A REVIEW OF NON-TIDAL SCALE MODEL STUDIES IN BANGLADESH

Submitted by

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C E R T I F I C A T E

This is to certify that this work has been done by me and it has not been submitted elsewhere for the award of any degree or diploma.

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We hereby recommended that the project thesis prepared by MD. ABUL KASHEM entitled 'A REVIEW OF NON-TIDAL SCALE MODEL STUDIES IN BANGLADESH be accepted as fulfilling this part of the requirements for the degree of Master of Engineering (Water Resources).

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ABSTRACT

A survey was conducted to compile the scale model studies carried out at River Research Institute, Dhaka, Bangladesh. It was found that 97 model studies had been completed so far. Four additional models are ready for operation. The models were classified on the basis of the nature of boundary, scale distortion and purpose. It was found that 67 models were mobile bed and 30 models were fixed bed. Again 47 models were distorted and 50 models were undistorted. On the basis of the purpose it was found that 39 models were for irrigation, 26 for town protection and bank erosion, 7 for flood control, 8 for drainage and the rest 17 were for various other purposes. Short description of the selected models are also furnished.

Three selected mobile bed scale model studies conducted at River Research Institute, Bangladesh, were critically reviewed to examine and compare the design, construction, operation and data collection procedures. The selected models were (i) model for silt excluder tunnels of Teesta Barsage Project, (ii) model for protection of Kustia town from erosion of the river Gorai and (iii) model for protection of right flood embankment of the Brahmaputra-Jamuna river. It was found that model techniques practiced at River Research Institute did not comply fully with the standard practice.

Finally suggestions have been made for possible extension of the work.

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Md. Abul Kashem.

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LIST OF ABBREVIATIONS

ASCE	-	American Society for civil Engineers
BWDB	-	Bangladesh Water Development Board.
BPDB	-	Bangladesh Power Development Board
BRTC	-	Bureau of Research, Testing and Consultation
BUET	-	Bangladesh University of Engineering and Technology
BIWTA	-	Bangladesh Inland Water Transport Authority
CBIP	-	Central Board of Irrigation and Power
CHR	-	Canal Head Regulator
C.S	-	Cross-section
cfs	-	cubic feet per second
C.B	-	Cross-bar
DHL	-	Delft Hydraulic Laboratory
d/s	-	Down stream
ft.	-	feet
FRG	-	Federal Republic of Germany
Fig	-	Figure
HRL	-	Hydraulic Research Laboratory
HRS	-	Hydraulic Research Station
IAHR	-	International Association for Hydraulic Research
M.I.T	-	Massachussets Institute of Technology
M.S.	-	Mild steel
mm	-	Milimeter
NATO	-	North Atlantic Treaty Organization
R.L.	-	Reduced level
R	-	Report
RRI	-	River Research Institute

LIST OF ABBREVIATIONS (Contd..)

U/S	-	Up-stream
U.P.	-	Uttar Pradesh
U.S.A.	-	United States of America
V.E.	-	Vertical exaggeration

CHAPTER ONE

INTRODUCTION

1.1 GENERAL

The study of models, the application of model techniques and methods have found increasing use in engineering science during the past hundred years. The methods of physical modelling have been applied to a wide variety of problems, among which river and hydraulic problems are notable. Owing to a number of complex factors in the design of hydraulic structures, all details can not be obtained by analytical methods or use of emperical formulae. Hydraulic models offer an effective and handy tool in these cases. These models, that incur a small portion of expenditure of the project, eliminate the designers doubt and indecisions, enable him to visualise the problem better and come out with improvement in design (Kobus, 1980).

About a century ago Fargue built the first known movable bed model of the Garrone river near Bordeaux (Devries, 1974). The model was undistorted with a length scale of 100; the time and velocity scales were, however, not properly defined. It was reported that the model was used with appreciable success. Since then physical models have been used for solving various problems in river engineering. Problems related to change in channel cross section and meander geometry caused by construction of dams, etc; problems related to navigation such as execution of cut-offs, optimum location and spacing of spurs etc., rejuvenation of dying channels, control of sediment entry into canal; location and alignment of bridges, control of rivers at bridges and barrages, protection of banks, scour and silting in the vicinity of intake structures etc. can be solved through physical models.

In Bangladesh, a Hydraulic Research Laboratory established in 1948 and recently been named River Research Institute (RRI) is under the control of Bangladesh Water Development Board (BWDB). The institute has been conducting physical model tests on problems related to hydraulic structures river training, and water development projects. More than one hundred model studies are reported to have been accomplished at RRI. Most of these studies were carried out for BWDB. They have also conducted a number of model studies for other organizations and private sectors.

In India numerous hydraulic model studies have been undertaken at different research stations, like the Poona Research Station; Hydraulic Research Station, Bahadrabad; U.P.; Irrigation Institute, Roorkee; Hydraulic Research Station, Malakpur (Joglekar, 1971). The subject of the model experiments in these research studies were river models, models on river training works, models on barrage, weir, canal head-works, bridges, models of tidal estuaries, ports, harbours and coastal erosion, etc. In Pakistan the biggest hydraulic laboratory is located at Nandipur near Lahore. There are numerous reputed laboratories engaged in conducting model studies on the field of water resources engineering in the world. Notable few among them are Delft Hydraulics Laboratory (DHL), Netherlands, Hydraulics Research Station

(HRS), Wallingford, U.K.; Danish Hydraulic Institute, Denmark, US Corp of Engineers Laboratory at Vicksburgh, USBR Laboratory at Denver and SOGREA at Greenoble, France.

The Hydraulic problems related to water resources development of Bangladesh on which model studies have been performed, so far, has not yet been reported in a single volume. This compilation would help the hydraulic engineers associated with the development of water resources to have a quick reference about the extent and varieties of model studies conducted in Bangladesh. The comparison of the model techniques practiced at the RRI with standard modelling techniques will give an insight into practices in Bangladesh and enable us to improve the techniques now in use.

According to the flow conditions these models can be built either for tidal rivers or non-tidal rivers. The present study will be devoted on non-tidal river models only.

1.2 OBJECTIVE OF THE STUDY

The objectives of the present study are as follows:

i) To conduct a survey of the non-tidal scale models carried out in Bangladesh by the River Research Institute (RRI).

ii) To critically examine the design, construction, operation and data collection procedures for selected mobile bed models conducted at the Institute.

iii) To make recommendations towards improvement of modelling techniques at RRI.

CHAPTER TWO

REVIEW OF LITERATURE ON SCALE MODELS

2.1 INTRODUCTION

During the latter part of the nineteenth century, model began to be used for the study of water flow phenomena. A vast amount of literature on scale models is available. However, only a few texts have been produced so far;among the notable are the works of Allen (1947), ASCE (1963), Yalin (1971), Ivicsics (1975), Shen (1979), Jansen (1979) and Sharp (1981). Langhaar (1956) provided a good introduction to dimensional analysis; Birkhoff (1960) contributed to the philosophy of the the use of physical models.

