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GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH

BANGLADESH WATER DEVELOPMENT BOARD

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River Training Studies of The Brahmaputra River

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FINAL REPORT ON PHYSICAL MODEL STUDIES

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Sir William Halcrow & Partners Ltd.
Danish Hydraulic Institute
Engineering & Planning Consultants Ltd.
Design Innovations Group

MODEL STUDY BY
RIVER RESEARCH INSTITUTE

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FINAL REPORT ON PHYSICAL MODEL STUDIES

VOL III - MODEL BASED ON FULCHARIGHAT BATHYMETRY

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Sir William Halcrow & Partners Ltd.
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MODEL STUDY BY RIVER RESEARCH INSTITUTE

RIVER TRAINING STUDIES OF THE BRAHMAPUTRA RIVER

VOL III - MODEL BASED ON FULCHARIGHAT BATHYMETRY

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Acknowledgement

Particular thanks are due to the large number of BWDB and RRI staff and others who have contributed for the completion of the model study for Fulcharighat Area. Without their active cooperation the model test programme could not have been accomplished.

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BRAHMAPUTRA RIVER TRAINING STUDIES
MODEL BASED ON FULCHARIGHAT BAHTYMETRY

1. INTRODUCTION

1.1 Background

The security of the Brahmaputra Right Embankment (BRE) and consequently the area protected by the BRE has been seriously threatened by continued bank erosion. Since the economic and social consequences of the present approach in dealing with the problem may not be acceptable in the long-term, the Government of Bangladesh (GOB) has commissioned the River Training Studies of the Brahmaputra River (BRTS) to seek a long-term strategy for the protection of the BRE. The project, funded under the IDA sponsored Bangladesh Second Small Scale Flood Control, Drainage and Irrigation Project (Credit No. 1870 BD), will be executed by the Bangladesh Water Development Board (BWDB).

BWDB appointed Sir William Halcrow and Partners Ltd. (Halcrow) in association with Danish Hydraulic Institute (DHI), Engineering and Planning Consultants Ltd. (EPC) and Design Innovations Group (DIG) to undertake this three-year study.

An advisory group from the Bangladesh University of Engineering and Technology (BUET) works with the Consultants' Team. The River Research Institute (RRI) have been nominated to carry out the physical modelling studies required by the BRTS. These studies are guided and sponsored by BRTS.

A letter of Intent was issued by the BWDB on 24th January 1990 to commence the project. The contract for consultancy services was signed between BWDB and Halcrow on 12th March 1990. The Consultant commenced the project on 6th February 1990 by making arrangements to mobilize staff and establish an office and support facilities. Staff inputs commenced on 1st March 1990.

In November 1989, a five year Flood Action Plan (FAP), coordinated by the World Bank, was initiated with the Government of Bangladesh. The FAP is connected with an initial phase of studies directed towards the development of a comprehensive system of long term flood control and drainage works. Priority has been given to the alleviation of flooding from major rivers, of which the Brahmaputra is a significant source. The BRTS therefore, forms component No. 1 of a total of 26 components comprising the FAP during the plan-period 1990-1995.

The present final report on the Fulcharighat Area is the third of a series of reports presenting the results of the physical model studies performed at RRI, Faridpur.

1.2 The BRTS Project

The Brahmaputra-Jamuna river system is one of the largest in the world, and is also the largest and most important river system in Bangladesh, accounting for more than 50% of the total inflow into Bangladesh from all cross border rivers.

The Brahmaputra moved to its present course about 200 years ago. It is a braided river without fixed banks and with frequently shifting channels. Short-term channel migration can be quite drastic with annual rates of movement as high as 800 m. The bank erosion process is a complex mechanism and is influenced by a number of factors. In Bangladesh the total river width varies between 6 km and 15 km. The river cross-section has a highly irregular bed elevation and the main channel may be up to 30 m deep.

A 220 km long earthen embankment, known as the Brahmaputra Right Embankment (BRE), has been constructed on the western bank of the Jamuna River to protect the land against the ravages of yearly flood. However, every year this embankment has to be retired landward at several places due to bank erosion; a total length of about 140 km of retired embankment has been constructed over the past 20 years.

River erosion is also causing serious problems at specific locations such as ferry crossings, where the terminal stations (ghats) have to be shifted as a result of eroding river banks.

Since the economic and social consequences of the present approach in dealing with the problem of bank erosion may not be acceptable in the long-term, the Government of Bangladesh has commissioned the BRTS to seek a long-term strategy towards its solution.

1.3 The Situation at Fulcharighat

Fulcharighat is one of the most important Sites on the Brahmaputra Right Bank. The ferry terminal at Fulchari is joining the northern districts with Dhaka and central part of the country. Fulcharighat handles both railway passengers and wagon ferries. It is thus a vital communication link point. For the last 10 years, Fulchari upazila township has also grown as a local economic centre.

A flow channel has developed along the right bank. The funnel shape of the upstream reach of the river associated with a secondary channel is causing an amplification of flow velocities at the right bank causing erosion upstream of the ghat (see Figure 1.1). Due to the continued erosion, the present location of the ferryghat and the railway may have to be abandoned causing major dislocation, to the vital railway link.

There are low pockets of land and a dead anabranch adjacent to the ferry ghat. The eroding bank near the mosque and further upstream of Fulchari cross-bar I and cross-bar II may in the worst possible situation join with the low pockets and with the dead anabranch, thus causing serious erosion and damage on to the existing ghat, the railway and the Fulchari township.

Due to the erosion and active channel development in this confluence situation Fulchari needs priority protective measures for stabilisation of the bank for the railway ferry terminal and the Fulchari township. The present report deals with the hydraulic studies made to support the design engineers on the choice of remedy solution and the flow conditions to be used in the design.

1.4 Objectives of the Model Study

(a) To determine the flow field and velocities in the existing situation for bankful and 100 year flood.

(b) To determine the influence of new training/protection works on the current pattern at bankfull and flood conditions.

(c) To obtain data such as local velocities and scour depth for design of the training work which will be implemented.

(d) To assist the BRTS design team in finding optimum economical and durable solution for the training/protection works at Fulcharighat.

2. THE MODEL

2.1 Design of the Model

An open air distorted model with prototype dimensions (Length 5.7 km x width 7.60 km) was constructed including the upstream river bend. The model covered an area about 30 m x 38 m. The model plan is shown in Figure 2.1. The following scales apply for the model.

Horizontal	1:200
Vertical	1:120
Discharge	1:263000
Velocity	1:10.95
Distortion	1:1.67

All cross-section data for bed elevations were obtained from BRTS river surveys. The model also covered the flood plain upto the BRE.

Two kinds of experiment were planned by BRTS for this model. These are (a) Fixed bed experiment and (b) Mobile bed experiment.

For fixed bed testing sand of 0.20 mm was used. For mobile bed experiments part of the river bed was moulded in coal dust with d_{50} of 0.50mm, specific gravity 1.42 and submerged angle of repose nearly 25°.

The discharge in the model was measured by a sharp rectangular weir installed upstream. For a particular discharge head (H) over the weir the discharge Q was calculated by the following Rehboks (S1 version) formula.

$$Q = \left(0.403 + 0.053 \frac{He}{P}\right) \times b \times (2 \times g)^{1/2} \times He^{3/2}$$

where $He = (H + 0.011)$, $p = 0.650$ m
$g = 9.8$ m/s^2, $b = 0.927$ m

The head over the sharp crested weir was measured by a gauge installed at a distance of approximately six times the head behind the weir position to avoid an influence from the curvature of the water at the weir. Atmospheric air pressure was maintained below the nappe to reduce the drag effect which otherwise would increase the discharge. The discharge water was thereafter led through an approach channel constructed in such a way that the direction of the main flow in the model reproduced prototype conditions including the curved upstream flow pattern derived from the available Maps and BRTS surveys.

For velocity measurement, each section was divided into six equal parts and the first part near the right bank was again divided into three parts and the second was divided into two parts. At these points velocities were measured by a current meter.

For precise measurements of the water level three point gauges were used. One at the representative cross section, cs #6 and the two others upstream and downstream of the middle section of the model. Two tilting tail gates were installed downstream of the model. They had an elevation allowing the discharge water to leave the model to the circulation channel. A staff gauge was used to control the water level.

The principal data used in the model are presented in Table 2.1.

Table 2.1: Fulcharighat Test Bed. Water Level and Discharge Data

Conditions	Water Level (m PWD)	Discharge Prototype (m3/s)	Model (l/s)
Bankfull	+ 19.15	12,000	46
100 yrs flood	+ 21.92	35,000	133

2.2 Data Requirements and Availability

The following data were required for the model study:

(a) Present bathymetry & topography data of the river including river bank line, positions of cross sections, flood plains and different important existing structures such as cross bars, railway lines etc.

(b) Hydrological data - discharge at different stages and conditions, water levels at representative cross sections (see details in Appendix I).

(c) Recent field survey data such as river bed elevations, bank & flood plain levels.

(d) Data required for calibration/verifications.

Index map, different cross sections and water level at bankfull & 100 years discharge were supplied by BRTS. Elevation's of the plain were taken as average bank elevation.

2.3 Model Calibration

The object of the model calibration was to confirm hydraulic similitude between the model and the prototype. In this test water level and velocity were measured as accurately as possible at the representative section cs#6.

It was found that the average velocity across this section and neighbouring sections was in the range 2.1 to 2.4 m/s which corresponds satisfactorily with a target average velocity of 2.2 m/s. It is on this basis concluded that the velocity found elsewhere in the model, including the very high velocities near the bank and at groyne noses are correctly reproducing prototype conditions.

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2.4 Test Programme

The test programme is shown in Table 2.2.

Table 2.2 Test Programme for Fulcharighat Physical Model

Test No	WL (m)	Discharge (m^3/s)	Purpose	Comments
Fixed Bed Experiments				
1	+ 19.15	12,000**	Flow Measurements	Existing Situation as per BRTS Surveys
2	+ 21.92	35,000*	Flow Measurements	Existing Situation as per BRTS Surveys
3	+ 19.15	12,000	Flow Measurements	Training works present ***
4	+ 21.92	35,000	Flow Measurements	Training works present ***
Mobile Bed Experiments				
5	+ 21.92	35,000	Flow & scour Measurements	Layout with Revetments from Cross-Bar 2 to C/S.8.

Notes:
- * 100-year discharge
- ** Bank full discharge
- *** Training works consist of three upstream groynes G-2, G-3, G-4 and five downstream groynes G-5, G-6, G-7, G-8 and G-9 and a revetment between the two sets of groynes from location E to M.

3. FIXED BED EXPERIMENTS

3.1 General

Fixed bed experiments (Tests Nos. 1 & 2) were carried out for two discharges corresponding to bankfull and 100 year flood respectively. These tests were later on repeated (Test Nos. 3 & 4) with training/protection works in the form of a series of groynes. Test No. 5 concentrated on measuring velocities and scour depths for a second alternative comprising the use of revetments as protection of the eroding riverbank.

3.2 Tests with the Existing Situation

Two test (Tests Nos. 1 & 2) were conducted with the existing situation (bathymetry) to determine the present flow pattern & transverse velocity distribution. These data form the basis for understanding the existing situation and the basis for selection of means for remedy of the erosion problem. It appears clearly from Figure 3.1 & 3.2 that the flow in the three upstream flow channels meet off the end of the railway line and that downstream this point very high velocities occur. This is the result of a number of factors including the convergence of the flow channels, the relative small cross sectional area of the anabranch and the corresponding high upstream mean flow velocity of about 2.2 m/s.

3.3 Maximum Velocity

Table 3.1 and 3.2 shows the maximum velocities measured (in the model at the different sections).

For bankfull discharge the maximum velocity was 3.3 m/s at profile, cs#9. For 100 years flood discharge it was 4.3 m/s at profile cs#8.

It is to be noted that these velocity profiles are both to the south of the bend on the river bank and the railway ghat. The velocity of 4.3 m/s is the highest velocity measured in any of the site specific model studies performed under BRTS. As explained previously this velocity should be seen in comparison with the average velocity in the anabranch of v=2.2 m/s. The amplification factor on velocities, a = 4.3/2.2 = 1.9 is not considered unusual as analysed in the summary report on all site specific model studies. (Vol I of BRTS Final Report on Physical Modelling).

Table 3.1: Fulcharighat Test Bed. Fixed Bed Experiment, Maximum Velocity at Bankfull Discharge No Training Works, Test 1

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Cross Section	Distance from Right Bank (m)	Velocity (m/s)	Remarks
A	658	1.3	
B	144	1.4	
1	142	2.0	
2	140	2.6	
3	116	2.3	
4	870	3.0	
5	92	2.7	Max value close to Bank
6	84	3.0	
7	576	2.7	
8	252	3.0	
9	252	3.3	Max. Value

Table 3.2: **Fulcharighat Test Bed. Fixed Bed Experiment, Maximum Velocity for 100 year Flood Discharge, No Training Works, Test 2**

Cross Section	Distance from Right Bank (m)	Velocity (m/s)	Remarks
A	658	1.8	
B	144	3.2	
1	284	3.4	
2	140	3.5	
3	116	3.8	
4	96	3.7	Max value close to Bank
5	92	3.8	
6	84	4.0	
7	192	3.9	
8	252	4.4	Max. Value
9	252	4.0	

3.4 Tests with Training/Protection Works (Tests Nos. 3 & 4)

These tests were conducted with a series of groynes and revetment specified by BRTS. Detailed locations of the groynes and revetment are shown in Figure 3.3. Specifications for the groynes are shown in Table 3.3. During these tests velocities were measured at additional points near the groyne heads. The measured transverse velocity profiles for 100 year flood conditions are shown in Figure 3.4.

Table 3.3: **Specifications for Groynes**

Groyne Nos.	Length (m)	Top Width (m)	Side Slope (V:H)
G-2	100	3	1:2
G-3	150	3	1:2
G-4	100	3	1:2
G-5	75	3	1:2
G-6	75	3	1:2
G-7	75	3	1:2
G-8	75	3	1:2
G-9	50	3	1:2

Maximum Velocities

Tables 3.4 & 3.5 show the maximum velocities at different sections. For bankfull discharge the maximum velocity was 3.5 m/s and for 100 years flood discharge the maximum velocity was as high as 5.9 m/s.

Velocity Measurements near the Groyne Head

Velocity measurements were also performed along the groyne head. These data are shown in Table 3.6 and 3.7 corresponding to bankfull and 100 year flood discharge respectively.

Table 3.4: Fulcharighat Test Bed. Fixed Bed Experiment Maximum Velocities at Bankfull Discharge With Training Works, Test 3

Cross Section	Distance from Right Bank (m)	Velocity (m/s)
A	2198	1.2
B	1728	1.3
1	284	2.8
2	840	1.5
3	524, 1050*	1.6
4	96	2.1
5	92, 276*	1.6
6	84, 252*	1.6
7	864	2.7
8	252	3.5
9	252	2.8

Notes: * When two numbers are shown it indicates that the same maximum velocity was measured in two places.

Table 3.5: Fulcharighat Test Bed. Fixed Bed Experiment Maximum velocities at 100 year flood discharge With Training/Protection Works, Test 4

Cross Section	Distance from Right Bank (m)	Velocity (m/s)
A	1758	2.7
B	864	2.5
1	284	4.6
2	280	3.4
3	232	2.5
4	1450	3.2
5	184	2.8
6	168,756,1008*	2.8
7	288, 576*	4.2
8	252	5.6
9	252	5.9

Notes: * When two or three numbers are shown it indicates that the same maximum velocity was measured in more than one location.

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Table 3.6: Fulcharighat Test Bed. Fixed Bed Experiment Bankfull Discharge Velocity In Front of Groyne Heads

Cross Section	Distance from Right Bank (m)	Velocity (m/s)	Distance from Head (m)
Groyne No.2	152	0.7	52
	208	0.7	108
Groyne No. 3	182	2.5	32
	216	2.5	66
Groyne No. 4	140	1.9	40
	182	1.6	82
Groyne No. 5	118	3.2	43
	140	3.2	65
Groyne No. 6	108	1.0	33
	144	3.4	69
Groyne No. 7	110	1.6	35
	134	2.9	59
Groyne No. 8	112	1.6	37
	132	2.7	57
Groyne No. 9	74	1.0	24
	102	1.8	52

Table 3.7: Fulcharighat Test Bed. Fixed Bed 100 year Flood Discharge
Velocity In Front of Groyne Heads

Cross Section	Distance from Right Bank (m)	Velocity (m/s)	Distance from Head (m)
Groyne No.2	140	2.0	40
	190	2.0	90
Groyne No. 3	182	4.3	32
	208	4.3	58
Groyne No. 4	130	1.4	30
	170	3.3	70
Groyne No. 5	106	4.7	31
	148	4.5	73
Groyne No. 6	120	3.0	45
	154	5.2	79
Groyne No. 7	116	2.5	41
	154	3.7	79
Groyne No. 8	116	3.6	41
	142	4.9	67
Groyne No. 9	84	3.0	34
	122	4.8	72

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Interpretation of Test 3, Figure 3.4

By comparison of Figure 3.1 and Figure 3.4 it is seen that the introduction of groynes at different sections influenced the flow pattern. Before introduction of the groynes maximum velocities were measured at different sections near the right bank. But after introduction of the groynes the maximum velocities shifted away from the right bank. But the velocity at cs#8 increased slightly near the right bank. Eddies were observed between the groynes G2, G3, and G4.

Interpretation of Test 4, Figure 3.4

By comparison of Figure 3.2 & 3.4 it is seen that the velocity near the right bank is also influenced by the groynes for the 100 years flood discharge. The maximum velocities shifted away from the right bank.

The near bank velocity decreased, but from cs#B to cs#G the maximum velocity occurred further away from the bank and was larger than in the situation without training works.

At cs#7 to cs#9, the maximum velocities shifted away from the right bank and increased significantly. At these high velocities it was observed that the high char, downstream of cs#9, was eroded due to the constraints on the width of the river and the higher velocity at cs#9. At highest velocity was 5.9 m/s. This is the highest velocity recorded in any of the physical models for the BRTS project.

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4. MOBILE BED EXPERIMENT TEST NO. 5

4.1 General Information

Upon completion of Tests No. 3 and 4 with the groynes it was decided to test a solution where the bank protection consisted of revetments. This solution is shown in Figure 4.1. The mobile bed experiment was carried out for 100 years flood discharge.

The main objectives of Test No. 5 were to determine the maximum scour depth in front of the revetment and the flow velocities after scour had occurred. Test No. 5 was performed with a revetment with an upstream limit 250 m north of cs#2 and a downstream limit at cs#8. The revetment toe was taken down to the lowest point of the cross-section. Crushed brick 5 to 10 mm size were used as revetment material. The thickness of revetment was equal to 2 layers and the falling apron thickness was 4 layers of crushed bricks.

4.2 Scour Depth Measurements

Some additional sections were selected for measurements of the scour depth. Several points were also selected for measurements of scour depths in these sections and near the revetment toe. Elevations were taken before the test. Velocities were determined near the right bank after the scour had reached equilibrium state. The scour varied from 0 to 6 m, with some minor accretion. The scour was mostly in the range 2 to 4 m below the existing river bed (see Table 4.1). This is the maximum scour depth measured in front of revetments in all the site specific models for BRTS. To determine the rate of the development of scour depth continuous measurements were performed at 15 min's intervals. This process was repeated until the scour depth reached its equilibrium.

The development of scour with time was determined in two profiles namely cs#4 and cs#6. The results of these measurements are shown in Figure 4.2. It appears that the scour equilibrium was reached after 75 - 90 mins test duration. Comments to the time scale of scour development is given in the summary report on all site specific model tests.

This scouring of the bed represents adjustment of the section to the 100 year peak discharge with the right bank stabilised. It is thus only indirectly related to the presence of the revetment.

<u>Velocity Measurements</u>

Table 4.2 shows the maximum velocities measured near the right bank. By comparison with the measured velocities for the existing situation (Figure 3.2) it appears that the velocity is reduced by approximately 25 percent. This may be attributed to the increased water depth after scouring.

Table 4.1: Fulcharighat Test Bed Scour Depth/Deposition Found in Revetment Test for 100 Year Discharge

Cross Section	PTS	Distance from R/B (m)	Bed Elevation before run (m PWD)	Bed Elevation after run (m PWD)	Scour Depth (m)	Depth below 100 yr W.L*	Remarks
1A	1	118	10.20	9.12	-1.1	12.8	182 d/s from CS#1
	2	184	7.56	8.16	+0.6	13.8	
	3	250	9.96	9.72	-0.2	12.2	
2	1	110	7.32	6.96	-0.4	15.0	
	2	176	6.36	9.72	+3.4	12.2	
	3	242	13.2	14.52	+1.3	7.4	
2A	1	90	4.92	2.64	-2.3	19.3	152 m d/s from CS#2 perpendicular to the bank
	2	156	7.08	3.72	-3.4	18.2	
	3	222	13.56	7.2	-6.4	14.7	
3	1	86	3.96	3.12	-0.8	18.8	
	2	152	7.56	5.52	-2.0	16.4	
	3	218	13.56	13.32	-0.2	20.6	
4	1	84	4.56	2.16	-2.4	18.6	
	2	150	6.84	4.44	-2.4	17.5	
	3	216	11.16	10.92	-0.4	11.0	
5	1	90	5.64	3.36	-2.3	18.6	
	2	156	6.72	3.36	-3.4	18.6	
	3	222	9.24	9.72	+0.5	12.2	
6	1	102	5.52	0.48	-4.9	18.6	
	2	168	7.80	4.32	-3.5	15.2	
	3	234	9.36	8.88	-0.5	13.0	
6A	1	106	11.16	6.36	-4.8	15.6	158 d/s from CS#6
	2	172	5.52	2.28	-3.2	19.6	
	3	238	5.52	3.12	-2.4	18.8	
7	1	114	8.76	3.12	-5.6	18.8	
	2	180	4.44	0.00	-4.4	21.9	
	3	246	8.40	6.36	-2.0	15.6	
7A	1	124	9.36	9.72	+0.4	12.2	240 m d/s from CS#7
	2	190	7.92	1.68	-6.2	20.2	
	3	256	8.64	4.92	-3.7	17.0	

Notes: 100 Year water level = 21.92 m PWD.
* Average Depth is 16.0m

Table 4.2: **Fulcharighat Test Bed. Mobile Bed Experiment Maximum Velocity Near the Right Bank During Revetment Test, 100 Year Discharge: Test 5**

Cross Section	Distance from Right Bank (m)	Velocity (m/s)	Fixed Bed Velocity (Test 2) (m/s)
A	432	2.0	2.1
B	146	1.6	1.6
	292	1.6	2.9
1	142	2.7	3.3
2	140	3.0	3.5
3	116	2.8	3.8
4	192	2.6	2.1
	288	2.6	2.2
5	276	2.5	2.2
6	168	2.6	3.5
	252	2.6	2.5
7	192	3.0	3.8
8	252	3.1	4.3
9	252	3.0	4.0

Discussion on the Results of the Mobile Bed Experiment, Test 5

The test has shown that a scour ranging from 0 to 6 m below the existing river bed can occur from the existing anabranch configuration. Maximum scour depth occurs downstream of cs#7, where the river flow is converging. The revetment has negligible influence on the flow velocity because a revetment is a passive way to protect the bank.

In the design it will be required to assume that maximum scour can occur at the toe of revetment in any section. The two chars situated downstream of cs#6, may change in the future and for example form a high char. This will further increase flow velocities near the right bank and erosion will take place. The revetment should consequently be designed for high flow velocities. Section 5 presents the conclusions of the study for Fulcharighat.

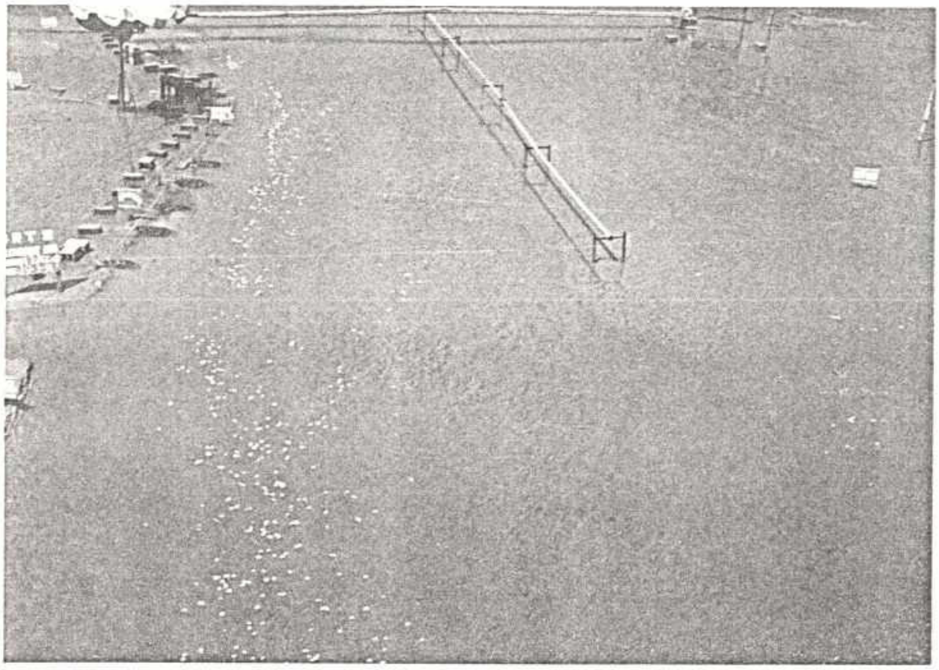
5. SUMMARY AND CONCLUSIONS

The model test for Fulchari have included tests for bank full discharge and 100 year discharge for the existing situation as well as for a situation after a groyne field has been introduced.

