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River Training Studies of The Brahmaputra River

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FINAL REPORT ON PHYSICAL MODEL STUDIES

INTRODUCTION AND PROGRAMME

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VOL I - MODEL BASED ON KAZIPUR BATHYMETRY

VOL II - MODEL BASED ON SIRAJGANJ 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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FINAL REPORT ON PHYSICAL MODEL STUDIES

INTRODUCTION AND PROGRAMME

for

MODELS BASED ON
KAZIPUR, SIRAJGANJ,
FULCHARIGHAT & SARIAKANDI
BATHYMETRIES

JANUARY 1993

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RIVER RESEARCH INSTITUTE

RIVER TRAINING STUDIES OF THE BRAHMAPUTRA RIVER

FINAL REPORT ON RIVER BANK PROTECTION PROJECT

CONTENTS

1. INTRODUCTION

1.1 Background

The Brahmaputra - Jamuna River System is the largest of the three major river systems in Bangladesh. An earth embankment, known as the Brahmaputra Right Embankment (BRE) was built during the late 1960's along the west bank of the Jamuna, extending for some 240 km, as a protection against flooding. On - going bank erosion by the river, however, has led to breaches of the BRE, with attendant crop loss and damage to buildings and infrastructure and successive costly retirements of the BRE.

The Government of Bangladesh therefore decided to commission the Brahmaputra River Training Study (BRTS) comprising, amongst other components, physical and mathematical model studies, which would provide the basis for assessing structural requirements for a strengthening of the BRE as a flood protection against river erosion.

The BRT study which commenced in February 1990, has as its overall object the formulation of a master plan for the long term protection of the BRE. A second object is the design of short term (i.e. priority) measures at critical locations along the right bank for early implementation.

Consistent with the study Terms of Reference Physical Model Studies have been undertaken at the River Research Institute (RRI) in a collaborative effort between RRI and staff from the BRTS office.

The programme for physical modelling was amended during the execution of the programme. The background and details of the revised programme is presented in section 3 of this introduction to the technical reports.

1.2 Physical Modelling Using Prototype Bathymetries

The technical report on the above four mentioned bathymetries, presented as four volumes, Vol I, II, III, IV respectively, covers the First Phase of the programme.

The physical modelling component was initiated early on in the overall BRTS study programme.

At that stage and development of the project it was not fully realised that site specific models would not be able to provide all the answers to question put forward by the river morphologists and the design engineers of the BRTS team. As explained below in section 3 the programme was therefore modified later on.

In the course of the physical modelling described in this volume the different models (especially on Kazipur and Sirajganj bathymetries) were used for studying other more generalized aspects of flow conditions, scour patterns as function of flow channel configuration and man introduced structures etc. These more generalized tests were thus aimed at building up the understanding of the relationship between various variables with special emphasize on flow velocity amplification near structures and in sharp bends and confluences of flow channels.

Therefore the four volumes of this report should be read not only as tests on bathymetries representing four different sites, but much more as pertinent examples of flow conditions in different characteristic planforms of the river and associated chars near the BRE. All four bathymetries except Sariakandi represents very severe situations in terms of water depth and flow velocity near the BRE.

When reading the four volumes the reader should further recognize that the specific values obtained from the models relate only to the bathymetry used in the model. Owing to the fact that the morphology of the river varies so rapidly, within one or two years the flow channel configuration and water depths can be completely different. The model results and specifically measured flow velocities are not directly applicable to long term conditions at the specific site. In other words emphasize should be put on the flow field and amplification factors that have been derived and the interpretation of these in relation to the prediction of conditions that can occur at any site.

A summary of the results of the four volumes were briefly presented in the Second Interim Report of December 1991 and will be presented as part of the final reporting on physical modelling on this project.

1.3 Basic Data for the Modelling

The physical modelling in Kazipur, Sirajganj, Fulcharighat & Sariakandi Bathymetries were based on large amount of data and information as described in the four separately bound reports. To assist the reader to understand the basis for the models, various Appendices have been included as follows:

Vol I - Kazipur Bathymetry
Appendix I and II presents details of velocity measurements

Vol II - Sirajganj Bathymetry
Appendix I presents details of how the model discharges were derived for the model based on Sirajganj Bathymetry. For all the other three models, the discharge was derived in the same manner.

Vol III - Fulcharighat Bathymetry
Appendix I shows details of flow measurements.

Vol IV - Sariakandi Bathymetry
Appendix I shows Tables with flow velocities.
Appendix II shows cross-sections used for model construction. For all the other three models similar type of cross-sectional data was used.

2. THE RRI FACILITIES

The hydraulic research facilities at the River Research Institute (RRI) in Faridpur (Figure 2.1) consist of two main components. One is an outdoor model area (see Figure 2.2) and the other is an indoor facility, which itself consists of two test halls, Test Hall I and Test Hall II. The test halls are presently under construction.

The first component, illustrated in Figure 2.2, is actually a large open-air river model platform (260 m x 130 m), with its own pump house, water supply, recirculation canals and storage pool. The platform is provided with a deep sand bed (sand diameter = 0.20 mm) and is subdivided in nine independent compartments, of which three are 125 m x 40 and six are 60 x 38 m.

The total available discharge was originally 0.5 m^3/s. However, RRI has increased this to about 2.3 m^3/s due to the large number of model studies to be conducted simultaneously. In the test bed (compartment) used for this study a maximum discharge of about 0.6 m^3/s could be provided.

During the monsoon season weather conditions impose constraints on the test execution since the model require protection against both wind and rain.

Regarding the indoor modelling facilities, the building works for the Test Hall I have been completed. The hall consists of four compartments, namely a wave and current basin, two river model section and a flume. However, the hydraulic circuit of the hall has not been completed yet.

As for the other hall, Test Hall II, it is still under construction. This hall has been considered as a pure river model facility and it has been planned to comprise four sections.

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3. THE REVISED PROGRAMME

3.1 Introduction

The BRTS physical modelling programme has been undertaken by the RRI at Faridpur under a Memorandum of Agreement with Halcrow dated 11.8.90. Appendix B of this Agreement specifies, inter alia, the schedule of models that are to be under taken in accordance with the overall study programme. There is provision in the Agreement for changes to be made to the modelling programme and the specifications subject to approval by the Client.

Model work commenced at the RRI Faridpur in December 1990, following the substantial completion of their outdoor facilities and continued through into June 1991, although weather conditions severely interfered with the work from March 1991 onwards. The modelling presented in these reports covers work done during the First Phase of the programme in the period December 1990 to June 1991. From September 1991 until completion of the revised programme in the first weak of May 1992 the Model Tests were performed in a New Flume protected by a large specially constructed shed, for which reason the weather disturbance has been minimum.

While priority has been given to physical model testing that was directly linked to the design of the short-term works, there have been occasions while decisions regarding the ranking of the locations were being finalised when this priority work has had to be temporarily put in abeyance. On these occasions the opportunity was taken to undertake some of those tests that are associated more with the wider considerations of the master plan.

As the overall study has progressed a better appreciation of the river's characteristics has been obtained and from this initial insight it became clear that the rapidity with which the morphology of the river varies means that, in contrast to less volatile rivers, site specific model are of very limited value for the investigations and studies leading to the design of individual river training works. The emphasis has consequently shifted to an approach that while being specific to the Brahmaputra river concentrates on severe conditions that can occur at any point in time and at any location on the river, and on investigating the appropriate physical measures for addressing these situations.

The engineering studies, drawing on the early results from the mathematical and physical modelling and the associated morphological studies have shown that for most situations encountered on the Brahmaputra, bank stabilization by means of revetment was more cost effective than the use of groynes, at least for the conventional methods of construction. The conclusion was therefore that for the immediate requirements revetment should be adopted for bank stabilization but that further consideration, for the purpose of the master plan study, should be given to alternative forms of groyne, particularly for situations such as ferry ghats. It was therefore proposed that the first priority during the second phase of modelling, which commenced in October 1991, should be the study of the behaviour of the key elements of revetment under varying flow conditions.

Following on from that were series of tests addressing the hydraulic and scour characteristics of alternative groyne types and revetment and finally a series focussed on the training of the river in the vicinity of ferry ghats.

3.2 **Review of Programme**

The model testing that has been undertaken at the RRI for the BRTS comprised a total of 28 models. It represents a combination of site specific model tests and more generalized ones. The former are aimed at a better understanding of specific conditions at high priority locations which display physical features of particular interest, such as the pronounced concave bend at Kazipur, the railway ghat a Fulchari and the existing groynes at Sariakandi and Sirajganj. They also provide the opportunity to compare the model results with those of the prototype. The more generalized tests are aimed at building up an understanding of the relationship between variables such as anabranch planform and scour patterns which can occur at any location along the river bank.

These completed tests have provided the necessary information for the design of the short-term works and also much valuable information on the flow and scour patterns associated with individual and sets of groynes in different situations that are representative of typical right bank planforms of the Brahmaputra river in the study area. The results have been written up jointly by the BRTS and RRI and are presented in a Final Summary Report.

3.3 **Modelling Programme September 1991 to May 1992**

The broad methodology that was followed for the remainder of the physical modelling component of the BRTS study were discussed and agreed in principle at a meeting at the RRI Faridpur on 11 May 1991 attended by the RRI Director General and Director of River Hydraulics, the Director Planning (General), BWDB, representing the Chief Engineer, Planning, and the BRTS Team Leader, Physical Modelling Specialist and Senior Research Engineer.

Following this a preliminary working paper was produced and circulated by the BRTS team, setting out the broad principles agreed at the Faridpur meeting and describing the proposed programme in outline terms.

The models under this second phase comprised a total of 18 models (denoted models Nos. 1 to 18) covering 12 models for the study of the stability and flow conditions of revetment and 3 models for the study of local scour and one model of a ferry ghat and one comprising three different types of permeable groynes.

Towards the end of the modelling programme the design of Town Protection for Sirajganj progressed and the third last model, denoted model No. 16, was used specifically to study the flow and scour conditions at the upstream termination of the proposed works where the new revetment joins the existing Ranigram Groyne.

In September 1991 a revised programme "Physical Modelling Component Review of September 1991 was prepared and subsequently approved by all parties concerned including BWDB, WB, BUET & RRI. Table 3.1 gives a summary of the revised schedule and Table 3.2 a review of the actually executed programme comprising 28 individual models.

Table 3.1: Summary of Revised Schedule for Physical Modelling

Test series Title	Number of models	Item in the agreement
Sariakandi	1	Item 3 (a)
Fulcharighat	1	Item 3 (a)
<u>Kazipur</u>		
Series 1	1	Item 3 (a)
Series 2	1	Item 3 (g)
Series 3	1	Item 3 (i)
Series 4	1	Item 3 (i)
Series 5	1	Item 3 (i)
<u>Sirajganj</u>		
Series 1	1	Item 3 (a)
Series 2	1	Item 3 (h)
Series 3	1	Item 3 (k)
<u>Revetment Stability Test</u>		
Calibration and assessment for priority locations	2	Item 3 (a)
Seven Model Studies relating to priority work design	4 3	Item 3 (b) & Item 3 (c)
<u>Permeable groyne Tests</u>		
1. Model Study	1	Item 3 (m)
	1	Item 3 (f)
	1	Item 3 (k)
	1	Item 3 (m)
<u>Study Ferry Ghats/Groynes</u>		
1. Model Study	1 3	Item 3 (d) & Item 3 (e)
Number of Models	28	

Table 3.2: List of Physical Model as Constructed and Executed

Model No.	Phase	Model Number in Phase 2	"Task" of Model
I	1		Sariakandi
II	1		Fulcharighat
III	1		Kazipur - Series 1
IV	1		Kazipur - Series 2
V	1		Kazipur - Series 3
VI	1		Kazipur - Series 4
VII	1		Kazipur - Series 5
VIII	1		Sirajganj - Series 1
IX	1		Sirajganj - Series 2
X	1		Sirajganj - Series 3
XI	2	1	Revetment - Series 1
XII	2	2	Revetment - Series 2
XIII	2	3	Revetment - Series 3
XIV	2	4	Revetment - Series 4
XV	2	5	Revetment - Series 5
XVI	2	6	Revetment - Series 6
XVII	2	7	Revetment - Series 7
XVIII	2	8	Revetment - Series 8
XIX	2	9	Revetment - Series 9
XX	2	10	Revetment - Series 10
XXI	2	11	Revetment - Series 11
XXII	2	12	Revetment - Series 12
XXIII	2	13	Vertical sided groyne
XXIV	2	14	Revetments and Groyne Head
XXV	2	15	Groyne Head & Piled structure
XXVI	2	16	Sirajganj Town Protection Scheme
XXVII	2	17	Ferry Ghat Scheme
XXVIII	2	18	Permeable groyne (Piled structures)

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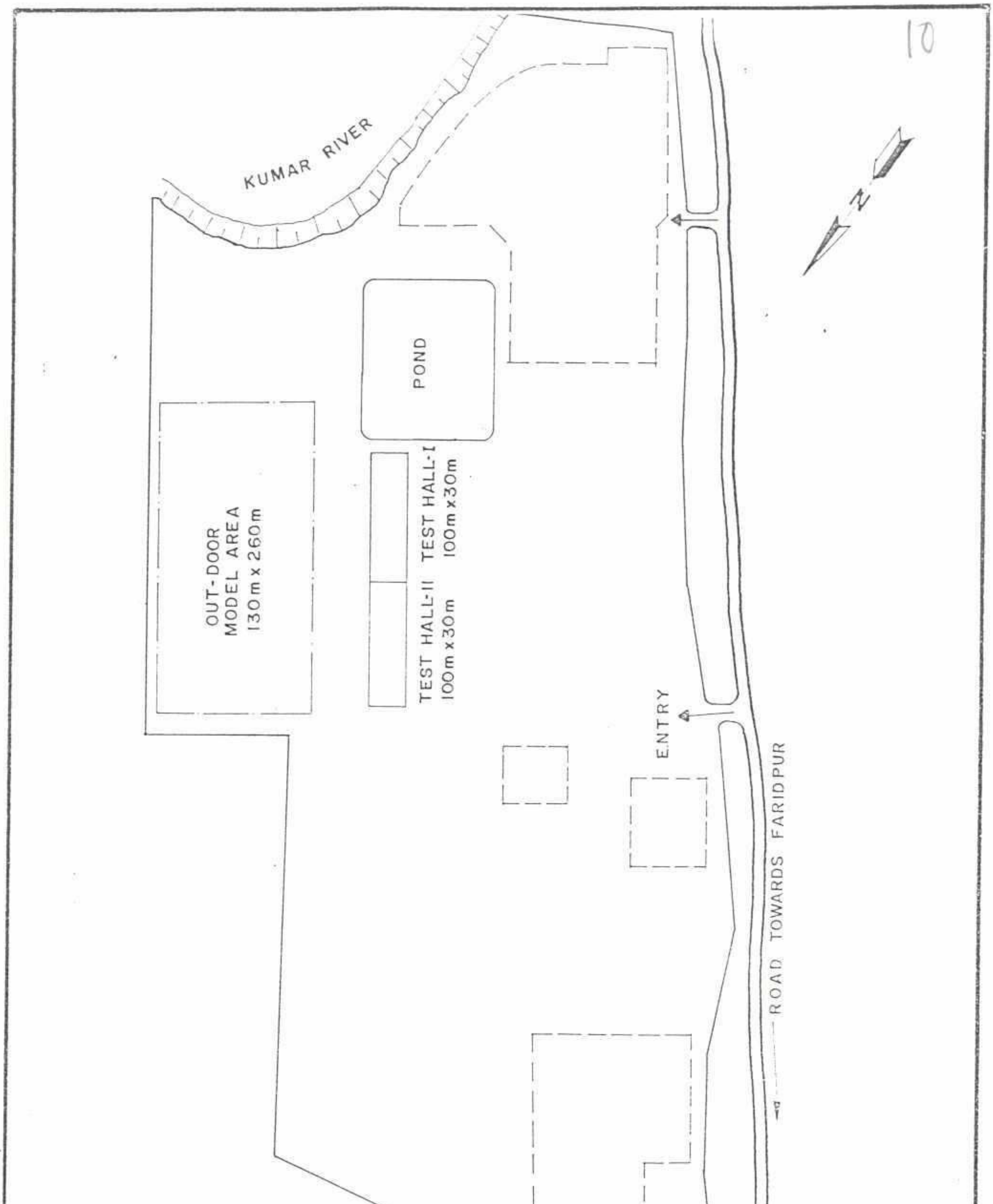
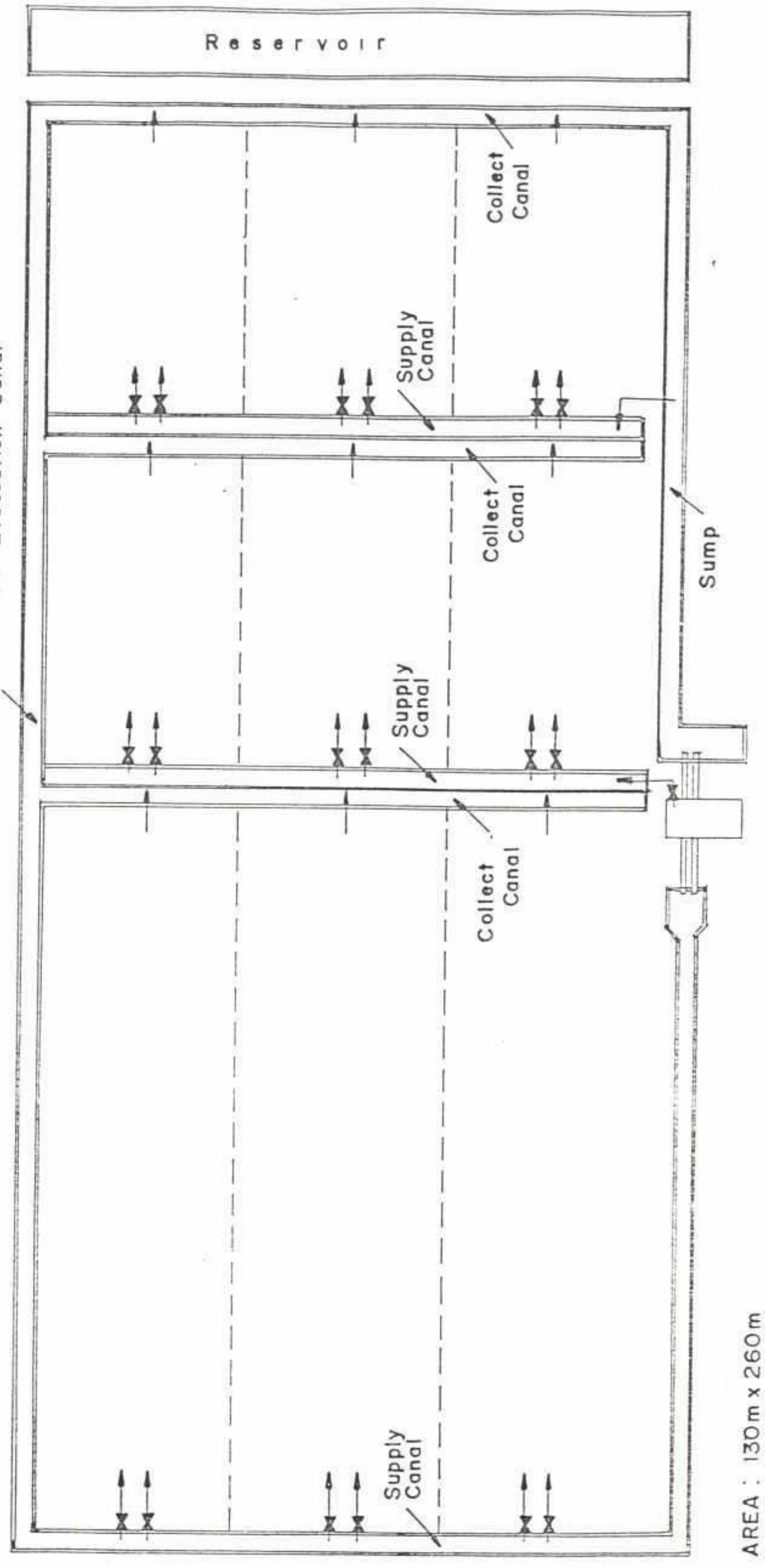


RRI Premises

Figure 2.1



RRI Out-Door Model Area

Figure 2.2

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River Training Studies of The Brahmaputra River

FINAL REPORT ON PHYSICAL MODEL STUDIES

VOL I - MODEL BASED ON KAZIPUR BATHYMETRY

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MODEL STUDY BY
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River Training Studies of The Brahmaputra River

FINAL REPORT ON PHYSICAL
MODEL STUDIES
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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 herein do so at their own risk.

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in association with

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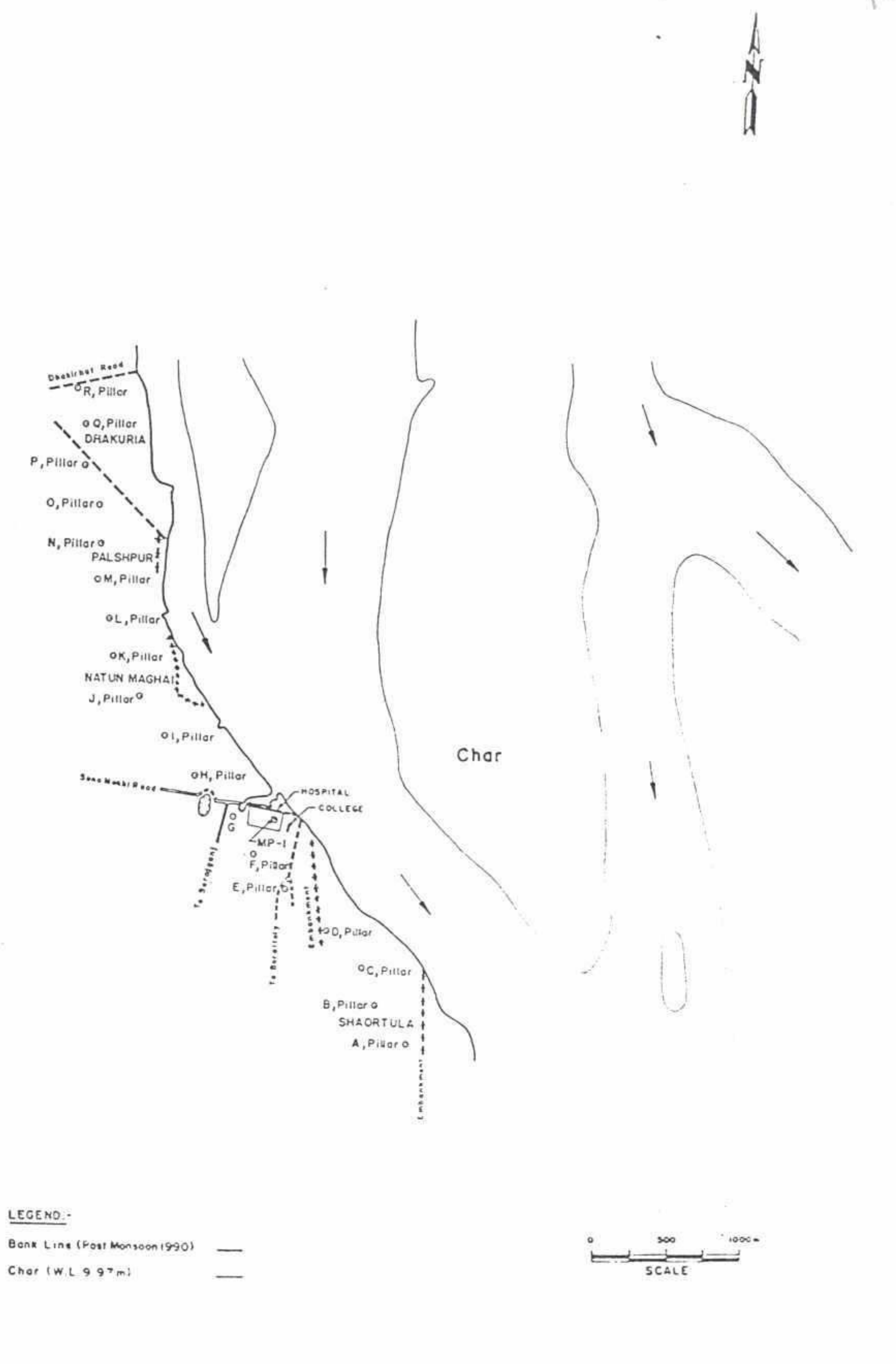
MODEL STUDY BY RIVER RESEARCH INSTITUTE



The Situation at Kazipur

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RIVER TRAINING STUDIES OF THE BRAHMAPUTRA RIVER

FINAL REPORT ON PHYSICAL MODEL STUDIES

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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 Kazipur Area. Without their active cooperation the model test programme could not have been accomplished.

BRAHMAPUTRA RIVER TRAINING STUDIES
BASED ON KAZIPUR 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 Kazipur Area is the first 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 (See Figure under the cover) 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 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 Kazipur

Kazipur is a small town (Upazila) situated on the right bank of the river Brahmaputra-Jamuna in the northern district of Sirajganj at about 135 kms downstream from the confluence of the Jamuna-Teesta River.

At Kazipur the erosion of the right bank is presently threatening to destroy the medical centre complex and the college and to breach the BRE over a considerable length.

Just opposite the college and hospital complex a deep scoured trench has developed with depths down to approximately 22 m below the bank level.

The objective of the studies of Kazipur is therefore to investigate alternative arrangements for stabilising the bankline in this vicinity and thereby create a hard point that it is anticipated will contribute to a general strategy of limiting bank retreat in this reach of the river and thereby provide longer term protection to the BRE.

Kazipur represents a situation of unusually deep scour close to the bank associated with a particular aggressive bend with low radius/width ratio.

1.4 Objectives of Model Study

Within the context of the particular situation at Kazipur (section 1.3) and the overall BRTS physical modelling programme, the model study had the following objectives.

(a) To investigate the present flow conditions at the site and alternative layouts of works for mitigating and controlling the severe bank erosion.

(b) To study in a general manner the influence from shifting the direction of the upstream flow channel including scouring and flow pattern trends.

(c) To study the efficacy of sets of as a means of stabilising a severely concave eroded bank line, including various layouts, spacing and variable length of the groynes in the groyne field and the associated scouring of the bed.

(d) To investigate the influence of modification in groyne nose geometry on the scour hole configuration.

(e) To derive data such as local velocities and scour characteristics at the toe of bank revetment as an alternative form of bank stabilisation to be implemented at Kazipur and in other places where similar conditions prevail in a concave river bend subjected to erosion.

Thus the test are designed to provide information that is applicable to the stabilisation of eroding embayments on the Brahmaputra, of which Kazipur is a representative example, and are not confined to any one location in particular.

Kazipur, bring an example of restively severe eroding embayment which can occur anywhere along the bankline, is an appropriate basis for this set of tests.

When designing the model tests, the rapidly changing conditions experienced in the prototype must be constantly borne in mind.

2. THE MODEL

2.1 Design of the Model

About three kilometers of the right most channel near Kazipur area and about one kilometer in width of the Brahmaputra River was reproduced in the model with the following scales:

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Horizontal	:	1:200
Vertical	:	1:120
Discharge	:	1:263,000
Velocity	:	1:10.95
Distortion	:	1:1.67

The small vertical to horizontal scale distortion was chosen to give adequate depths of flow in the model with a practical channel width.

Cross-sections provided by BRTS, based on the recent river surveys, were used. A portion of the left flood-plain upto the right embankment was included in the model. The model area along with flood-plain is shown in Figure 2.1.

The section of the river was reproduced in 0.2 mm sand in model scale in a 55 m x 21 m wide model bed. The 0.2 mm mean diameter of the sand used was shown to provide fixed bed conditions for the flow range to be used in the tests.

A rectangular sharp-crested weir was installed at the upper end of the model flume to measure the in-flow discharge. Two gauges were installed at the model bed, one at section B (upstream) and another at section 12 (downstream) to record the water surface elevations 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 and Availability

The following data are required for the present type of physical model study:

(a) Bathymetrical (and Topographical) data such as index map of the area showing present river bank line, existing structures (if any), locations of cross-sections, position of flood-embankment, flood plains etc.

(b) River bathymetry cross-sections.

(c) Hydrological data such as discharge, water levels etc.

(d) Data for model calibration/verifications.

Index map and river cross-sections for the river branch under consideration were supplied by BRTS. Discharge for bankfull level and 100-years flood for the model branch and corresponding water levels were also supplied. The elevation of the flood-plain was taken as the corresponding bank elevation.

2.3 Model Calibration

The object of model calibration is to confirm hydraulic similitude between the model and actual field (prototype) conditions. The average velocity at the representative cross-section (c/s-6) was measured in the model and the result compared with the calculated value as shown in Table 2.1.

Table 2.1: Kazipur Test Bed, Comparison Model v.s Prototype Model Calibration Results

Sl. No.	Factor	Calculated Value for Prototype	Value Observed in the Model
1.	Water level for bank-full stage at the Downstream	15.31 m	15.00 m
2.	Water level for 100 year flood stage at the Downstream	17.17 m	17.25 m
3.	Water surface slope for bankfull discharge	--	6.0×10^{-5}
4.	Water surface slope for 100 year flood discharge	--	8.0×10^{-5}
5.	Average velocity for bankfull discharge	0.7 m/s	0.8 m/s
6.	Average velocity for 100 year flood discharge	1.12 m/s	1.35 m/s

3. MODEL TEST PROGRAMME

The complete model test based on the Kazipur bathymetry programme appears in Tables 3.1 to 3.5. The tests have been performed in five phases each mainly dealing with specific study subjects.

For reporting convenience the results of Phases I, II and III are presented in Section 4 of this Report, while the results of phases IV and V are presented in Sections 5 and 6.

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The study consists mainly of two type of experiments.

- Fixed bed experiments
- Mobile bed experiments

Among fixed-bed experiments one set of tests were carried out without any protective works and other tests were carried out with the introduction of structure works two discharges were chosen for each experiment:

- Bankfull discharge (9,000 m^3/s)
- 100-years flood discharge (17,000 m^3/s)

The values in parentheses being the calculated discharges applicable to the Kazipur anabranch geometry.

Arrangements were made to fill the model with water from the downstream to ensure that the model bed was not disturbed prior to testing.

The purpose of the fixed bed experiments, phases I, II and III, was to study the flow condition in this branch for the present river bathymetry and the effects of groynes on the flow field.

Table 3.1: Kazipur Test Bed: List of Phase I Model Tests - Fixed Bed Experiments

Test No	WL (m)	Discharge (m^3/s)	Purpose	Comments
1A	+15.0	9,000	Flow Measurements	Approach Channel 1
1B	+15.0	9,000	Flow Measurements	Approach Channel 2
1C	+17.25	17,000	Flow Measurements	Approach Channel 1
2A	+15.0	9,000	Flow Measurements with 6 Groynes	Approach Channel 1
2B	+17.25	17,000	Flow Measurements with 6 Groynes	Approach Channel 1

For Approach Channel definition see Section 4.2

Table 3.2: Kazipur Test Bed: List of Phase II, Model Tests Fixed Bed Experiments

Test No	WL (m)	Discharge (m^3/s)	Purpose	Comments
3A	+15.00	9,000	Flow Measurements with 5 Groynes. Groyne A removed. Other Groynes shortened	Approach Channel 2
3B	+17.25	17,000	Flow Measurements New Groyne Layout	Approach Channel 2
4A	+15.0	9,000	Flow Measurements with one groyne with changed direction	Approach Channel 2
4B	+17.25	17,000	Flow Measurements with one groyne with changed direction	Approach Channel 2

Table 3.3: Kazipur Test Bed: List of Phase III Model Tests - Fixed Bed Experiments

Test No	WL (m)	Discharge (m^3/s)	Purpose	Comments
5A	+15.0	9,000	Flow Measurements Groyne B with changed direction	Approach Channel 2
5B	+17.25	17,000	Flow Measurements Groyne B with changed direction	Approach Channel 2
6A	+15.00	9,000	Flow Measurements changed groyne layout	Approach Channel 2
6B	+17.25	17,000	Flow Measurements changed groyne layout	Approach Channel 2
7A	+15.00	9,000	Flow Measurements Groyne F shifted upstream to c/s 10	Approach Channel 2
7B	+17.25	17,000	Flow Measurements Groyne F shifted upstream to c/s 10	Approach Channel 2

Table 3.4: Kazipur Test Bed: List of Phase IV Model Tests - Mobile Bed Tests - Layout with Groynes B, C, D, E & F

Test No	Duration hours	WL (m)	Discharge (m^3/s)	Purpose	Remarks
8	4	+15.00	9,000	Scour Measurements	
9	7	+17.25	17,000	Scour Measurements	
10	7	+17.25	17,000	Scour Measurements With Guiding vanes at groyne nose	
11	3	+21.00	17,000	Scour Measurements	
12	3	+14.5	17,000	Scour Measurements	
13	7	+16.25	14,500	Scour Measurements Groyne F moved at c/s10	
14	7	+18.25	20,000	Scour Measurements	
15	7	+17.25	17,000	Scour Measurements	
16		+17.25	17,000	Scour Measurements Sand 0.2 mm used as Mobile bed material	

Table 3.5: Kazipur Test Bed: List of Phase V Model Tests with Revetment Alternative

Test No	WL (m)	Discharge (m^3/s)	Purpose
16A	+15.00	9,000	Embayment/Scour Development
16B	+17.25	17,000	Embayment/Scour Development
17	+17.25	17,000	Embayment/Revetment Study
18	+17.25	17,000	Embayment/Revetment Study
19	+17.25	17,000	Study of Deflector

4. RESULTS OF THE MODEL STUDY

4.1 Fixed Bed Experiments - Phase I, II & III

This section presents the results of the model tests in Phase I, II and III.

4.2 Tests Without Protective Works

Three experiments were performed without protective works.

Test No. 1A

In this test, the existing flow channel configuration denoted by Approach Channel no. 1 was reproduced. The discharge was 9,000 m^3/s (bankfull) and the downstream water level was + 15.0 m. The flow velocity along all the cross-sections at different locations and at three depths (0.2D, 0.5D and 0.8D) were measured by a current meter. The measured velocities are given in Appendix II.

The surface flow line was recorded with still photographs, as well as by video recording. The flow field measured in the model appears in Figure 4.1.

Test No. 1B

In this test another 15° more inclined approach channel, denoted by Approach Channel no.2 was used. The object of this experiment was to study the effects from changing the angle of flow attack on the flow field near the bank. The discharge was 9,000 m^3/s (bankfull). The flow velocity was measured along the sections at different locations. The measured flow field is shown in Figure 4.2.

Test No. 1C

In this test, the original Approach Channel No. 1 was used. The discharge was 17,000 m^3/s (100-years flood) and the downstream water level was + 17.25 m. The flow velocity was measured at the same points as in Test No. 1A. The measured velocities are shown in Appendix III. The flow velocity was also measured over the flood plains along C.S. No. 6 by mini-flow meter, the results of which are shown in Table 4.1. The flow field measured in the model appears in Figure 4.3.

Table 4.1: **Kazipur Test Bed, Velocity Over Flood-Plain for 100-years Flood Discharge**

SL.No.	Distance from Bank in metres	Velocity in m/s	Remarks
1	0	1.00	Left Bank
2	200	1.37	"
3	400	1.10	"
4	600	0.39	"
5	800	very low velocity	Right Bank
6	0	0.91	"
7	100	0.91	"
8	180	0.78	"

4.3 Velocity Measurements with Groynes

Based on the results from the three tests without protective works, initially a series of six groynes along the right bank was proposed. The position, alignment and length of the proposed groynes are shown in Table 4.2. During tests it was observed that there was no influence of groyne A on the flow patterns. As such groyne A was found to be redundant and removed.

Table 4.2: **Kazipur Test Bed, Specification of Groynes (Original Proposal)**

SL. No.	Groyne No	Location	Length (m)	Top Elevation (m)	Upstream Angle
1	A	59 meters upstream from c.s. # A	80.0	18.21	80°
2	B	95 m downstream from c.s # A	120.0	18.21	80°
3	C	453 m downstream from c.s # A	250.0	18.21	75°
4	D	134 m downstream from c.s # 2	460.0	17.85	110°
5	E	28 m upstream from c.s # 7	270.0	19.62	120°
6	F	63 m downstream from c.s # 11	80.0	17.94	85°

Notes: All the dimensions are in prototype. Upstream angle was measured with respect to present bankline.

Twelve experiments were carried out with groynes. The model bed was made as fixed bed with cement mortar where necessary especially around the groynes. The velocity distributions were measured as in the previous tests (at 0.5 depth only).

A summary of the tests carried out with groynes is given in Table 4.3, 4.4 and 4.5 for test Phases I, II and III respectively.

Table 4.3: Kazipur Test Bed Phase I
Summary of the Tests Carried out with Groynes

Test No.	Test Conditions	Objective
2A	Approach Channel 1. Number of groynes 6, length and position of groynes as shown in Table 4.2, Q=9,000 m^3/s	Preliminary test with groynes for bankfull discharge
2B	All other test conditions are similar to test Number 2A, Q=17,000 m^3/s	Preliminary test with groynes for 100 years flood discharge

Table 4.4: Kazipur Test Bed Phase II
Summary of the Test Carried out with Groynes

Test No.	Test Conditions	Objective
3A	Approach Channel 2, Groyne-A removed, number of groynes 5, position and alignment of groynes similar to Test No. 2A but groyne lengths were reduced, Q=9,000 m^3/s	Adjust the lengths of the groyne-set to improve flow curvature
3B	All other conditions were the same as for Test No.3A Q=17,000 m^3/s	To see the performance of the new groyne set for flood discharge
4A	The angle of groyne B relative to the bank alignment was changed from 80° to 110°. All other conditions were the same as in Test No.3A, Q=9,000 m^3/s	To see the influence by changing the alignment of 1 groyne on flow pattern
4B	Q= 17000 m^3/s, All other conditions unchanged	To see the influence by changing the alignment of 1 groyne on flow pattern

Table 4.5: Kazipur Test Bed Phase III
Summary of the Test Carried out with Groynes

Test No.	Test Conditions	Objective
5A	The angles of groyne B and C were changed to 110° from 80° and 75° respectively, Q=9,000 m^3/s	To see the influence by changing the alignment of two groynes on the flow patterns
5B	Q= 17,000 m^3/s. All other conditions unchanged	To see the influence by changing the alignment of two groynes on the flow patterns
6A	Groyne E with a T of length 100 meter, Angle of groyne C was 90°. The length of groyne F was increased to 80 m from 62.5 m, Q=9,000 m^3/s	To divert the flow between c/s 9 to c/s 12 away from the right bank
6B	Q=17,000 m^3/s. All other test conditions were the same as in test no. 6A	To divert the flow between c/s 9 to c/s 12 away from the right bank
7A	Groyne F was shifted upstream and placed at c/s 10. All other test conditions were the same as in test 6A Q=9,000 m^3/s	To minimise the reverse eddies forming between groynes E and F (for bankfull discharge)
7B	Q=17,000 m^3/s. All other test conditions were unchanged	To minimise the reverse eddies forming between groynes E and F (for (for 100 years flood discharge)

4.4 Discussion of Results from Fixed-bed Experiments, Phases I, II & III

4.4.1 Study of Groyne Fields

In the fixed bed experiments, the performance of the proposed set of groynes was tested in order to determine maximum velocities at the nose of the groynes and the near-bank maximum velocities in the reverse eddies in the pockets between the groynes. Tests were carried out with various alternatives, aiming at improvement of the proposed lay-out. Also the effect from changing the angle of attack was tested during these experiments. The horizontal velocity distributions along the cross-sections (measured at 0.5 depth) for Test No. 1A to Test NO. 7B (excluding tests 5B & 7A) are shown in Figure 4.1 to Figure 4.13).

It was realised after Test Nos. 2A and 2B that groyne A was unnecessary and the groyne lengths could be reduced. So, in the following experiments, groyne A was removed and the length of the remaining five groynes were reduced to form a more gentle curvature of the groyne noses. The original lengths and the new lengths of groynes are shown in Table 4.6

Table 4.6: Kazipur Test Bed
Original and New Lengths of Proposed Groynes

SL.No.	Groyne No.	Originally proposed length [m]	New Length [m]
1.	A	80	removed
2.	B	120	90
3.	C	250	220
4.	D	460	330
5.	E	270	185
6	F	80	62

* N.B: The length of groyne F increased subsequently.

It was found that the groynes generated reverse eddies between the groynes. This was especially noticeable between groynes E and F. It was tried to reduce this undesirable effect in the tests nos. 6A to 7B. Experiments 4A to 5B were carried out to see the influence of changing the alignment of the groynes, but no significant effect was found.

