Study on The Hydraulics During The Construction of A Closure In A Tidal Channel at Meghna Estuary

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Abstract

The study was conducted to assess the hydrodynamic changes during construction of a closure in a 4 km wide tidal channel between Subornachar and Swarnadip island located in the Meghna Estuary. Two construction methods have been considered - vertical and horizontal closing method. A 2D hydrodynamic model, MIKE-21FM, has been set up for the simulations of critical hydrodynamics at different construction stages of these two closing methods. For the horizontal closing method, seven construction stages were considered and for the vertical closing method five construction stages were considered. Model simulation shows that the maximum flow velocities during the construction of the closure simulated during neap flood tide vary from 1.43 m/s to 4.76 m/s at different stages of horizontal closing. For the vertical closing method, the simulated maximum flow velocities vary from 2.76 m/s to 3.88 m/s during neap flood tide. For such a wide channel having a width of 4 km, the vertical closing method of closure construction prevails more feasible as it has lower flow velocities during final construction stage as compared to horizontal closing method.

Keywords: Meghna estuary, Land reclamation, Tidal closure, Hydrodynamic model.

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1. Introduction

The estuary of Lower Meghna River of Bangladesh undergoes a natural process of continuous land accretion and erosion. Natural accretion is observed in the shallow water areas of the Meghna estuary due to the transportation of approximately 1.1 billion tons (Islam et al. 1999) of sediment to the Bay of Bengal (BoB) through the Lower Meghna River. Over a period of 20 years, the south central coast has accreted at a rate of 7.0 km^2/year near the Ganges–Brahmaputra–Meghna (GBM) mouth and the southwest coast has been eroding at a rate of 1.9 km^2/year (Sarwar and Islam, 2013). Due to high demand for agriculture lands through accretion, the natural process in Meghna Estuary requires acceleration by means of structural intervention. Closing of tidal channel by cross dam or tidal closure is one of the effective land reclamation methods.

A number of studies have been carried out in Meghna Estuary for the purpose of land reclamation from the sea to fulfill the demand of agricultural land. Two tidal closures have already been constructed in the Meghna Estuary in 1957 and 1964. The success of these tidal closures has encouraged the Bangladesh Government to construct new tidal closures in the surrounding areas. Several projects including the Land Reclamation Project (LRP), the Meghna Estuary Study (MES) and the Estuary Development Program (EDP) were implemented to assess the potential for additional land reclamation in the Meghna Estuary. A team from the Bangladesh Water Development Board (BWDB) made a priority list of 19 potential cross dam sites based on the LRP and MES findings. The objective of the cross dam sites was to accelerate the natural process of land accretion. From the EDP study, 3 potential sites for construction of cross dam were recommended specifically at the Sandwip-Urir Char- Noakhali mainland. Among the recommended sites, the first planned site for cross dam construction is the dam connecting Urir Char and Noakhali mainland. A study of Feni River Closure Dam in Bangladesh was carried out to redesign the geometric dam profile and sea side slope protection by Stroeve (1993). The Feni River River Closure Dam was designed in 1983, constructed in 1985 and through time a huge area at downstream of the dam was accreted.

The morphological changes in the tidal basin due to construction of a closure dam were studied by Dastgheib (2012). Delft3D model was used to investigate the characteristics and time scale of the morphodynamic effects of construction of the closure dam Afsluitdijk. In this research the focus was mainly on tidal forces. The main outcome of the research was that as soon as the closure was applied the sediment transport regime of the basins changed from exporting to importing. In the study by Ha et al. (2010), a 33 km long sea dike was constructed in the Saemangeum coastal waters in the mid-west area of South Korea. The project which reclaimed a surface area of 40,100 ha, included well-developed tidal flats, two estuaries of the Mankyeong and Dongjin rivers, and a chain of small islands in the outer area off the dike. Three open gaps in the project needed to be closed off. A method of combined vertical and horizontal closure was successfully applied to block off the gaps. Hydraulics at the closure gap during construction stages are the key factors in determining the extent of the closure difficulty (Kooij, 1993). Depending on the hydraulic conditions and the available material and equipment, a choice for the best closing method can be made (Lu et al., 2016). It is essential to study the changes of velocities in and near the closure gap during the closure period, and the way in which they can be computed in the tidal channel during construction of a tidal closure (IWM, 2014). Therefore, devising a suitable option for the construction of the tidal closure without failure during construction is very important, which is the main target of this research.

