


Figure 6.14.3: Variation of bed level with time to reach the maximum scour around CBM (T14)

Non-dimensional plot in log paper (hs /h0) vs. (t/t1) for maximum scour at C/S-55 is as follows. Here hs= scour depth, h0 = initial average water depth, t = time in hours required for scour development and t1= equivalent time defined as the time at which hs= h0.

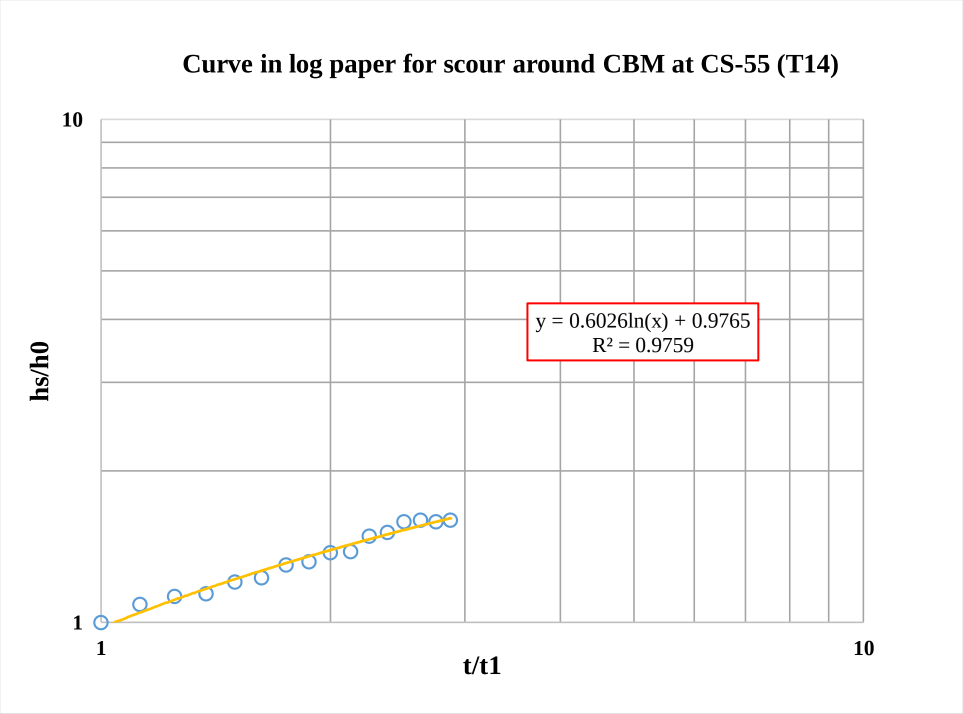
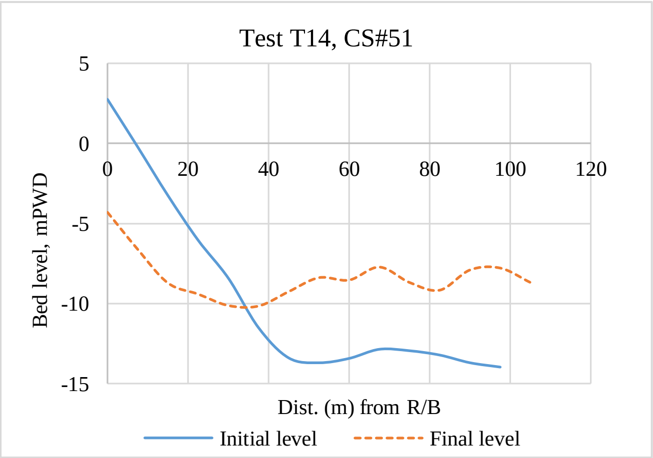
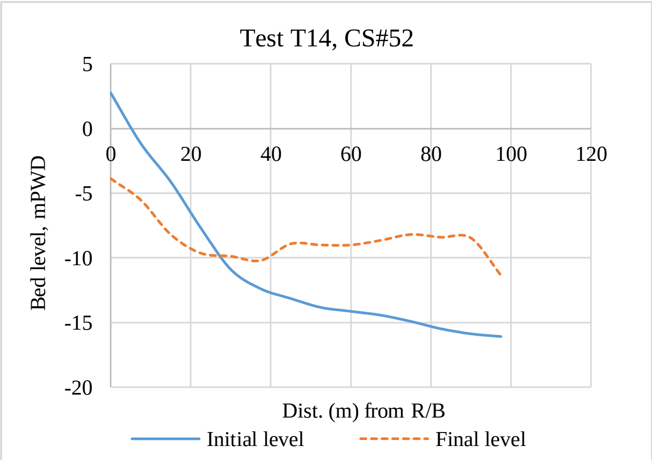


Figure 6.14.4: Non-dimensional plot of (hs /h0) vs. (t/t1) in log paper for scour around CBM (T14)

Bed Level

The bed level before and after test run was measured for each cross-section within the model boundary using levelling staff. Thus the initial & final bed level have been obtained and these are superimposed to have an idea of scour or deposition. Some of the superimposed cross-sections through and around the protective structure (C/S51-C/S58) are shown below.





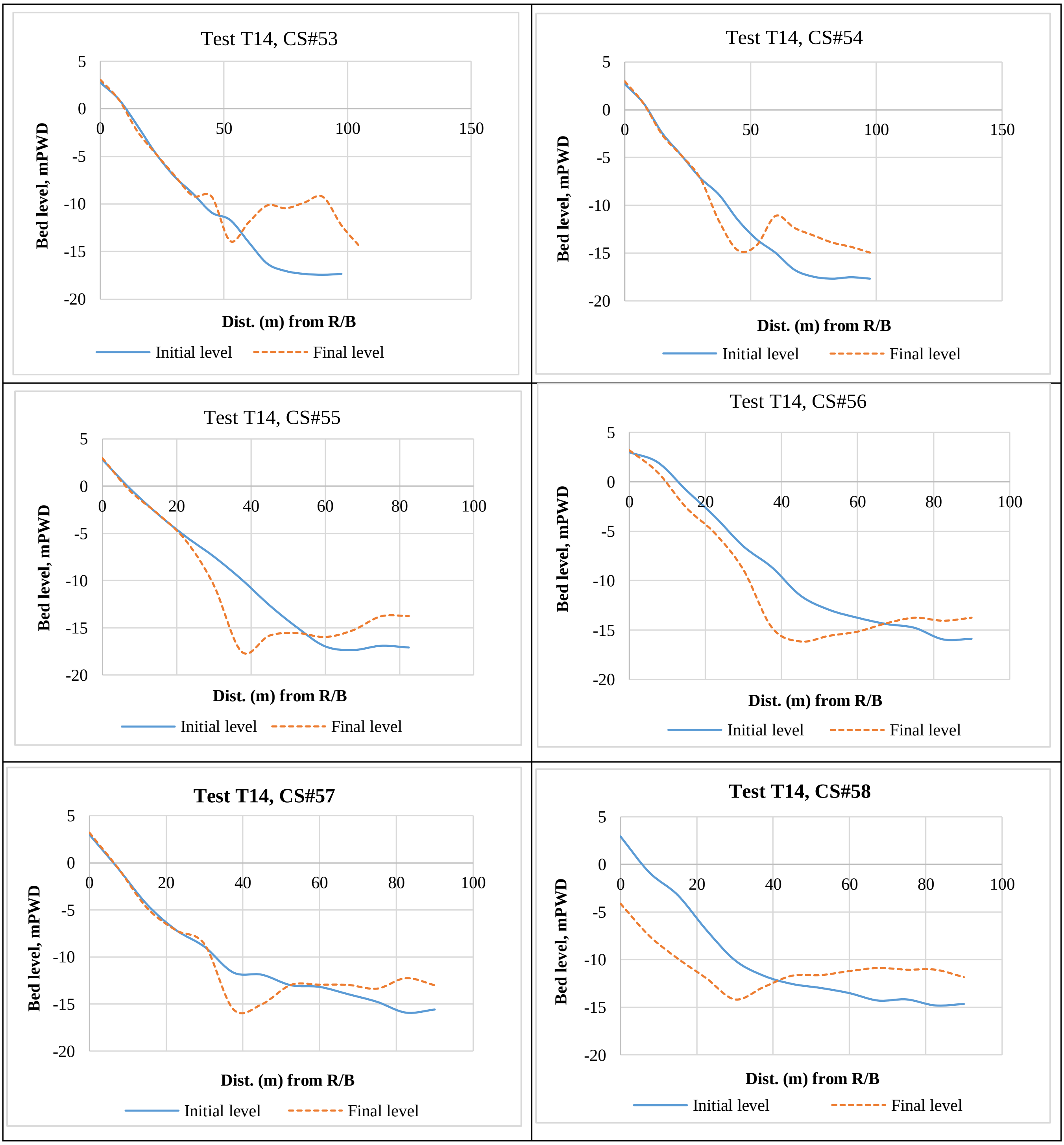


Figure 6.14.5: Superimposed initial and final bed level for C/S51-C/S58 in test T14 of CBM model

Bank Erosion

The tentative river bank erosion after the application test T10 is measured along the right bank of Arial Khan river and is shown in **Table 6.14.3.** It is seen from the table that maximum bank erosion is 27.0 m at C/S-44.

Table 6.14.3: Tentative bank erosion after the application test T14

Sl. No.	C/S No.	Tentative bank erosion, m in test T14
1	**C/S-41**	12.3
2	**C/S-42**	21.3
3	**C/S-43**	21.9
4	**C/S-44**	27.0
5	**C/S-45**	25.5
6	**C/S-46**	26.1
7	**C/S-47**	17.7
8	**C/S-48**	20.4
9	**C/S-49**	21.0
10	**C/S-50**	20.7
11	**C/S-51**	20.7
12	**C/S-52**	11.7
13	**C/S-53**	0.0
14	**C/S-54**	0.0
15	**C/S-55**	0.0
16	**C/S-56**	0.0
17	**C/S-57**	0.0
18	**C/S-58**	10.8
19	**C/S-59**	12.6
20	**C/S-60**	14.4
21	**C/S-61**	21.0
22	**C/S-62**	23.4
23	**C/S-63**	18.9
24	**C/S-64**	21.0
25	**C/S-65**	26
26	**C/S-66**	26.1

Observation

- For lower bank protection by CBM, several CC block columns from top layer have been detached (there is another bottom layer of CC block columns below it) under medium flow but filter materials are still in position.

- The lower bank is not exposed and CBM works well because here protection consists of 2 (two) layers of filter materials & 2 layers of CC block columns.