The two types of model:physical model and mathematical model, generally have their own fields of application but may occasionally be used in conjunction. Brifly the areas of application depend upon the characterstics and nature of each of the problem. Mathematical models can cover large areas but they give little detail of the physical phenomena. Physical models usually cover relatively small areas and can therefore give much more detail information. The advantages and disadvantage of the two model types are sometimes balanced by combination of physical models and mathematical models (de Vries, 1973). Both types of model involve the schematization of physical phenomena and river geometry. This means that they must be calibrated and only used to forecast new situations when they have proved to reproduce existing situations correctly.

The accuracy of reproduction or prediction of real situations depends upon the accuracy and extent of data available when setting up model. The model itself cannot subtitute for lack of prototype data; on the contrary additional field data are often required before reliable results can be obtained.

2.2 NATURE OF HYDRAULIC PROBLEMS

Phenomena involved in the study of hydraulic problems generally relate to the irrotational motion of flow over weirs and through sluices, viscous flow in pipes, turbulent flow in pipes and open channels, non-uniform flow and back-water curves, sediment transportation and control, wave motion and wave action, tidal flow, density currents, air entrainment, water hammer, caviation, etc. Newtons law of motion is the fundamental relation governing all the hydraulic phenomena mentioned above. This law can be expressed in the form of a dimensionless number called the Newtons Number. Besides the forces of inertia, other forces are due to (a) gravity, (b) fluid friction, (c) capillarity and (d) elasticity. Corresponding to each of these forces, there is a dimensionless number, viz., a) Froude number (b) Reynolds number (c) Weber number and (d) Cauchy or Mach Number. In general the number of dominant forces operating in any fluid movement is one or, sometimes two, the effects of other forces being negligible for most practical purposes.

2.3 DIMENSIONAL ANALYSIS

Dimensional analysis is a process whereby the variables pertinent to a physical problem are systematically organised into dimensionless groups. Such organization effectively reduces the number of unknowns and generalize the problem in a way that eleminates the need for specifying any system of unit. The methods of dimensional analysis are based upon the principle of dimensional homogenity, which states that an equation expressing a physical relationship between quantities must be dimensionally homegeneous, i.e. the dimensions of each term of an equation must be the same. Dimensional analysis is a necessary adjunct to the principle of similarity.

Barr (1983) has classified and critically compared the different procedures for dimensional analysis namely Rayleigh, Buckingham, stepwise, echelon matrix and proportionalities stepwise.

Barr (1969, 1971), has introduced a procedure for formulation of non-dimensional groups known as the methods of synthesis. This method is best defined as a procedure for the formulation of non-dimensional functional equation in n terms from dimensionally homogeneous equation in (n+1) terms and where the components of the (n+1) term equation have been reduced by a similitude argument. Details of this procedure are available elswhere (Barr 1969,1971, Hossain 1985,1987).

2.4 SIMILITUDE APPROACH

Two physical systems of different size in which one accurately reproduces the phenomena of the other, are called the similar system. The same particular laws apply to both systems and the equations written for one system must be equally valid for the other. If the systems are the same size, one is called a replica of the other.

Similarity is a general term covering different kinds of similarities, such as geometric, kinematic and dynamic. Dynamic similarity is the similarity of forces. If two systems are dynamically similar, then the magnitude of forces at similarly located points in each system are in a fixed ratio. Geometric similarity is probably the most obvious requirements for a model study in hydraulic engineering. This is usually achieved by making sure that each length of the pototype is some ratio of the model. Kinematic similarity is the similarity of velocities, acceleration. It is achieved by ensuring that the shape of the streamlines at any particular time is the same in the model and prototype.

For dynamic similitude to be possible between two compared systems where acceleration is taking place, the ratio of representative intertial force ($\rho L^2 V^2$) to representative active force must be the same, in both cases. This leads to formation of some non-dimensional groups. Different type of active forces and corresponding non-dimensional groups are shown in table 2.1.

In the problems to be studied by models, one has to consider initially which of the forces predominate and influence the hydraulic phenomena. If gravity is only force producing the motion, Froude's Law will be applicable. If frictional forces govern the motion, Reynolds' Law will be applicable. Generally Froude's and Reynolds' Laws are decisive in fixing the type and scales of models. Froude's Law postulates direct variation of velocity with respect to the square root of the depth, where as Reynolds Law requires inverse variation of velocity to depth. Consequently, complete similitude is scarcely attainable in hydraulic model testing. Model testing is not based on absolute similitude but rather on several partial similitudes which can be exploited as required.

2.5 ANALYTICAL CRITERIA FOR SIMILITUDE

According to Newton's Law of motion:

$$F_i = M \times a$$

where, F_i = Inertial force, M = mass, and a = acceleration.

Writting, $M = \rho L^3$ and $a = \frac{L}{T^2}$

$$F_{ir} = \rho_r \; L_r^3 \; X \; \frac{L_r}{T_r^2}$$

$$= \rho_r \; L_r^2 \; X \; V_r^2$$

The suffix referes to the model prototype ratio.

Thus, $\frac{F_{ir}}{\rho_r L_r^2 V_r^2} = 1$ .... (1)

$\frac{F_i}{\rho L^2 V^2}$ is a dimensionless number disignated as Newton's Number which is independent of the nature of operating forces.

Thus dynamic similarity can exist in two fluid motions if the ratio of the inertial forces F_{ir} equals the ratio of the vector sum of the active forces (model to prototype). When gravity is the predominant force, then $F_{ir} = F_{gr}$, where F_{gr} represents the ratio of the forces imposed on the liquid mass by gravity.

$$F_{gr} = \nu_r L_r^3$$
$$= \rho_r g_r L_r^3.$$

But according to equation (1)

$$F_{ir} = \rho_r L_r^2 V_r^2$$

So, $F_{ir} = F_{gr}$

or, $\rho_r L_r^2 V_r^2 = \rho_r g_r L_r^3$

or, $\frac{V_r^2}{L_r g_r} = 1$ ..... (2)

In otherwords, when dynamic similarity exists in two fluid systems and gravity force is the dominant force then Froude's

Number of the model $\left(\frac{V}{\sqrt{gL}}\right)_m$ is equal to the Froude's Number of the prototype, $\left(\frac{V}{\sqrt{gL}}\right)_p$.

Similarly, when viscous forces dominate the fluid system, for dynamic similarity, Reynolds' Number of the model, $\left(\frac{VL}{\nu}\right)_m$ is equal to the Reynolds' Number of the prototype, $\left(\frac{VL}{\nu}\right)_p$. When surface tension dominates the fluid system, for dynamic similarity, Weber Number of the model $\left(\frac{V^2\rho}{\sigma/L}\right)_m$ is equal to the Weber Number of the prototype $\left(\frac{V^2\rho}{\sigma/L}\right)_p$. When pressure dominates the fluid system, for dynamic similarity, Euler Number of the model $\left(\frac{V^2}{p/\rho}\right)_m$ is equal to the Euler Number of the prototype $\left(\frac{V^2}{\rho/\rho}\right)_p$. And when elastic force dominate the fluid system, for dynamic similarity, Mach Number of the model $\left(\frac{V}{\sqrt{E/\rho}}\right)_m$ is equal to the Mach Number of the prototype $\left(\frac{V}{\sqrt{E/\rho}}\right)_p$.

