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Experimental Study on Transportation of Suspended Sediment on Side Basin

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Synopsis

Bangladesh is the biggest delta of the world. Construction of numbers of polders is one of the flood resilient approach. But the presence of coastal polders de-linked the flood plain. The siltation in river causes riverbeds to become higher than the adjacent crop lands, and vast area under the polders became permanently water logged rendering large tract of land uncultivable. The current practice is temporarily de-poldering by cutting embankment for selected tidal basin. An attempt has been made to study the phenomena of tidal basin management reviewing some secondary data and processes involved in successfully operated tidal basins of Bangladesh. And preliminary laboratory experiments are carried out to precisely look into the suspended sediment transport at side basin representing tidal basin. With varying outflow discharge and sediment supply, the transport processes are investigated. Sediment transport mainly depends upon direction of flow and magnitude of flow discharge.

Keywords: TBM, Beel, Side Basin, Sediment Concentration

1. Introduction

The transport of suspended sediment is a key process associated with flows in rivers, reservoirs, estuaries and coastal regions (Zhou et al, 2003). The rivers of southwestern region in Bangladesh are characterized by active deposition of sediment. In addition, the sedimentation problem has been aggravated in this region by the construction of costal polders that de-linked the floodplains from the rivers (IWM, 2005).

In the 1990s, government initiated a drainage congestion removal project Khulna–Jessore Drainage Rehabilitation Project (KJDRP), which later adopted the tidal basin concept according to the demand of the local people. Temporary de-poldering is done and certain areas are to be kept aside as tidal floodplain so that sediments can be deposited on the floodplain rather than on the rivers itself. Such tidal basins are to be rotated among various lowlands within the system so that farmers of one tidal basin do not have to suffer for long time, the process known as Tidal Basin Management (TBM).

The beel is a Bengali term used for relatively large surface, static waterbody that accumulates surface run-off water through an internal drainage channel (Banglapedia, 2004). This type of shallow, seasonal waterbody is common in low-lying floodplain areas throughout Bangladesh (Hossain M. A. R. et al, 2009). The major purpose of TBM is to get suspended sediment deposits gradually under a controlled system on selected tidal beel (Tutu A. A., 2005). TBM is an environment friendly, cost effective and economically viable process to raise coastal lands for enhancing agricultural opportunities (EGIS, 1998).

The present practice is that link canal is constructed which connects the tidal basin with the river by cutting embankment as shown in Fig. 1. Muddy water enters the tidal basin during high tide, depositing major portion of suspended sediments before flowing back towards the ocean during low tide (Khadim et al, 2013; Kibria Z and Hirsch D., 2011). An attempt has been made through laboratory experiments to study transport of suspended sediment at side basin to understand TBM precisely.

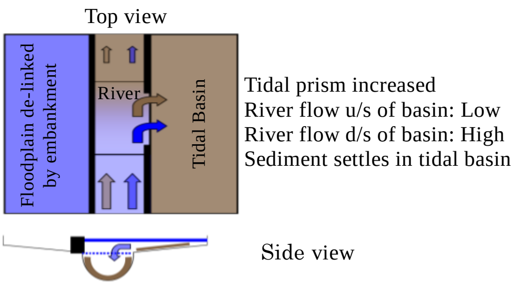

Fig.1 Embankment cut to connect with tidal basin (Leender D. 2013)

2. Data and Methods

Secondary data sources both published and unpublished records such as books, thesis papers, newspapers, articles, magazines, reports of NGOs, different government and non-government project works etc. were used to enrich to study. Key issues addressed included processes involved in three operated tidal basin management, sedimentation processes at beel and morphological changes in river. Additionally preliminary experiment was conducted using experimental facility. Experimental collected data were used to understand the complex process of sediment dynamics.

2.1 Literature Review

With about half of its surface below the 10m contour line, Bangladesh is located at the lowermost reaches of three mighty river systems - Ganges , Brahmaputra and Meghna (Banglapedia, 2012) shown in Fig. 2. In order to increase agricultural production, a series of polders enclosing the low-lying coastal areas was built (BWDB, 2003). The presence of coastal polders de-linked the flood plain. Due to confinement of the rivers by the polders, rivers gradually started to be silted up, and by 1980s, many of the riverbeds became higher than the adjacent crop lands and vast area under the polders became permanently water logged, rendering large tract of land uncultivable (Leender D., 2013).