4.4.2 Observations on Near-Bank Velocities

It was found that in the anabranch under study, the maximum flow velocity occurred near the right bank at cross-sections 7 to 12 (Results are presented in Appendix II and III). After introducing the proposed groynes, the velocity distribution changed. As the cross-sectional area of the anabranch is reduced, the velocity increases, mainly at the nose of the groynes, and at the same time the near bank velocities were reduced substantially. Table 4.7 shows a comparison of the magnitude of nearbank velocities without protective works and with protective works (Five groynes, groyne F at c/s-10).

Table 4.7: Kazipur Test Bed
Near bank flow velocity without and with training works. (measured at 0.5 depths)

C.S. #	Velocity without protective works		Velocity with protective works	
	Bankfull Discharge (m/s)	100 years flood Discharge (m/s)	Bankfull Discharge (m/s)	100 yr Flood Discharge (m/s)
7	2.0	2.3	0.0	0.0
8	2.0	2.3	-0.7	-0.8
9	2.0	2.2	0.0	0.0
10	1.9	2.3	0.0	0.0
11	2.2	2.8	-0.5	-0.6
12	2.1	2.5	-0.8	-1.0

4.4.3 'T' Shaped Groyne

Tests Nos. 6A and 6B were carried out with groyne E 'T shaped'. The objective was to divert the flow, between c/s 9 to c/s 12 away from the bank more effectively and to minimise the reverse eddies formed between the groynes E and F. The measured velocity profiles are shown in Figures 4.11 and 4.12 for bankfull and 100 year flood respectively. Comparing with those in Figures 4.6 and 4.7, no significant improvement was found. Moreover this type of structure will increase the cost of the bank protection works. It was consequently found to be a better solution to shift groyne F to cfs # 110. The results of the test (see Test 7 B) on this arrangement were better than for the T - groyne.

4.4.4 Change in Angle of Groynes to Bank

Test Nos. 4A to 6B were carried out with different alignment of groynes B and C with respect to the present bank line. Angles in the range from 75° to 110° were tested. The results are shown in figures 4.8 to 4.12 for different flow conditions. No significant difference in flow pattern was found.

4.4.5 Comments on 'T' Shaped Groynes

Results from Test Nos. 6A and 6B revealed that for the groyne field studied the introduction of a 'T' shaped groyne with 100 m length of the flow parallel section instead of a normal groyne does not improve the situation significantly. This type of structure was therefore not considered further.

4.4.6 Change in Angle of Groynes to Bank

The results from Test Nos 4A to 6B involving a change in the angle of groynes alignment to bank line revealed that the change has no significant effect on the flow pattern if

- the change is within the range tested (± 15° from 90°)
- the channel configuration remains stable
- the projection of the groyne into the river is the same

5. PHASE IV, MOBILE BED EXPERIMENTS

5.1 General Information

The objective of the mobile bed experiments in Phase IV was to determine the maximum scour or deposition to be expected around the groynes and to observe the general performance of a groyne-set in live-bed conditions. The groynes were constructed from 2.5 cm, brick-chips. In these tests a portion of the sand-bed was removed and refilled with coal-dust as bed material. The coal-dust used in the tests had the following properties:

Mean diameter,	d = 0.7 mm
Specific gravity	= 1.31 g/cm^3
Angle of repose in water	= 26.2°

The gradation curve of the bed material (coal dust) is shown in Figure 5.1

The grain size was observed to be small enough to get a weak sediment transport everywhere on the model bed even at distances far away from the groynes. Thus, in the tests, so called live-bed conditions were achieved.

5.2 Scour Tests with Groynes

A total of eight tests were conducted with mobile-bed in Phase IV. The test conditions are given in Table 5.1.

Table 5.1: Kazipur Test Bed, Phase IV.
Test Conditions for Mobile-bed Experiments

Test No.	Test Condition	Duration [H]	Objective
8	Mobile bed test with five groynes, Q = 9,000 m^3/s W.L = 15.00 m	4.0	To observe the bed level development and maximum scour around groynes for bankfull stage. Also to monitor the development of scour with time.
9	100 Year flood conditions Q = 17,000 m^3/s W.L = 17.25 m	7.0	Same as Test No.8, but with 100 year flood condition.
10	Same as Test No. 9 but with guiding vanes placed at the nose of groynes (see Figure 5.4 and Photo 6)	7.0	To determine the effective-ness of guiding vanes to minimise the scour develop- ment at the nose of groynes suppressing the formation of vortices.
11	Test with a special condition Q = 17,000 m^3/s W.L = 21.00 m	3.0	To observe the bed material movement for comparatively low velocity
12	Test with special condition Q = 17,000 m^3/s W.L = 14.50 m	3.0	To observe the bed material movement for high velocity
13	Test with special condition Q = 14,500 m^3/s W.L = 16.25m groyne F moved to c/s#10	7.0	Sensitivity test with the same average velocity but different stage. Also to minimise the reverse eddy formed between groynes E and F.
14	Test with special condition Q = 20,000 m^3/s W.L= 18.25 m groyne F at c/s#10	7.0	
15	Test with 100 year flood condition with groyne F at c/s # 10. Q = 17,000 m^3/s W.L = 17.25	7.0	Same as Test NO. 13

5.3 Discussion of Results from Scour Tests

It was found from Test No. 8 that maximum scour occurred downstream of the nose of groyne E. The contour lines are shown in Figure 5.8. Figure 5.3 shows the scour development with time at this point. After about 4 hours (model time), the scour attained its maximum of about 8 m below original bed level for bankfull flow. Figure 5.2 shows similarly the development of scour at the nose of groyne D.

Test No. 9 was carried out with 100 years flood discharge on the undisturbed bed after running the previous test (Test No. 8). Figure 5.3 shows how the scour hole at the nose of groyne E developed with the increase of discharge and water depth. However, the scour development stopped and the situation became stationary after about 7 hours (model time). Figures 5.9 and 5.11 shows the contour lines and the erosion/deposition pattern.

5.4 Test on Guiding Vane & Sensitivity Tests on Water Level for Fixed Discharge

In test no. 10, guiding vanes were placed at the nose of each groyne as sketched in Figure 5.4. The contour lines of the model bed are shown in Figure 5.10. The concept behind this arrangement was to suppress the formation of vortices downstream of the groyne-nose. The result of the experiment indicates that the guiding vanes only marginally improve the situation.

Test Nos. 11 and 12 were sensitivity tests in which the discharge was 17,000 m3/s but water levels were 21.00 m and 14.5 m respectively. It was found that bed material movement was practically nil in test 11, whereas it was very rapid in test 12.

5.5 Sensitivity Test with Respect to Flow Depth

The purpose of Test nos 13 to 15 was to determine experimentally the parameter 'flow-depth to groyne length ratio' which is a major parameter governing the scour depth. The discharge and water levels were calculated so that the average flow velocity was the same in all the three experiments whereas the water levels were different. Another point to be noticed here is that in these three tests, the groyne F was shifted upstream to c/s-10 to minimise the reversing eddies. After analysis of test results of Test no. 14 the results appear to be inconsistent and this test has consequently been abandoned. The results of test 13 and 15 are presented in Figure 5.5. A comparison of the two diagrams clearly indicate that there is no detectable influence of the flow depth on the bed bathymetry for the same flow velocity.

5.6 Velocity over Scoured Bed

After the completion of Test No. 15, when the scour/deposition process had reached its equilibrium stage for the 100 year flood, the horizontal flow velocity along the measuring sections was determined (at half-flow depth). The results appear in Figure 5.6.

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Comparison of these velocity profiles with the velocity profiles obtained in the fixed bed experiments, in Test No. 7B (Figure 4.13), shows some difference between the two cases. Generally, the velocity in the critical regions, such as at the groyne - noses for instance, are reduced substantially in comparison to undisturbed bed situation. Table 5.2 summarises the results. This reduction is explained by the increased water depth caused by the scour near the nose of groynes.

Table 5.2: Kazipur Test Bed, Phase IV, Comparison of Maximum Velocities from Fixed Bed and Mobile Bed Experiments:

Groyne No.	Maximum Velocity at the nose of groynes (m/s)		Maximum nearbank velocity of reversing eddies between groynes (m/s)	
	Fixed bed Experiments	Mobile bed Experiments	Fixed bed Experiments	Mobile bed Experiments
Groyne B				
Groyne C				
Groyne D	3.2 - 3.6	2.0 - 2.4	1.3	1.1
Groyne E	3.2 - 3.6	2.8	0.9	0.8
Groyne F	3.0	2.8		

The reference bed bathymetry, contour maps after Test Nos 8, 9 and 10 are shown in Figures. 5.7 to 5.10. Figure 5.12 shows the formation of vortex at the downstream of groynes and Figures 5.13 and 5.14 are two sections showing the bed bathymetry before and after introducing the groynes. Figure 5.11 shows the areas of erosion and deposition.

5.7 Maximum Scour

It was found, as stated earlier, that scour occurs near the nose of groynes. However, the deepest scour holes develop at the downstream side of the nose of the groynes. This is mainly caused by the vortices formed at the downstream of the groynes (Figure 5.12), where the two effects, namely the contraction of stream-lines plus the action of vortices, superimpose. The maximum value of the scour depth is also of great interest for the design of groynes. Table 5.3 summarises the lowest elevations measured in Test 9.

Table 5.3: Kazipur Test Bed Phase IV.
Maximum Scour near the nose of groynes

Groyne No.	Bed elevation after test (m.a.s.l)	Original Bed Elevation (m.a.s.l)	Scour (m)	Flow Depth (m)
Groyne B	- 4.8	- 1.0	3.8	22.50
Groyne C	- 6.0	2.0	8.0	23.50
Groyne D	- 3.0	6.2	9.2	20.50
Groyne E	- 7.0	6.3	13.3	24.30
Groyne F	-12.0	-6.0	6.0	29.30

Note: Test No 9, Q=17,000 m^3/s, WL = + 17.25 m, Test duration 7 hours.

6. PHASE V: STUDY OF REVETMENT ALTERNATIVE

6.1 General Information

The object of these test series was to investigate bank erosion protection by revetments as an alternative to a groyne field.

In preparation for the revetment tests, a nine hundred meter long revetment was constructed to scale on the natural bank slope of the river along the reach where near-bank velocities were highest. The revetment was constructed from crushed brick of 1.0 cm size as per plans in Figures 6.1 and 6.3. The thickness of the revetment was two layers of materials whereas, the thickness of falling apron was three/four layers of materials. The coal-dust used in the groyne tests, was re-used as the bed material near the falling apron of the revetment. Also the bank upstream and downstream of the revetment ends was made with coal dust.

6.2 Test Programme with Revetment

A total of five tests were carried out with revetment alternatives. The test conditions are shown in Table 6.1.

Test Nos 16A and 16B were carried out with rounded end revetment for the bankfull and 100 years flood discharges respectively. Test No 17 was with small artificial embayments at both ends of the revetment, whereas in Test No 18, a larger elliptical sized artificial embayment was formed. The object of these two tests was to observe the effect of the embayments on the flow pattern and on the revetment. Test No 19 was carried out with a deflector at the down stream end of the revetment in order to divert the flow off the bank. Tests Nos 17 to 19 were carried out with 100 year flood discharge only.

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Table 6.1: Kazipur Test Bed, Phase V.
Test Conditions for Revetment Test

Test No.	Test Conditions	Objective	Remarks
16A	Test with rounded end revetment (Figures 6.1-6.3 Q=9,000 m3/s (bankfull), W.L = 15.00 m	To study the Development of embayment and scour for bank-full discharge	No significant scour occurred
16B	Rounded end revetment Q = 17,000 m3/s (100 years flood), W.L = 17.25m	To study the Development of embayment and scour for 100 yr flood discharge	
17	Revetment test with embayment shape-1 as sketched in Figure 6.4 at upstream and downstream Q=17,000m3/s W.L = 17.25 m	To see the effect of embayment on the revetment	Reverse eddy forms in the embayments
18	Test with embayment shape 2 in both ends as sketched in Figure 6.5 Q=17,000 m3/s W.L = 17.25 m	To see the effect of embayment on the revetment	Reverse eddy forms in the embayments
19	Test with deflector blocks placed at the downstream end of the revetment without embayment, length of deflector 150 m, height of deflector 65 m as sketched in Figure 6.6 Q=17,000 m3/s	To divert the flow away from the bank at the downstream end of the revetment	

6.3 Discussion of Results of Revetment Tests

The test results have shown that the maximum near-bank velocity occurs at c.s.#11, the value of which is 2.8 m/s for 100 year flood discharge. Table 6.2 shows the near bank velocities for bankfull and 100 year flood discharge measured at half flow depth at a distance of 30.0 m from the right bank. The bed elevations, at the edge of falling apron before Test 16A and after Test No 16B were recorded. The results are shown in Table 6.3. It appears that maximum scour of 3.0 m occurs at C.S. 12, but in terms of elevation, the bed is deepest at c/s # 10 (Elevation - 7.4 m). The bank at both ends of the revetment remained almost intact.

In Test Nos 17 and 18 (with artificial embayments) it was found that reverse eddies form in the embayments which is stronger in the downstream bay (Figure 6.7). The maximum velocity in this eddy was observed at 1.0 m/s and 0.7 m/s for embayment shape 1 and 2 respectively. It was also observed that the flow velocity at the upstream nose of the revetment increased a little.

Table 6.2: Kazipur Test Bed, Phase V.
Near Bank Velocity with revetment

Sl.No.	c/s #	Velocity for bankfull discharge (m/s)	Velocity for 100 yr flood discharge (m/s)
1	3	0.9	1.2
2	4	1.0	1.3
3	5	1.2	1.6
4	6	0.7	1.2
5	7	2.0	2.3
6	8	2.0	2.3
7	9	2.0	2.2
8	10	1.9	2.3
9	11	2.2	2.8
10	12	1.0	1.2

Note: Velocities measured at the half flow depth (0.5 D) at a distance of 30.0 m from the right bank (Test 16A and 16B)

Table 6.3: Kazipur Test Bed, Phase V.
Scour along the revetment toe

c/s#	Bed Elevation before test (m)	Bed Elevation after test (m)	Scour (m)
4	1.0	-1.4	2.4
5	3.0	0.8	2.2
6	2.0	0.0	2.0
7	2.3	-0.1	2.4
8	-4.0	-5.0	1.0
9	-7.0	-7.2	0.2
10	-6.0	-7.4	1.4
11	-4.0	-5.5	1.5
12	0.0	-3.0	3.0

Note: Scour measured at the end of the falling apron after running bankfull discharge for 3 hours and 100 year flood for 3 hours (Test 16A and 16B)

C/S # 12 is located 200 m downstream of the revetment. Mean scour increment omitting C/S # 12 is 1.6m.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 General

This section presents conclusions and recommendations derived from the model tests performed in the physical model based on the Kazipur Bathymetry. It is important to mention that the model tests in addition to the site specific investigation covered many aspects of a more general nature.

7.2 Kazipur Site Characteristics

The river plan configuration and bathymetry at Kazipur following the 1990 monsoon was characterised by the following (see Frontispiece).

(a) The anabranch at Kazipur turns to the left and Kazipur is situated at the outward westward side of the bend anabranch.

(b) The water depth is very large near the right (western) bank with bed levels down to -10.00m m.a.s.l at the C/S # 6 (see Appendix IV). This depth was found at about 160 m from the right bank. For the 100 years water level of 17.25 m the water depth is equal to 27.25 m at this location. The bathymetry measured in Kazipur therefore constitute a good example for studying the conditions that can prevail in a concave river bend.

(c) The Kazipur site is exposed to severe erosion and the BRE has been shifted (retired) a number of times.

In conclusion these conditions represent a case of relatively severe scour close to the river bank and reflect conditions that can occur at any location along the BRE during the design life of any bank stabilisation works.

7.3 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 higher velocity. Disadvantages associated with the use of groynes in these conditions include:

(a) A groyne therefore needs larger blocks and very heavy scour protection at its nose to prevent the structure from failing due to scour.

(b) A field of groynes and its layout can be designed to be optimum for given flow characteristics and up-and downstream river/anabranch configuration. If the river changes as the Brahmaputra does continuously, the groyne field is not necessarily optimum any longer.

(c) The active deflection of the flow away from the right bank and reduction in effective channel cross-section will tend to induce erosion elsewhere.

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 severe scour development as is always the case for a groyne.

If the river changes its course, the revetment may obstruct 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 more suitable where bank stabilisation is the primary objective. It is to be noted that provided the revetment toe is capable of adjusting to the scour, the most vulnerable part of the revetment is its up-and downstream terminations where embayment may form resulting in increased velocities at the exposed embankment corners.

7.4 Phase I, Results of Flow Measurements Approach Channel I and 2

The test results of flow measurements in the existing bathymetry in Figures 4.1 and 4.3 for bankfull and 100 years flood discharge respectively show a similar trend on flow patterns. An important amplification of the flow velocity occurs near the right bank in front of the Upazila Hospital and the College. For 100 years flood conditions the velocity reaches 2.8 m/s.

The Phase I programme comprised test on two upstream flow channels (see Figures 4.1 and 4.2). The flow channels differ with respect to their inclination. By comparison of the test results (flow field) it was concluded that the flow field and velocities near the Hospital and College are almost not influenced by the upstream channel inclination within the range of inclinations tested (15°).

The average flow velocity in the model was 1.3 m/s and with the above maximum velocity, the velocity amplification factor in the concave bend is 2.15. This amplification is slightly higher than found in the other physical models (see Appendix I of the BRTS Final Report on Physical Modelling Vol.I).

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7.5 Phase II & III, Results of Model Tests with Groyne Field for Flow Measurements

Phase II and III comprised testing of many different layouts of groyne fields for different flow conditions. The aim of the test programme for Phase II and III was to find a suitable configuration for a groyne field for protection of a concave river bend.

Figures 4.4 to 4.13 show the results of the many tests with different configurations of the groyne field for different flow conditions, i.e. bank-full and 100 years flood respectively. The details of the test results are presented in Section 4. The tests examined different groyne arrangements leading to a final configuration considered to be the best configuration for the site specific conditions.

This configuration is shown in Figure 7.1 and in Table 7.1. It is important to notice that this configuration is only optimal for the existing upstream conditions and that if constructed the river may change its coarse in a way leading to the configuration not being optimal anymore.

Table 7.1: Kazipur Test Bed.
Specification of the Final groyne Layout

Groyne	Location	Length (m)	Top elevation (m)	Angle with bank line
B	95.0 m downstream from C/S#A	90	19	80°
C	453m downstream from C/S#A	220	19	75°
D	134m downstream C/S#2	330	19	110°
E	28m upstream from C/S#7	185	19	120°
F	At C/S#10	80	19	85°

N.B.: The shank should be extended up to the BRE. The angle with the bank line is measured from the upstream bank.

7.6 Phase IV, Scour Tests for Groyne Fields

Scour tests (mobile bed experiments) on the groyne arrangement has been made. The tests have shown that the groynes provoke the development of scour near the groyne nose, however with the deepest scour at the downstream side of the nose. This is mainly caused by the vortices formed at the downstream of the groynes. The tests have further shown that practically no scour occurs along the shank of the groynes and along the protected bank in between the groynes. At the downstream sides of the groynes distinct patches of sediment deposition occurred forming a bar-like formation running parallel to the bank-line.

The depth of the scour holes near the groyne noses varied, with a maximum of about 13 m below original bed level. The total maximum depth of flow varied in the range 23-29 m below 100 year flood level.

7.7 Phase V, Study With Revetment Alternative

The model tests for investigation of the effect of revetments comprised both tests to determine the flow field and mobile bed tests on the scour development.

The following general conclusions were derived.

(a) The introduction of revetment is a passive measure that does not affect the flow field significantly.

(b) The introduction of a revetment does not change the flow pattern significantly and consequently it does not provoke the development of scour. The mobile bed model tests with revetments showed developments of the bed with scour of 0.2-3.0 m for the 100-year flood after introduction of the revetment.

(c) In conclusion the results of model tests on flow field and velocities have been used to derive maximum velocities to be expected in front of a revetment for the specific bathymetry configuration used in the model tests.

7.8 Phase V, Other General Conclusions from the Model Tests

7.8.1 Tests on Guiding Vanes

Tests were conducted to study the effect from introducing guiding vanes at the nose of the groynes (Figure 5.4). The purpose of such vanes is to suppress the formation of vortices and thereby improve the development of nose scour. The test showed that on the average a significant reduction in the nose scour was obtained, but the practical difficulties of construction and maintaining such vanes must be balanced against the benefits and in this respect the improvement must be considered as at best marginal.

7.8.2 Sensitivity Tests with Respect to Flow Depth

From theoretical considerations and studies by various researchers it is known that the main parameter governing the scour depth at the end of a groyne, or any other object representing an obstacle to the flow, is the water depth to groyne length (or horizontal dimension of the flow obstacle).

The model for Kazipur was distorted with a distortion factor of 200/120 -1.67, and consequently the water depth/groyne length was not correctly reproduced. Sensitivity tests were performed to investigate the influence of this parameter. The tests were conducted with two water depths being + 1 m and - 1m larger and smaller respectively than the 100-years flood depth. To obtain the same water velocity irrespective of the average water depth, the water discharge was increased and reduced accordingly.

The tests showed the same scour development for the different tests and it is concluded that within the range tested the influence of the flow depth is insignificant. Therefore the scour depth measured in the distorted model is taken as representative for natural conditions using Froude's Model law for conversion from model to prototype.

7.8.3 Velocity Measurements over scoured Bed

Measurements taken in the model during fixed bed experiments have been compared with similar measurements taken in the mobile bed tests after the equilibrium situation had developed. The tests showed, as expected from theoretical assessment, that the development of scour causes an increase in the local water depth and thereby a decrease in the flow velocity until equilibrium is reached.

7.8.4 Embayment Tests

An embayment is a bay shaped erosion in the river bank which may develop either upstream or downstream of a stretch of stabilised length of bank (see photo 9).

Model tests with artificial embayments were performed to see the effect of such possible future developments on the terminations of the proposed revetment. The model test was performed with coal dust as mobile bed material in the embayments. The test showed that the embayment vortices develop with lower velocity than in the main stream. The velocity near the upstream termination increased a little (about 10%) relative to the situation without embayment. The tests showed no scour in the embayment because the velocity in the model embayments were too low to move the coal dust.

The inference is that embayments are a feature of the overall river morphological and will not be developed directly as a consequence of the construction of bank protection works.

7.8.5 Study of Deflector Blocks

Deflector blocks are triangle shaped structures introduced at the downstream termination of a revetment with the purpose of deflecting the flow away from the bank in an attempt to avoid the formation of a downstream bank erosion.

One test run was performed with a deflector block (Test 19). The deflector was placed at the downstream end of the Revetment. It was a

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linear deflector, protruding 65 m into the river and 150 m in length. It was observed that the deflector was able to divert the flow away from the bank (see photo no. 10), but a reversing eddy formed at its downstream end. The maximum velocity in the eddy was 0.9 m/s. The situation can be improved by adjusting the size and inclination of the deflector as well as by using more than one in series. But in practice, this type of structures are difficult to construct and will increase the cost of the protective works substantially. As such the test was made only for preliminary assessment of this type of structure and it was concluded that the costs and construction difficulties would offset the advantages.

7.9 Summary of Conclusions on the Model Studies

The model studies using the Kazipur Bathymetry comprised five phases of and a total of 29 tests. The main findings and conclusions can be summarised as follows.

(a) The flow field in a concave river bend as the one studied has high velocities near the bank. To characterize the magnitude of velocities in the bend the ratio between maximum velocity and average velocity in the river anabranch is used. The flow amplification was found to be as high as 2.15. This is the highest amplification found in all the BRTS model studies.

(b) The area of high flow velocities coincides very well with the stretch of river bank where erosion has been experienced in nature.

(c) A groyne field can be used to protect the bank in the river bend against erosion. Many different configurations were tested leading to a set of five groynes as the best arrangement.

However this layout is only optimum for the present bathymetry and river planform. As the river during its natural development changes its braid pattern, the groyne field will not be an optimal solution any longer.

(d) Deep scour holes develop near the groyne noses with its deepest section slightly to the downstream side.

The total maximum scour found in the scour tests with groyne fields varied corresponding to total water depths in the range 23 to 29 m below 100 year flood level. Deeper scour would be expected in the case of a lone groyne.

(e) Bank parallel revetments is an appropriate way to protect the river bank in a concave bend against further erosion.

The revetment does not significantly change the flow conditions and does not by its own presence provoke the development of deep scour holes. Additional bed scour was found to be in the range of 0.2-3.0 m for the 100-year flow conditions after introduction of the revetment. In front of the revetment the average scour was 1.6 m while the maximum of about 3.0 m was measured about 200 m downstream of the revetment.

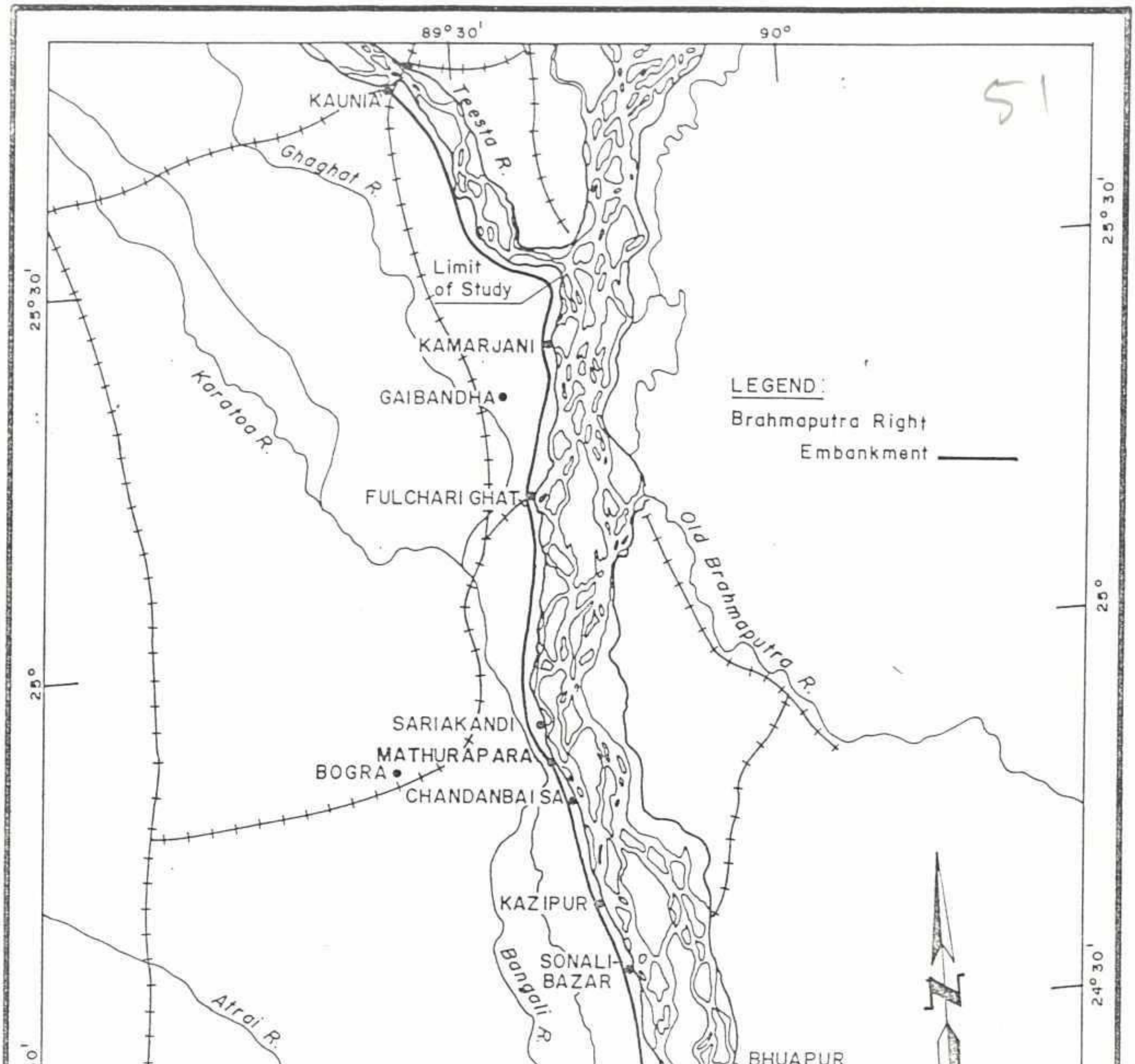
(f) Other structural elements such as guiding vanes at the nose of a groyne and deflector blocks at revetment terminations were also studied.

They were both found to have positive effects but the practical difficulties of construction and maintenance must be balanced against the benefits.

(g) The flow field in embayments was also studied and it was found that the generation of an embayment increases the velocity at the terminations up-and downstream. An increase of 10% was found near the upstream termination. This aspect will be further studied in the revetment tests in a non-distorted model.

(h) Tests to study the sensitivity with respect to flow depth were conducted to verify whether scour measurements in the distorted model are representative for natural conditions when using Fourde's Model Law for conversion from model to prototype. This was found to be the case.

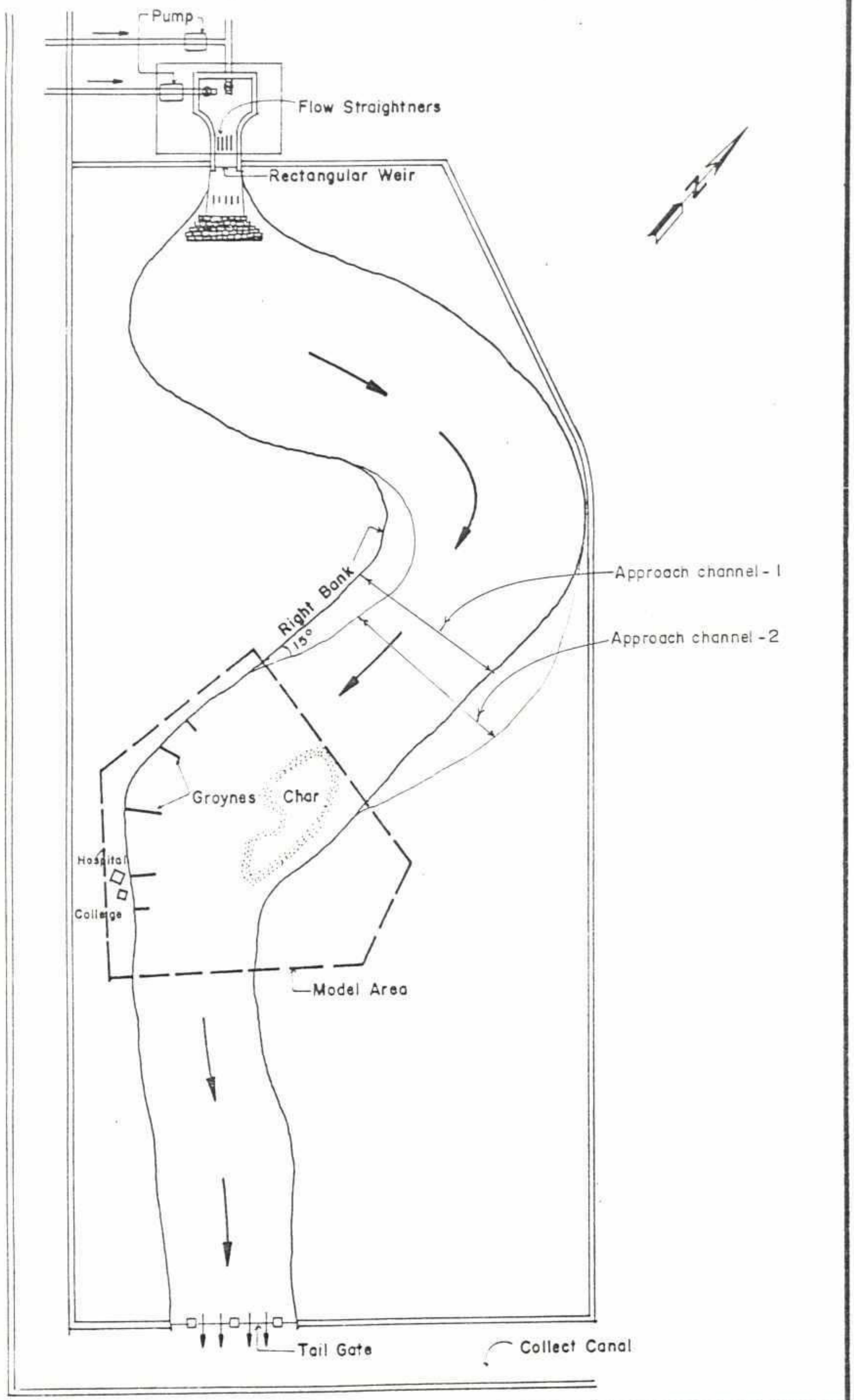
(i) The velocity over a scoured river bed was also studied in the mobile bed model. It was found that the increase in water depth due to the scour decreased the local flow velocity. This important aspect is further analysed in the Annex 3 to the BRTS Second Interim Report.



KAZIPUR PHYSICAL MODEL

LOCATION MAP

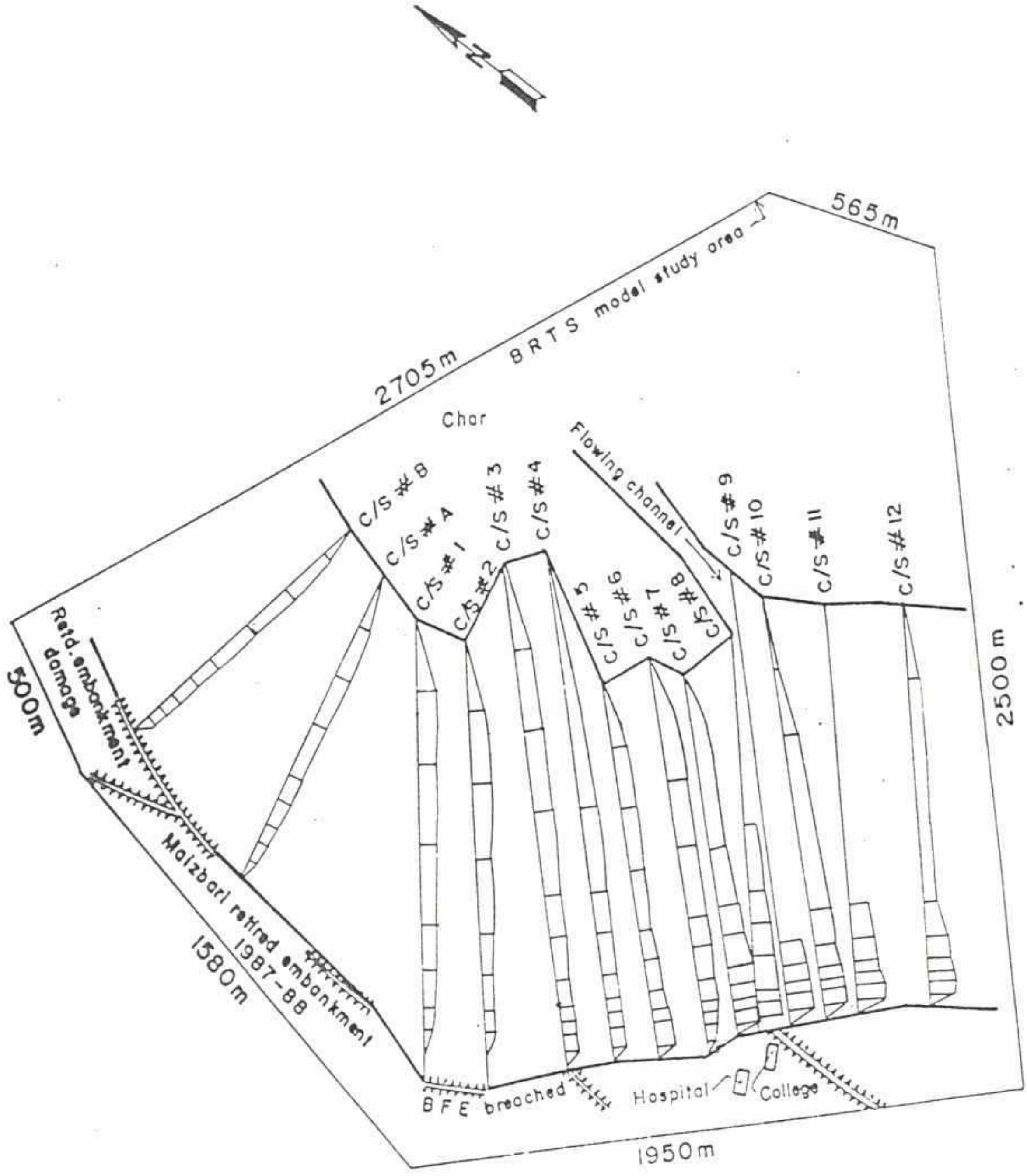
FIGURE 1.1



KAZIPUR PHYSICAL MODEL

PLAN OF KAZIPUR MODEL TEST BED

FIGURE : 2.1

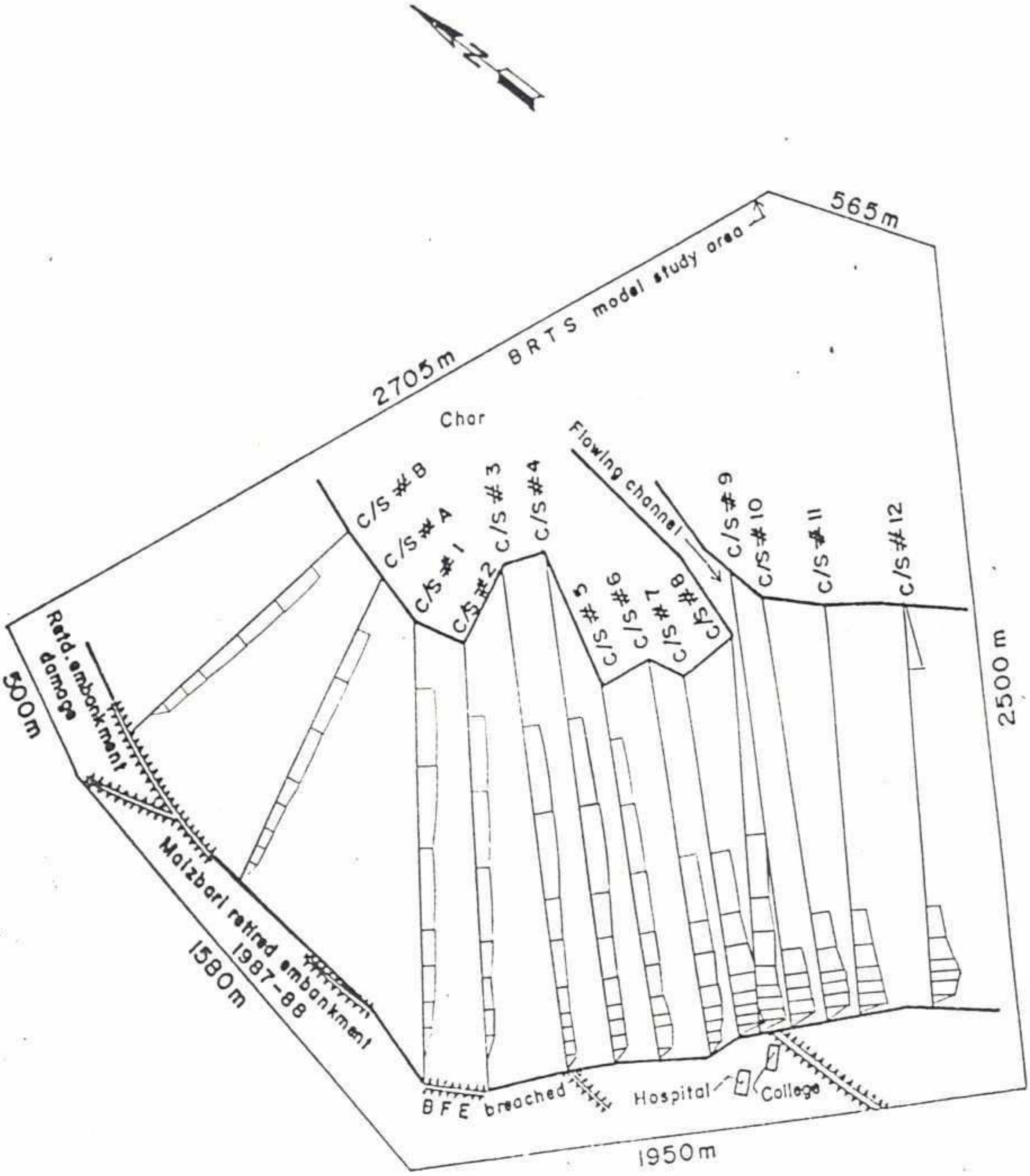


Test Conditions

WL = 15.00m
$Q = 9000\ m^3/S$
Fixed Bed
Approach Channel - I
Without Protective Works

