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OPTIMIZATION OF SEDIMENT MEASUREMENTS IN A BRAIDED RIVER

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ABSTRACT : The Jamuna river is very dynamic, the variability of different hydraulic parameters is large even in short time span. Therefore it is desirable to complete sediment measurements in a transact within a minimum time to avoid error in a set of data. Moreover, optimization can lead to less work in taking and processing samples. The data of the River Survey Project (FAP 24) was collected from the Jamuna river at Bahadurabad and was used in this analysis. The analysis is based on the transports computed by Straub and Chinese methods from 2-point sampling at 0.2 and 0.8 depths and they are compared from 6-point sampling giving a good agreement with Straub method and Chinese method. On the optimization of density of vertical over a transect, two Indexes are developed which show that number of verticals can be reduced without an intolerable reduction of the accuracy of the calculated sediment transport with greater number of verticals. The u^2/h-Index where 'u' is the depth average flow velocity and 'h' is the local water depth, indicates how far the flow field is adopted to the shape of the cross-section . As long as the flow pattern is congruent, the transverse 'u^2/h' distribution remains the same. If this distribution is more regular and stable in time, then a stronger reduction in a number of vertical is possible. Another q_s/q^n-Index, where 'q_s' is suspended sediment transport, 'q' is water discharge and 'n' is an exponent determined from the data set, is used to see how far the sediment transport is adopted to the flow field. The more regular the transverse distribution of the Index, the more reductions in number of velocity verticals are possible. The results of the test gauging data 1993 show an accuracy of 2 (plus 2) percent by using these Indexes where 8 (eight) verticals are removed from 19 (nineteen) verticals. If this accuracy is sufficient then the time needed to measure the sediment transport in a transact can be reduced considerably.

KEY WORDS : Optimization, Braided river, Sediment transport, Straub method, Chinese method.

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INTRODUCTION

Sediment transport in the main river is not uniformly distributed but varies in the longitudinal as in the transverse directions. These variations are partly caused by large scale changes in water depth, flow velocity and mean grain size. Moreover the river bed is covered with sand waves over which the sediment transport is highly non uniform. This makes sediment sampling very complex and time consuming. As the variability of sediment transport is large, faster methods are sought to maintain the required accuracy. Additionally, minimum cost for gauging is also desired.

In the study of river behavior, the sediment transport (bed material load in suspension and bed load) in a reach is of main interest. Ordinarily, in large sand-bed rivers, only suspended sediment is sampled due to the difficulties and uncertainties associated with using bed-load samplers in such river. In this paper optimization of sediment measurements pertains to suspended bed material load. Fine particles or wash load is rather uniform in transverse distribution.

Suspended sediment discharge over an entire cross-section is usually measured by dividing the cross-section into a number of sections. Sediment discharge passing through each section is first obtained by taking measurements at several points in a vertical. The number of points can vary according to the depth of the river and the size of the sediment in suspension. Proper arrangement of the verticals in the cross-section has considerable influence on the accuracy if the transverse sediment distribution is uneven. However, if the main purpose is to determine the total suspended bed material discharge than fewer verticals could be allowed without introducing appreciable error (WMO, 1989).

The sediment measurements of the River Project (RSP) and the Bangladesh Water Development Board (BWDB) were used in the analysis. The simplified Chinese and Straub methods were used for optimization of number of points in a vertical. Two Indexes are developed for optimization of number of verticals in a cross-section.

DATA USED IN THE ANALYSIS

A test gauging was performed by the RSP in the Jamuna River at the cross-section near Bahadurabad in the month of August 1993. The data from this gauging was the main basis of the analysis. The data from 28 July 1995 at Bahadurabad of the RSP was also used. The BWDB data from the month of July 1993 was used for verification of the methods developed for optimization of number of verticals.

The moving boat methods of the RSP using Acoustic Doppler Current Profiler (ADCP) measures and visualizes on-line velocity and back-scatter (sediment concentration). The selection of verticals was based on the transverse distribution of the suspended sediment. Primarily, the measuring verticals were selected densely in the zone of high concentration and less in the zone of low concentration.

RSP'S TEST GAUGING DATA

With the Ott propeller and the S4 current meter six point measurements were carried out in each vertical. The points were selected as follows: as close to the surface as possible, 0.2 D, 0.4 D, 0.6 D, 0.8 D, as close to the bottom as possible. Where D denoting total depth at each vertical. Measurement were carried out with 300 seconds integration time for each velocity sampling and with record of sampling for each 50 seconds interval. Suspended sediment samples were collected at the same verticals and depth where the velocities were measured and was done simultaneously. It was done by point sampling by pumping into 0.51 bottles.

RSP'S SURVEYED DATA ON 28 JULY 1995

These data are only used for further elaboration of the analysis for optimization of number of measuring verticals in a cross-section. Here depth integrated suspended sediment samples were collected at the same verticals where the velocities were measured.

BWDB DATA

The BWDB data used for verification of the developed Indexes for optimization of number of measuring verticals. The optimized number of verticals are selected from the survey of 2nd August 1993 and from the position of these selected verticals, sediment transport were estimated from the sediment measurements of 9th August 1993. Suspended sediment samples were collected at 2 points in a vertical where the velocities were measured.