2. Study Area and Study Aim

The study area is situated in the Meghna Estuary. It covers a 24 km long tidal channel between Subarnochar Upazilla of Noakhali district and an Island named Swarnadip. Swarnadip is a newly accreted Island located in the Meghna Estuary, bordering the Bay of Bengal to the south and was previously known as Jahizzer char as shown in Figure 1. In recent times, the shoreline of this char at north side, north-west side, and north part of the west side have been experiencing severe erosion. However, the char has been experiencing expansion in the south-west, south and south-eastern direction into the Bay of Bengal. During the spring high tide in the monsoon season the land becomes entirely submerged. It is believed that there will be a possible natural merge of Noakhali main land, Swarnadip and Sandwip due to the continuous enlargement of Swarnadip Island in different directions and also the due to the presence of tidal meeting zones between Swarnadip and Noakhali mainland as well as Swarnadip and Sandwip (IWM 2016).

The aim of this study is to simulate the hydraudynamic challenges during the constrction of a closure as hsown in Figure one. Bay of Bengal (BoB) hydraodynamic model based on MIKE21-FM has been set up and the hydraulics at and near the location of the tidal closure during its construction stages have been simulated. The specific objectives of this study were:

(i) to update the BoB model along the study channel and calibration and validation of the model using available data, (ii) to study the coastal hydraulics during closing the study channel under different options- vertical closing and horizontal closing modset and (iii) to devise the suitable option for closing the tidal channel considering both flood tide and ebb tide.