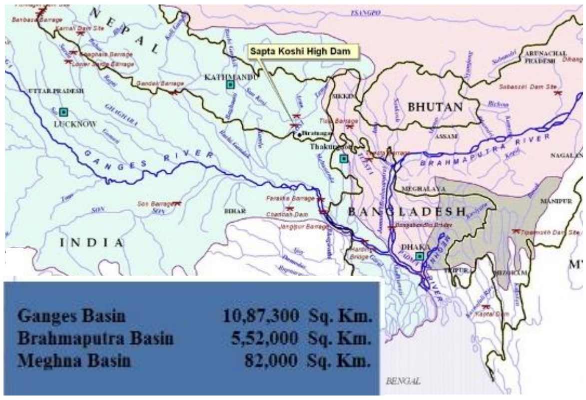

Fig. 2 The catchments of the Ganges, Brahmaputra and Meghna

(Source: www.jrcb.gov.bd/image/Basin_map.jpg)

Observing in decadal timescale, the processes could be roughly categorized as follow:

Coastal Embankment Project in the 1960s
Good crop production in the 1970s
Drainage congestion in the 1980s
Drainage rehabilitation project in the 1990s
Tidal basin operation in 2000s
Tidal basin again not functional in 2010s

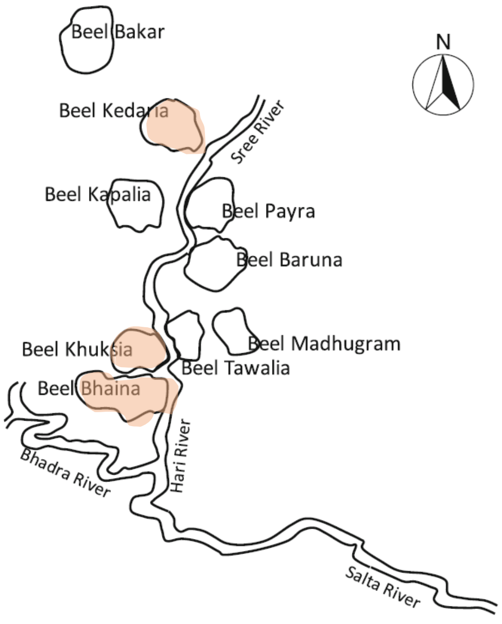

Fig. 3 Location of proposed tidal basins in KJDRP (Rahman R. and Salehin M., 2013)

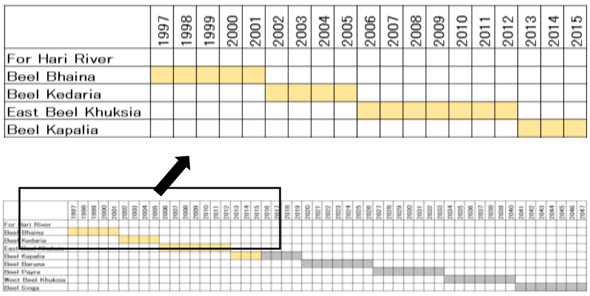

Fig. 4 The proposed plan for rotational tidal basins in the Hari-Mukteswari river (IWM, 2010)

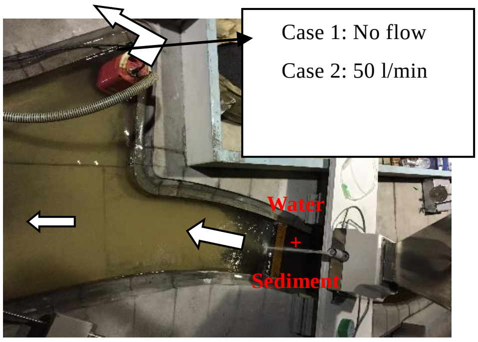

Photo 1 Experimental facility

Three operated tidal basins highlighted in Fig. 3 and mentioned in Fig. 4 were investigated specifically to understand processes of TBM.

