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SHORT COMMUNICATION

Erosion-Deposition in Hooghly Estuary

T. Sanyal, A.K. Chatterjee and G.C. Mandal
Calcutta Port Trust, Calcutta – 700 043

ABSTRACT

An attempt has been made to give an overall idea of erosion-deposition at the Balari-Haldia-Gangra reach of the Hooghly estuary in India. The sediment transport relationships developed by van Rijn and Ackers-White have been tried. Calculation of bed-load transport has been made based on bed material sizes, flow conditions, depth and width of the channels, during 1993-97. Comparison of the results indicates the discrepancies between calculated and observed quantum of deposition/erosion to the extent of 0.6 to 1.8 times in case of van Rijn's equation and 0.8 to 1.8 times in case of Ackers-White's model. Results suggest that the Haldia-Balari channel is deteriorating due to accumulation of sediment.

NOMENCLATURE

T	Transport stage parameter
D_*	dimensionless particle parameter
q_b	Bed-load transport per unit width (m^2/s)
X	Sediment transport, mass flux per unit mass flow rate
D_{gr}	Dimensionless particle size
F_{gr}	Sediment mobility number
G_{gr}	Dimensionless sediment transport rate
D	Sediment diameter
A	Value of F_{gr} at nominal initial motion
A'	As above, but for graded sediment
c	Coefficient in sediment transport function
m	Exponent in sediment transport function
n	Transition exponent depending on sediment size
g	Acceleration due to gravity
D_i	Mean diameter of sediment for one fraction of grading curve
i	Hydraulic gradient
s	Specific density of sediment
d	Mean depth of flow
C	Chezy coefficient
u	Mean velocity of flow
$u_{*,cr}$	Critical bed shear velocity according to Shields curve
u'_*	Effective bed shear velocity related to grains
u_*	Overall bed shear velocity
α	Coefficient in rough-turbulent equation
ν	Kinematic viscosity coefficient
C'	Chezy coefficient related to grains

1. INTRODUCTION

In the tidally active Hooghly estuary in India with varied head water supply, a reach of about

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15 km at 100 km downstream of Calcutta, has been considered in Balari-Gangra region (Fig.1). It occupies a strategic position wrt to navigation because of its location at the southern extremity of the low water crossings for out-bound vessels from the Calcutta port as well as from the Haldia dock.

Improvement of navigational channel in this region is thus of great importance for the deep-drafted cargo vessels, especially with regard to oil and coal traffic. Apart from the commercial traffic, it also handles passenger ships that serve other locations strategically important from the defence point of view, like the Andaman & Nicobar islands. Naval battleships of the Indian Navy also visit Calcutta port. Battleships of friendly foreign countries also visit Calcutta port as a part of goodwill mission. It can thus be seen that keeping the navigational channel open is also of prime importance from the defence point of view.

After several studies, a guide wall of 2.8 km was constructed at the northern end of Nayachara island (Fig. 1) as a part of overall comprehensive scheme for improving navigation. A periodic fall in navigable depth over this region still occurs due to silt deposition of variable magnitudes, causing great hindrance to navigation in the Calcutta port and the Haldia dock.

This paper attempts to quantify erosion-deposition over a period of four years (1993-97) based on survey data and estimate the net bed-load transport of sediment in this region.

2. THEORETICAL BACKGROUND

To investigate erosion-deposition in a river reach, it is necessary to understand the mechanics of sediment transport which can further be divided into two categories, cohesive sediment transport and non-cohesive sediment transport. Extensive literature[1-5] exists primarily dealing with cohesionless sediment transport in steady, uniform and unidirectional flow. Most of these sediment transport relationships have been developed mainly using laboratory data. Some limited field data have also been used for validation of the formulae. No such specific formula exists to compute sediment transport in unsteady and reversible flow as is encountered in tidal flow condition. Basically, the transport of sediment depends on the geo-technical properties of the bed material and flow characteristics.

3. ANALYTICAL CONSIDERATION & METHODOLOGY

The problem under investigation is for a tidal flow regime where the flow varies with time and is reversible. So, certain inherent assumptions and simplifications are required for applying sediment transport formulae developed under steadystate conditions. If one assumes shorter time interval for computation, the discharge can be considered as quasi-steady. Accordingly, the steadystate formulae can be assumed to be applicable under tidal conditions. In the present study, the erosion-deposition due to bed-load sediment transport only has been considered, and the formulae adopted for computations are the ones proposed by van Rijn[1,2] and Ackers-White[4,5] which can be expressed as:

(a) van Rijn's equation for calculation of bed-load transport

$$q_b = (0.053)\sqrt{\{(s-1)g\}}.(D_{50})^{1.5}.(T)^2 .(D_* \quad (1)$$

where

$$T \quad (u'_* / u_* \quad 1 \quad (2)$$

$$D_* = D_{50}[(s-1)g/v^2]^{1/3} \quad (3)$$

(b) Ackers-White's equation for calculation of sediment transport

$$X \quad G \quad sD/d).(u/u_*)^n \quad (4)$$

where

$$G_{gr} = c[(F_{gr}/A')-1]^m \quad (5)$$

$$F = [(u_*)^n / \sqrt{\{gD(s-1)\}}].$$
$$[u/\{(\sqrt{32})\log_{10}(\alpha d/D)\}]^{(1-n)} \quad (6)$$

$$D_{gr} = D\left[g(s-1)/\nu^2\right]^{1/3} \qquad (7)$$

$$n = 1.0 - (0.56)\log_{10} D_{gr}$$

$$m = (9.66/D_{gr}) + 1.34 \qquad (9)$$

$$\log_{10} c = (2.86)\log_{10} D_{gr} - (\log_{10} D_{gr})^2 - 3.53 \qquad (10)$$

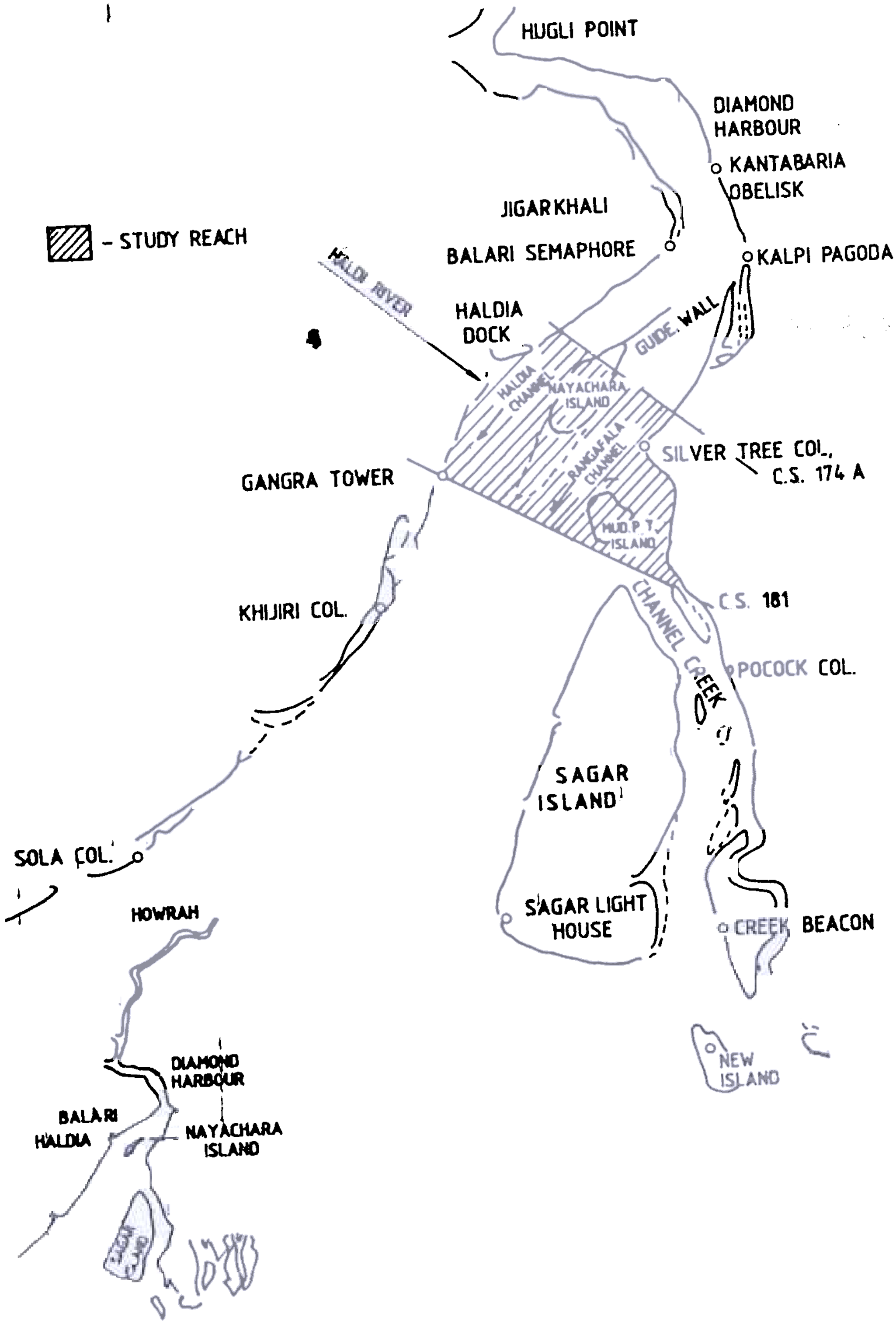

Figure **Hooghly estuary**

$$A = (0.23/\sqrt{D_{*}} \quad 0.$$

$$A \quad A(D_{*}/D.$$

$$D \quad (D_{84} + D_{16})/2 \qquad (13)$$

For computing the bed-load transport rate the estimation of parameters, such as $u_*, u'_*, u_{*cr}, C, C', \alpha$, i (hydraulic gradient), d, etc., are required. The detailed procedure for estimating the parameters is as follows:

(a) Grain sizes (D_{16}, D_{50}, D_{84}) of bed materials, which are collected and later analysed in the Analytical Laboratory of Hydraulic Study Department of Calcutta Port Trust, have been used. Median diameter of grain sizes varies between 0.087 mm and 0.2 mm.