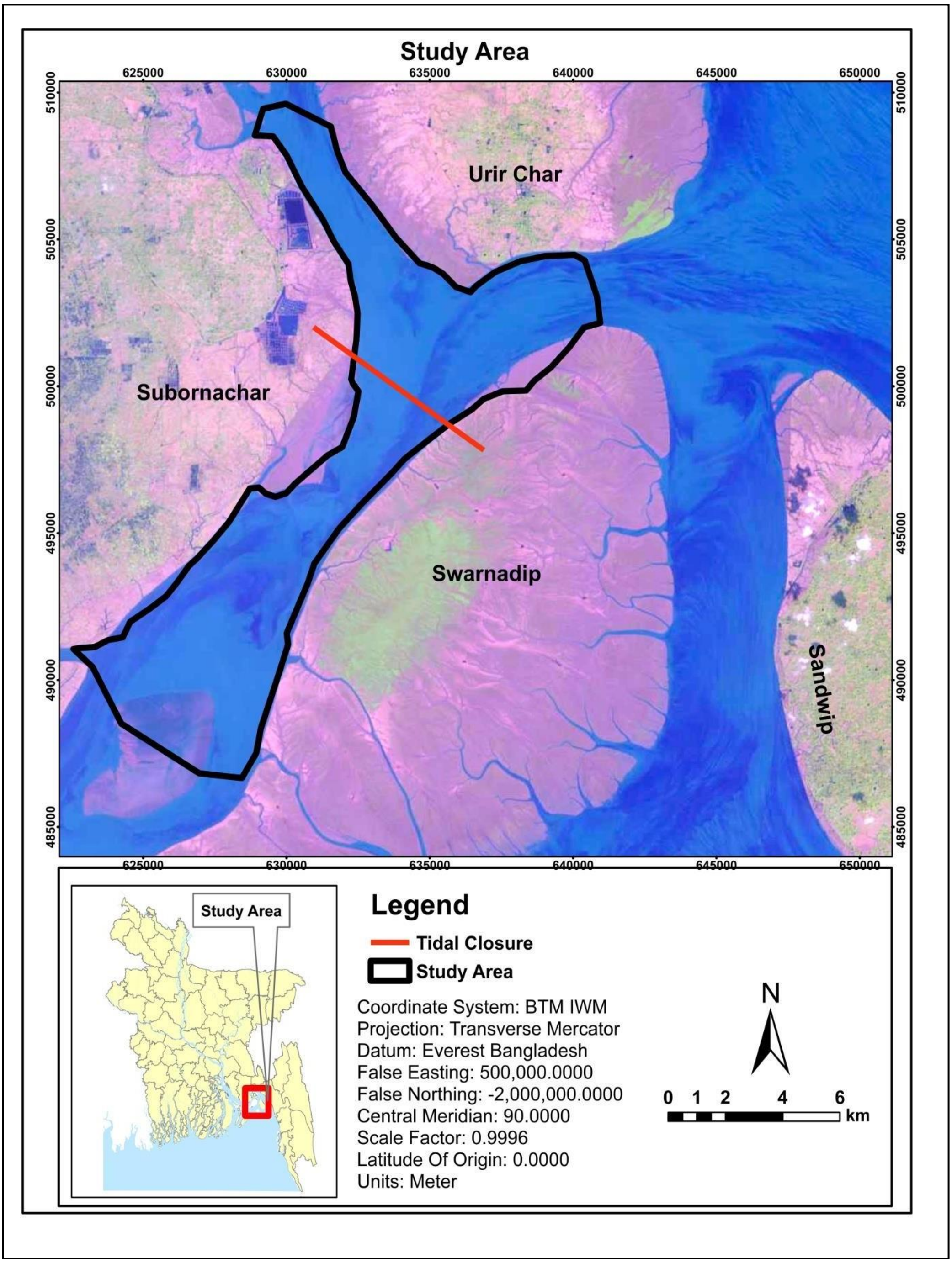

Figure 1: Study area–a tidal channel between Swarnadip and Subornachar

3. Theory and Methodology

The hydrodynamics has been studied using a numerical model software developed by DHI Water and Environment known as MIKE21. MIKE 21 has a number of modules for different purpose and each module solves different sets of equations. In this study hydrodynamic module of MIKE 21FM has been used. It simulates unsteady two-dimensional flows taking into account density variations, bathymetry and external forcing such as meteorology, tidal elevations, currents and other hydrographical conditions. The basic partial differential equations are the depth integrated continuity and momentum equations (shallow water equations and have been presented in Equation (1), (2) and (3).

Conservation of mass equation:

$$\frac{\partial \varepsilon}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=0 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Conservation of momentum equation:

The momentum equation in the x-direction is given by:

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+gh\frac{\partial \varepsilon}{\partial x}+\frac{gp\sqrt{p^2+q^2}}{C^2.h^2}-\frac{1}{p_w}\left[\frac{\partial}{\partial x}(h\tau_{xx})+\frac{\partial}{\partial y}(h\tau_{xy})\right]-\Omega.p$$

$$-fWW_x+\frac{h}{p_w}\frac{\partial p_a}{\partial x}=0$$

....(2)

The momentum equation in the y-direction is given by:

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+gh\frac{\partial \varepsilon}{\partial y}+\frac{gq\sqrt{p^2+q^2}}{C^2.h^2}-\frac{1}{p_w}\left[\frac{\partial}{\partial y}(h\tau_{yy})+\frac{\partial}{\partial x}(h\tau_{xy})\right]-\Omega.p$$

$$-fWW_y+\frac{h}{p_w}\frac{\partial p_a}{\partial y}=0$$

....(3)

where,

p and q	flux in x and y directions respectively $(m3/s/m)$. x and y (m) are Cartesian Co-ordinate(s).
t	time (s)
h	water depth (m).
g	acceleration due to gravity (9.81 $m/s2$)
ε	sea surface elevation (m).
f	wind friction factor = 0.0008 + 0.000065W
W, Wx, Wy	wind speed (m/s) and its components in x, y directions

Ω	Coriollis parameter
pa	atmospheric pressure (N/m2)
C	Chezy resistance (m1/2 /s)
$\tau yy, \tau xy, \tau xx$	components of effective shear stress (N/m2)

There are several methods to close a tidal channel. Depending on the hydraulic conditions and the available material and equipment, a choice for the best closing method can be made. In this study two of the following closing methods (vertical closing method and horizontal closing method) have been used as shown in Figure 2. Each of these methods differ in the hydraulic conditions during closure construction.