The test with 100 year flow conditions (flow measurements) has shown very high velocities both on the existing situation (upto 4.3 m/s with the existing bathymetry and reducing to 3.1 m/s after bed adjustment had taken place) and after introduction of a groyne field (upto 5.9 m/s). A velocity of 4.4 m/s can be dealt with in the design of protecting structures while a velocity as high as 5.9 m/s requires very heavy blocks in the protecting structures. A velocity of 5.9 m/s requires concrete blocks with a side length of about 1.3 m (volume 2.2 m^3 and weight ≈ 4.5 t) to form a stable groyne head. Therefore and for cost reasons a groyne field was found not to be the optimum solution and a revetment was tested instead in Test No. 5.

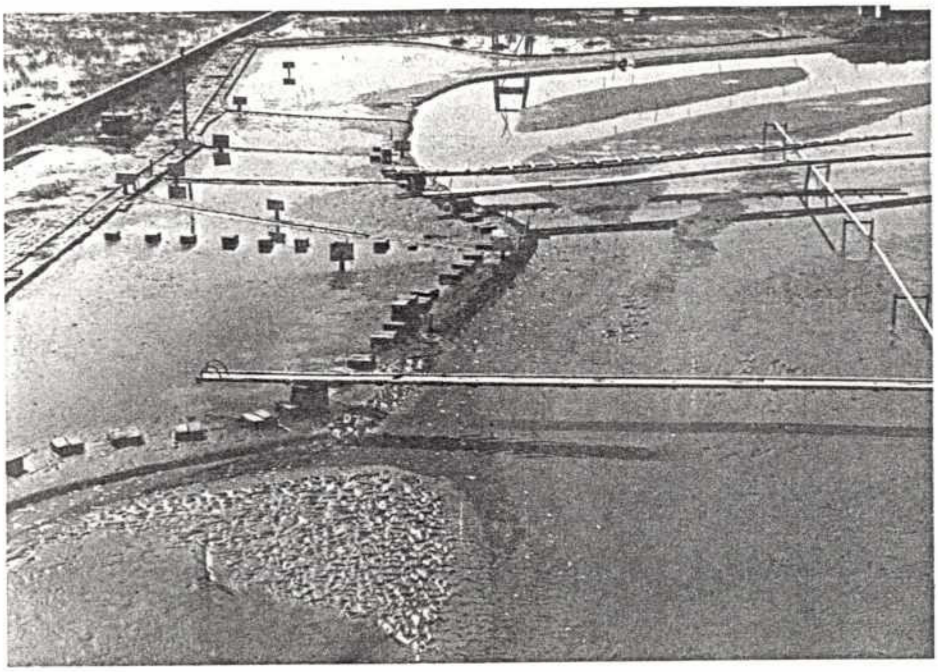
Test No. 5 with revetment showed that at Fulcharighat the 100 year flow conditions induced scour in the order of 2-4 m for the existing bathymetry conditions at the site and a maximum in excess of 6 m. The maximum water depth reached 22 m. The summary report on all model studies presents further details on this aspect.

Test 1:   Bankfull Discharge Existing Situation

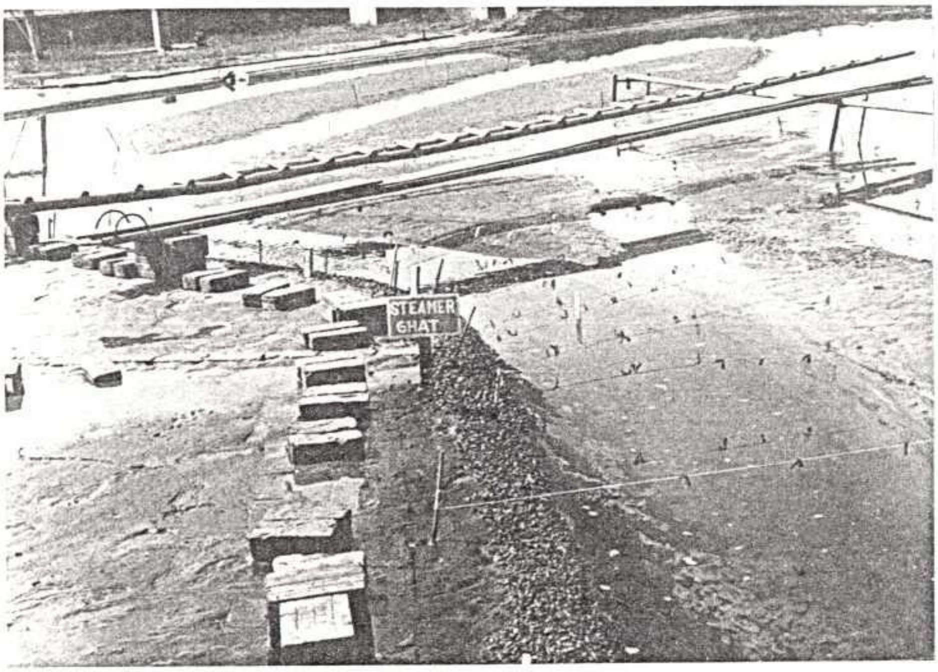


Test 3:   Bankfull Discharge with Groyne Field

Fulchari-Model
Photos 1

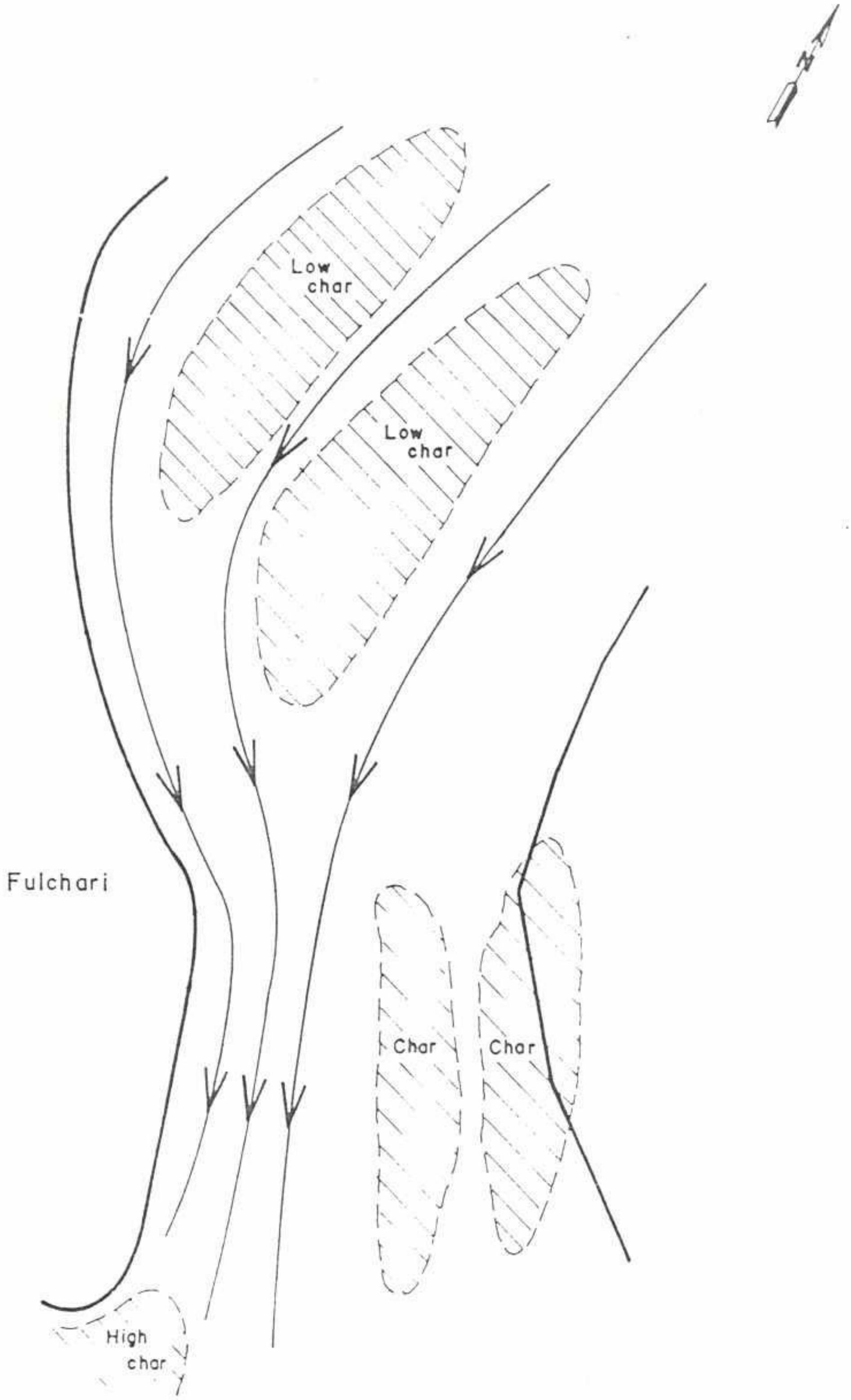


After Test 5, Mobile Bed Test Looking Upstream



After Test 5, Mobile Bed Test, Close-up at Revetment

Fulchari
Model
Photos 2



Note :

The intense concentration of the streamlines near the right bank

FULCHARI PHYSICAL MODEL

THE FLOW SITUATION AT FULCHARI

FIGURE : 1·1

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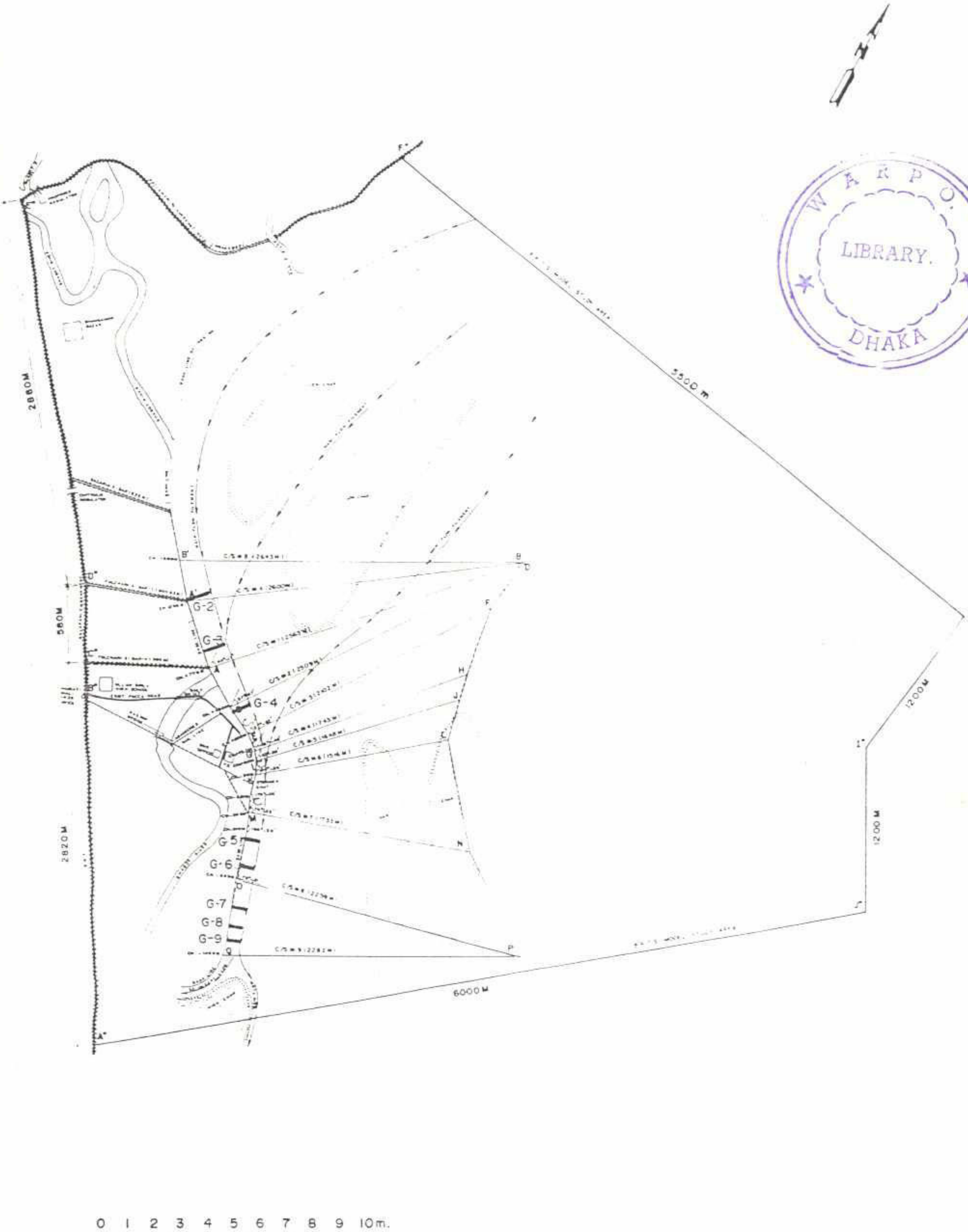
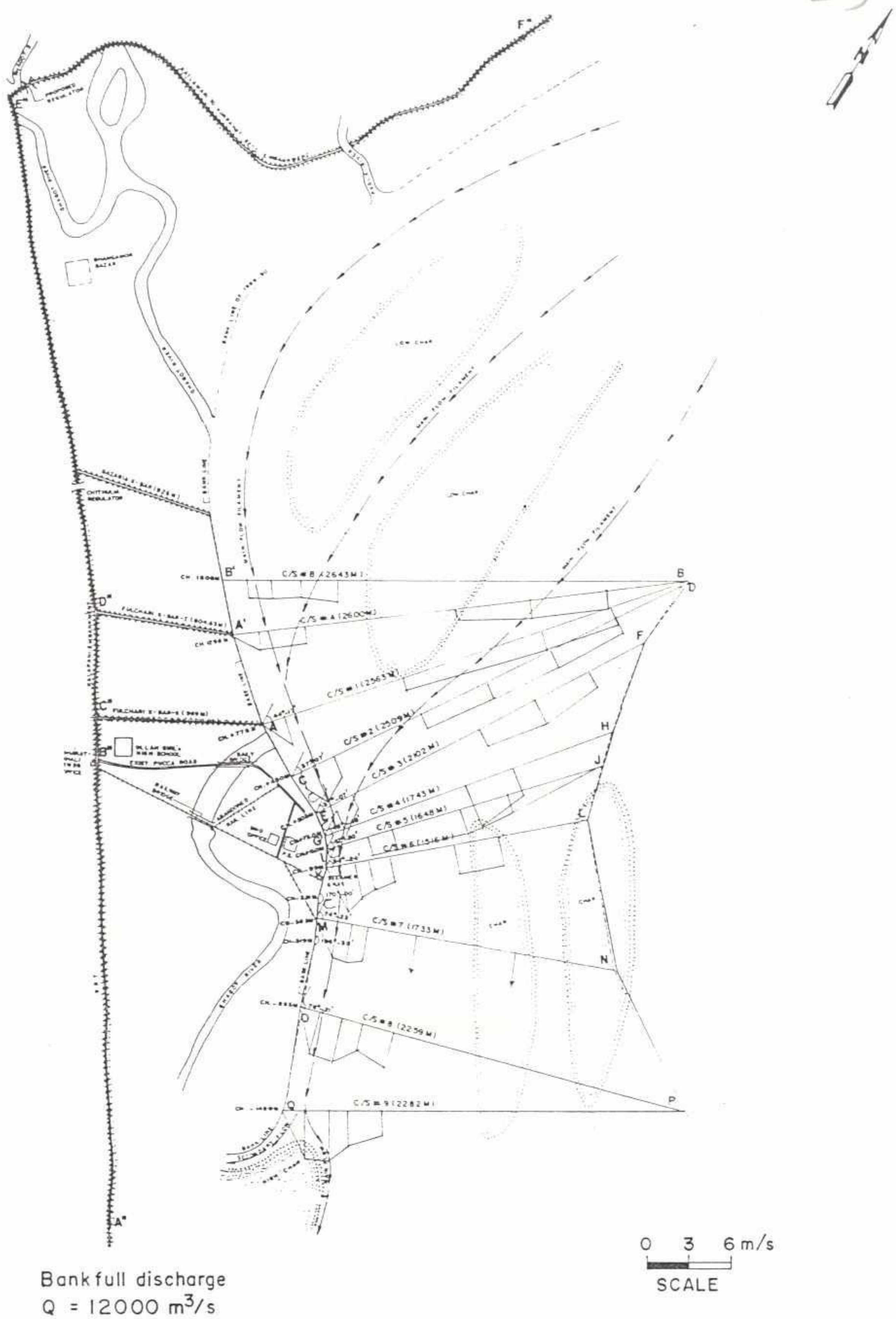


FULCHARI PHYSICAL MODEL

PLAN OF THE MODEL

FIGURE : 2.1



Bank full discharge
Q = 12000 m^3/s
W.L. = 19.15 m.

FULCHARI PHYSICAL MODEL

Test no. 1 ,	EXISTING SITUATION, VELOCITY MEASUREMENTS	FIGURE : 3.1

0 3 6 m/s

SCALE

Flood discharge

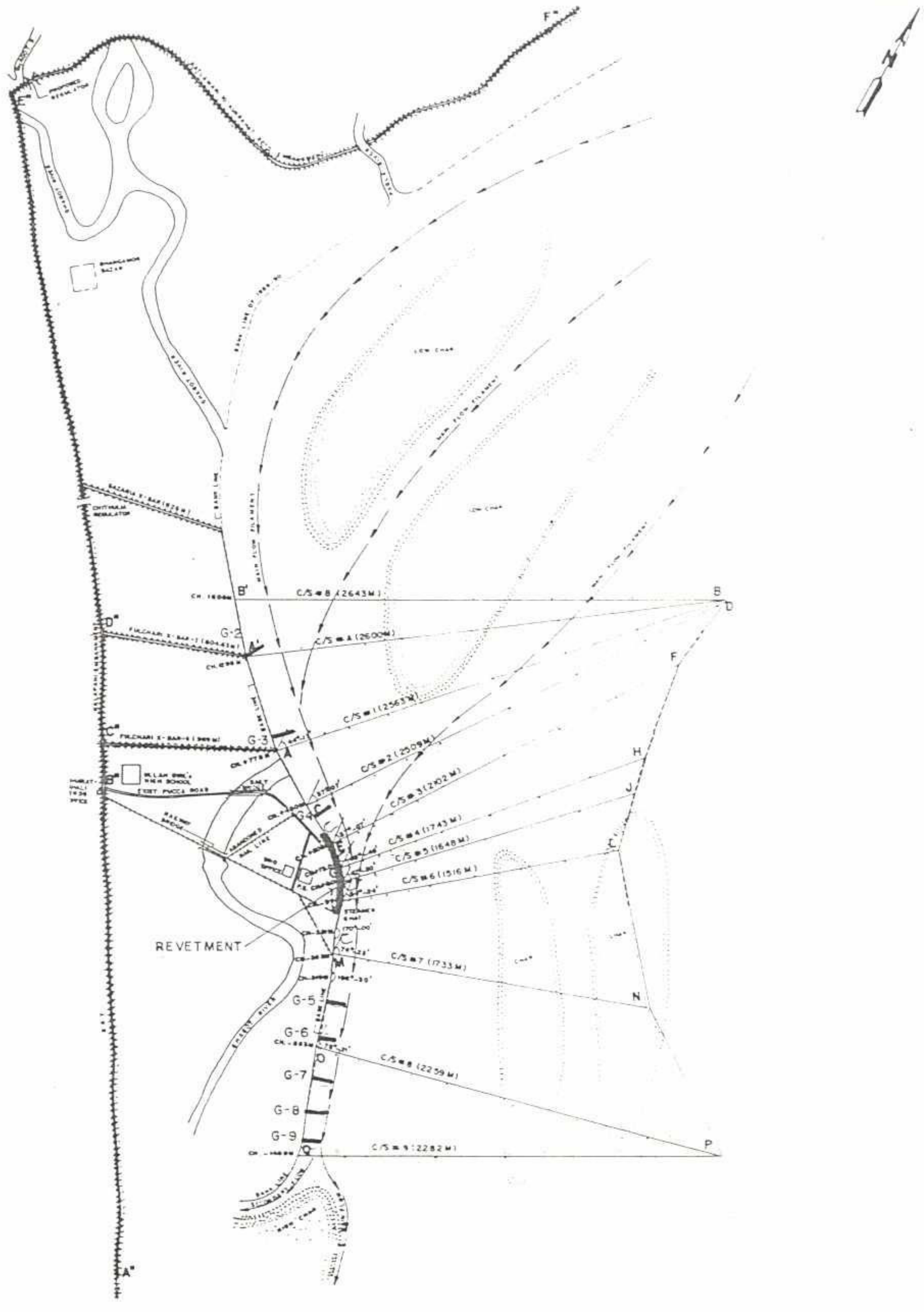
Q = 35000 m^3/s

W.L = 21.92 m

FULCHARI PHYSICAL MODEL

Test no. 2, EXISTING SITUATION, VELOCITY MEASUREMENTS

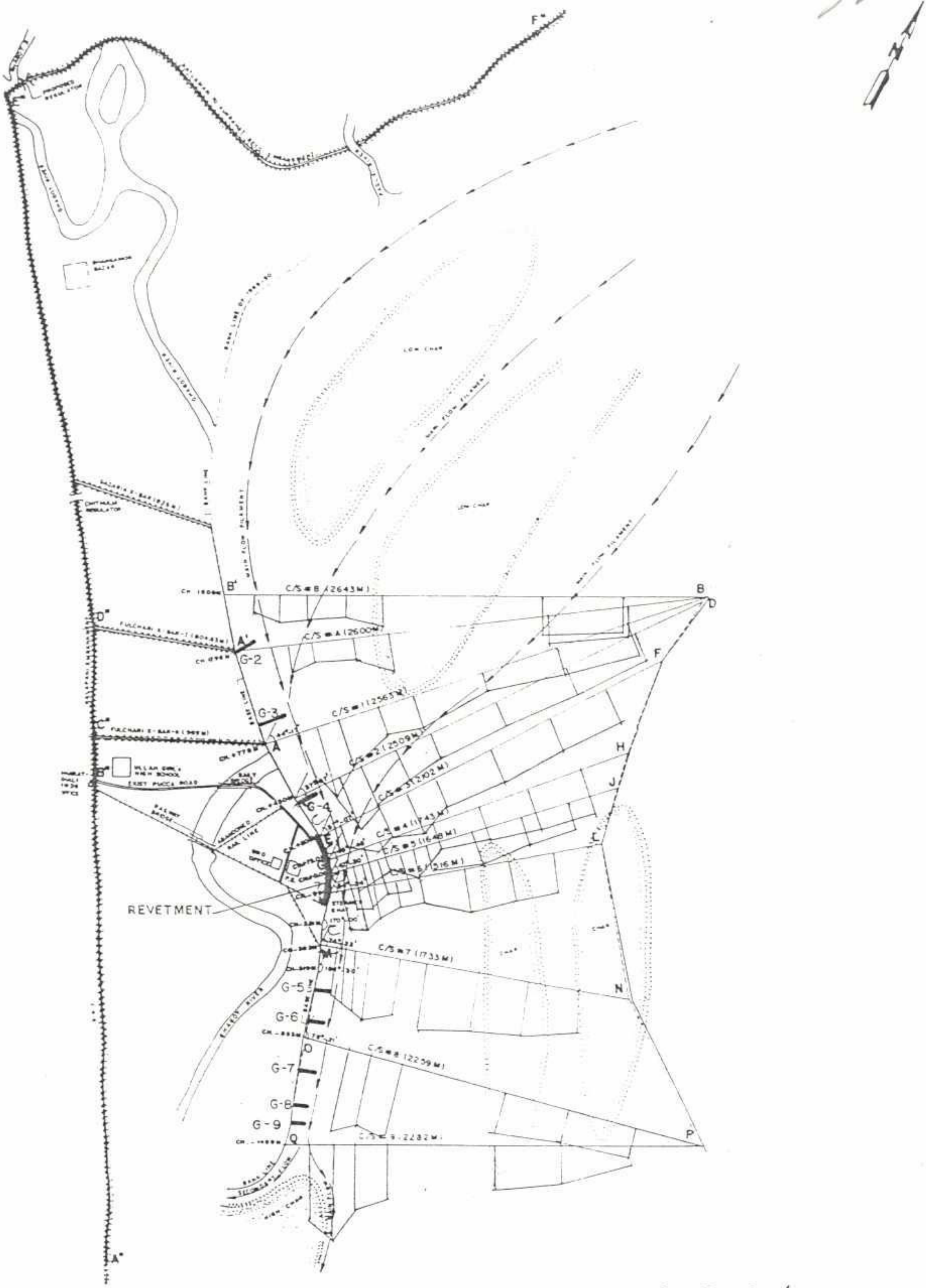
FIGURE : 3.2



FULCHARI PHYSICAL MODEL

LAYOUT OF TRAINING WORKS, REVETMENT AND GROYNES.