2.2 Experimental Setup

The experiments were carried out in a flume located at the Ujigawa Open Laboratory (UOL) of Disaster Prevention Research Institute (DPRI), Kyoto University. The experimental facility is illustrated in Photo 1 and schematic view of the experimental setup is shown in Fig. 5. Several parameters were measured during the experimental studies, namely: 2D water surface velocity by Particle Image Velocimetry (PIV) techniques, flow velocity by electromagnetic current meter, bed profile by laser displacement sensor, surface water level by ultrasonic sensor and water discharge by bucket method.

The flume used is reinforced concrete flume of re-circulating type with wooden base at bottom where water flows. The shape of side basin is limited to triangular shape particularly in this research due to unavailability of space. 3 portions were attempted to study precisely. They are inlet, side basin and outlet. 9 sampling points namely 1 – 9 representing inlet by 1-2-3, side basin/tidal beel by 4-5-6 and outlet by 7-8-9 as shown in Fig. 4 were adopted to study sediment behavior. All experiments were conducted using a constant flow discharge of 125 l/min (Qw) in experimental flume, referred to as inflow and were limited to fixed bed . Dry sediment of mean diameter equal to 80 µm and density 1.76 gm/cc was fed from adjustable sediment feeder. The critical shear velocity is calculated by using the Iwagaki Formula (1956).

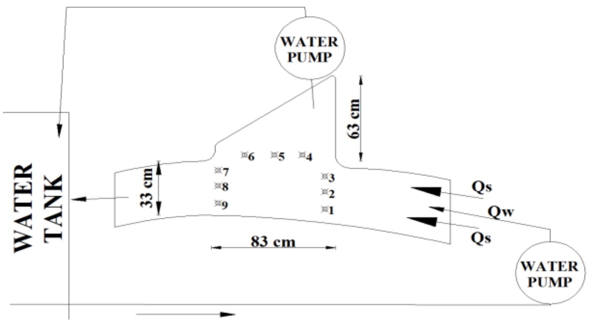

Fig. 5 Schematic view of the experimental setup (Talchabhadel R. et al, 2016)

The details of hydraulic conditions is shown in Table 1. With the Rubey's Formula (1933), the sediment falling velocity was estimated to be w_s=0.32 cm/s.

Table 1 Details of Hydraulic Conditions

Discharge Q(l/s)	2.08
Mean velocity u (cm/s)	6.97
Flow Depth h (cm)	9.05
Shear Velocity u_* (cm/s)	1.07
Shear Velocity Ratio (u_*/u_{*c})	0.47
Reynolds number	2565
Froude number	0.07
Rouse number	1.40

Firstly two cases were investigated as Case 1 where outflow discharge from side basin was not allowed to flow and Case 2 where discharge of 50 l/min was allowed to flow using water pump. The maximum rate that can be given from sediment feeder available in laboratory is 110 gm/min (Qs). To understand direction of sediment flow and final deposited bed level, the maximum rate was used in both cases for 4 hours. Turbidimeter was used in mentioned 9 sampling points to take concentration data continuously. Using siphon pipe of 4 mm, 500 ml of water was drawn in every 30 min taking a sample at inlet (1-2-3), side basin (4-5-6) and outlet (7-8-9) 2 cm below water surface to compare concentration derived after filtration and weighing.

For PIV measurement, the flow was seeded with powdered particles [poly vinyl chloride (PVC) powder] with mean diameter equal to 50 µm. Sony HD camera was used to record the images. The PIV technique determines the velocity of water flow and its flow direction indirectly by measuring the velocity of tracer particles within the flow. Final Bed level data were measured using laser displacement sensor. The output data of bed level measurements are analogical voltage values which were saved in laptop computer using a data collection system (A/D conversion card – Keyence NR-110 and data logger software). Before the bed level measurement a calibration of equipment with predefined thickness as reference levels were used to determine relation between the voltages registered and measured bed level.