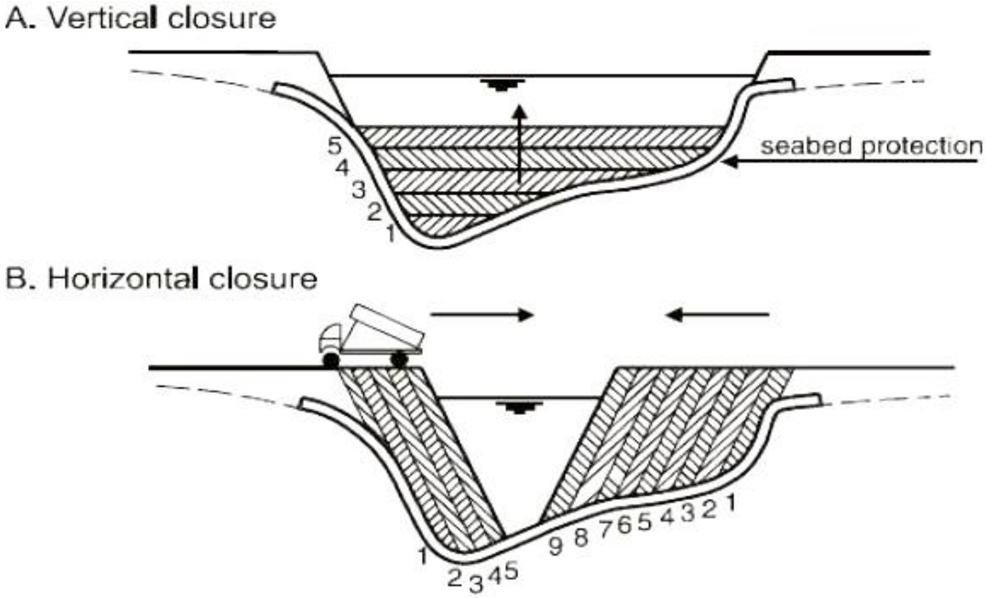

Figure 2: Gradual closing methods showing vertical and horizontal closing (Franco et al. 2007)

3.1 Vertical Closing Method

When applying a vertical closing method, a sill is built over the entire length of the cross section. To include the energy loss in the hydrodynamic model, the sill is included as a structure (dike) in the model. Unfortunately, the model does not give the flow velocity at the crest of the sill. This velocity is computed using appropriate weir formula using the model results of the discharge through the gap and water levels and flow velocities at its upstream and downstream. Current speed at the tidal closure locations for different closure openings and sill level were calculated based on three conditions as shown in Equation (4), (5) and (6).

Formula for overflow weir: $q_o = \mu h_2 \sqrt{2g(H - h_2)};$ when $h_2 \geq {}^{2}/_{3} H \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$

where, qo is the over flow discharge per unit width of the sill, µis a over flow weir coefficient, H is the total head, h2 is the downstream water level and g is the gravitational acceleration.

Formula for submerged weir: $q_s = m * {}^{2}/_{3} \sqrt{{}^{2}/_{3}\, g} * H^{\frac{3}{2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$

Villemonte formula used in MIKE21: $Q = wc(H_{us} - H_w)^k [1 - (\frac{H_{ds} - H_w}{H_{us} - H_w})]^{0.385} \ldots\ldots\ldots\ldots (6)$

where,q_s is the submerged discharge per unit width over the sill, *m* is a submerged weir coefficient, *g* is the gravitational acceleration and *H* is the total head

where Q is the discharge through the structure, w is width, c is weir coefficient, k is the weir exponential coefficient, H_{us} is upstream water level, H_{ds} is downstream water level and H_w is weir level taken with respect to the global datum. The value of the weir exponent is 1.5 and the default value of the weir coefficient is 1.838 (DHI, 2014).

3.2 Horizontal Closing Method

In case of a horizontal closing method, the channel will be closed by building out the roundheads from both sides. As a result of decreasing the cross section horizontally, the flow velocities will increase continuously up to the final closure stage. These high flow velocities in the final stage demand large closuring elements such as concrete cubes, gabions or large rock units. This method can therefore only be applied in cases where the head over the closure gap is not large (Kooij, 1993).

3.3 Data Collection

In order to simulate the hydrodynamic model, water level, bathymetry and discharge data at the study area were collected from Institute of Water Modelling (IWM) and Bangladesh Water Development Board (BWDB) for the year 2014. The data were collected at Swarnadip West, Swarnadip East and West Sandwip.

4. Hydrodynamic Model Set up and Run Conditions

The Bay of Bengal (BoB) model is based on the MIKE 21FM module of the Danish Hydraulic Institute (DHI). MIKE 21 FM modeling, in turn, is based on an unstructured, flexible mesh that consists of linear triangular elements. The BoB model domain extends from Chandpur on the lower Meghna River in the north to 16° N latitude in the Bay of Bengal in the south. The grid or mesh size of the BoB model decreases from 200 km^2 in the deep ocean to 0.1 km^2 near the coastlines and islands (Figure 3).