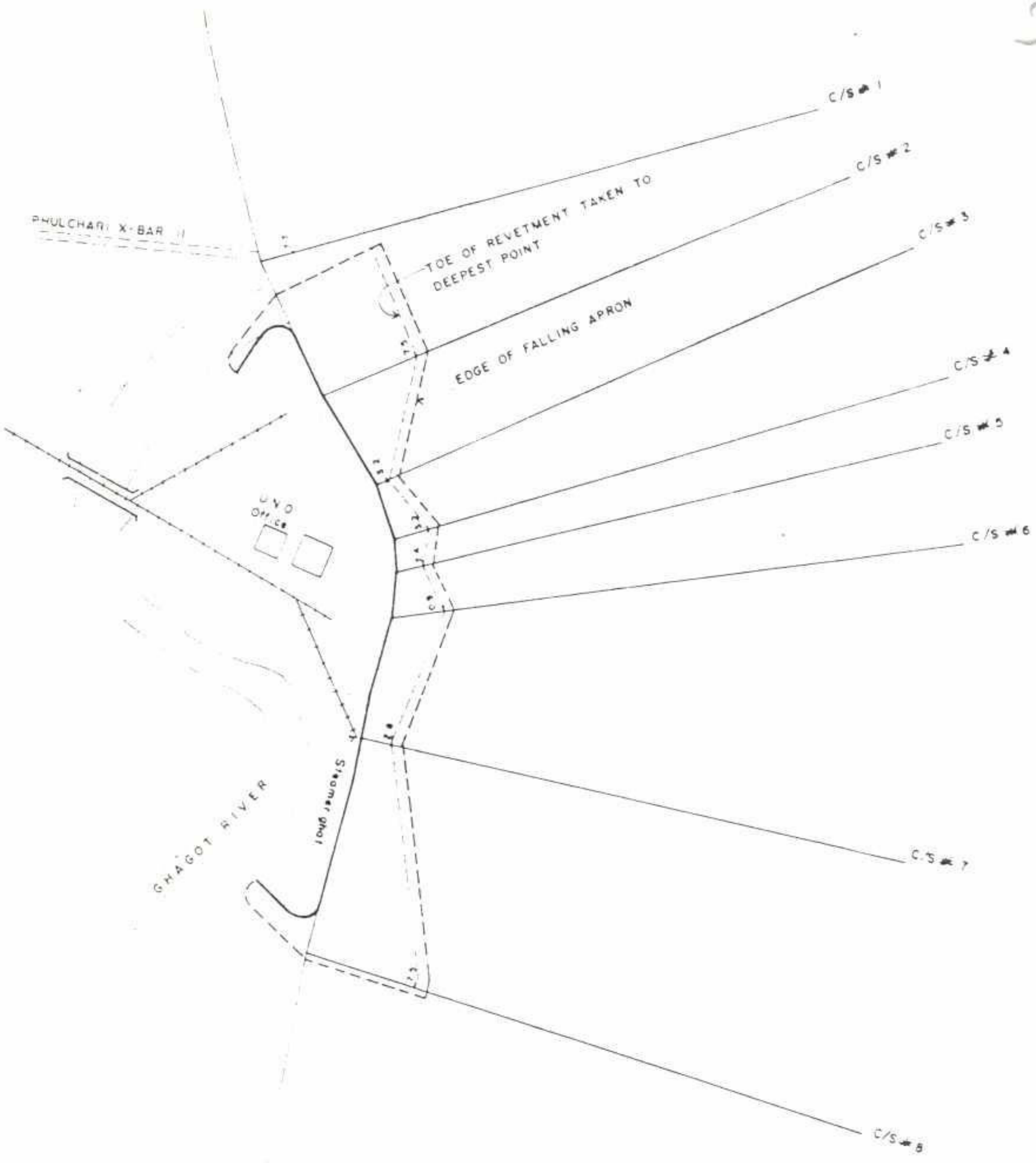
FIGURE : 3.3



100yrs. flood discharge
with training works.
Q.= 35,000 m^3/s

FULCHARI PHYSICAL MODEL

Test no. 4,	VELOCITY MEASUREMENTS, 100 YEARS FLOOD DISCHARGE WITH TRAINING WORKS	FIGURE: 3.4



Notes :

1. Upstream limit of revetment is 250m upstream from cross section # 2
2. Downstream limit of revetment is at cross-section # 8
3. Overall length of revetment along the bank is 1450 m
4. Falling apron is 24m wide from upstream end to cross-section # 3 and from cross-section # 7 to downstream end. It is 17m wide between cross-section # 3 and # 7.
5. Lowest near bank bed level, and its position, is shown on each cross-section line.

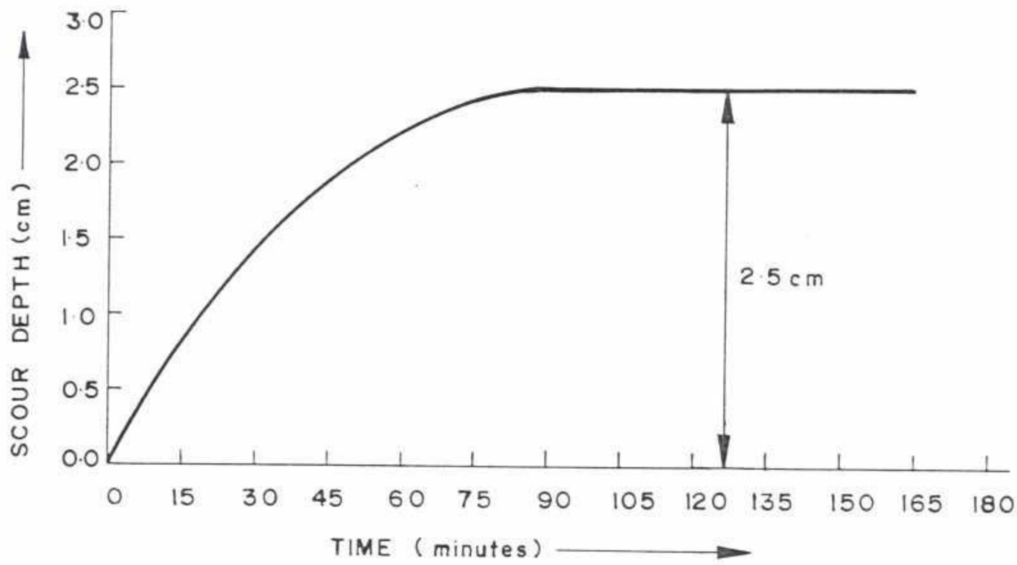
0 100 200 300 400 500 m

SCALE

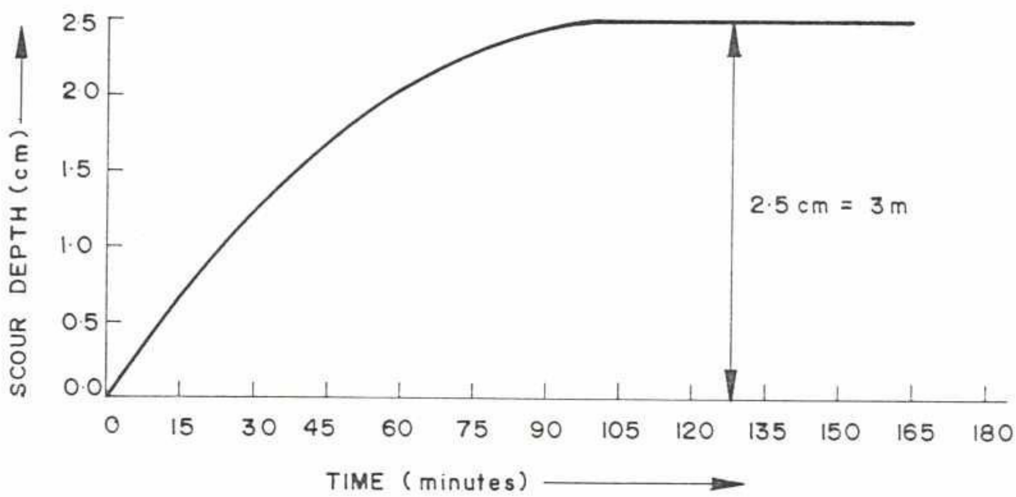
FULCHARI PHYSICAL MODEL

LAYOUT OF REVETMENT ALTERNATIVE

FIGURE : 4·1



C. S. No. 6



C. S. No. 4

FULCHARI PHYSICAL MODEL

Test no.5 — SCOUR DEVELOPMENT ON PROFILE C.S. No. 4 AND C.S. No. 6 — FIGURE: 4·2

FULCHARI

Appendix I
Tables with Flow Velocities
Measured in The Model

Fixed Bed Experiment, Test 1
Bankfull Discharge with no Training Works
Q = 12000 m3/s (46 lt/s model)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
B	146	1.02	
	292	1.08	
	438	0.954	
	658	1.270	
	878		
	1318		
	1758	1.02	
	2198	1.08	
A	144	1.33	
	288	1.204	
	432	1.020	
	648		
	864		
	1296	0.704	
	1728	1.27	
	2160	1.14	
1	142	2.02	
	284		
	426		
	640		
	854	0.891	
	1280	1.02	
	1706	1.209	
	2132	1.27	

APPENDIX I

Test 1 (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
2	140	2.60	
	280	1.52	
	420		
	630		
	840	14.2	
	1258	1.45	
	1676	1.27	
	2094	1.142	
3	116	2.27	
	232	0.954	
	348		
	524	1.71	
	700		
	1050	1.39	
	1400	1.58	
	1750	1.27	
4	96	2.54	
	192	1.08	
	288	1.08	
	434	1.52	
	580		
	870	2.96	
	1160	1.96	

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Test 1 (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
5	92	2.71	
	184	1.71	
	276	1.52	
	414	1.33	
	552	1.39	
	826	1.58	
	1100	1.204	
	1374	0.891	
6	84	3.02	
	168	2.39	
	252	2.08	
	378	1.64	
	504		
	756	1.89	
	1008	1.83	
	1260		
7	96	2.24	
	192	2.52	
	288	2.27	
	434		
	576	2.71	
	864		
	1152	2.39	
	1440		

Test 1 (Cont'd)

C/S NO	Distance from Right Bank in (m)	Velocity in (m/sec)	Remarks
8	126	2.87	
	252	2.97	
	378	1.83	
	566	2.46	
	754		
	1130		
	1506		
	1882		
9	126	3.08	
	252	3.29	
	378	2.16	
	568	1.52	
	758		
	1138		
	1518	1.142	
	1898		

Fixed Bed Experiment, Test 2
100 Years Flood Discharge with no Training Works
Q = 35000 m3/s (133 lt/s model)

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Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
B	146	1.58	
	292	1.71	
	438	1.52	
	658	1.77	
	878	2.21	
	1318	1.39	
	1758	1.33	
	2198	1.33	
A	144	3.14	
	288	2.89	
	432	2.08	
	648	2.02	
	864	1.58	
	1296	1.77	
	1728	1.71	
	2160	1.71	
1	142	3.27	
	284	3.33	
	426	3.01	
	640	1.96	
	854	1.96	
	1280	1.64	
	1706	2.27	
	2132	1.77	

Test 2 (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
2	140	3.47	
	280	2.54	
	420	2.33	
	630	2.58	
	840	1.454	
	1258	2.142	
	1676	2.27	
	2094	1.83	
3	116	3.79	
	232	2.39	
	348	2.27	
	524	2.46	
	700	2.27	
	1050	2.39	
	1400	2.39	
	1750	2.33	
4	96	3.70	
	192	2.14	
	288	2.21	
	434	3.02	
	580	2.02	
	870	2.46	
	1160	3.33	
	1450	3.3	

Test 2 (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
5	92	3.80	
	184	2.89	
	276	2.21	
	414	2.52	
	552	2.02	
	826	2.46	
	1100	2.08	
	1374	2.14	
6	84	4.02	
	168	3.52	
	252	2.52	
	378	3.21	
	504	2.08	
	756	2.83	
	1008	3.33	
	1260	3.46	
7	96	3.77	
	192	3.83	
	288	3.46	
	432	2.83	
	576	3.27	
	864	3.08	
	1152	2.89	
	1440	1.89	

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Test 2 (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
8	126	3.33	
	252	4.33	
	378	2.71	
	566	3.39	
	754		
	1130	2.64	
	1506	2.46	
	1882	1.33	
9	126	3.70	
	252	3.96	
	378	2.52	
	568	2.33	
	758	1.77	
	1138		
	1518	2.77	
	1898	1.33	

Fixed Bed Experiment, Test 3
Bankfull Discharge with Training Work
Q = 12000 m^3/s (46 lt/s model)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
B	146	*	
	292	*	
	438	0.55	*velocity nil
	658	0.829	due to effect
	878	*	of groyne
	1318	*	
	1758	0.985	
	2198	1.204	
A	144	*	
	288	0.704	
	432	0.579	
	648	1.02	
	864	1.02	
	1296	0.55	
	1728	1.27	
	2160	1.142	
1	192	*	
	284	2.83	
	426	*	*velocity nil
	640	2.83 *	
	854	0.55	
	1280	0.766	
	1706	1.142	
	2132	1.454	

Test 3 (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
2	140	*	*velocity nil
	280	*	due to effect
	420	*	of groyne
	630	*	
	840	1.454	
	1258	1.080	
	1676	1.080	
	2094	1.161	
3	116	0.973	
	232	*	
	348	0.770	
	524	1.58	
	700	1.52	
	1050	1.58	
	1400	1.454	
	1750	1.642	
4	96	2.08	
	192	0.77	
	288	1.52	
	434	1.142	
	580	1.27	
	870	1.27	
	1160	2.02	
	1450	*	

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Test 3 (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
5	92	1.58	
	184	1.39	
	276	1.58	
	414	1.14	
	552	1.454	
	826	1.517	
	1100	1.204	
	1374	*	
6	84	1.58	
	168	1.45	
	252	1.58	
	378	1.204	
	504	1.454	*velocity nil
	756	1.52	due to effect
	1008	1.52	of groyne
	1260	*	
7	96	1.58	
	192	2.08	
	288	2.142	
	432	2.142	
	576	*	
	864	2.643	
	1152	*	
	1440	2.142	

Test 3 (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
8	126	*	
	252	3.52	
	378	2.96	
	566	2.27	
	754	*	
	1130	*	
	1506	*	
	1882	*	
9	126	1.705	
	252	2.83	
	378	2.08	
	568	*	*velocity nil
	758	*	due to effect
	1138	*	of groyne
	1518	*	
	1898	*	

Fixed Bed Experiment, Test 4
100 Years Flood Discharge with Training Works
Q = 35,000 m^3/s (135 lt/s model)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
B	146	1.204	
	292	1.705	
	438	1.52	
	658	1.39	
	878	2.08	
	1318	*	
	1758	2.64	
	2198	2.21	
A	144	#	
	288	1.96	
	432	1.27	
	648	1.39	
	864	2.46	#velocity nil
	1296		due to effect
	1728	2.08	of groyne
	2160	1.96	
1	142	*	
	284	4.58	
	426	3.33	
	640	1.96	
	854	2.27	
	1280	1.33	
	1706	2.02	
	2132	2.21	

Test 4 (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
2	140	-2.0	
	280	3.33	
	420	2.64	
	630	2.142	
	840	1.58	
	1258	1.642	
	1676	1.89	
	2094	1.96	
3	116	1.454	
	232	2.52	
	348	2.27	
	524	2.83	
	700	1.89	
	1050	2.33	
	1400	2.33	
	1750	2.46	
4	96	2.39	
	192	2.33	
	288	2.08	
	434	3.08	
	580	2.02	
	870	2.21	
	1160	2.89	
	1450	3.14	

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Test 4 (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
5	92	2.71	
	184	2.83	
	276	2.33	
	414	2.46	
	552	1.77	
	826	2.142	
	1100	2.02	
	1374	1.77	
6	84	2.52	
	168	2.83	
	252	2.33	
	378	1.705	
	504	1.642	
	756	2.83	
	1008	2.83	
	1260	2.46	
7	96	2.96	
	192	3.77	
	288	4.21	
	432	3.83	
	576	4.21	
	864	3.703	
	1152	3.52	
	1440	2.83	

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Test 4 (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
8	126	#	
	252	5.55	
	378	4.71	
	566	4.77	
	754		
	1130	2.71	
	1506	2.21	
	1882	1.52	
9	126	4.58	
	252	5.91	
	378	4.14	
	568	3.27	
	758		
	1138	2.58	
	1578	2.46	
	1898	1.454	

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Mobile Bed Experiment, Test 5
100 Years Flood Discharge with Revetment
Q = 35000 m^3/s (133 lt/s model)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
B	146	1.58	
	292	1.58	
A	144	1.83	
	288		
	432	1.96	
1	142	2.71	
	284	2.52	
2	140	2.96	
	280	2.33	
3	116	2.83	
	232	2.142	
4	96	2.21	
	192	2.58	
	288	2.58	
5	92	2.2	
	184	2.3	
	276	2.52	
6	84	2.21	
	168	2.58	
	252	2.58	
7	96	3.02	
	192	2.96	
	288	3.21	

Test 5 (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
8	126	3.04	
	252	3.14	
	378	2.96	
9	126	2.58	
	252	2.96	
	378	2.89	

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GOVERNMENT OF THE PEOPLE'S
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BANGLADESH WATER
DEVELOPMENT BOARD

River Training Studies of The Brahmaputra River

FINAL REPORT ON PHYSICAL MODEL STUDIES

VOL IV - MODEL BASED ON SARIAKANDI BATHYMETRY

JANUARY 1993

Sir William Halcrow & Partners Ltd.
Danish Hydraulic Institute
Engineering & Planning Consultants Ltd.
Design Innovations Group

MODEL STUDY BY
RIVER RESEARCH INSTITUTE

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BANGLADESH WATER DEVELOPMENT BOARD

River Training Studies of The Brahmaputra River

FINAL REPORT ON PHYSICAL MODEL STUDIES

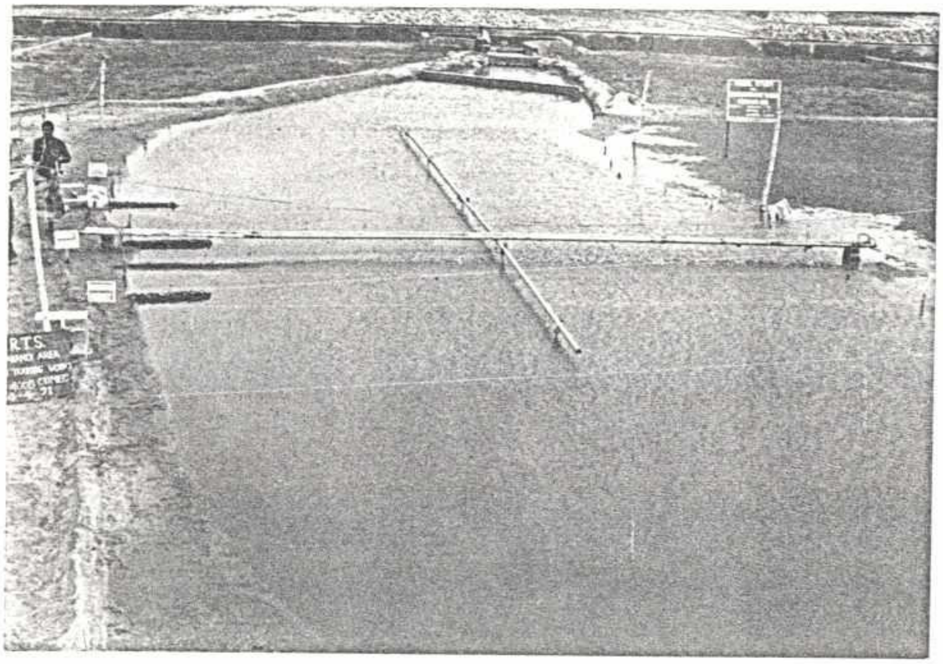
VOL IV - MODELS BASED ON SARIAKANDI BATHYMETRY

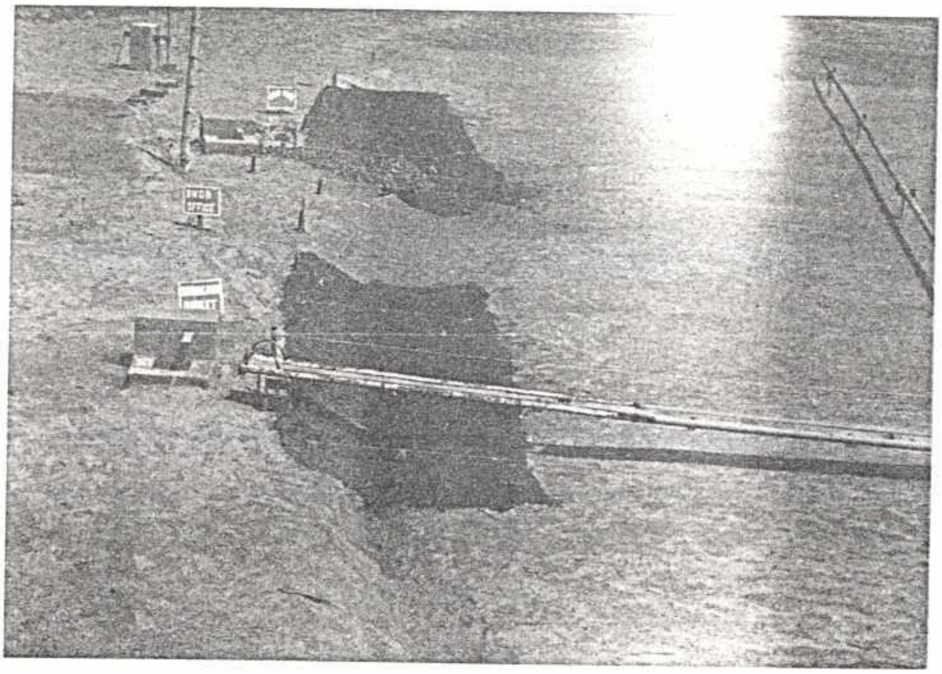
The RRI have prepared this report under the direction of Sir William Halcrow & Partners Ltd. and DHI in accordance with the instructions of the Bangladesh Water Development Board for their sole and specific use. Any other persons who use any information contained hereby do so at their own risk.

Sir William Halcrow & Partners Ltd.
in association with

Danish Hydraulic Institute
Engineering & Planning Consultants Ltd.
Design Innovation Group

MODEL STUDY BY RIVER RESEARCH INSTITUTE





Sariakandi Model
Above Test 2, Existing Situation for Bankfull Discharge
Below Test 5, Preparation for Mobile Bed Test

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RIVER TRAINING STUDIES OF THE BRAHMAPUTRA RIVER

FINAL REPORT ON PHYSICAL MODEL STUDIES
VOL IV - MODELS BASED ON SARIAKANDI BATHYMETRY

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APPENDICES

TABLES

FIGURES

Acknowledgement

Particular thanks are due to the large number of BWDB and RRI staff and others who have contributed for the completion of the model study for Sariakandi Area. Without their active cooperation the model test programme could not have been accomplished.

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BRAHMAPUTRA RIVER TRAINING STUDIES
MODEL BASED ON SARIAKANDI BATHYMETRY

1. INTRODUCTION

1.1 Background

The security of the Brahmaputra Right Embankment (BRE) and consequently the area protected by the BRE has been seriously threatened by continued bank erosion. Since the economic and social consequences of the present approach in dealing with the problem may not be acceptable in the long-term, the Government of Bangladesh (GOB) has commissioned the River Training Studies of the Brahmaputra River (BRTS) to seek a long-term strategy for the protection of the BRE. The project, funded under the IDA sponsored Bangladesh Second Small Scale Flood Control, Drainage and Irrigation Project (Credit No. 1870 BD), will be executed by the Bangladesh Water Development Board (BWDB).

BWDB appointed Sir William Halcrow and Partners Ltd. (Halcrow) in association with Danish Hydraulic Institute (DHI), Engineering and Planning Consultants Ltd. (EPC) and Design Innovations Group (DIG) to undertake this three-year study.

An advisory group from the Bangladesh University of Engineering and Technology (BUET) works with the Consultants' Team. The River Research Institute (RRI) have been nominated to carry out the physical modelling studies required by the BRTS. These studies are guided and sponsored by BRTS.

A letter of Intent was issued by the BWDB on 24th January 1990 to commence the project. The contract for consultancy services was signed between BWDB and Halcrow on 12th March 1990. The Consultant commenced the project on 6th February 1990 by making arrangements to mobilize staff and establish an office and support facilities. Staff inputs commenced on 1st March 1990.

In November 1989, a five year Flood Action Plan (FAP), coordinated by the World Bank, was initiated with the Government of Bangladesh. The FAP is connected with an initial phase of studies directed towards the development of a comprehensive system of long term flood control and drainage works. Priority has been given to the alleviation of flooding from major rivers, of which the Brahmaputra is a significant source. The BRTS therefore, forms component No. 1 of a total of 26 components comprising the FAP during the plan-period 1990-1995.

The present final report on the Sariakandi Area is the fourth of a series of reports presenting the results of the physical model studies performed at RRI, Faridpur.

1.2 The BRTS Project

The Brahmaputra-Jamuna river system is one of the largest in the world, and is also the largest and most important river system in Bangladesh, accounting for more than 50% of the total inflow into Bangladesh from

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all cross border rivers.