Secondly the outflow discharges of side basin were varied. Different cases from 0, 10, 25, 50, 65, 80 l/min were investigated for an hour each to understand transportation phenomena of suspended sediment. Sediment supply of 50 gm/min was allowed and same 9 sampling points were adopted to take measurements for sediment concentration.

Finally by adjusting speed and aperture of sediment feeder 10, 25, 50, 65, 85, 95, 110 gm/min dry sediment were supplied with constant side basin outflow discharge of 50 l/min for an hour each to understand the relationship of sediment concentration at side basin and outlet with sediment concentration at inlet using the same 9 sampling points.

3. Results

3.1 Secondary Data Analysis

During the drainage rehabilitation project, 9 Water Management Associations (WMA) were established, and 68 Water Management Groups (WMG). The WMAs were established based on hydrological boundaries, and WMGs were established in villages or groups of villages.

TBM involves natural tide movement in rivers and taking full advantage from it. During flood tide, tidal water is allowed to enter into an embanked low-lying area (selected tidal basin) where the sedimentation takes place during long storage period and thus acts as a sedimentation trap. During ebb tide, the water flows out of the tidal basin with greatly reduced sediment load and eventually erodes the downstream riverbed and increases the drainage capacity. The natural movement of flood and ebb tide along the tidal basin and downstream river, maintains a proper drainage capacity in that river (Ibne Amir M.S.I et al 2013).

Beel Bhaina has benefitted considerably from the sediment deposition. Farming practices are diverse in beel Bhaina: most farmers grow rice from February to April, cultivate salt water Bagda shrimp from May to July and sweet water Golda shrimp from August to December. Sediment deposition in the basin is high at close to the opening and less at the furthest end of the basin, which varies from few 10 of cm to more than 2 m (Leender D., 2013).

The land levels in beel Bhaina and east beel Khuksia were raised by approximately 80 cm and 1.5 m respectively. In case of beel Kedaria, its impact was not so much significant which might be due to its position of cut where tidal influence is very less (approximately 0.20m in contrast to approximately 2.00m in beel Bhaina). But there was no drainage congestion during the operation of beel Kedaria tidal basin.

Beel Khuksia has been a tidal basin for 7 years, but the initial plan was to only open it for 3 years. Beel Kapalia was planned to be inundated from 2012 onwards for a period of 5 years, but violent protests on June 2nd prevented this. Some of the reasons are compensation mechanism, officially land was not registered with government and lack of trust in government.

According to Leender D. (2013) much land in beel Kapalia and possibly also in other beels was abandoned by Hindus in 1948 when (East) Pakistan and India separated. This land was taken by Muslim settlers and never formally registered, which poses problems with the compensation process in beel Kapalia today. Moreover such extreme viewpoint can be partly attributed to the economic interests of the (shrimp) farmers, who do not want to lose their leased land under any circumstances. Some are landless people who will lose their day job of cultivating in that land. Additionally, they seem to have lost trust in government completely.

The Hari River, which was heavily silted up before implementation of TBM in beel Bhaina tidal basin, was triple its width within only two years of TBM operation and its depth consequently increased to almost 10 m just downstream of the basin(Khadim F. K. et al, 2013). Fig. 6 shows the temporal variation of long profile of Hari River. In July 1997, the river was shallow due to regular siltation whereas in May 2000, river bed in the immediate upstream of beel Bhaina tidal basin dropped by 4 m below MSL and at some downstream locations, bed elevation dropped by around 14 m. Due to TBM, sediments carried by the river were deposited inside the basin, causing heavy scouring river bed at downstream of beel Bhaina tidal basin.