However, in a fluid flow system occasionally more than one dominating force system may occur. These situations are illustrated below.

Case-I: When only gravitational force governs the flow characteristics i.e., in case where Froude's Law governs the fluid flow, then for dynamic similarity the Froude number in the model and prototype would be same.

So, $\left(\frac{V^2}{gL}\right)_m = \left(\frac{V^2}{gL}\right)_p$

or, $\frac{V_r^2}{g_r L_r} = 1$

or, $V_r^2 = g_r L_r$

or, $V_r = \sqrt{L_r}$ ... (3) (Since $g_r = \frac{g_m}{g_p} = 1$)

Time scale ratio, $Tr = \frac{L_r}{V_r}$

$$= \frac{L_r}{\sqrt{L_r}}$$

$$= \sqrt{L_r} \quad \ldots (4)$$

These expressions find extensive use in hydraulic laboratory practice, since a majority of model studies are of the type in which the force of gravity predominantly controls the motion. Other scale relations can be derived from equations (3) and (4), e.g.

Discharge Scale, $Qr = L_r^2 \cdot V_r$

$$= L_r^2 \quad (\sqrt{L_r})$$

$$= (L_r)^{5/2}$$

Force scale, $F_r = \rho_r \; L_r^3 \cdot \frac{L_r}{T_r^2}$

$$= \rho_r \; L_r^3 \; \frac{L_r}{(\sqrt{L_r})^2}$$

$$= \rho_r \; L_r^3$$

Case II: When viscous forces dominate the fluid system i.e., Reynolds' Law governs the flow characteristics then for dynamic similarity the Reynolds' Number in model and in prototype would be same, i.e.,

$$\left(\frac{VL}{\nu}\right)_m = \left(\frac{VL}{\nu}\right)_p$$

or, $$\frac{L_r V_r}{\nu_r} = 1$$

or, $$V_r = \frac{\nu_r}{L_r} \quad \ldots (5)$$

Time scale, $$T_r = \frac{L_r}{V_r}$$

$$= \frac{L_r}{\nu_r / L_r}$$

$$= L_r^2 / \nu_r$$

Discharge scale, $$Q_r = L_r^2 \; V_r$$

$$= L_r^2 \, . \, \nu_r / L_r$$

$$= L_r \; \nu_r$$

Force scale, $$F_r = \rho_r \; L_r^3 \; \frac{L_r}{T_r^2}$$

$$= \rho_r \; L_r^3 \; \frac{L_r}{(L_r^2 / \nu_r)^2}$$

$$= \rho_r \; \nu_r^2$$

Case III: When surface tension dominates the fluid system i.e. Weber Law governs the flow characteristics, then for dynamic similarity,

$$\left(\frac{V^2}{\sigma/L}\right)_m = \left(\frac{V^2}{\sigma/L}\right)_p$$

$$V_r^2 \ \rho_r = \frac{\sigma_r}{L_r}$$

$$V_r = \left(\frac{\sigma_r}{L_r \rho_r}\right)^{\frac{1}{2}}$$

Time scale, $T_r = \dfrac{L_r}{V_r} = \dfrac{L_r}{\sqrt{\dfrac{\sigma_r}{L_r \rho_r}}}$

$$= \frac{L_r^{3/2}}{\sqrt{\sigma_r / \rho_r}}$$

Discharge scale, $Q_r = L_r^2 \ V_r$

$$= L_r^2 \ \left(\frac{\sigma_r}{L_r \rho_r}\right)^{\frac{1}{2}}$$

$$= \frac{L_r^{3/2}}{\sqrt{\rho_r / \sigma_r}}$$

Force scale, $F_r = \rho_r L_r^3 \ . \ \dfrac{L_r}{T_r^2}$

$$= \rho_r L_r^4 \ . \ \frac{\sigma_r}{L_r^3 \ \rho_r}$$

$$= L_r \ \sigma_r$$

Case IV: When pressure force dominates the fluid system i.e. Euler law governs the flow characteristics, then for dynamic similarity,

$$\left(\frac{V^2}{P/\rho}\right)_m = \left(\frac{V^2}{P/\rho}\right)_p$$

$$V_r^2 = \frac{P_r}{\rho_r}$$

$$V_r = \sqrt{\frac{P_r}{\rho_r}}$$

Time scale, $T_r = \frac{L_r}{V_r} = \frac{L_r.}{\sqrt{P_r}} \sqrt{\rho_r}.$

$$= \frac{L_r \sqrt{\rho_r}}{\sqrt{P_r}}$$

Discharge scale, $Q_r = L_r^2 \cdot V_r$

$$= L_r^2 \sqrt{\frac{P_r}{\rho_r}}$$

$$= \frac{L_r^2 \sqrt{P_r}}{\sqrt{\rho_r}}$$

Force scale, $F_r = \rho_r L_r^3 \cdot \frac{L_r}{Tr^2}$

$$= \rho_r L_r^3 \cdot \frac{L_r P_r}{L_r \rho_r}$$

$$= L_r^2 P_r$$

Case V: When Elastic force dominates the fluid system i.e. Mach law governs the flow characteristics, then for dynamic similarity

$$\left(\frac{V}{E/\rho} \right)_m = \left(\frac{V}{E/\rho} \right)_p$$

$$V_r = \left(\frac{E_r}{\rho_r} \right)^{\frac{1}{2}}$$

Time scale, $T_r = \frac{L_r}{V_r} = \frac{L_r}{(E_r/\rho_r)^{\frac{1}{2}}}$

$$= \frac{L_r \sqrt{\rho_r}}{\sqrt{E_r}}$$

Discharge scale, $Q_r = L_r^2 \cdot V_r$

$$= L_r^2 \left(\frac{E_r}{\rho_r} \right)^{\frac{1}{2}}$$

$$\frac{L_r^2 \sqrt{E_r}}{\sqrt{\rho_r}}$$

Force scale, $F_r = \rho_r L_r^3 \cdot \frac{L_r}{T_r^2}$

$$= \rho_r L_r^4 \frac{E_r}{L_r^2 \rho_r}$$

$$= L_r^2 E_r$$

The scale ratios for different flow conditions are summerised in Table 2.2.

When more than one type of forces are significant in a phenomenon, for example the gravititional and frictional forces, a number of model techniques have been developed. The similitude relationship requires in such a case, the equivalence of the value of Froude's number and Reynolds number for the two systems simultaneously, or in other words:

$$V_r = \sqrt{L_r} = \frac{\nu_r}{L_r}$$

or, $\nu_r = (L_r)^{3/2}$

Hence the condition of similitude could be fulfilled only if the liquids in the model and prototype satisfy the above relation. If the same liquid (water) is used in the model as in the prototype, $\nu_r = 1$ and hence $L_r = 1$, or the model length should be equal to those in the prototype, which means a model is theoretically impossible.

A different line of approach is, therefore adopted, which utilises the similitude of Mannings Equation:

Manning Equation, $V = \frac{1.486}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$

where n = Mannings roughness coefficient or rugosity coefficient which accounts for frictional forces, R = hydraulic mean depth, and S = is the slope of the energy line.