KAZIPUR PHYSICAL MODEL

Test no. 1A,	VELOCITY PROFILE WITHOUT TRAINING WORKS	PHASE I FIGURE : 4.1

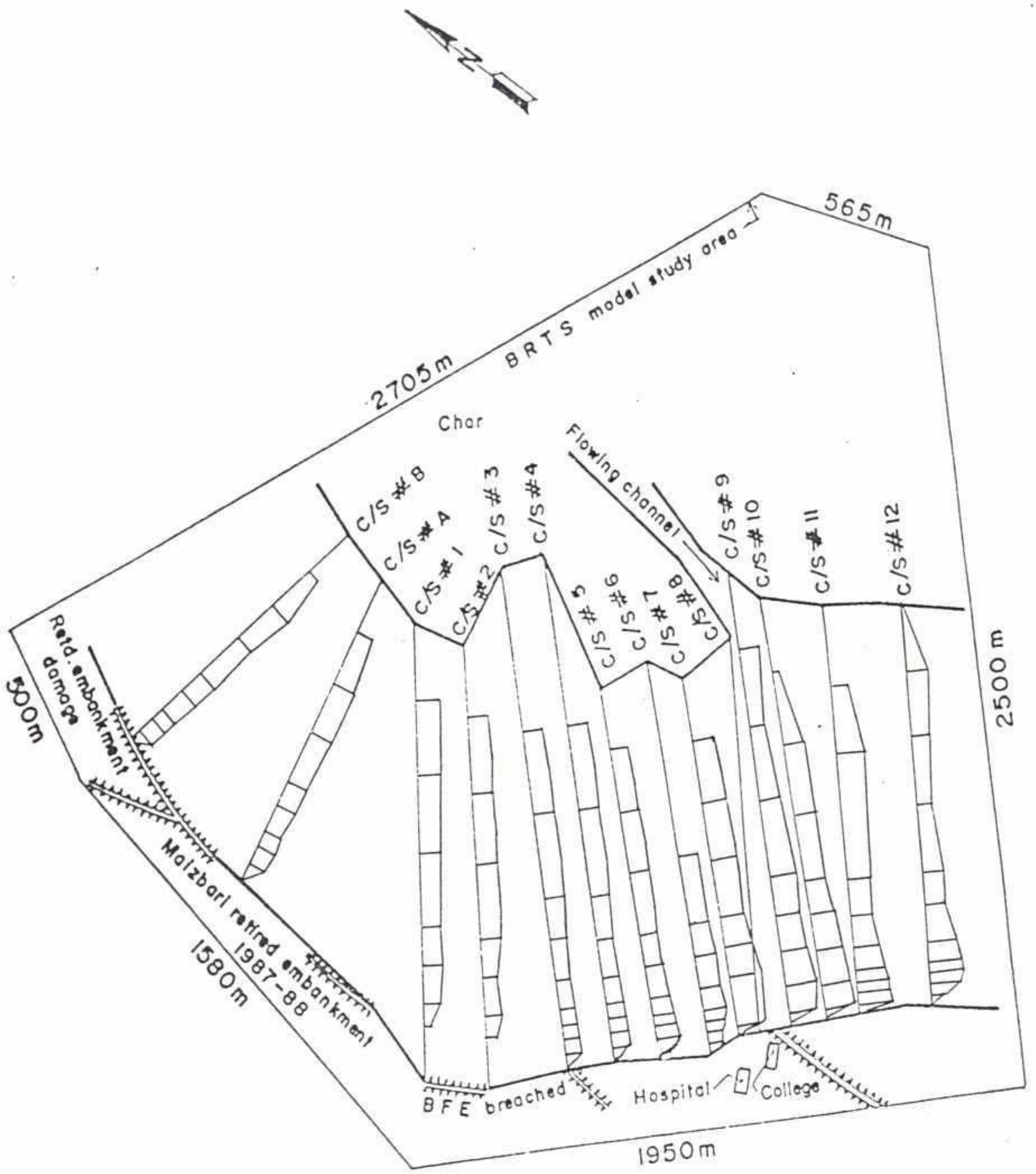


Test Conditions

W.L. = 15.00 m
Q = 9000 m^3/S
Fixed Bed
Approach Channel – 2
Without Protective Works

0 4m/sec
Velocity Scale

KAZIPUR PHYSICAL MODEL		
Test no. 1B,	VELOCITY PROFILE WITHOUT TRAINING WORKS	PHASE I
		FIGURE ; 4.2



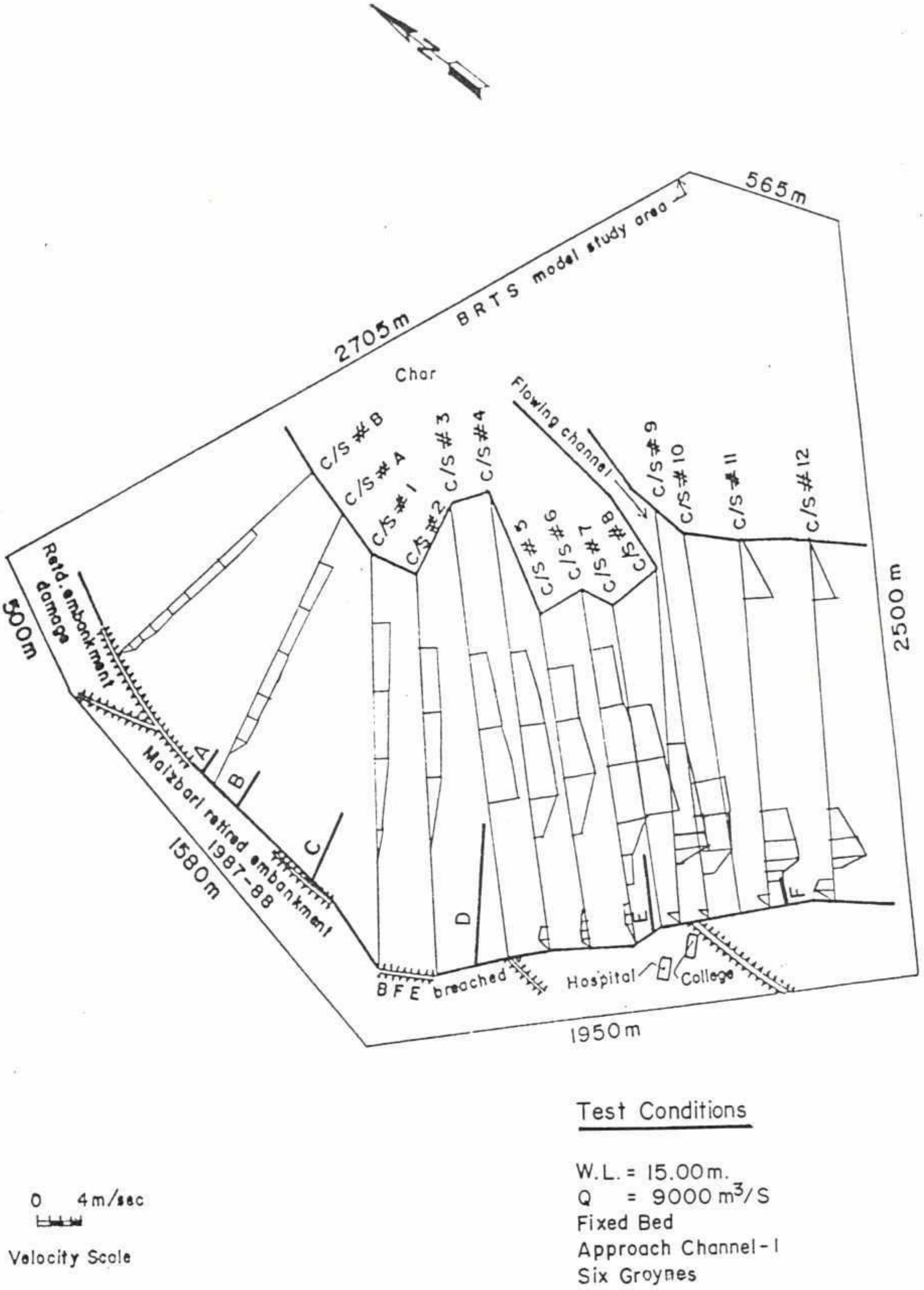
0 4m/sec

Velocity Scale

Test Conditions

W.L. = 17.25 m.
Q = 17 000 m^3/S
Fixed Bed
Approach Channel - I
Without Protective Works.

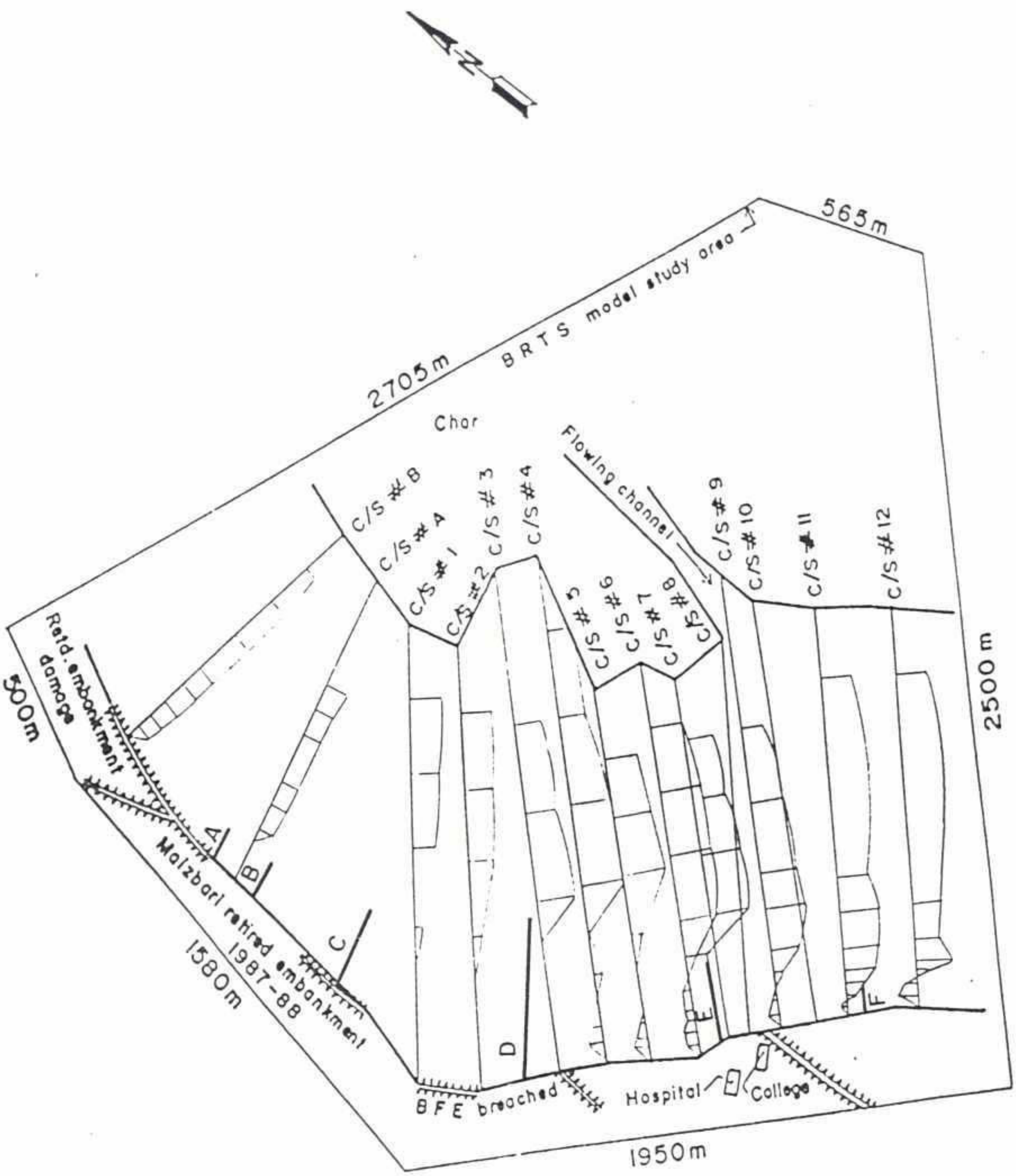
KAZIPUR PHYSICAL MODEL		
Test no. 1C.	VELOCITY PROFILE MEASURED AT HALF FLOW DEPTH	PHASE I FIGURE : 4.3



<u>Test Conditions</u>

W.L. = 15.00m.
Q = 9000 m^3/S
Fixed Bed
Approach Channel - I
Six Groynes

KAZIPUR PHYSICAL MODEL		
Test no. 2A ,	VELOCITY PROFILE WITH SIX GROYNES	PHASE I
		FIGURE : 4.4



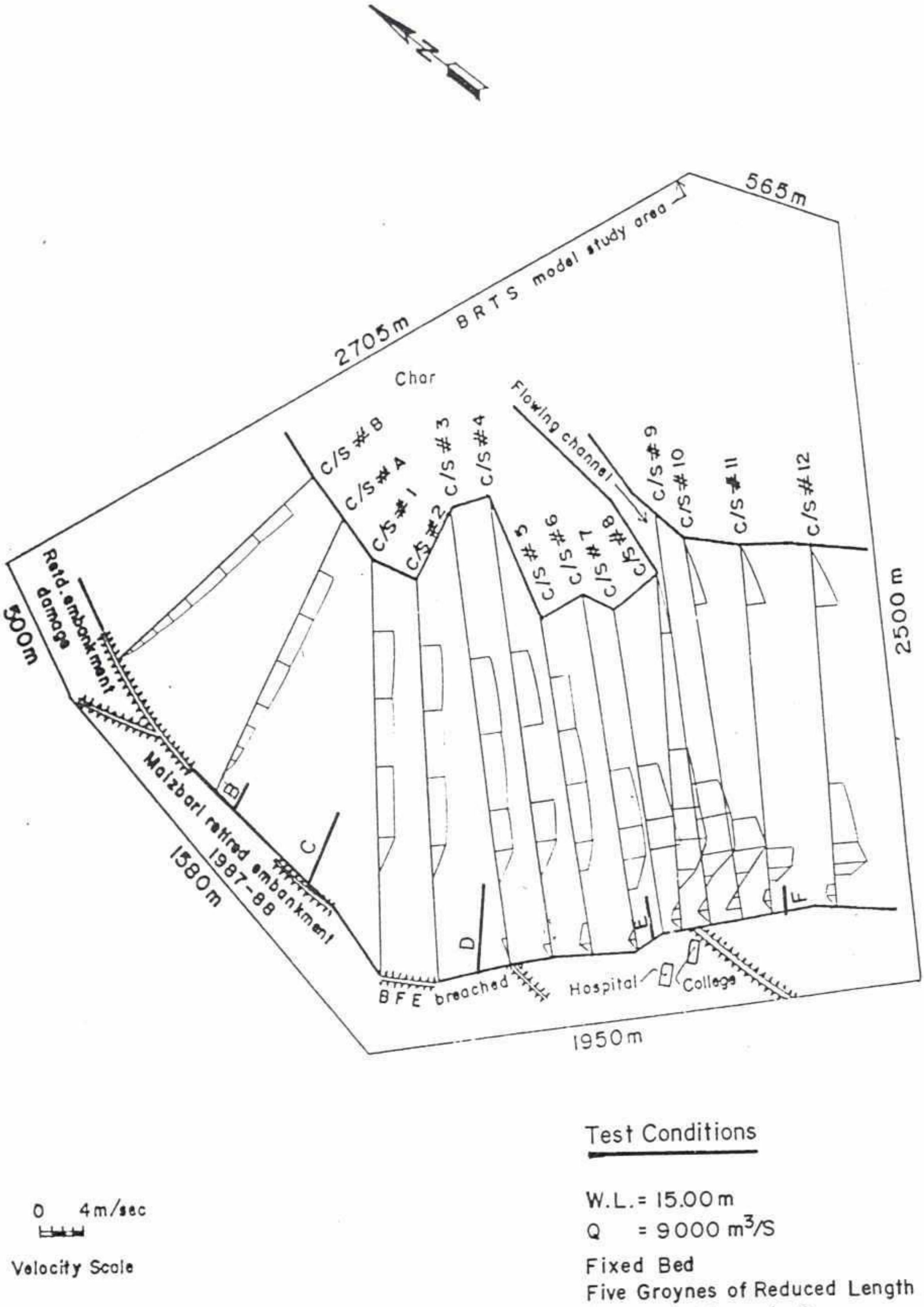
0 4m/sec

Velocity Scale

Test Conditions

W.L.= 17.25 m.
Q = 17000 m^3/S.
Fixed Bed
Six Groynes

KAZIPUR PHYSICAL MODEL		
Test no. 2B ,	VELOCITY PROFILE WITH SIX GROYNES	PHASE I
		FIGURE : 4.5



Test Conditions

W.L. = 15.00 m
Q = 9000 m^3/S
Fixed Bed
Five Groynes of Reduced Length
Approach Channel - 2.

KAZIPUR PHYSICAL MODEL

Test no. 3A,	VELOCITY PROFILE WITH FIVE GROYNES	PHASE II
		FIGURE : 4.6

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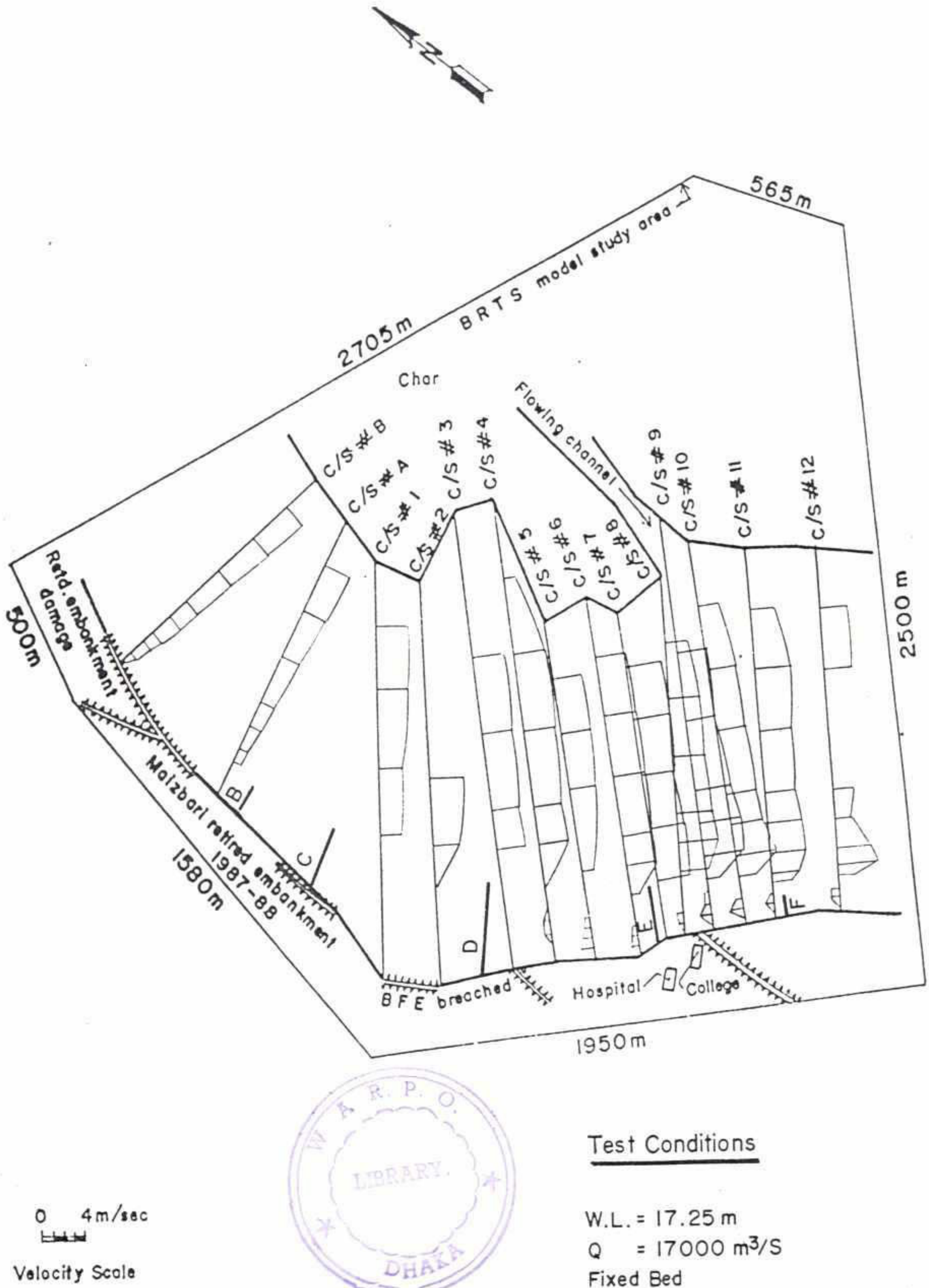

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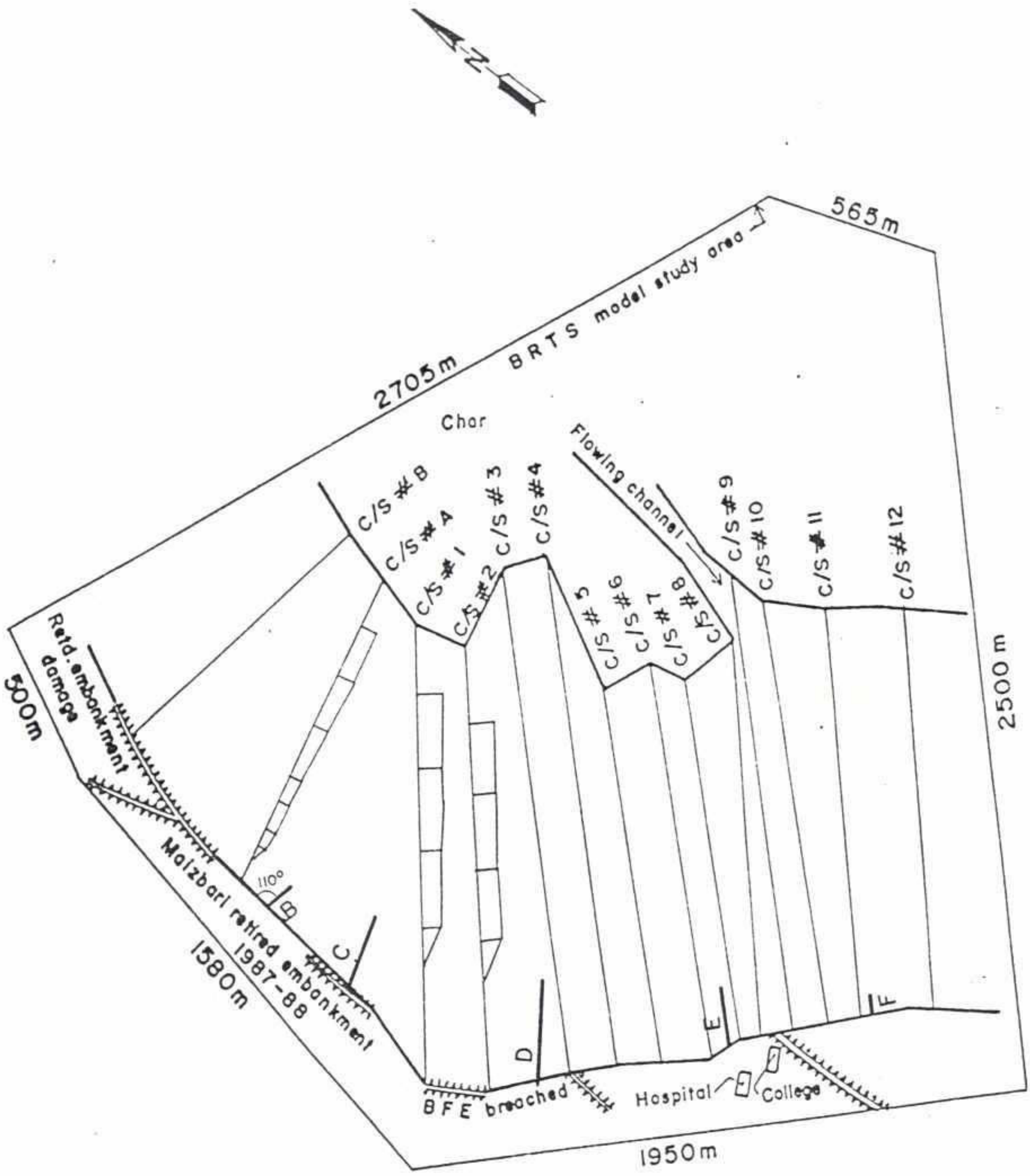
Test Conditions

W.L. = 17.25 m
Q = 17000 m^3/S
Fixed Bed
Five Groynes of Reduced Length
Approach Channel - 2.

KAZIPUR PHYSICAL MODEL		
Test no. 3 B,	VELOCITY PROFILE WITH FIVE GROYNES	PHASE II FIGURE : 4.7



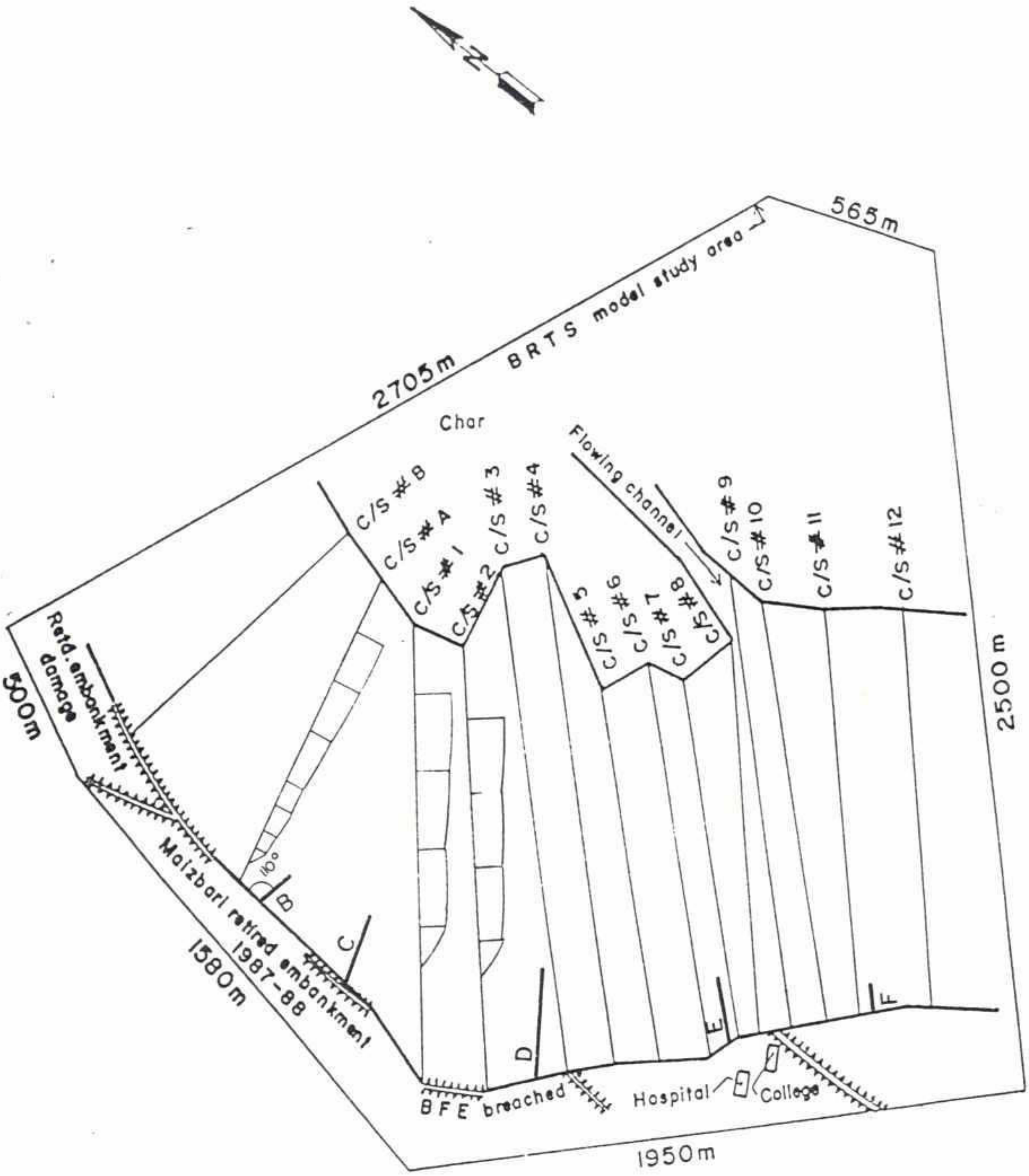
0 4m/sec

Velocity Scale

Test Conditions

W.L. = 15.00m
Q = 9000 m^3/S
Fixed Bed
Five Groynes of Reduced Length
Angle of Groyne B=110°

KAZIPUR PHYSICAL MODEL		
Test no. 4A ,	VELOCITY PROFILE WITH FIVE GROYNES	PHASE II FIGURE : 4.8



0 4m/sec

Velocity Scale

Test Conditions

W.L. = 17.25m

Q = 17000 m^3/S

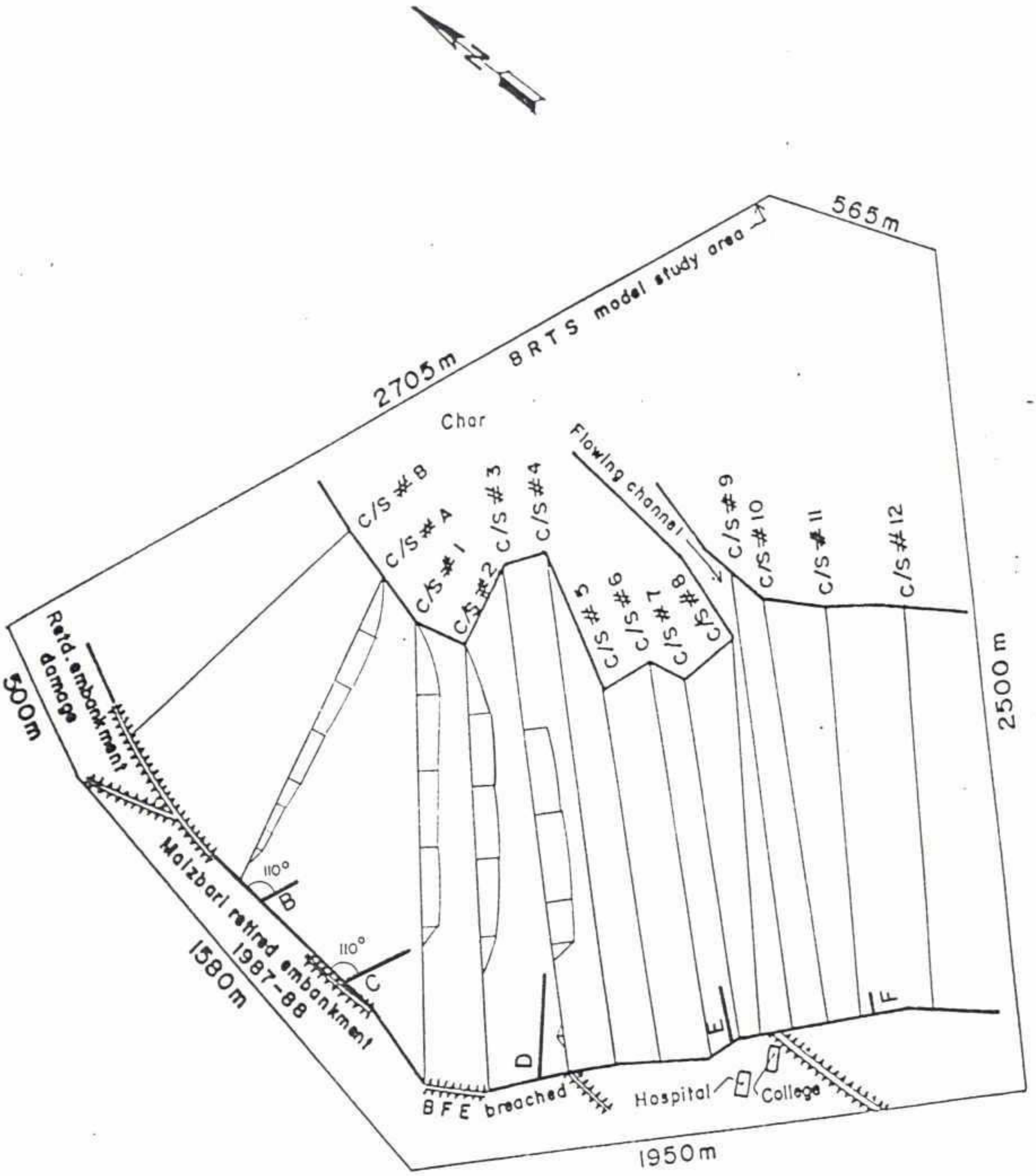
Fixed Bed

Five Groynes of Reduced Length

Angle of Groyne B = 110°

KAZIPUR PHYSICAL MODEL

Test no. 4B,	VELOCITY PROFILE WITH FIVE GROYNES	PHASE II FIGURE : 4.9

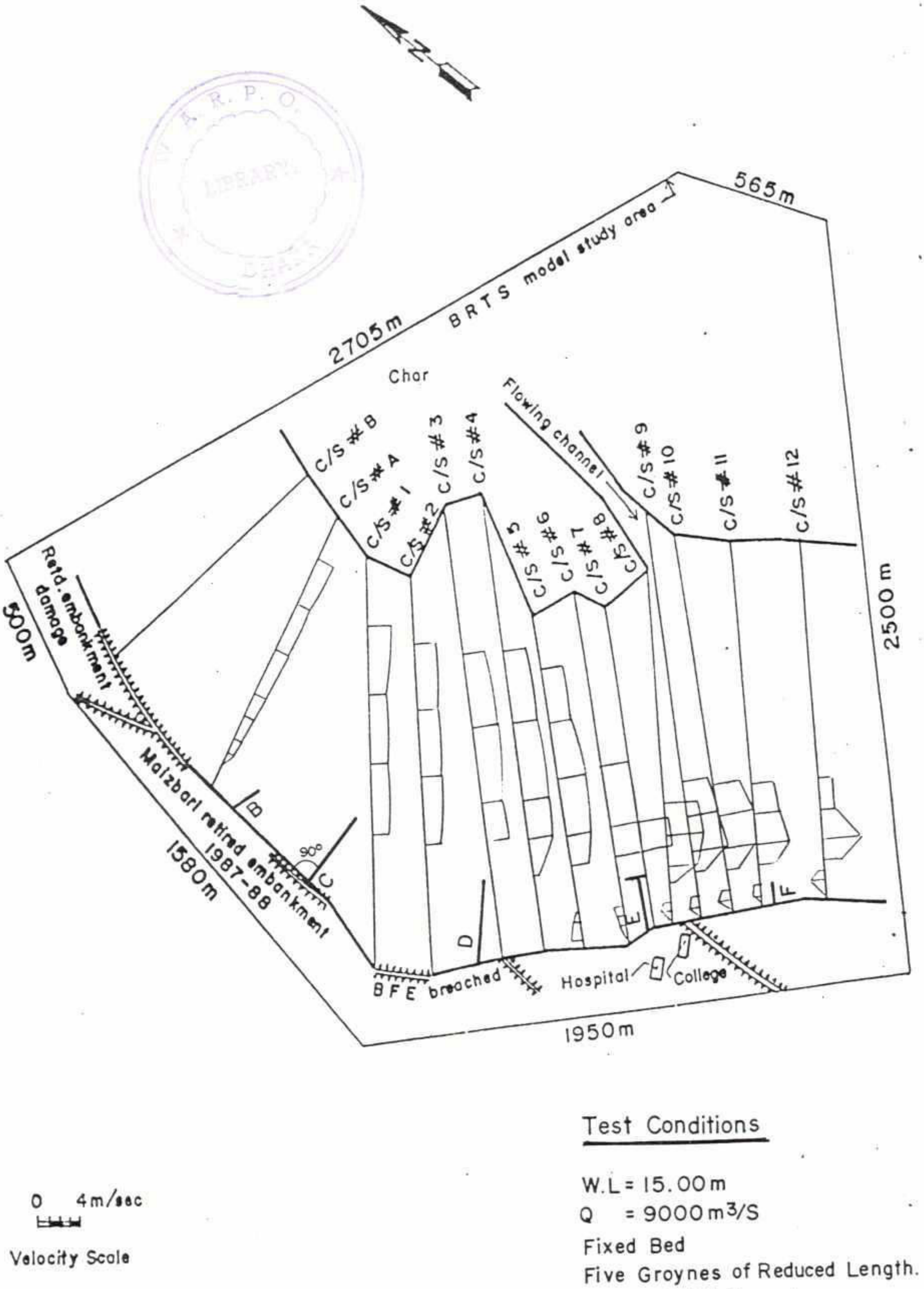


Test Conditions

W.L. = 15.00 m
Q = 9000 m^3/S
Fixed Bed
Five Groynes of Reduced Length
Angle of Groyne B & C = 110°

KAZIPUR PHYSICAL MODEL

Test no. 5A,	VELOCITY PROFILE WITH FIVE GROYNES	PHASE III
		FIGURE : 4.10



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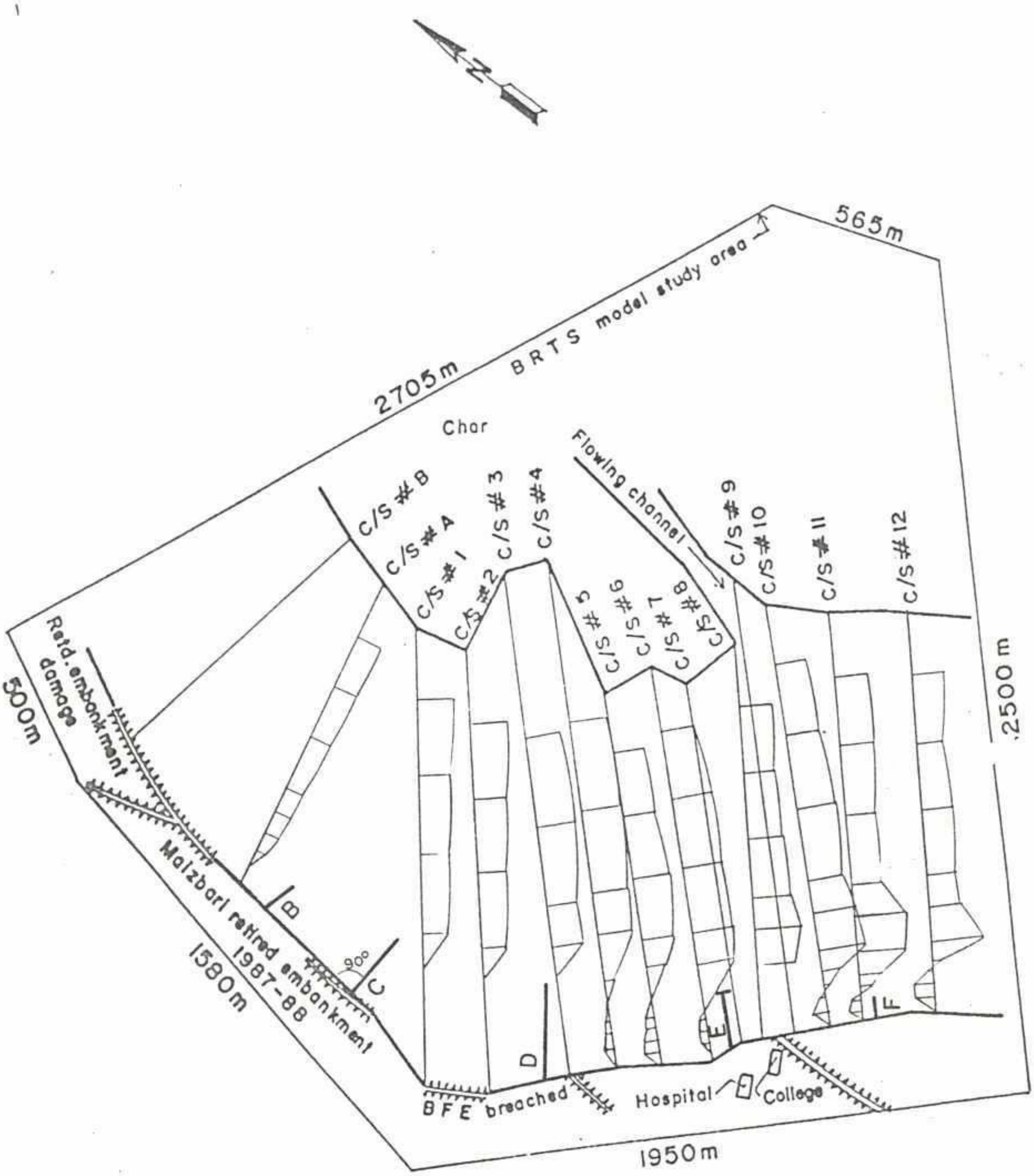
Test Conditions