Some photos of test T14 for CBM model can be seen in **Photo 6.14.1-6.14.3.**

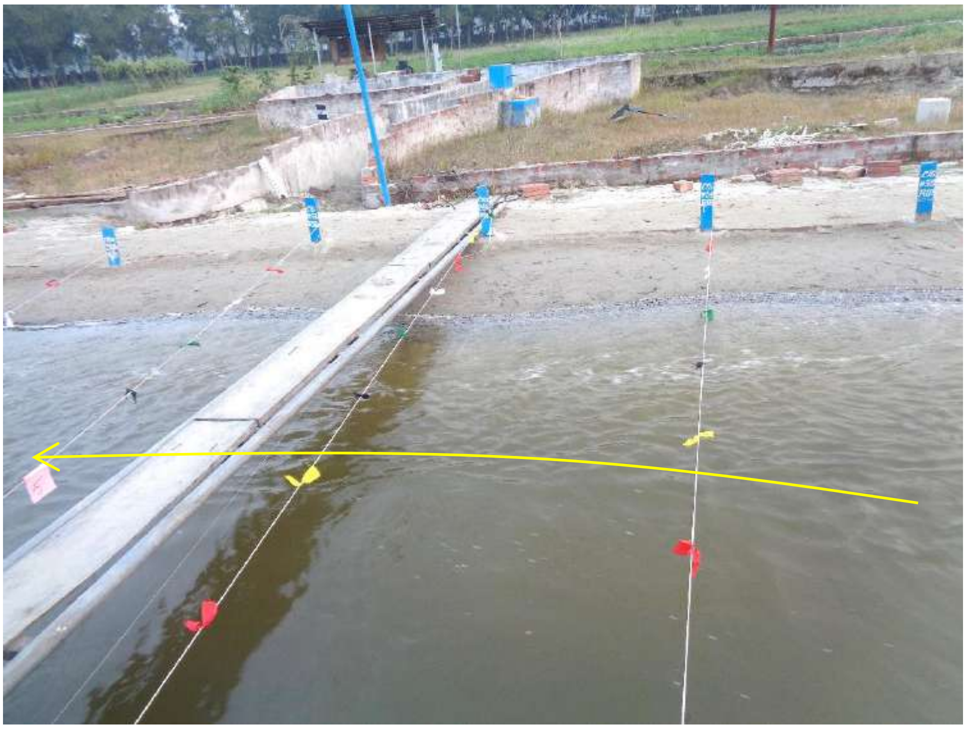


Photo 6.14.1: Model is under running condition (T14)

Photo 6.14.2: Scour pattern u/s & d/s of CBM after test run (T14)

Photo 6.14.3: CBM after test run (T14) in the model

6.15 Test T15

This test is conducted with the same design as in test T12 with the introduction of oblique flow under low flow condition. The lower bank protection work is done applying loosely placed concrete block mats on filter and upper bank protection work is done applying closely placed concrete block mats with some gaps on filter using low flow. Here the gaps in the upper bank protection on filter are filled with small grasses. Here a char is reproduced in the model which makes an angle of 140-degree oblique flow attack with the incoming flow as per recommendations of Chief Engineer (Design), BWDB as shown in **Photo 6.15.1.**

The sectional discharge ($Q_{sectional}$) corresponding to low water level is 808 cumec. The model bed is prepared according to the bathymetric survey of March 2017. Scour discharge is run until equilibrium condition is reached and Froudian discharge is run for 12 hrs. The design details of proposed concrete block mats (CBM) are as follows:

- River bank level: 3.0mPWD
- Low water level: 0.24mPWD
- Block type: Holed concrete block
- Block size used in the model: 13.33mmX13.33mmX3.33mm (40cmX40cmX10cm in proto)
- Length of river reach to be protected: 5.6m (168m in proto)
- Length of upper bank protection: 0.22m (6.6m in proto)
- Length of lower bank protection: 1.15m (34.5m in proto)
- Length of RCC pipe: 12 inch (360 inch in proto)
- Diameter of RCC pipe: 0.5 inch (15 inch in proto)
- Width of filter: 12 inch (360 inch in proto)
- Total nos. of CC blocks in each 12 inch (360 inch in proto) wide strip at top & bottom layer in lower bank: 58x5+58x5=580
- Here each 12 inch (360 inch in proto) wide strip contains 5 column of CC blocks at the top layer & 5 column of CC blocks at the bottom layer. Each column containing 58 blocks. These strips are overlapped by 50 % over each other. The top 5 column of CC blocks have been placed over the spaces among CC block columns at the bottom layer. Here 2 layers of CC blocks & 2 layers of filter in each strip.
- Length of u/s termination 0.75 m (22.5m in proto) & d/s termination 0.50 m (15 m in proto)
- Angle of flow attack: 140-degree with the incoming flow

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 6.15.1** It is seen that flow lines are close to the right bank and passing through the different cross-sections of the river reproduced in the model. Flow severely attacks the CBM protection work due to the oblique flow introduced by the charland causing additional bed scour around charland & protective structure. Severe right bank erosion also occurred at u/s & d/s of protection work due to low flow.

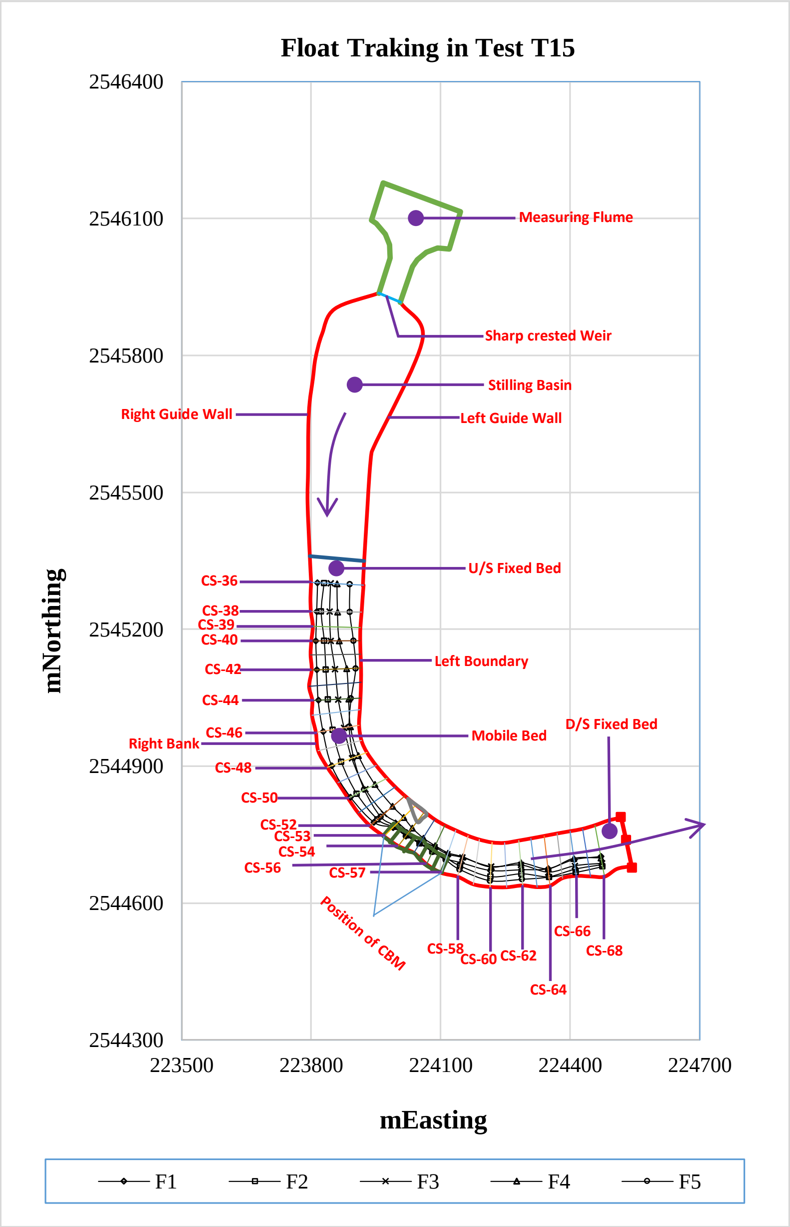


Figure 6.15.1: Flow lines recorded in test T15

Velocity Measurement

The average velocities measured in this test along different cross-sections of the river reproduced in the model are shown in **Table 6.15.1.** The maximum cross-sectional velocity is 1.72 m/s.

Table: 6.15.1: Velocity along different cross-sections of river model in test T15

Sl. No.	C/S No.	C/S Velocity (m/s) in test T15									
		Distance from Right Bank (m)									
		0	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**
1	**C/S-36**	0.00	1.14	0.97	1.09	1.14	0.97	0.39	0.00	0.80	
2	**C/S-38**	0.00	1.14	1.03	1.20	1.03	0.91	0.68	0.62		
3	**C/S-40**	0.00	1.20	1.09	1.14	1.03	0.80	0.51	0.62		
4	**C/S-42**	0.85	1.20	1.14	1.14	1.14	1.14	0.97	0.80		
5	**C/S-44**	1.20	1.49	1.49	1.43	1.49	1.38	1.32	0.91		
6	**C/S-46**	0.00	1.32	1.49	1.43	1.26	1.49	1.32			
7	**C/S-48**	0.00	1.20	1.26	1.26	1.26	1.26	0.97			
8	**C/S-50**	0.00	1.14	1.20	1.14	1.09	0.91	0.21			
9	**C/S-52**	0.00	1.03	1.20	1.20	1.03	0.85	0.21			
10	**C/S-53**	0.00	1.38	1.55	1.49	1.26	0.97	0.62			
11	**C/S-54**	0.00	0.80	1.55	1.49	1.61	0.00				
12	**C/S-55**	0.00	1.43	1.72	1.61	0.85	0.00				
13	**C/S-56**	0.00	0.45	1.49	1.67	1.55	0.00	0.00			
14	**C/S-57**	0.00	0.27	0.33	1.67	1.49	1.09	0.21			
15	**C/S-58**	0.00	0.00	0.80	1.61	1.55	1.26	0.00			
16	**C/S-60**	0.00	0.45	1.09	1.43	1.49	1.38	1.14			
17	**C/S-62**	0.00	0.97	1.14	1.38	1.32	1.20	0.68			
18	**C/S-64**	0.00	0.80	1.09	1.38	1.49	1.32	0.91	0.68		
19	**C/S-66**	0.00	1.03	1.38	1.55	1.32	1.03	0.62			

Velocity is also measured at the top of concrete block mats (CBM) @ 7.5m interval along the right bank from upstream to downstream as shown in **Table 6.15.2**. From this table it is seen that maximum velocity is 2.36 m/s.

Table: 6.15.2: Velocity around the top of CBM along right bank u/s to d/s in test T15

Sl. No.	Dist. from start of CBM (m) from u/s	Velocity (m/s)
1	0.00	1.55
2	7.50	1.90
3	15.00	1.72
4	22.50	-0.19
5	30.00	-0.08
6	37.50	-0.19
7	45.00	0.04
8	52.50	0.00
9	60.00	0.56
10	67.50	0.85
11	75.00	1.09
12	82.50	1.61
13	90.00	2.36
14	97.50	1.43
15	105.00	0.00
16	112.50	0.00
17	120.00	-0.60
18	127.50	-0.66
19	135.00	-0.71
20	142.50	-0.66
21	150.00	-0.71
22	157.50	-0.77
23	165.00	-1.00

Observation

- For lower bank protection by CBM, several CC block columns from top layer have been detached under low flow but filter materials are still in position in spite of additional velocity caused by oblique flow. The lower bank is not exposed and CBM works well because here protection consists of 2 layers of filter materials & 2 layers of CC block columns

- Here additional bed scour occurred around the protective structure due to oblique flow.

- Local scour also occurred in the vicinity of oblique char

Some photos of test (T15) for CBM model can be seen in **Photo 6.15.1-6.15.3.**

Photo 6.15.1: Model is fed with water under oblique flow condition (T15)

Photo 6.15.2: Model is under running condition (T15)

Photo 6.15.3: Model bed after running condition (T15)

6.16 Test T16

This test is conducted with the same design as in test T12 but medium flow with the introduction of oblique flow under medium flow condition. The lower bank protection work is done applying loosely placed concrete block mats on filter and upper bank protection work is done applying closely placed concrete block mats with some gaps on filter using medium flow. Here the gaps in the upper bank protection on filter are filled with small grasses. Here a char is reproduced in the model which makes an angle of 140-degree oblique flow attack with the incoming flow as per recommendations of Chief Engineer (Design), BWDB.

The sectional discharge ($Q_{sectional}$) corresponding to medium water level is 1381 cumec. The model bed is prepared according to the bathymetric survey of March 2017. Scour discharge is run until equilibrium condition is reached and Froudian discharge is run for 12 hrs. The design details of proposed concrete block mats (CBM) are as follows:

- River bank level: 3.0mPWD
- Medium water level: 1.23mPWD
- Block type: Holed concrete block
- Block size used in the model: 13.33mmX13.33mmX3.33mm (40cmX40cmX10cm in proto)
- Length of river reach to be protected: 5.6m (168m in proto)
- Length of upper bank protection: 0.22m (6.6m in proto)
- Length of lower bank protection: 1.15m (34.5m in proto)
- Length of RCC pipe: 12 inch (360 inch in proto)
- Diameter of RCC pipe: 0.5 inch (15 inch in proto)
- Width of filter: 12 inch (360 inch in proto)
- Total nos. of CC blocks in each 12 inch (360 inch in proto) wide strip at top & bottom layer in lower bank: 58x5+58x5=580
- Here each 12 inch (360 inch in proto) wide strip contains 5 column of CC blocks at the top layer & 5 column of CC blocks at the bottom layer. Each column containing 58 blocks. These strips are overlapped by 50 % over each other. The top 5 column of CC blocks have been placed over the spaces among CC block columns at the bottom layer. Here 2 layers of CC blocks & 2 layers of filter in each strip.
- Length of u/s termination 0.75 m (22.5 m in proto) & d/s termination 0.50 m (15 m in proto)
- Angle of flow attack: 140-degree with the incoming flow

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 6.16.1** It is seen that flow lines are close to the right bank and passing through the different cross-sections of the river reproduced in the model. Flow attacks the CBM protection work more and more due to the oblique flow introduced by the charland causing additional bed scour around charland & protection work. Severe right bank erosion also occurred at u/s & d/s of protection work due to more velocity.