The Brahmaputra moved to its present course about 200 years ago. It is a braided river without fixed banks and with frequently shifting channels. Short-term channel migration can be quite drastic with annual rates of movement as high as 800 m. The bank erosion process is a complex mechanism and is influenced by a number of factors. In Bangladesh the total river width varies between 6 km to 15 km. The river cross-section has a highly irregular bed elevation and the main channel may be up to 40 m deep.

A 220 km long earthen embankment, known as the Brahmaputra Right Embankment (BRE), has been constructed on the western bank of the Jamuna River to protect the lands against the ravages of yearly flood. However, every year this embankment has to be retired landward at several places due to bank erosion; a total length of about 140 km of retired embankment has been constructed over the past 20 years.

River erosion is also causing serious problems at specific locations such as ferry crossings, where the terminal stations (ghats) have to be shifted as a result of eroding river banks.

Since the economic and social consequences of the present approach in dealing with the problem of bank erosion may not be acceptable in the long-term, the Government of Bangladesh has commissioned the BRTS to seek a long-term strategy towards its solution.

1.3 The Situation at Sariakandi

Sariakandi is an Upazilla headquarters (lat 24.53' long 89.35') on the right bank of the Brahmaputra river adjacent to station 130 km on the BRE.

After the occurrence of catastrophic flooding and bank erosion in the fifties the contemporary Government invited foreign experts to perform studies to find means for the remedy of the problems.

Based on expert opinion the EPWAPDA (now BWDB) decided to construct embankments along the right bank of the Brahmaputra River. The Construction of the first BRE took place in the sixties.

In the years following its construction, the embankment was subject to erosion and breaches occurred at different places. This process of breaching continued and compelled the BWDB to retire (displace landward) the embankment a number of times.

In recent years bank erosion leading to breaches in the BRE has been experienced in the vicinity of Sariakandi. To divert the flow away from the right bank the Kalitola groyne was constructed. In addition four cross-bars were constructed a few kilometres upstream to keep the flow away from the BRE.

In 1990 the Kalitola groyne at Sariakandi was under threat of failure due to bank erosion both upstream and downstream. The total length of the eroded bank was about 1000 m and it is only about 250 m from the retired embankment at certain places.

The possibility of the BRE breaching is directly linked with the progressive river bank erosion. If the erosion continues the Brahmaputra River may break into the adjacent Bangali river.

Thus in conclusion the present model study for Sariakandi serves two purposes, firstly to assess alternative measures to protect Sariakandi Town and secondly as part of a broader investigation aimed at preventing the Brahmaputra River to join the Bangali River.

1.4 Objectives of Model Study

The model study had the following objectives:

(a) To determine the detailed current conditions in the Sariakandi Area with special emphasis on the conditions in the vicinity of the Kalitola Groyne and the neighbouring river banks.

(b) To determine the influence from new bank stabilisation works on the current pattern and velocities at bankfull and flood conditions.

(c) To determine data such as local velocities and possible scour depths for design of the stabilisation works to be implemented.

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2. THE MODEL

2.1 Design of the Model

An open air distorted model was chosen for the area considering the nature of the problem. The model plan is shown in Figure 2.1. About 5 kilometers of the channel near Sariakandi area and about three and half kilometers in width of the Brahmaputra River was produced in the model. Initially three alternative linear scale ratios were considered. The first one was horizontal: 1:100 and vertical 1:100, the second one was horizontal: 1:200 and vertical: 1:120 and the third alternative was horizontal: 1:125 and vertical: 1:60. Finally considering all factors for successful representation of the prototype the third alternative was selected. For this model the following scales apply:

Horizontal Scale : 1:125
Vertical Scale : 1:60
Discharge Scale : 1:58,000
velocity Scale : 1:7.74
Time Scale : 1:16.14
Distortion factor : 1:2.08

Appendix I presents an assessment of water levels and discharges. The principal data used in the model are presented in Table 2.1

Table 2.1: Sariakandi Test Bed. Water level and Discharge data

Condition	Water Level (m PWD)	Discharge Prototype (m3/s)	Model (l/s)
Bankfull	+ 16.63 m	4,000	69
100 years flood	+ 19.27 m	17,000	293

Cross-sections prepared by BRTS based on recent river surveys were used. The whole of the left flood - plain up to the BRE was included in the model.

The section of the river was reproduced in 0.2 mm sand, which made it possible to conduct fixed bed modelling for the range of flow conditions applied. A rectangular sharp - crested weir was installed in the upper end of the model flume to measure the inflow discharge. Two gauges were installed, one at upstream and another at downstream, to record the water surface elevation with an accuracy of about one tenth of a millimeter. A tilting gate was fixed at the downstream end of the flume to control the water level in the model.

2.2 Data Requirement for the Model

2.2.1 Data Required for Construction

The following data were used as basis for the model construction.

(a) Available Topographical and bathymetry data of the site indicating present river bank line, position of the cross-sections, flood plain and different important existing structures such as embankments cross-bars, rail line, offices etc.

(b) Hydrological data

- Discharge at different water levels.
- Water level statistics i.e. probability of exceedance (Return Period) of different water levels at Sariakandi

(c) Recent field survey data such as bathymetry/topography of the river bed, bank and flood plain.

(d) Data required for model calibration.

For the purposes of model construction the levels of the flood plain and the river bank were assumed to be the same.

2.2.2 Preparation of the Model Bed

The natural river bed at Sariakandi consists of medium to fine sand, $d_{50} \approx 0.18$ mm (see Figure 2.2). The model of Sariakandi was constructed of sand, $d_{50} = 0.2$mm. By calculation of the velocity initiating sediment movement it was shown that the model would behave as a fixed bed model.

The model was constructed in scale using the data of different cross-sections to reproduce the actual bed configuration as measured in the prototype. The model discharge was measured by a point gauge in the inlet chamber upstream at the measuring weir. The calculation curve for discharges is shown in Figure 2.3. A pipe was installed in the downstream end of the model to allow for filling of the model with water also from the downstream side thus minimising erosion of the model bed during the filling operation prior to the model tests.

2.3 Calibration of the Model

The principal objectives of the calibration of the model were to verify that the model correctly represents the prototype or, if not, to determine what further adjustment was required.

In this regard after having obtained stationary flow in the model, the water level at the representative section (c/s-1) was rigidly maintained. The average velocity at the representative section and water surface slope were measured. It was possible to obtain good correlation between model and prototype.

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2.4 Test Programme

Table 2.4 Sariakandi Physical Modelling - List of Model Tests

Test No	WL (m PWD)	Discharge (m^3/s)	Purpose	Comments
Fixed Bed Experiments				
1	+ 19.27	17,000	Flow Measurements	Existing bathymetry. 100 y discharge
2	+ 16.63	4,000	Flow Measurements	Existing bathymetry. 100 y discharge
3	+ 19.27	17,000	Flow Measurements	Tests on Groynes A, B, & C and u/s revetment (layout A)
4	+ 16.63	4,000	Flow Measurements	Tests on Groynes A, B & C and u/s revetment (layout A)
Mobile Bed Experiments				
5	+ 19.27	17,000	Scour Measurements	Scour Study of layout with revetments to the north and south of the Kalitola Groyne (layout B)

Notes: * Bankfull WL = 16.63 m PWD
100 y flood WL = 19.27 m PWD

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3. FIXED BED EXPERIMENTS

3.1 Test Programme

Fixed bed experiments were carried out both for the existing situation with the Kalitola groyne in place and for situations with additional training/protection works in the form of groyne or revetment.

The tests were preformed for two discharges namely the bank full discharge (4,000 m^3/s) and the 100 year flood discharge (17,000 m^3/s).

3.1.1 Tests Without Training Works (Tests Nos. 1 & 2)

Two tests (Nos. 1 & 2) were conducted, the first for bankfull discharge and the second for 100 year flood discharge.

The velocity was measured at several selected points at each cross-section.

Figures 3.1 and 3.2 show a graphical presentation of the velocity measurements and Table 3.1 and 3.2 the maximum measured velocities.

3.1.2 Tests with Additional Training/Protection Works (Tests Nos. 3 & 4)

These tests comprised two configurations of protection works, namely revetment and groynes as specified by BRTS. Revetment upstream of the Kalitola cross-bar and two extra groynes in addition to the existing groyne were constructed. Length, position and alignment of the groynes and revetment are given in Table 3.3 and shown in Figure 3.3. During these tests, velocities were measured in additional points near the groynes heads. (see Tables 3.6 and 3.7). The tests results are shown in Tables 3.4 and 3.5 and in Figures Nos. 3.3 and 3.4.

Test 3, Figure 3.3

By comparison with Figure 3.1 it is seen that the introduction of revetment upstream of the Kalitola groyne and the two new downstream groynes have no significant effect on the flow upstream of the Kalitola groyne.

Downstream the Kalitola groyne, the groyne field (three groynes) are able to divert the flow away from the river bank. It is however seen that south of the third groyne, the sheltered reach of river bank where an eddy has formed has only a limited extension as the flow runs hard on the bank at cs # 10 located about 400 m south of the third groynes.

Test 4, Figure 3.4

Upstream the Kalitola groyne the flow conditions are identical to the present configuration (compare with Figure 3.2). Downstream of the three groynes the situation is basically similar to the situation for bankfull discharge (compare Figures 3.3 and 3.4).

Table 3.1: Sariakandi Test Bed. Test 1, Fixed Bed Test: Existing Situation, Bankfull Stage. Maximum Velocities

Cross Section	Distance from Right Bank (m)	Maximum velocity (m/s)
A	73	1.1
B	74	1.1
1	71	1.1
2	69	1.0
3	214	1.1
4	221	1.0
5	356	1.0
6	219	1.0
7	145	1.0
8	69	1.0
9	128	1.0
10	64	1.0

Notes: Mean velocity 0.7 m/s.

No Training Work Present (Except Kalitola Groyne)
Q = 4000 m^3/s (bank-full stage).
Water Level = 16.63m

Table 3.2: Sariakandi Test Bed. Test 2, Fixed Bed: Existing Situation; 100 y Stage. Maximum Velocities

Cross Section	Distance from Right Bank (m)	Maximum velocity (m/s)
A	435	1.8
B	73	1.9
1	425	1.8
2	412	1.7
3	427	1.9
4	442	2.0
5	712	2.0
6	328	1.8
7	216	2.0
8	137	2.0
9	127	2.0
10	127	2.1

Notes: Mean velocity 1. 4 m/s

No Training Works Present (Except Kalitola Groyne)
$Q = 17,000\ m^3/s$ (100-year flood)
Water level = 19.27 m PWD

Velocity Measurements

Table 3.1 and 3.2 show the maximum velocities measured in the model area for the existing bathymetry. For bankfull discharge it was at 1.1 m/s in several profiles upstream of the groyne. For the 100-year conditions the maximum velocity was 2.1 m/s measured downstream of section 10. Near the groyne nose the velocity reaches 1.9-2.0 m/s.

Tables 3.4 and 3.5 show the measured maximum velocity in each section for Tests 3 and 4 with two additional groyne in place. For bankfull discharge the maximum was 1.1 m/s and for 100 year flood conditions 2.5 m/s.

Test 1 - Figure 3.1

It appears that the flow is almost uniform in the entire area of measurements except near the groyne. The groyne is affecting the flow to a substantial distance upstream. But on the contrary its effect is very limited in the downstream direction. The eddy forming is only extending about 200-300 m downstream. Further, to the south the water is again running hard on the bank.

Test 2 - Figure 3.2

For the 100 - year flood conditions, the effect of the groyne is even less pronounced and almost no influence is seen 200-300 m upstream and downstream respectively.

Table 3.3: Sariakandi Test Bed. Tests 3 & 4, Fixed Bed. Length and alignment of the training works

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Type of Training Works	Location	Length (m)	Alignment
Revetment	From and upstream of Kalitola cross-bar	600	Along the right bank
Groyne A Existing	Kalitola	150	-
Groyne B	360 m downstream of Kalitola cross-bar	150	Perpendicular to right bank line
Groyne C	700 m downstream of Kalitola cross-bar	120	-do-

Table 3.4: Sariakandi Test Bed. Test 3, Fixed-Bed: With Training Works: Bankfull Stage. Maximum Velocities

Cross Section	Distance from Right Bank (m)	Maximum velocity (m/s)
A	72	1.1
B	73	1.1
1	71	1.0
2	68	1.0
3	321	1.0
4	221	1.0
5	712	1.0
6	875	1.0
7	216	1.1
8	206	1.0
9	190	1.0
10	190	1.0

Notes: Mean velocity 0.7 m/s.

$Q = 4{,}000\ m^3/s$ (bank full stage)
Water Level = 16.63 m PWD

Table 3.5: Sariakandi Test Bed. Test 4, Fixed-Bed: With Training Works: 100 y Stage. Maximum Velocities

Cross Section	Distance from Right Bank (m)	Maximum velocity (m/s)
A	435	1.7
B	330	2.0
1	425	1.7
2	412	1.7
3	427	1.9
4	442	1.8
5	712	1.8
6	328	2.0
7	323	2.3
8	310	2.5
9	190	1.4
10	190	2.1

Notes: Mean velocity 1.4 m/s

Q = 17,000 m^3/s (100-years flood)
Water Level = 19.27 m PWD

Velocity Measurement near Groyne

Velocity measurements were also performed riverwards of the groyne nose along the axis of the groynes at their upstream side. The results of these measurements are presented in Tables 3.6 and 3.7.

Test 3, Table 3.6, Bankfull Discharge

The measurements for the groynes B and C appear to be almost identical with velocities in the range from 0.8 to 1.0 m/s.

Test 4, Table 3.7, 100 Year Flood Conditions

Table 3.2 shows more variations than for the bankfull discharge. Again the maximum velocity is almost the same for the three groynes ranging from 2.0 to 2.1 and 2.2 m/s for groynes A, B and C respectively. At groyne C the flow pattern seems to have changed as the velocity is only

1.0 m/s near the groyne nose and 2.2 m/s at 75 m from the nose.

Table 3.6: **Sariakandi Test Bed. Test 3. Fixed-bed, with Training Works Bank-Full Stage. Velocities along the axis of the Groynes**

Groyne	Distance from the nose of groyne (m)	Velocity (m/s)
A Existing	18	2.0
	38	2.0
	56	2.0
B	18	1.0
	38	0.9
	56	0.8
C	18	0.8
	38	0.8
	56	0.9

Table 3.7: Sariakandi Test Bed. Test 4. Fixed-Bed with Training Works. 100-year Stage. Velocities along the axis of the Groynes

Groyne	Distance from groyne nose (m)	Velocities (m/s)
A Existing	18	2.0
	38	2.0
	56	2.0
	75	1.7
B	18	1.9
	38	2.1
	56	2.1
	75	2.0
C	18	1.0
	38	1.6
	56	2.1
	75	2.2

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4. MOBILE BED EXPERIMENTS

4.1 General

The objectives of the mobile bed experiment were to measure scour depths near the training/protection works and flow velocities after scour had occurred. The test was performed with the Kalitola groyne and revetment along the bank to the north and south of the groyne. The two groynes B and C were thus omitted after assessment of the model test results and cost estimates of the groyne versus the revetment alternative. The revetment started 500 m downstream from the Kalitola groyne and extended to a distance of 1,400 m. Details are shown in Figure 3.5. The mobile bed experiment was carried out for 100 year flood discharge.

4.1.1 Measurement of Scour Depths

For measurement of scour depths, points were selected off the groyne and revetment and the levels were taken before and after the test. To determine the development of scour with time continuous measurements were performed at two points. The test was run until the scour had reached its equilibrium.

The final after-test elevations of the selected points were recorded. From the difference of elevation the actual depths of scour were obtained.
The results are shown in Figures 3.6 and 3.7 and in Tables 3.8 and 3.9. The scour development with time in a selected point is shown in Figure 3.6. It appears that the scour stabilizes after about two hours model time. Figure 3.7 shows the velocity distribution after scour has occurred. As the scour is limited the velocity field is almost identical to the situation shown in Figure 3.2 for Test 2.

4.1.2 Discussion of the Results from Mobile-Bed Experiment, Test 5

In the mobile bed experiment there were no extra groynes present in addition to the existing Kalitola groyne. Revetments were introduced along the new bank north and south of the groyne where erosion occurs today.

The maximum near bank velocity was recorded to be 2.2 m/s. The minimum velocity was 1.4 m/s.

The test has for the 100-year situation shown a scour development of about 1.8 m below the existing river bed. This limited scour is due to the fact that the Kalitola groyne has been in position for quite some time and consequently scour has already developed near its nose. The introduction of the revetment does not have any significant influence on the flow velocities as revetment is a passive way of protecting the bankline.

The test has thus shown that it will require a change of the anabranch bathymetry to provoke development of scour at Sariakandi.

This is a possible future development and the Kalitola groyne as well as the new revetments should be made in a way to ensure their stability for this possible development. For the groyne it will most likely be necessary to reinforce significantly the toe apron of the structure and place additional blocks in the upper slope where required. For the revetment design it will be necessary to assume that maximum scour can develop in front of any section consequently the toe apron of the revetment will have to be strong and flexible enough to resist such development. This structural design will be the subject of specific revetment model tests in a larger scale in a non-distorted model.

Table 4.1: Sariakandi Test Bed. Test 5. Mobile-Bed. With Training Work. 100 y Stage. Maximum Velocities

Cross Section	Distance from Right Bank (m)	Maximum velocity (m/s)
A	72	1.9
B	73	1.9
1	142	1.9
2	68	1.9
3	214	2.0
4	221	2.0
5	356	2.0
6	437	1.8
7	323	1.9
8	206	2.0
9	190	2.2
10	285	2.4

Notes: Mean velocity 1.4 m/s.

Q = 17,000 m3/s (100-years flood)
Water Level = 19.27 m PWD

Table 4.2: Sariakandi Test Bed. Test 5: Mobile Bed with Training Works: 100 Year Stage.
Maximum erosion and deposition at selected points

Cross Section	Distance from Right Bank (m)	Maximum Erosion (m)	Maximum Deposition (m)
1	46	1.5	-
2	143	1.2	-
3	107	1.6	-
4	51	-	1.0
8	76	1.2	-
9	154	1.5	-
X(100 m d/s from c/s#9)	141	1.2	-
Y(200 m d/s from c/s#9)	100	1.8	-

The deepest water is present around Cross-section 4 where the Kalitola groyne is situated.

The deepest scour level prior to testing was at -1.0 to -2.0 m PWD. With levels of -1.0 m approximately in the scour hole and a 100 year water level of 19.27 m at Sariakandi, the maximum water depth is about 20-21 m for this situation.

5. CONCLUSION AND RECOMMENDATIONS

5.1 General

This section presents the conclusions and recommendations derived from the studies for Sariakandi Area.

5.2 Sariakandi Site Characteristics

Sariakandi is located approximately halfway along the right bank of the Brahmaputra River covered by the BRTS.

Sariakandi is an important township situated between the Brahmaputra and the Bangali Rivers being only about 2 km apart at this location. The town has been under threat from erosion from the Brahmaputra for many years. In recent years the BWDB has constructed the Kalitola groyne at Sariakandi in an attempt to reduce the erosion and to secure the township. The groyne has improved the situation, but still the river bank is subject to severe erosion to the north and to the south of the groyne.

Also the groyne itself is under threat of failure due to scour. At the nose in the section facing northeast the slope of the groyne armour - layer appeared very steep (Inspection on 1 June 1991) probably due to toe scour and lack of sufficient number of blocks at the apron. Also the shank and the root of the groyne requires urgent maintenance.

5.3 Purpose of the Model Study

The purpose of the model study has been the following:

(a) To study the flow conditions and velocities in the area for the present configuration.

(b) To study the influence on flow and velocities from introducing new training/protection structures in addition to the existing Kalitola Groyne.

The new structures considered comprise groynes and revetment.

(c) For selected configuration of training/protection works, to study the scour development in case of 100 year water level/discharge conditions.

5.4 Possible Solutions for Bank Protection

For protection of the river bank against erosion different solutions have been considered:

(a) Groyne Field
(b) Revetments
(c) Combination of Groynes and Revetment

With respect to the above solutions it is important to note that the introduction of groynes is considered an active measure aiming at deflecting the river flow away from the bank. Due to the blockage effect of the groynes high concentration of flow occurs near the nose of the groynes leading to velocity amplification. A groyne therefore needs very heavy scour protection at its nose to prevent the structure from failing due to scour. Besides this, a field of groynes and its layout can be designed to be optimum for given flow characteristics and only upstream and downstream river/anabranch configuration. If the river changes as the Brahmaputra does continuously, the groyne field is not necessarily optimum any longer.

Bank parallel revetment on the contrary is a passive way of protecting the bank against erosion. This is because the revetment in itself is not significantly changing the flow conditions and thus not provoking scour development as is always the case for a groyne.

If the river changes its course, the revetment may be in the way for the natural development of the anabranch and consequently deep water can develop in front of the revetment at any section. Therefore a revetment also requires a strong scour protection at the toe. In conclusion it can be said that a revetment by its passive effect on the flow is better suited where bank stabilisation is the primary objective. Provided the revetment toe is capable of adjusting to the scour, the most vulnerable part of the revetment is its upstream and downstream terminations where embayment may form resulting in large velocities at the exposed embankment corners.

5.5 Results of Model Tests

The model tests comprised five test runs:

Tests 1 & 2

Tests with fixed-bed and existing layout and configuration for study of flow conditions and velocities.

Tests 3 & 4

Tests with fixed-bed and with two new groynes to the south of the Kalitola groyne for studying of flow conditions and velocities. (layout shown in Figure 3.3).

Test 5

Test with mobile bed in the vicinity of the Kalitola groyne nose and in front of revetment. The layout composed revetments to the north and south of the Kalitola groyne in addition to the existing groyne. (layout shown in Figure 3.5).

Tests 1 & 2, Existing Situation

The existing situation with respect to anabranch bathymetry and Kalitola groyne layout was studied with fixed bed. The results appearing in Figure 3.1 and 3.2 show fairly regular flow in the entire flow channel except near the Kalitola groyne. For bankfull discharge the groyne has an effect on the flow especially upstream of the groyne while downstream the effect is limited to about 300 m. The maximum flow velocity measured for 100 year flood was 2.1 m/s at cross-section 10 downstream the Kalitola groyne.

For the 100 year flood the groyne has only very limited effect on the flow. The zone of protection is about 200 - 300 m both upstream and downstream of the groyne.

Tests 3 & 4 - Layout A

The Layout A with two additional groynes to the south of the Kalitola groyne results in protection of the river bank in between the groynes and to a distance of about 500 m downstream of the third southernmost groyne for 100 years flood conditions. However the construction of such two groynes represents a larger capital investment than the construction of bank parallel revetments for which reason Layout B in Figure 3.5 was developed. The groynes B and C in layout A had length of 150 and 120 m respectively. The spacing between Kalitola and groyne B was 360 m and between groyne B and C the spacing was 340 m.

Test 5 - Layout B

Layout B comprised the construction of about 600 m bank parallel revetment to the north of the Kalitola Groyne and about 1,400 m to the south as shown in Figure 3.5. Test 5 was performed with mobile bed consisting of 0.5 mm Coal dust near the structures. This test has shown that the introduction of the revetments has only limited effect on the flow and current velocity conditions. The maximum velocity along the revetment was measured at 2.4 m/s downstream the groyne at cross-section 10 for 100 year flood conditions.

The scour measurements for 100-year flood showed only limited scour development relative to the present bathymetry conditions with a maximum of 1.8 m. scour.