W.L = 15.00 m
Q = 9000 m³/S
Fixed Bed
Five Groynes of Reduced Length.
Groyne E 'T' Shaped.
Angle of Groyne C = 90°

KAZIPUR PHYSICAL MODEL		
Test no. 6A,	VELOCITY PROFILE WITH FIVE GROYNES	PHASE III FIGURE : 4.11



0 4m/sec

Velocity Scale

Test Conditions

W.L.= 17.25m

Q = 17000 m^3/S

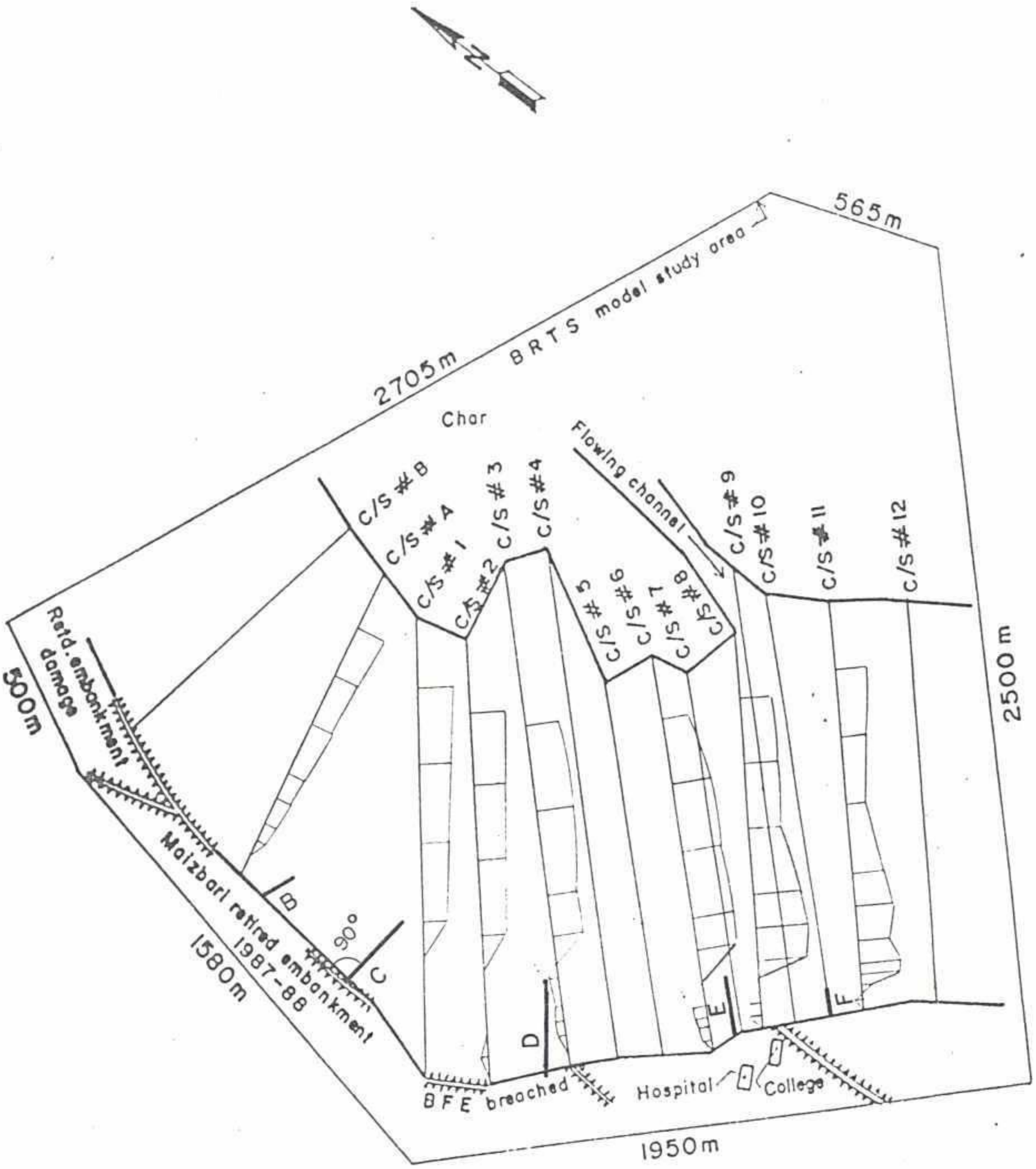
Fixed Bed

Five Groynes of Reduced Length

Groyne E 'T' Shaped

Angle of Groyne C= 90°

KAZIPUR PHYSICAL MODEL		
Test no. 6B,	VELOCITY PROFILE WITH FIVE GROYNES	PHASE III FIGURE : 4.12



0 4m/sec

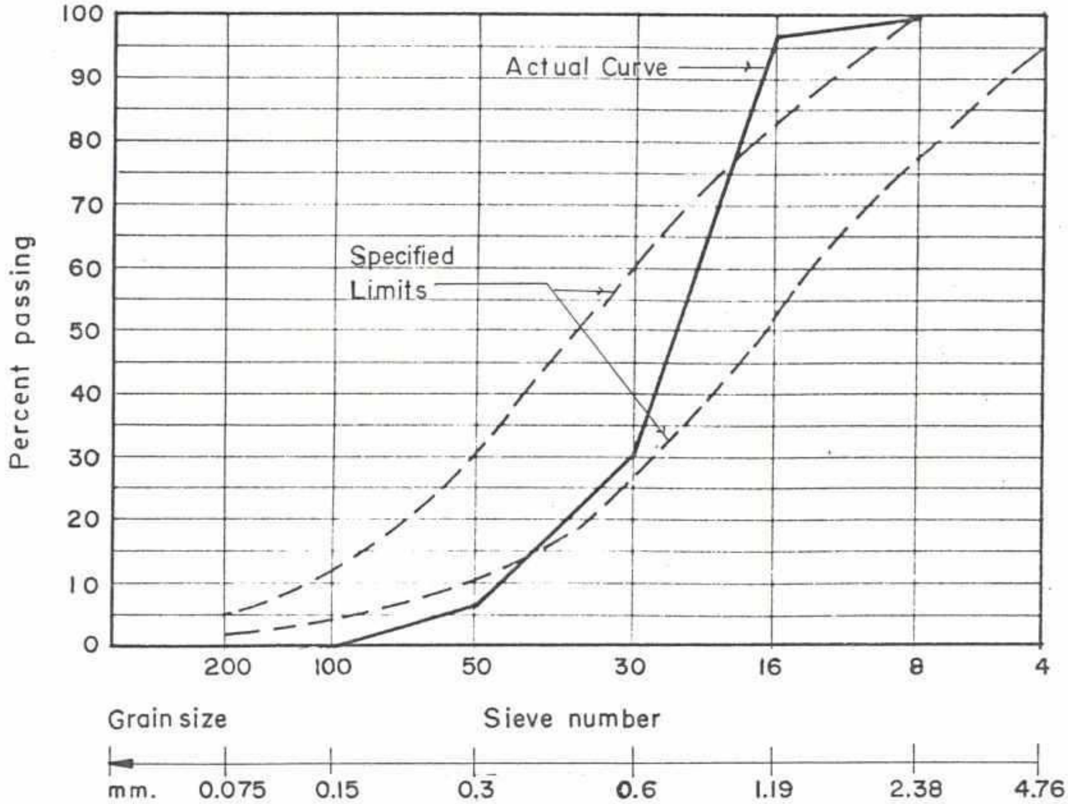
Velocity Scale

Test Conditions

W.L. = 17.25 m.
Q = 17000 m^3/S
Fixed Bed
Five Groynes of Reduced Length
Groyne F Shifted to C. S. 10.

KAZIPUR PHYSICAL MODEL

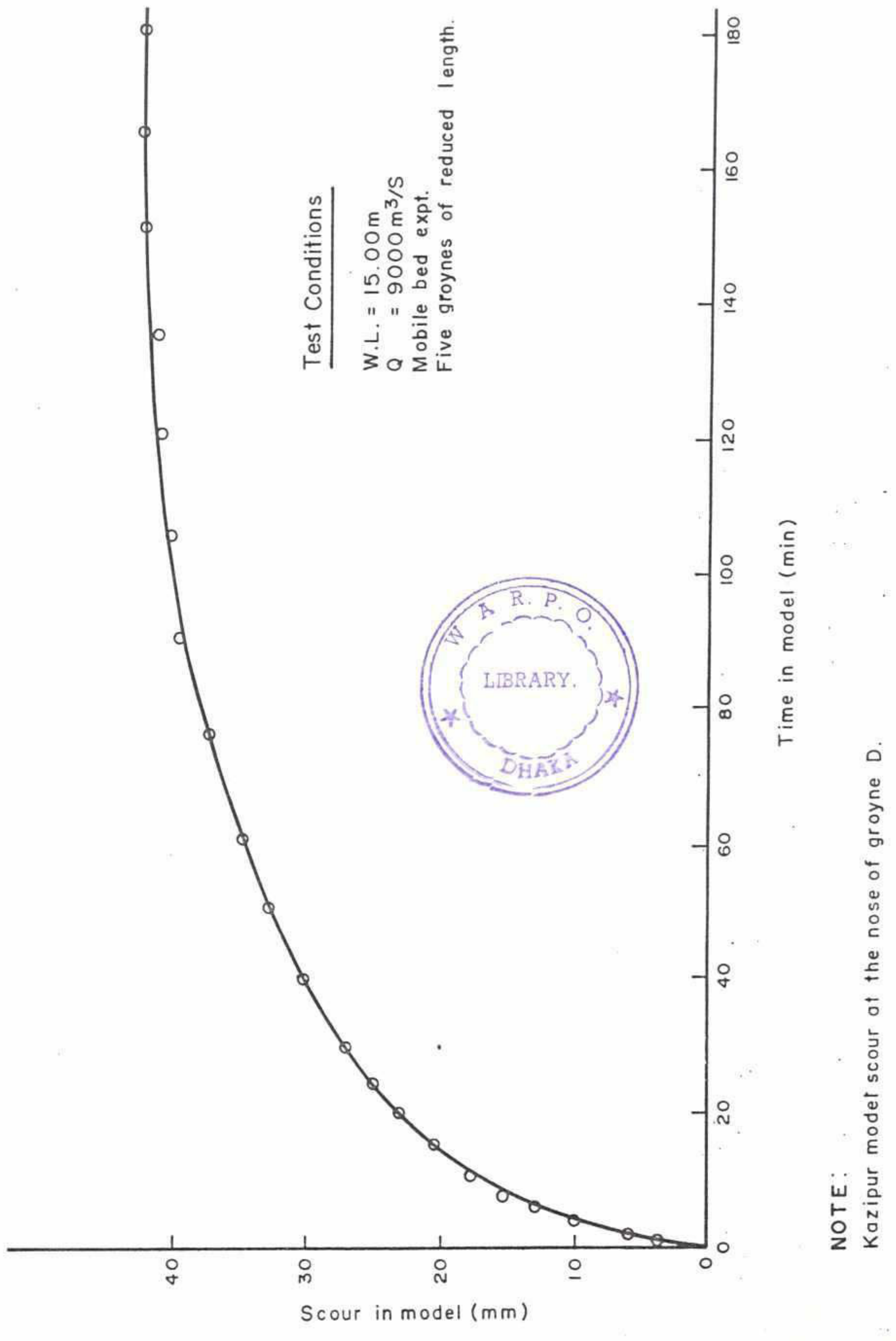
Test no. 7B,	VELOCITY PROFILE WITH FIVE GROYNES	PHASE III
		FIGURE : 4.13



Coal dust used for mobile bed model tests.

KAZIPUR PHYSICAL MODEL

COAL DUST GRAIN SIZE DISTRIBUTION	PHASE IV
	FIGURE : 5.1



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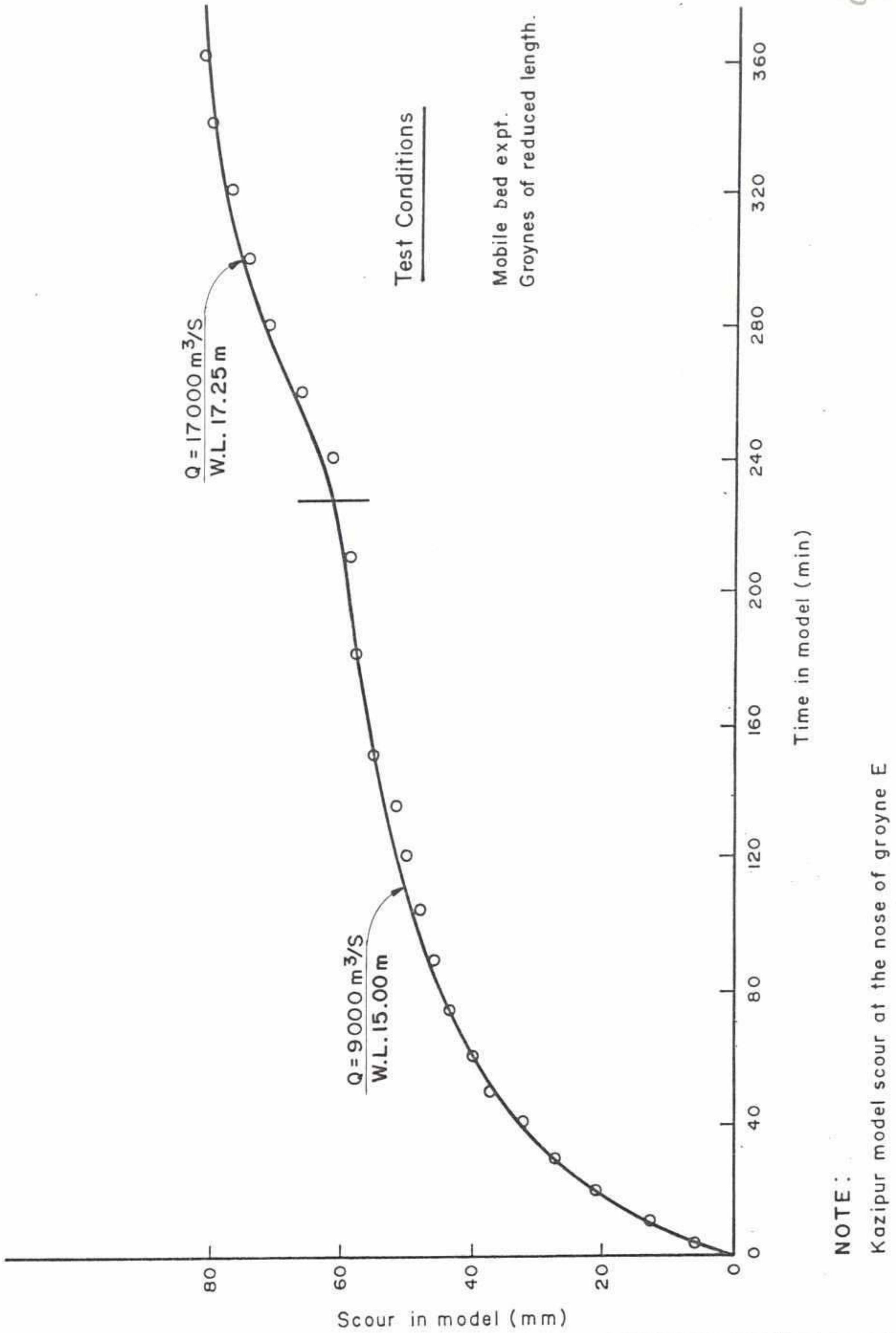
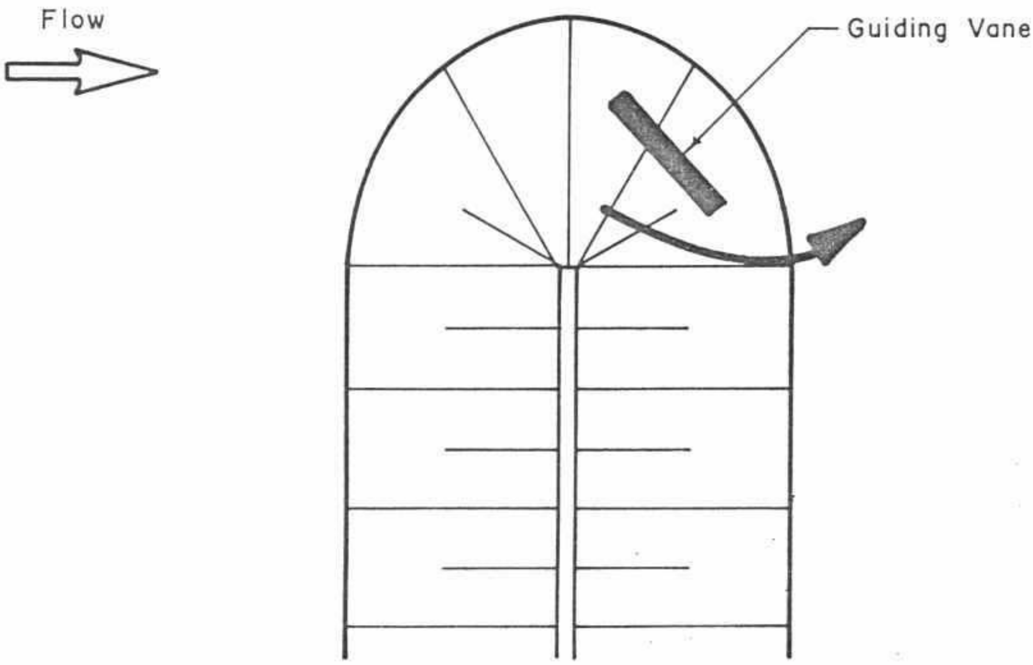
KAZIPUR PHYSICAL MODEL

Test no. 8, DEVELOPMENT OF SCOUR WITH TIME.	PHASE IV
	FIGURE : 5.2



KAZIPUR PHYSICAL MODEL

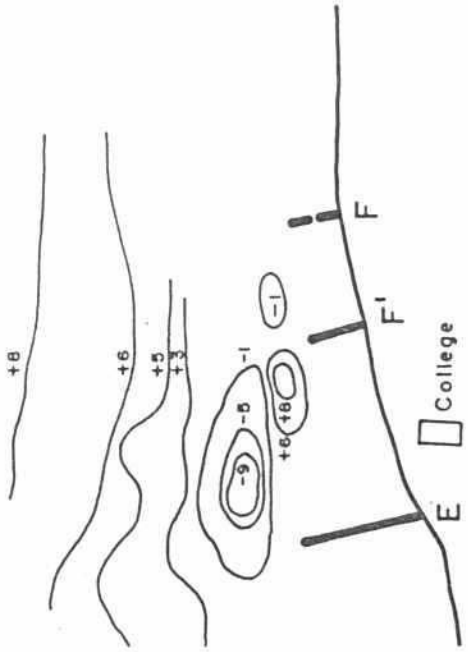
TEST No. 8-9, DEVELOPMENT OF SCOUR WITH TIME	PHASE IV
	FIGURE : 5.3



KAZIPUR PHYSICAL MODEL

Test no. 10,	GUIDING VANE AT THE NOSE OF GROYNE	PHASE IV
		FIGURE : 5.4

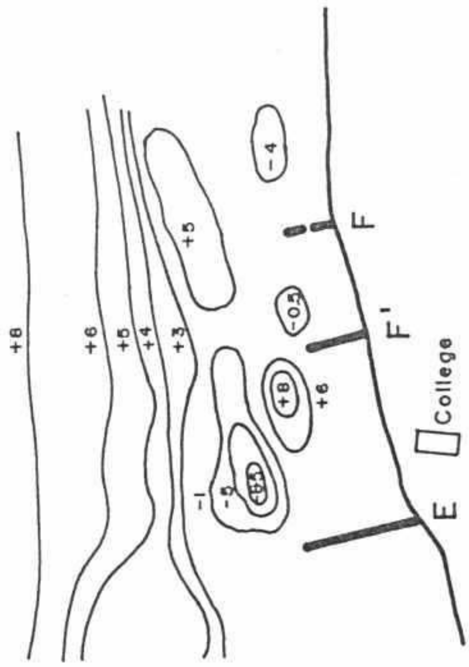
TEST No. 15



Test Conditions

W.L. = 17.25m
Q = 17000 m^3/S
Five Groynes
Groyne F at c/s-10
Test Duration 7 hours

TEST No. 13



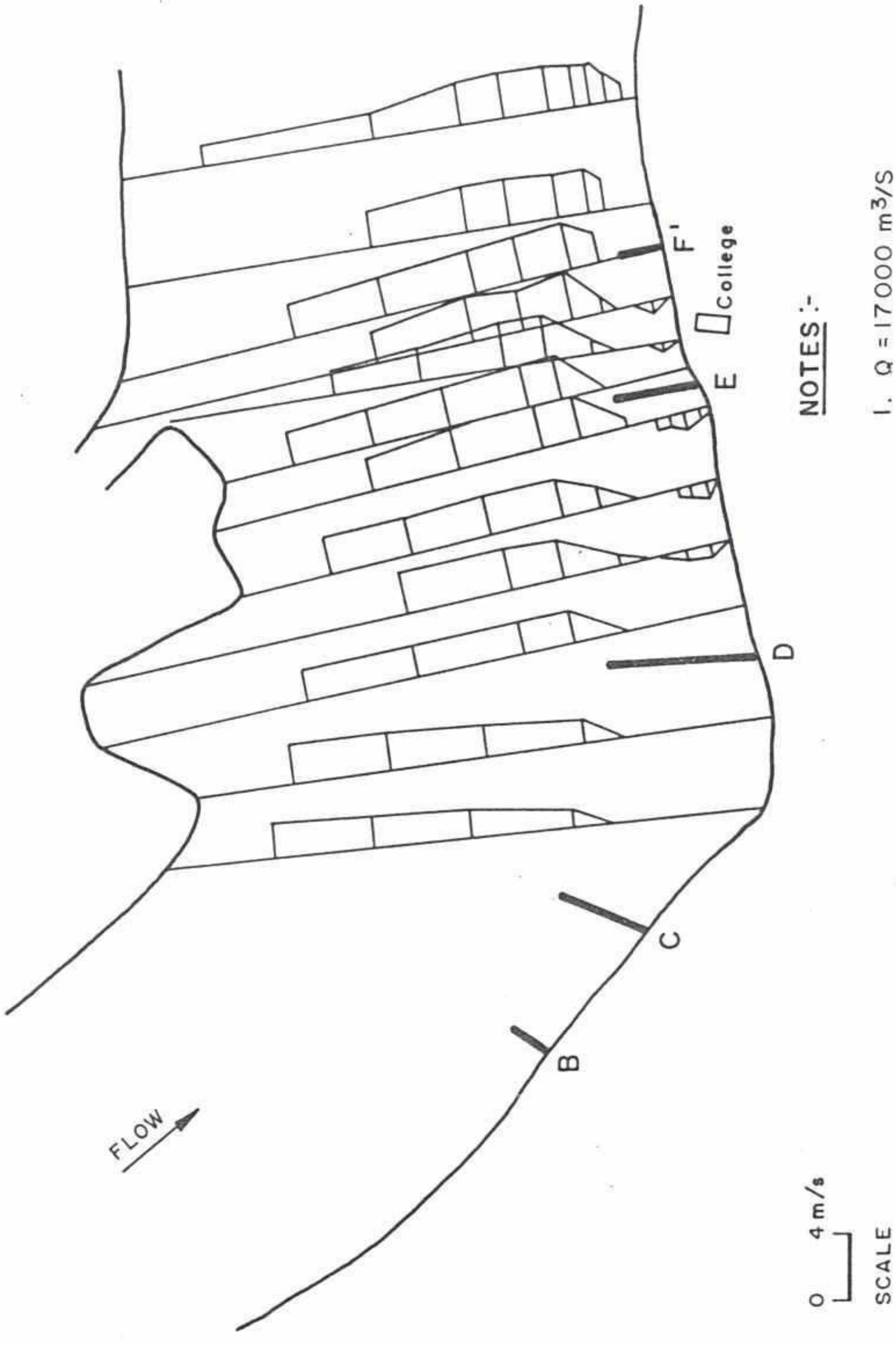
Test Conditions

W.L. = 16.25m.
Q = 14.500 m^3/S
Five Groynes
Groyne F at c/s-10
Test Duration 7 hours

NOTE: Test no. 13 and 15 were carried out with different water levels and flow discharges but the same average velocity.

KAZIPUR PHYSICAL MODEL

Test nos. 13 & 15, BED CONTOURS AFTER TEST	PHASE IV
	FIGURE : 5.5

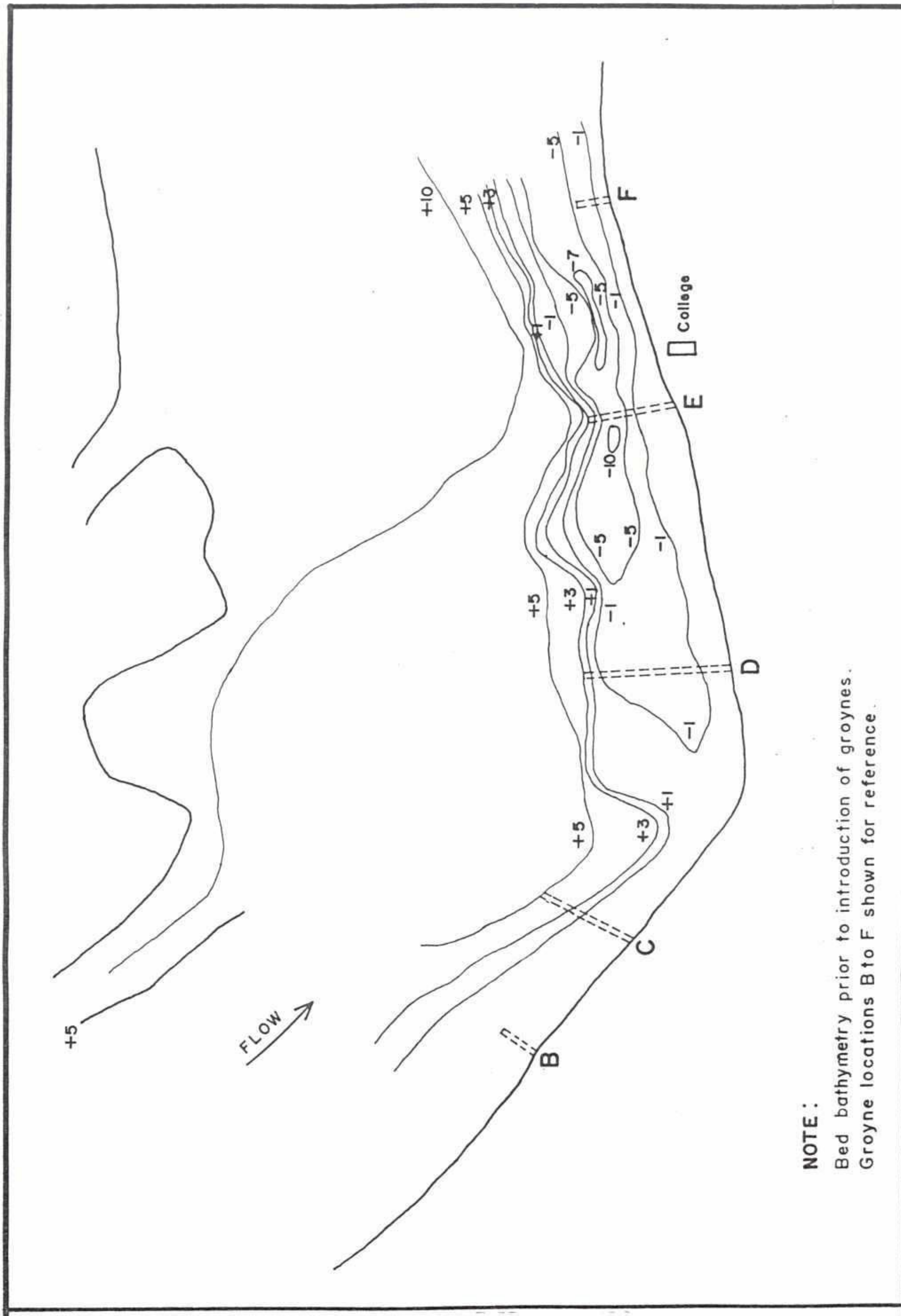


NOTES :-

1. Q = 17000 m^3/S
2. Velocity taken at half depth.
3. Measurement made after the scour/ deposition process had reached equilibrium.

KAZIPUR PHYSICAL MODEL

Test no.15,	VELOCITY PROFILES OVER SCOURED BED	PHASE IV FIGURE : 5.6



KAZIPUR PHYSICAL MODEL

REFERENCE BED TOPOGRAPHY OF KAZIPUR MODEL

PHASE IV

FIGURE : 5.7

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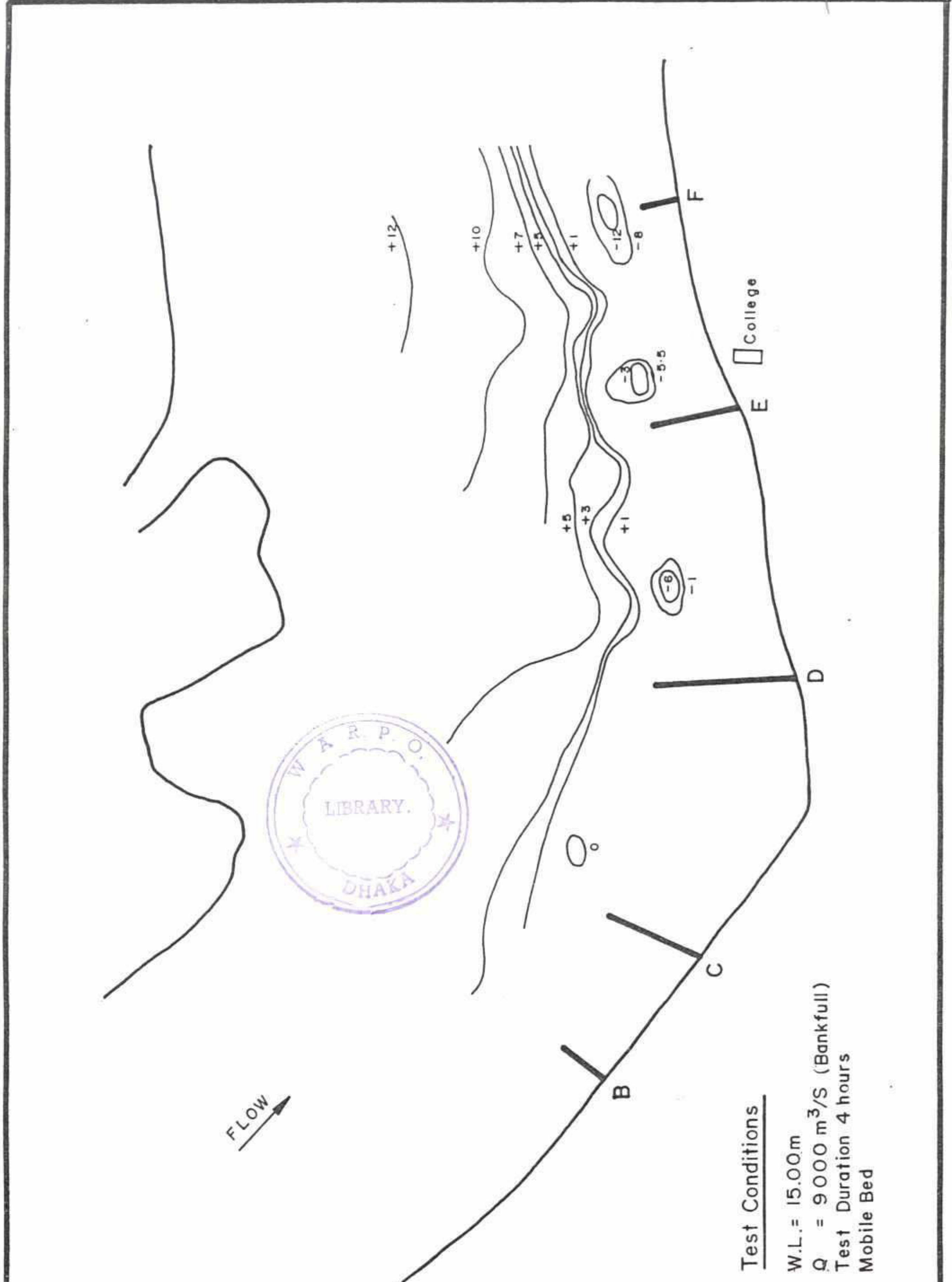

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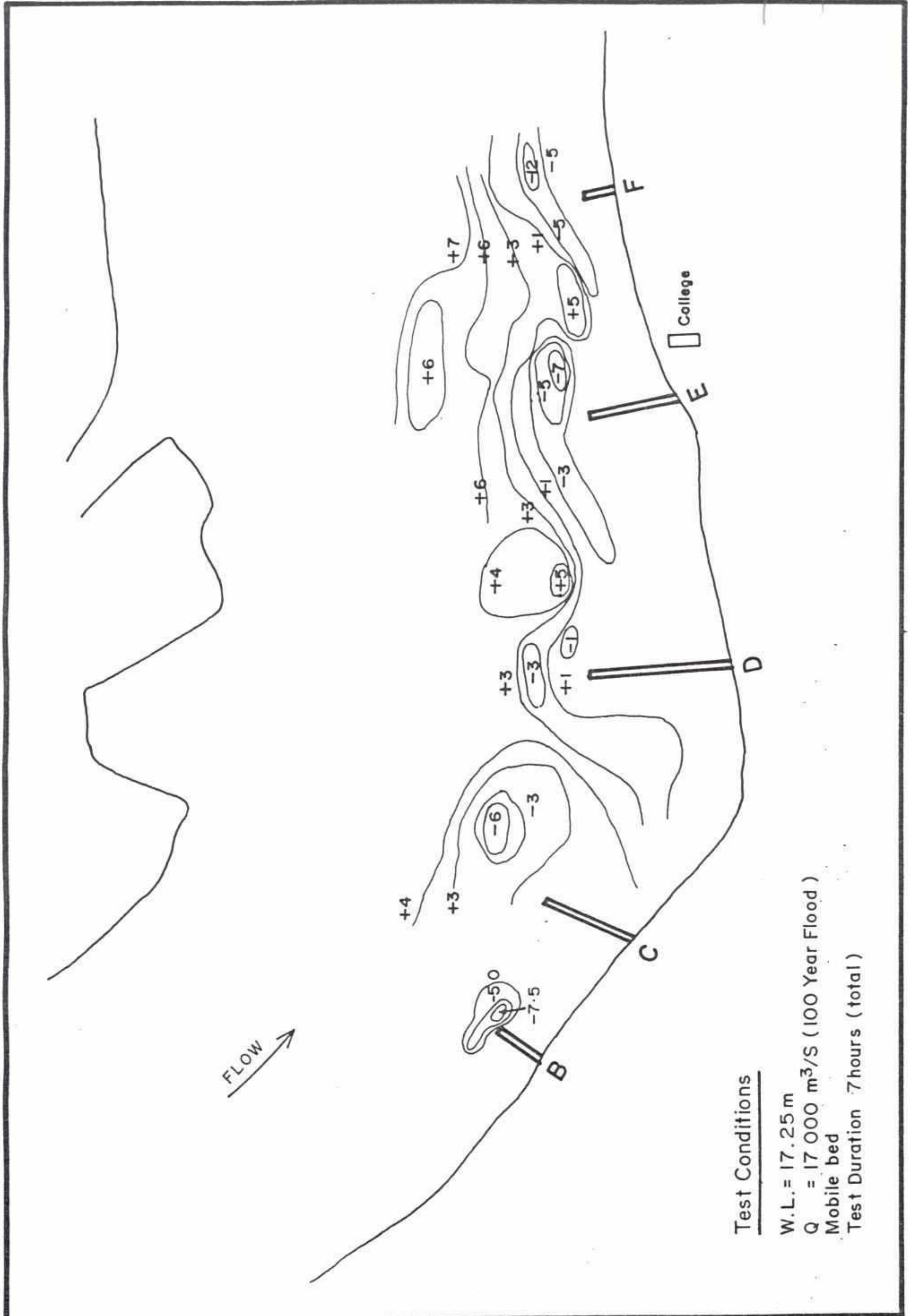
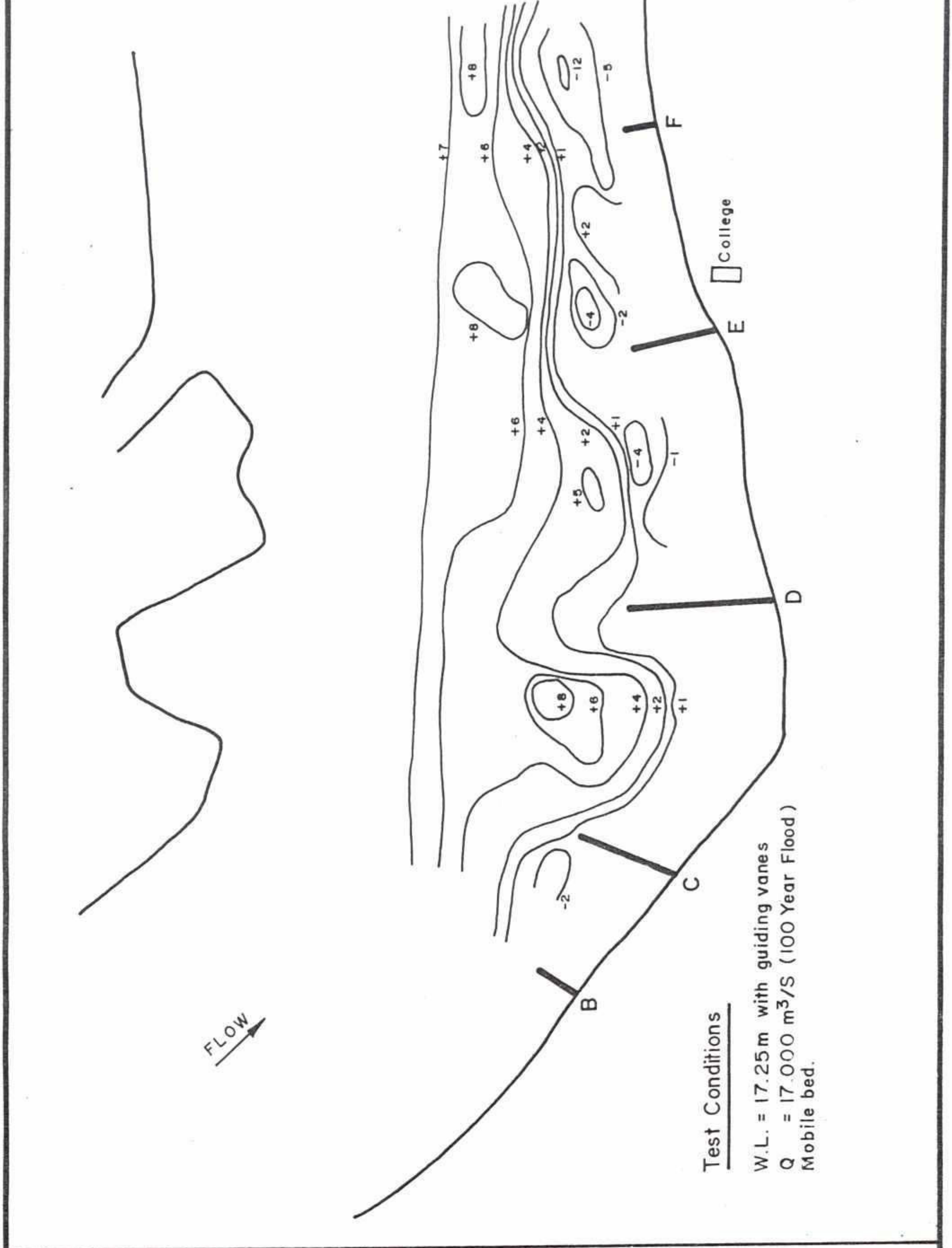
KAZIPUR PHYSICAL MODEL