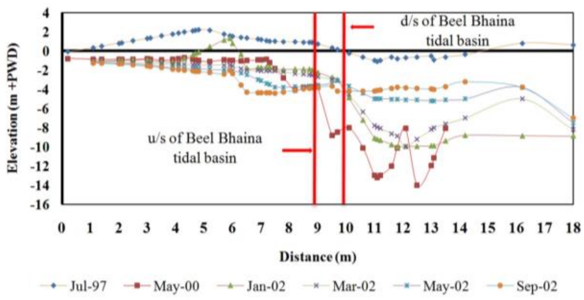

Fig. 6 Temporal variation of profile of Hari River (Khadim F. K. et al, 2013)

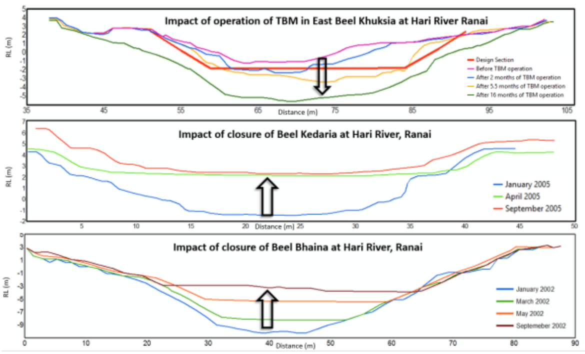

Fig. 7. Impact of operation and closure of TBM at Hari River during different time (IWM, 2010)

During implementation of TBM in beel Kedaria (after beel Bhaina), which is located around 11 km downstream of beel Bhaina, river reach along beel Bhaina tidal basin continued to be silted up again (Fig. 6 and Fig. 7). Similarly impact of operation of TBM in east beel Khuksia and closure of beel Kedaria also shows similar process of bed aggradation in river after closure whereas deepening after operation of TBM. As shown in Fig. 7, the operation of TBM in east beel Khuksia resulted deepening of cross section of river even deeper than designed section. The closure of TBM resulted substantial siltation of river bed in few months.

3.2 Experimental Result

In case 1 water discharge is confined towards outlet so most of the sediment is deposited on the way towards the outlet and very little sediment enters into side basin. But in case 2 around 40-50 % of flow is towards side basin so more sediment is deposited in side basin. The scenario of final bed level measured from laser displacement sensor after 4 hours of experiment for both the cases is shown in Fig. 8.

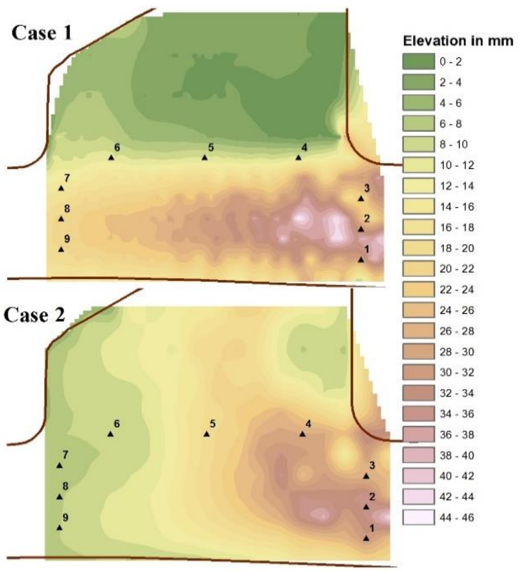

Fig.8 Final bed level in case1 and case2 (Talchabhadel R. et al, 2016)

Change in elevation between two cases is also calculated to see which part of sediment deposited in case 1 have been transported in case 2. Up to 26 mm of extra sediment deposition has been seen in side basin when water is allowed to flow from side basin (Fig. 9). It clearly shows that more the tidal flow in tidal basin more will be sediment transport and deposition.

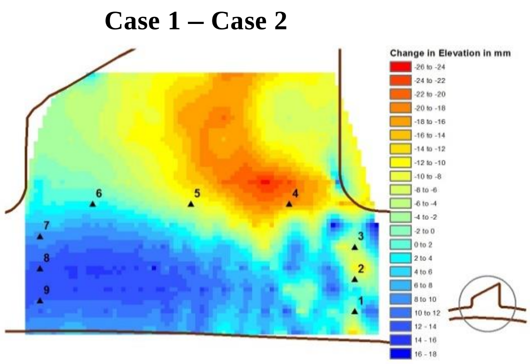

Fig.9 Change in elevation between two experimental cases (Talchabhadel R. et al, 2016)

In Fig. 10, photos in left sides are at a time of initiation of PIV and right sides are during PIV operation in two cases. The flow direction is directed towards outlet in case 1 and side basin in case 2.