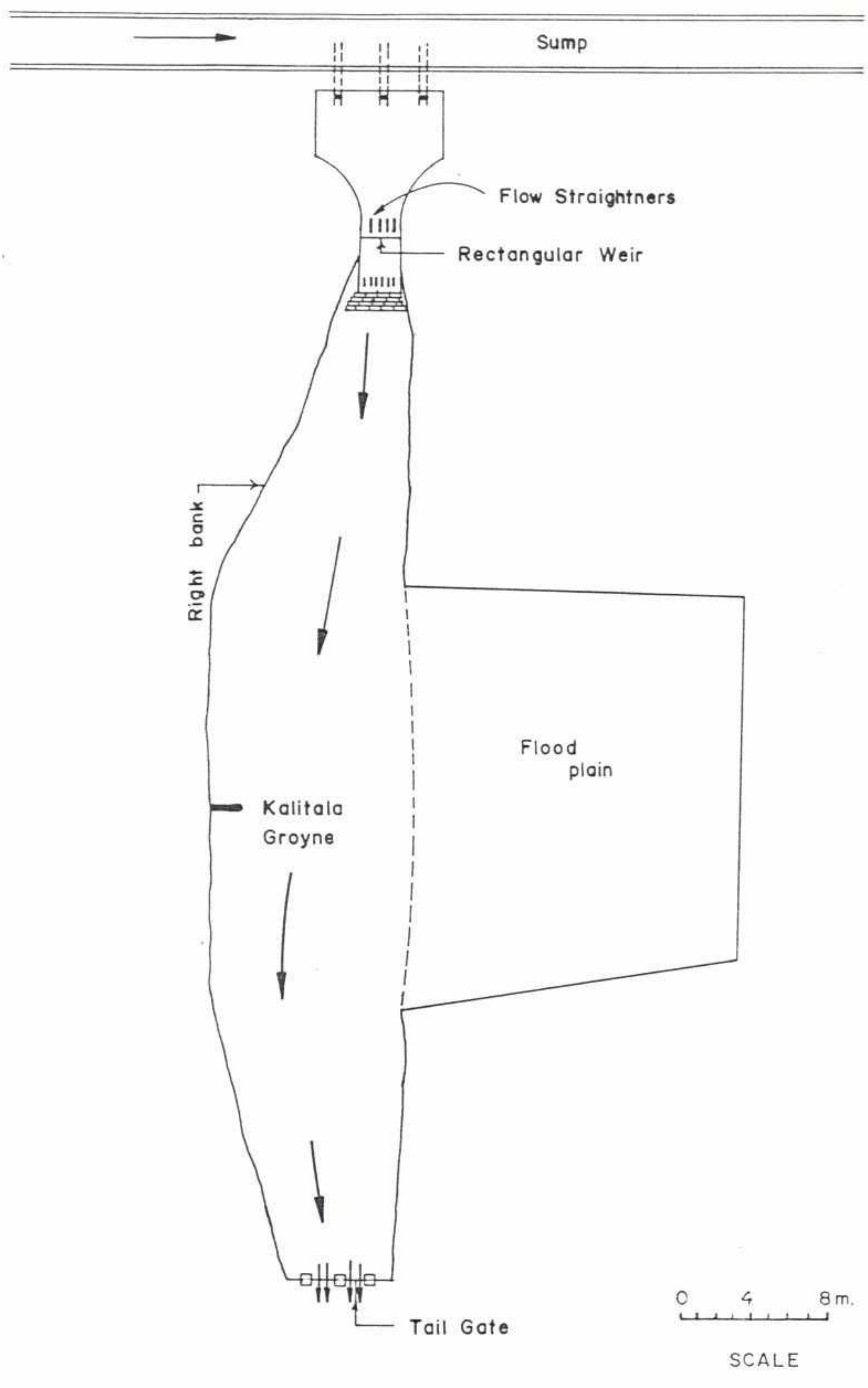
It is possible that the future development of the Brahmaputra River and its western most anabranch at Sariakandi will worsen the situation and that larger velocities will result. Scour at the toe can then develop in front of any section of protection works.

Final Recommendations for Sariakandi.

For protection of the township it is recommended that the existing Kalitola groyne is reinforced to ensure its long term stability. In addition thereto revetments structures should be implemented.

The revetments will be designed with a strong toe apron to resist future scour and in addition the groynes rehabilitation and strengthening as part of the overall programme for training/protection works at Sariakandi should be carried out.

With respect to the risk of the Brahmaputra River breaching through to the Bangali River ongoing studies will reveal which further works are required. Such new revetment works will have to be designed in such a way that they together with the reinforced Kalitola Groyne provide an optimum solution of river training and bank protection to protect both the Sariakandi town as well as the strip of land between Brahmaputra and Bangali Rivers from further erosion.

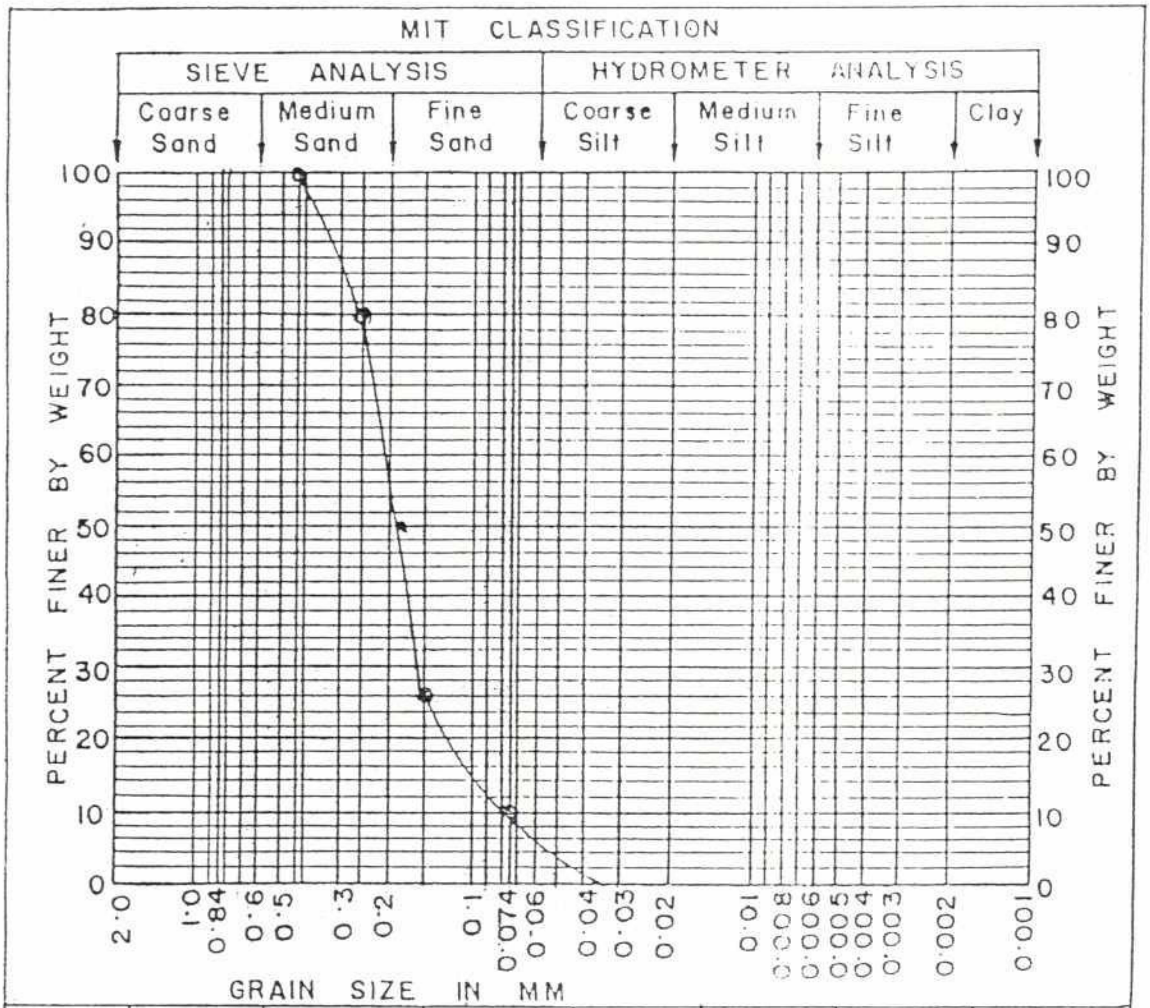


SARIAKANDI PHYSICAL MODEL

SKETCH OF MODEL SET UP

FIGURE : 2·1

RIVER :— BRAHMAPUTRA STATION :— SARIAKANDI

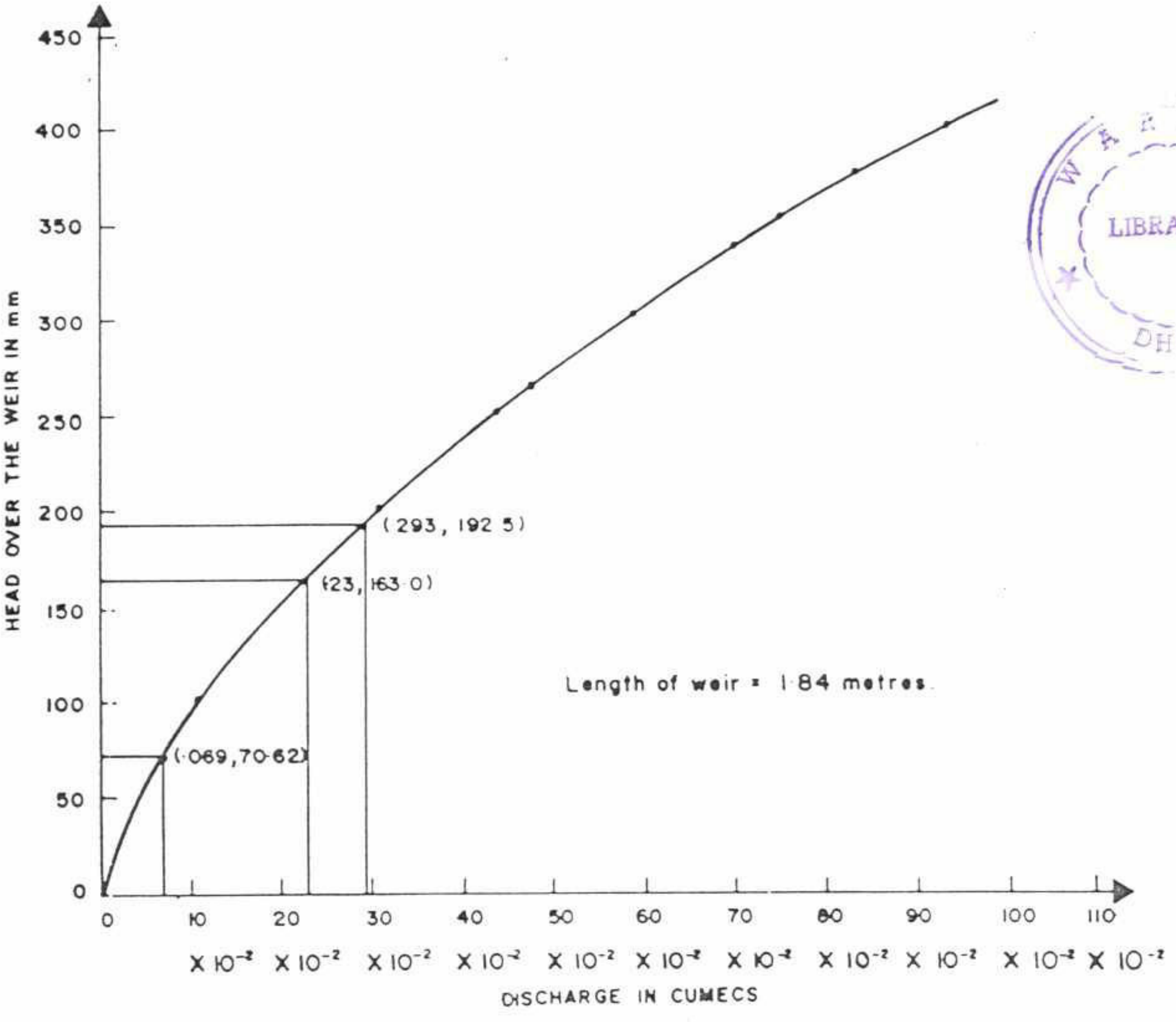


DATE	LEGEND	SAMPLE NO	DEPTH, FT	D_{65} mm	D_{35} mm	D mm	Sp. Gr.
10·12·96	-o-o-o-	1	-	0.223	0.17	0.195	-

SARIAKANDI PHYSICAL MODEL

GRADATION CURVES OF BED MATERIALS

FIGURE : 2·2



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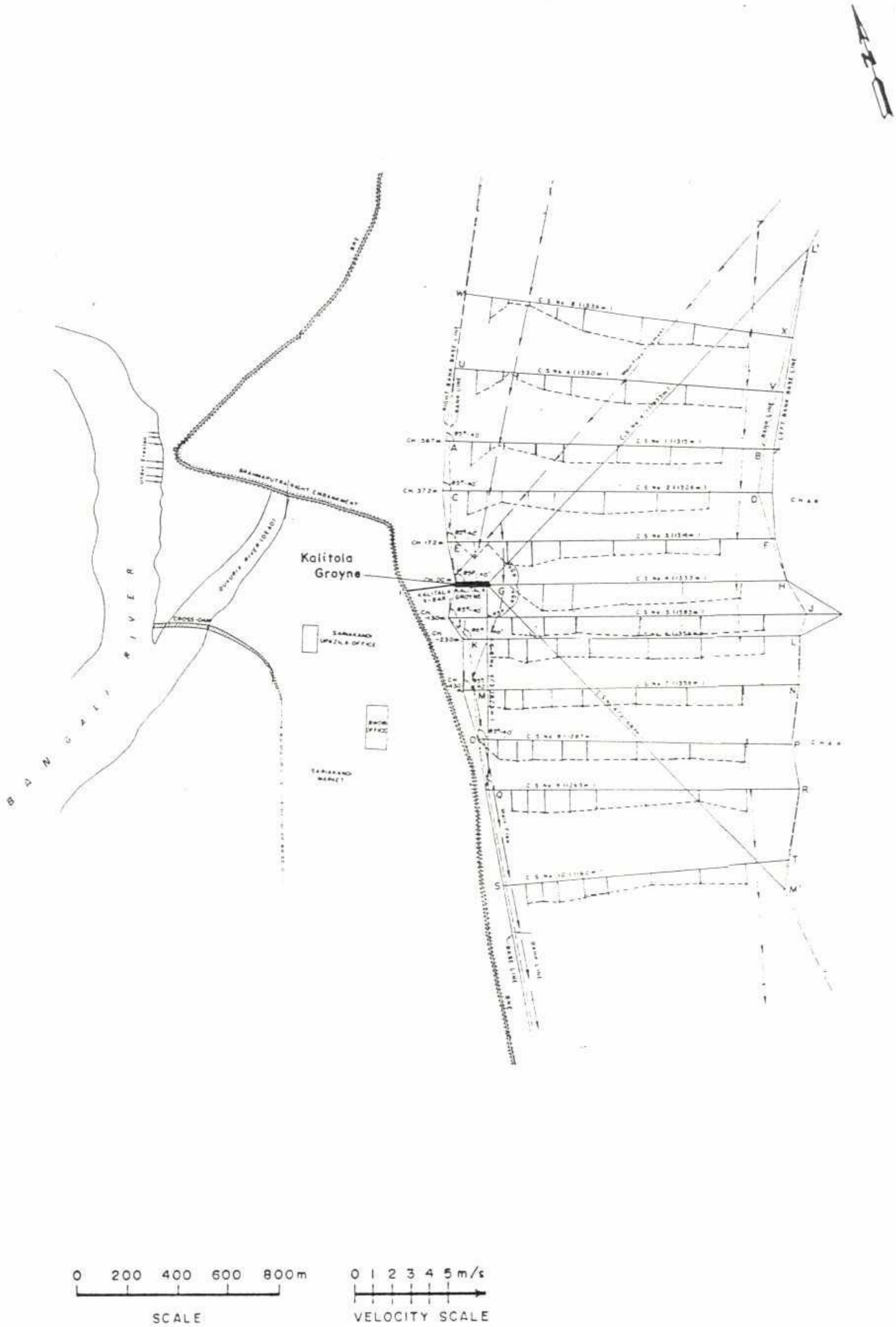
SARIAKANDI PHYSICAL MODEL