APPROACH

Selection of measuring points in a vertical has been proposed by standards issued by various countries. Simplified methods differ from the multi-point methods in that samples are taken at fewer points in the interest of lessening the work involved in taking and processing samples. Such methods should be adopted only after results obtained with them are checked against measurements obtained with multi-point or other accurate methods. In this analysis, the Straub method and the Chinese standard are followed for optimization of the number of sampling points in a vertical.

The number of verticals required for sediment discharge measurement depends on the size distribution and concentration distribution of the sediment, as well as on the desired accuracy for data collection. Verticals should be spaced closely in zones of large transverse variation in sediment concentration and in the main current (WMO, 1989). The test gauging 93 of the RSP was mainly related to this concept. The ADCP's online profiles give a basis for this transverse variation of the suspended sediment. The data surveyed on 28 July 1995 of the RSP was used for further elaboration of the analysis. Two indexes were followed for optimization of the number of verticals which are discussed in the following sections.

The BWDB data were used for verification of the indexes. The data of the RSP for two consecutive shorter time period was not available for a transact for this sort of verification.

DATA ANALYSIS

Suspended sediment concentration

The transverse distribution of total suspended sediment (test gauging data) along the cross section are shown together with the sampling verticals in Figure 1. The verticals were selected from ADCP's on line backscatter (measure of relative sediment concentration) profile. The verticals were relatively dense in the section having high sediment concentration. The concentration of

..spended sediment between the lowest measured point and the reference level (the theoretical border between suspended and bed load transport) was difficult to measure. A theoretical approach was made to compute the concentration at the reference level (Van Rijn, 1992) by using concentration profile and prediction method. In the case with depth integrated samples, unmeasured zone was not taken into consideration. The quality of the sediment data were verified by plotting in a graph paper and the deviation of each data from the mean was checked. No significant outliers (sediment plume) were found in the test gauging data.

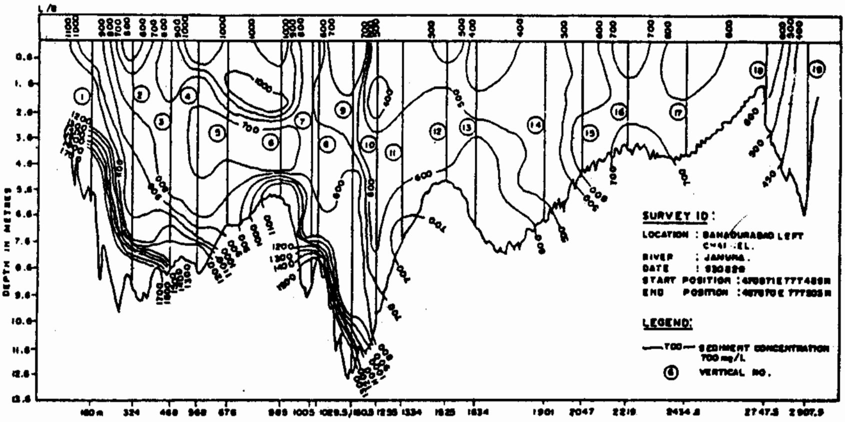

Fig 1. Transverse suspended sediment distribution

Computation of suspended sediment discharge

The suspended sediment discharge per meter width q_s, the dependent variable, at each vertical are used as an indicator to optimize sampling procedure in terms of space.

The suspended sediment transport is calculated as the depth integration of the product of velocity (u) and concentration (c) at each point in a vertical. The total measured sediment transport during test gauging was 22,588 kg/s.

The sediment rating curve (Figure 2) from the test gauging data read as :

$$q_{st}=0.30(u*h)^{1.42}$$

Where,

q_{st}= suspended sediment (fine and coarse) discharge per unit width (kg/s)

u = depth average velocity (m/s)

h = water depth at respective vertical (m)

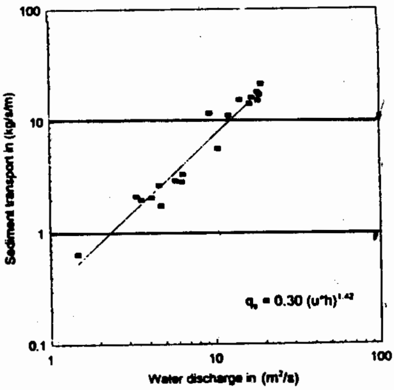

Fig 2. Suspended sediment rating curve at Bangladesh (Test 93)

OPTIMIZATION

Optimization of sediment measurement means that methods are sought aiming at reducing the survey work without loosing the required accuracy. The test gauging data of August 1993 of the RSP have been subjected to a more detailed analysis in order to optimize sediment measurements.