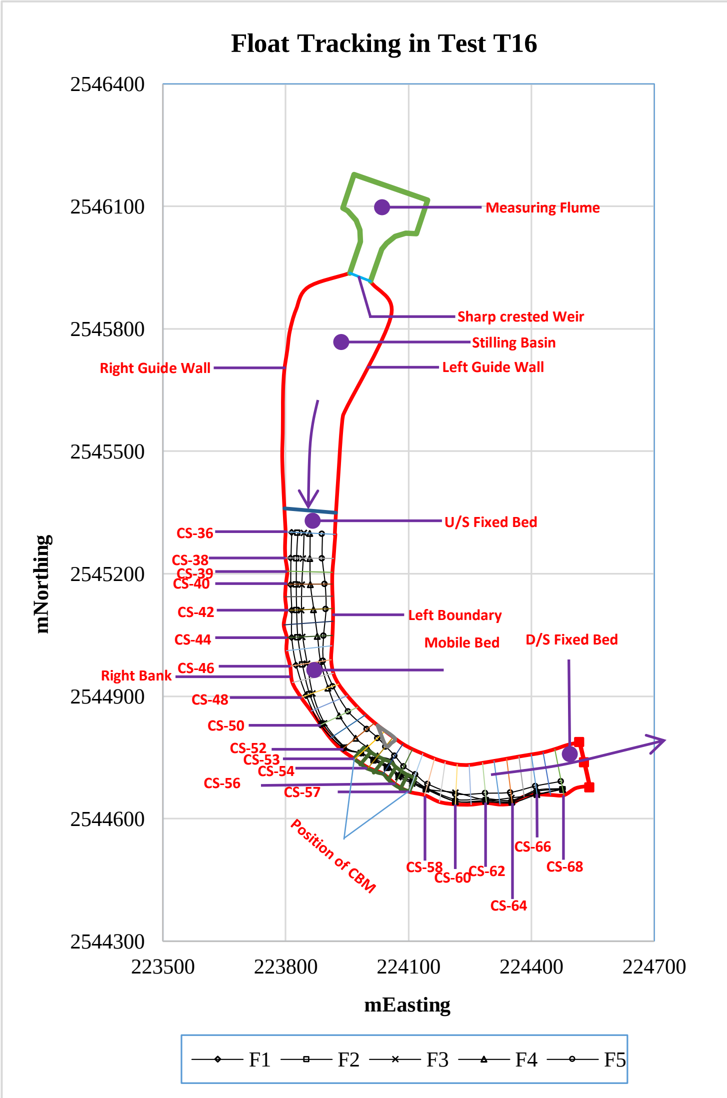


Figure 6.16.1: Flow lines recorded in test T16

Velocity Measurement

The average velocities measured in this test along different cross-sections of the river reproduced in the model are shown in **Table 6.16.1.** The maximum cross-sectional velocity is 2.94 m/s.

Table: 6.16.1: Velocity along different cross-sections of river model in test T16

Sl. No.	C/S No.	C/S Velocity (m/s) in test T16									
		Distance from Right Bank (m)									
		0	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**
1	**C/S-36**	0.00	2.89	2.42	2.25	2.42	2.65	0.51	2.36	2.30	
2	**C/S-38**	0.00	2.36	2.01	2.30	2.36	1.72	0.68	1.32		
3	**C/S-39**	0.00	2.42	2.25	2.36	2.13	1.49	1.09	1.61		
4	**C/S-40**	0.00	2.25	1.96	2.19	2.19	1.32	1.03	1.38		
5	**C/S-42**	2.25	2.36	1.96	2.30	2.07	1.43	1.32			
6	**C/S-44**	2.30	2.36	2.01	2.25	2.48	2.36	1.84	1.55		
7	**C/S-46**	2.36	2.48	2.36	2.54	2.89	2.65	2.48			
8	**C/S-48**	1.96	2.36	2.42	2.48	2.54	2.54	2.13			
9	**C/S-50**	1.78	2.19	2.25	2.25	1.84	1.38	0.27			
10	**C/S-52**	1.09	1.96	2.07	2.13	1.96	1.38	0.51			
11	**C/S-53**	0.00	2.94	2.94	2.60	2.19	1.67	0.00			
12	**C/S-54**	0.00	0.80	2.77	2.65	2.48	0.00				
13	**C/S-55**	0.00	2.83	2.94	2.30	1.78	0.62				
14	**C/S-56**	0.00	0.00	2.94	2.13	2.13	0.97	0.33			
15	**C/S-57**	0.00	0.62	2.83	2.07	2.48	1.90	0.33			
16	**C/S-58**	0.68	2.25	1.84	2.19	2.01	0.80	0.80			
17	**C/S-60**	1.20	1.84	2.01	2.25	2.19	1.90	1.26			
18	**C/S-62**	2.13	2.30	2.30	2.13	2.01	1.61	1.14			
19	**C/S-64**	1.67	2.19	2.30	2.54	2.36	1.96	1.43	1.14		
20	**C/S-66**	2.07	2.48	2.60	2.30	2.25	1.78	1.32			

Velocity is also measured at the top of concrete block mats (CBM) @ 7.5m interval along the right bank from upstream to downstream as shown in **Table 6.16.2**. From this table it is seen that maximum velocity is **2.83** m/s.

Table: 6.16.2: Velocity at top of CBM along right bank u/s to d/s in test T16

Sl. No.	Dist. from start of CBM (m) from u/s	Velocity (m/s)
1	0.00	1.26
2	7.50	2.83
3	15.00	1.61
4	22.50	0.85
5	30.00	-0.48
6	37.50	-0.77
7	45.00	-0.54
8	52.50	0.00
9	60.00	0.00
10	67.50	1.09
11	75.00	1.26
12	82.50	2.01
13	90.00	2.65
14	97.50	1.55
15	105.00	0.00
16	112.50	-0.60
17	120.00	-0.60
18	127.50	-0.71
19	135.00	-0.77
20	142.50	-0.71
21	150.00	-0.31
22	157.50	-0.42
23	165.00	-0.48

Observation

- During lower bank protection by CBM, several CC block columns from top layer have been detached under medium flow but filter materials are still in position in spite of additional velocity caused by oblique flow. The lower bank is not exposed and CBM works well because here protection consists of 2 layers of filter materials & 2 layers of CC block columns.

- Here additional bed scour occurred around the protective structure due to oblique flow.

- Local scour also occurred in the vicinity of oblique char

Some photos of test (T16) for CBM model can be seen in **Photo 6.16.1-6.16.3.**

Photo 6.16.1: Model is under running condition (T16)

Photo 6.16.2: Local scour due to oblique flow in the model (T16)

Photo 6.16.3: Scour pattern in the vicinity of CBM due to oblique flow (T16)

6.17 Test T17

This test is conducted with the same design as in test T12 but using high flow with the introduction of oblique flow. The lower bank protection work is done applying loosely placed concrete block mats on filter and upper bank protection work is done applying closely placed concrete block mats with some gaps on filter using high flow. Here the gaps on filter are filled with small grasses. Here a char is reproduced in the model which makes an angle of 140-degree oblique flow attack with the incoming flow as per recommendations of Chief Engineer (Design), BWDB.

The sectional discharge ($Q_{sectional}$) corresponding to high water level is 1967 cumec. The model bed is prepared according to the bathymetric survey of March 2017. Scour discharge is run until equilibrium condition is reached and Froudian discharge is run for 12 hrs. The design details of proposed concrete block` mats (CBM) are as follows:

- River bank level: 3.0mPWD
- High water level: 2.93mPWD
- Block type: Holed concrete block
- Block size used in the model: 13.33mmX13.33mmX3.33mm (40cmX40cmX10cm in proto)
- Length of river reach to be protected: 5.6m (168m in proto)
- Length of upper bank protection: 0.22m (6.6m in proto)
- Length of lower bank protection: 1.15m (34.5m in proto)
- Length of RCC pipe: 12 inch (360 inch in proto)
- Diameter of RCC pipe: 0.5 inch (15 inch in proto)
- Width of filter: 12 inch (360 inch in proto)
- Total nos. of CC blocks in each 12 inch (360 inch in proto) wide strip at top & bottom layer in lower bank: 58x5+58x5=580
- Here each 12 inch (360 inch in proto) wide strip contains 5 column of CC blocks at the top layer & 5 column of CC blocks at the bottom layer. Each column containing 58 blocks. These strips are overlapped by 50 % over each other. The top 5 column of CC blocks have been placed over the spaces among CC block columns at the bottom layer. Here 2 layers of CC blocks & 2 layers of filter in each strip.
- Length of u/s termination 0.75 m (22.5 m in proto) & d/s termination 0.50 m (15 m in proto)
- Angle of flow attack: 140-degree with the incoming flow

Float Tracking

In this test, flow field is taken by releasing floats from upstream and recording the flow track in each cross-section from upstream to downstream as shown in **Figure 6.17.1** It is seen that flow lines are close to the right bank and passing through the different cross-sections of the river reproduced in the model. Flow tremendously attacks the CBM protection work due to the oblique flow introduced by the charland causing additional bed scour around charland & protective work. Tremendous right bank erosion also occurred at u/s & d/s of protection work due to high velocity of flow.

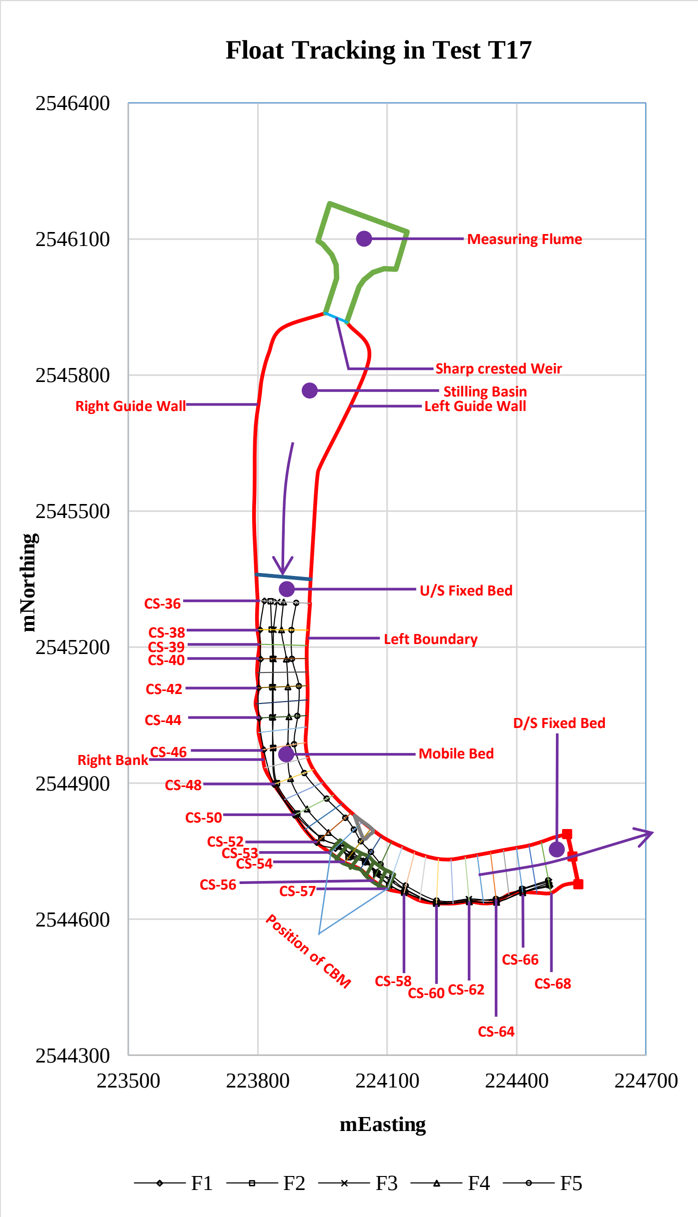


Figure 6.17.1: Flow lines recorded in test T17

Velocity Measurement

The average velocities measured in this test along different cross-sections of the river reproduced in the model are shown in **Table 6.17.1.** The maximum cross-sectional velocity is 4.05 m/s.