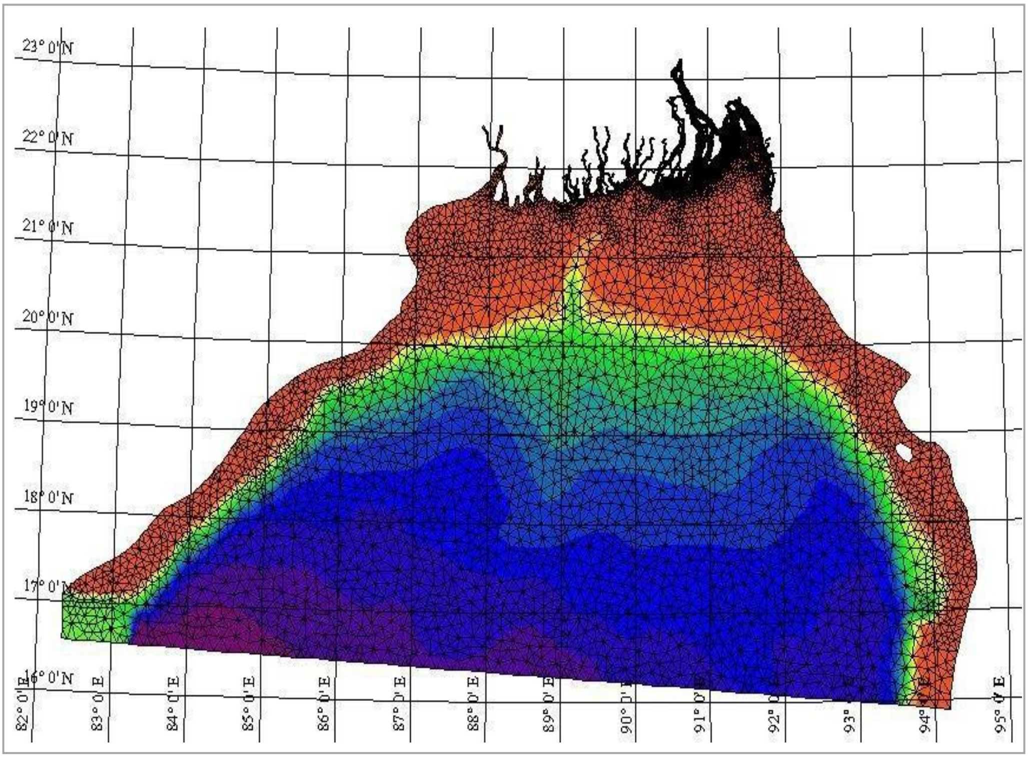

Figure 3: Boundary of the Bay of Bengal (BoB) Model

The model consists of three boundaries- first one is water level in the lower Meghna River near Chandpur area, second one is the water level at Padma River at Baruria Transit and the third one is the open boundary in the sea area along the line extending from Vishakhapatnam of India to Gwa Bay of Myanmar. In shallow areas bed friction is important and can effectively be used to adjust the amplitude of tides. Bed friction is defined by the Manning number, M. The Manning number, M used for calibration and validation in this study. The Manning number ranges from 75 to 80 within the Swarnadip-Subornachar channel during the dry period and from 90-95 during the wet period.Initially the mesh size was altered. The maximum area of the triangular mesh in the Swarnidp-Subornachar channel was reduced from 450000 m^2 to 15000 m^2. The bathymetry was updated according to the updated mesh size for the model input as shown in Figure 4.