In this paper, the optimization of sediment measurements is concentrated on spatial reduction:

- Optimization of sampling point in a vertical
- Optimization of number of verticals in cross-section

Optimization of Sampling Points in a Vertical

Methods may be classified into six-point and simplified methods. During test gauging 1993, mostly a six-point method was followed in order to increase the accuracy and to provide a good base line for comparison with other simplified methods.

a) Straub Method

In this method, samples are taken at 0.2 depth and 0.8 depth and the values are weighted 5/8 and 3/8 respectively (Straub, 1945). The mean sediment concentration in a vertical read as :

$$C_S = \frac{3}{8} C_{0.8h} + \frac{5}{8} C_{0.2h}$$

Where C_S = the sediment concentration in mg/l averaged over the vertical

h = depth of water from water surface

The sediment discharge computed by this method from the measured data shows good correlation with the measured sediment discharge (6-point) with $R^2 = 0.98$ (Figure 3). The total discharge computed is 21,640 kg/s which is 4.2 percent less (Table 2) than the discharge computed from the measured six points method.

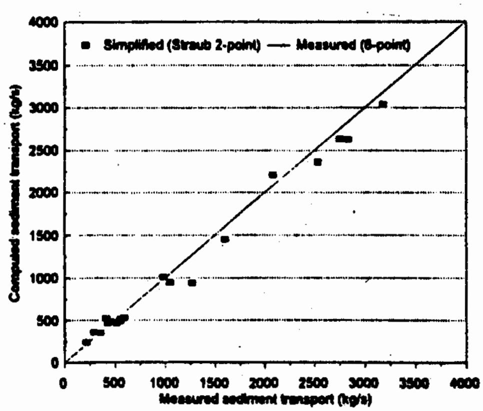

Fig 3. Comparison between measured and Simplified (Straub) methods

b) Chinese Standards

In this method fractions of depth k is considered as a weight to be applied to the products of the velocity and sediment concentration which can be written as :

$$q_s = \frac{h}{n} \sum_{i-l}^{n} k_i \, c_i \, u_i$$

in which qs = Sediment discharge per unit width in kg/s/m;

c_i = sediment concentration at the measuring point in kg/m³;

u_i = velocity at the measuring point in m/s

k = weighting factor for i th sample;

n = sum of the weighing factors at a vertical.

Values of the factor k, as recommended in the Chinese standards (Ministry of Water Conservancy, 1975b), are given in Table 1.

Table 1. Values of depth factor K used for weighted concentration according to Chinese standards

Number of measuring points in a vertical	N	Measuring at relative depth										
		0	0.1	0.2	03	0.4	0.5	0.6	0.7	0.8	0.9	1.0
5	10	1		3				3		2		1
3	4			2				1		1		
	3			1				1		1		
2	2			1						1		
1	1							1 or 1				

The above formula applies to the method which measures velocity and sediment concentration simultaneously at each sampling point. The 2-point Chinese method is plotted against the measured sediment discharge in Figure 4, having correlation R^2 = 0.97 and 3-point with the measured having correlation R^2 = 0.98 (Figure 5). Using 2-point method gives sediment transport 22.448 kg/s which is 0.60 percent less than the measured sediment transport. 3-point method gives sediment transport 22,402 kg/s which is 0.80 percent less than the measured sediment transport. Table 2, indicates the sediment transport at each vertical.

Table 2. Six-point and optimized (simplified methods) sediment discharge

Vertical no.	Water discharge Qw m^3/s	measured sed. disch. Qs kg/s	computed sediment discharge		
			Straub 2-point kg/s	Chinese 2-point kg/s	Chinese 3-point kg/s
1	2281	2831	2630	2634	3002
2	2662	3182	3041	3467	3117
3	2345	2080	2208	2274	2100
4	1978	1597	1452	1426	1412
5	2721	2752	2634	2837	2820
6	2809	2530	2363	1951	2005
7	1163	1045	948	1013	1023
8	1366	978	1012	997	974
9	1237	1266	940	1124	1126
10	994	546	484	516	527
11	885	452	487	501	497
12	697	289	355	306	314
13	1040	550	515	573	592
14	1215	587	531	657	648
15	766	425	464	473	497
16	720	410	521	501	516
17	789	507	464	607	627
18	677	212	241	219	227
19	948	349	350	373	378
Total	27294	22588	21640	22448	22402
Diff (%)			4.2	0.62	0.82