CALIBRATION CURVE FOR THE MEASURING WEIR

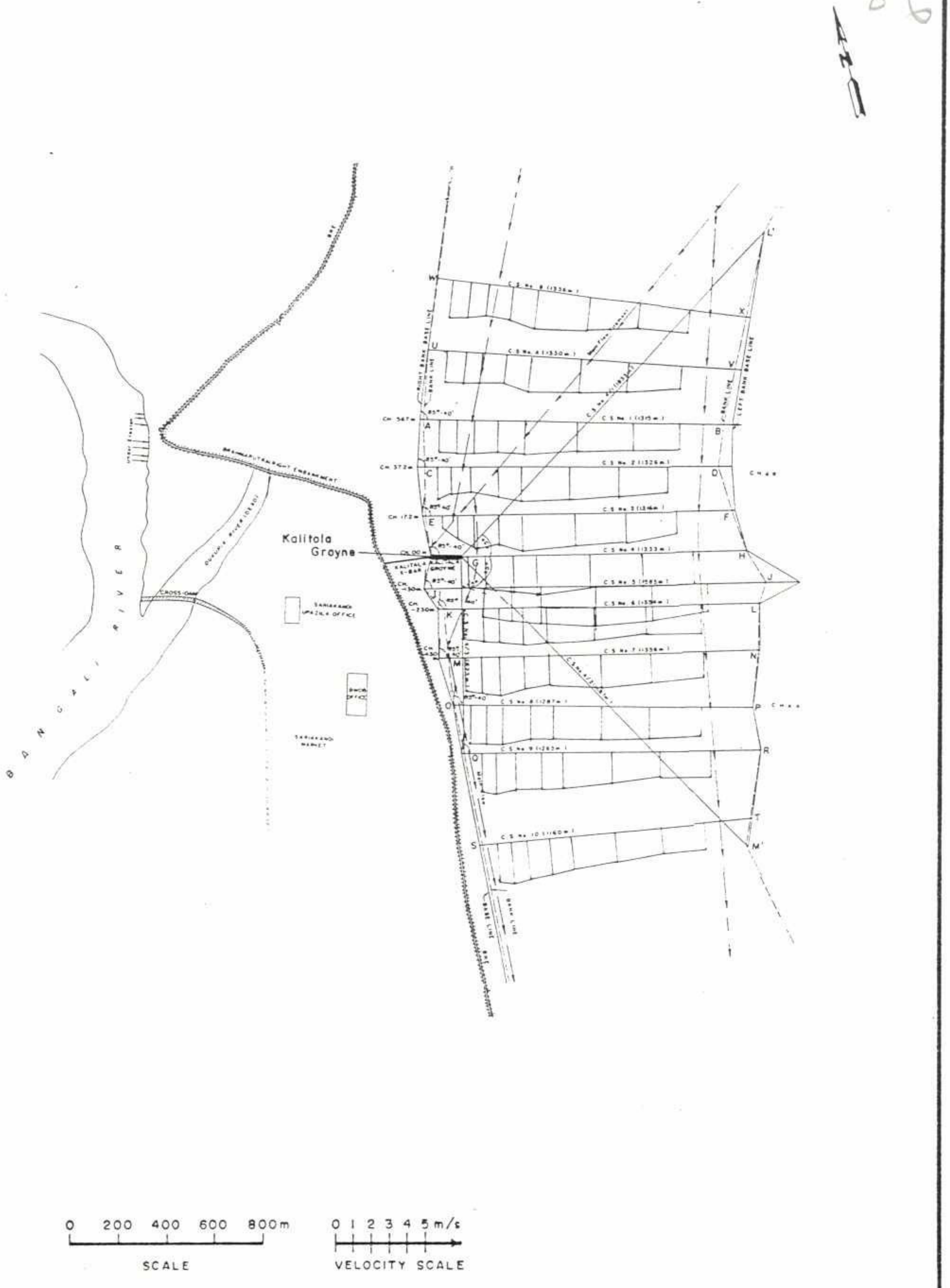
FIGURE: 2.3



SARIAKANDI PHYSICAL MODEL

Test no. 1, VELOCITY MEASUREMENTS

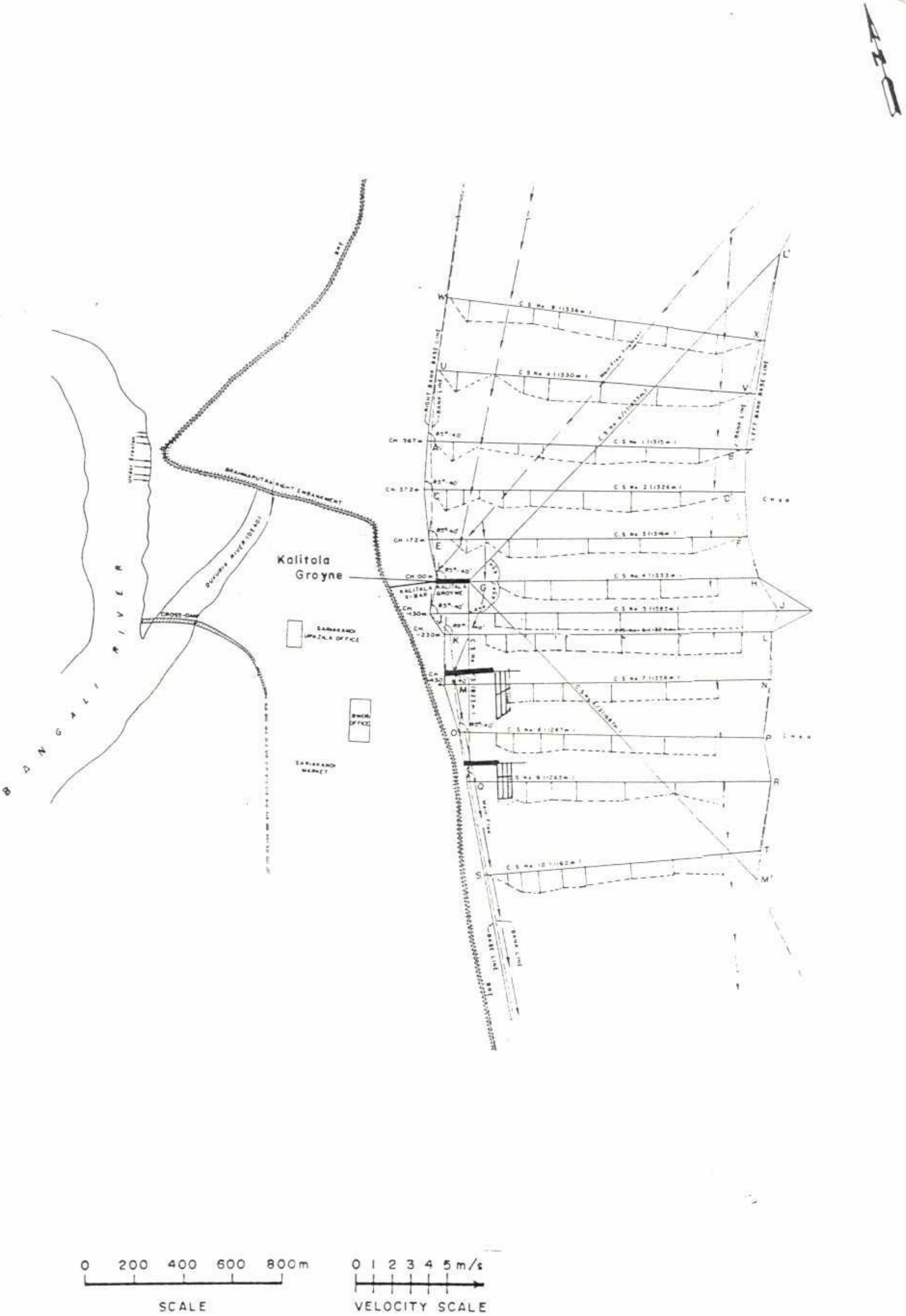
FIGURE : 3.1



SARIAKANDI PHYSICAL MODEL

Test no. 2, VELOCITY MEASUREMENTS

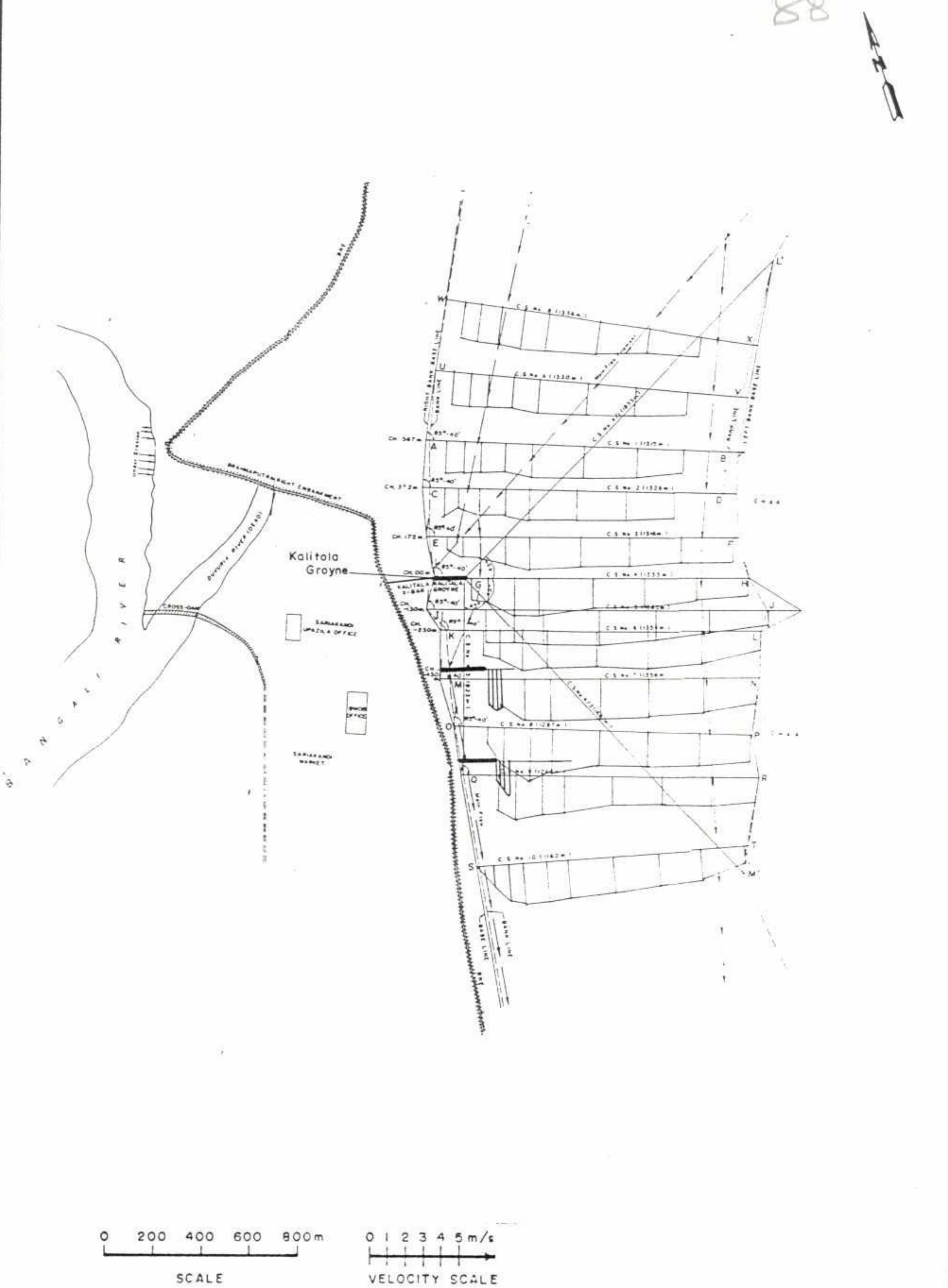
FIGURE : 3.2



SARIAKANDI PHYSICAL MODEL

Test no. 3, VELOCITY MEASUREMENTS

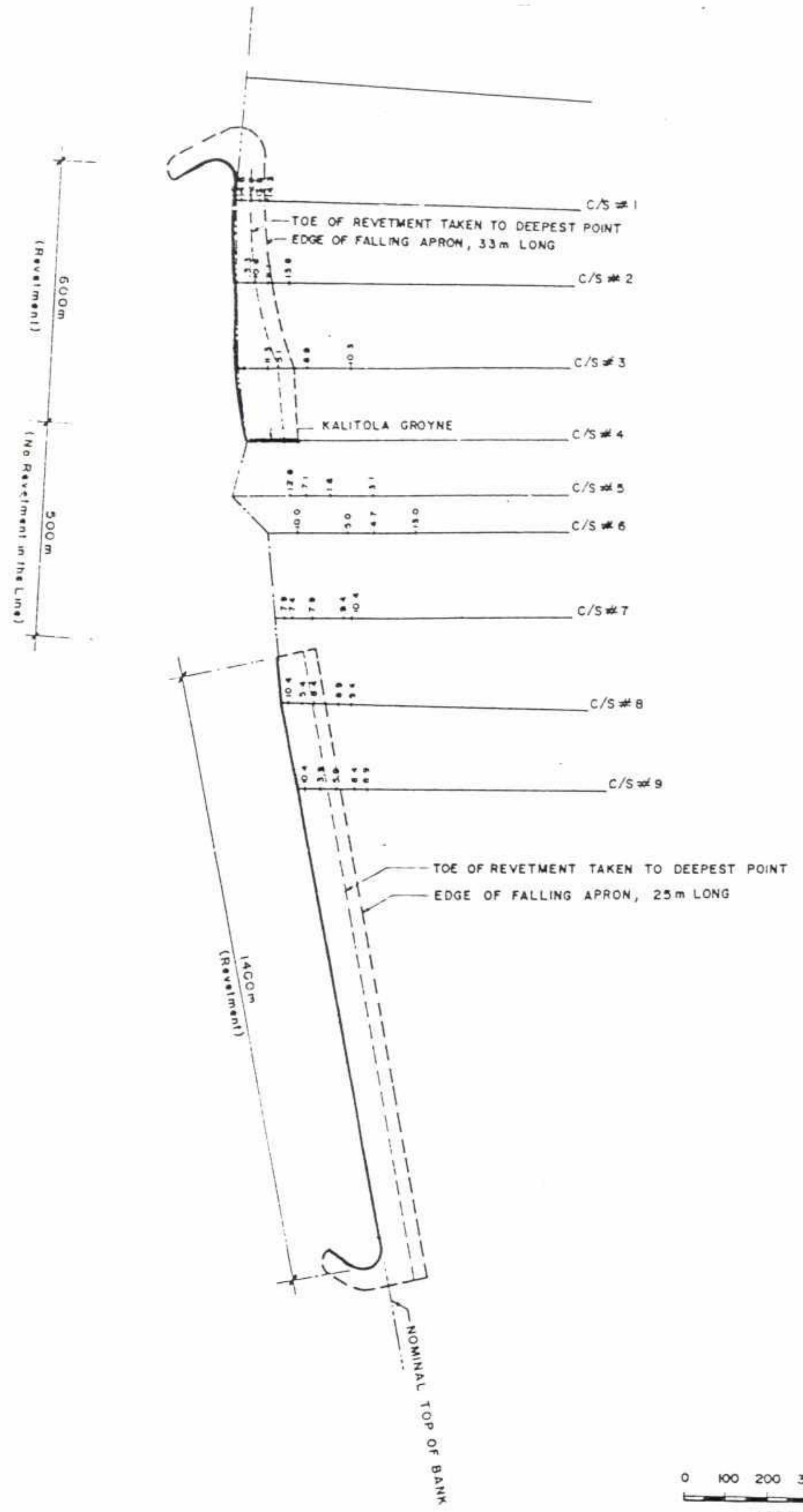
FIGURE : 3.3



SARIAKANDI PHYSICAL MODEL

Test no. 4, VELOCITY MEASUREMENTS

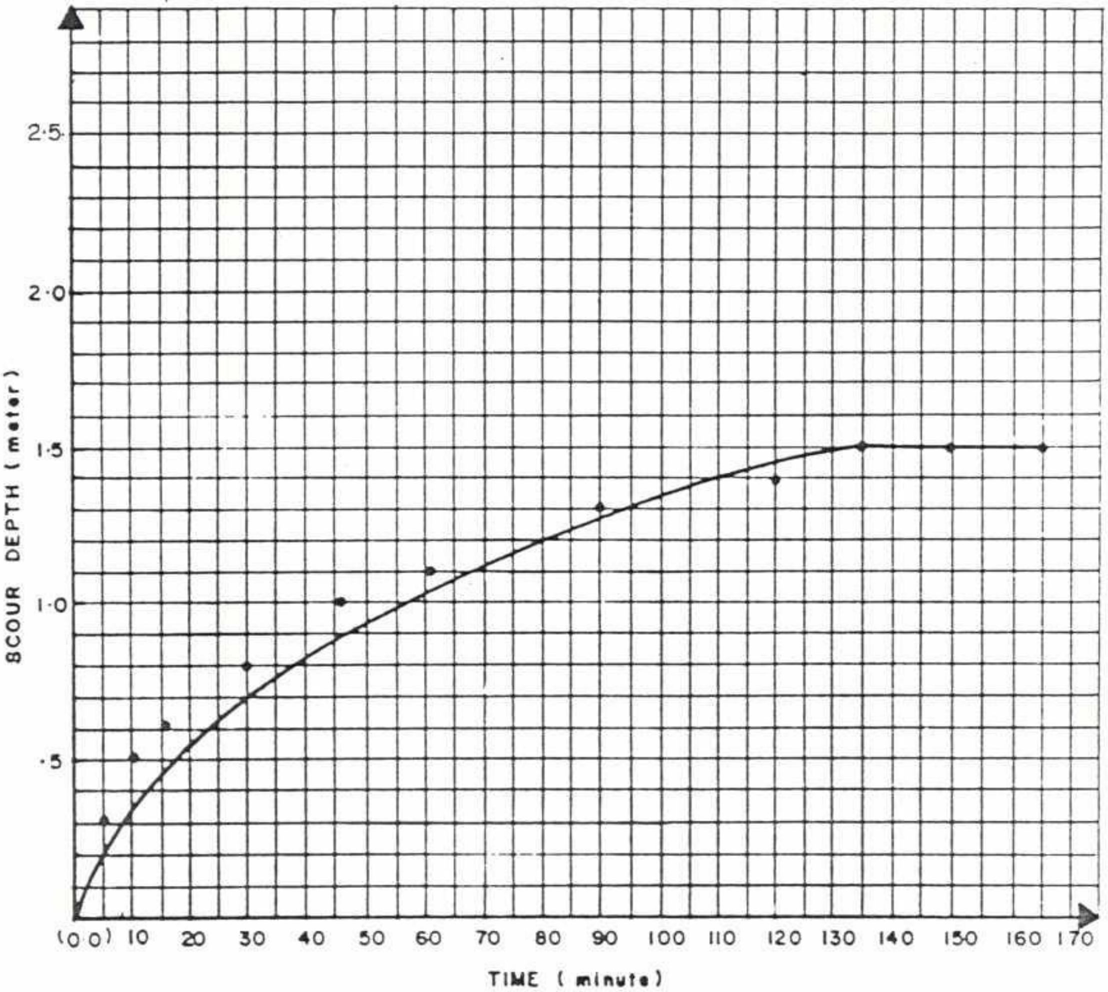
FIGURE : 3.4



SARIAKANDI PHYSICAL MODEL

Test no. 5, DETAILS OF SET UP FOR SCOUR

FIGURE : 3·5



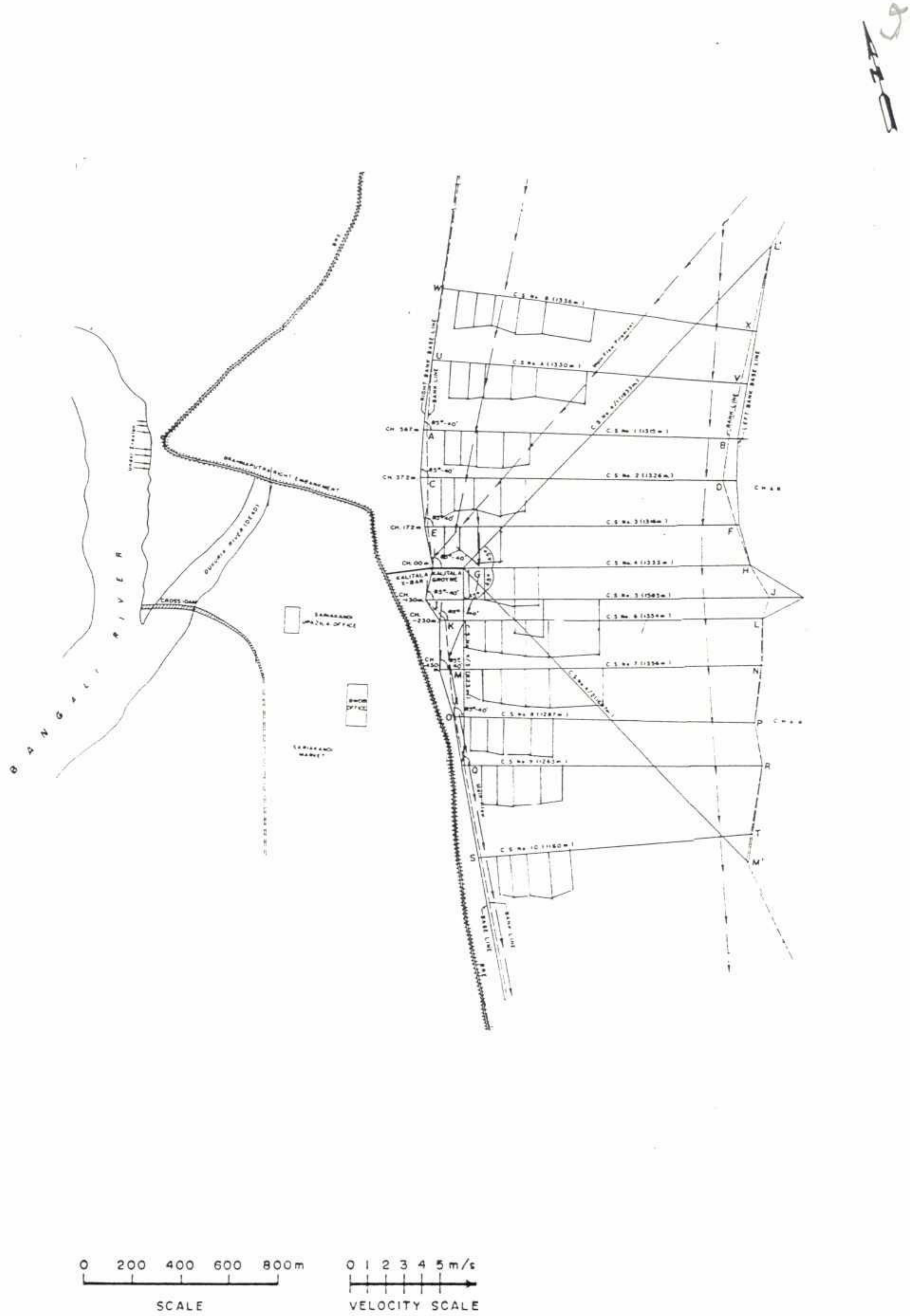
SARIAKANDI PHYSICAL MODEL

DEVELOPMENT OF SCOUR WITH TIME

FIGURE : 3·6

SARIAKANDI

Appendix I
Tables with
Measured Flow Velocities



SARIAKANDI PHYSICAL MODEL

Test no. 5, VELOCITY MEASUREMENTS

FIGURE : 3.7

APPENDIX I

Section A

Velocities in fixed-bed experiments without training work (bank-full discharge)

Test - 1

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
A	72	1.10	
	145	-	
	217	-	
	326	0.70	
	435	0.70	
	652	0.98	
	868	0.80	
	1085	0.95	
B	74	1.10	
	147	-	
	220	-	
	330	0.70	
	440	0.95	
	660	1.10	
	880	0.85	
	1100	0.70	

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Section A (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
1	71	1.10	
	142	-	
	212	-	
	318	0.55	
	425	0.95	
	637	0.80	
	850	0.80	
	1062	0.70	
2	68	1.0	
	137	0.70	
	206	0.40	
	310	0.70	
	412	0.80	
	620	1.0	
	827	0.85	
	1033	0.70	

Section A (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
3	71	0.70	
	142	0.70	
	213	1.10	
	321	1.10	
	427	0.85	
	642	0.80	
	857	0.70	
	1072	0.80	
4	73	-	
	147	-	
	221	1.0	
	332	1.0	
	442	1.0	
	663	0.95	
	883	0.85	
	1105	0.80	

Section A (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
5	78	0.0	
	157	0.0	
	237	0.70	
	356	0.95	
	475	0.70	
	712	0.95	
	950	0.85	
	1187	0.80	
6	72	0.70	
	145	0.80	
	218	1.0	
	328	0.85	
	437	0.89	
	656	0.95	
	875	0.95	
	1093	0.95	

Section A (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
7	72	0.80	
	145	1.0	
	216	0.95	
	323	0.95	
	431	0.80	
	647	0.85	
	863	0.80	
	1080	0.80	
8	68	1.0	
	137	1.0	
	206	0.95	
	310	0.95	
	412	0.80	
	620	0.80	
	827	0.80	
	1035	0.85	

APPENDIX I

Section A (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
9	63	0.95	
	127	1.0	
	190	0.95	
	285	0.95	
	380	0.85	
	570	0.80	
	760	0.50	
	950	1.0	
10	63	0.95	
	127	0.85	
	190	0.85	
	285	0.70	
	380	0.80	
	568	0.50	
	760	0.60	
	950	0.95	

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Section B

Velocites in the fixed-bed experiments without training work (100-years flood)

Test 2

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
A	72.50	1.50	
	145.00	1.60	
	217	1.50	
	326	1.50	
	435.00	1.80	
	652	1.60	
	868	1.50	
	1085	1.20	
B	73	1.95	
	147	1.80	
	220.00	1.50	
	330.00	1.50	
	440.00	1.80	
	660.00	1.60	
	880.00	1.10	
	1100.00	1.10	

Section B (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
1	71	1.55	
	142	1.60	
	212	1.60	
	318	1.50	
	425.00	1.80	
	637	1.55	
	850.00	1.50	
	1062	1.30	
2	68	1.60	
	137	1.50	
	206	1.30	
	310.00	1.55	
	412	1.70	
	620.00	1.60	
	827	1.55	
	1033	1.40	

Section B (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
3	71	0.60	
	142	1.20	
	213	1.10	
	321	1.60	
	427	1.85	
	642	1.80	
	857	1.55	
	1072	1.20	
4	73	-	
	147	-	
	221	1.50	
	332	1.85	
	442	1.95	
	663	1.70	
	883	1.60	
	1105	1.30	

Section B (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
5	78	0	
	157	0	
	237	1.30	
	356	1.60	
	475	1.80	
	712	1.95	
	950	1.80	
	1187	1.50	
6	72	1.50	
	145	1.60	
	218	1.60	
	328	1.80	
	437	1.70	
	656	1.60	
	875	1.55	
	1093	1.55	

Section B (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
7	72	1.70	
	145	1.80	
	216	1.95	
	323	1.60	
	431	1.55	
	647	1.55	
	863	1.55	
	1080	1.30	
8	68	1.80	
	137	1.95	
	206	1.95	
	310	1.60	
	412	1.55	
	620.00	1.55	
	827	1.55	
	1035.00	1.40	

Section B (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
9	63	1.95	
	127	2.00	
	190	1.95	
	285	1.85	
	380	1.80	
	570	1.55	
	760	1.30	
	950	1.40	
10	63	1.95	
	127	2.10	
	190	2.00	
	285	1.95	
	380	1.80	
	568	1.55	
	760	1.50	
	950.00	1.30	

Section C

Velocities in fixed-bed experiments with training works (bank-full discharge)

Test 3

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
A	72	1.10	
	145	-	
	217	-	
	326	0.80	
	435	0.70	
	652	0.95	
	868	0.85	
	1085	0.95	
B	73	1.10	
	147	-	
	220	-	
	330	0.80	
	440	0.95	
	660	0.95	
	880	0.80	
	1100	0.70	

Section C (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
1	71	1.00	
	142	-	
	212	-	
	318	0.60	
	425	0.70	
	637	0.90	
	850	0.70	
	1062	0.70	
2	68	1.00	
	137	0.60	
	206	0.40	
	310	0.70	
	412	0.70	
	620	0.80	
	827	0.80	
	1033	0.60	

Section C (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
3	71	0.80	
	142	0	
	213	0.80	
	321	0.90	
	427	0.85	
	642	0.60	
	857	0.80	
	1072	0.85	
4	73	-	
	147	-	
	221	0.95	
	332	0.80	
	442	0.80	
	663	0.90	
	883	0.85	
	1105	0.80	

Section C (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
5	78	0	
	157	0	
	237	0.60	
	356	0.70	
	475	0.85	
	712	0.90	
	950	0.80	
	1187	0.80	
6	72	0	
	145	0.50	
	218	0.80	
	328	0.70	
	437	0.80	
	656	0.80	
	875	0.90	
	1093	0.90	

Section C (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
7	72	0	
	145	0	
	216	1.00	
	323	0.80	
	431	0.80	
	647	0.80	
	863	0.80	
	1080	0.80	
8	68	0	
	137	0.50	
	206	0.95	
	310	0.95	
	412	0.85	
	620	0.70	
	827	0.70	
	1035	0.85	

Section C (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
9	63	0	
	127	0.70	
	190	1.00	
	285	0.70	
	380	0.80	
	570	0.85	
	760	0.50	
	950	0.95	
10	63	0.55	
	127	0.80	
	190	0.95	
	285	0.70	
	380	0.70	
	568	0.60	
	760	0.60	
	950	0.85	

Appendix D

Velocities in fixed-bed experiments with training works (100-years flood)

Test 4

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
A	72	1.55	
	145	1.55	
	217	1.55	
	326	1.50	
	435	1.65	
	652	1.55	
	868	1.30	
	1085	1.00	
B	73	1.80	
	147	1.85	
	220	1.85	
	330	1.95	
	440	1.80	
	660	1.70	
	880	1.15	
	1100	1.10	

Appendix D (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
1	71	1.55	
	142	1.55	
	212	1.55	
	318	1.40	
	425	1.70	
	637	1.70	
	850	1.40	
	1062	1.20	
2	68	1.55	
	137	1.25	
	206	1.40	
	310	1.40	
	412	1.70	
	620	1.70	
	827	1.55	
	1033	1.40	

Appendix D (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
3	71	0.60	
	142	1.30	
	213	1.30	
	321	1.55	
	427	1.85	
	642	1.55	
	857	1.50	
	1072	1.30	
4	73	-	
	147	-	
	221	1.50	
	332	1.70	
	442	1.80	
	663	1.65	
	883	1.55	
	1105	1.20	

Appendix D (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
5	78	0	
	157	0	
	237	1.55	
	356	1.55	
	475	1.65	
	712	1.80	
	950	1.70	
	1187	1.25	
6	72	-	
	145	1.30	
	218	1.55	
	328	2.00	
	437	1.95	
	656	1.85	
	875	1.85	
	1093	1.65	

Appendix D (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
	72	0	
	145	0	
	216	1.95	
	323	2.25	
	431	2.20	
7	647	2.10	
	863	2.00	
	1080	1.80	
	68	0	
	137	0.80	
	206	2.40	
	310	2.50	
8	412	2.25	
	620	2.00	
	827	1.80	
	1035	1.80	

Appendix D (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
9	63	0	
	127	1.85	
	190	2.35	
	285	2.20	
	380	2.00	
	570	1.50	
	760	1.50	
	950	1.50	
10	63	0.85	
	127	2.95	
	190	2.10	
	285	2.10	
	380	1.95	
	569	1.80	
	760	1.65	
	950	1.55	

Section E

Velocities in mobile-bed experiment with training works (100 - years flood)

Test 5

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
A	72	1.85	
	145	1.80	
	217	1.65	
	326	1.65	
	435	1.60	
B	73	1.85	
	147	1.85	
	220	1.60	
	330	1.70	
	440	1.55	
1	71	1.80	
	142	1.85	
	212	1.80	
	318	1.80	
	425	1.65	
2	68	1.85	
	137	1.70	
	206	1.60	
	310	1.80	
	412	1.65	

Section E (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
3	71	1.65	
	142	1.20	
	213	2.10	
	321	1.95	
4	221	1.95	
	332	1.40	
	442	1.90	
	663	1.85	
5	78	0	
	157	0	
	237	1.85	
	356	1.95	
	475	1.50	
6	72	1.40	
	145	1.65	
	218	1.60	
	328	1.75	
	437	1.80	

Section E (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
7	72	1.50	
	145	1.60	
	216	1.80	
	323	1.85	
	431	1.80	
8	68	1.85	
	137	1.85	
	206	1.95	
	310	1.90	
	412	1.95	
9	63	1.75	
	127	2.00	
	190	2.20	
	285	2.00	
	380	1.85	

Section E (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
10	63	2.20	
	147	2.25	
	190	2.15	
	285	2.35	
	380	2.15	
X (100 d/s of c/s#9)	101	1.90	
	141	1.90	
	181	2.15	
	261	1.75	
	347	1.95	
Y (200 m d/s of c/s#9)	100.00	2.0	
	140.00	2.0	
	180.00	2.10	
	260.00	2.15	
	340.00	2.10	

Section F

Erosion(-)/Deposition in mobile-bed test

Test 5

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
1	46	-1.50	
	86	0.06	
	126	-0.50	
2	63	0.30	
	103	0.90	
	143	-1.14	
3	107	-1.60	
	147	-0.12	
	187	-0.30	
4	51	1.00	
	91	-0.54	
	131	-0.60	

Section F (Cont'd)

Cross Section	Distance from Right Bank (m)	Velocity (m/sec)	Remarks
8	76	-1.20	
	116	-0.90	
	156	-0.60	
9	73	-1.20	
	113	-1.20	
	153	-1.50	
X (100 m d/s of c/s#9)	101	-0.90	
	141	-1.14	
	181	-0.42	
Y (200 m d/s of c/s #9)	100	-1.8	
	140	-0.90	
	180	-1.10	

Appendix II
Cross-Sections
used for
Model Construction

Sariakandi C.S. # 4
Chainage 0.0 m

Sl. No.	Distance m	RL m
1	1314	16.63
2	1303	10.13
3	1277	9.63
4	1256	12.63
5	1103	12.13
6	1014	13.13
7	803	12.98
8	764	12.38
9	714	12.63
10	518	12.88
11	491	13.63
12	385	10.13
13	239	-1.37
14	182	-1.37
15	147	11.13
16	138	16.63
R. Bank		17.688

Sariakandi C.S. # 4/1

Sl. No.	Distance m	RL m
1	1809	16.598
2	1752	10.598
3	1445	10.848
4	1092	11.598
5	765	10.098
6	676	11.098
7	420	11.598
8	376	11.098
9	371	11.848
10	344	11.348
11	213	10.348
12	157	9.848
13	150	5.348
14	59	-0.402
15	41	8.348
16	20	16.598
R. Bank		17.688

Sariakandi C.S. # 4/2

Sl. No.	Distance m	RL m
1	1677	16.618
2	1667	14.618
3	1627	11.368
4	1526	10.368
5	1552	10.868
6	1407	6.868
7	1330	9.118
8	1203	8.868
9	1115	9.618
10	1056	10.618
11	1022	13.368
12	994	15.118
13	957	15.118
14	922	14.868
15	883	14.368
16	835	14.118
17	753	14.368
18	610	14.368
19	549	13.618
20	524	12.368
21	477	12.618
22	461	13.118
23	455	12.118
24	422	11.618
25	397	12.618
26	386	11.618
27	321	6.618
28	237	3.618
29	169	1.618
30	131	0.868
31	83	0.118
32	52	-2.132
33	38	2.618
R. Bank		17.688