Table: 6.17.1: Velocity along different cross-sections of river model in test T17

Sl. No.	C/S No.	C/S Velocity (m/s) in test T17									
		Distance from Right Bank (m)									
		0	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**
1	**C/S-36**	0.00	3.06	2.71	2.71	2.48	2.89	1.03	0.68	2.30	
2	**C/S-38**	0.00	2.60	2.30	2.54	2.65	1.96	1.49	1.78		
3	**C/S-39**	0.00	2.77	2.48	2.60	2.36	1.72	1.38	1.90		
4	**C/S-40**	0.00	2.54	2.25	2.30	2.36	1.55	1.14	1.67		
5	**C/S-42**	2.01	2.42	2.30	2.30	2.42	2.25	1.32	1.32		
6	**C/S-44**	2.25	2.54	2.48	2.54	2.48	2.30	1.90	1.72		
7	**C/S-46**	2.01	2.54	2.30	2.36	2.36	2.42	2.36			
8	**C/S-48**	2.19	2.54	2.65	2.54	2.71	2.83	2.54			
9	**C/S-50**	2.48	2.77	2.71	2.77	2.19	2.30	1.96			
10	**C/S-52**	2.07	2.48	2.65	2.65	2.36	2.25	1.55			
11	**C/S-53**	0.00	4.05	3.58	2.94	2.77	2.36	1.96			
12	**C/S-54**	0.00	-0.48	3.23	3.00	2.89	0.85				
13	**C/S-55**	0.00	3.70	3.12	3.00	1.38	0.56				
14	**C/S-56**	0.00	2.60	3.18	2.83	2.30	1.26	0.39			
15	**C/S-57**	0.00	2.25	2.94	2.77	2.89	1.84	1.03			
16	**C/S-58**	2.07	2.71	2.71	2.07	2.30	1.38	1.43			
17	**C/S-60**	1.96	2.42	2.54	2.71	2.42	1.96	1.72			
18	**C/S-62**	2.48	2.36	2.60	2.19	2.19	1.49	1.49			
19	**C/S-64**	2.48	2.60	2.71	2.30	2.30	1.72	1.49			
20	**C/S-66**	2.36	2.77	2.48	2.30	2.13	1.61	1.49			

Velocity is also measured at the top of concrete block mats (CBM) @ 7.5m interval along the right bank from upstream to downstream as shown in **Table 6.17.2**. From this table it is seen that maximum velocity is 3.64 m/s.

Table: 6.17.2: Velocity around the top of CBM along right bank u/s to d/s in test T17

Sl. No.	Dist. from start of CBM (m) from u/s	Velocity (m/s)
1	0.00	2.71
2	7.50	3.64
3	15.00	2.25
4	22.50	-0.37
5	30.00	-0.83
6	37.50	-0.77
7	45.00	-0.89
8	52.50	-0.77
9	60.00	-0.31
10	67.50	0.04
11	75.00	0.74
12	82.50	1.84
13	90.00	2.60
14	97.50	1.55
15	105.00	-0.42
16	112.50	-0.08
17	120.00	-0.42
18	127.50	-0.13
19	135.00	-0.25
20	142.50	0.00
21	150.00	0.00
22	157.50	0.00
23	165.00	0.04

Scour Measurement

Scour was measured in the vicinity of protective work by CBM. Maximum local scour around CBM structure is 7.65m (-22.27mPWD) which is 37.50m away from R/B along C/S-54 in test run T17.

The development of maximum scour with time around the CBM is shown in **Figure 6.17.2**. It is seen from the figure that it takes around 13-15 hours to reach dynamic equilibrium condition for maximum scour development around the CBM. The variation of bed level with time to reach the maximum scour around CBM is shown in **Figure 6.17.3.** Non-dimensional plot for CBM is shown in **Figure 6.17.4.**

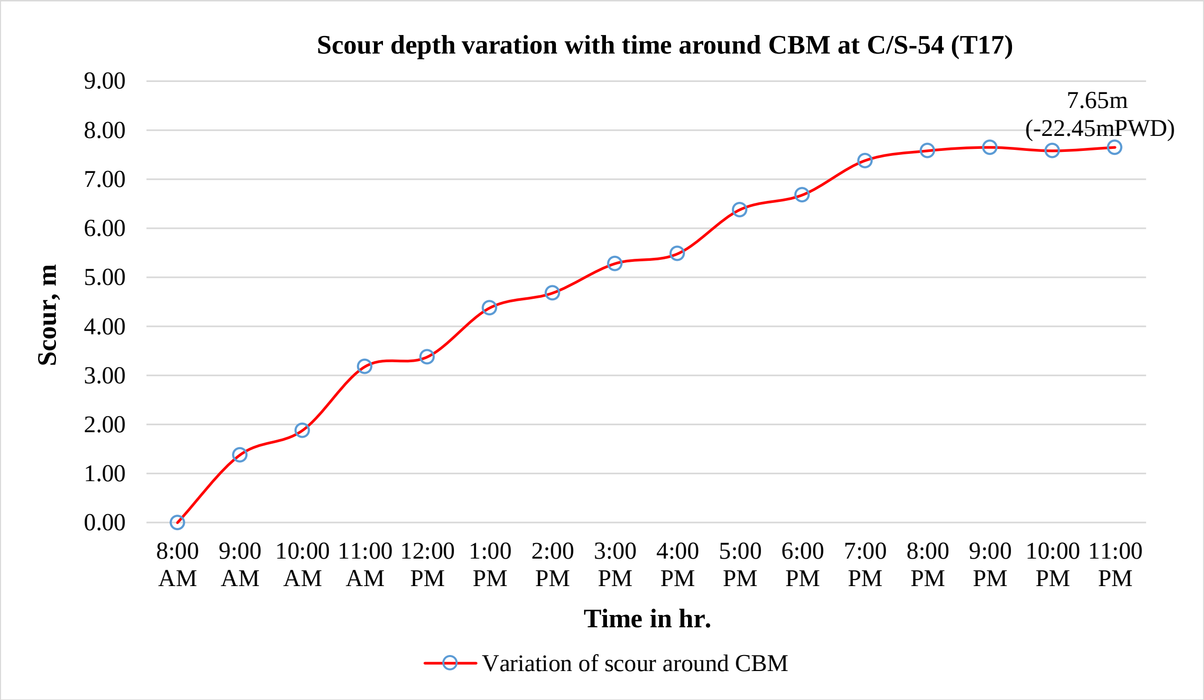


Figure 6.17.2: Development of maximum scour with time around the CBM (T17)

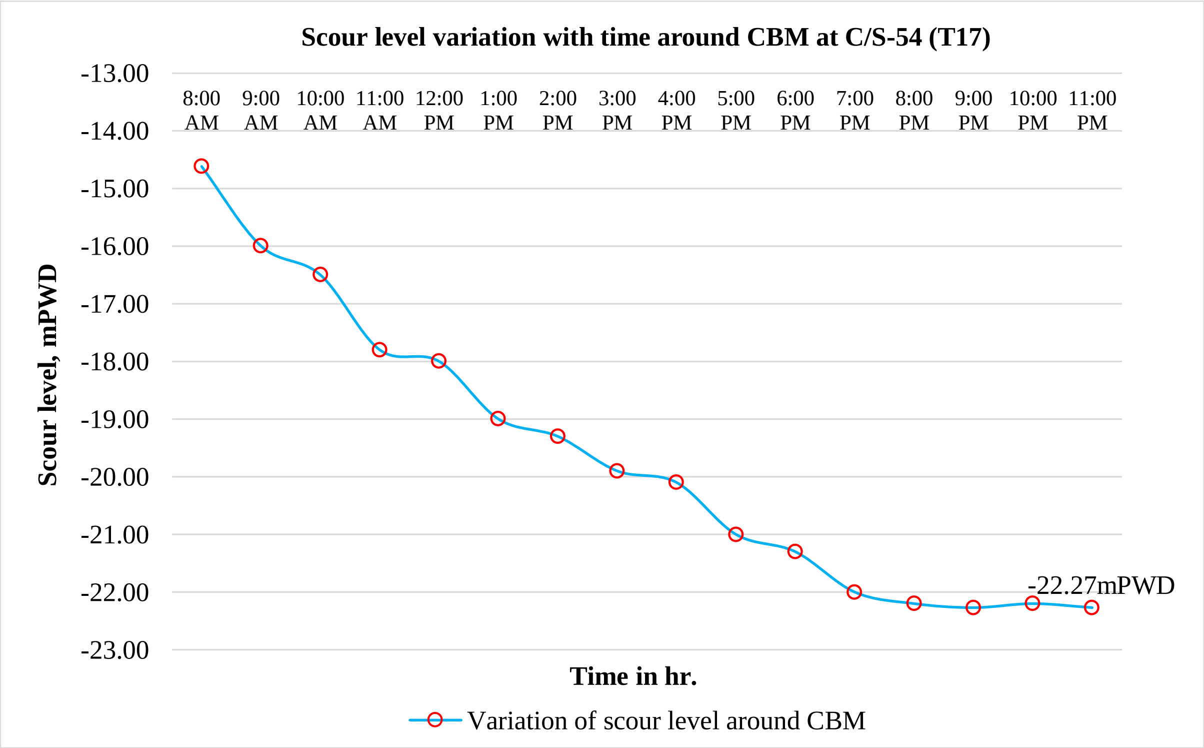


Figure 6.17.3: Variation of bed level with time to reach the maximum scour around the CBM (T17)

Non-dimensional plot in log paper (hs /h0) vs. (t/t1) for maximum scour **around the CBM** is as follows. Here hs= scour depth, h0 = initial average water depth, t = time in hours required for scour development and t1= equivalent time defined as the time at which hs= h0.