It should be remembered that Manning's n is strictly, a roughness characteristic, and that the Manning's formula applies only for sufficiently high value of Reynolds Number when resistance forces are proportional to the square of the velocity. For similitude in prototype and model:

$$V_r = \frac{1}{n_r} R_r^{\frac{2}{3}} S_r^{\frac{1}{2}}$$

whereas according to Froude's relationship:

$$V_r = (g_r L_r)^{\frac{1}{2}}$$

Equating these: $(g_r L_r)^{\frac{1}{2}} = \frac{1}{n_r} R_r^{\frac{2}{3}} S_r^{\frac{1}{2}}$ ... (6)

$$\frac{1}{n_r} L_r^{1/6} S_r^{\frac{1}{2}} = 1 \quad \ldots \quad (7)$$

Equation (7) gives the relationship between L_r, S_r and n_r for fulfilling the requirements of dynamic similitude. Three distinct cases arise from this equation:

Case 1: Consider a geometrically similar model with surface fall in prototype equal to that in model i.e., $S_r = 1$.

$$n_r = L_r^{1/6} \qquad \ldots \qquad (8)$$

Once the scale is selected, the above equation states the requirement of roughnes coefficients in the two systems.

Case 2: Consider next a geometrically similar model with S_r variable. If it is not possible to alter the roughness of the model boundary, similitude can be accomplished by fitting the model so as to satisfy the equation.

$$S_r^{\frac{1}{2}} = \frac{n_r}{L_r^{1/6}} \qquad \ldots \qquad (9)$$

Case 3: Finally consider a distorted model with

$$\frac{Y_r}{X_r} = S_r$$

where, Y_r = vertical scale ratio, and

X_r = horizontal scale ratio.

$$\frac{1}{n_r} \cdot R_r^{\frac{2}{3}} \; Sr^{\frac{1}{2}} = \sqrt{Lr} \qquad \text{(from eqn. (6))}$$

$$\frac{1}{n_r} \; Y_r^{\frac{2}{3}} \; (Y_r/X_r)^{\frac{1}{2}} \doteq \sqrt{Y_r} \qquad (R_r = Y_r, \; L_r = Y_r)$$

or $$\frac{Y_r}{X_r} = \left(\frac{n_r}{(Y_r)^{1/6}}\right)^2 \qquad \ldots \qquad (10)$$

Once the horizontal scale is chosen, the amount of distortion necessary for establishing similitude can be computed without altering the roughness of model surfaces.

Another method of an emperical nature is that of extrapolation. It consists of conducting experiment on at least three models constructed to different scales and inferring from the trend of the results the true performance of the prototype.

2.6 HYDRAULIC MODELS

Hydraulic models can be classified as undistorted and distorted. In the former, all dimensions are reduced to the same scale whereas in the latter, the scales for vertical and horizontal dimensions are different. Hydraulic models can also be classified as rigid bed models and mobile bed model depending on bed condition.

2.6.1 Undistorted Models

While experimenting with models one would naturally like to get quantitative results as far as possible, in respect of flow conditions, velocity and acceleration of flow, forces involved, etc. This can be achieved if a close dynamic similarity is obtained while operating the models, which is possible only when undistorted or geometrically similar models are used. Generally from undistorted models results obtained can be transferred quantitatively, with simple laws of similarity to the prototype. In some cases, however,qualitative interpretations of the observed phenomena have to be made.

2.6.2 Distorted Models

It is frequently necessary to design hydraulic models with vertical scales greater than the horizontal scale. The need for distortion arises because of the following reasons:

a) In nature when the size of the stream is small, depths increase relatively in proportion to widths, which is nature's way of maintaining turbulence. To conform with this, river models are made with vertical scales larger than horizontal scale.

b) Prototype flow is, almost without exception, turbulent. If, likewise, the model flow is turbulent, the model will be suitable for the study of flow conditions. This is possible, usually if vertically exaggerated models are adopted.

c) When prototype dimensions are scaled down, hydraulic forces are so much reduced that bed movement is not properly reproduced in the model unless very large models are used, which owing to the considerations of cost, available space, water supply, etc. is generally impracticable. It is usually necessary to distort the scale to obtain adequate bed movement.

d) By choosing small depth scales, accuracy in vertical measurements will have to be sacrified.

2.6.3 Rigid Models

Models with rigid boundaries are generally employed for studies of flood levels. These models require considerable data extending over a number of years since the models cannot adjust themselves to all the different flow conditions. In such models bed roughness is adjusted, generally by means of small blocks or studs fixed to the sides and the bed, this adjustment by trial and error takes a long time. Spill areas may be roughened with course sand.

2.6.4 Semi-Rigid Models

In these models, the sides and sometimes parts of the bed are made rigid. A bank slope exaggeration can thereby be adopted far in excess of what would otherwise be possible. However, results of measures in the non-rigid reach would not be reflected in the rigid portion, unless the rigid reach itself is so far away as not to be affected by the measures tested. Thus the interpretation of results in semi-rigid models require great caution, keeping in view all the limitation involved.

2.6.5 Mobile Bed Models

In these models, both bed and sides are made erodible. However banks may have to be made rigid if they become steeper than the natural angle of repose of the bed material. The advantage of erodible models is obvious, since they can indicate changes in channel geometry and channel configuration brought about by various measures tested.

2.7 CHOICE OF SCALE

The choice of the scale depends on the type of the river for which experiments are to be carried out. Broadly there are two types; wide and shallow, as against deep and narrow rivers. The former have steep slopes relative to their discharge, and carry generally heavy loads. On the other hand, the latter have high banks, indicating a high proportion of silt charge in suspension, a relatively small bed load. Variations exist between these extremes and have to be considered while fixing scale ratios.

2.7.1 Horizontal Scale

It is determined from considerations of discharge and space available. The following considerations are pertinent while fixing the linear scale:

i. The scale selected should be such that the width of channels are adequate. A minimum width of 0.9 to 1.2 m is considered satisfactory.

ii. For the examination of cut-offs and river diversions in low stages, adequate widths should be available for study in models. For instance, with a horizontal scale 1/600, it would be difficult to study the effect of a 15.2 m wide cut. Similarly, for river diversion experiments, model discharges, corresponding to the minimum discharges in the prototype, with which a diversion is to be carried out, should be measurable and effective.

iii. If width of the models kept very small, surface tension will be prominant and dominate the fluid system. Then for dynamic similarity both Froudes Law and Weber Law govern the flow characteristics. As a result a more complicated model techniques have to be developed.

2.7.2 Vertical Scale

Given the horizontal scale, the depth scale can be worked out with the help of one of the following formulae:

i) $d = (L)^{0.75}$ ... according to Mannings formula

ii) $(L^{0.65}) > d > L^{0.75}$ ... according to Cutter's formula

iii. $d = (L)^{0.728}$ ... according to Winkells formula.

iv) $d = f^{\frac{1}{3}} L^{.67}$ ... according to Lacey's formula

where, f = silt factor = $1.76 \sqrt{m}$, m being the median diameter of sand in mm.