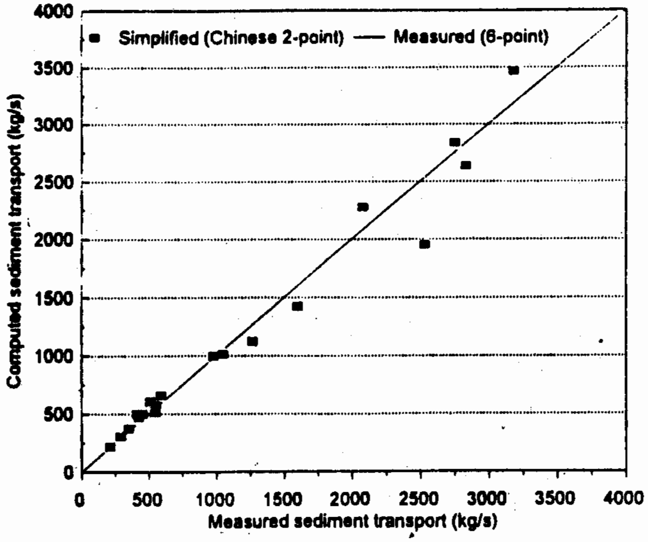

Fig 4. Comparison between measured and Chinese (2-point) methods

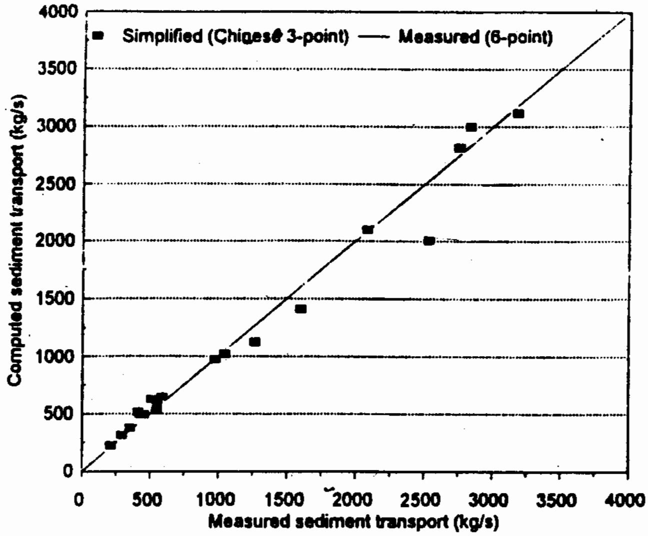

Fig 5. Comparison between measured and Chinese (3-point) methods

OPTIMIZATION OF SAMPLING VERTICALS IN A CROSS-SECTION

Suspended sediment discharge is computed by summing the products of the q_s and section width for each of the verticals. Proper arrangement of the verticals in the cross section has considerable influence on the accuracy if the transverse sediment distribution is uneven. There are several existing methods for selection of number of verticals (WMO, 1989) which are mentioned in the following :

(i) Transverse distribution of concentration

(ii) EDI method "Equal Discharge Increment"

(iii) Equally Spaced Verticals or ETR method

The methods are all conventional methods. Simplified methods (to optimize verticals) are those in which the number of verticals taken is less than the conventional methods.

Analysis of a group of suspended sediment discharge measurements may show that the number of sampling verticals can be reduced without intolerable reduction in accuracy.

Following Indexes were evolved in order to reduce the number of verticals :

(a) Square of the average velocity over total depth, u^2/h-Index

The u^2/h-Index indicates how far the flow field is adopted to the shape of the cross-section. As long as the flow pattern is congruent, which may be expected for a range of stages, the transverse u^2/h distribution remains the same. The more regular the distribution and the more stable in time, the stronger reductions in the number of verticals are possible. In Figure 6, u^2/h is plotted over the cross section of the left channel at Bahadurabad with the test gauging data. Apparently, u^2/h has slopes between verticals 1-2, between 2-4, between 4-6, between 6-9, between 6-9, between 9-12, between 12-14, between 14-16, between 16-17, between 17-18, and between 18-19. Sampling at verticals 1, 2,4, 6,12,14,16, 17, 18 and 19 can led to computation of velocities and consequent discharges at other verticals (Table 3) or at new verticals. The measured total suspended sediment transport by sampling from 19 verticals is 22588 kg/s. The total suspended sediment transport from the optimized verticals is

22892 kg/s which is only 1.4 percent more than the measured transport.

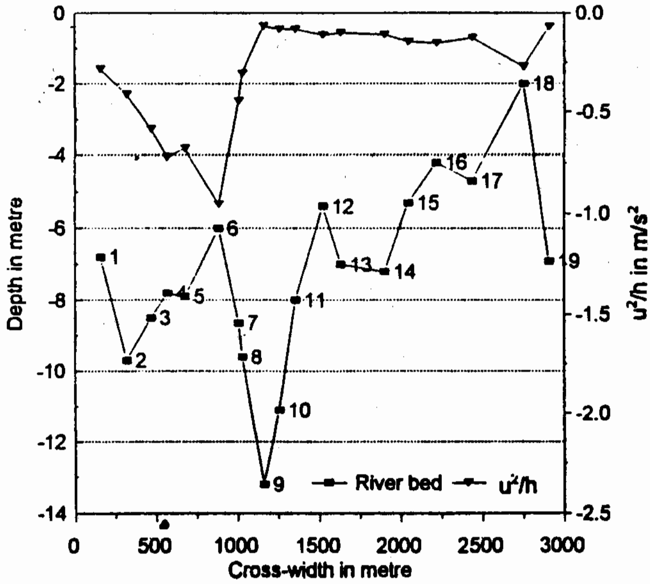

Fig 6. Transverse distribution of u^2/h in the test gauging cross-section

(b) Sediment rating Index, $q_s/(u^*h)^n$

The sediment transport is proportional to the power of velocity. The sediment rating parameter per meter width $q_s/q^n = q_s/(u^*h)^n$ = constant at a vertical for a particular river. The value of "n" is 1.42 for measurement of test gauging 1993 at Bahadurabed. This value is consistent to the other FAP's analysis and studies. The Index $q_s/(u^*h)^{1.42}$ is used to see how far the sediment transport is adopted to the flow field. The more regular the transverse distribution of the index the more reductions in number of velocity verticals are possible. The variation of this constant for the Test Gauging '93 is within the range 0.2-0.5 over the width (Figure 7). The similar number of verticals (as from u^2/h-Index) are found from the slope of this Index. In addition, vertical 10 is suggested for consideration. In Table 3, the measured suspended sediment transport over the width is 22,588 kg/s and the computed sediment transport is 22,568 kg/s which is 0.1 percent less than the measured sediment transport.