Sariakandi C.S. # 4/3

Sl. No.	Distance m	RL m
1	763	16.638
2	721	11.138
3	716	12.138
4	628	9.388
5	561	5.388
6	547	5.638
7	525	6.388
8	498	7.638
9	485	8.388
10	458	6.138
11	439	6.638
12	414	7.638
13	395	7.638
14	373	7.638
15	348	7.138
16	328	6.638
17	303	7.138
18	269	7.638
19	231	9.388
20	199	9.888
21	174	12.388
22	138	12.888
23	97	9.138
24	59	3.638
25	33	4.138
26	18	12.888
27	12	16.638
R. Bank		17.688

Sariakandi C.S. # 5
Chainage (-)130.0 m

Sl. No.	Distance m	RL m
1	1434	16.558
2	1407	12.558
3	1407	11.808
4	1340	9.558
5	1201	14.058
6	1143	13.808
7	1112	13.558
8	1020	13.558
9	882	13.558
10	761	12.058
11	554	13.558
12	517	12.058
13	409	6.058
14	334	3.058
15	231	1.558
16	175	7.058
17	139	12.808
18	2	16.558
R. Bank		16.803

Sariakandi C.S. # 6
Chainage (-)230.0 m

Sl. No.	Distance m	RL m
1	1352	16.545
2	1338	13.454
3	1307	10.954
4	1263	9.954
5	1235	8.454
6	1197	13.454
7	1134	13.954
8	1084	13.954
9	1029	12.954
10	952	13.704
11	798	13.454
12	651	11.954
13	520	12.954
14	377	12.954
15	277	4.704
16	212	4.954
17	94	9.954
18	22	16.454
R. Bank		16.761

Figure 1

Sariakandi C.S. # 7
Chainage (-)430.0 m

Sl. No.	Distance m	RL m
1	1351	16.445
2	1338	9.945
3	1301	6.945
4	1255	7.445
5	1230	8.945
6	1191	10.195
7	1127	13.445
8	986	13.945
9	873	13.945
10	759	14.195
11	658	13.945
12	562	13.945
13	469	13.695
14	376	11.945
15	218	10.945
16	200	9.445
17	126	7.945
18	78	7.445
19	63	7.945
20	39	16.445

R. Bank 16.800

Sariakandi C.S. # 8
Chainage (-)830.0 m

Sl. No.	Distance m	RL m
1	1276	16.44
2	1262	11.94
3	1240	8.19
4	1222	7.4
5	1208	8.44
6	1082	14.44
7	909	14.94
8	795	14.94
9	711	14.44
10	586	14.19
11	458	13.69
12	372	12.69
13	241	9.69
14	176	9.44
15	143	8.94
16	87	8.44
17	57	5.44
18	20	10.44
19	10	16.44

R. Bank 16.950

Sariakandi C.S. # 9
Chainage (-)830.0 m

Sl. No.	Distance m	RL m
1	1257	16.43
2	1209	12.43
3	1175	10.93
4	1040	7.93
5	979	6.43
6	897	8.68
7	850	11.431
8	818	15.43
9	751	14.93
10	652	14.18
11	508	13.93
12	381	11.93
13	281	10.93
14	217	9.43
15	179	8.93
16	149	6.43
17	101	5.93
18	63	3.93
19	29	10.43
20	15	16.43

R. Bank 16.63

Sariakandi C.S. # 3
Chainage 172.0 m

Sl. No.	Distance m	RL m
1	1308	16.332
2	1280	12.832
3	1151	9.832
4	1102	8.832
5	977	11.832
6	937	12.582
7	855	12.582
8	776	12.332
9	675	12.332
10	542	12.332
11	525	12.332
12	402	11.332
13	282	10.332
14	179	8.832
15	110	5.082
16	83	11.332
17	11	16.332

R. Bank 17.032

Sariakandi C.S. # 2
Chainage 372.0 m

Sl. No.	Distance m	RL m
1	1270	16.312
2	1251	11.062
3	1172	8.812
4	886	11.812
5	868	12.062
6	726	11.812
7	625	12.312
8	583	12.062
9	519	11.812
10	428	11.312
11	354	10.812
12	282	12.312
13	219	13.562
14	159	13.812
15	106	11.062
16	70	10.562
17	53	13.312
18	35	16.312

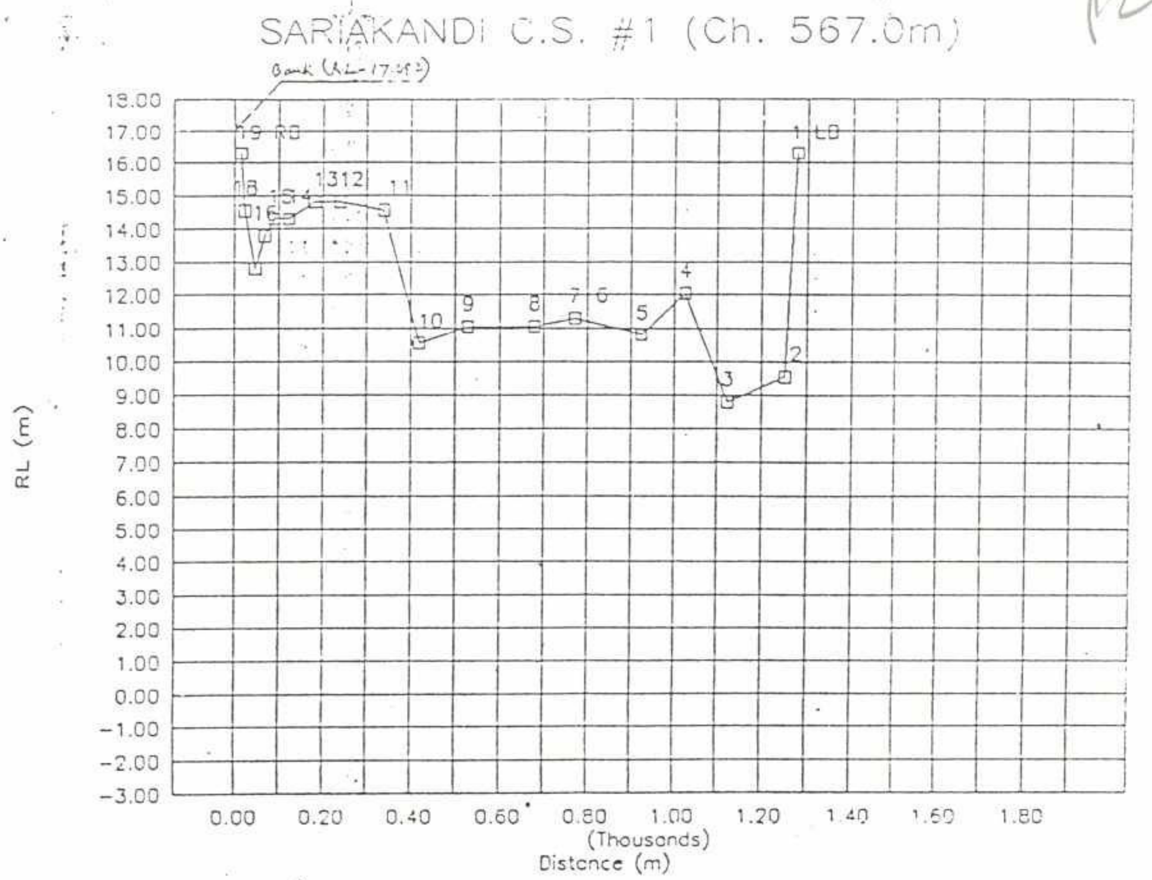
R. Bank 17.492

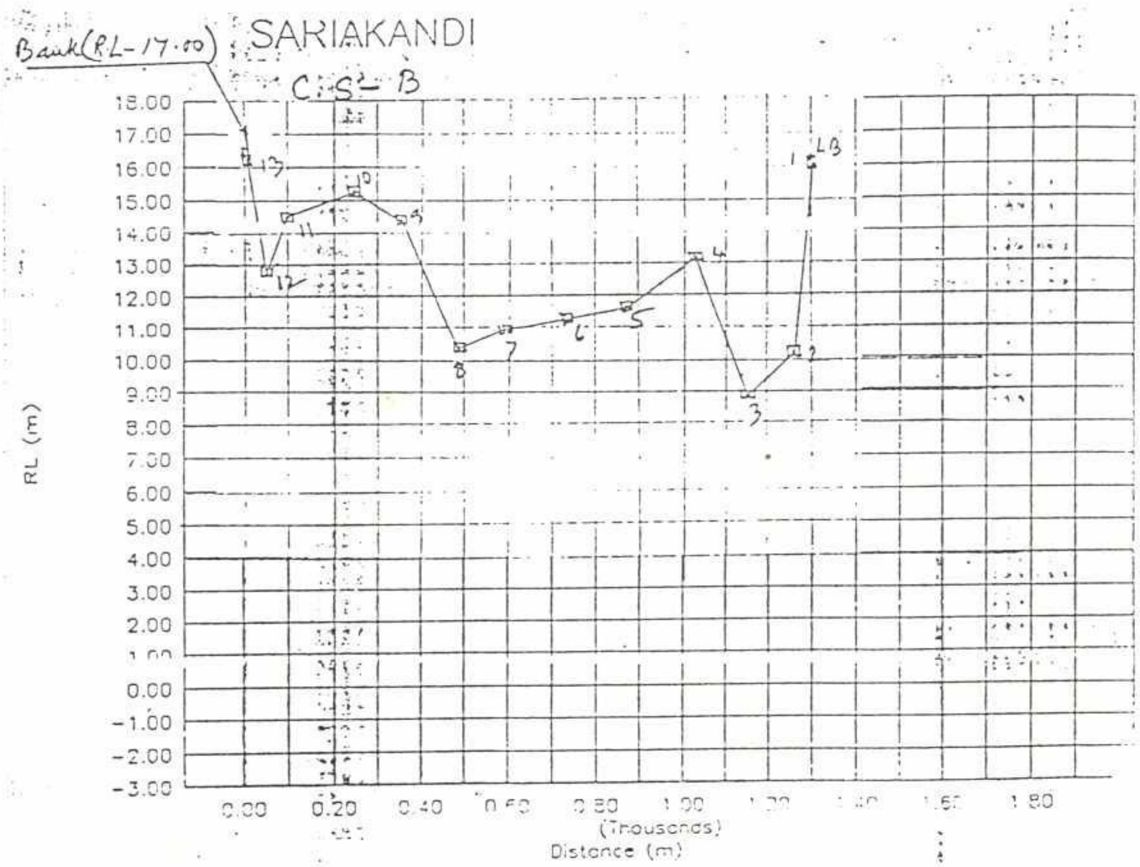
Sariakandi C.S. # 1
Chainage 567.0 m

Sl. No.	Distance m	RL m
1	1277	16.302
2	1251	9.552
3	1123	8.802
4	1025	12.052
5	923	10.802
6	773	11.302
7	771	11.302
8	679	11.052
9	528	11.052
10	419	10.552
11	339	14.552
12	238	14.802
13	180	14.802
14	121	14.302
15	88	14.302
16	66	13.802
17	46	12.802
18	23	14.552
19	14	16.302

R. Bank 17.082

Figure 2

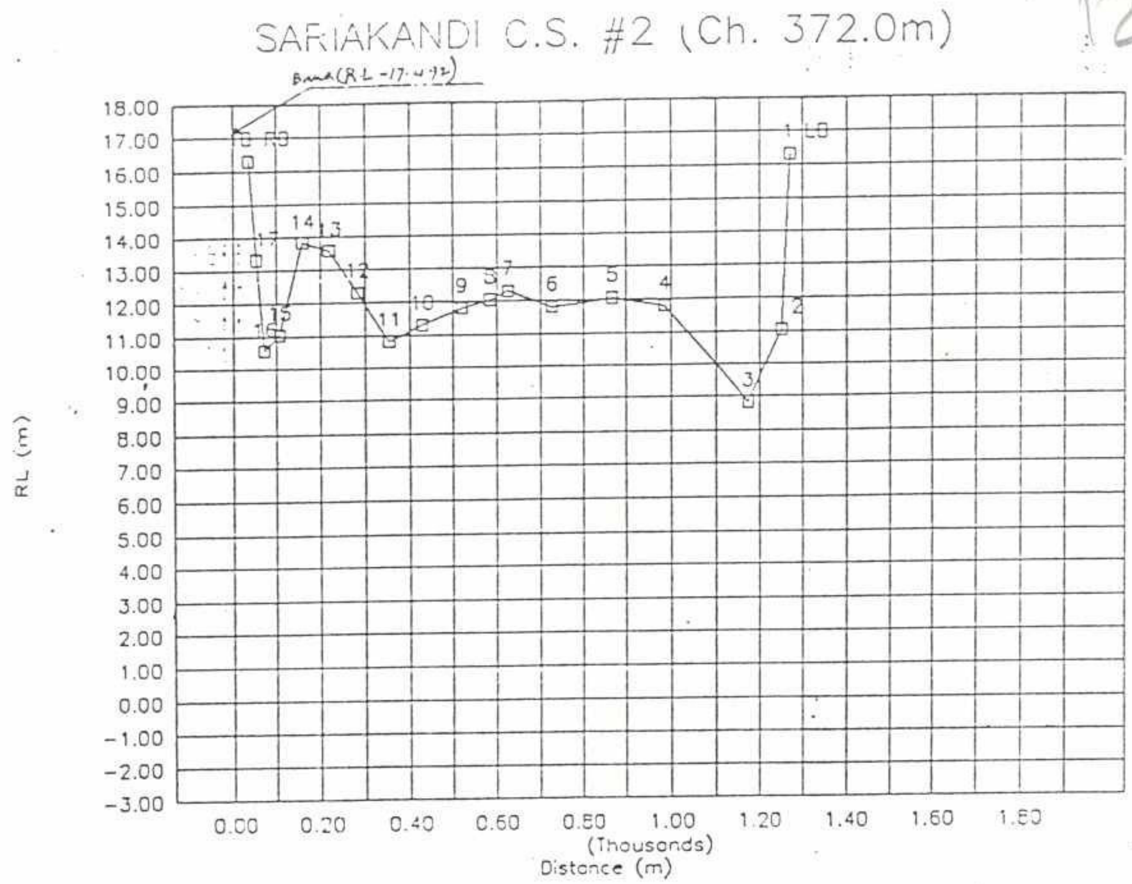


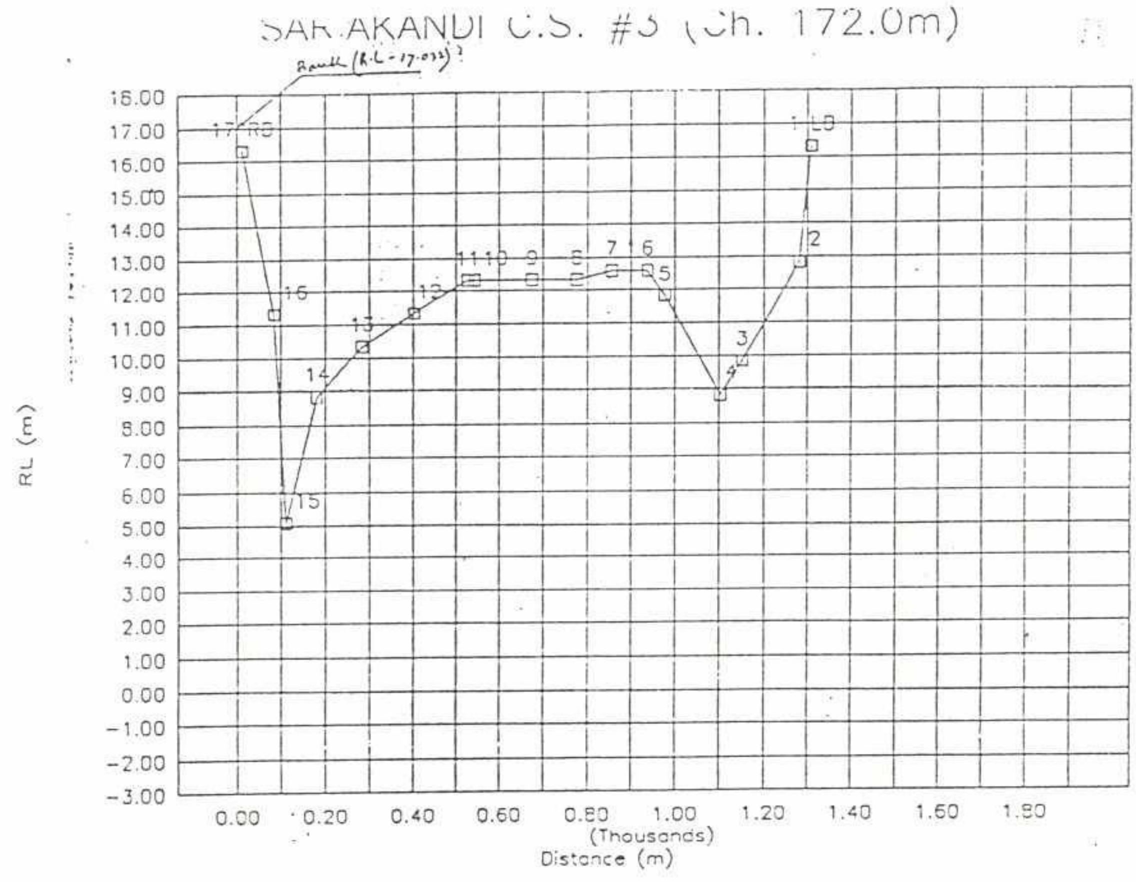


BRTS - Physical Modelling. Sariakandi Model Bed

Cross-sections CS # 1 & CS - B

Figure 3





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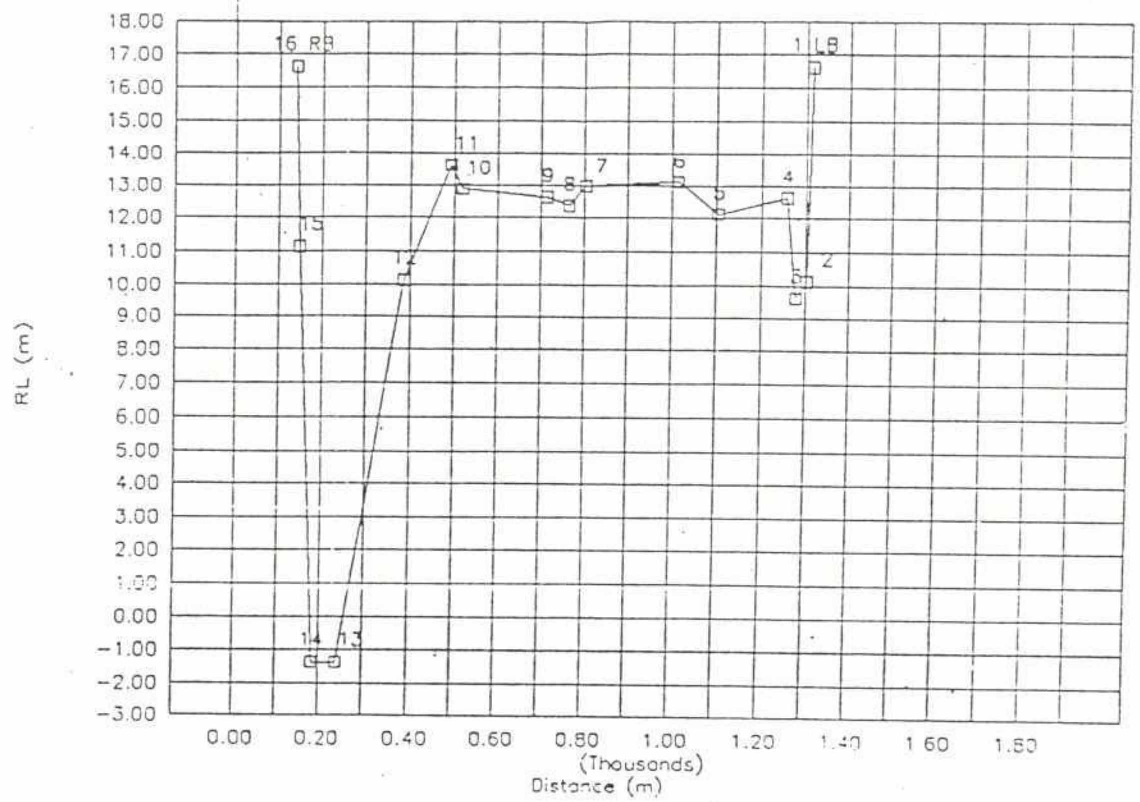
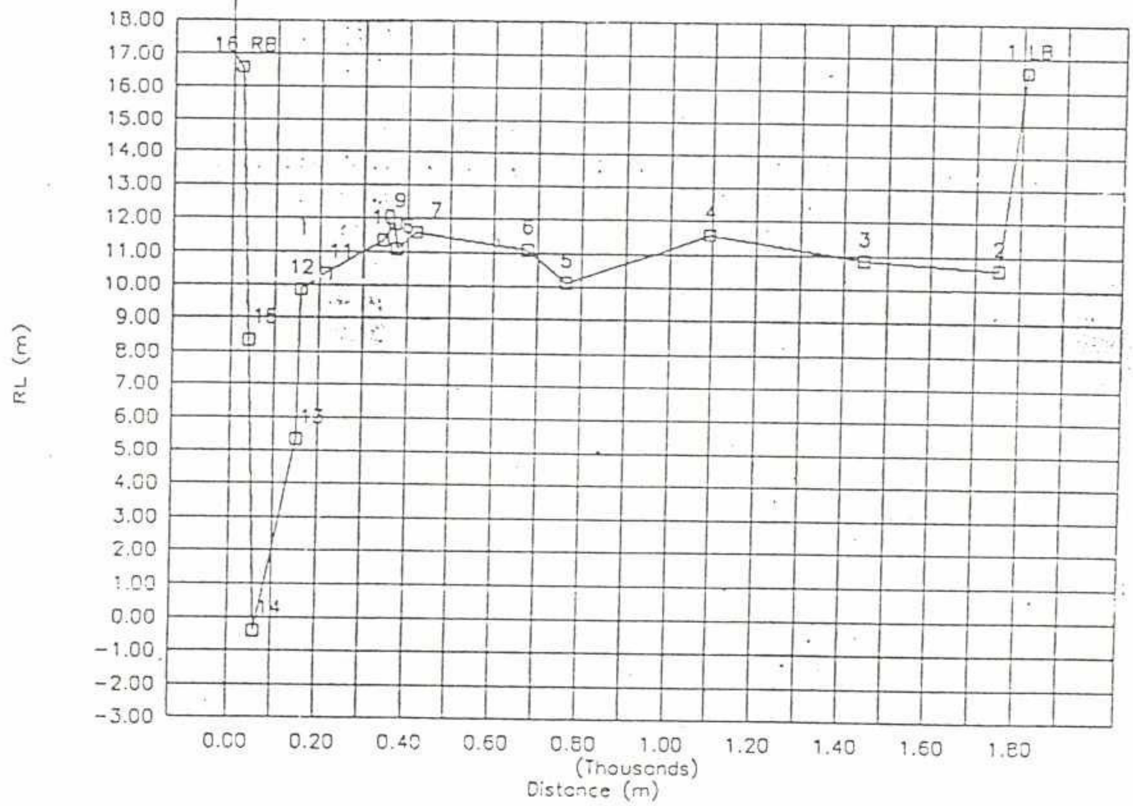
Cross-sections CS # 2 & CS # 3

Figure 4

SARIAKANDI C.S. #4 (Ch. 0.0m)