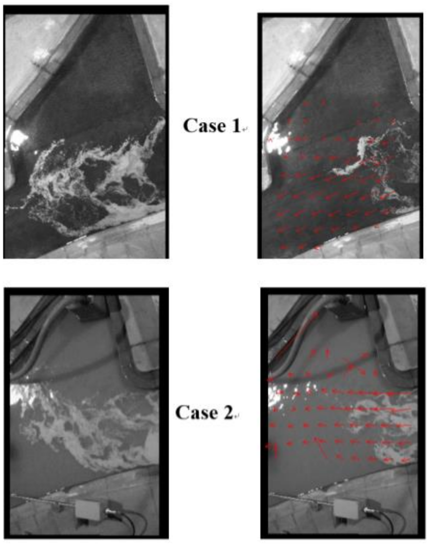

Fig.10 Surface flow visualization using PIV technique (Talchabhadel R. et al, 2016)

In real scenario, transported sediment is finally deposited inside beel but in this experiment, entry of tidal beel is only represented by side basin and whole tidal beel has not been represented. So to understand the sediment transport phenomena, sediment concentration passing through entrance is taken as primary compared to deposited thickness. Even at the beginning of experiment it doesn't have any bed load, but sediment is deposited during experiment and it behaves as bed load which makes sediment concentration to increase with time in all sampling points as shown in Fig. 11. In case 1 sediment concentration at outlet (7-8-9) is greater than sediment concentration at side basin (4-5-6) whereas in case 2 sediment concentration at side basin (4-5-6) is greater than sediment concentration at outlet (7-8-9).

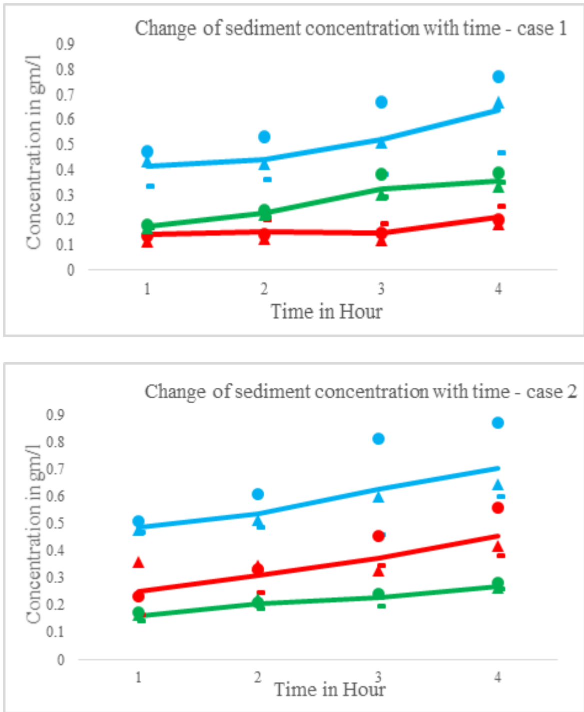

Fig.11 Sediment Concentration at 9 sampling points for case 1 and case 2 (Talchabhadel R. et al, 2016)

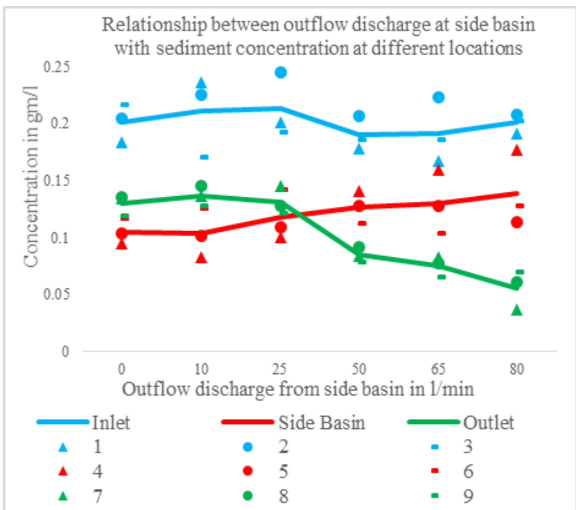

Fig. 12 Sediment concentration at 9 sampling points with varying outflow discharge from side basin (Talchabhadel R. et al, 2016)

With changing outflow discharge from side basin, sediment concentration at inlet (1-2-3) is almost constant. But it has significant effects in outlet (7-8-9) and side basin (4-5-6). Sediment concentration is increasing in side basin (4-5-6) whereas decreasing in outlet (7-8-9) with increase in discharge at side basin (Fig. 12). When higher outflow discharge is allowed to flow from side basin higher sediment is transported towards it and lesser sediment on the course of river.