In these formulae, the following assumptions are made:

$V \alpha \sqrt{d}$ where, V = velocity

$R \alpha d$ where R = Hydraulic mean radius

$n_r = n_p$

However, results obtained from these formulae differ appreciably from one another and hence, the formulae cannot be taken as accurate guides. The depth scale should be fixed so that sufficient tractive force, γds, is available for the bed material used in the model. Thus, the depth scale has to be fixed in conjunction with the slope scale. The scale should be determined in order to obtain a sufficiently high Reynold's number and thus ensure turbulent flow in the model for the lowest discharge. For maintaining terbulent flow, Karman Number, $k = K\sqrt{\frac{gRS}{\nu}}$ should be kept greater than 50.

2.7.3 Slope Scale

This is fixed so as to induce proper movement of bed material, and at the same time, control friction for correct reproduction of water levels. The Lacey formula:

$$S = 0.542\ f^{5/3}/Q^{1/6}$$

is sometimes used to determine this scale. However, the formula takes into account only the grade of the bed material, but does not guarantee bed movement for the grade adopted. It does not, therefore, yield satisfactory results.

While operating hydraulic models, it is convenient to have equal slope and vertical exaggeration, since it results in considerable simplification. Vertical exaggeration of models of the wide, shallow and steep river is required to be greater than that of the narrow and deep rivers. However, a higher vertical exaggeration, accentuates the initially steep slopes of model of wide and shallow rivers causing intense bed movement. On the contrary, the vertical exaggeration permissible in models of deep and narrow rivers is small; likewise is the slope exaggeration which results in unsatisfactory bed movement.

2.7.4 Discharge Scale

Models are operated according to Froude's relationship: velocity scale = (depth scale)$^{\frac{1}{2}}$ and, hence the discharge scale equals $LD^{1.5}$. For alluvial rivers the mender length is proportional to $\sqrt{Q}$. If the law holds good in models, then the discharge scale must be proportional to L^2. The practice is, however, to make $LD^{1.5}$ equal to L^2 to avoid complication especially when there are rigid structures to be tested in the reach. Another method is to adjust the discharge scale by trail and error. Water is introduced into the model so as to reproduce certain known prototype gauges. The ratio of actual discharge of the prototype to the model discharge, capable of reproducing known prototype gauges, gives the discharge scale.

2.7.5 Time Scale

Theoretically, the time scale is equal to $L/\sqrt{D}$. Model discharge stages are based on the nature of the hydrograph; duration of each run is determined according to the theoretical time scale and adjustments are made by trail and error. Generally low discharges have to be run in the model for a longer time and higher discharges for a shorter time than that worked out theoretically. So that scouring is not exaggerated and prototype conditions are reproduced in the model.

2.8 Choice of Material

Sufficient bed movement is the criterion deciding the choice of material, so that bed configuration is properly simulated. Figure 2.1 shows the relation between thrshold velocities and material sizes. For material between 0.15 and 0.25 mm in diameter, velocity required for movement is least. For finer material higher velocity is required.

Wherever velocities in models are not enough to move sand on bed, lighter materials are used as described below:

i) Coal dust: Coal dust from collieries is of an average specific gravity of 1.4 to 1.5 and serve as an excellent bed material. The main objection against using coal dust is that it does not give a uniform size of material;

ii) Saw dust: Pure saw dust, when used floats in water and to some extent, it can simulate suspended load. But as soon it becomes wet, it slowly sinks forming into a lump like cohesive clay. This is due to the action of fungas . To prevent fungal action, the saw dust is teated with saturated lime water and then treated with 1% solution of copper sulphate which corrects this tendency.

iii) Pumic stone of specific gravity1.4 to 1.7 and grain size 1 to 3 mm is also tried in some place.

iv) Plexiglass or plastic sand of specific gravity 1.18 is popular in Europe. Its cost prohibits its use on a large scale.

v) Polysterence is a byproduct of synthetic rubber and of specific gravity 1.05 and is used in Europe. This material also is costly for a large scale use.

vi) Powdered bakelite has a specific gravity of 1.37 and being free from defects like absorption of moisture, lump formation, etc. it is quite suitable as a bed material.

vii) Lignite has a specific gravity of 1.2 to 1.6, but its main defect is that it is a water repellent. If treated with a wetting agent, it gives a satisfactory result; and

viii) Lac and Lac products are also useful in this respect. Shellac (Sp.gr. 1.47) mixed with barytes or shellac mixed with a small quantity of calcium stearate (3%) and urea (2%) gives a satisfactory account as the model bed material.

2.9 ARTIFICIAL MATERIAL FEED

In models, materials has to be injected artifically at suitable places to simulate the prototype. The rate of injection is adjusted so that model is equal to that injected upstream to obtain equilibrium conditions. The rate of injection is worked out usually by trail and error. The bed and suspended materials are used by selecting suitable types considering similarity to the prototype. Garde has worked out an equation for the rate of total load in alluvial streams, viz.,

$$\left(\frac{q_t}{V^* d}\right) = 16 \left(\frac{\tau_o}{\Delta\gamma_s d}\right)^{4.0} \qquad \text{(Joglekar, 1971)}$$

in which

q_t = the rate of total sediment transport.

V^* = Shear velocity

d = bed material size, mm

τ_o = γ_f RS, γ_f = specific weight of fluid

R = Hydraulic radius,

S = Slope

$\Delta\gamma_s$ = Difference in specific weight between sediment and water.

The above equation can be written as : $q_{tr} = B^{1.5} h_r^{4.5} S_r^{4.5} d_r^{-3.0}$

where $B = \frac{h}{R}$, h = depth , r = scale ratio.

It is worth-while to test the above formula in river models and compare results obtained by trail and error method of silt injection.

2.10 VERIFICATION OF MODELS

The design of scales is no guarantee for the satisfactory performance of the model. Additions and alterations, imposition of flow conditions at entry or exit, etc. become necessary conditions, such as water levels, velocities, flow conditions, bed changes, tidal characteristics with proper phase-lags and velocity of propagation of tidal wave, tidal influx and range, reflection, refraction, defraction, attenuation and breaking of waves, and other peculiarities observed in the prototype. For want of reproduction of prototype conditions to any degree of accuracy it will not be safe to predict prototype behaviour from the model results.

Before a model can be used as handy tool for answering problems it is necessary to reproduce known phenomena in the prototype. Considerable time may be required for this stage of simulating the model. Complete dynamic similarity is not possible. It becomes necessary to adjust various hydraulic forces so as to bring about in the model corresponding prototype conditions. However, the adjustments have often to be based on judgement and experience. Though a strict hydraulic similitude cannot be obtained but it can be closely approximated by means of an emperical process known as "verification" which is a progressive modification of the hydraulic forces and the model operating technique, until the model reproduces hydraulic changes known to have occured in the prototype.