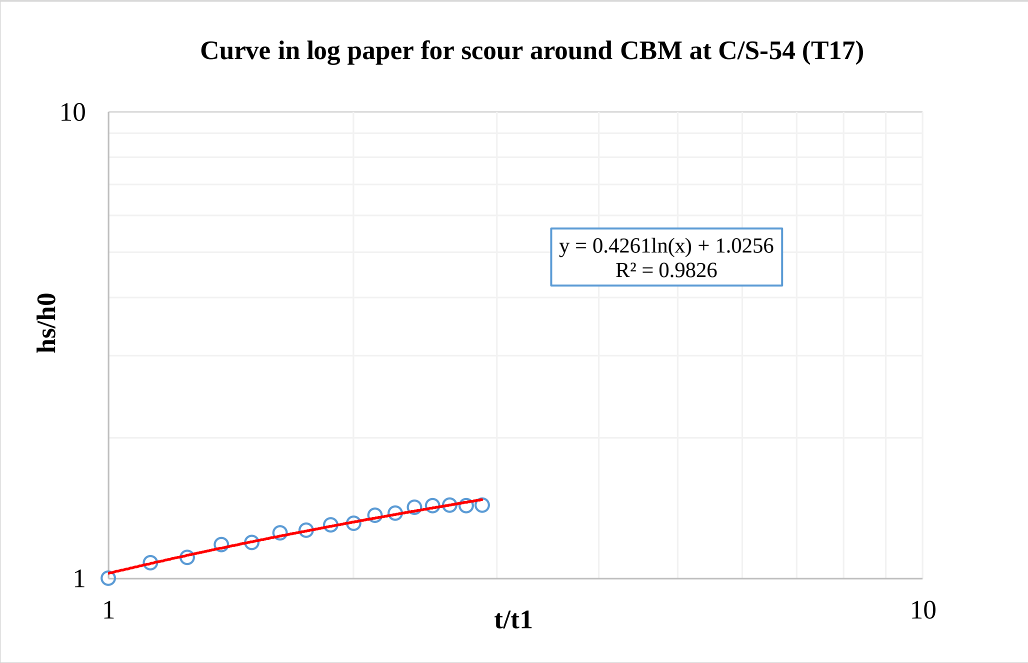


Figure 6.17.4: Non-dimensional plot of (hs /h0) vs. (t/t1) in log paper for scour around the CBM (T17)

Maximum local scour around the oblique char is 7.80m (-22.45 mPWD) in test run T17. The development of maximum scour with time around oblique char is shown in **Figure 6.17.5**. It is seen from the figure that it takes around 13-15 hours to reach dynamic equilibrium condition for maximum scour development around oblique char. The variation of bed level with time to reach the maximum scour around oblique char is shown in **Figure 6.17.6.** Non-dimensional plot for oblique char is shown in **Figure 6.17.7.**

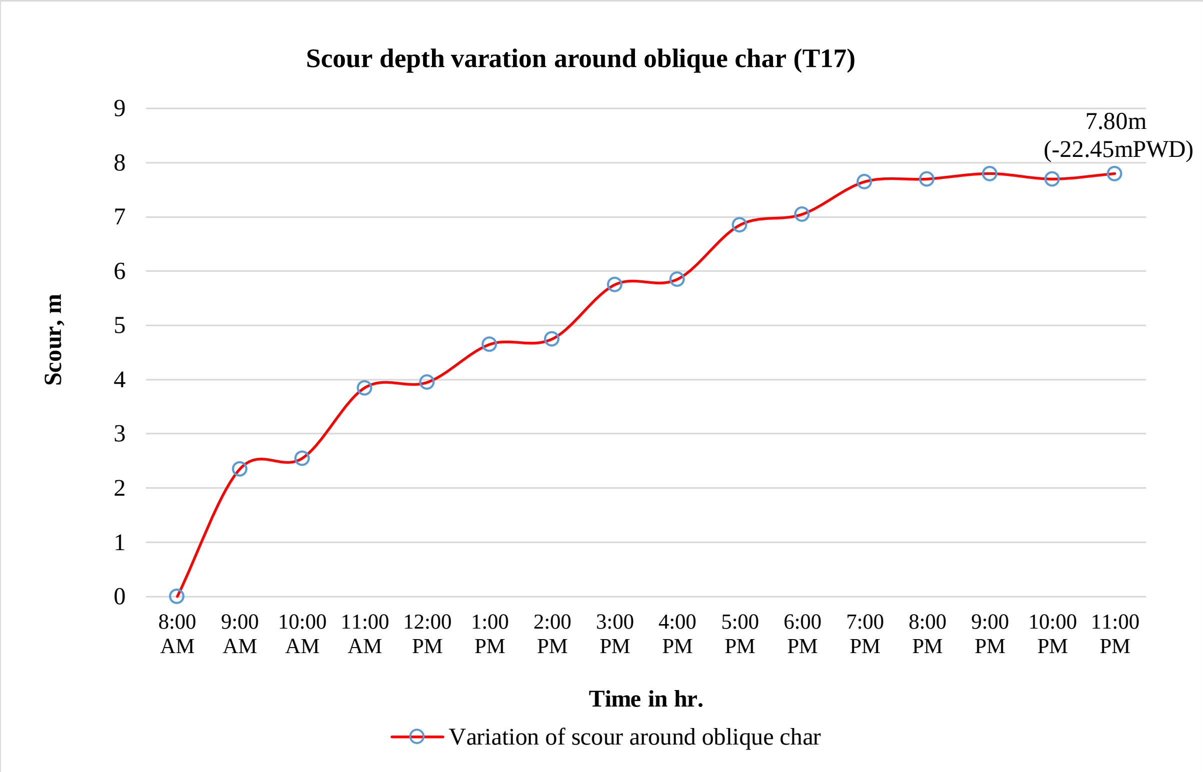


Figure 6.17.5: Development of maximum scour with time around oblique char (T17)

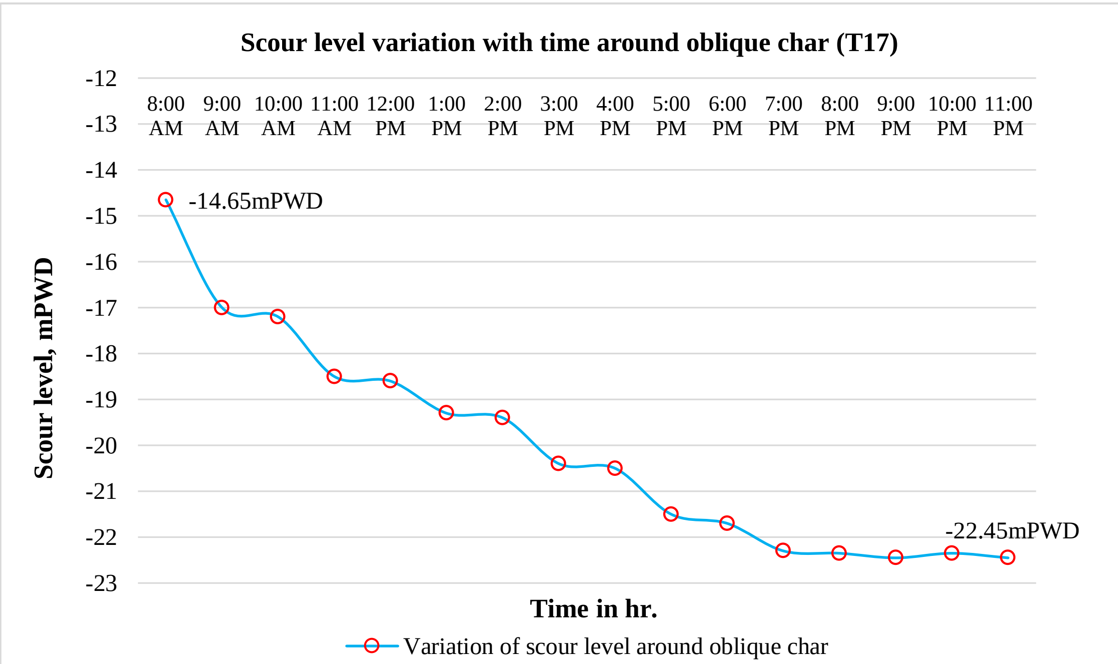


Figure 6.17.6: Variation of bed level with time to reach the maximum scour around oblique char (T17)

Non-dimensional plot in log paper (hs /h0) vs. (t/t1) for maximum scour **around oblique char** is as follows. Here hs= scour depth, h0 = initial average water depth, t = time in hours required for scour development and t1= equivalent time defined as the time at which hs= h0.

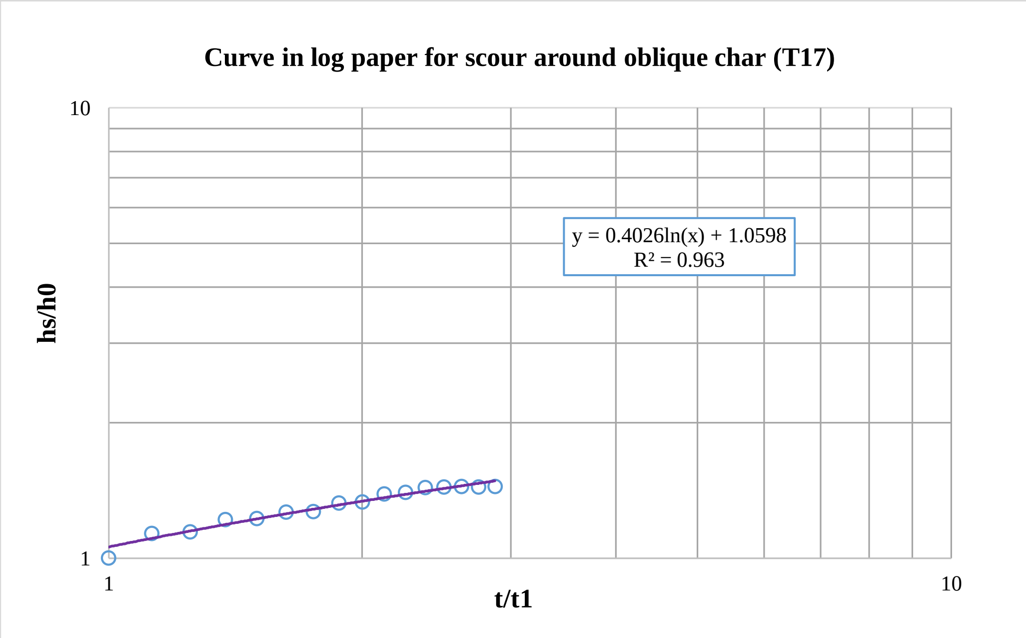
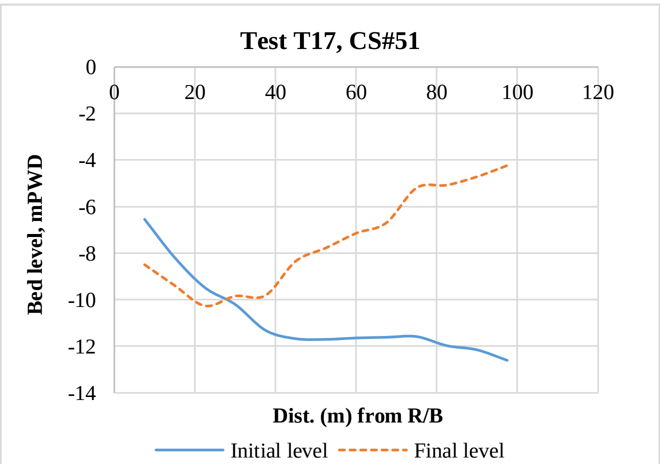


Figure 6.17.7: Non-dimensional plot of (hs /h0) vs. (t/t1) in log paper for scour around oblique char (T17)

Bed Level

The bed level before and after test run was measured for each cross-section within the model boundary using levelling staff. Thus the initial & final bed level have been obtained and these are superimposed to have an idea of scour or deposition. Some of the superimposed cross-sections through and around the protective structure (C/S51-C/S58) are shown below.