Table 3. Computation of suspended sediment from optimized verticals

vertical no.	total depth (m)	measured velocity (ms)	measured sed. trans (kg/s/ (m)	measured sed. trans (kg/s)	u^2/h index optimized vertical no.	u^2/h index computed sed. trans (kg/s)	qs/q^n-index optimized vertical no.	qs/q^n-index computed sed. trans (kg/s)
1	6.80	1.386	11.699	2831	1	2831	1	2831
2	9.70	1.993	20.995	3182	2	4283	2	4283
3	8.50	2.228	16.980	2080				
4	7.80	2.377	15.081	1597	4	4230	4	4230
5	7.90	2.320	17.920	2752				
6	6.00	2.393	15.378	2530	6	4560	6	4560
7	8.65	1.957	16.038	1045				
8	9.60	1.712	14.150	978				
9	13.20	0.932	11.231	1266	9	3594	9	2078
10	11.10	0.947	5.629	546			10	1289
11	8.00	0.807	3.353	452				
12	5.40	0.772	2.060	289	12	762	12	665
13	7.00	0.832	2.935	550				
14	7.20	0.882	2.878	587	14	999	14	939
15	5.30	0.876	2.676	425				
16	4.20	0.801	2.108	410	16	566	16	566
17	4.70	0.766	1.970	507	17	507	17	507
18	2.00	0.738	0.643	212	18	212	18	212
19	6.90	0.687	1.744	348	19	348	19	348
Total				22588		22892		22568
Diff (%)						1.35		-0.09

ELABORATION OF THE OPTIMIZATION INDEXES

A further elaboration on the above Indexes is done with the data of the Jamuna river, right channel, Bahadurabad, surveyed on 28th July 1995 by the RSP. Initially 22 verticals were selected for sediment measurement from the on-line back-scatter profile of the ADCP. The depth integrated sediment transport data were collected. In the analysis, only the coarse sediment data were used which are validated by plotting all the data in a normal graph paper and are shown in

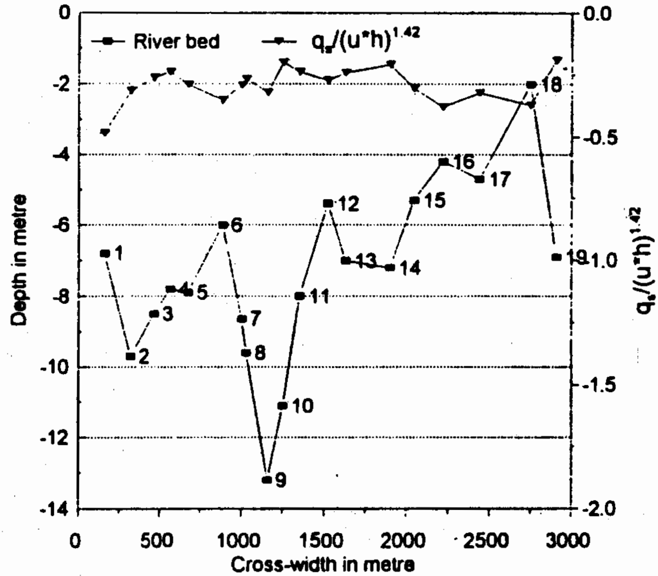

Fig 7. The $qs/q^{1.42}$ index plotted as a function of the width

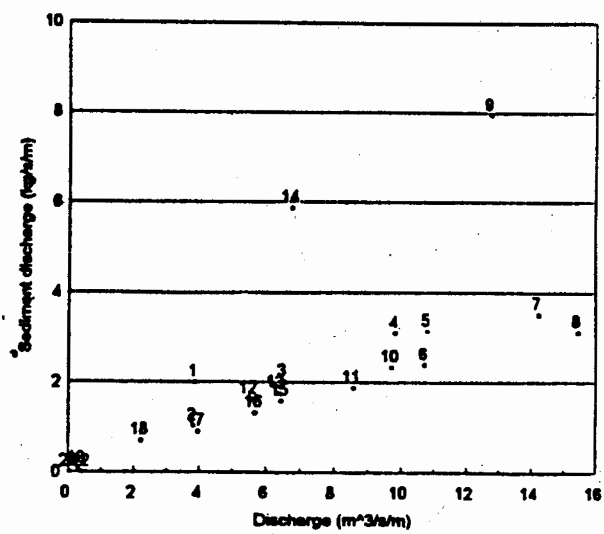

Fig 8. Sediment transport data of 28 July 1995, right channel, Bahdurabad

Figure 8. In figure 8, it is evident that sediment transport at vertical 9 and 14 were exceptionally high. The reason for this is not investigated for the present analysis. However, an attempt is made to compare the measured depth average sediment concentration with the depth average back-scatter at each vertical and are plotted in Figure 9.