2.11 MODEL LIMITATION AND DIFFICULTIES

Model limitation and difficulties are discussed briefly below:

a) <u>Reproduction of silting and scouring:</u> In models the bed movement is due to particles which roll on the bed forming ripples, and very little material goes into suspension. Silting as a result of movement of bed load is reproduced fairly in the model. But silting resulting from the deposition of material in suspension does not occur naturally in models (Joglekar 1971). Various methods are used to reproduce this latter mode of silting. Deficient silting in models can be accelerated by using materials of low specific gravity which go easily into suspension with model velocity gradients and turbulence. Another method used to reproduce silting, consists of injecting very fine silt or clay in the model. The deficiency in natural silting is then overcome by artificially silting the reaches thus indicated. Unless this procedure is adopted, it is obvious that scour, channel development and flow conditions cannot be obtained accurately in the model. It may be noted that in a model, scour occurs much more rapidly than silting. Unless both these are simulated correctly at the same time, model channels and shoals can not be reproduced and, hence, hydraulic flow conditions will not be correct.

b) <u>Adjustment of the model to variable conditions:</u> It has been observed that in models, two thirds of the maximum scour takes place during 5 percent of the operation time, whereas silting is slower than in the prototype and has to be exaggerated. Cross-sections in the prototype are measured generally in the dry season, since it is difficult to obsrve them during floods.

In models, when flood hydrographs are run, most of the sand gets washed away and the cross-section, obtained are quite different from those with which the model was originally laid. Proper allowance should be made for this divergence while interpreting the model results. Another difficulty in model studies in the material scoured round rigid structures like groynes, pitched islands, vanes, etc. gets deposited immediately down stream to form an unnatural sand shoal. This excess deposit has to be removed from time to time to get correct results.

c) Exaggerated scour holes: Vertically exaggerated models give in general, approximately correct maximum depths of scour but because the angle of repose of bed material remains the same both in the model and in the prototype, the model gives too large an extent of the scour hole. Care has to be taken, therefore, to counteract exaggeration of extent of scour occuring due to the distortion of model scales.

d) Necessity of fitting masonry stuctures: In vertically exaggerated models, bank becomes steeper than permitted by the angle of repose of material forming them. They have, therefore, to be made rigid, which conforms with rigid bed channel, steep banks affect flow conditions; flow is attracted towards the banks contrary to prototype conditions and model performance is vitiated. Allowance should be made for this while interpreting results.

e) Reproduction of obstruction: In vertically exaggerated models where tests are made for bridges, weirs, barrages, etc. the number of piers should be reduced to maintain the width to depth relation of the waterway to simulate the obstruction. Failing this, flow conditions would not be reproduced correctly in the model. Other minor limitation of the models are:

f) Exaggerated vortices: Vortices in models are magnified in plan. To minimise this effect, adjustment of bed contours may be necessary.

g) Reproduction of size and specific gravity of stone or block for river protection works in models.

h) Effect of fitting vertically exaggerated models on back-water-length and height.

i) Necessity of having different vertical scale ratios for rigid and non-rigid portions of models and

j) Incorrect throw-off.

2.12 INTERPRETATION OF MODEL RESULTS

Due to model limitations as described above the interpretation of model results is of importance. This requires good knowledge of model technique, a long experience of working on the models and study of model and prototype behaviour of river under varying conditions; e.g. the behaviour of a spur or guide bank can best be judged from the trend of scour scooped out at the nose of spur or head of guide bank. The direction of contours give the probable deflection of flow by the spur or guide bank. The stilling created by the spur on its upstream can be judged from the lines of flow.

2.13 IMPORTANCE OF FIELD INSPECTION AND ANALYSIS OF DATA IN MODEL INVESTIGATIONS

It is always describle to visit the site for field inspection specially in the case of river problems. Discussions with local officers and the people is always helpful; because this alone makes it possible to visualise conditions adequately to arrive at a comprehensive diagnosis of the case. The limitation of models must, however, be kept clearly in mind and in the case of mobile models success will depend mainly on the ability of the person directing the experiments to visualise and diagnose the conditions which have led up to the present position and, in the light of that knowledge to predict changes which will take place in years to come. A model cannot possibly give reliable information unles the conditions imposed are correct. Field inspections enable one to understand where the model fails to reproduce the river conditions, and why, and how far inherent differences must be taken into account.

2.14 MODEL PROTOTYPE CONFORMITY

Rapid progress has been made, in recent years, in the use of hydraulic models as an aid in the design of hydraulic structures. However, sufficient data are not available for comparison between model and prototype results. Such comprisons are evidently necessary, since they alone can instil confidence in the designer.

Difficulties in collecting prototype data are multiplied because various factors in the prototype operation cannot be controlled as readily as in the model. During flood flows, it is often impossible to obtain accurate measurements because of changes in the river section due to bed movement. Difficulties are also encountered in measuring velocities in large high head outlets because of the tremendous forces involved, necessitating the use of study instruments; or the use of instruments may not be possible at all for lack of access.

The science of hydraulics is yet in the emperical stage. For further advance it is essential that prototype and model conformity is considered at every stage of operation and should also be encouraged by the authorities in-charge of prototype structures.

2.15 CONDLUDING REMARKS ON RIVER MODELS

Models are always helpful, in that they make it easier

i) to visualise the problems;

ii) to verify data, to see whether they are correct and adequate or whether important details have been omitted;

iii) to evaluate the relative effects of different treatments making allowances for model limitations, but it must be clearly understood that success depends primarily on a correct diagnosis and evaluation of all the factors causing change.

In general, the tendency is to place too great reliance on thought numbing formulae. They should be used only as a guide for initial laying. Thereafter, observation and comparison of model behaviour with river conditions should be the basis for further modifications.

Factors involved in reproducing river condition in a model include:

i) natural slope exaggeation;

ii) natural width reduction;

iii) a very much quicker time scale in the model than in the river;

iv) much steeper side slopes in the model though the material has practically the same angle of repose as in the river.

v) fluctuating discharge and bed silt charge;

vi) exaggerated effects in the model due to rigid portions. These cause elongated vortices, and distorted lines of flow.

vii) Meanders, spills, cut-offs are affected by the relatively coherence and angle of repose of the material in the river and model the relation varying with variation in discharge;

viii) difference in flood cycles from year to year which have to be assumed and imposed in the model to predict future changes;

ix) difference in vertical scale and length scale affects rigid and non-rigid portions of a model.

No formula can be devised to take all these varying factors into consideration, all that can be done is to carry out experiments with mobile models to evaluate divergences from matural conditions resulting from various disturbing factors in order to see how far these effects can be minimised. Though alluvial river models have many clear cut limitation yet they give essential information to those who can interpret them. They should not be expected to show what will happen over a long period of years, their chief value being as an aid to engineering skill, which they can never replace.

CHAPTER - THREE

MODEL STUDIES UNDERTAKEN AT THE RIVER RESEARCH INSTITUTE, BANGLADESH

3.1 INTRODUCTION

The River Research Institute of Bangladesh Water Development Board started functioning from 1953 (at that ime it was known as Hydraulic Research Laboratory) and performed the first model study entitled "Model investigation of spillway design of dam at Kaptai in the Karnafuli River". Since then it has been engaged in conducting model studies on varous projects. In 1977 the Hydraulic Research Laboratory had been renamed as "River Research Institute" (RRI). A comprehensive list of the model studies are furnished in the following articles with brief description.