Test no. 8,	CONTOUR LINES ON MOBILE BED AFTER TEST	PHASE IV
		FIGURE : 5.8



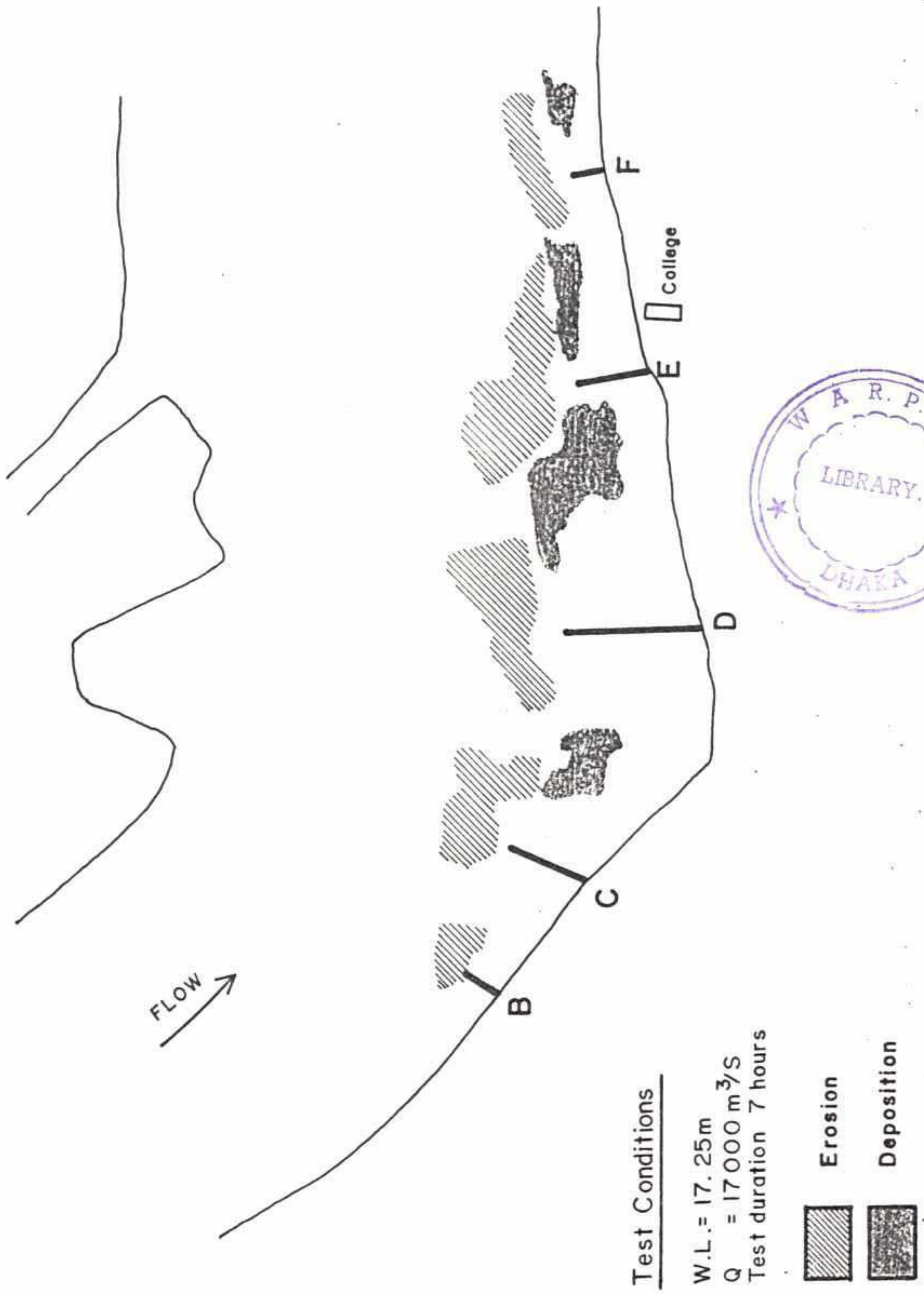
KAZIPUR PHYSICAL MODEL

Test no. 9,	CONTOUR LINES ON MOBILE BED AFTER TEST	PHASE IV
		FIGURE : 5.9



KAZIPUR PHYSICAL MODEL

Test no. 10,	CONTOUR LINES ON MOBILE BED AFTER TEST	PHASE IV
		FIGURE : 5.10



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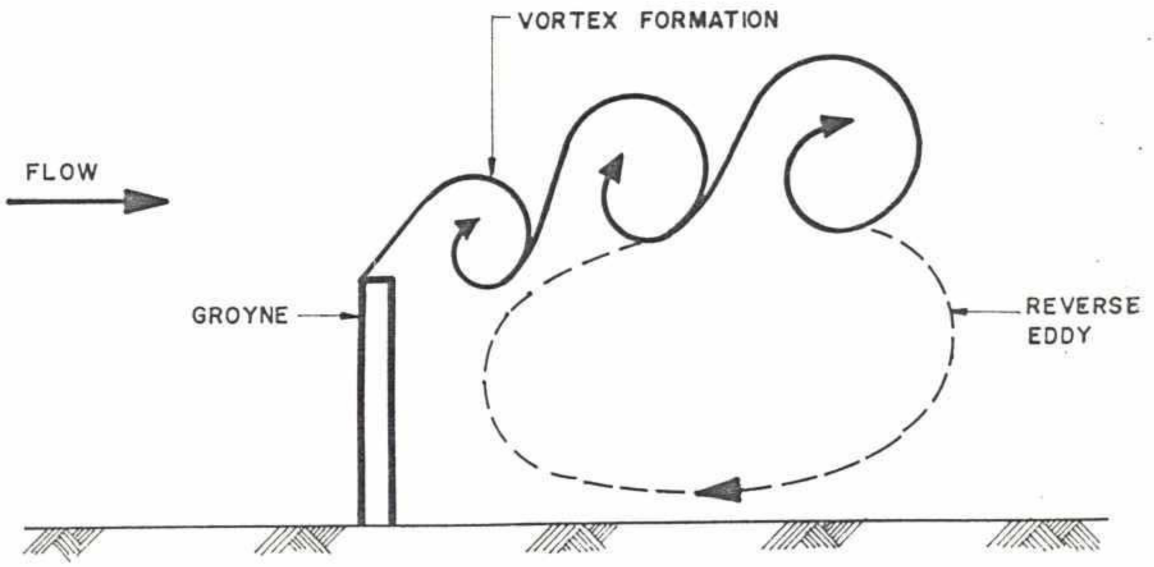
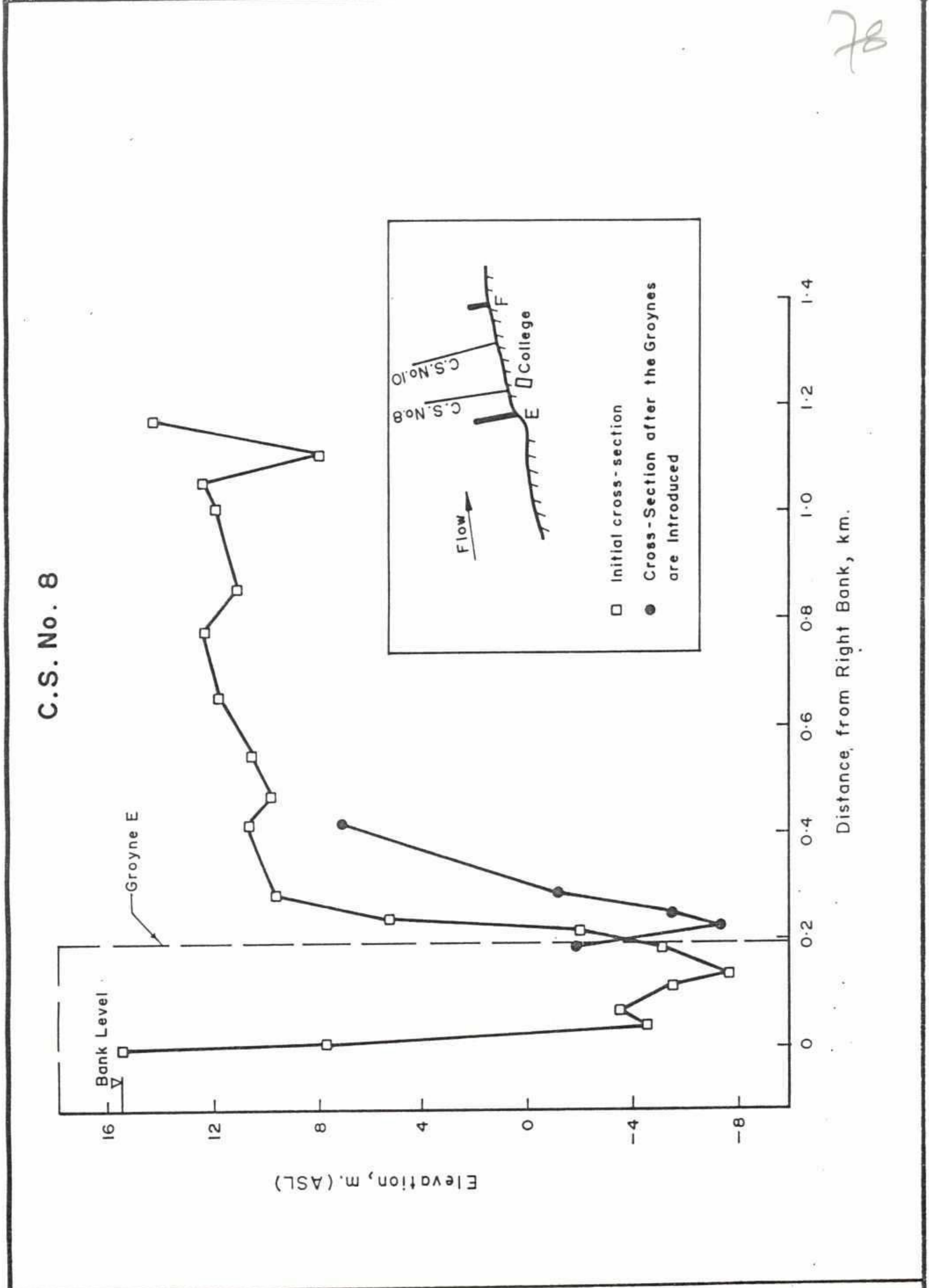
KAZIPUR PHYSICAL MODEL

Test no. 9, LOCATION OF SCOUR AND DEPOSITION	PHASE IV
	FIGURE : 5.11



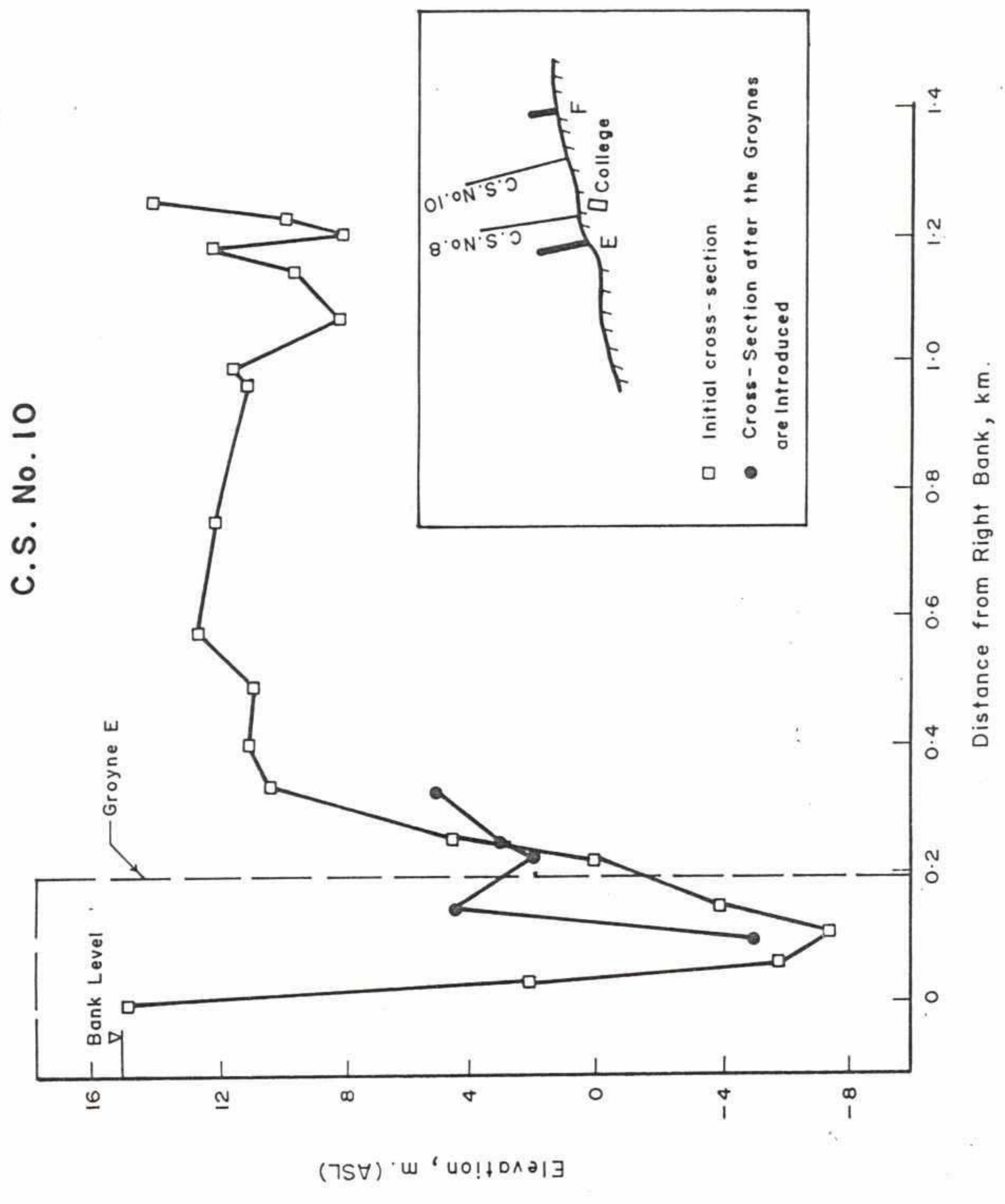
KAZIPUR PHYSICAL MODEL

VORTEX FORMATION AT THE DOWNSTREAM OF GROYNE	PHASE IV
	FIGURE : 5.12



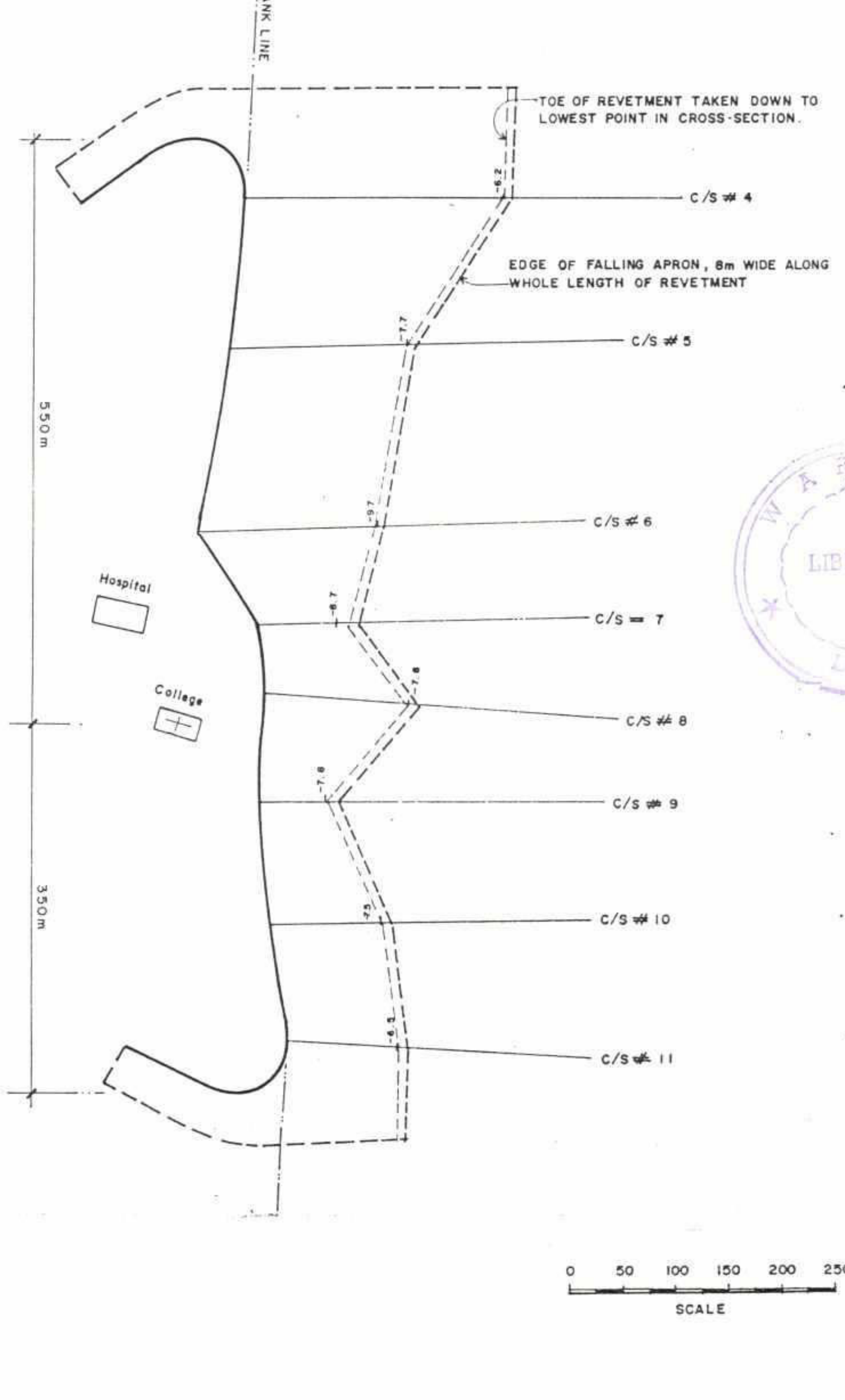
KAZIPUR PHYSICAL MODEL

CROSS-SECTION BEFORE AND AFTER INTRODUCING GROYNES	PHASE IV
	FIGURE : 5.13



KAZIPUR PHYSICAL MODEL

CROSS-SECTION BEFORE AND AFTER INTRODUCING GROYNES	PHASE IV
	FIGURE : 5.14



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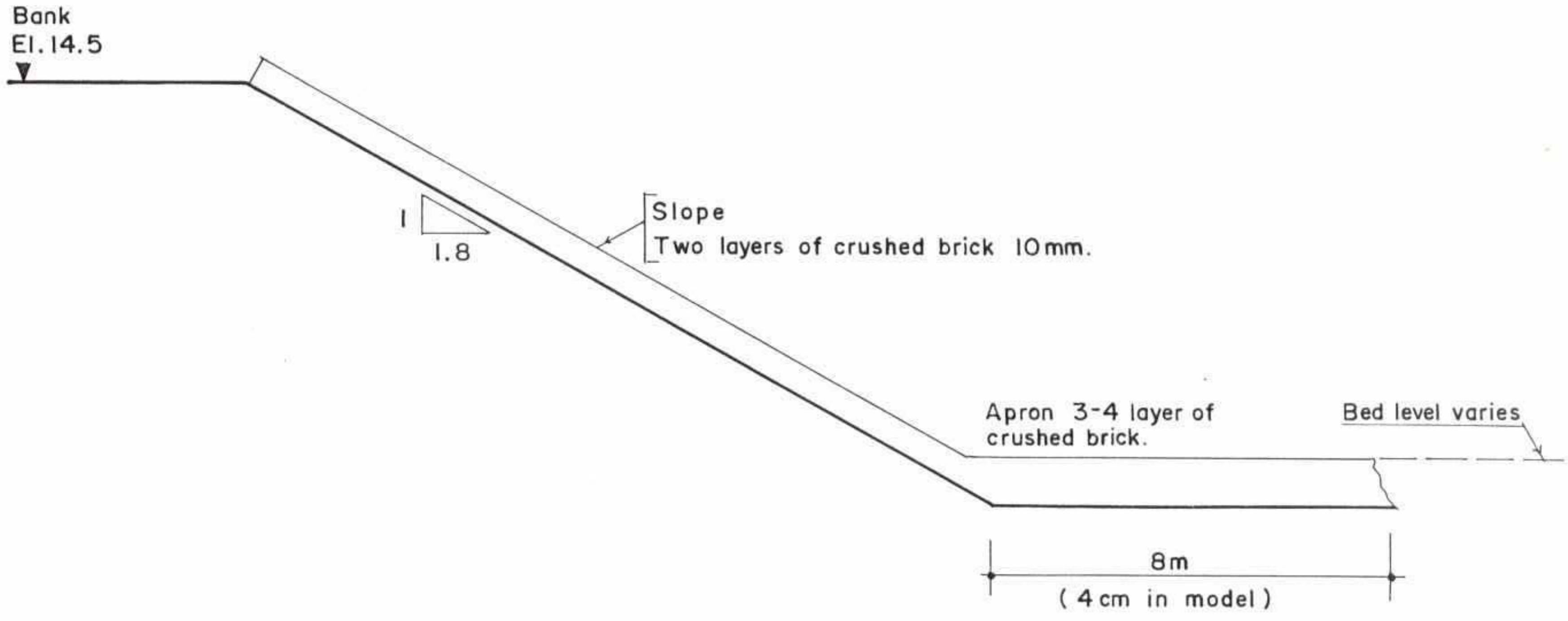
KAZIPUR PHYSICAL MODEL

REVETMENT TEST SERIES LAYOUT OF REVETMENT	PHASE V FIGURE: 6.1



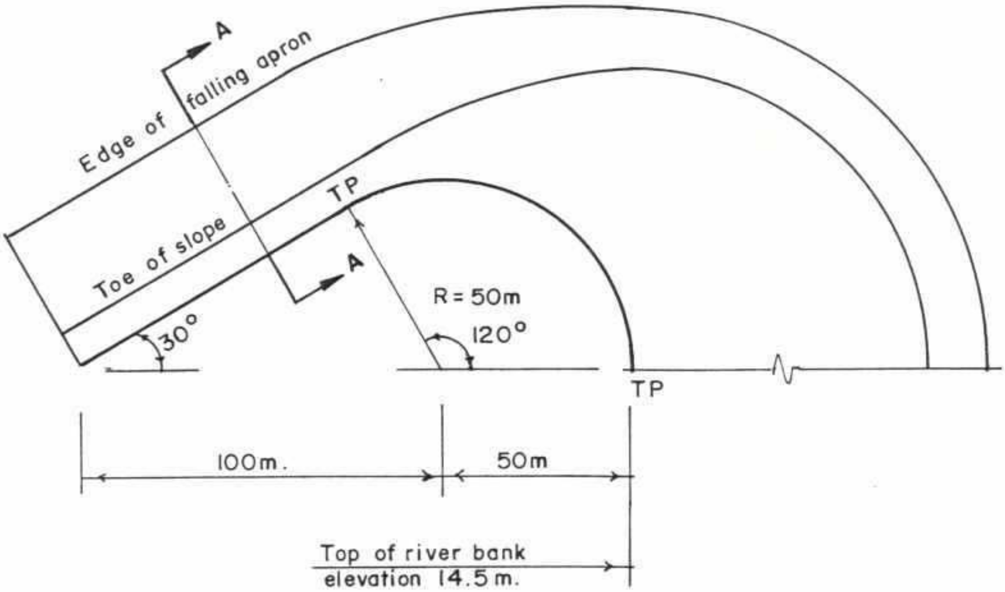
NOTE: Prototype slope assumed 1 : 30
With distorted model 1 : 200 horizontal and 1 : 120 vertical
The model slope of the revetment is 1 : 1.8

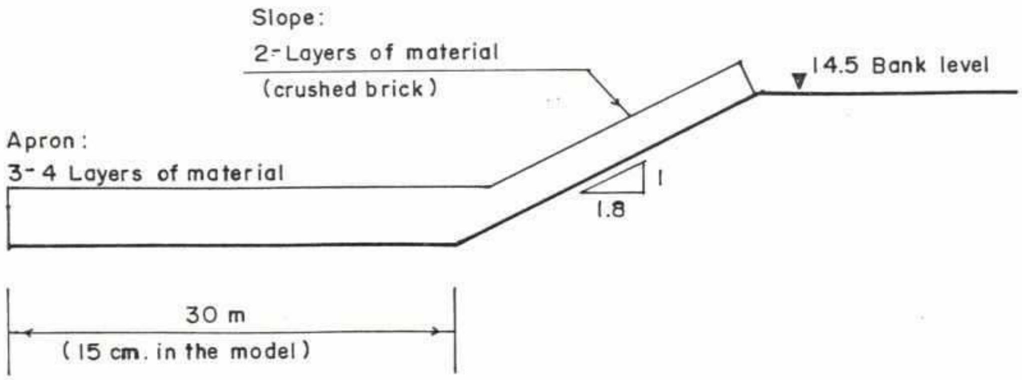
KAZIPUR PHYSICAL MODEL

REVETMENT TEST SERIES
CROSS-SECTION OF REVETMENT

Phase V

Figure : 6.2

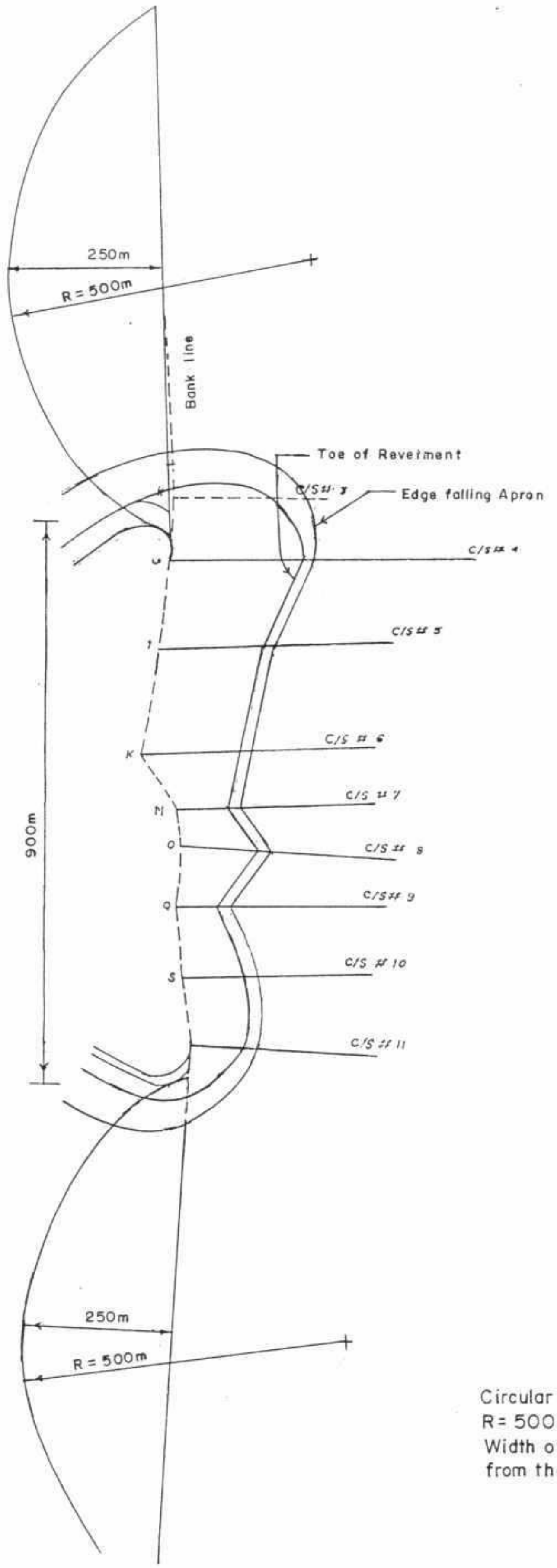




SECTION A-A
NOT TO SCALE

KAZIPUR PHYSICAL MODEL

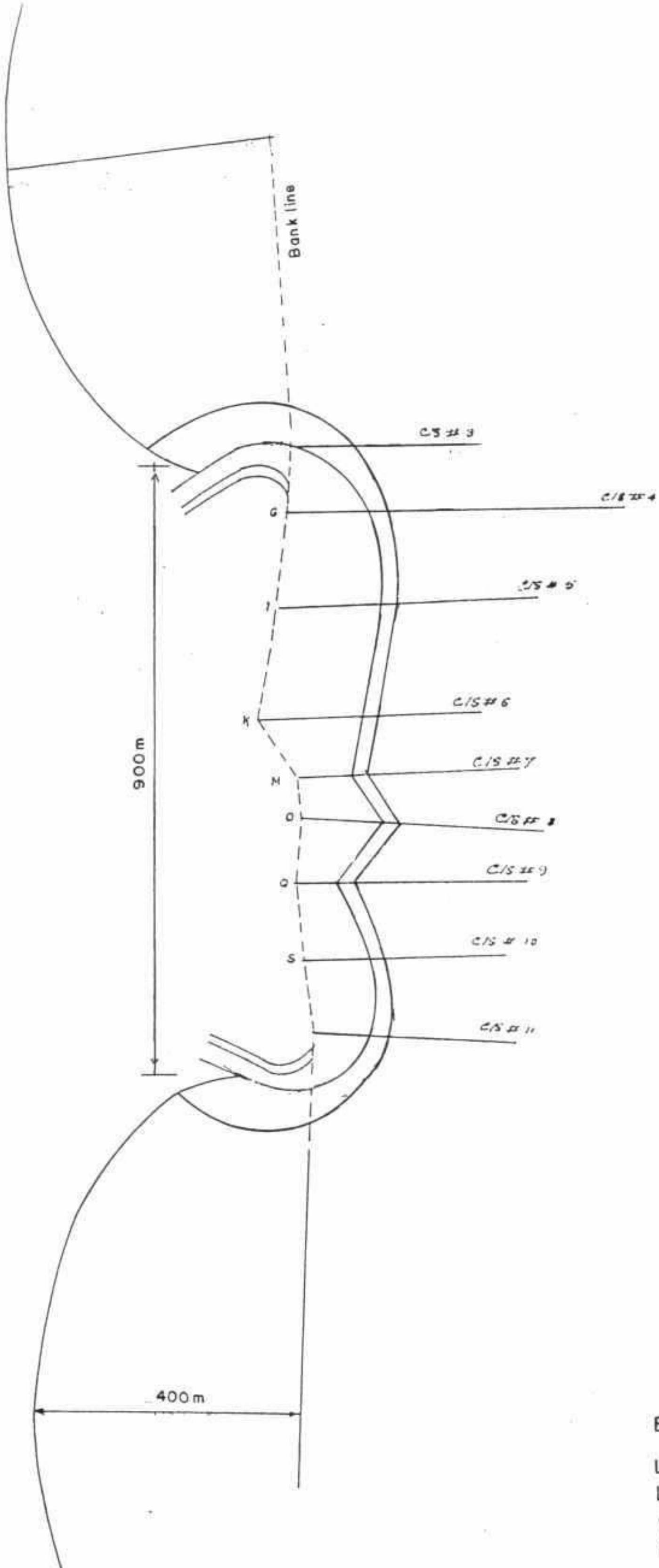
REVETMENT TEST SERIES: UPSTREAM AND DOWNSTREAM TERMINATION	Phase V
	Figure : 6.3



Circular Embayment Radius,
R = 500m.
Width of Penetration = 250m
from the bank line.

KAZIPUR PHYSICAL MODEL

Test no. 17, PLAN OF EMBAYMENT SHAPE - I	PHASE V
	FIGURE : 6.4

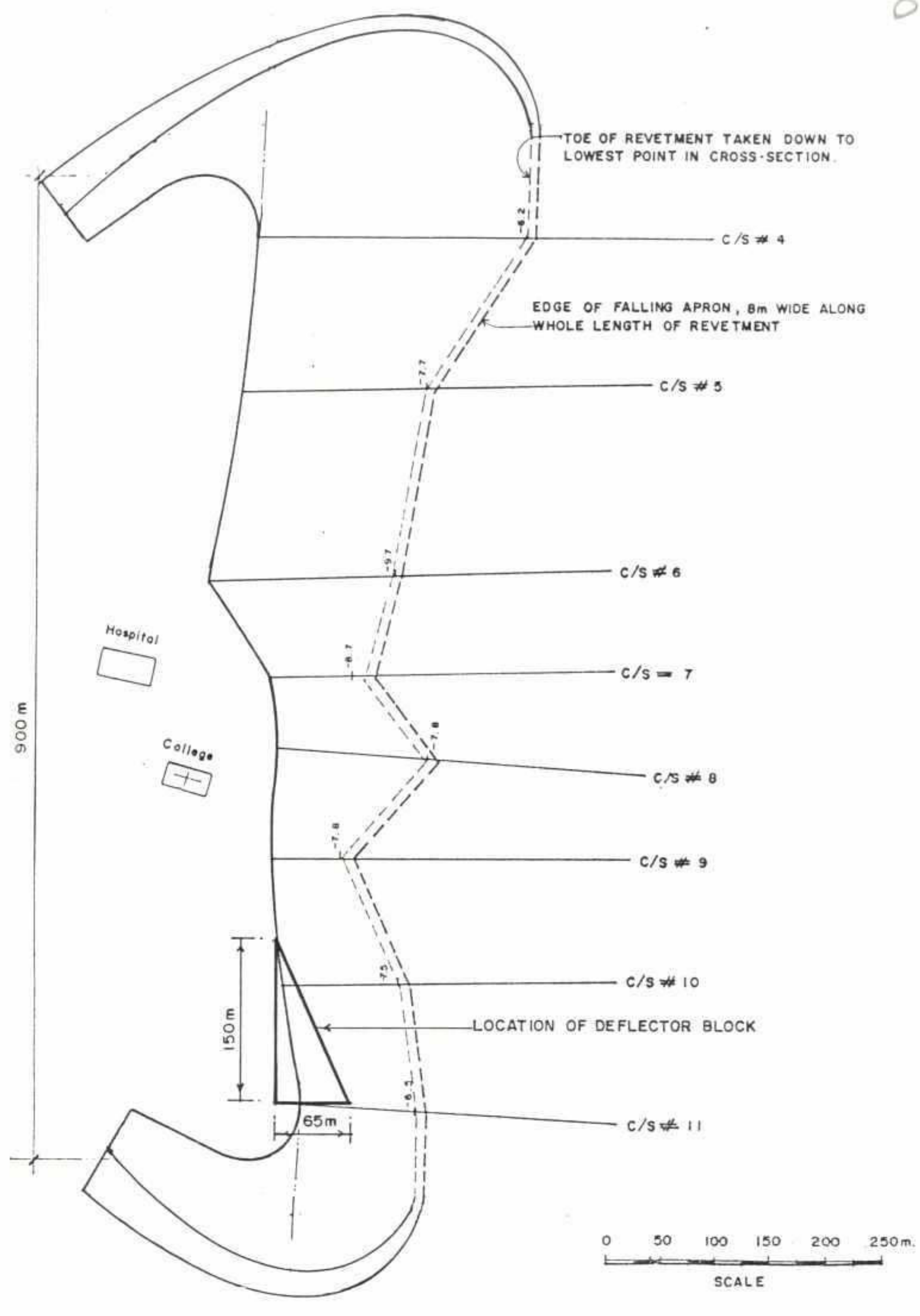


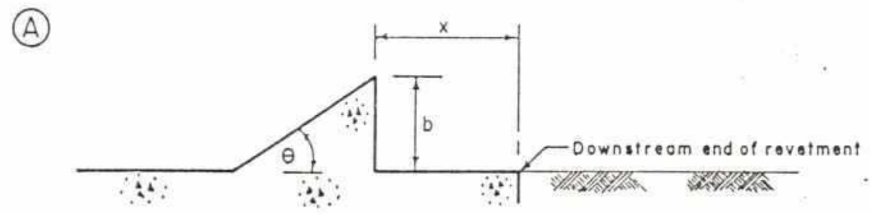
Elliptical Embayment

Length of Major axis = 940 m.
Length of Minor axis = 600m
Width of Penetration = 400m from the bankline.

KAZIPUR PHYSICAL MODEL

Test no. 18, PLAN OF EMBAYMENT SHAPE - II	PHASE V
	FIGURE : 6.5





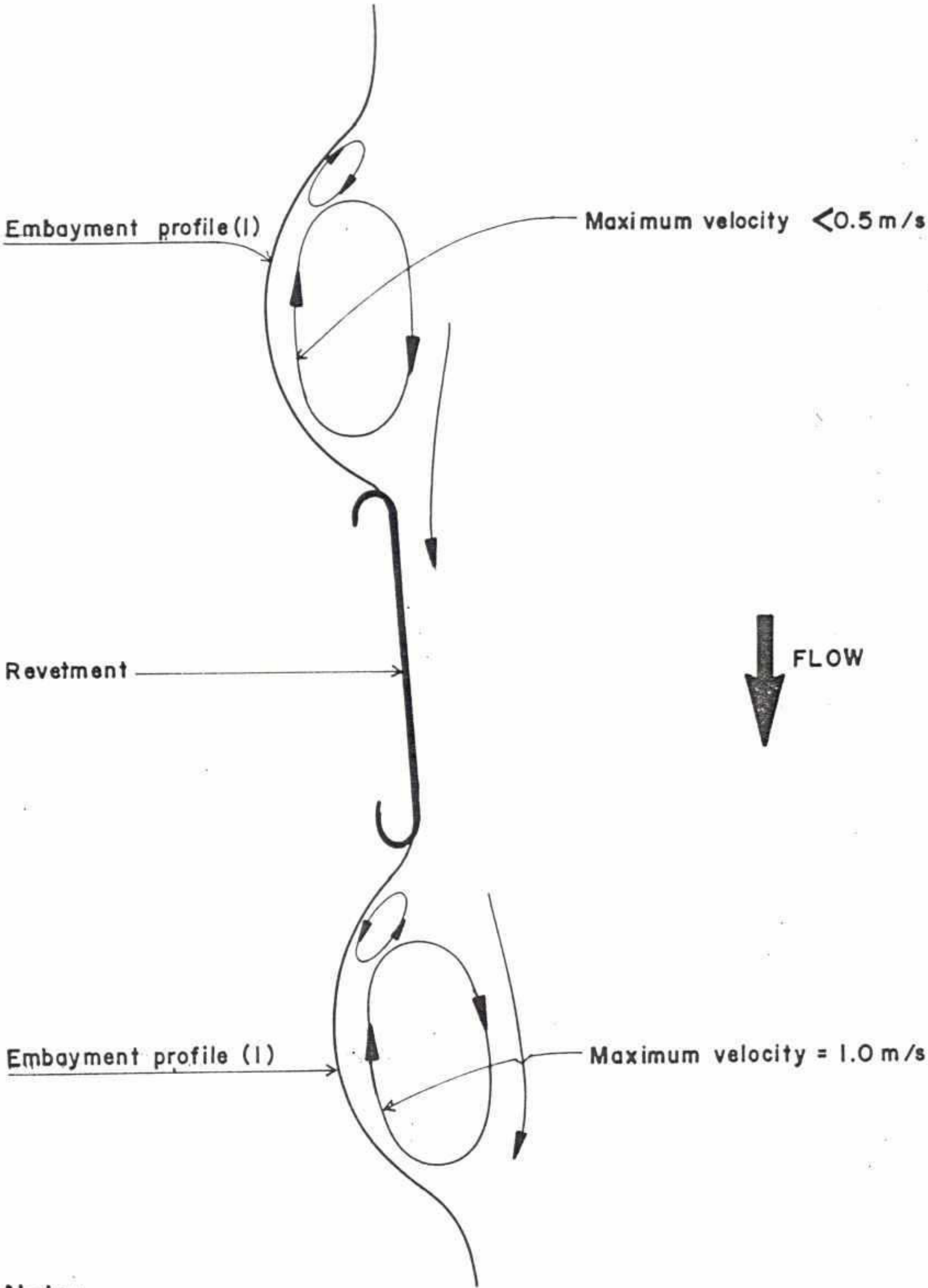
Variables : x = 0

b = 65m

θ = 23°

KAZIPUR PHYSICAL MODEL

Test no. 19 REVETMENT TEST SERIES PLAN OF DEFLECTOR BLOCK	Phase V
	Figure : 6.6

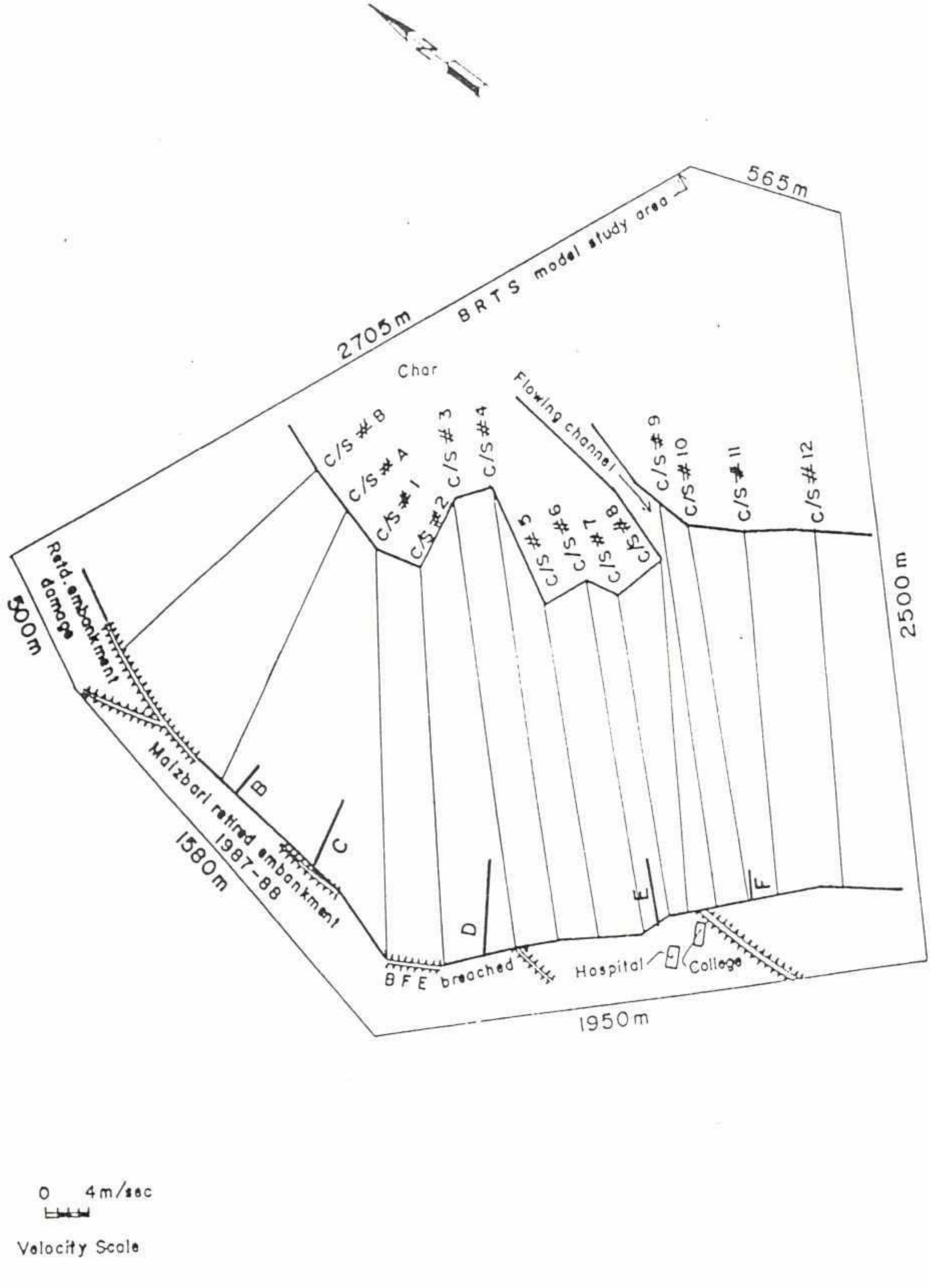


Note:

The bank along the embayments remained intact.