Finally with varying sediment supply at inlet in sediment feeder, sediment concentration recorded at inlet has minimum value of 0.05 gm/l to maximum of 0.7 gm/l during experiment. It is obvious that increase in concentration at inlet will surely increase concentration at side basin and outlet. But distribution of sediment towards side basin to outlet is almost same in all conditions with ratio varying from 1.41 – 1.67 particularly in this case with 50 l/min outflowed from side basin (Fig.13).

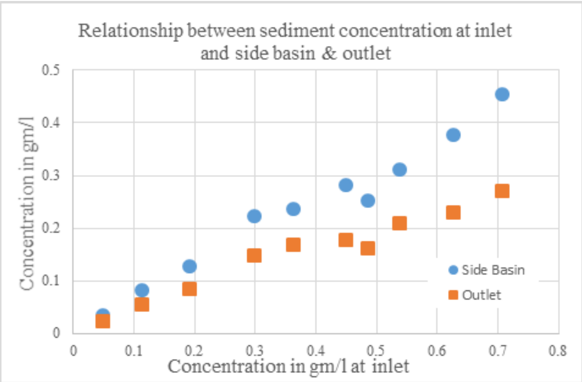

Fig.13 Sediment concentration at side basin and outlet Vs sediment concentration at inlet (Talchabhadel R. et al, 2016)

4. Discussions

Tidal basins are able to drastically decrease riverbed levels or at least stabilize them. If rotation of TBM beels is not carried out very systematically and in a planned manner, then the incoming tides are more likely to drop their sediment in the river channels themselves, which will further accelerate such deposition.

Tidal basins can be an economically and environmentally friendly way of controlling sediment deposits alternative to dredging and large-scale concrete infrastructure (like regulators). The challenges that pertain are, however, of social and political rather than physical nature.

The burning of 12 government and Bangladesh Water Development Board (BWDB) cars during violent protests against the development of a tidal basin in beel Kapalia in June 2012 can be attributed to the lack of interaction between the BWDB and local informal water management entities. Currently, informal water managers control almost all gates (and thus water levels). The official water management associations and groups established during the drainage rehabilitation project have lost much of their power.

In this context TBM should be discussed in different dimensions and perceptions like

- Does TBM raise the required land level of our beel?
- Is TBM a livelihood threat?
- Is TBM method of silt management in river?
- Is TBM an indigenous water management practice?
- Is TBM enough? Do we need more sediment management practice simultaneously?
- Do we need concrete solutions than TBM?

Since sedimentation determines the life span of basin and the rate of raising the land it is recommended that better understanding of sedimentation process is necessary. One significant hydraulic fact is that the faster the river flow is, the more sediment it can carry with it, as its sediment-carrying capacity is a function of velocity. If direction of flow is made easy towards selected tidal beel, more sediment can be transported and deposited. Those tidal basins where more flow passes have more sediment transport. This might happen due to either large size of tidal basin, large size of openings of beel, proper orientation of intake or larger water holding capacity of beel.

Side basin in current study represents only the entrance of tidal basin. Moreover it has other limitations like fixed bed, no tidal effect, constant inflow discharge, no lateral widening of side basin, shape and size of side basin etc. It has to be expanded in the next experiment with larger size of side basin, availability of facility to address tidal effect and varying size of link canal joining flume and side basin.