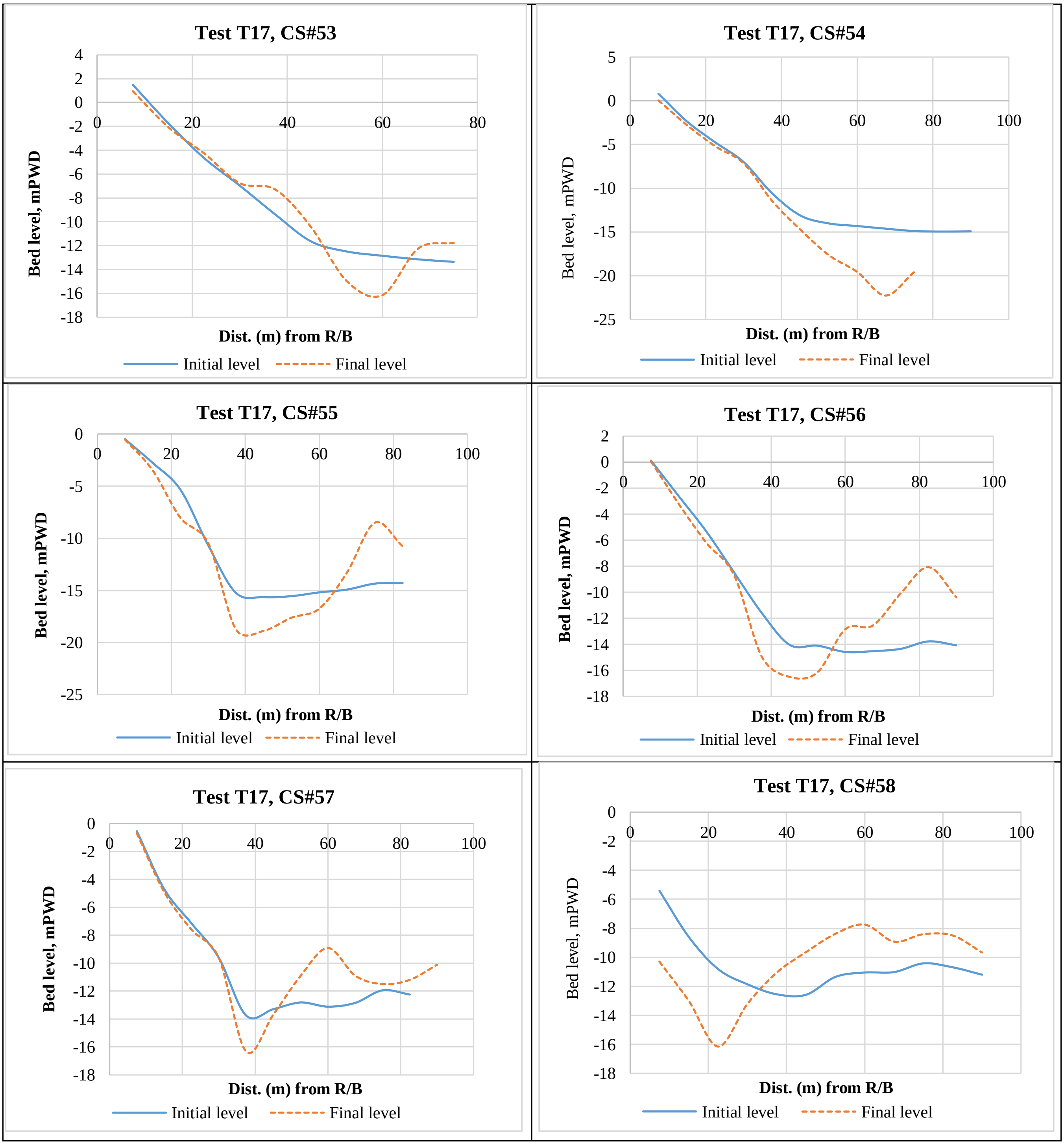


Figure 6.17.5: Superimposed initial and final bed level for C/S51-C/S58 in test T17 of CBM model

Bank Erosion (T17)

The tentative river bank erosion after the application test T17 is measured along the right bank of Arial Khan river and is shown in **Table 6.17.3.** It is seen from the table that maximum bank erosion is 32.1 m at C/S-49.

Table 6.17.3: Tentative bank erosion after the application test T17

Sl. No.	C/S No.	Tentative bank erosion, m in test T17
1	**C/S-41**	15.0
2	**C/S-42**	21.6
3	**C/S-43**	21.6
4	**C/S-44**	27.9
5	**C/S-45**	27.6
6	**C/S-46**	31.2
7	**C/S-47**	26.1
8	**C/S-48**	28.2
9	**C/S-49**	32.1
10	**C/S-50**	28.8
11	**C/S-51**	25.8
12	**C/S-52**	15.9
13	**C/S-53**	0
14	**C/S-54**	0
15	**C/S-55**	0
16	**C/S-56**	0
17	**C/S-57**	0
18	**C/S-58**	16.8
19	**C/S-59**	15
20	**C/S-60**	16.5
21	**C/S-61**	16.2
22	**C/S-62**	22.5
23	**C/S-63**	25.5
24	**C/S-64**	29.1
25	**C/S-65**	30.6
26	**C/S-66**	27.9

Observation

- For lower bank protection by CBM, several CC block columns from top layer have been detached under high flow but filter materials are still in position in spite of additional velocity caused by oblique flow.

- The lower bank is not exposed and CBM works well because here protection consists of 2 layers of filter materials & 2 layers of CC block columns.

- Here additional bed scour occurred around the protective structure due to oblique flow. Local scour also occurred in the vicinity of oblique char

Some photos of test (T17) for CBM model can be seen in **Photo 6.17.1-6.17.5.**

Photo 6.17.1: Model is under running condition (T17)

Photo 6.17.2: Local scour due to oblique flow in the model (T17)

Photo 6.17.3: Scour pattern in the vicinity of CBM and oblique char (T17)

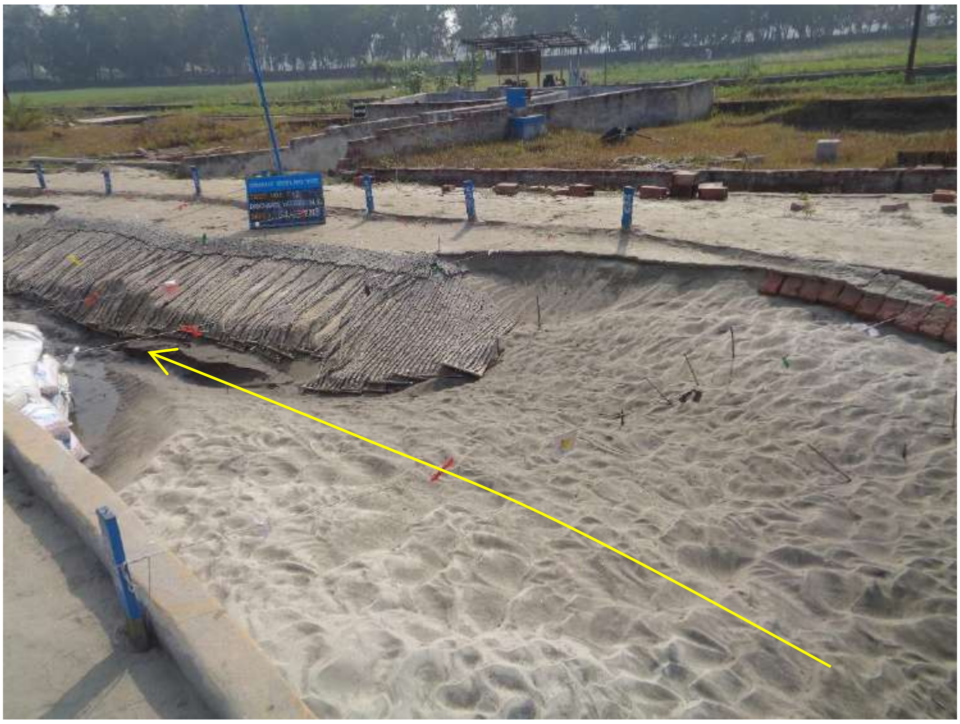


Photo 6.17.4: Scour pattern u/s of CBM due to oblique flow (T17)

Photo 6.17.5: Scour pattern d/s of CBM due to oblique flow (T17)

6.18 Comparative Statement between Conventional & Proposed Concrete Block Method

A comparative statement made by Senior Design Engineer, Syed Imdadul Haque between conventional method and proposed concrete block method with respect to Technical Performance, Workability and Sustainability for river bank protection is given below:

Table 6.18.1: Comparison of conventional & proposed new method

Considering Topics	Conventional Method	Proposed Concrete Block Method
(1) Technical Performance	a) In conventional method, loose concrete blocks are used at upper bank and lower bank for river bank erosion control. So, the placed position of individual blocks can change easily due to soil erosion. b) Block can move from one position to other due to free connection with other blocks when underlying soil erode. c) In lower bank, huge blocks are accumulated by dump which attract sedimentation, blocks can move to the river bed. So, river depth can decrease.	a) In proposed new method, concrete block mats can be used at upper bank and lower bank for river bank erosion control. So, the placed position of individual blocks can't change easily due to erosion. b) Block can't move from one position to other due to inter connection with other blocks when underlying soil erode. But, direction of block can change due to flexible inter connection. c) In lower bank, two layer concrete block mats can be used which don't attract sedimentation, blocks can't move to the river bed. So, river depth can increase.
(2) Workability	a) Easy to construct in the field. It is practiced from British period. b) Workers are already acquainted with the construction procedure due to practice for a long time. c) For construction no diver, swimmer and barge required.	a) Not easy to construct in the field but possible. b) Workers are not acquainted with the construction procedure. So, training will be required. c) For construction diver, swimmer and barge may be required.
(3) Sustainability	a) Sustainable if huge expenditure for maintenance is ensured. b) Less durable than new method.	a) Sustainable with negligible expenditure for maintenance. b) More durable than the conventional method.

6.19 Relationship between velocity, discharge and water level

A correlation between velocity, discharge and water level used in different application test runs is developed and shown in **Figure 6.19.1.**

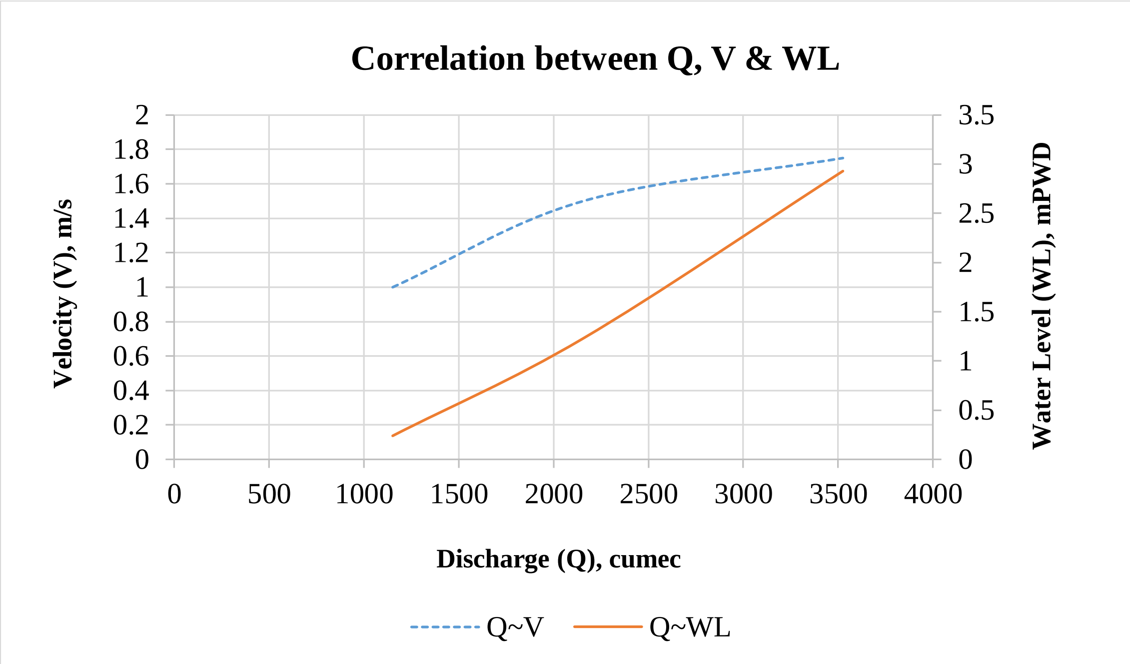


Figure 6.19.1: Correlation between velocity, discharge and water level

7 CONCLUSION AND RECOMMENDATION

Concrete Block Mat (CBM) model is constructed to meet the objectives as mentioned in the Terms of Reference (ToR) [please see **Appendix-B**]. The river reach about 1.0 km length (0.5 km upstream and 0.5 km downstream of centre line of bend, C/S-53, **Figure 2.1**) and average width about 133m is reproduced in the model. It is an undistorted model and the scale used in the model is 1:30. After calibration of the model, different application test runs are conducted with different test scenarios and CBM bank protection work using low, medium and high flows. The CBM protective work is provided in the model from C/S53 to C/S57 covering a reach of about 168m along the R/B of the river. The following conclusion and recommendation are made based on the test results of physical model study.

7.1 Conclusion

- The effectiveness of the proposed CBM is not so attractive compared to the traditional method as a whole, though the cost estimate supplied by the Senior Design Engineer appears to be relatively less.

- The construction of concrete blocks, filter placement under water, block placement through the wire etc. are found very complex in the model. But in nature it might be more and more complex.