SARIAKANDI C.S. #4/1

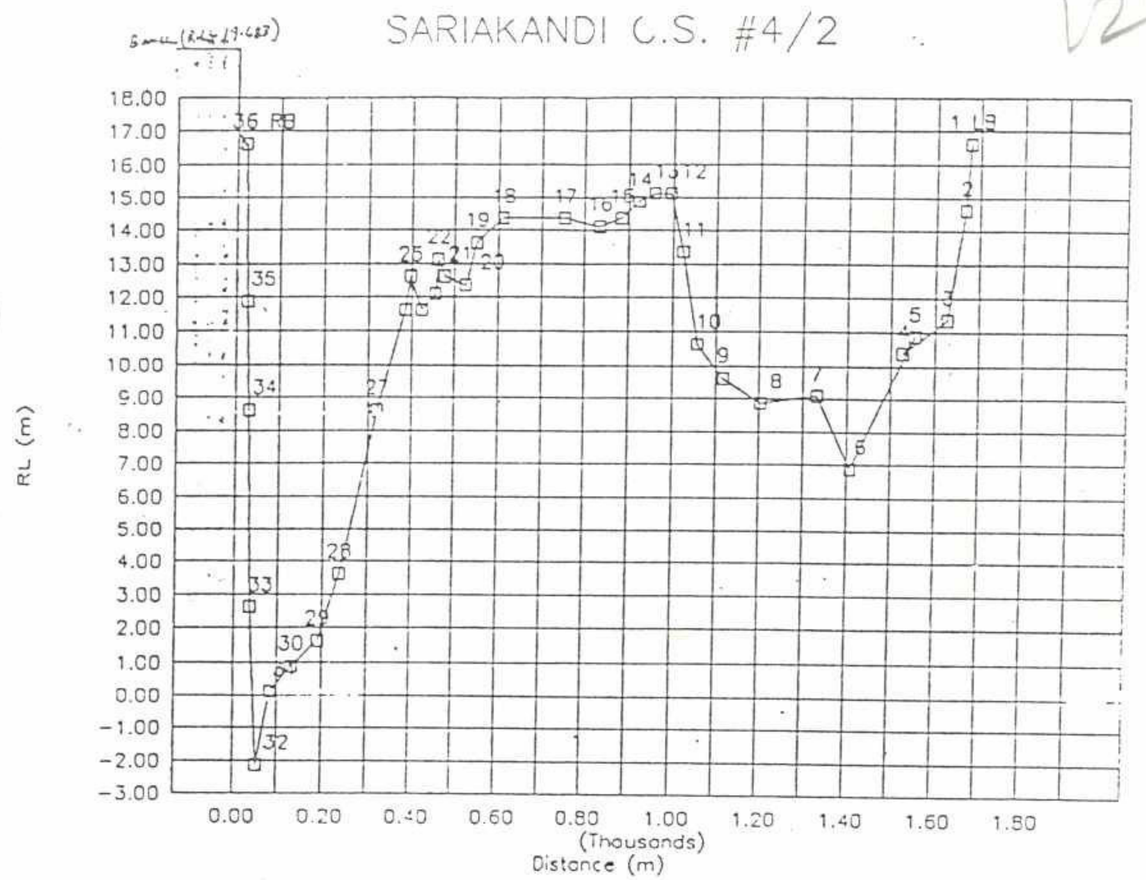


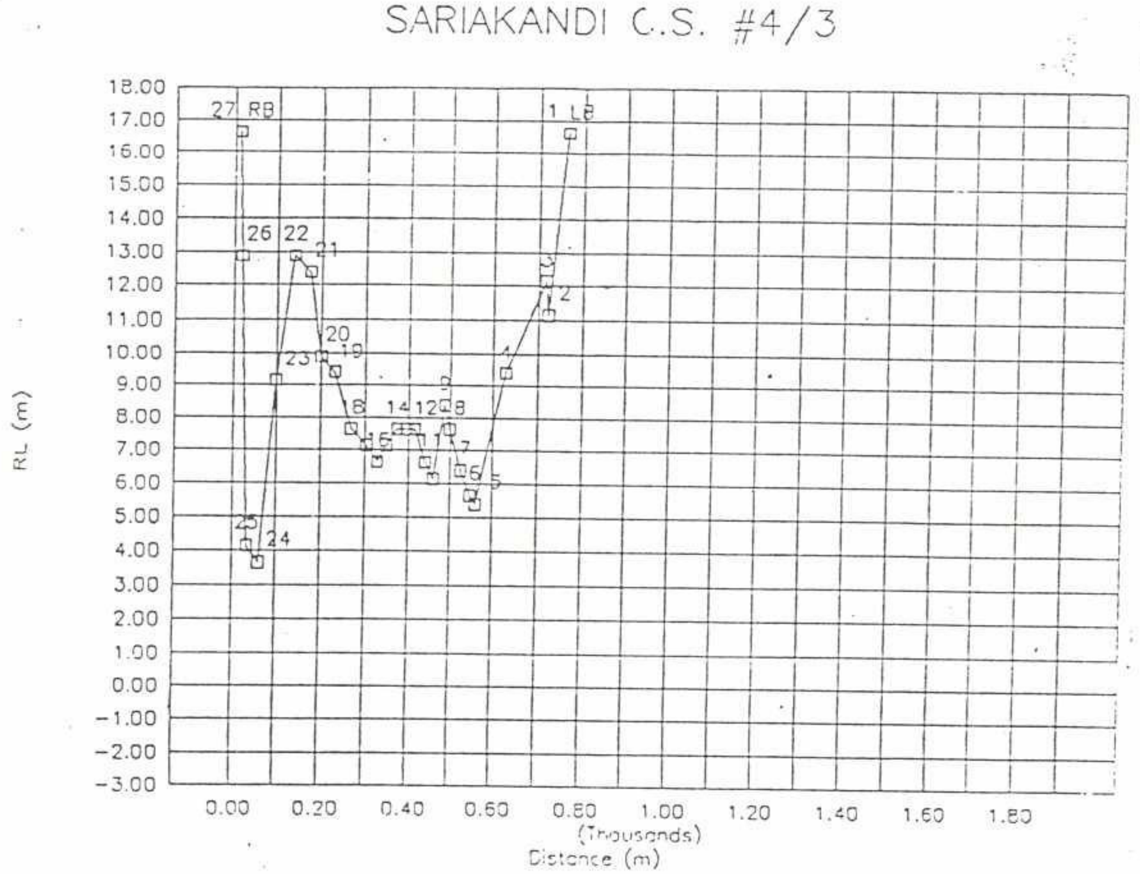
BRTS - Physical Modelling. Sariakandi Model Bed

Cross-sections CS # 4 & CS # 4/1

Figure 5

129

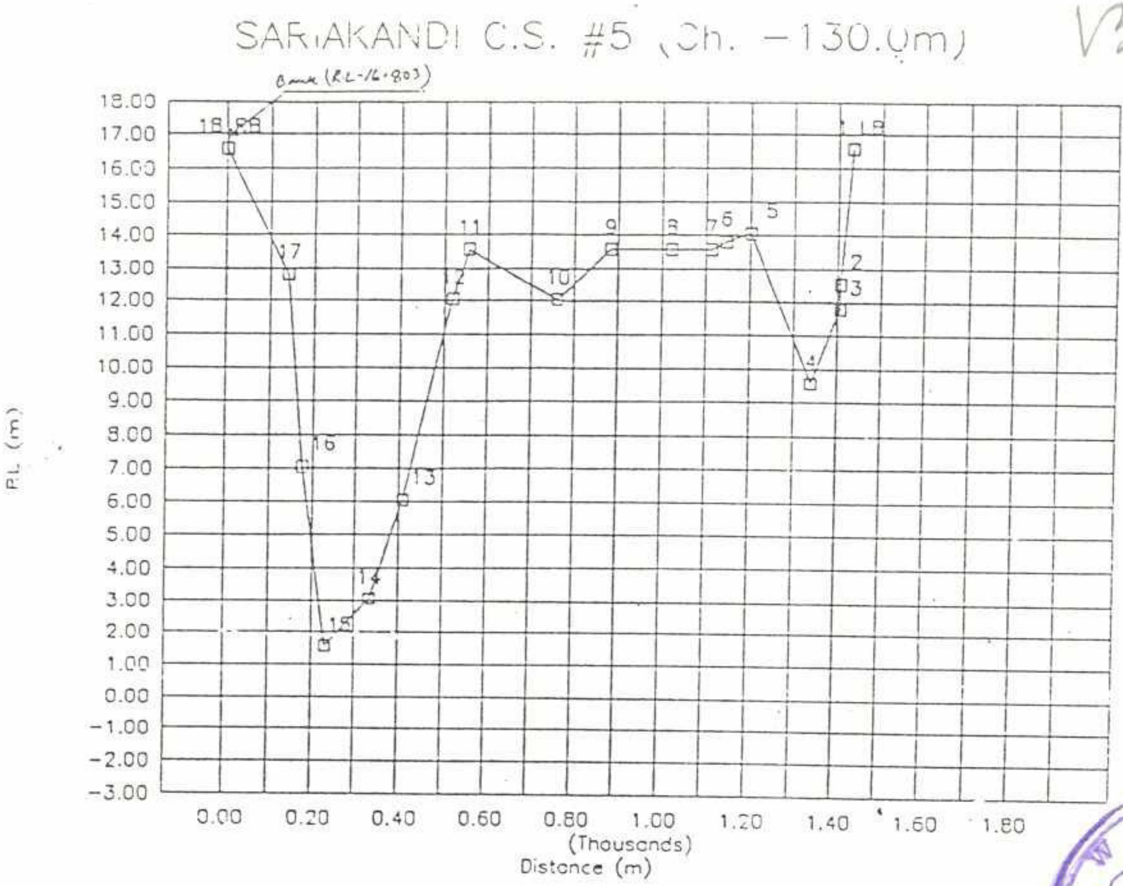


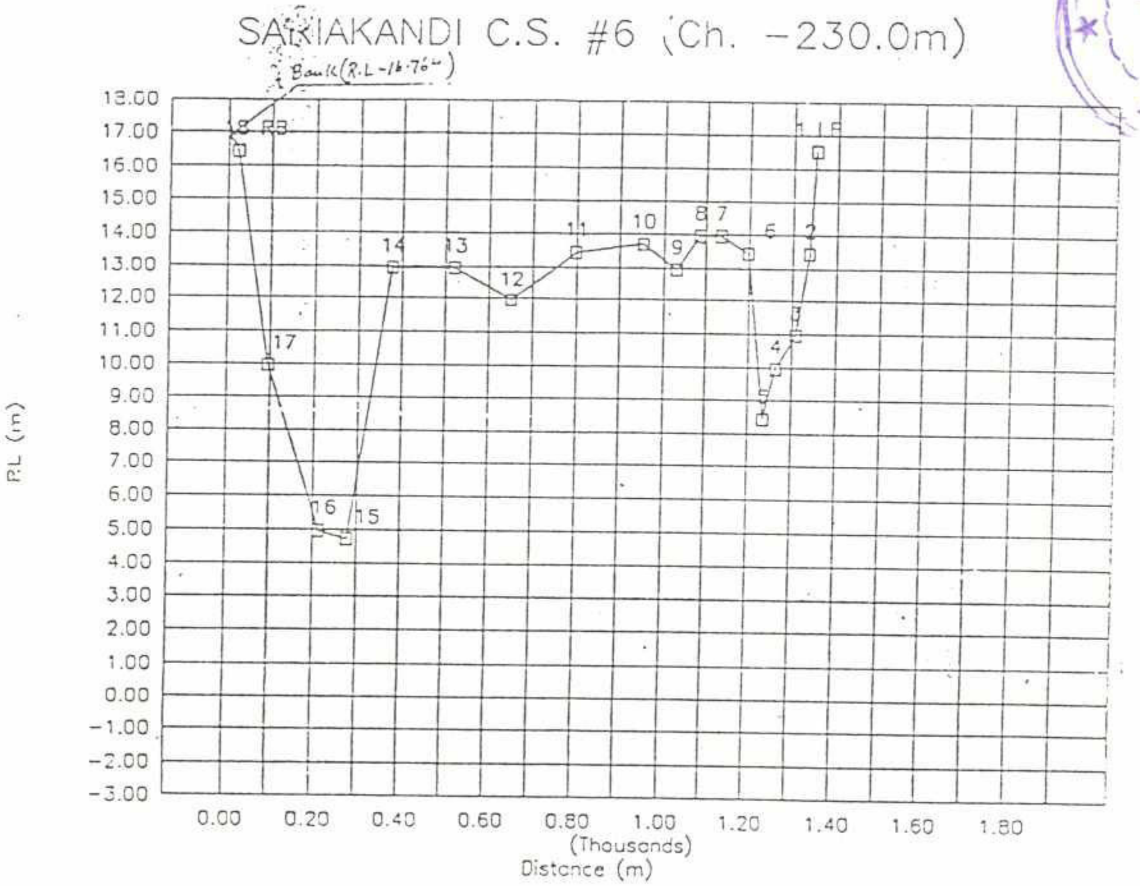


BRTS - Physical Modelling. Sariakandi Model Bed

Cross-sections CS # 4/2 & CS # 4/3

Figure 6





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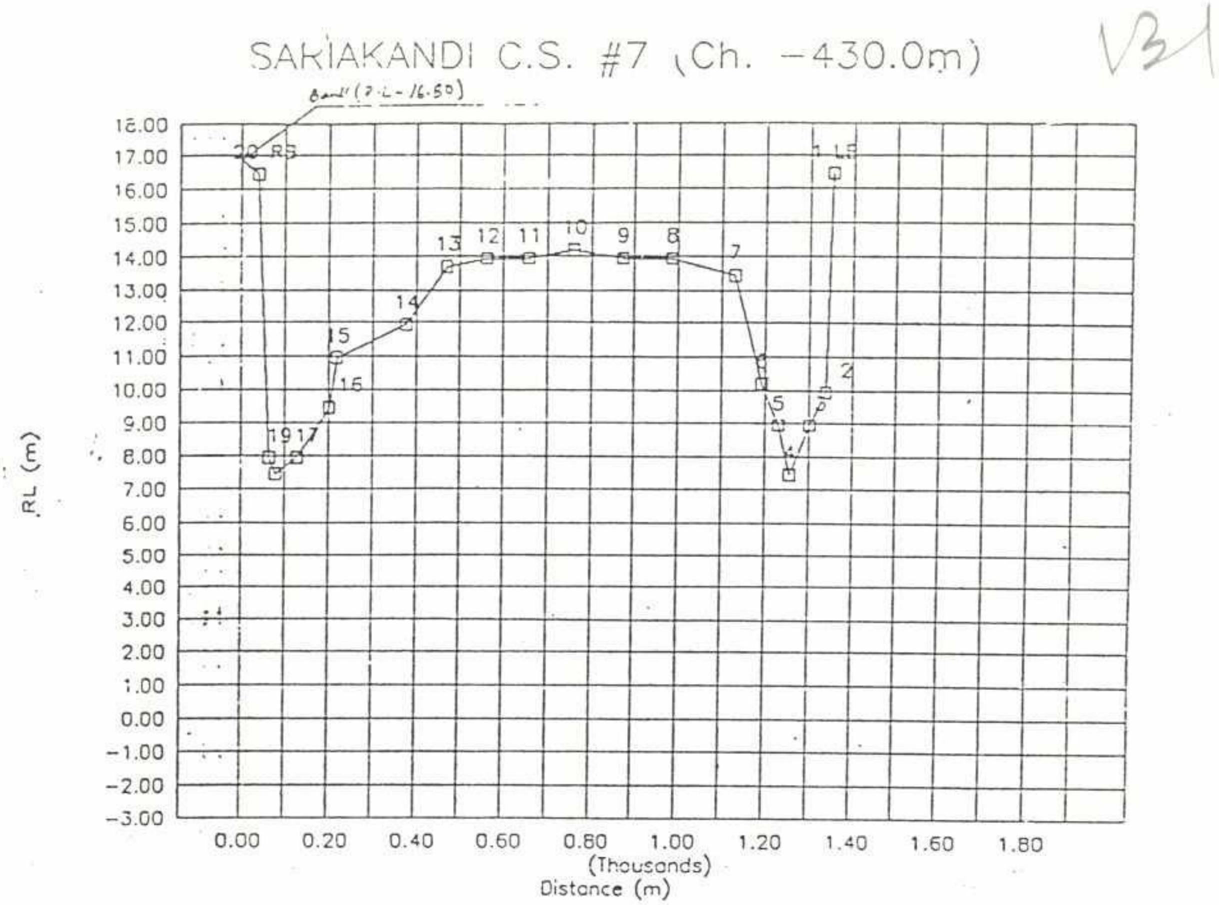
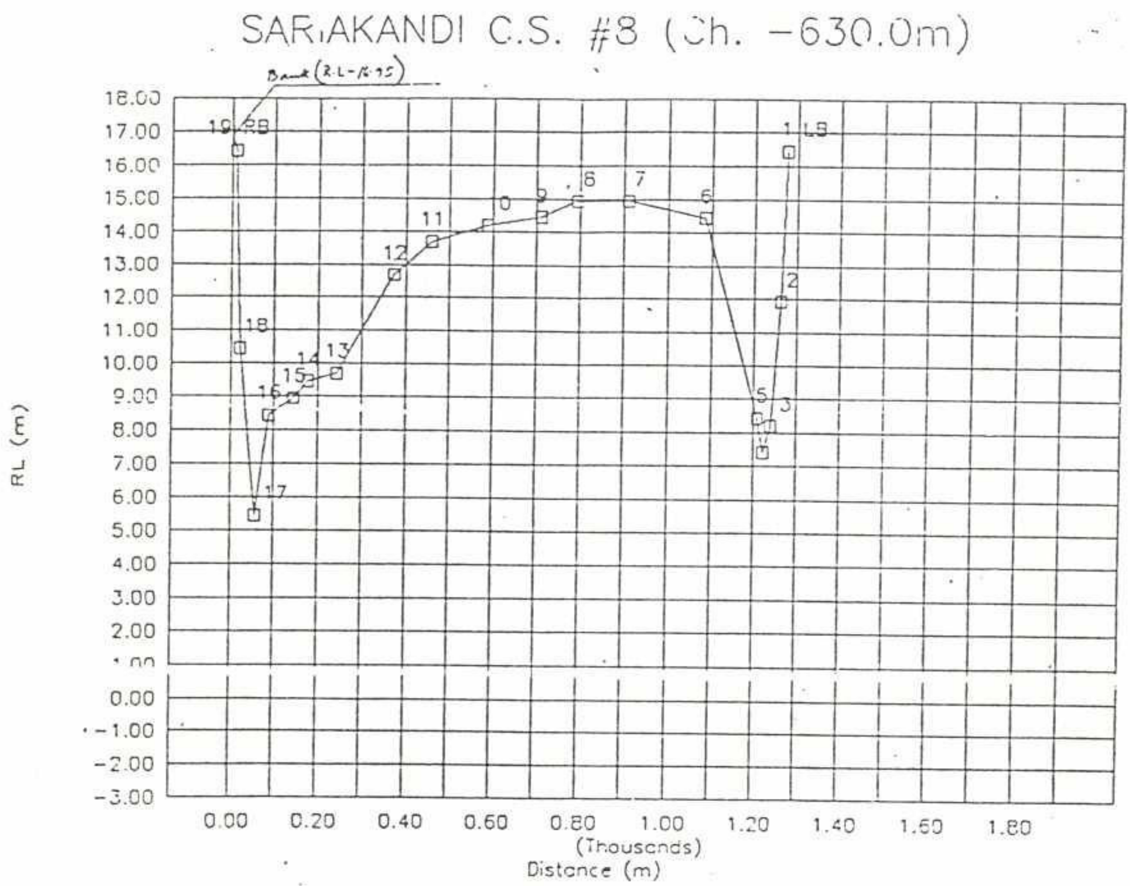
BRTS - Physical Modelling. Sariakandi Model Bed

Cross-sections CS # 5 & CS # 6

Figure 7

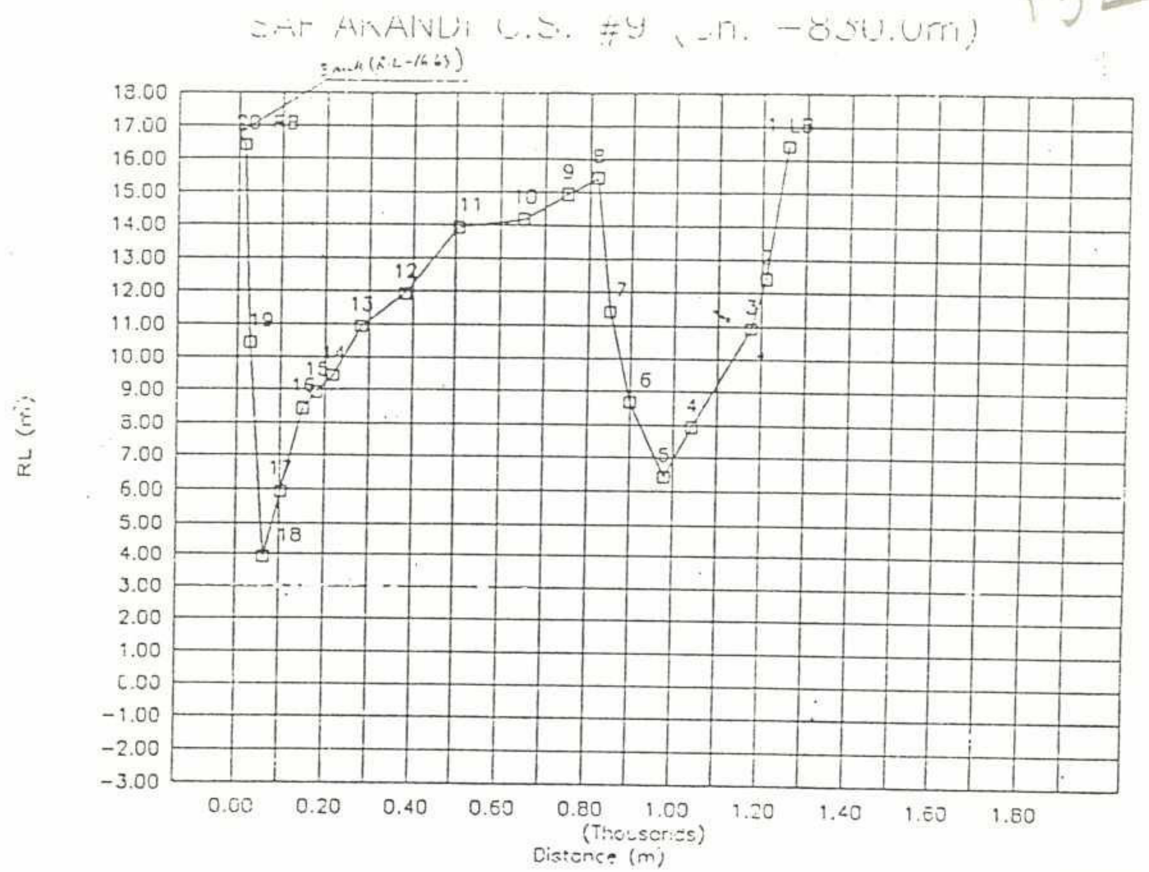


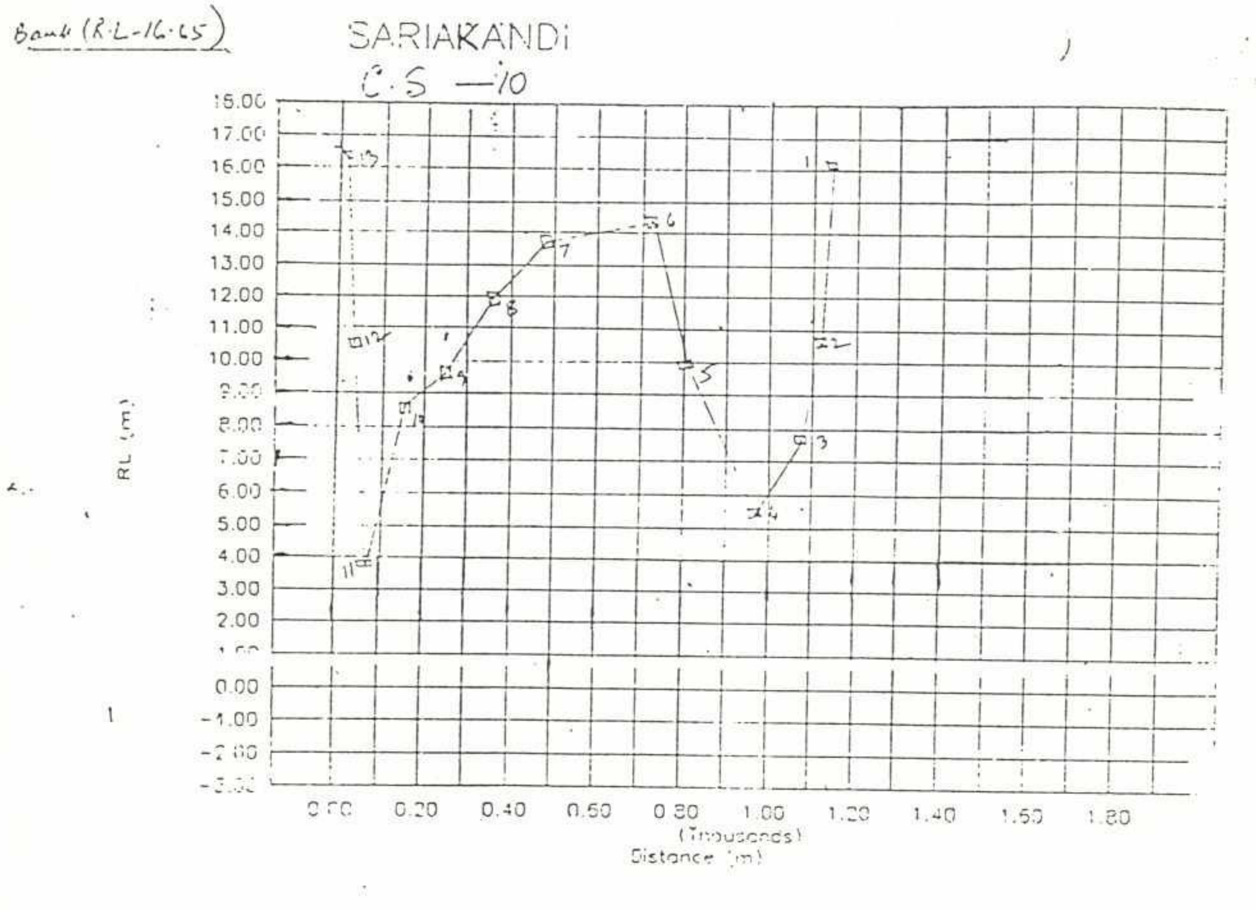


BRTS - Physical Modelling. Sariakandi Model Bed

Cross-sections CS # 7 & CS # 8

Figure 8





BRTS - Physical Modelling. Sariakandi Model Bed

Cross-sections CS # 9 & CS - 10

Figure 9