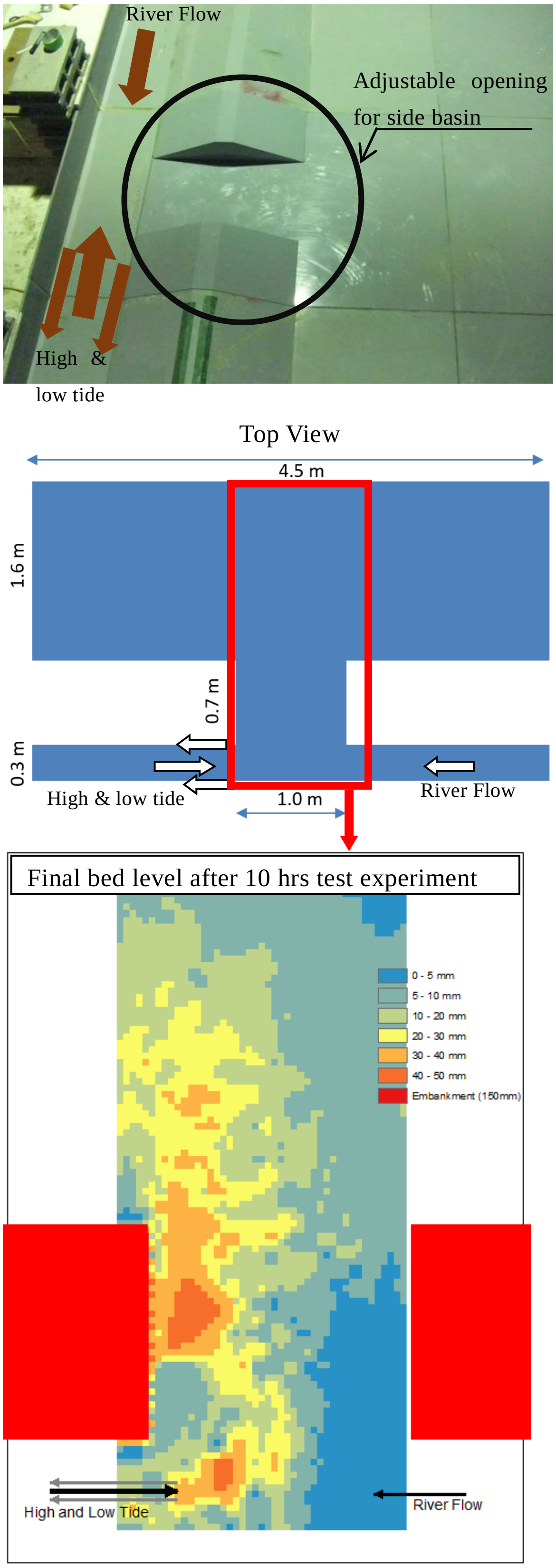

Fig. 14 New stage experiment currently in progress

The next stage experiment for this scenario is currently in progress. Some sets of experiments have been completed and some are still in process. It is equipped with high tide and low tide facility in downstream of flume. Additionally opening for side basin can be adjusted (Fig. 14). Next step will be to develop and verify numerical model which would enable to estimate deposition of suspended sediment in side basin.

5. Conclusions

Tidal basins can be an economically and environmentally friendly way of controlling sediment deposits alternative to dredging and large-scale concrete infrastructure like regulators in the river. The challenges that pertain are, however, of social and political rather than physical nature. Moreover, effective compensation and adaptation mechanism for those people who are impacted by the inundation needs to be secured. There is a large gap in the interaction between different levels of government and between water management entities on river basin level (BWDB) and the field level (informal water management groups).

The present experimental work investigated the suspended sediment transport and deposition at side basin representing tidal beel to see the effectiveness of tidal basin management. From preliminary experiments, it can be inferred that deposition of suspended sediment mainly depends upon direction of flow and magnitude of discharge limiting no tidal discharge in present context. Field based data of size of tidal beel, topographical condition of beel, sediment concentration at river, tidal effects on discharge, lateral widening process of channel, average deposition of suspended sediment in operated tidal basin are very much important to understand the phenomena of TBM precisely.

The current research has to be expanded in next experiment and simultaneously has to be simulated numerically. The next stage experiment will consist of realistic tidal flow condition, moveable bed condition and currently progressing.

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