- The construction of proposed bank protective structure (CBM) might be very difficult to implement in the field.

- The construction of proposed new method of bank protection (CBM) is time-consuming.

- CBM needs special working technology to construct in the field.

- The optimized design tested in test T12 is found to work better compared to other tests.

- The design of CBM tested in test T12, T13 & T14 is found to work better in spite of its other complexity. The optimised design is shown in **Figure 7.1.1-7.1.3 (a&b).**

- Proper monitoring & supervision of CBM is necessary during and after construction phase if implemented in the field.

The velocity and scour in different test runs are given below:

i) Velocity and flow field

- Severe flow concentration was observed along the R/B of river.
- Maximum cross-sectional velocity measured in test T0-1 is 2.13 m/s.
- Maximum cross-sectional velocity measured in test T0-2 is 0.51 m/s.
- Maximum cross-sectional velocity measured in test T1 is 2.65 m/s.
- Maximum cross-sectional velocity measured in test T2 is 2.01 m/s.
- Maximum cross-sectional velocity measured in test T3 is 2.54 m/s.
- Maximum cross-sectional velocity measured in test T4 is 3.18 m/s.
- Maximum cross-sectional velocity measured in test T5 is 1.49 m/s.
- Maximum cross-sectional velocity measured in test T6 is 2.48 m/s.
- Maximum cross-sectional velocity measured in test T7 is 3.93 m/s.
- Maximum cross-sectional velocity measured in test T8 is 1.67 m/s.
- Maximum cross-sectional velocity measured in test T9 is 3.12 m/s.
- Maximum cross-sectional velocity measured in test T10 is 3.64 m/s.
- Maximum cross-sectional velocity measured in test T11 is 1.49 m/s.
- Maximum cross-sectional velocity measured in test T12 is 1.49 m/s.
- Maximum cross-sectional velocity measured in test T13 is 2.54 m/s.
- Maximum cross-sectional velocity measured in test T14 is 3.23 m/s.
- Maximum cross-sectional velocity measured in test T15 is 1.72 m/s.
- Maximum cross-sectional velocity measured in test T16 is 2.94 m/s.
- Maximum cross-sectional velocity measured in test T17 is 4.05 m/s.
- Maximum velocity measured around the top of CBM along the right bank is 1.38 m/s in test T1.
- Maximum velocity measured around the top of CBM along the right bank is 0.97 m/s in test T2.
- Maximum velocity measured around the top of CBM along the right bank is 1.61 m/s in test T3.

Velocity and flow field (Contd.)

- Maximum velocity measured around the top of CBM along the right bank is 2.19 m/s in test T4.
- Maximum velocity measured around the top of CBM along the right bank is 0.85 m/s in test T5.
- Maximum velocity measured around the top of CBM along the right bank is 1.61 m/s in test T6.
- Maximum velocity measured around the top of CBM along the right bank is 2.36 m/s in test T7.
- Maximum velocity measured around the top of CBM along the right bank is 0.97 m/s in test T8.
- Maximum velocity measured around the top of CBM along the right bank is 2.36 m/s in test T9.
- Maximum velocity measured around the top of CBM along the right bank is 2.89 m/s in test T10.
- Maximum velocity measured around the top of CBM along the right bank is 0.80 m/s in test T11.
- Maximum velocity measured around the top of CBM along the right bank is 0.91 m/s in test T12.
- Maximum velocity measured around the top of CBM along the right bank is 1.43 m/s in test T13.
- Maximum velocity measured around the top of CBM along the right bank is 2.30 m/s in test T14.
- Maximum velocity measured around the top of CBM along the right bank is 2.36 m/s in test T15 with oblique flow situation.
- Maximum velocity measured around the top of CBM along the right bank is 2.83m/s in test T16 with oblique flow situation.
- Maximum velocity measured around the top of CBM along the right bank is 3.64m/s in test T17 with oblique flow situation.
- Flow is severely concentrated at start & end of CBM protective structure.

ii) Scour and bank erosion

- Severe bank erosion was observed immediate at start & end of CBM protective work.
- Maximum scour is 10.26m (-13.21mPWD) which is 22.50m away from R/B along C/S-48 in calibration test run T0.
- Maximum local scour around CBM structure is 3.69m (-14.89mPWD) which is 45.00m away from R/B along C/S-56 in test run T4.
- Maximum local scour around CBM structure is 3.6m (-14.2mPWD) which is 37.50 m away from R/B along C/S-56 in test run T7.
- Maximum local scour around CBM structure is 7.29m (-14.89mPWD) which is 30.00 m away from R/B along C/S-55 in test run T10.
- Maximum local scour around CBM structure is 7.65m (-17.53mPWD) which is m away from R/B along C/S-55 in test run T14.
- Maximum local scour around CBM structure is 7.65m (-22.27mPWD) which is 37.50m away from R/B along C/S-54 in test run T17.
- Maximum local scour around the oblique char is 7.80m (-22.45 mPWD) in test run T17.
- Maximum tentative bank erosion is 10.8m at C/S-55 at the right bank of river after calibration test run T0.
- Maximum tentative bank erosion is 25.2m at C/S-44 at the right bank of river after test run T4.
- Maximum tentative bank erosion is 28.2m at C/S-44/45 at the right bank of river after test run T7.
- Maximum tentative bank erosion is 28.5m at C/S-44 at the right bank of river after test run T10.
- Maximum tentative bank erosion is 27m at C/S-44 at the right bank of river after test run T14.
- Maximum tentative bank erosion is 32.1 at C/S-49 at the right bank of river after test run T17.

The summary of the test results can be seen in **Table 7.1.1.**

Table 7.1.1: Summary table for velocity and scour measured in the model

Test No.	Velocity around top of CBM structure, m/s		Cross-sectional velocity, m/s		Maximum local scour around the CBM structure, m	Test conditions
	V_{max}	Range of velocity	V_{max}	Range of velocity		
T1	1.38	0.27-1.38	2.65	0.0-2.65	-	Q= 808 m3/s, LWL= 0.24 mPWD
T2	0.97	0.27-0.97	2.01	0.0-2.01		Q= 808 m3/s, LWL= 0.24 mPWD
T3	1.61	0.27-1.61	2.54	0.0-2.54	3.69m (-14.89mPWD)	Q= 1381 m3/s, MWL= 1.23 mPWD
T4	2.29	0.45-2.29	3.18	0.0-3.18		Q= 1967 m3/s, HWL= 2.93 mPWD
T5	0.85	0.0-.85	1.49	0.0-1.49		Q= 808 m3/s, LWL= 0.24 mPWD
T6	1.61	-0.54-1.61	2.48	0.0-2.48	3.6m (-14.2mPWD)	Q= 1381 m3/s, MWL= 1.23 mPWD
T7	2.36	-0.54-2.36	3.93	0.0-3.93		Q= 1967 m3/s, HWL= 2.93 mPWD
T8	0.97	-0.25-0.97	1.67	0.0-1.67		Q= 808 m3/s, LWL= 0.24 mPWD
T9	2.36	-0.66-2.36	3.12	0.0-3.12	7.29m (-14.89mPWD)	Q= 1381 m3/s, MWL= 1.23 mPWD
T10	2.89	-071-2.89	3.64	0.0-3.64		Q= 1967 m3/s, HWL= 2.93 mPWD
T11	0.80	0.0-0.80	1.49	0.0-1.49	-	Q= 808 m3/s, LWL= 0.24 mPWD
T12	0.91	0-0.91	1.49	0.0-1.49		Q= 808 m3/s, LWL= 0.24 mPWD
T13	1.43	-0.31-1.43	2.54	0.0-2.54	7.65m (-17.53mPWD)	Q= 1381 m3/s, MWL= 1.23 mPWD
T14	2.13	-0.71-2.13	3.23	0.0-3.23		Q= 1967 m3/s, HWL= 2.93 mPWD
T15	2.36	-1.00-2.36	1.72	0.0-1.72	7.65m (-22.27mPWD)	Q= 808 m3/s, LWL= 0.24 mPWD
T16	2.83	-0.77-2.83	2.94	0.0-2.94	& around the oblique char	Q= 1381 m3/s, MWL= 1.23 mPWD
T17	3.64	-0.89-3.64	4.05	-0.48-4.05	7.80m (-22.45 mPWD)	Q= 1967 m3/s, HWL= 2.93 mPWD

7.2 Recommendation

- This concept can be applied in any shorter reach of a small river as a pilot project to verify its effectiveness as well as to identify its various complexity in the field conditions.

- Further future study can be conducted in the different scenarios.