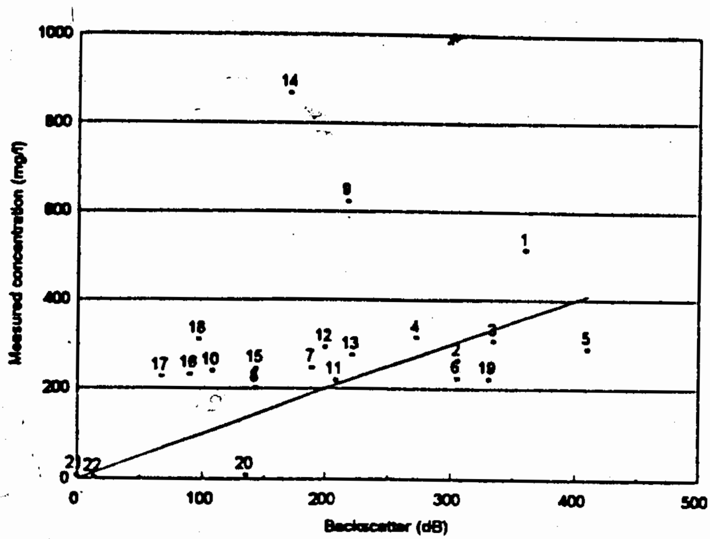

Fig 9. Comparison of measured sediment concentration versus backscatter

Apparently, this figure also shows that sediment measurement at vertical 9 and 14 are exceptionally different than their backscatter values in comparison with the sediment transport at other verticals. Therefore, sediment transport data at vertical 9 and 14 are deleted from the present analysis as their presence may give erroneous results.

The transverse distribution of the u^2/h distribution over the cross section is plotted in Figure 10. Apparently, u^2/h has slopes between verticals 2-3, between 3-4, between 4-6, between 6-8, between 8-10, between 10-12, between 12-19, and between 19-22. Sampling at verticals 2, 3, 4, 6, 8, 10, 12, 19, and 22 would led to computation of velocities, consequent discharges at other verticals.

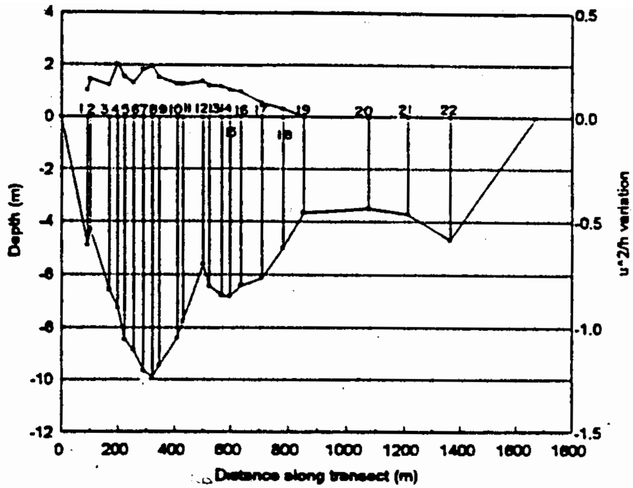

Fig 10. Transverse distribution of u^2/h-index, right channel at Bahadurabad

The sediment rating equation read as :

$$q_s = 0.085(u{*}h)^{1.6}$$

Where,

q_s = suspended sediment (coarse) discharge per unit width (kg/s)

u = depth average velocity (m/s)

h = water depth at respective vertical (m)

The transverse distribution of sediment rating Index, $q_s/(u{*}h)^n$ distribution is plotted in Figure 11. The q_s/q^n-Index suggest similar number of optimization of verticals as the u^2/h-Index. The measured sediment transport by sampling from 22 verticals is 1363 kg/s. The sediment transport from the optimized verticals is 1394 kg/s which is only 2.2 percent more than the measured sediment transport.

VERIFICATION OF THE SEDIMENT MEASUREMENTS INDEXES

Attempt has been made to verify the Indexes developed for optimization of number of verticals. Verification has been done by selecting number of optimized verticals from the conventional number of verticals in a cross-section by the use of those Indexes. These optimized verticals are then applied to another gauging having conventional number of verticals surveyed later on and comparison has been made between the sediment transport of the optimized and the conventional number of verticals. The RSP did not have data for a transect for such comparison. Therefore the BWDB's data are used for verification of the Indexes because series of consecutive gauging data at a station are available.