KAZIPUR PHYSICAL MODEL

Test no. 17,	EMBAYMENT SHAPE-I REVERSING EDDY IN EMBAYMENTS	PHASE V FIGURE : 6.7



KAZIPUR PHYSICAL MODEL

FINAL LOCATION AND LENGTH OF GROYNES

FIGURE: 7.1

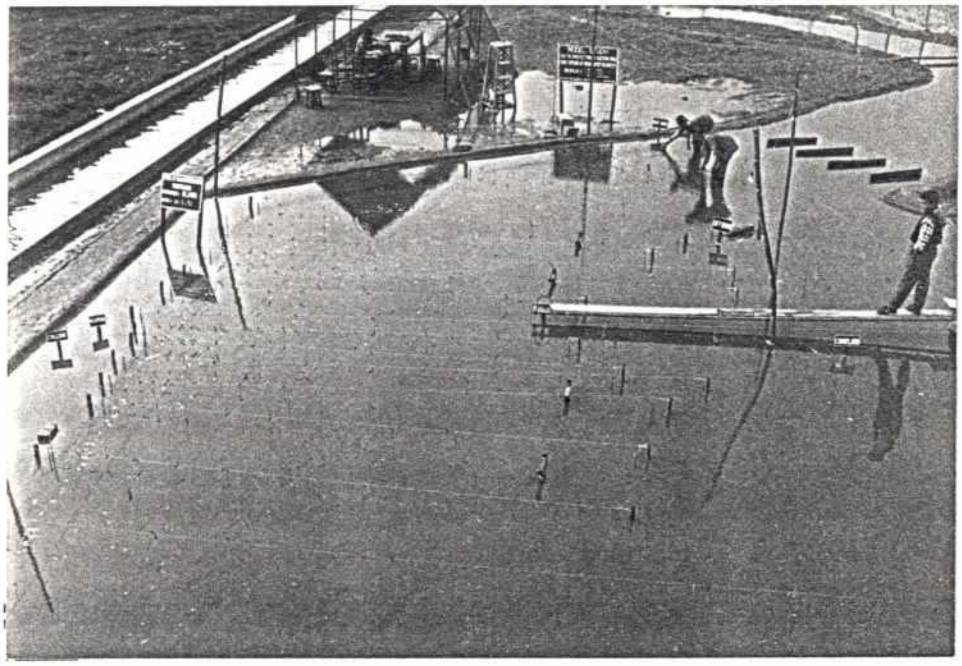


Photo 1. Test 1C, Flow Measurements
100-years Flood Looking Upstream

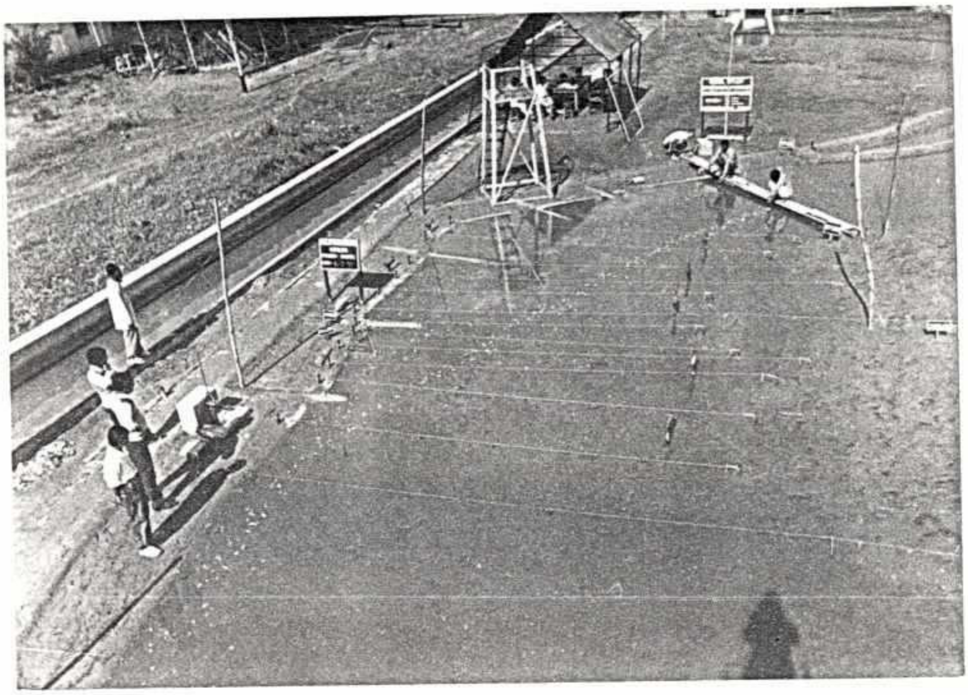


Photo 2. Test 3A, Flow Measurements
Bankfull discharge, Five groynes

	KAZIPUR PHYSICAL MODEL	
Photos.	Tests 1C and 3A	Plate 1

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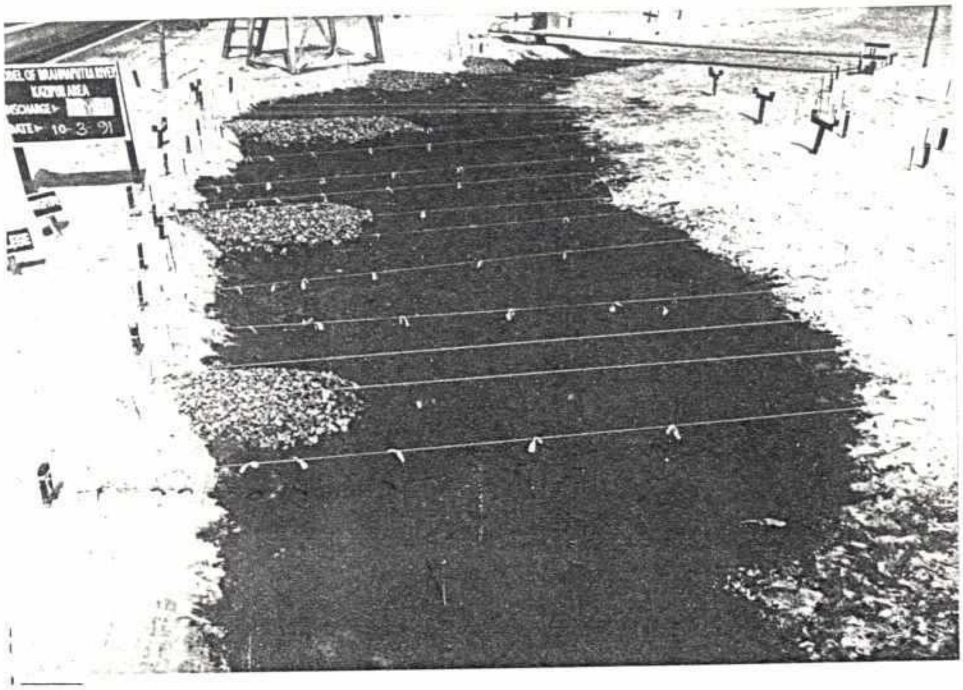

Photo 3. Before Test: Dry bed before mobile bed experiment with five groynes of reduced lengths

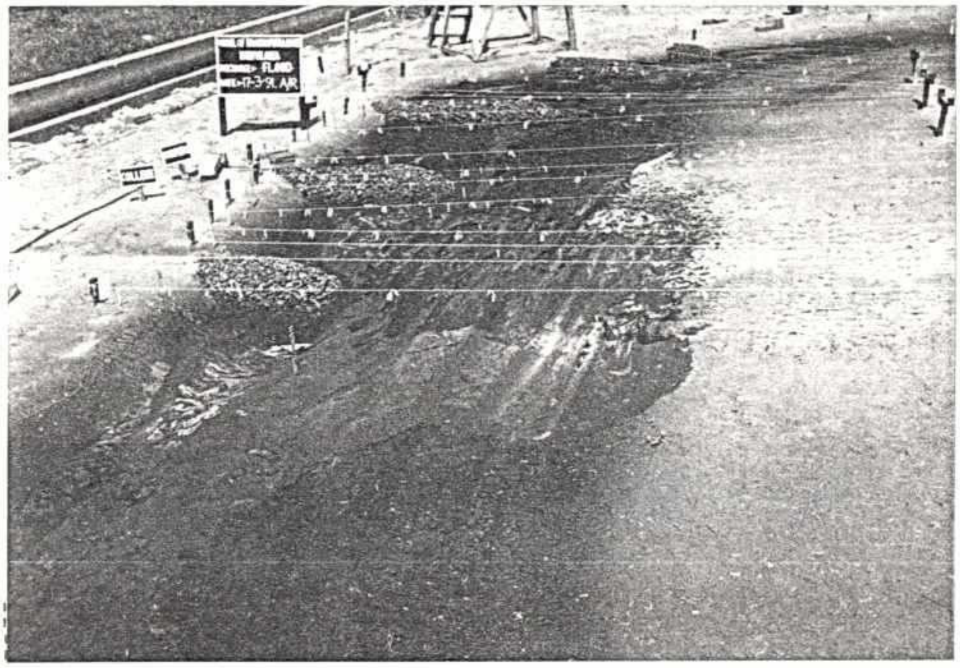

Photo 4. After Test 9: Bed condition after running 100-years flood discharge over mobile bed

	KAZIPUR PHYSICAL MODEL	
Photos.	Tests 9	Plate 2

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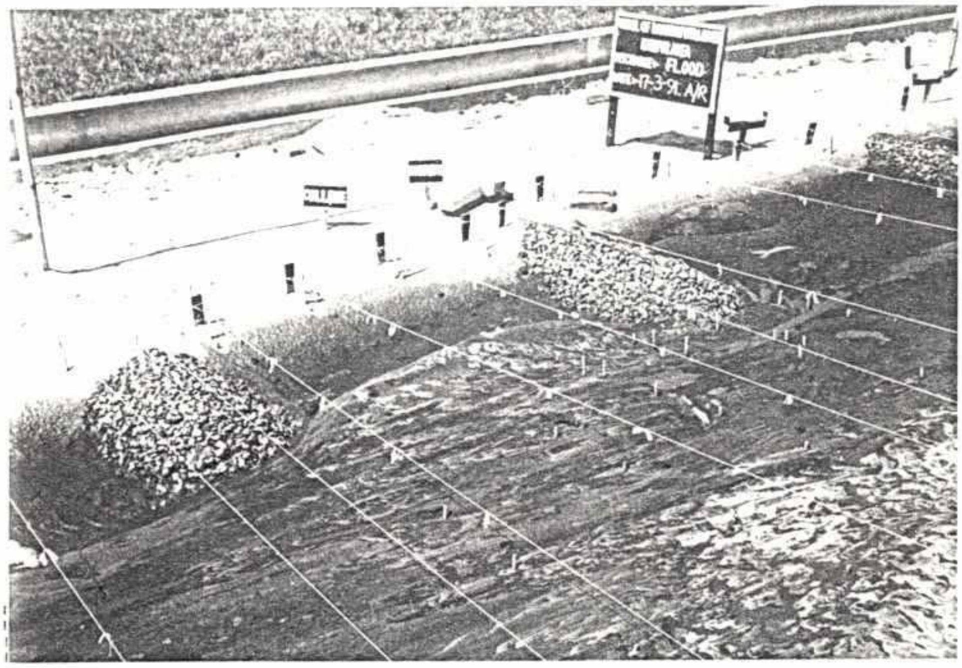

Photo 5. Test 9: Bed condition after running 100-years flood discharge (close view) showing the point of maximum scour at nose of Groyne E off the Hospital

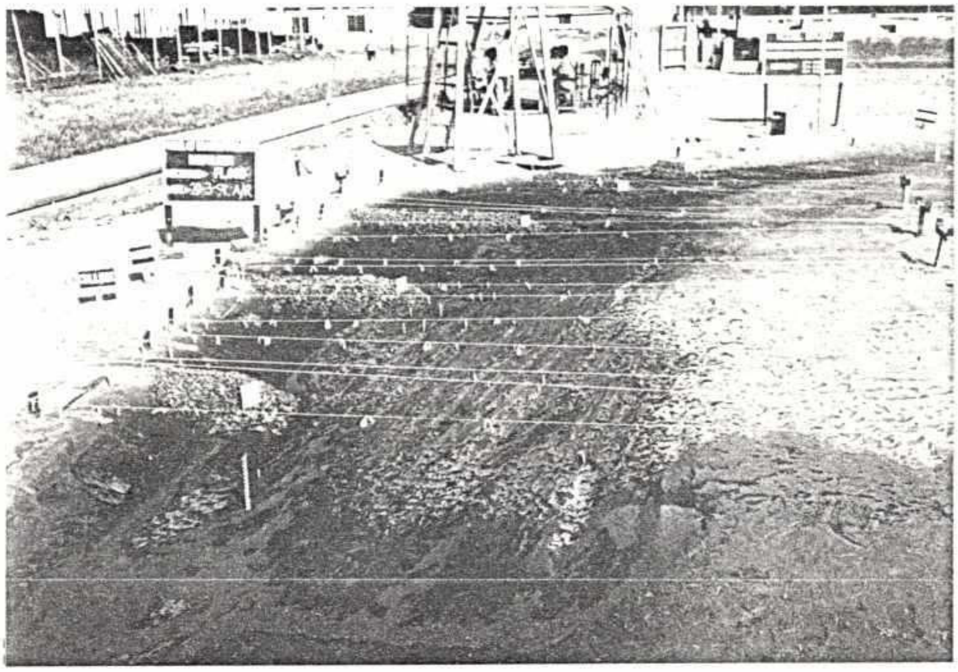

Photo 6. Test 10: Guiding vanes, placed at the nose of groynes

KAZIPUR PHYSICAL MODEL	
Photos. Tests 9 and 10	Plate 3

Photo 7. Test 16B: 100-years Flood discharge test with rounded-end revetment

Photo 8. Test 16A: Bed condition after test with rounded end revetment

	KAZIPUR PHYSICAL MODEL	
Photos.	Tests 16A and 16B	Plate 4

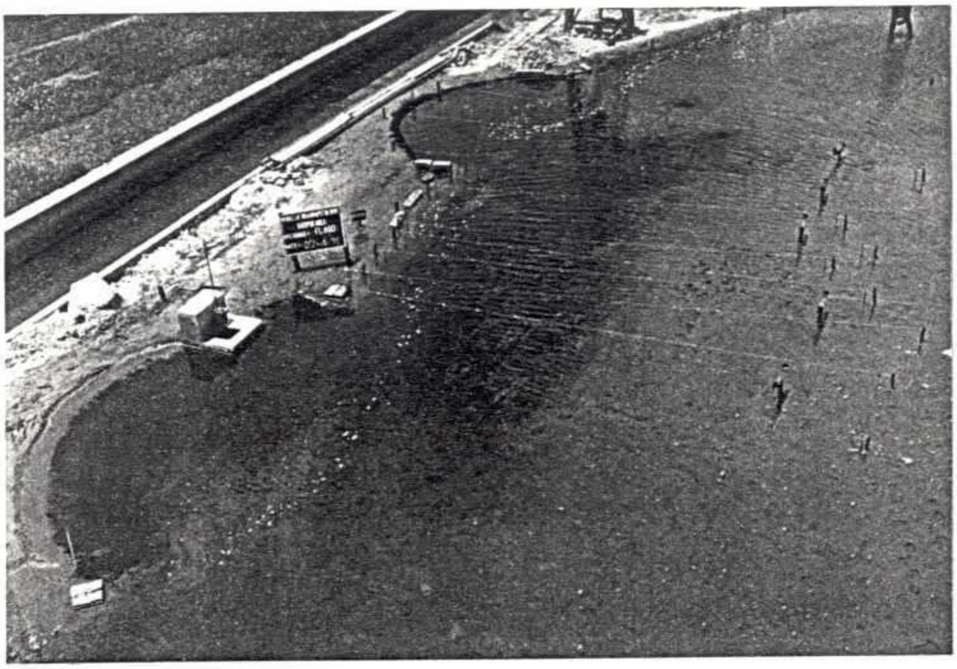

Photo 9. Test 18: Flow conditions with artificial embayment Shape-2, 100-years flood discharge

Photo 10. Test 19: Flow condition with deflector at the downstream end of the revetment, 100-years flood discharge

	KAZIPUR PHYSICAL MODEL	
Photos.	Tests 18 and 19	Plate 5

Appendix I
BRTS (Kazipur)

Velocity profile along the cross-sections for the bankfull discharge
(9000 m^3/s ; proto) without protective works

C.S. No. and top width in meter	Distance from the right bank in meter (Pr)	Proto velocity in meter/sec at the depth of			Remarks
		.2D	.5D	.8D	
1	2	3	4	5	6
	50.0	0.69	0.68	0.66	Velocity was taken at verticals after $\frac{1}{18}, \frac{1}{18}, \frac{1}{18}, \frac{1}{12}, \frac{1}{12}, \frac{1}{6}, \frac{1}{6}, \frac{1}{6}$ times the top width of the section respectively from Right Bank (c.s.no.B to c.s.no2
	100.0	0.77	0.76	0.69	
# B	150.0	0.86	0.80	0.71	
	225.0	0.97	0.89	0.73	
900m	300.0	0.97	0.89	0.82	
	450.0	1.00	0.90	0.86	
	600.0	1.00	0.93	0.86	
	750.0	0.84	0.83	0.73	
	55.3	0.78	0.69	*	
	110.6	0.84	0.82	0.78	
A	165.8	0.89	0.86	0.82	
	248.7	0.97	0.93	0.86	
995m	331.6	1.08	0.97	*	x/* Not measurable
	497.4	1.08	1.00	0.86	
	663.2	1.16	1.13	*	
	829.0	0.93	0.86	*	
	77.4	**	**	**	
	154.9	0.62	0.67	0.58	
1	232.3	0.86	0.82	0.73	
	348.5	1.15	1.11	*	
1394m	464.7	*	1.17	*	** very low velocity
	697.0	*	1.17	*	
	929.4	1.39	1.26	1.13	
	1161.7	*	1.39	*	
	73.6	**	**	**	
	147.2	0.76	0.67	0.53	
2	220.8	0.82	0.80	0.65	
	331.2	0.89	0.76	0.60	
1325m	441.6	1.02	0.85	*	
	662.4	*	1.08	*	
	883.3	1.22	1.22	*	
	1104.1	1.35	1.24	*	
	42.3	0.87	0.89	0.84	Velocity was taken at verticals after $\frac{1}{36}, \frac{1}{36}, \frac{1}{36}, \frac{1}{36}, \frac{1}{18}, \frac{1}{12}, \frac{1}{12}, \frac{1}{6}, \frac{1}{6}, \frac{1}{6}$, times the top width of the section respectively from Right Bank (c.s. no 3 to c.s.no 12)
	84.6	0.95	0.84	0.78	
3	126.9	1.00	0.91	0.82	
	169.2	1.02	0.93	0.78	
1523m	253.8	1.00	0.91	0.82	
	380.7	1.11	1.20	0.89	
	507.6	1.12	1.08	*	
	761.4	*	1.34	*	
	1015.2	*	1.26	*	
	1269.0	*	*	*	

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C.S. No. and top width in meter	Distance from the right bank in meter (Pr)	Proto velocity in meter/sec at the depth of			Remarks
		.2D	.5D	.8D	
1	2	3	4	5	6
	42.1	1.02	0.93	*	
	84.2	0.97	0.97	0.91	
	126.3	1.08	1.04	0.87	
4	168.4	1.19	1.08	0.87	
	252.7	1.08	1.08	0.91	
1517m	379.1	X	1.13	X	
	505.5	X	1.22	X	
	758.3	X	1.39	X	
	1011.1	X	X	X	
	1263.9	X	X	X	
	31.0	X	1.24	X	
	62.0	X	X	X	
	93.0	1.32	1.30	1.22	
	124.0	1.24	1.26	0.84	
5	185.8	1.19	1.14	0.97	
	278.7	1.08	1.02	0.82	
1115m	371.6	1.11	0.93	0.87	
	557.4	*	1.19	*	
	743.2	*	1.15	*	
	929.0	*	1.06	*	
	33.8	*	0.65	*	
	67.6	1.04	1.02	0.91	
	101.3	1.22	1.19	1.04	
	135.1	1.30	1.28	1.06	
6	202.7	1.26	1.19	1.16	
	304.0	1.26	1.19	*	
1216m	405.3	*	1.19	*	
	608.0	*	1.19	*	
	810.7	*	*	*	
	1013.4	*	*	*	
	30.1	X	2.01	X	
	60.2	1.98	1.98	1.78	
	90.3	1.88	1.86	1.84	
7	120.4	1.86	1.84	1.82	
	180.6	2.03	2.01	X	
	270.9	1.78	1.65	X	
1084m	361.2	X	1.59	X	
	542.0	X	1.28	X	
	722.6	X	X	X	
	903.2	X	X	X	
	32.6	2.09	1.97	1.88	
	65.2	1.97	1.90	1.86	
	97.8	1.78	1.74	1.59	
8	130.4	1.67	1.57	1.40	
	195.7	1.71	1.65	1.40	
1174m	293.5	X	1.52	X	
	391.3	X	1.19	X	
	587.0	X	1.13	X	
	782.7	X	X	X	
	978.3	X	X	X	

C.S. No. and top width in meter	Distance from the right bank in meter (Pr)	Proto velocity in meter/sec at the depth of			Remarks
		.2D	.5D	.8D	
1	2	3	4	5	6
9 1374m	38.2	1.67	1.97	1.28	
	76.3	1.76	1.90	1.41	
	114.5	1.92	1.88	1.59	
	152.7	2.01	1.82	1.61	
	229.0	2.01	1.59	1.31	
	343.5	X	X	X	
	458.0	X	X	X	
	687.0	X	X	X	
	916.0	X	X	X	
	1145.0	X	X	X	
10 1261m	35.0	1.92	1.88	1.69	
	70.0	1.90	1.92	1.80	
	105.1	1.92	1.88	1.44	
	140.1	1.95	1.80	1.26	
	210.2	1.76	1.52	1.41	
	315.3	X	1.61	X	
	420.4	X	X	X	
	630.5	X	X	X	
	840.7	X	1.26	X	
	1050.9	X	0.32	X	
11 1196m	33.2	2.19	2.24	2.18	
	66.4	2.22	2.19	2.03	
	99.6	2.01	1.97	1.76	
	132.9	2.03	1.86	1.48	
	199.3	1.76	1.84	1.41	
	299.0	X	1.54	X	
	398.7	X	X	X	
	598.0	X	X	X	
	797.4	X	X	X	
	996.7	X	X	X	
12 1175m	32.6	X	1.00	X	
	65.2	2.07	2.09	2.05	
	97.9	2.07	2.09	2.01	
	130.5	1.97	1.98	1.84	
	195.8	1.78	1.71	1.37	
	293.7	1.34	1.13	1.11	
	391.6	X	X	X	
	587.5	X	X	X	
	783.3	X	X	X	
	979.1	X	0.90	X	

Appendix II
BRTS (Kazipur)

Velocity profile along the cross-sections for the 100 years flood ($17000\ m^3/s$; proto) without protective works

C.S. No. and top width in meter including flood plain)	Distance from the right bank in meter(pr)	Proto velocity in meter/sec at the depth of			Remarks
		.2D	.5D	.8D	
1	2	3	4	5	6
B 1990m	50.0	1.26	1.32	1.13	Velocity was taken at verticals after B/18, B/18, B/18, B/12, B/12, B/6, B/6 B/6 respectively where B is the width of the main channel without flood plain (c.s.no. B to c.s.no. 2)
	100.0	1.37	1.40	1.30	
	150.0	1.43	1.32	1.32	
	225.0	1.65	1.57	1.52	
	300.0	1.52	1.50	1.40	
	450.0	1.63	1.32	1.30	
	600.0	1.95	1.82	1.57	
	750.0	0.86	1.04	0.78	
A 1880m	55.30	1.41	1.26	1.15	* Not measurable
	110.60	1.50	1.43	1.19	
	165.80	1.54	1.52	1.37	
	248.70	1.71	1.61	1.40	
	331.60	1.65	1.54	1.35	
	497.40	1.88	1.65	1.57	
	663.20	1.91	1.80	1.63	
	829.0	1.24	1.21	1.15	
1 2292m	77.40	**	**	**	** very low velocity
	154.90	0.86	0.80	0.77	
	232.30	1.46	1.39	1.24	
	348.50	1.76	1.69	*	
	464.70	*	1.77	*	
	697.00	1.86	1.70	*	
	929.40	2.05	2.00	1.86	
	1161.70	*	1.97	*	
2 2376m	73.6	**	**	**	
	147.2	1.10	1.06	1.04	
	220.8	1.41	1.39	1.08	
	331.2	1.33	1.08	0.98	
	441.6	1.52	1.52	*	
	662.4	*	1.72	*	
	883.3	1.84	1.76	*	
	1104.1	1.84	1.67	*	
3 2372m	42.3	1.10	1.00	0.91	Velocity was taken at verticals after a distance of B/36, B/36 B/36, B/36, B/18, B/12, B/12, B/6, B/6, B/6, respectively. (c.s.no.3 to c.s.no.1
	84.6	1.26	1.13	1.06	
	126.9	1.43	1.22	1.11	
	169.2	1.46	1.30	1.04	
	253.8	1.35	1.19	0.91	
	380.7	1.50	1.39	1.26	
	507.6	1.52	1.57	1.50	
	761.4	*	1.97	*	
	1015.2	*	1.59	*	
	1269.0	*	*	*	

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		.2D	.5D	.8D	Remarks
1	2	3	4	5	6
	42.1	1.46	1.32	1.32	
	84.2	1.54	1.40	1.34	
	126.3	1.61	1.52	1.31	
4	168.4	1.59	1.52	1.37	
	252.7	1.44	1.26	1.02	
	379.1	1.34	1.32	1.06	
2420m	505.5	1.57	1.52	*	
	758.3	*	1.63	*	
	1011.1	*	1.57	*	
	1263.9	*	*	*	
	31.0	*	1.56	*	
	62.0	*	1.75	*	
	93.0	1.77	1.70	1.61	
	124.0	1.76	1.71	1.61	
5	185.8	1.63	1.59	1.48	
	278.7	1.59	1.35	1.19	
2460m	371.6	1.59	1.46	1.17	
	557.4	*	1.65	*	
	743.2	*	1.65	*	
	929.0	*	1.52	*	
	33.8	*	1.23	*	
	67.6	1.44	1.41	1.37	
	101.3	1.74	1.69	1.41	
	135.1	1.77	1.77	1.70	
6	202.7	1.77	1.77	1.50	
	304.0	1.96	1.82	1.71	
2520m	405.3	*	1.52	*	
	608.0	*	1.84	*	
	810.7	*	*	*	
	1013.4	*	*	*	
	30.1	*	2.34	*	
	60.2	2.45	2.36	2.16	
	90.3	2.36	2.36	2.16	
	120.4	2.36	2.39	2.32	
7	180.6	2.52	2.52	2.43	
	270.9	2.30	2.16	*	
2554m	361.2	*	1.91	*	
	542.0	*	2.11	*	
	722.6	*	1.97	*	
	903.2	*	1.84	*	
	32.6	2.34	2.28	2.20	
	65.2	2.32	2.23	2.11	
	97.8	2.23	2.16	1.88	
	130.4	2.09	1.97	1.63	
8	195.7	2.19	1.92	1.69	
	293.5	*	2.03	*	
2640m	391.3	*	1.84	*	
	587.0	*	2.11	*	
	782.7	*	1.73	*	
	978.3	*	*	*	

		.2D	.5D	.8D	Remarks
1	2	3	4	5	6
	38.2	2.28	2.22	2.03	
	76.3	2.34	2.32	2.07	
	114.5	2.45	2.34	2.17	
	152.7	2.45	2.34	2.17	
9	229.0	2.47	2.07	2.01	
	343.5	*	2.01	*	
2650m	458.0	*	2.12	*	
	687.0	*	1.75	*	
	916.0	*	1.50	*	
	1145.0	*	1.50	*	
	35.0	2.45	2.34	2.22	
	70.0	2.41	2.41	2.22	
	105.1	2.45	2.45	2.05	
	140.1	2.47	2.34	1.80	
10	210.2	2.43	2.22	2.05	
	315.3	*	2.03	*	
2670m	420.4	*	1.90	*	
	630.5	*	1.71	*	
	840.7	*	1.71	*	
	1050.9	*	0.58	*	
	33.2	2.85	2.78	2.55	
	66.4	2.78	2.66	2.64	
	99.6	2.57	2.62	2.34	
11	132.9	2.41	2.34	1.97	
	199.3	2.22	2.05	1.90	
2716m	299.0	*	1.88	*	
	398.7	*	1.82	*	
	598.0	*	*	*	
	797.4	*	2.16	*	
	996.7	*	1.13	*	
	32.6	1.59	1.22	*	
	65.2	2.47	2.47	2.39	
	97.9	2.96	2.80	2.66	
12	130.5	2.70	2.73	2.28	
	195.8	2.47	2.34	1.97	
2600m	293.7	1.92	1.65	1.65	
	391.6	*	1.63	*	
	587.5	*	1.26	*	
	783.3	*	1.40	*	
	979.1	*	1.46	*	

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GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH

BANGLADESH WATER DEVELOPMENT BOARD

River Training Studies of The Brahmaputra River

FINAL REPORT ON PHYSICAL MODEL STUDIES

VOL II - MODEL BASED ON SIRAJGANJ 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 II - MODELS BASED ON SIRAJGANJ 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 herein do so at their own risk.

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Engineering & Planning Consultants Ltd.
Design Innovation Group

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RIVER TRAINING STUDIES OF THE BRAHMAPUTRA RIVER

FINAL REPORT ON PHYSICAL MODEL STUDIES

VOL - II MODELS BASED ON SIRAJGANJ BATHYMETRY

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APPENDICES

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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 Sirajganj. Without their active cooperation the model test programme could not have been accomplished.

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BRAHMAPUTRA RIVER TRAINING STUDIES
MODEL BASED ON SIRAJGANJ 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 Sirajganj is the Second 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 5 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 Sirajganj

Sirajganj, the largest town on the right bank of the Brahmaputra River in the area covered by the present FAP-1 project, is situated 170 km downstream from the confluence of the Jamuna-Teesta Rivers.

Sirajganj town is partly protected by the Ranigram Groyne upstream of the town. The groyne and the existing bank protecting revetment south of the groyne down to the B. L. School protect the bank in this region. The groyne needs presently periodical repair/maintenance to cope with settlements and displacement or sliding of the concrete blocks at the groyne nose. The existing bank revetment also requires regular reinforcing and parts are seriously unstable.

From the School and Southwards to the Ferry Ghats the river bank faces considerable problems of bank erosion and the deep channel is very close to the bank.

This section of the river bank presently accommodate many ships for loading and unloading and consequently this section is of great economical importance to Sirajganj and this region of Bangladesh.

1.4 Objectives of the Model Study

The Objectives of the Model Study in the Sirajganj Model Bed is, as in the case of the Kazipur Test Bed, to provide both site specific information and in addition to provide general information on the flow characteristics and influence of upstream river bed configuration on the flow field and associated flow velocities to be used for other sites. The study has thus the following purposes:

(a) To investigate the flow characteristics in the entire area of Sirajganj for the "existing" anabranch and depth configuration for Bankfull and 100 years Flood Conditions.

(b) To determine the influence on downstream condition from extending the Ranigram Groyne. An extension of the groyne has previously been considered an important measure on further protecting the town against erosion. In the present model study two lengths of extension of 300 m and 600 m respectively have been studied.

(c) The unprotected section of the bank south of the B.L. School is a long almost straight section of river bank with a deep channel in front. An important and general study objective is to determine the maximum velocities that can occur along such a straight river bank section as function of the upstream anabranch and char configuration. As it is known that rapid changes occur and that almost any configuration found along the Brahmaputra River may produce itself at Sirajganj the model investigation comprised four different upstream configurations.

(d) To study in a mobile bed model the maximum scour level in the area adjacent to the nose of a large groyne such as the Ranigram Groyne and the possible scour or deposition if revetment bank protection is introduced south of the B. L. School.

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2. THE MODEL

2.1 Design of the Model

A distorted local model was chosen for the Sirajganj Area. The right most anabranch of the Brahmaputra river near Sirajganj town was reproduced in the model with the following scales:

Horizontal	: 1:300
Vertical	: 1:120
Distortion factor	: 2.5
Discharge	: 1:394360
Velocity	: 1:10.95

The anabranch was about seven kilometers in length from upstream of Ranigram groyne to downstream of the Railway Ferry Ghat. The area upto the BRE was included in the model but the char to the left was excluded.

The model was constructed in a 55 m x 21 m wide model bed (see Figure 2.1). Cross-sections prepared by BRTS based on the recent near bank surveys in April 1991 were used. The model was moulded with 0.2 mm local sand which has been shown to be suitable for fixed bed experiments.

A rectangular sharp crested weir was installed in the upper end of the model flume to measure the in-flow discharge. Two gauges were installed on the model bed, one at c/s # C-57.0 and another at c/s # C-52.0 to record the water surface elevations. A tilting gate was fixed at the downstream end of the flume to control the water level in the model.

2.2 Data Requirement and Availability

The following data are required for the present type of physical model study:

(a) Bathymetrical (and Topographical) data such as index map of the area showing present river bank line, existing structures (if any), locations of cross-sections, position of flood-embankment, flood plains etc.

(b) River bathymetry cross-sections.

(c) Hydrological data such as discharge, water levels etc.

(d) Data for model calibration/verifications.

Index map and river cross-sections for the river branch under consideration were supplied by BRTS. Discharge for bankfull level and 100-years flood for the model branch and corresponding water levels were also supplied. However, the elevations on the char area were not known. They were consequently estimated based on observations in the field by BRTS survey team.

2.3 Model Calibration

The object of model calibration is to confirm hydraulic similitude between the model and actual field (prototype) conditions. The average velocity at the representative cross-section (C-57.00) was measured in the model and the result agreed with the calculated value as shown in Table 2.1.

Table 2.1: Model Calibration Results

Sl. No.	Factor	Calculated Value for Prototype	Value Observed in the Model
1.	Water level for bank-full stage at c/s C-57.0	12.70 m	12.70 m
2.	Water level for 100 year flood stage at c/s # C-57.0	15.75 m	15.75 m
3.	Water surface slope for bankfull discharge	7.0×10^{-5}	n/a
4.	Water surface slope for 100 year flood discharge	9.0×10^{-5}	n/a
5.	Average velocity for bankfull discharge at c/s C-57.0	0.85 m/s	n/a
6.	Average velocity for 100 year flood discharge at c/s C-57.o	1.6 m/s	1.8 m/s

2.4 Test Programme

Model Plans:

The investigation comprised the following four Bathymetry Plans for the Upstream Area.

Bathymetry Plan I - Three Upstream Channels

Profile C 51.5 to C 57.00 and profile c/s A are in accordance with available survey data.

The profile to the north of c/s. A is synthetic, representing three upstream flow channels (See Figure 3.1).

This bathymetry comprises three channels & two chars.

Bathymetry Plan II - Two Upstream Channels & One Extra Char

The Bathymetry to the north of section C-57.0 was moulded in accordance with the results of the BRTS survey of 8 to 10 April 1991 (see Figure 3.3).

Bathymetry Plan III - Two Upstream Channels

The Bathymetry plan III shown in Figure 5.1 aims at producing maximum flow velocity at the Ranigram Groyne by removing the char to the north of the groyne. The river bed is set at elevation + 5.0 m in the area of the removed char.

Bathymetry Plan IV - One Upstream Channel

This plan IV shown in Figure 5.3 aims at producing maximum flow velocity at the river bank south of the B.L. school by assuming the existing flow Channel between the Ranigram Groyne and the large char silted up.

Experimental Conditions:

100 years flood conditions

Flow discharge 30,000 m^3/s (with the flood plain).

Flow discharge 25,000 m^3/s (without flood plain - Test Conditions).

In model 0.064 m^3/s. Water level + 15.75 m.

Bank full discharge

Flow discharge 9,300 m^3/s. In model 0.024 m^3/s. Water level + 12.7 m.

Test Programme

The test programme shown in Table 2.2, is divided into three phases:

Phase I concentrated on studying the flow conditions for Plan I and II (Flow Fields for Two Bathymetries). Phase II investigated the effect of having the groyne nose close to the char (char shifted towards the groyne nose) while Phase III concentrated on studying the "Scour at groyne and revetment". In addition Phase III comprised measurements of the flow field for Bathymetry Plans III & IV.

Table 2.2: Sirajganj Test Bed
Test Programme, Phases I, II & III

Test No	Bathymetry	Discharge (m^3/s)	WL (m)	Purpose	Comments
Phase I					
1	Plan I	25,000	+ 15.75	Flow Measurement	
2	Plan I	9,300	+ 12.7	-do-	
3	Plan II	25,000	+ 15.75	-do-	
Phase II					
4	Plan II	25,000	+ 15.75	-do-	Groyne Ext.300 m
5	Plan II	25,000	+ 15.75	-do-	Groyne Ext.600 m
Phase III					
6	Plan III	25,000	+ 15.75	Scour study at Ranigram Groyne & Flow Measurements	
7	Plan IV	25,000	+ 15.75	Flow Measurements	
8	Plan IV	25,000	+ 15.75	Scour study along River Bank revetment	

3. RESULTS OF MODEL STUDY, PHASE I

3.1 General

This section presents the results of phase I of the model study and their interpretation. Overall conclusions and recommendations on the study are given in Section 6.

3.2 Test No. 1 - Velocity Measurements, Bathymetry Plan I, 100 year Flood

Presentation : See Figure 3.1
Test Conditions : Q = 25,000 m^3/s (100 year flood flow)
WL = + 15.75 m
Calculated mean velocity : 1.6 m/s

Results: Figure 3.1 shows the measured flow characteristics.

The following features are noted:

(a) The distribution of discharge between the three upstream channels is uneven. The middle channel carries the largest portion of the flow discharge with a velocity of 2.3 m/s in the middle of the anabranch to be compared with the calculated mean section velocity of 1.6 m/s.

(b) The narrow anabranch in the vicinity of the Ranigram Groyne has relatively low flow velocities. Due to the blockage of the groyne flow concentration occurs at the nose. This causes the velocity to increase to 2.4 m/s. Water is forced to flow over the char in the SE-direction.