3.2 LIST OF THE MODEL STUDIES

Begining in 1953 and upto the present period of 1988 numerous model studies have been conducted in the RRI. At present 4 model studies are in progress A list of the model studies is given below:

1. Model investigation of spillway design of dam at Kaptai in Karnafuli river, February 1953 (HRL-1953).
2. Model experiment on chute spillway over the main embankment of Buriband, June 1953 (Rahman-1953).
3. Model experiment for the prevention of erosion at Sirajgonj by the river Jamuna, July 1953 (HRL-1953).

4. Model study on the design of chute spillway over the main embankment of Buriband, Dec. 1953 (Rahman-1953).

5. Model experiment on diversion channel design of the dam at Kaptai in the Karnafuli river, March 1954 (Rahman-1954).

6. Model experiment on the study of seepage flow below the bed of Gulle Regulator, near Kaligonj in the district of Khulna(HRL-1955).

7. Model experiment of flood spillway inconnection with Pathraj Irrigation scheme, June 1955 (Rahman-1955).

8. Model study on the design of Buri Teesta flood spillway, June 1956 (HRL-1956).

9. Model experiment for the prevention of erosion at Kurigram by the river Dharla, July 1956 (HRL-1956).

10. Model studies on the Bridge-cum-Regulator over Senpatiler Khal inconnection with Tulshigonga scheme, January 1957(HRL-1957).

11. Model experiment of the outlet stilling basis of Govania Chara Reservoir Scheme, October 1958 (HRL-1958).

12. Model experiment of Intake channel of Ganges-Kobadak Project, November 1958 (HRL-1958).

13. Model experiment on the drainage sluice inconnection with Khulna multipurpose scheme, February 1960 (HRL-1960).

14. Model study on cofferdam for Teesta Barrage project May 1961 (HRL-1961).

15. Model study on sectional model of Teesta barrage project, July 1961 (HRL-1961).

16. Model study on sectional model of Bulli barrage, August 1961 (HRL-1961).
17. Model studies on Little Feni Regulator inconnection with coastal embankment project, January 1962 (HRL-1962).
18. Model studies for the checking of erosion of right bank of Feni river upstream of Sovapur bridge, February 1962(HRL-1962).
19. Model studies on sectional model of Magura barrage, August 1962 (HRL-1962).
20. Model studies on drainage sluice utilizing flexible paving in stilling basin inconnection with coastal embankment project, August 1962 (HRL-1962).
21. Model study on Karnafuli Dam spillway, October 1962(HRL-1962).
22. Model study of Magura Barrage-cum-Navigation Lock, August 1963 (HRL-1963).
23. Model study on Tiket sluice, April 1965(HRL-1964).
24. Model study on modified design of Tiket sluice, April 1965 (HRL-1965).
25. Model study on Intake of Sonaichari Irrigation project, May 1965 (HRL-1965).
26. Model study on Badalpur Intake structure inconnection with old Brahmaputra multipurpose project, October 1965(HRL-1965)
27. Model study on Faridgonj pumping station stilling basin, July 1966(HRL-1966).
28. Model studies on old Brahmaputra intake channel inconnection with old Brahmaputra multipurpose project, September 1966 (HRL-1966).
29. Model studies on Ganges-Kobadak regulator, March 1967(HRL-1967).

30. Model study on drainage regulator, Chandpur Irrigation Project, June 1967 (HRL-1967).

31. Model study on Typical Box sluice of Coastal Embankment project, April 1968 (HRL-1968).

32. Model studies on main pumps outlet stilling basin of Ganges-Kobadak project, August 1968 (HRL-1968).

33. Model study on Magura barrage for determining discharge, September 1968 (HRL-1968).

34. Model study of bank protection by permeable fence, November 1968 (HRL-1968).

35. Model study on tidal model of Chunar river, April 1969(HRL-1969).

36. Model study on the location of Teesta bar-rage, July 1969(HRL-1969).

37. Model study of Rahmat Khali Khal regulator, November 1969(HRL-1969).

38. Model study of Feni river for protection of Sovapur bridge, December 1969 (HRL-1969).

39. Model study on Typical R.C. Box sluice for coastal embankment project, December 1969 (HRL-1969).

40. Model study on loop-cutting of Rahmat Khali Khal, June 1970 (HRL-1970).

41. Sectional model studies on Teesta barrage project, July 1970 (HRL-1970).

42. Model study on Teesta barrage project July 1970 (HRL-1970)

43. Model study on sluice channel of Teesta barrange project, 1971 (HRL-1971)

44. Model study on Teesta barrage project, 1971(HRL-1971).

45. Model study on Kushtia town protection from erosion of river Gorai, February 1972 (HRL-1972).

46. Model study on Matamuhuri river for protection of Chiringa bridge and closure of diversion channel, March 1972 (HRL-1972).
47. Sectional model study of the modified stilling basins of main barrage and under-sluice of the Teesta Barrage project, 1972 (HRL-1972).
48. Model study of protection of right bank embankment downstream of Kazirhat regulator in little Feni river, 1973(HRL-1972).
49. Model study on erosion problem in Khowai river, 1975(HRL-1975).
50. Model study on erosion problem in Khowai river on the basis of Indian proposal, 1975(HRL-1975).
51. Sectional model study of Manu barrange, May 1976(HRL-1976).
52. Model study of Manu river inconnection with Manu barrage project, June 1976 (HRL-1976).
53. Model study on ratio of super projection and its effects on scour under different conditions of flow for a straight and a 15° curve approach channel, October 1976(HRL-1976)
54. Model study for protection of Sovapur bridge on Feni river, January 1977 (HRL-1977).
55. Model study of old Brahmaputra river in connection with the protection work of Mymensingh Jute mills at Shamvogonj, September 1977(HRL-1977).
56. Model study of Tengapara Weir-cum-Regulator, February 1978 (HRL-1978).
57. Model study on Kurigram town protection scheme, 1978(RRI -1978).
58. Sectional model study of Feni regulator, October 1978(RRI -1978).

59. Model study on Hazimara regulator to protect it from the erosion of Meghna river, 1978,1979 (RRI-1978).

60. Model study on Feni regulator, April 1979 (RRI-1979).

61. Model study on protection of Kushtia town from erosion of Gorai river, December 1979.(RRI-1979).

62. Model study on erosion problem of Khowari river, 1979(RRI-1979). (RRI-1979).

63. Model study on protection of Hazimara regulator from the erosion of Meghna river, December 1979 (RRI-1979).

64. Model study on Manu river barrage project, February, 1980(RRI-1980).

65. Sectional model study of Tengapara submerged weir, 1980(RRI-1980).

66. Model study on Rajshahi town protection scheme, 1980(RRI-1980)

67. Model study on Teesta barrage project, November, 1980(RRI-1980)

68. Model study on siltation problem in the G.K. Intake channel(RRI-1980). November 1980 (RRI-1980).

69. Model study on Manu barrage structure,1981 (RRI-1981).

70. Model study on the first proposed site of barrage for the Ganges barrage project, 1981 (RRI-1981).

71. Sectional model study of Teesta barrage project, 1981 (RRI-1981)

72. Model study of the canal head regulator of Teesta barrage project, February 1982 (RRI-1982)

73. Model study on the location of Teesta barrage project,1982 (RRI-1982)

74. Model study on cofferdam of Teesta barrage , April 1982 (RRI-1982)

75. Model study on sluice channel of Teesta barrage project, May 1982 (RRI-1982).

76. Model study of sediment excluder tunnel of Teesta barrage, June 1982.(RRI - 1982).

77. Model study on demonstration model of water control structure, 1982.(RRI- 1982).

78. Model study of Rajshahi town protection works, January 1983 (RRI - 1983).

79. Model study on the closure of Dalia channel of Teesta river, 1983.(RRI - 1983).

80. Model study on erosion of Khowai river for protection of Shaistagonj Railway bridge & Road bridge,Sylhet,April 1983 (RRI- 1983).