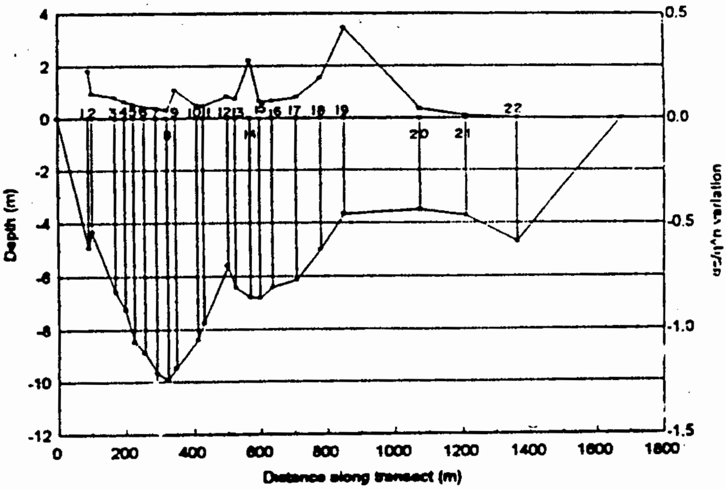

Fig 11. Transverse distribution of qs/q^n index, right channel at Bahadurabad

The BWDB's suspended sediment transport data of 2nd and 9th August 93 are chosen for verification. On 2nd August 1993, conventional sediment measurement was carried out at 18 verticals in Fulchuri channel. The transverse distribution of u^2/h and q_s/q^n Indexes are plotted over the cross-section with the total number of verticals in Figure 12 and Figure 13 respectively. Both the Indexes show the optimization of similar number of verticals. The optimized verticals are 1, 5, 7, 9, 10, 12, 13, 14, 16, and 18. The measured sediment transport by sampling from 18 verticals is 1032 kg/s. The sediment transport from optimized 10 verticals is 1062 kg/s which is

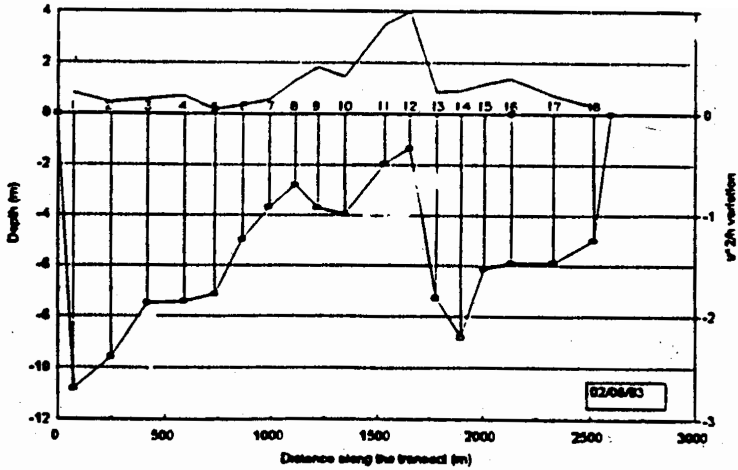

Fig 12. Transverse distribution of u^2/h-index, Fulchari channel, BWDB

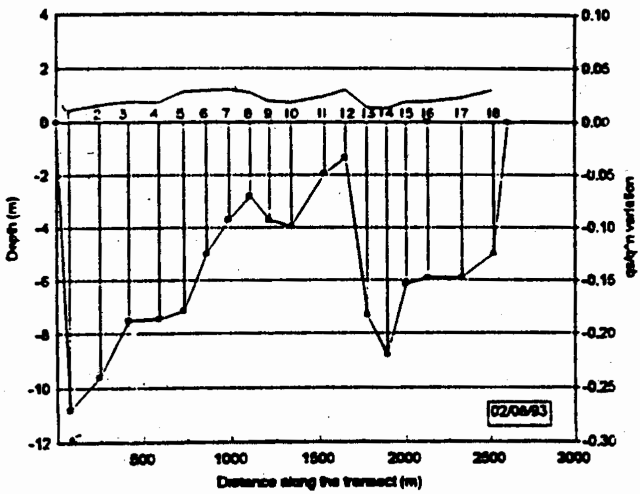

Fig 13. Transverse distribution of qs/q^n index, Fulchari channel, BWDB

only 2.9 percent more than the measured sediment transport. These optimized 10 verticals are suggested for the next measurements in the same transect until any big hydrological event occurs. The selection of these 10 verticals are verified on the conventional sediment gauging of BWDB on 9th August 1993. On 9th August 1993, sediment gauging was carried out at 16 vertical and the measured sediment transport is 1268 kg/s. Now the sediment measurement is calculated from the survey of 9th August 1993 using the position of the optimized 10 verticals selected from the survey of 2nd August 1993. The sediment transport from the optimized 10 verticals selected from the survey of 2nd August 1993. The sediment transport from the optimized 10 verticals are 1234 kg/s which is only 2.75 percent less than the measured sediment transport from the 16 verticals.