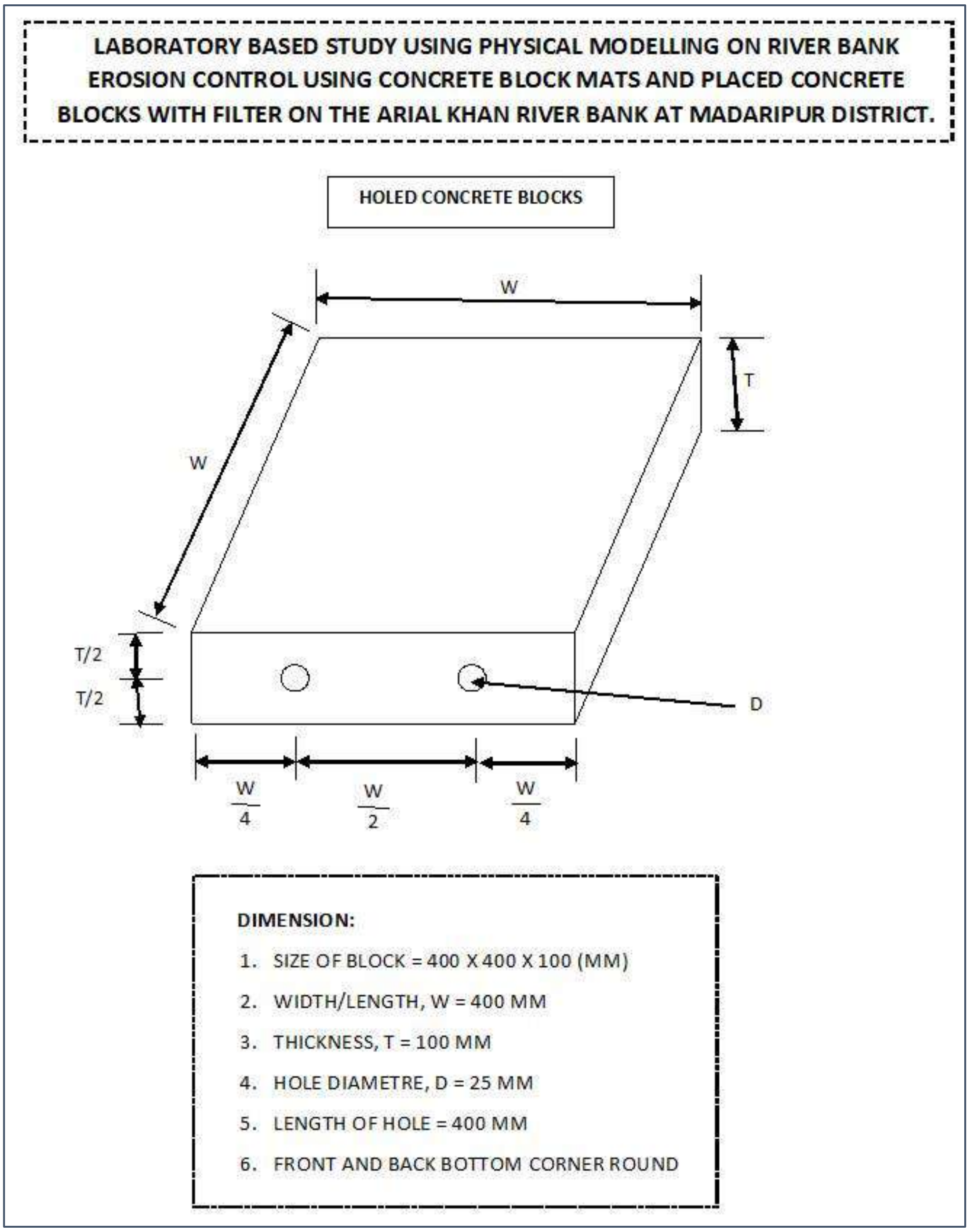


Figure 7.1.1: Typical holed block of CBM

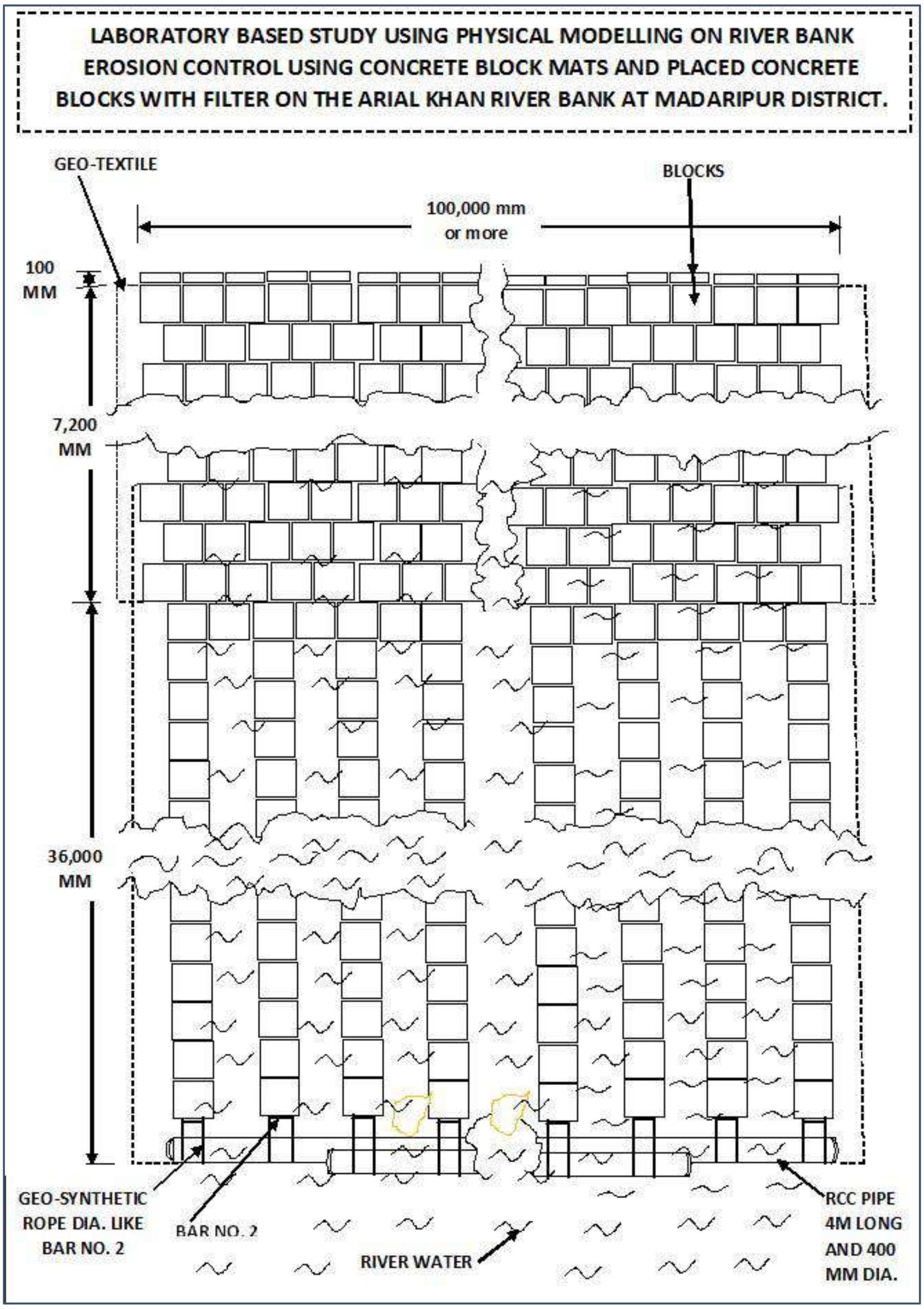


Figure 7.1.2: Typical plan of erosion control measure by CBM at Arial Khan River bank

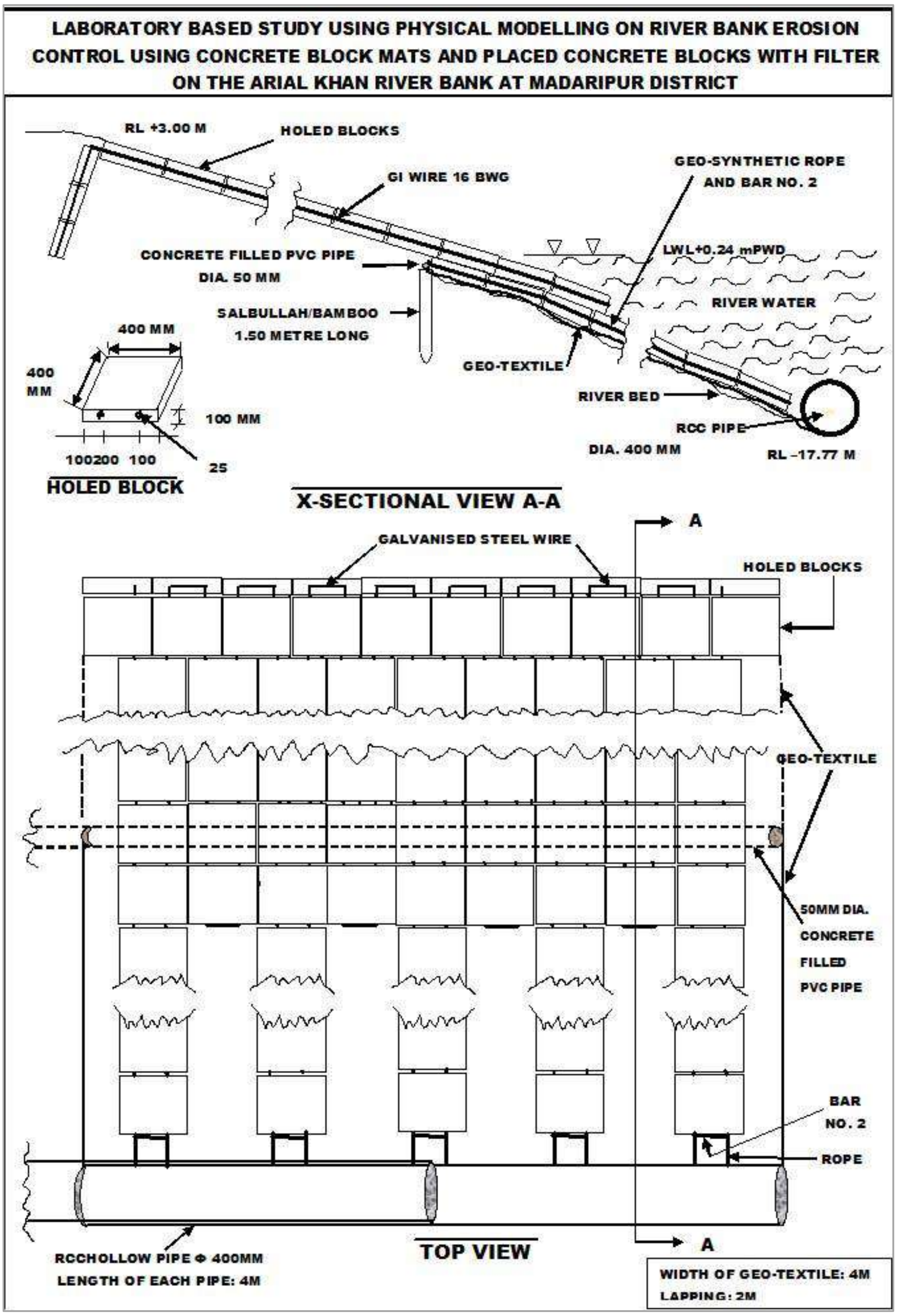


Figure 7.1.3 (a): Typical section (A-A) of erosion control measure by CBM at Arial Khan River bank

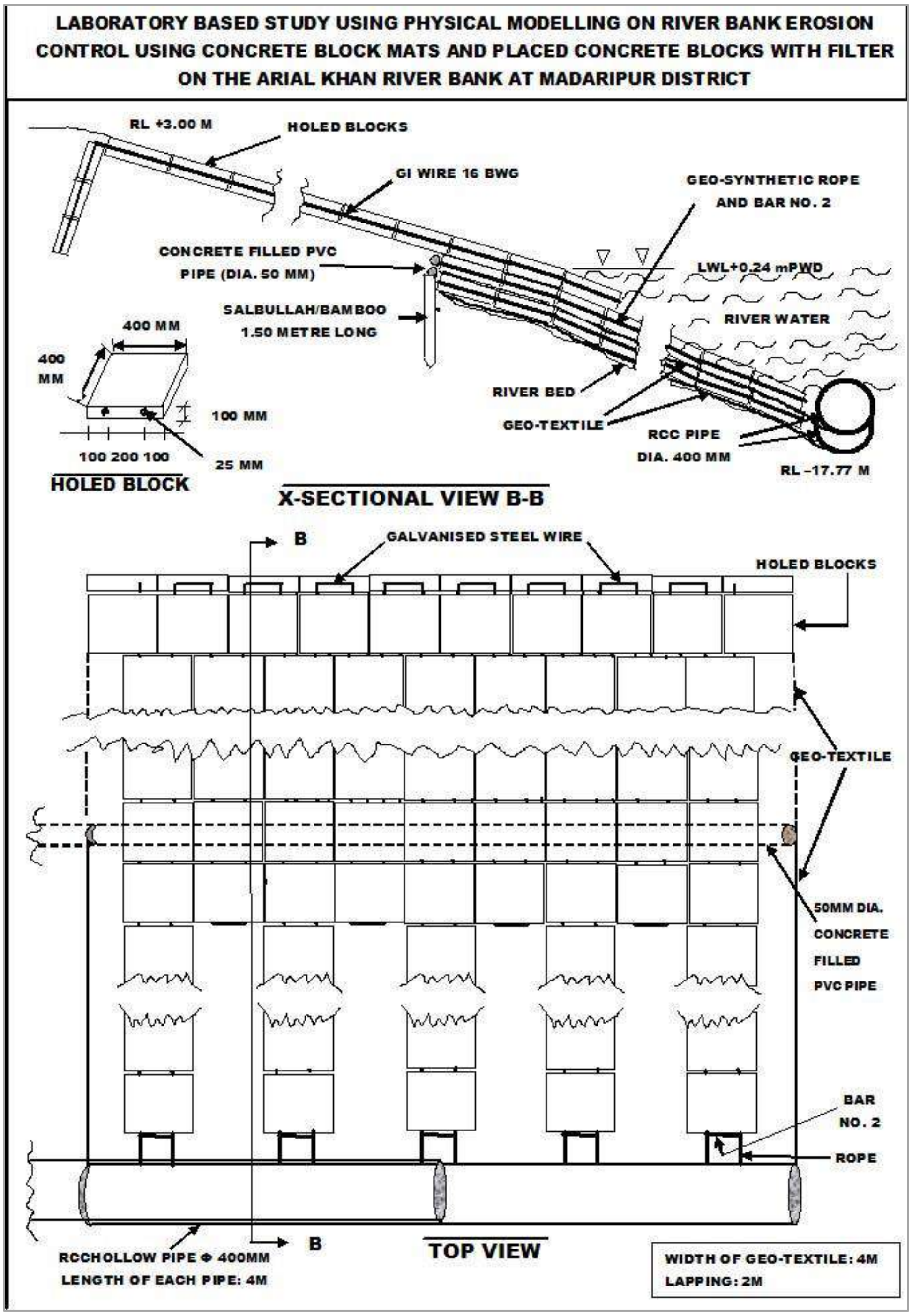


Figure 7.2.3 (b): Typical section (B-B) of erosion control measure by CBM at Arial Khan River bank

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