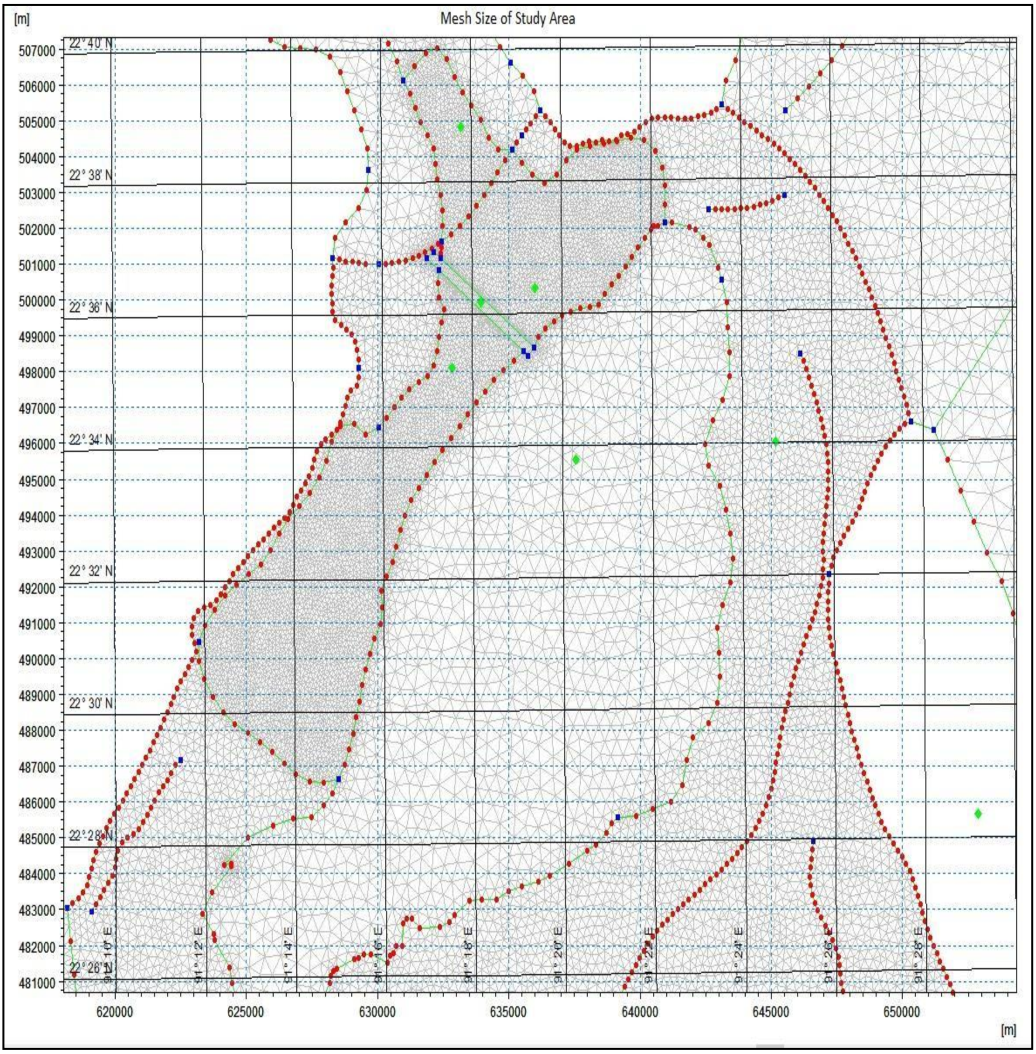

Figure 4: Updated flexible mesh of the hydrodynamic model area

4.1 Run Conditions

For horizontal closing method, seven construction stages were studied before the final closure. The flow velocities were simulated at different locations. For the vertical closing the sill was raised starting at -5mPWD to 5mPWD before the final closure. The increments were done in 2 m. A list of the construction stages for both closing methods are given in Table-1.

Table-1: Description of the construction stages for horizontal and vertical closing method

Horizontal closing		Vertical closing	
Stage	Size of opening in the channel	Stage	Crest level of closure
H1	3650 m	V1	- 5 mPWD
H2	2850 m	V2	- 3 mPWD
H3	2050 m	V3	- 1 mPWD
H4	250 m, 250 m, 1050 m	V4	+1 mPWD
H5	250 m, 250 m, 300 m, 300 m	V5	+5 mPWD
H6	300 m, 300 m		
H7	250 m, 250 m		

5. Results and Analysis

The model was run for the period of February to March with a time step of ten minutes for calibration. For validation the model was run for the month of October with a time step of ten minutes. The model was calibrated at East Swarnadip and West Swarnadip for water level. The validation shows good agreement between the measured and simulated water level from the model.

The model simulation was done for different stages of vertical and horizontal closing of the channel. The model was run from 10th March to 13th March at a time step of ten minutes (neap tide) and from 18th March to 21st March at ten minute time step (spring tide) respectively. Mainly the hydraulics during construction at and near the location of the tidal closure were studied. The details of the different closing methods are discussed in the following sections.

5.1 Before Construction of the Closure

Before the construction of the closure, the flow velocities at the vicinity of the proposed closure have been simulated along with the water level variations during spring flood and ebb tide. The spring flood tide simulation results have been presented in Figure 5. It is seen that the maximum flow velocities are found to be 1.37 m/s during flood tide and 1.20 m/s during ebb tide.