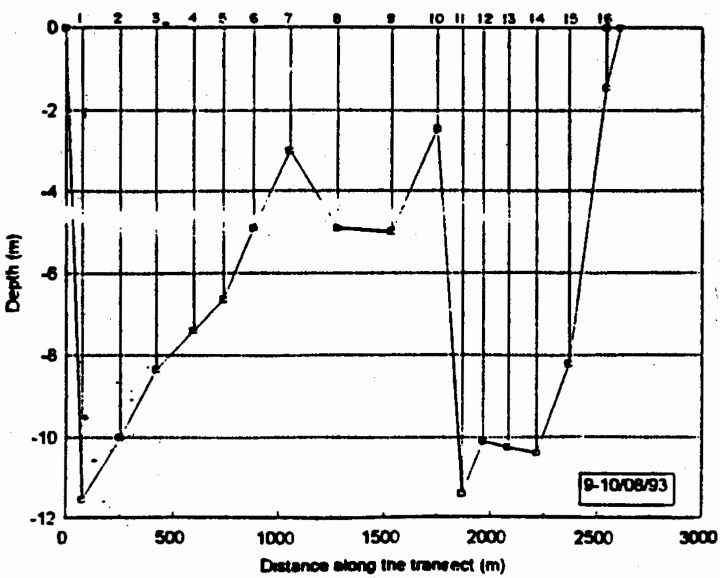

Fig 14. Cross section showing nos of vertical (without optimization, Fulchari channel)

DISCUSSION ON THE RESULTS

Analysis of the test gauging data revealed the following findings :

A comparison of the sediment measurement by a six point pump bottle method and sediment measurement by simplified methods indicates that the number of point measurements by manual profiling may be reduced from 6 to 2 or 3.

A constant u^2/h distribution indicate a regular flow distribution in balance with the erodible cross-section. Apparently there is an imbalance in the deeper part of the test gauging cross-section whereas the shallow majority of the cross-section seems to be in balance. This indicate a regular horizontal flow distribution in the shallow majority of the cross-section. Consequently only a few measurement verticals are needed in the shallow majority of the cross-section compared to the conventional specification of verticals (WMO, 1989).

Inspite of the irregular cross-section and flow field the $q_s/q^{1.42}$-Index is regular, indicating a possibility for number of sediment measurement verticals in the cross-section.

Further analysis of the RSP's data surveyed on 28th July 1995 indicate the following :

The u^2/h distribution shows regular balance with the cross-section. Shallow part of the cross-section seems to be in well balance. Therefore like the test gauging, few measurement vertical needed in the shallow part of the cross-section. In the deeper section, verticals are to be selected with the change of slope of the u^2/h distribution.

The q_s/q^n-Index distribution is regular, indicating similar number of sediment measurement verticals in the cross-section like the u^2/h-Index distribution.

Verification of the Indexes from the BWDB's data revealed that the following : verification of u^2/h and q_s/q^n distribution is very promising showing good results.

CONCLUSION AND RECOMMENDATION

General

The number of verticals required for sediment discharge measurement depends on the size distribution and concentration distribution of the sediment, as well as on the desired accuracy for data collection. Verticals should be spaced closely in zones of large transverse variation in sediment concentration and in the main current (WMO, 1989). The Test gauging 93 was mainly related to this concept. The ADCP's online profiles gives a basis for this transverse variation of the suspended sediment. Although verticals are selected more densely in the high concentrated zone based on the conventional methods.

In natural rivers, the discharge as well as the sediment concentration vary with time, in particular during floods when it would be impractical to take measurements at verticals using either the multi-point or the multi-verticals method. Reasonable simplification of measurement is indispensable. Rules for the arragement of verticals using developed Indexes may be considered using one of the following approaches. First choice would be the selection of conventional verticals based on the transverse distribution of concentration of ADCP or Equal Discharge Increment (When ADCP is not available). The second approach is to choose verticals with the use optimization Indexes (simplified method). The thired approach is to apply these verticals (optimized) for later gauging until another serious flood or change in the morphology of the channel occurs.

Optimization of Sampling point in a vertical

The Test Gauging '93 result shows that simplified methods seems reliable and accurate but need further confirmation with more data analysis. The present analysis shows, the 2-point Straub Method and 2-point Chinese Standard are consistent but 2-point Chinese Standard gives higher accuracy for the Test Gauging data. The 3-point Chinese standard also shows very high degree of accuracy.

Optimization of verticals

The u^2/h and q_s/q^n Indexes provide successfully the basis for the simplified measuring methods. The analysis of the RSP's data and the verification analysis of BWDB's data show that the number of sampling verticals can be reduced by the use of those indexes without intolerable reduction in accuracy.

Reduction of verticals at each station should be chosen according to the local hydrological condition, the availability of technical equipment and the desired accuracy of the data required.

The observation recommends that in addition to verticals selected from the use to those indexes, few more verticals may be selected in a case where the river bed changes sharply.

Results obtained by optimized indexes (simplified method) should be compared with more series of consecutive sediment data (2-4 months) obtained by a more detailed or conventional method.

REFERENCES

DELFT/DHI,(1993),Test Gauging Report, Survey Procedures and Data Presentation, River Survey Project FAP 24, October.

Ministry of Water Conservancy, (1975b): Tentitive standards for hydrometric measurement, Beijing.

Rijn, L.C. van, (1992), Lectures notes on Principles of Sediment Transport in Rivers, Estuaries, Coastal Seas and Oceans.

Straub, L.G., (1945), Terminal report on transportation characteristics, Missouri river sediment, SAF, MRD, series no. 4, corps of Engineers, Apr. 1945.

Task Committee on Hydrographic Investigations, (1983): Measurement of hydrographic parameters in large sand-bed streams from boats, ASCE.

WMO, (1989), Manual on operational methods for the measurement of sediment transport. Operational hydrology report No. 29, 1989.