(c) The groyne creates to the south an area with stagnant water and a weak eddy. The velocities are low. The effect of the groyne is noticeable about 1,200 m downstream. The flow runs southwards from section 300 (situated about 400 m to the north of the Jail). South of the Jail the water runs fairly regularly along the entire right bank. The measured velocity varies generally in the range 1.5 to 2.5 m/s, with maxima in sections G and K of 2.8 m/s and 2.9 m/s respectively.

3.3 Test No. 2 - Velocity Measurements, Bathymetry Plan I, Bank - Full Discharge

Test 2 was performed with the same bathymetry as Test 1 but with lower discharge and water level corresponding to bank-full conditions.

Presentation : See Figure 3.2
Test Conditions: Q = 9,300 m^3/s
WL = + 12.7 m

Results

The results in Figure 3.2 shows an almost similar pattern as for the 100 year flood. The maximum velocity was equal to 1.5 to 1.6 m/s. It is to be noted that the downstream effect of the Ranigram Groyne is less for Bank Full conditions than for 100 year flood.

It is to be noted that significant near-bank velocities occur near the bank in Section IA, being 950 m south of the groyne Nose, to be compared with about 1,200 m for 100 years flood conditions (Figure 3.1).

3.4 Test No. 3 - Velocity Measurements, Bathymetry Plan II 100-Year Flood

Test 3 had identical flow conditions as Test 1 but with changed upstream bathymetry configuration (Bathymetry Plan II).

This plan is identical to the BRTS survey of 8-10 April 1991.

Presentation : See Figure 3.3
Test Conditions: Q = 25,000 m^3/s
WL = + 15.75 m

The results in Figure 3.3 reveal the following:

(a) The situation with two chars to the east and north of the Ranigram Groyne produces larger flow resistance near the groyne, and velocities near the groyne nose were as low as 1.2 m/s. The effect of the groyne is seen to be limited as the water flows in most of the area south of the groyne between the long large char and the right bank is scarcely deflected.

(b) From the Jail and southwards the flow situation is again quite regular as for Bathymetry Plan I. The maximum velocity was reached in section G, 300 m north of the Railway char. The velocity was 2.8 m/s. It is important that this maximum velocity is identical to the one measured for Bathymetry Plan I (Test 1) and it thus appears that the change in upstream bathymetry configuration had no significant influence on conditions downstream in section G.

(c) The relatively narrow section B-B' does not generate velocities that are as high s at GG'.

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4. RESULTS OF MODEL STUDY, PHASE II

4.1 **This section presents the results of the tests performed for studying the influence arising from extending the Ranigram Groyne**

4.2 Tests 4 and 5, Extension of Ranigram Groyne

Velocity Measurements, Bathymetry Plan II, 100 years Flood.

Tests Nos, 4 and 5 were performed to study the effect on the flow field and velocities from extending the Ranigram Groyne. The extension was 300 m and 600 m respectively. The tests were performed using the Bathymetry Plan II (BRTS, 8-10 April 1991, Survey).

Presentation : See Figures Nos. 4.1 and 4.2
Test Conditions: Q = 25,000 m^3/s
WL = + 15.75 m

The tests have shown the following:

(a) Figures Nos 4.1 and 4.2 show that an extension of the groyne results in a larger southward area with an eddy and near stagnant water (mainly northern current).

(b) For 300 m extension the effect of the extension can be recognised in the near bank velocity down to between profile A and B, i.e. down to the Jail approximately.

(c) For 600 m extension the effect can be seen to extend another 500 m to the south at the B.L. School. To the south of this the results show that on the average an extension of the groyne up to about 600 m has no effect in reducing the near bank velocities causing the present erosion problems to the south of the B.L. School. Figure 4.3 shows a comparison of the near bank velocity measurements for the existing length of Ranigram Groyne and 300 m and 600 m extension respectively.

5. RESULTS OF MODEL STUDY, PHASE III

5.1 **Section 5 presents the results of the scour investigation to study "Scour at groyne and revetment".**

5.2 Tests 6, Velocity Measurements Bathymetry Plan III, 100 year Flood Conditions

Bathymetry Plan III is identical to Plan II, except with respect to the conditions to the north of Ranigram Groyne. In Bathymetry III the small char to the south of the groyne nose has been removed. The bed level in this area was moulded as level + 5.0 m to allow for low flow resistance for water flowing to the groyne from North and Northeast.

Presentation : See Figure 5.1
Test Conditions: Q = 25,000 m^3/s
WL = + 15,75 m

Test Results show the following:

(a) Comparison of Tests nos. 3 and 6 (Plan II and III respectively) reveals that the removal of the char has an effect on increasing the flow velocities in the anabranch between the groyne and the big char. The velocity near the nose of the groyne increases from about 1.2 m/s to about 1.5 m/s. The effect of removing the char (increased water flow in the western anabranch) can only be detected down to the B.L. School, South of which the near bank velocity on the average is identical to the velocity of Test No. 3 where the small char was in place. Figure 5.2 presents a comparison of the velocities for the two situations.

(b) This test shows together with the previous ones that measures that either reduces or increases the flow of water in the right (western) anabranch cannot be felt along the river bank south of the B.L. School. This is the section of river bank which is presently unprotected and suffering from erosion.

5.3 Test 7, Velocity Measurements, Bathymetry Plan IV, 100-year Flood Conditions

In an attempt to further reduce the flow of water in the vicinity of the Ranigram Groyne and have the majority of the flow coming in one channel hitting as a "jet" on to the bank in the zone of erosion. Bathymetry Plan IV which is purely synthetic, was constructed (see Figure 5.3).

Presentation : See Figure 5.3
Test Conditions: Q = 25,000 m^3/s
WL = + 15.75 m

The test showed the following:

(a) The large char at elevation + 8.0 m above mean sea level allows for a southward discharge of water and immediately south of the char in section SX-1 all velocity measurements were southward. At the B.L. School (section C) results in an about 20 % reduction Figure 3.3 or Figure 4.2 in the nearbank velocities.

(b) Immediately south of the School the effect is still noticeable and the expected large velocities in this zone didn't appear in the model. In section G for example the maximum velocity recorded was 2.7 m/s which is down from 2.8 m/s for all the other Bathymetry Plans. A comparison of velocities in the eastern anabranch for Bathymetry Plan III and IV shows that for Plan IV, the maximum velocity recorded was, 2.05 m/s to be compared with about 1.2 m/s for test No. 6 on Bathymetry Plan III. The flow velocity in Section G and at the Railway and further to the south is again seen to be only very little affected by the upstream configuration. Figure 5.2 shows a comparison of the flow velocities for the 100 years flood for all four Bathymetry Plans I, II, III and IV.

5.4 Mobile Bed Modelling, Test 6 & 8

5.4.1 General

In addition to the flow measurements mobile bed was introduced in two tests, namely nos. 6 and 8 respectively. The tests had the following objectives.

Test 6: To study the development of scour around the nose of the Ranigram groyne when exposed to 100 - year flood conditions. Note the tests was performed using Bathymetry Plan No. III. (small char removed).

Test 8: To study the possible development of scour at the toe of new revetments for bank protection south of the B. L. School. This test was performed with 100 - year flood conditions on Bathymetry Plan No. IV.

5.4.2 Results of Mobile Bed (Scour) Test for Ranigram Groyne

The model bed was moulded according to bathymetry plan III. The Ranigram Groyne had the existing length.

The results of the mobile bed test for the Ranigram Groyne are presented in Table 5.1. The test showed only a limited development of the scour at the nose of the groyne with an erosion of the deepest scour hole from level -7.9 m to - 8.5 m. (23.7 to 24.3 m below 100 year flood level).

At the nose of the groyne the scour was about 3.0 m and the development as seen in Figure 5.4. It takes about 4 hours model time for the scour to develop.

The test indicates that even if the upstream bathymetry develops in a way that will lead to increased flow velocities at the groyne only a further scour of a few extra metres should be expected. However, depending on the present situation of the toe and lowers part of the block protection on the groyne, this may cause failure of the nose of the groyne.

It is consequently recommended that this is kept under observation and that maintenance is performed regularly.

Table 5.1: Sirajganj Test Bed: Test No. 6
Scour Measurements Around Ranigram Groyne

C/S #	Sl.No.	Distance from R.B in metre		Bed Elevation before test [m]	Bed Elevation after test [m]	Scour/ deposition in meter Prototype	Remarks
		Model [m]	Protype [m]				
IC	(1)	1.23 (+.60)	370.0	-0.60	-1.2	-0.60	
(sx-4)	(2)	2.44 (+.60)	372.0	7.60	6.00	-1.60	
Ex-1	1)	1.23	750.0	-6.6	-7.0	-0.4	
	2)	2.75	825.0	-4.2	-5.1	-0.9	
	3)	3.00	900.0	-2.2	-3.2	-1.0	
	4)	3.25	975.0	-0.7	-0.8	-0.1	
	5)	3.50	1050.0	1.2	1.2	0	
ID (Sn.5)	1)	0.61	183.0	2.80	2.70	-0.1	
	2)	0.84	251.0	-3.40	-4.2	-0.8	
	3)	0.99	297.0	-6.30	-6.8	-0.5	
	4)	1.24	372.0	-7.70	-8.3	-0.6	
	5)	1.64	493.0	-7.90	-8.5	-0.6	
	6)	2.16	648.0	-5.20	-5.8	-0.6	
	7)	2.45	734.0	-0.80	-0.8	0	
Ex-2 Axis of Groyne	1)	0.25	75.0	0	-3.1	-3.1	Distances are measured from the nose of the groyne.
	2)	0.50	150.0	-5.2	-6.0	-0.8	
	3)	0.75	225.0	-6.6	-7.2	-0.6	
	4)	1.00	300.0	-5.6	-6.1	-0.5	
	5)	1.25	375.0	-4.0	-4.2	-0.2	
	6)	1.50	450.0	-1.8	-1.8	0	
IE (Sn-6)	1)	0.71	213.0	5.80	3.0	-2.0	
	2)	0.95	284.0	-0.1	0	+0.1	
	3)	1.18	353.0	3.0	0.8	-2.2	
	4)	1.38	413.0	0.5	1.0	+0.5	
	5)	1.75	525.0	2.6	1.8	-0.8	
	6)	1.91	572.0	1.40	2.6	+1.2	
IF (Sn-7)	1)	1.40	420.0	5.0	4.1	-0.9	
	2)	1.81	542.0	5.0	3.7	-1.3	

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Notes:

Q = 25,000 m^3/s (100 year flood)
W.L = 15.75 m at c/s c # 57.00

Convention: - = scour
+ = deposition

Test duration: 5 hours (model time)

5.4.3 Results of Mobile Bed Tests for Revetments South of B.L School, Test 8

Test 8 comprised mobile bed testing of revetments along the river bank south of the B.L. School. Appendix II shows the model set-up. The test was run with 100-year flood conditions. Measurements of the development of bed levels were performed at regular intervals in all the profiles c-53.0 to c-57.0 at distances of 50,100 and 200 m from the bank. The results of these measurements (after 5 hours model time) are shown in Figure 5.5.

It appears that generally an incremental scour of 0 to 2m takes place with the largest scour close to the revetment (50 m distance) and less scour further away from the revetment. The scour in sections c-53.0 to c-55.0 is fairly constant and about 2.0 m on the average.

Only in the deeper part near profile c-55.5 and c-56.0, no scour or limited deposition was observed.

In conclusion the test showed that for the April 91 bathymetry the occurrence the 100-year flood conditions would only produce scour of 2-3 m infront of the revetment toe.

The measurements of up to 2-3 m scour at the toe of the revetment seems not critical for the design of the revetment. However, as mentioned previously it cannot be excluded that in the future a different upstream configuration of the anabranch will occur that will result in more severe scour with maximum water depths of 28 - 30 m. For the 100-year water level of + 15.75 m this means bed levels of -10 to -12 m in front of the revetment. This is to be compared with the deepest scour found in the model at level -2.5 m in section C-55.5 (200 m from the revetment).

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6. SUMMARY AND CONCLUSIONS

6.1 General

This section presents a summary of the model study and the derived conclusions.

6.2 Objectives of the Study

The model investigation for Sirajganj had the following objectives:

(a) To investigate the flow characteristics in the entire area of Sirajganj for the "existing" anabranch and depth configuration for Bankfull and 100 years Flood Conditions.

(b) To determine the influence on downstream condition from extending the Ranigram Groyne. An extension of the groyne has previously been considered an important measure on further protecting the town against erosion. In the present model study two lengths of extension of 300 m and 600 m respectively have been studied.

(c) The unprotected section of the bank south of the B.L. School is a long almost straight section of river bank with a deep channel in front. An important and general study objective is to determine the maximum velocities that can occur along such a straight river bank section as function of the upstream anabranch and char configuration. As it is known that rapid changes occur and that almost any configuration found along the Brahmaputra River may produce itself at Sirajganj the model investigation comprised four different upstream configurations.

(d) To study in a mobile bed model the maximum scour level in the area adjacent to the nose of a large groyne such as the Ranigram Groyne and the possible scour or deposition if revetment bank protection is introduced south of the B.L. School.

6.3 The Model

The study was performed in a distorted physical model in scale 300 horizontally and 120 vertically. The prototype represented area in the model equals approximately 2.4 x 12 m corresponding to 7.2 x 3.6 km in nature (see Figure 2.1).

The model was constructed in loose sand of 0.2 mm diameter which lead to fixed bed or very limited sediment transport in the model. The fixed bed tests were used to determine the flow field and velocities for different bathymetry plans and set-ups such as different length of the Ranigram Groyne.

6.4 Discharge and Water Level Conditions

The discharge and water level conditions that were used in the model were derived from three sources, 1) measurements, 2) theoretical calculations using Chezy Type formulae, 3) MIKE 11 simulations.

Table 2.1 Shows the test conditions.

6.5. Flow Field and Velocity Measurements

The tests carried out shows the following.

6.5.1 Flow velocities along the River Bank South of the B.L School

The tests performed in three phases comprised in total four different upstream configuration I, II, III and IV. The tests have shown that the flow velocity along the river bank is only marginally influenced by the upstream char/anabranch configuration (within the range of configurations tested) and subject to the limitations imposed by a fixed bed model. Figure 5.2 shows near bank flow velocity as function of the Bathymetry plan.

The maximum velocity was found at the southern stretch of the bank in section and K. The maximum velocity was equal to 2.9 m/s. Almost similar velocities were found in Section G (2.8 m/s) sections: H, I & J (2.6 m/s).

6.5.2 Influence of Extension of Ranigram Groyne

The Ranigram Groyne was extended in two stages in the tests. The extensions tested were 300 m and 600 m respectively. These tests were conducted using the Bathymetry Plan II.

Figure 4.3 shows the results in terms of near bank velocities along the bank in front of the town. It is clearly seen, that the groyne extension is decreasing the velocity in the northern section, while even 600 m groyne extension is not having any measurable influence south of the B. L. School. This section of the river bank is presently unprotected and subject to erosion.

In conclusion an extension of the Ranigram groyne would have to be very long to protect the whole town area. The costs of the groyne extension is also very high and consequently other solutions involving bank protection by revetment were considered.

6.5.3 Scour at Ranigram Groyne Nose

A scour test was performed to study the possible development of scour at the nose of the Ranigram groyne for the 100-years flood conditions. The test showed that only limited additional scour for the situations tested. In the model the water depth in the deepest zone increased by 0.6m from level: 23.7 to 24.3 below 100 year flood level.

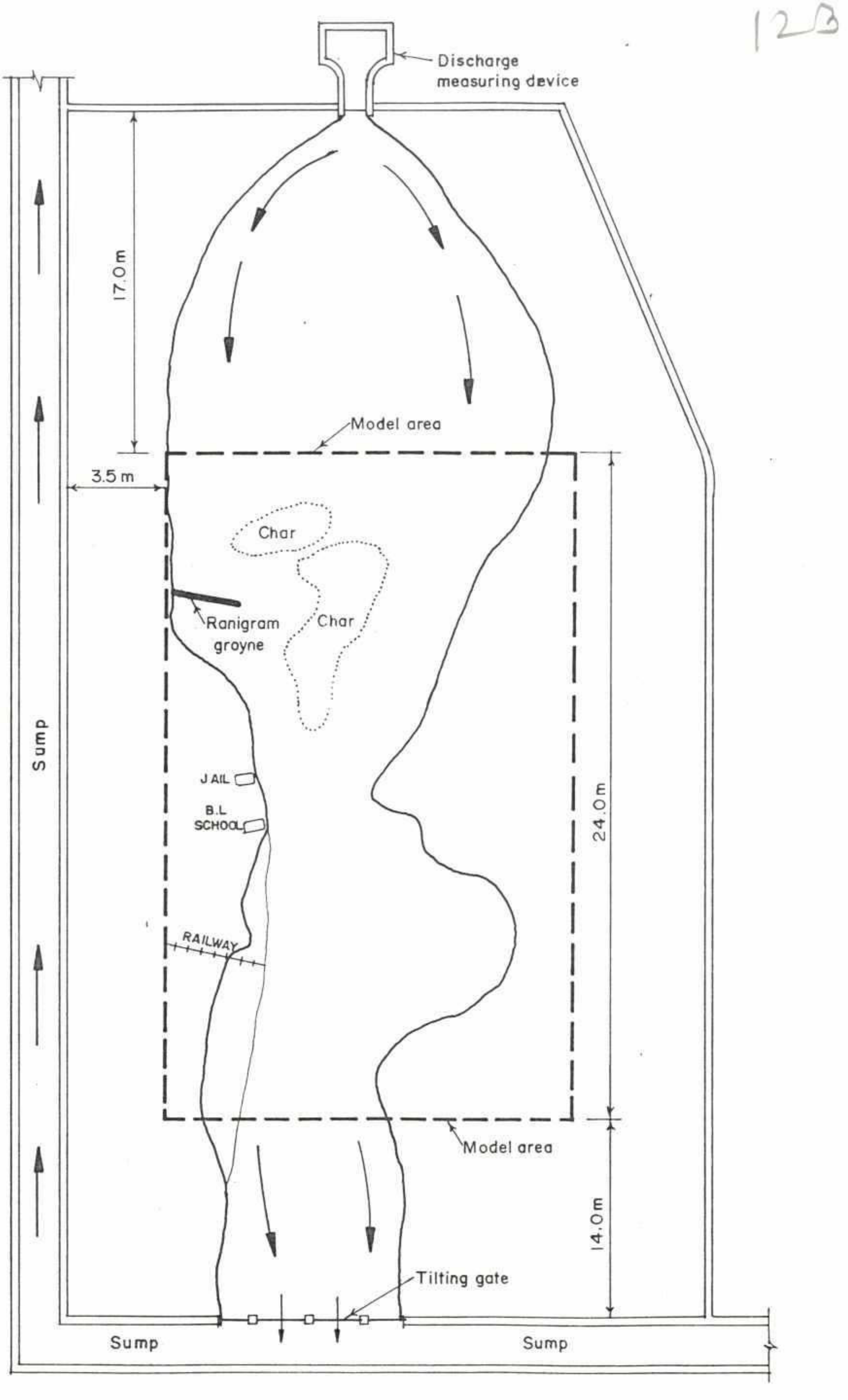
6.5.4 Scour in Front of the Unprotected River Bank South of the B. L. School after Introduction of Revetment

A test was carried out to study the possible scour development along the toe of a new revetment to be constructed south of the B.L. School.

The results of the test was an average scour of about 2m with a maximum of about 3m for the present bathymetry configuration. The test proves that the introduction of revetment is a relative passive measure in bank protection and that severe scour can only occur in front of the revetment if the river changes its course and the local anabranches at the revetment develops more unfavourable features such as more inclined flow attack and possibly higher flow velocities than in the present situation.

Figure 0.1: Sirajganj Model during Testing

Figure 0.2: Scour Tests with Coal Dust.
Above Ranigram Groyne, Below Revetment



SIRAJGANJ PHYSICAL MODEL

PLAN OF THE MODEL

FIGURE : 2.1

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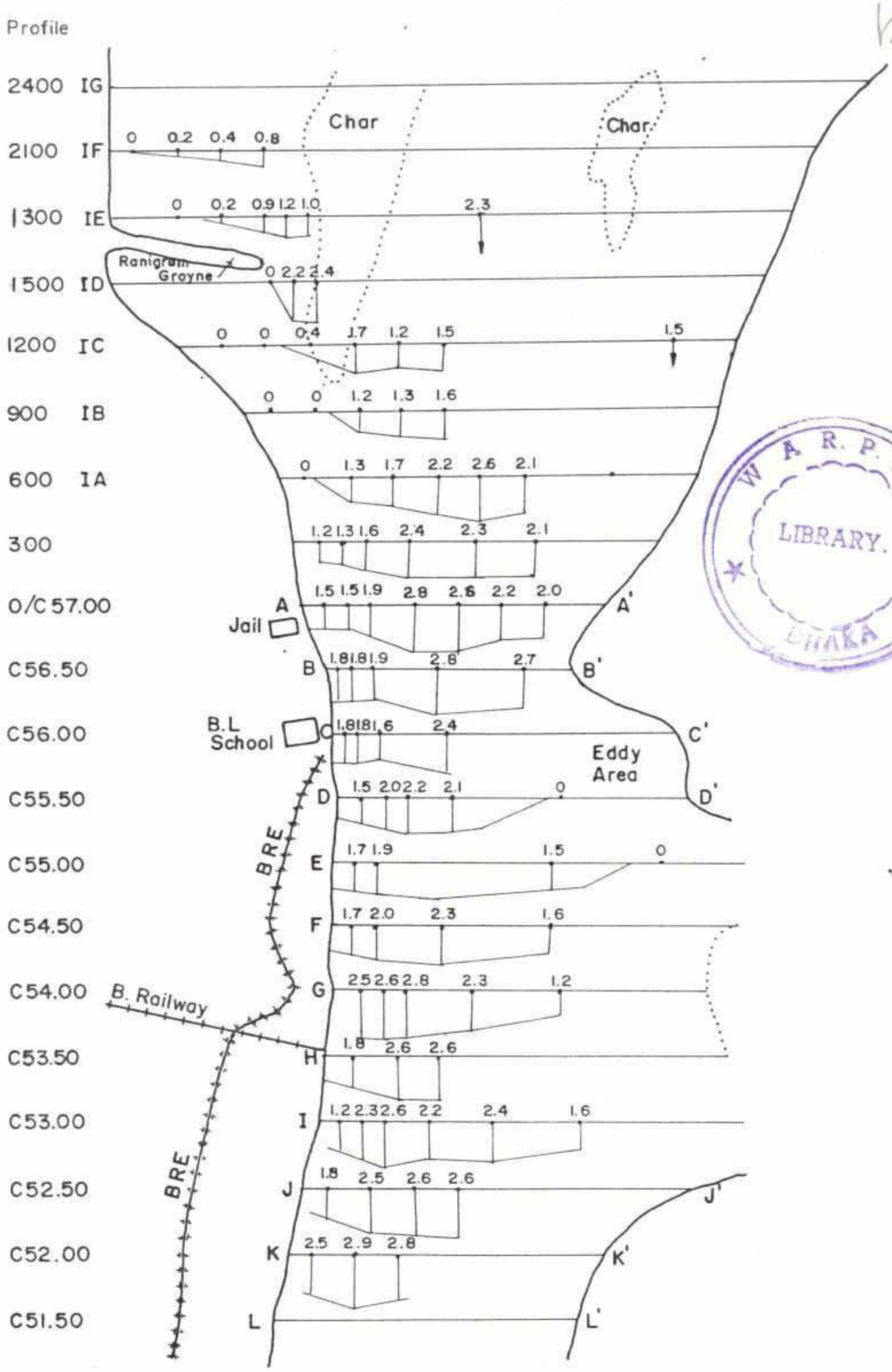


LEGEND:

1.5 Prototype velocity 1.5 m/s

NOTES:

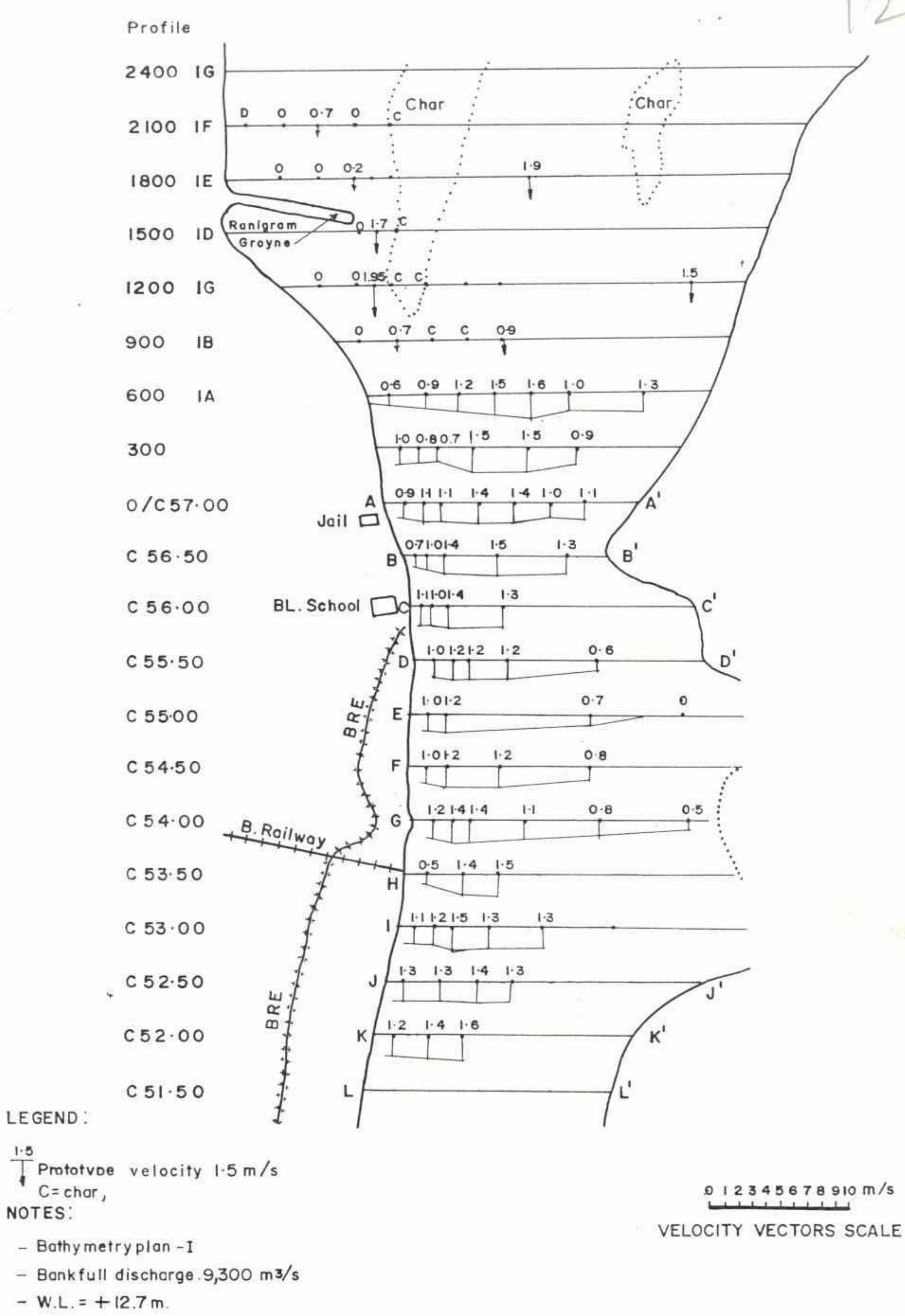
Bathymetry plan I
100 years flood
25.000 m^3/s
WL = +15.75 m
Calculated average velocity 1.60 m/s.

0 1 2 3 4 5 6 7 8 9 10 m/s

VELOCITY VECTORS SCALE

SIRAJGANJ PHYSICAL MODEL

Test no. 01,	VELOCITY MEASUREMENTS	PHASE : I
		FIGURE : 3.1

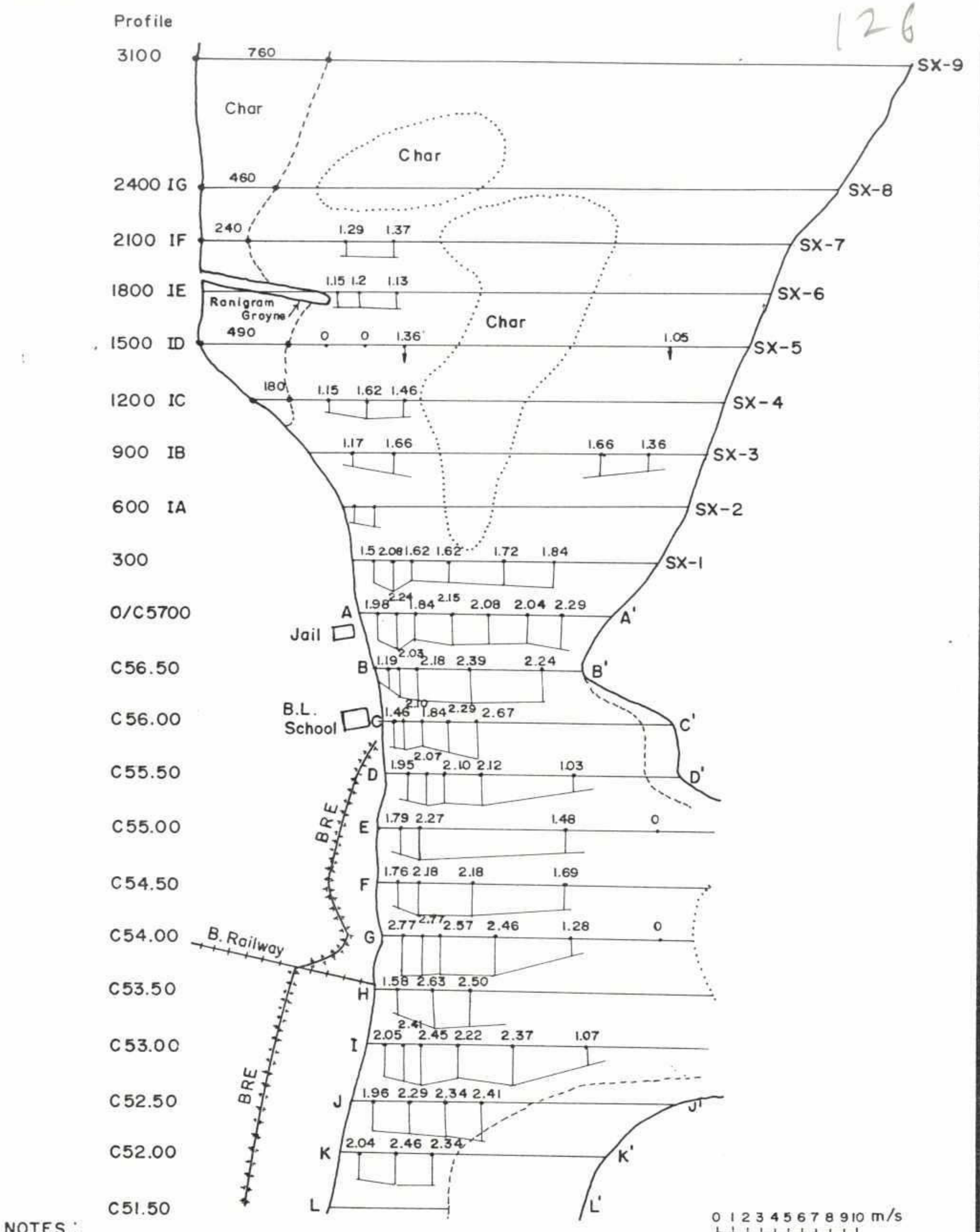


SIRAJGANJ PHYSICAL MODEL

Test no. 02, VELOCITY MEASUREMENTS

PHASE : I

FIGURE : 3.2



NOTES :

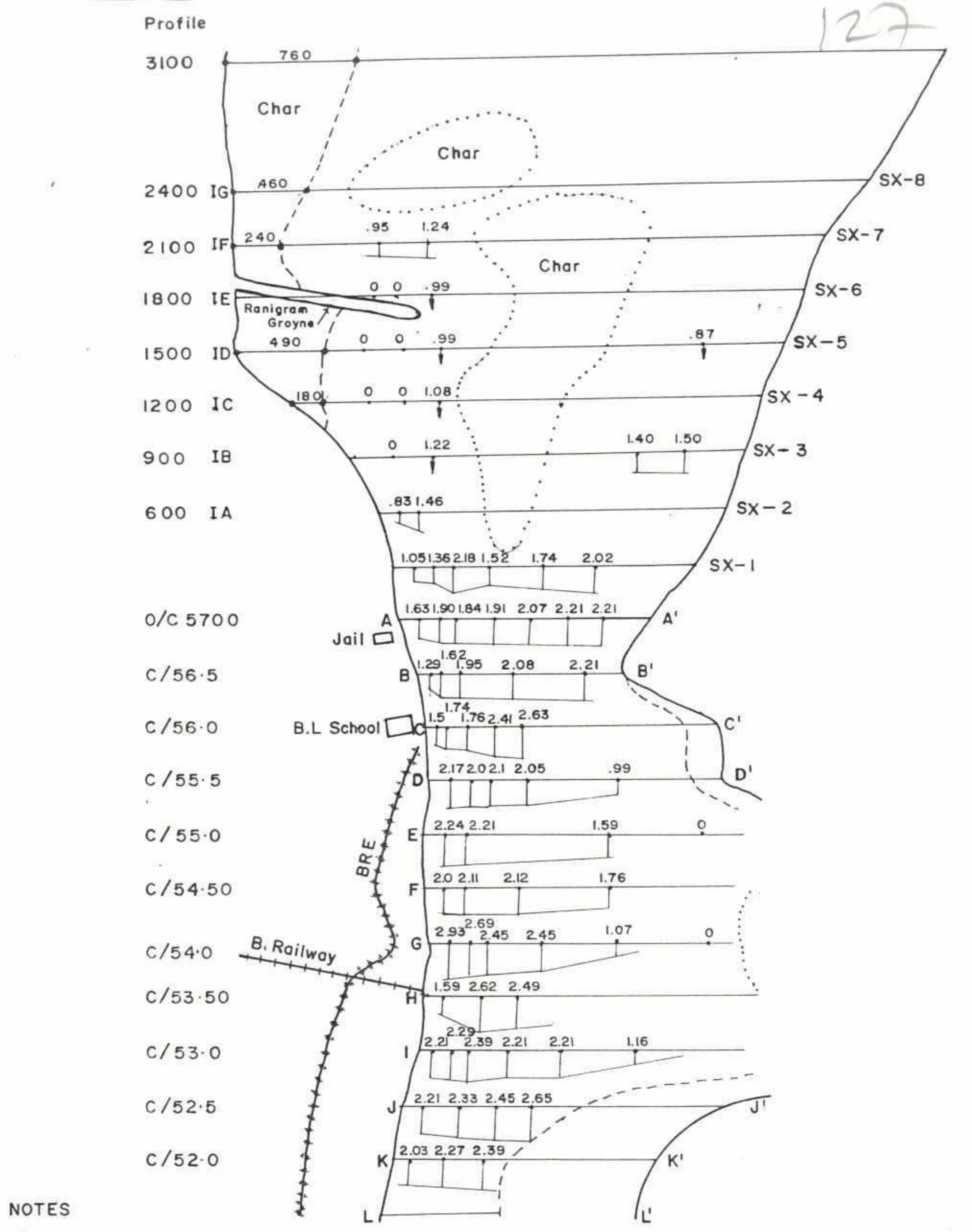
- Bathymetry plan II
  Survey 8 to 10 April 1991
- 100 years flood
  25,000 m³/s
- WL= +15.75 m
  Calculated average velocity 1.60 m/s

SIRAJGANJ PHYSICAL MODEL

Test no.03, VELOCITY MEASUREMENTS

PHASE : I

FIGURE : 3.3

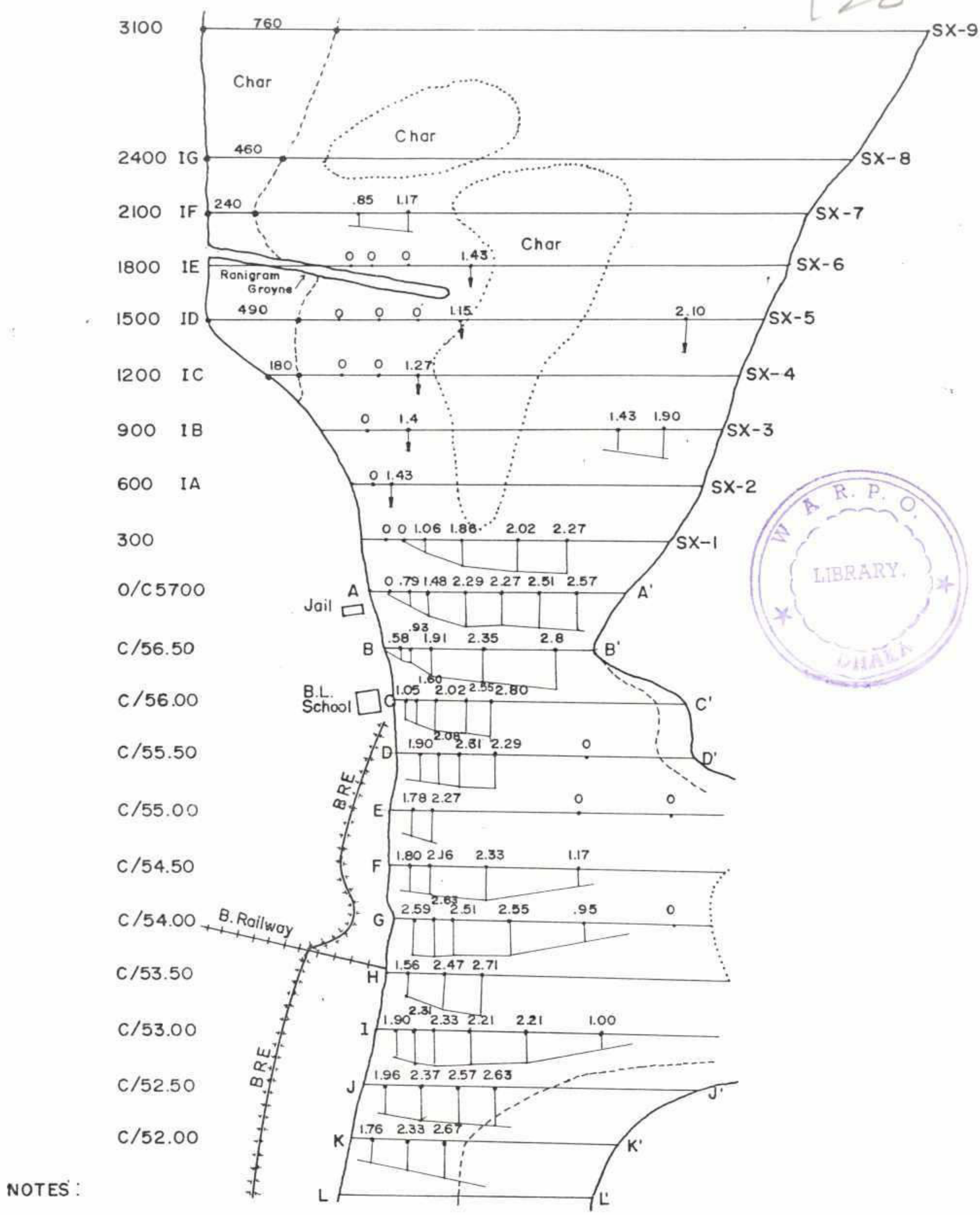


NOTES

Bathymetry plan – II
Survey – 8 to 10th April, 1991
100 years flood, 25,000 m^3/s
WL = + 15·75m Calculated
average velocity 1·6 m/s.