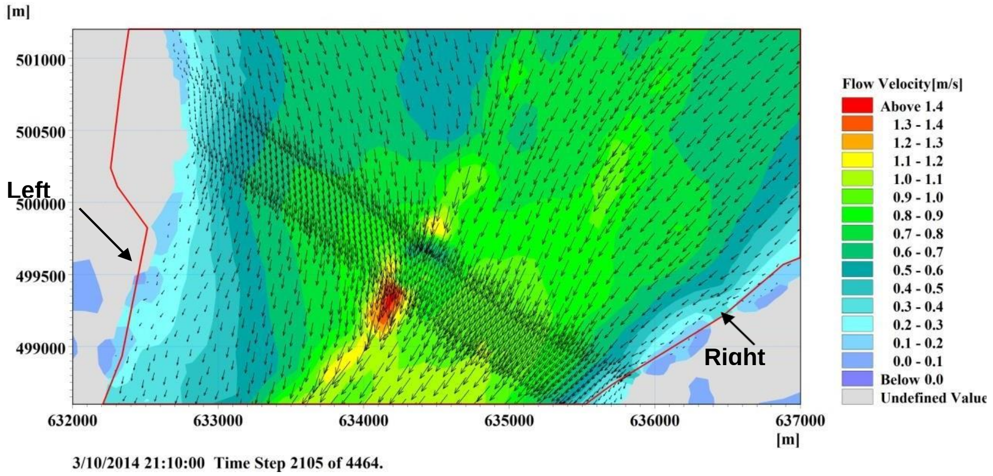

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Figure 5: The flow velocity in the Swarnadip-Subornachar Channel during spring flood tide before construction of closure

5.2 Horizontal Closing

Ananalysis of the flow velocity and water level in the vicinity of the proposed tidal closure during the construction stages have been done. The construction window for the tidal closure in this study is chosen as the neap tidal cycle within 10 to 11 March (for model simulation purposes based on existing data). Figure 6(a), 6(b) represent the flow velocities during the construction stage H1 at spring flood and spring ebb tide respectively. The maximum flow velocity is found to be 1.57 m/s during spring flood tide and 1.77 m/s during spring ebb tide at H1. Similarly, the model has been simulated for all other construction satges (H2 to H7) of horizontal closing.

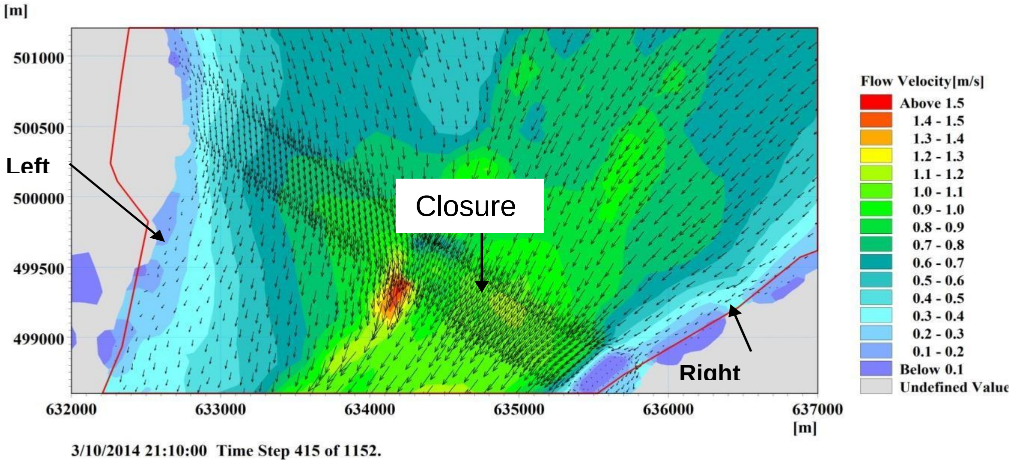

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Figure 6(a): Velocity vectors in the Swarnadip-Subornachar Channel during spring flood tide at construction stage H1