(b) Mean velocity of flow (u) has been computed by averaging the velocity components in the perpendicular direction of the cross-section from the observed velocity data at different depths.

(c) The mean depth of flow (d) has been calculated from the cross-sectional area divided by water surface width of the cross-section.

(d) The hydraulic gradient (i) has been computed from Chezy's equation considering the tidal elevations at different locations.

(e) Overall bed shear velocity (u_*) has been computed from the relation $u_* = \sqrt{(gdi)}$.

(f) Bed shear velocity related to grains (u'_*) has been computed from the relation $u'_* = (\sqrt{g})u/C'$ with maximum value equals to u_*.

(g) Critical bed shear velocity (u_{*cr}) is computed according to Shields curve.

(h) The values of α, C, C', ν, s have been assumed as 12.3, 50.0, 15.0, 0.000001 and 2.65, respectively with the help of references and using computer-based optimisation technique.

Values for the above parameters mentioned in (a)-(h) have been computed separately for the two channels, viz., Haldia channel and Rangafalla channel.

4. RESULTS & DISCUSSION

Based on the above assumptions, calculations have been made to find out net deposition-erosion volume in the study reach covered by the two channels using Eqns (1)-(3) and Eqns (4)-(13) separately for one tidal cycle first and then it has been considered over the whole year. The results are shown in Table 1. For comparison of the above results, erosion-deposition in the zone of study have been done for the two channels from the differential survey charts prepared by the Survey Wing of the Marine Department, Calcutta Port Trust. These results are shown channelwise in Table 1. Also, the combined net results for the whole reach covered by the two channels are shown in Table 1.

It is observed from Table 1 that for Haldia channel, deposition has taken place during 1993-94, 1994-95, 1996-97, while erosion has occurred in 1995-96. For the Rangafalla channel, erosion has taken place in 1993-94 and 1995-96, while deposition has occurred in 1994-95 and 1996-97. Table 1 shows the combined net amount of sediment erosion/deposition which follows the same trend as in case of Rangafalla channel.

Table 1. Calculated and observed volume of sediment at bed in 10^6 M^3

Year	Haldia channel			Rangafalla channel			Two channels taken together		
	Observed	Calculated		Observed	Calculated		Observed	Calculated	
		VR	AW		VR	AW		VR	AW
1993-94	+ 7.08	+13.0534	+13.0162	–28.48	–31.5430	–32.0238	–21.40	–18.4896	–19.0077
1994-95	+ 8.94	+ 6.1979	+15.7500	+31.11	+29.3995	+34.1633	+40.05	+35.5974	+49.9133
1995-96	–21.90	–12.3660	–19.6028	–21.00	–18.4047	–18.9795	–42.90	–30.7706	–38.5823
1996-97	+30.45	+30.4515	+33.0555	+23.67	+17.7910	+19.4984	+54.12	+48.3749	+52.6981

\+ Indicates deposition, – indicates erosion

VR and AW stand for van Rijn and Ackers-White, respectively

Table 2. Discrepancy ratios between calculated and observed quantum of sediment

Year	Haldia channel		Rangafalla channel		Two channels taken together	
	VR	AW	VR	AW	VR	AW
1993-94	1.84	1.84	1.11	1.12	0.86	0.89
1994-95	0.69	1.76	0.94	1.10	0.89	1.25
1995-96	0.56	0.90	0.88	0.90	0.72	0.90
1996-97	1.00	1.09	0.75	0.82	0.82	0.97

It is also revealed that the calculated quantum of sediment deposition/erosion made on the basis of Eqns (1)-(3) shows an increase or decrease by further 0.6 to 1.8 times the observed quantum of sediment deposition/erosion. These values are 0.8 and 1.8 for Eqns (4)-(13), respectively.

It has also been observed that the amount of sediment which gets deposited deep inside the Haldi river is about one million cubic meter.

5. CONCLUSIONS

Based on the above study it has been observed that Haldia channel is deteriorating continuously. Proper remedial measures are needed to improve the navigable depth of this channel.

The reasons for the discrepancy ratios between predicted and measured quantum of deposition/erosion shown in Table 2 may be attributed to the presence of Haldi river and disposal of dredged spoils as well as simplification in the computations and other sources of errors.

Further investigations and modifications of different parameters are required to improve upon the results of the present study so as to develop a separate mathematical model for the tidal estuary. By applying these concepts, the simulation of numerical model for the sediment transport in Hooghly estuary is in progress. More sets of field data are required for its calibration.

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