SIRAJGANJ PHYSICAL MODEL

Test no. 04,	VELOCITY MEASUREMENTS RANIGRAM GROYNE EXTENSION 300m	PHASE: II FIGURE: 4.1



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NOTES:

- Bathymetry plan-II survey 8 to 10 April 1991.
- 100 years flood, 25000 m^3/s
- WL = +15.75 m.
- Calculated average velocity = 1.6 m/s

0 1 2 3 4 5 6 7 8 9 10 m/s

VELOCITY VECTORS SCALE

SIRAJGANJ PHYSICAL MODEL

Test no.05,	VELOCITY MEASUREMENTS RANIGRAM GROYNE EXTENSION 600m	PHASE : II FIGURE : 4.2

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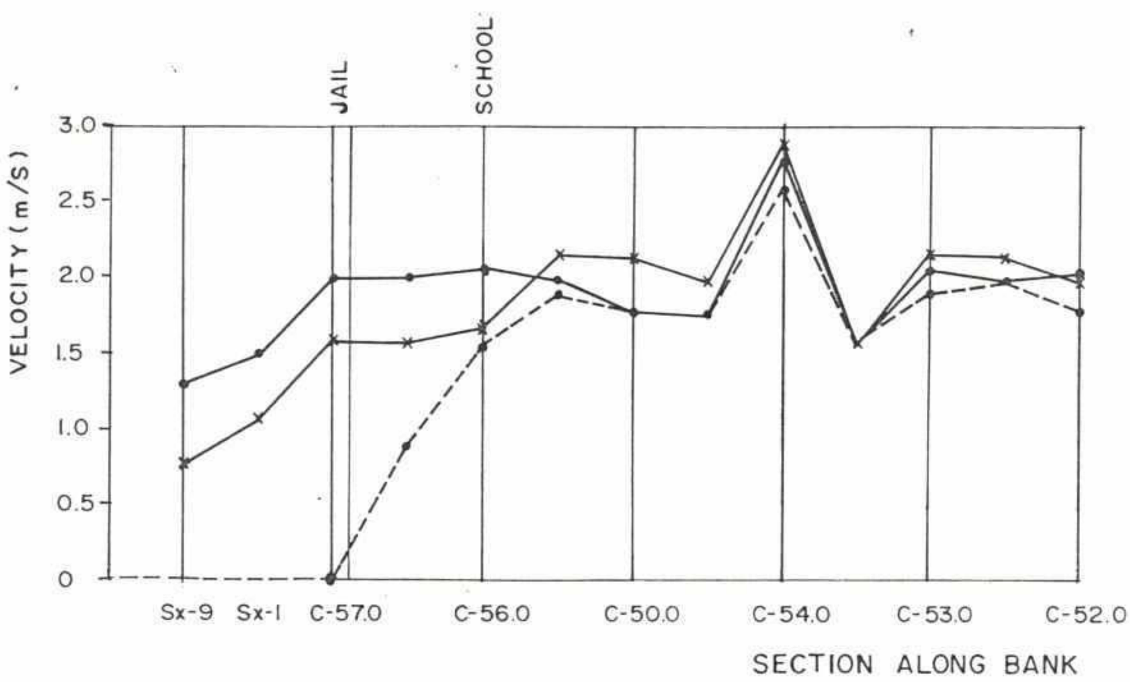


NOTE: Velocity measured 100m from the right bank

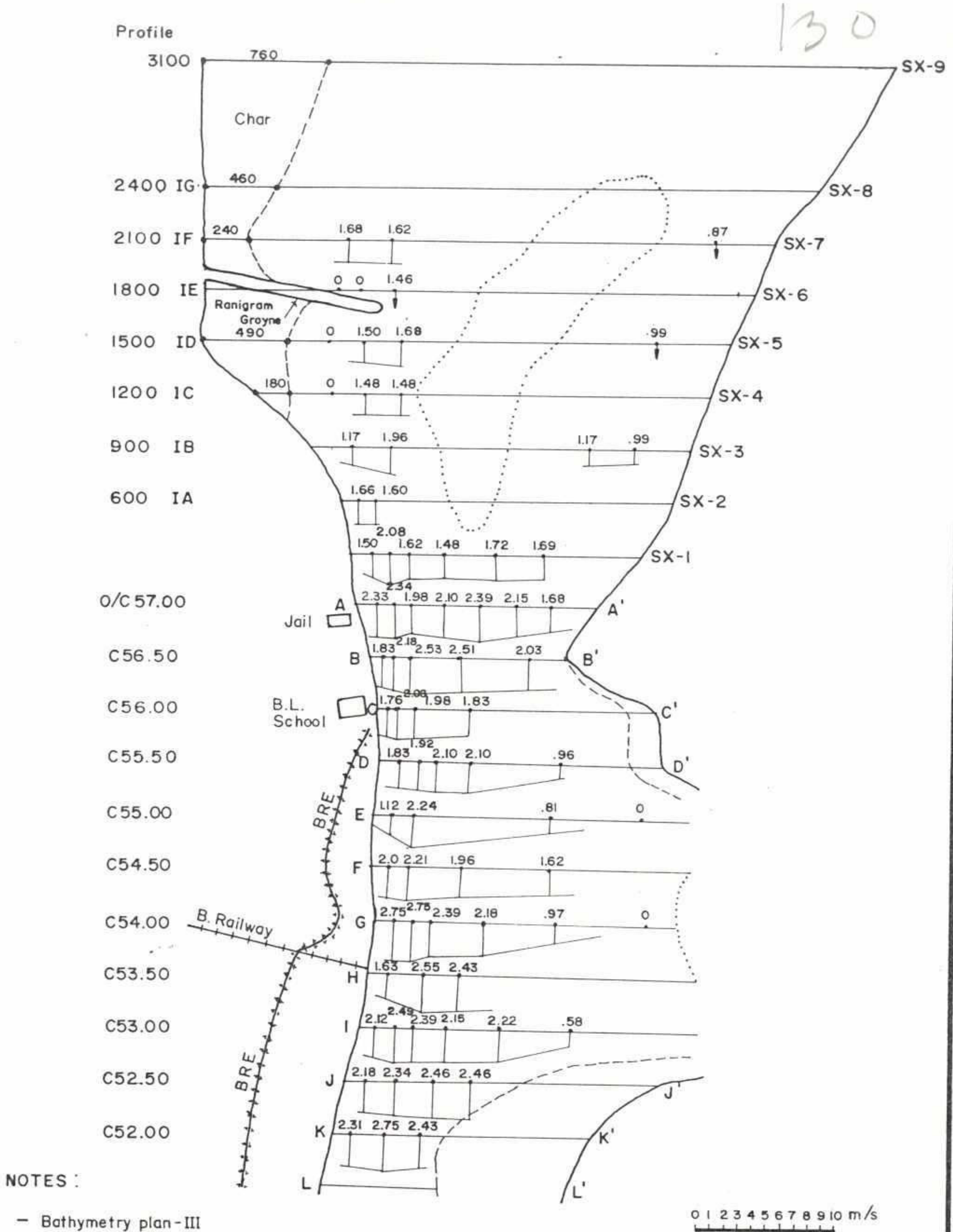
LEGEND:

•———• Velocity with Ranigram groyne of existing length.

×———× Velocity with Ranigram groyne +300m extension.

•- - - -• Velocity with Ranigram groyne +600m extension.

SIRAJGANJ PHYSICAL MODEL	
NEAR BANK VELOCITIES FOR EXISTING LENGTH OF THE RANIGRAM GROYNE AND 300m AND 600m EXTENSION	PHASE: II FIGURE: 4.3



NOTES :

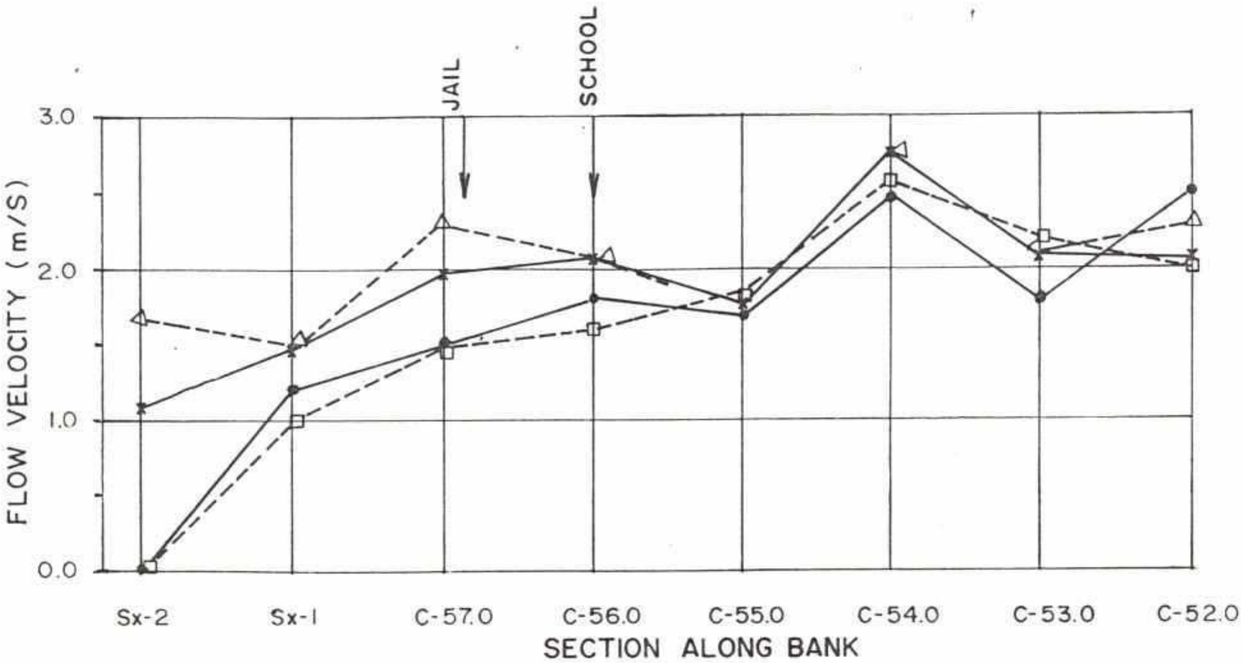
- Bathymetry plan-III
- 100 Years flood, 25,000 m³/s
- WL = +15.75 m.
- Calculated average velocity = 1.6 m/s

SIRAJGANJ PHYSICAL MODEL

Test no. 06, VELOCITY MEASUREMENTS

PHASE : III

FIGURE : 5.1

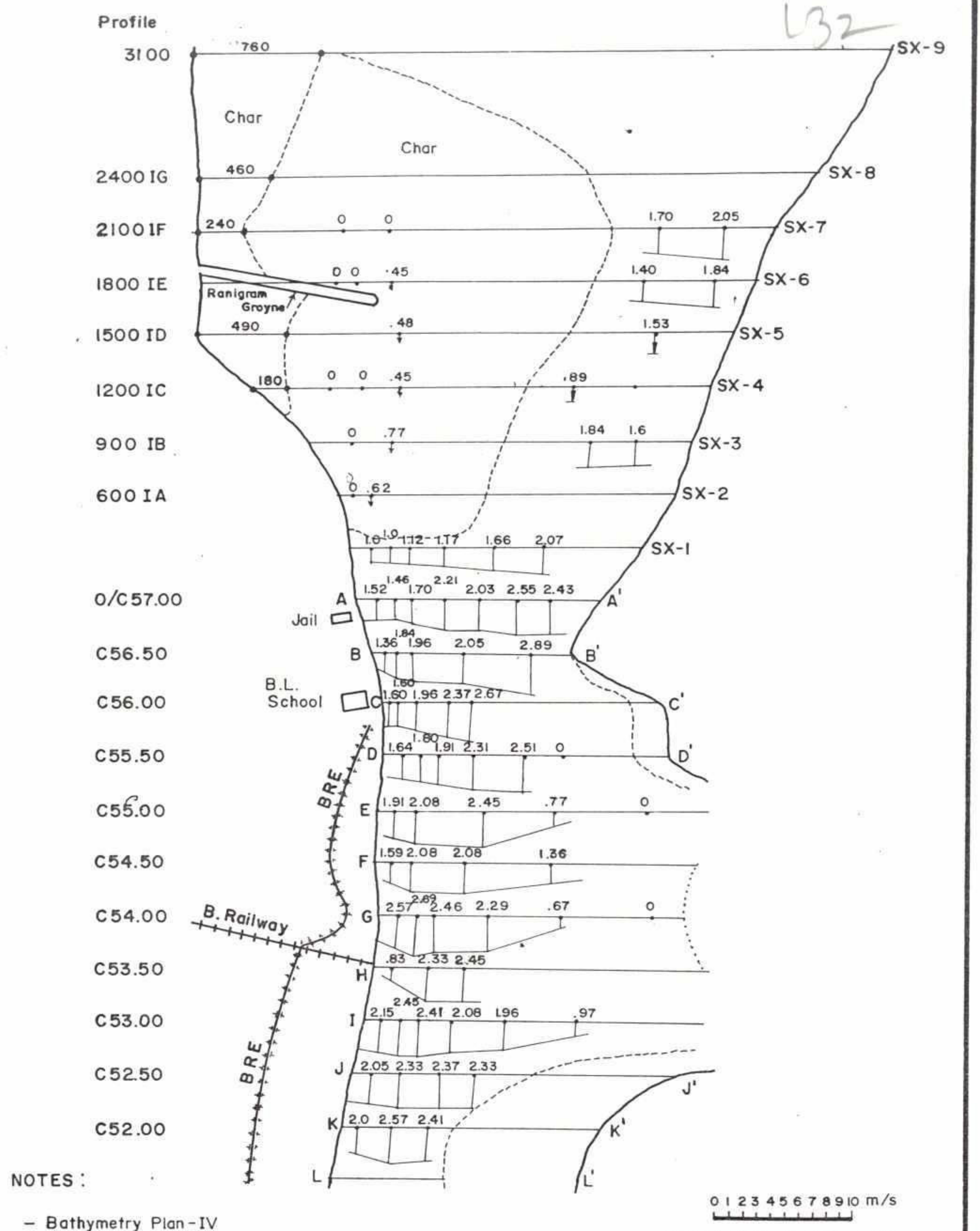


NOTE: Velocity measurements at 100m from right bank.

LEGEND:

- ●———● Velocity for plan - I
- ×———× Velocity for plan - II
- △- - - - △ Velocity for plan - III
- □- - - - □ Velocity for plan - IV

SIRAJGANJ PHYSICAL MODEL	
COMPARISON OF NEAR BANK FLOW VELOCITIES FOR PLANS I, II, III & IV	PHASE : III FIGURE : 5.2

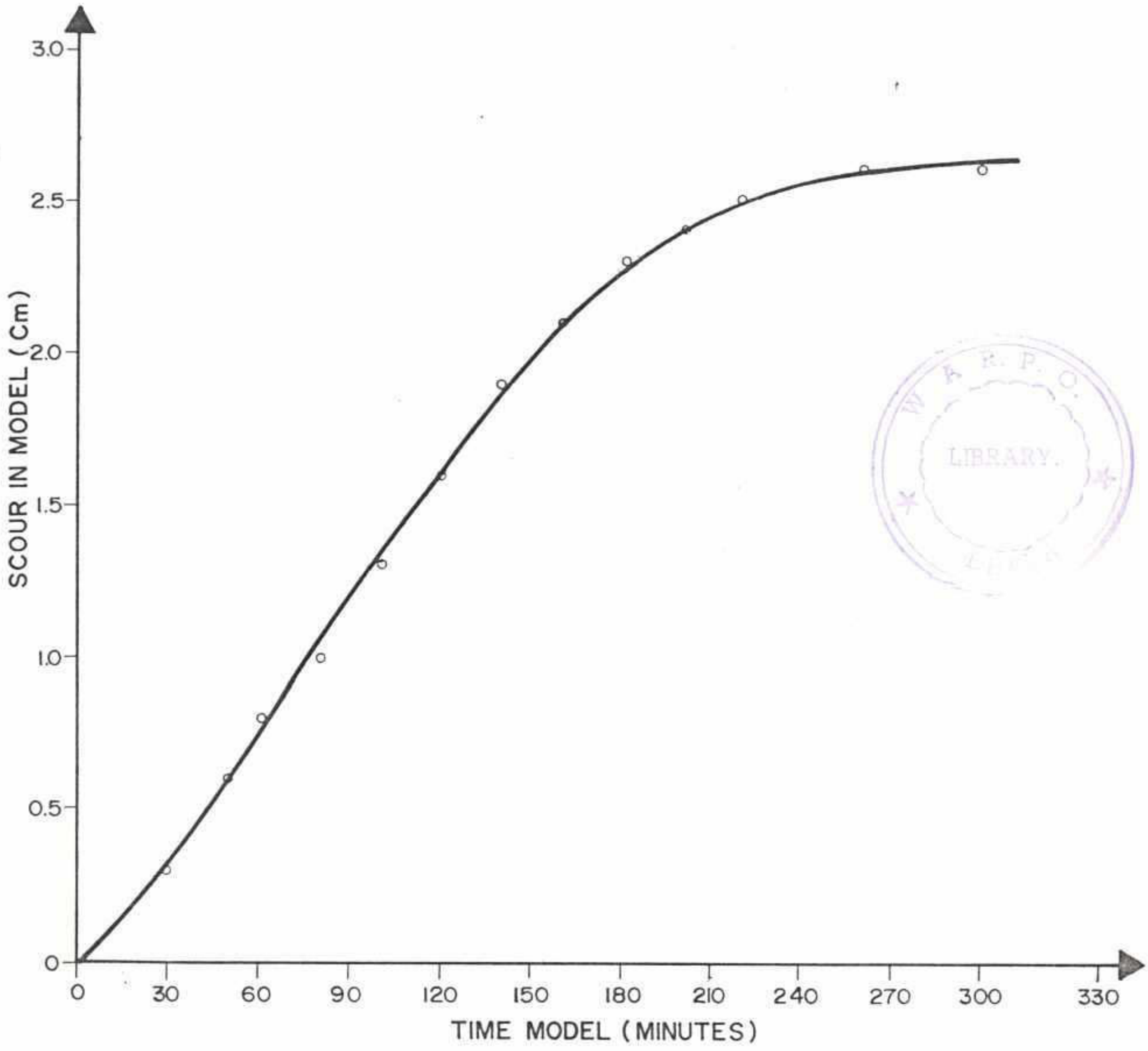


NOTES :

- Bathymetry Plan - IV
- 100 years flood, 25000 m³/s
- W.L. = + 15.75 m.
- Calculated average velocity = 1.6 m/s

SIRAJGANJ PHYSICAL MODEL

Test no. 07	VELOCITY MEASUREMENTS	PHASE : III
		FIGURE : 5.3



TEST NO. 6, Q = 25000 CUMECS.
W.L = 15·75m.

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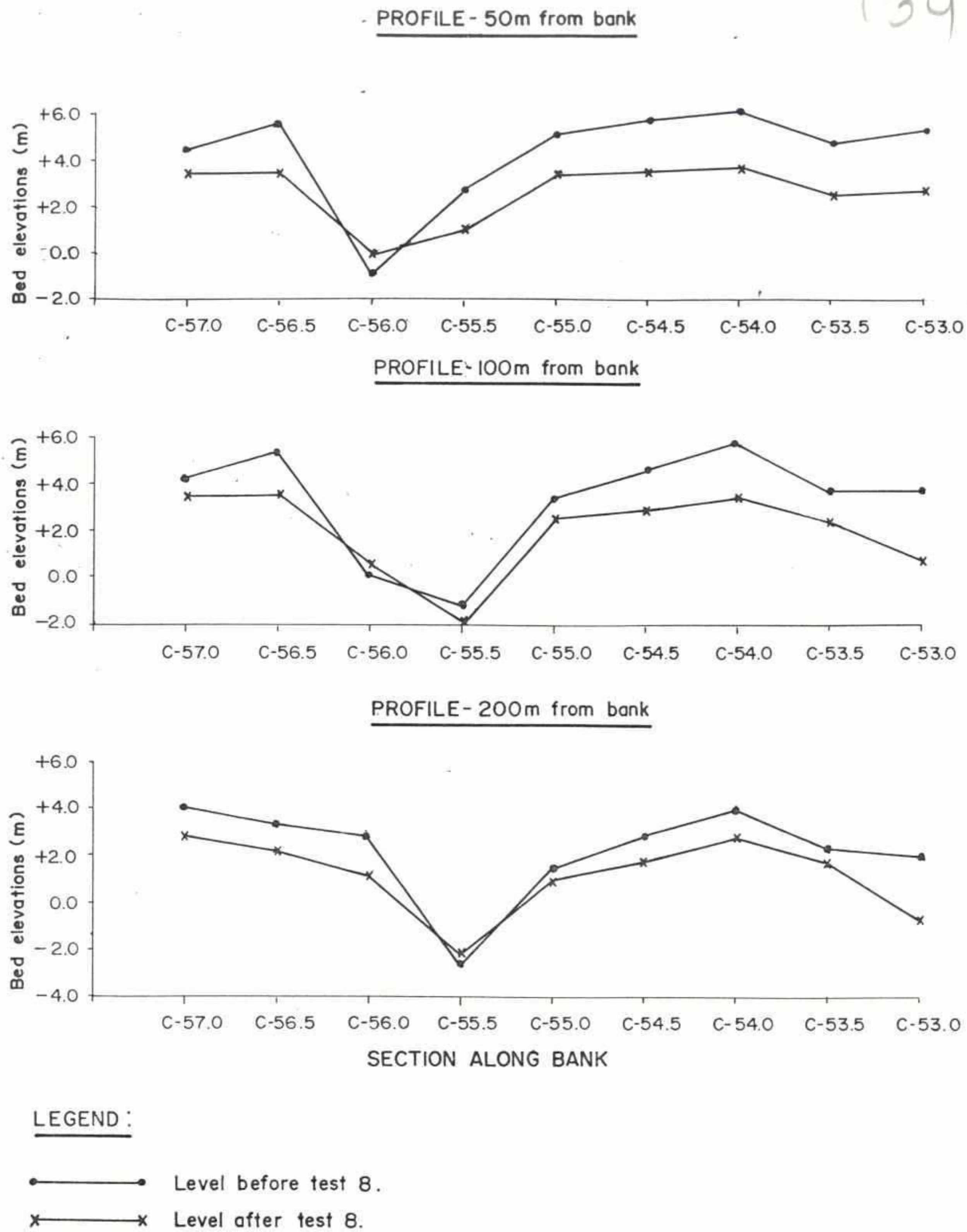
SIRAJGANJ PHYSICAL MODEL

DEVELOPMENT OF SCOUR AT THE NOSE OF RANIGRAM GROYNE	PHASE: III
	FIGURE: 5.4



SIRAJGANJ PHYSICAL MODEL		
Test no.08,	MEASUREMENTS OF SCOUR ALONG BANK	PHASE: III FIGURE: 5.5

SIRAJGANJ PHYSICAL MODEL
ASSESSMENT OF DISCHARGES AND OTHER ASPECTS FOR MODEL SET-UP

1. INTRODUCTION

The present note describes how the water discharges for the Sirajganj model were calculated.

2. CHANNEL GEOMETRY

The portion of the river reproduced in the model is located on a reach where two incoming channels meet leading to concentration of the flow near the right bank as sketched in Fig. 1. It extends from mileage 104 to 105.3 (Mileage zero is at Kaunia on the Teesta River). The latest data on the bathymetry of the channel comes from 11 cross-sections surveyed in December 1990 supplemented with 9 cross-sections surveyed in April 1991. The survey reveal that the width of the anabranch varies from 660 m to 2850 m and the maximum flow depth from 12.0 to 15.5 m below the level of the right bank (Level, 12.5 m).

For calculation of the design discharge the section, C-57, approximately in the middle is selected as representative. This section has a cross-sectional area of 10,900 m^2, an average depth of 7.6 m (below bank level + 12.50 m). The width of this anabranch is 1420 m. (see Fig. 2). At 100-years flood the area is 15520 m^2 and the average depth is 10.9 m.

3. WL V.S VELOCITY GRAPH

Fig. 3 shows the relationship between water level and mean velocity. The data comes from three sources, direct observations, hand calculations and numerical simulations by the MIKE 11. The first data as obtained by BWDB and the second by use of the Chezy Formula. These calculations are shown in Table 1. The third series of data were derived by BRTS during the 1-dimensional modelling using the MIKE 11. All these set of data appear to be in good agreement (see Fig. 3).

Table 1: Calculation of Velocity by Chezy Type Formulae

SIRAJGANJ PHYSICAL MODEL: CROSS SECTIONS

Sirajganj Physical Model Design
Calculations of Average Velocity using Chezy type Equation

Year	Water Level (m PWD)			Water Surface Slope S (m/m)	Water Depth Above Bank Level h'(m)	Hydraulic Radius R (m)	Average Velocity Equation 1 (m/s)	Average Velocity Equation 2 (m/s)
	Sirajanj	Jagannath ganj	Cross-Section J=7					
1	2	3	4	5	6	7	8	9
1962	14.145	15.485	14.708	0.00005180	2.208	9.875	1.273	1.435
1964	13.885	15.180	14.429	0.00005006	1.929	9.596	1.242	1.390
1966	13.870	15.230	14.441	0.00005257	1.941	9.608	1.274	1.426
1967	13.635	15.040	14.225	0.00005431	1.725	9.392	1.287	1.433
1968	13.940	15.250	14.490	0.00005064	1.990	9.657	1.252	1.403
1969	13.820	14.945	14.293	0.00004349	1.793	9.460	1.154	1.287
1970	14.220	15.795	14.882	0.00006088	2.382	10.049	1.386	1.569
1972	13.900	15.615	14.621	0.00006629	2.121	9.787	1.437	1.616
1973	14.220	15.910	14.930	0.00006533	2.430	10.097	1.437	1.629
1974	14.235	15.845	14.911	0.00006223	2.411	10.078	1.402	1.589
1975	13.600	14.980	14.180	0.00005334	1.680	9.347	1.274	1.417
1976	13.460	15.170	14.179	0.00006610	1.679	9.345	1.418	1.577
1977	13.900	15.490	14.568	0.00006146	2.068	9.735	1.382	1.552
1978	13.515	15.390	14.303	0.00007248	1.803	9.470	1.490	1.662
1979	13.670	14.830	14.157	0.00004484	1.657	9.324	1.168	1.297
1980	14.495	15.758	15.026	0.00004882	2.526	10.193	1.245	1.415
1983	14.190	15.475	14.730	0.00004967	2.230	9.897	1.247	1.407
1984	14.620	15.780	15.107	0.00004484	2.607	10.274	1.195	1.362
1985	14.150	15.740	14.818	0.00006146	2.318	9.985	1.390	1.572
1986	14.680	15.080	14.268	0.00005412	1.768	9.435	1.286	1.434
1987	13.570	16.004	15.173	0.00005543	2.673	10.339	1.331	1.519
1988	14.120	16.140	15.549	0.00003943	3.049	10.715	1.132	1.304
1989	15.634	14.680	14.074	0.00004043	1.574	9.240	1.106	1.226

Equation 1: $V = \left(\frac{8g}{f}\right)^{\frac{1}{2}} R^{\frac{1}{2}} S^{\frac{1}{2}}$

Equation 2: $V = \left(\frac{8g}{f + 4Rh}\right)^{\frac{1}{2}} R^{\frac{1}{2}} S^{\frac{1}{2}}$

g 9.81
zeta 0.0003236
f 0.012
f_bar 0.0195

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Summary on Velocities and Discharges

The 100-year flood discharge and the bank-full discharge is shown in Table 2.

Table 2: Calculated Flow - Velocity and Discharge in the present Anabranch in Section C-57

Flow Stage	Velocity	Discharge
Bank Full	0.85 m/s	9.300 m3/s
100-year Flood	1.60 m/s	25.000 m3/s

The 100-year flood discharge shown in Table 1, namely 25,000 m3/s is the discharge carried between the two banks of the anabranch. The total discharge taking the flow over the flood plain of the anabranch channel is 30000 m3/s. The Flood-plains extend to the BRE on the right bank and to a distance of 1.5 - 2.0 km over the neighbouring char on the left bank (see section 4 below).

4. FLOW OVER THE FLOOD PLAIN

The flow over the flood plain (with assumed width of 2000 m) is calculated in the following way.

Manning Formula:

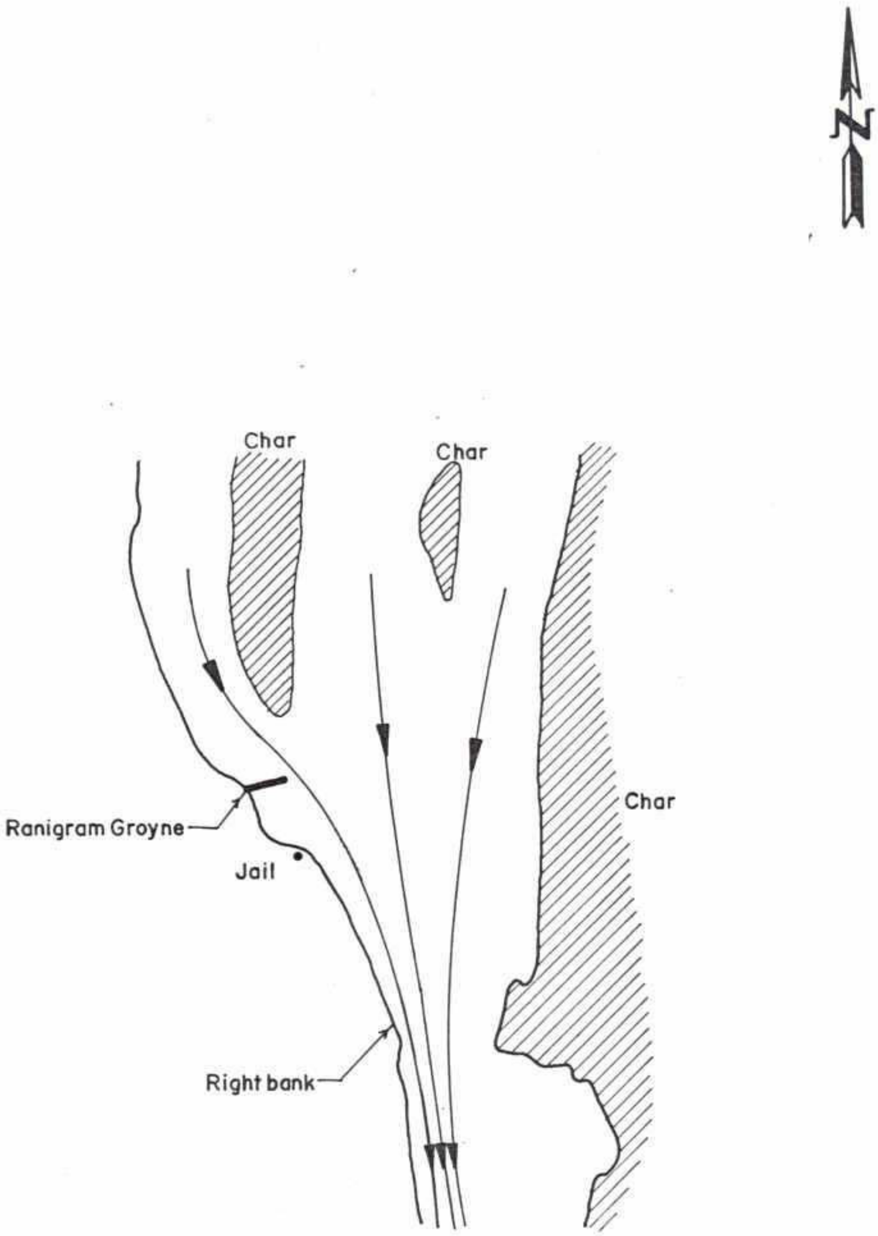
$$V = \frac{1}{n} \cdot R^{\frac{2}{3}} S^{\frac{1}{2}} = 0.58\ m/s$$

for: n = "roughness" coefficient = 0.035

R = (15.75 - 11.4) = 4.35 m

$S = 5.7 \times 10^{-5}$

$Q = A \times V = 4.35 \times 2000 \times 0.58 \approx \underline{5000}\ m^3/s$



SIRAJGANJ PHYSICAL MODEL

SKETCH OF MODEL AREA AND FLOW CHARACTERISTICS

APPENDIX : I

FIGURE : I

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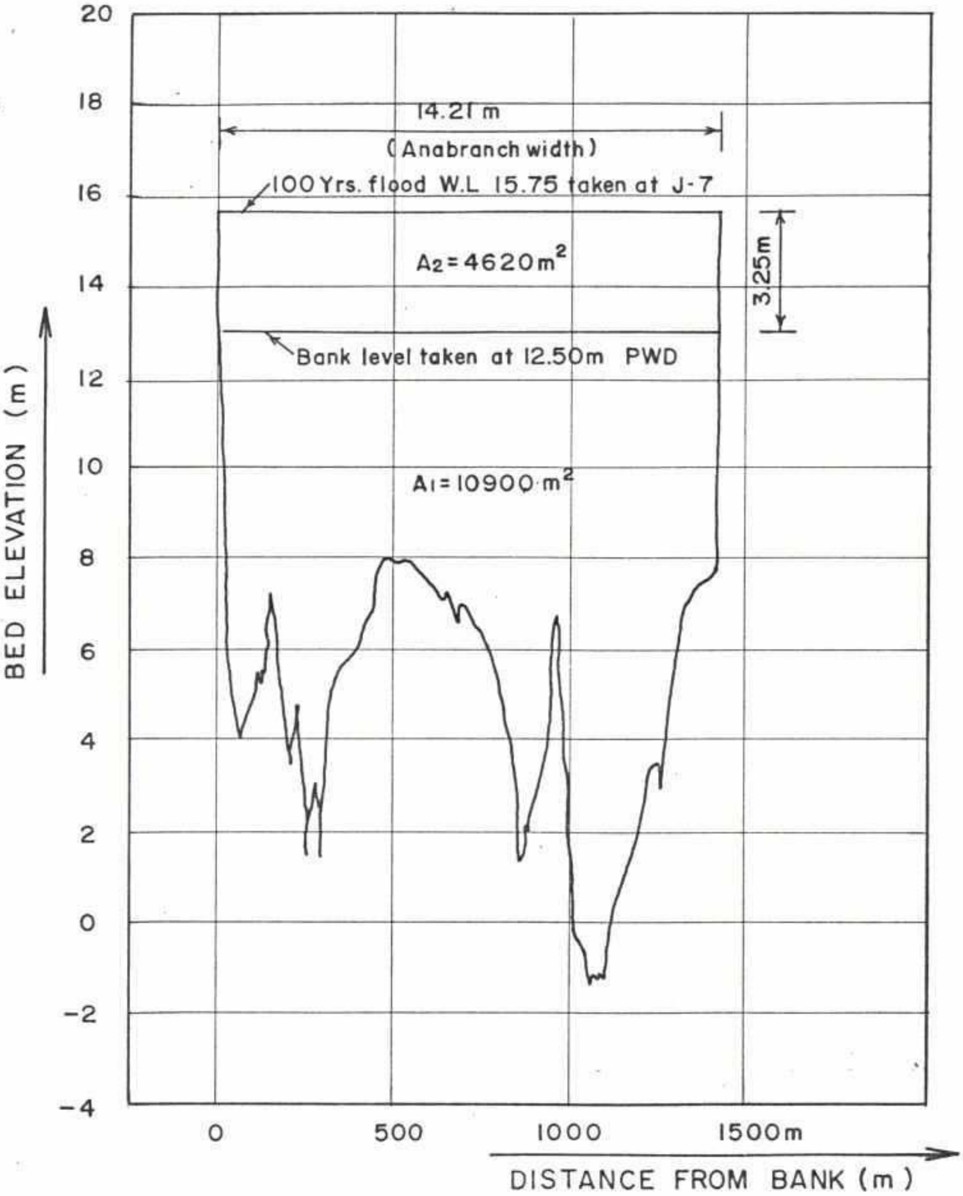


NOTES:

From WL V.S velocity graph (Fig. no-3).

Bank full: WL = + 12.50m, V= 0.85 m/S.

100 years flood: WL = +15.75m, V=1.60 m/S.

Bank full discharge: Q = A.V = 10.900 x 0.85 ≈ 9300 m^3/S.

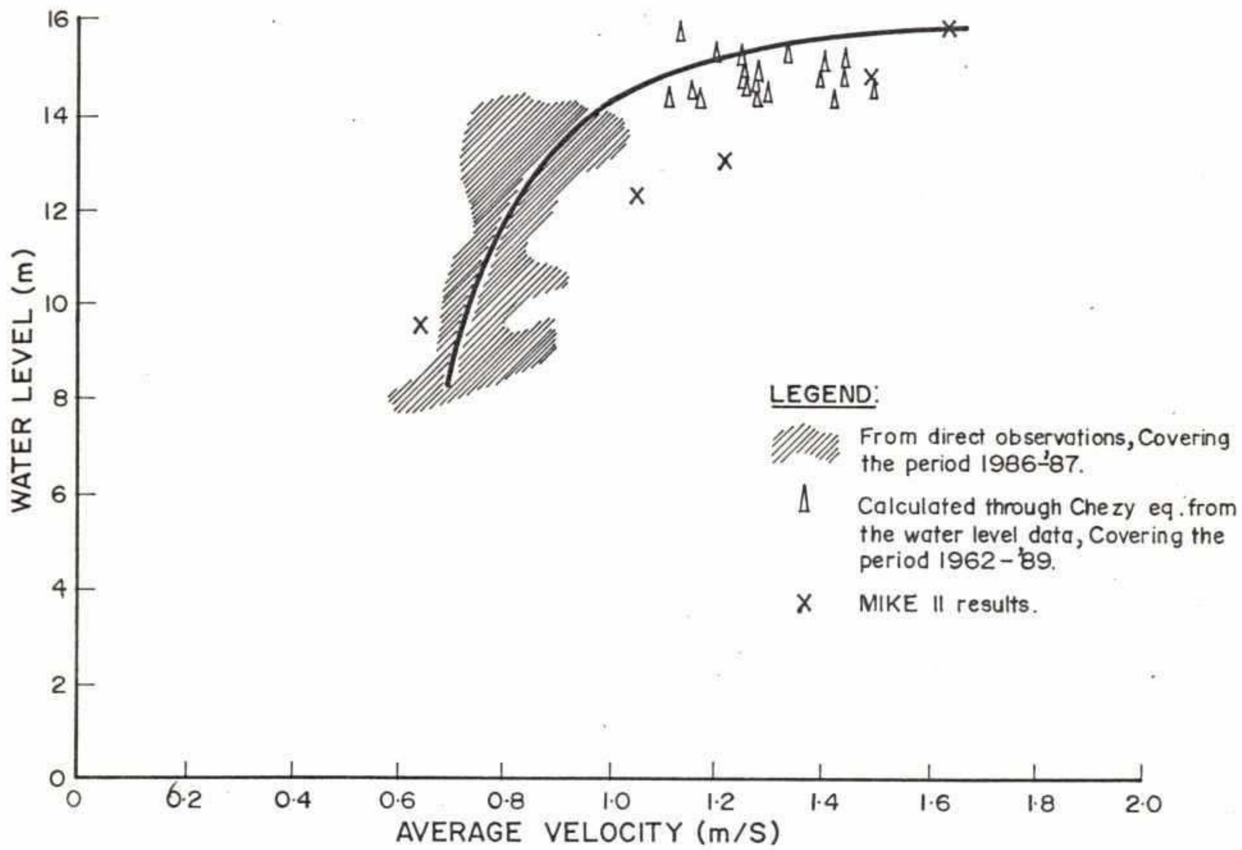
100 years discharge: Q= A.V= 15.520 x 1.60 ≈ 25000 m^3/S.

Average Depth (from bank level) =7.65m.

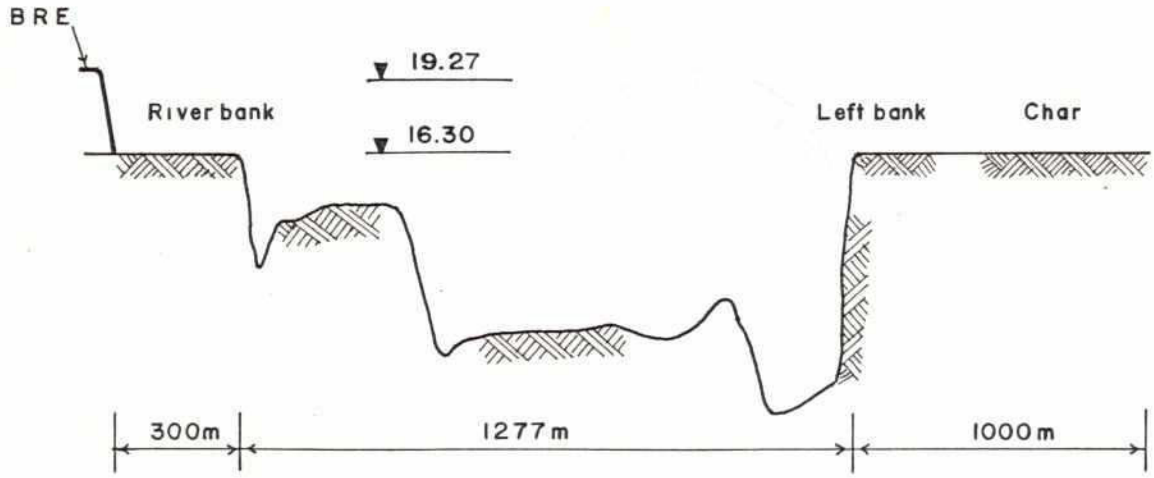
Average Depth (from 100 years level) =10.90m.

SIRAJGANJ PHYSICAL MODEL

CALCULATION OF DISCHARGE (cross-section C57)	APPENDIX : 1 FIGURE : 2



SIRAJGANJ PHYSICAL MODEL	
WATER LEVEL Vs. VELOCITY GRAPH	APPENDIX : I FIGURE : 3



SIRAJGANJ PHYSICAL MODEL
SKETCH OF THE ANABRANCH SITUATION AT CROSS-SECTION No. I

Appendix : I

FIGURE : 4

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