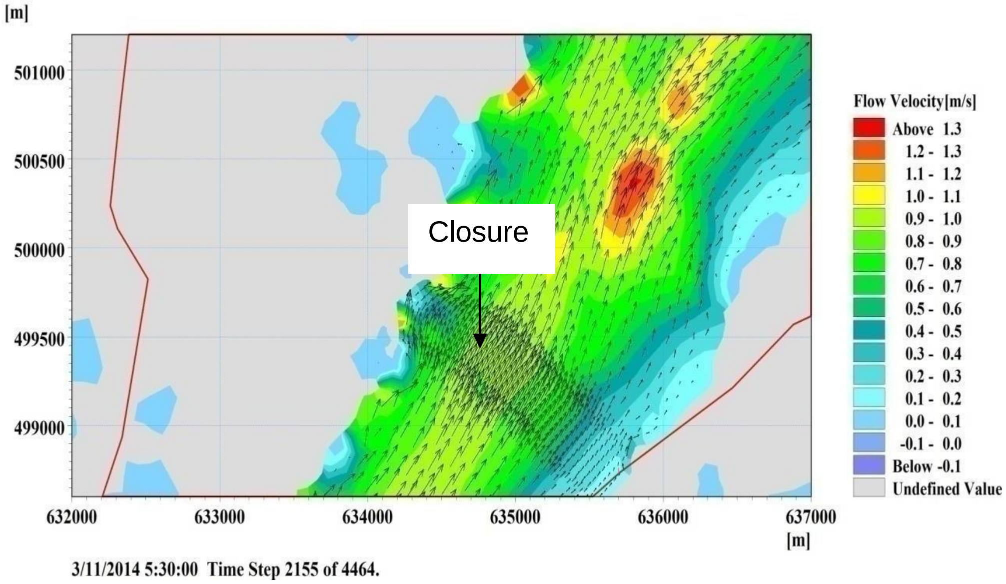

Figure 6(b): Velocity vectors in the Swarnadip-Subornachar Channel during spring ebb tide at construction stage H1

A summary of the maximum flow velocities obtained during the construction stages for the horizontal closing method is given in Table-2. It is seen that the flow velocities keep on increasing from construction stage H1 to construction stage H7 as closure length constantly increases and the opening in the channel reduces.

Table-2: Maximum flow velocities simulated during the different stages of horizontal closing

Construction Stage	**Flow Velocity (m/s)**							
	Spring Tide				**Neap Tide**			
	Flood	Percentage increase in flow velocity	Ebb	Percentage increase in flow velocity	Flood	Percentage increase in flow velocity	Ebb	Percentage increase in flow velocity
H1	1.57	6.08%	1.77	1.72%	1.43	4.38%	1.27	5.83%
H2	2.28	54.05%	1.84	5.75%	1.7	24.09%	1.65	37.50%
H3	3.04	105.41%	2.92	67.82%	2.28	66.42%	2.6	116.67%
H4	3.4	129.73%	4.07	133.91%	2.56	86.86%	3.44	186.67%
H5	4.51	204.73%	4.84	178.16%	4.36	218.25%	4.81	300.83%
H6	4.95	234.46%	4.88	180.46%	4.58	234.31%	4.9	308.33%
H7	5.02	239.19%	5.16	196.55%	4.76	247.45%	4.98	315.00%

As the channel width reduces flow velocities increase. The increase in flow velocities is 6.08% at construction stage H1 and 239.19% at consruction stage H7 during spring flood tide. During neap ebb tide these values are 5.83% and 315% respectively.

5.3 Vertical Closing

The maximum flow velocities during vertical closing over the sill of the closure were simulated for spring and neap tide at different construction stages. During spring flood tide the maximum flow velocities simulated over the sill are found to be 3.33 m/s, 3.60 m/s, 4.80 m/s, 4.16 m/s and 3.86 m/s for construction stages V1, V2, V3, V4 and V5 respectively. These values are 2.76 m/s, 3.07 m/s, 3.88 m/s, 3.14 m/s and 2.90 m/s respectively during neap flood tide.

6. Conclusions

The flow velocities obtained during the construction period for the horizontal closing method keep on increasing from construction stage H1 to construction sstage H7. At construction stages H3, H4, H5, H6 and H7, the channel is recommended to be closed during the neap flood tide. This is because the flow velocities at neap ebb tide are higher than the neap flood tide and vice-versa for H1 and H2. For the purpose of closing a tidal channel the lowest flow velocity periods are selected to reduce the possibilities of scouring during construction. It is suggested that the channel should be closed completely after construction stage H5 (four openings, total 1100 m) at once. It is practically very hard to close such a long channel during a single neap tidal cycle. Since the channel is about 4000 m wide at the location of the closure, there is a possibility that a few construction stages with the largest closure length and transition from one to the other construction stage might take two neap tidal cycles to finish the construction. Therefore, spring tide flow velocities should also be considered. It is seen that the flow velocities during vertical closing method are lower than that in the horizontal closing method. Therefore it is recommended that the vertical closing method should be chosen for closing the Swarnadip-Subornachar Channel. Though the simulations were done for the month of March, it is suggested that the construction should be done during the month of January which has the lowest water levels as well as the hydraulic condition throughout the year.

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