81. Model study of modified silt excluder tunnel of Teesta barrage project, September 1983 (RRI-1983).

82. Model study for protection of bank erosion of Teesta river at Tambulpur, Rangpur, 1983 (RRI- 1983)

83. Model study of Intake channel and intake structure of Kaptai Hydro-Electric power plant project, December 1983 (RRI- 1983).

84. Model study of tailrace structure of Kaptai Hydro-electric power plant project, December 1983 (RRI - 1983).

85. Model study of silt ejector in main canal of Teesta barrage project, December 1983 (RRI - 1983).

86. Model study on river training works upstream of Teesta barrage at Dalia, December 1983 (RRI - 1986).

87. Model study on Loop-cutting and protection of right bank embankment downstream of Kazirhat regulator in Little Feni river, 1983 (RRI -1983).

88. Model study of Barishal harbar area, January 1984 (Interconsultant, 1984). (RRI-1984).

89. Model study for protection of Kushtia town from right bank erosion of Gorai river, 1985 (RRI-1985).

90. Model study on Bifurcation of Bogra-Rangpur canal regulators for Teesta barrage project, March 1985 (RRI- 1985).

91. Model study for protection of Kumarkhali town from erosion of river Gorai, March 1985 (RRI - 1985).

92. Model study to see the effect on the cofferdam after construction of groyne for diversion of river flow, April 1985 (RRI-1985).

93. Model study for protection fo right bank erosion of river Gorai at Chapra, May 1985 (RRI - 1985).

94. Model study on the sectional model of Rangpur regulator structure R4R, under Teesta barrage project November 1985 (RRI- 1985).

95. Model study on Sirajgonj town protection works, March 1986 (RRI - 1986).

96. Model study for protection of Mohanpur bazar from bank erosion of Meghna river, March 1987 (RRI-1987).

97. Model study for protection of right flood embankment of the Brahmaputra-Jamuna river, June 1987 (RRI- 1987).

The 4 models studies in progress are:

1) Model study for protection of right flood embankment of the Brahmaputra-Jamuna river (2nd part).

2) Teesta flood by pass under Teesta barrage project.

3) Protection of Kaitala pumping station from erosion of Brahmaputra-Jamuna river.

4) Tidal model study of Doarika river.

3.3 ANALYSIS OF TYPE OF MODELS UNDERTAKEN AT RIVER RESEARCH INSTITUTE, DHAKA.

Models may be classified according to its nature of boundary as mobile bed model or fixed bed model, according to the scales adopted as distorted scale model or undistorted scale model and according to the purpose of the study e.g. for irrigation, town protection, navigation, drainage, flood control, coastal development, power development, etc.

Classification of models on the basis of the nature of boundary of the models are furnished in Table 3.1. Classification of models on the basis of the nature of scales are furnished in Table 3.2 and classification of models on the basis of purpose of study are furnished in Table 3.3.

An analysis of Table 3.1. reveal that models for town protection from river erosion, models for Intake channel, models for selection of location of barrage, models for loop-cutting, models for river training works, etc. are generally constructed as mobile bed at the River Research Institute. As for example model study for the prevention of erosion at Sirajgonj by the river Jamuna, model study of Intake channel of Ganges-Kobadak project, model study on the location of Teesta Barrage, model study on loop-cutting of Rahmatkhali Khal and model study on River Training Works upstream of Teesta Barrage at Dalia have been conducted in mobile bed model. It is found that most of the mobile bed models are distorted. But mobile bed models with undistorted scales are also common. Models for spillway design, models for stilling basin, models for drainage sluice, models for submerged weir, models for barrage structures and water control structure, etc. are constructed as fixed bed. Fixed bed models are usually undistorted. But fixed bed models with distorted scales are also used. It is also found that out of 97 models constructed at River Research Institute 67 are mobile bed and the rest 30 are fixed bed.

In Table 3.2 there is given a summary of models on the basis of scale distortion. River models, models for hydraulic structure in river like barrage, models for River Training Works to protect the river bank, etc. are constructed with scale distortion. Models for spillway, diversion channel, stilling basin, drainage sluice and sectional models are constructed with undistorted scale. It may be observed from Table 3.2 that 47 model studies had been undertaken with distorted scale and 50 models are with undistorted scale. Few distorted scale models are models for the river Teesta, Jamuna, Dharla, Gorai, Ganges, Brahmaputra, Meghna, etc. models for the Teesta barrage, cofferdam of Teesta Barrage etc., models for protection of right flood embankment of the Brahmaputra-Jamuna river,protection of Rajshahi town from erosion of the river Ganges, etc. Few undistorted models are, model for spillway design and diversion channel design of dam at Kaptai in Karnafuli river, model for the outlet stilling basin of Govania chara Reservoir scheme, model for drainage regulator of Chandpur Irrigation project, sectional models on Teesta Barrage project, Manu Barrage project, Feni regulator, etc. Distorted models as well as undistorted models are constructed with both mobile bed and fixed bed.

Hydraulic structures which went on model studies at the River Research Institute were mainly for the purpose of irrigation, flood control, drainage, bank protection, power development,coastal development, navigation, etc. It is found that majority of the model studies had been carried out for the irrigation purpose. About 39 model studies were on irrigation purposes. Among them are models in connection with Pathraj Irrigation scheme, Ganges-Kobadak project, old Brahmaputra multipurpose project, etc. Model studies for Bank protection from erosion occupies the second position considering the number of studies. 26 model experiments had been conducted on bank erosion. A few of them are for the prevention of erosion at Sirajgonj by the river Jamuna, at Kurigram by the river Dharla, at Sovapur bridge by the river Feni, at Kushtia town and at Kumarkhali by the river Gorai, at Rajshahi by the River Ganges at Sylhet by the river Khowai, at Mohanpur by the river Meghna and for protection of right flood embankment of the Brahmaputra-Jamuna river. 8 models studies were conducted on drainage purposes, 7 for power development, 7 for flood control, 6 for coastal development and 4 models for other purposes were constructed and experiment were carried out at River Research Institute. These are summarised in Table 3.3.

The river on which scale models have been developed so far are given in Appendix-C. Short description of some selected model studies undertaken at River Research Institute, Dhaka are attached in Appendix-D.

3.4 MODEL STUDIES OF BANGLADESHI PROJECTS CARRIED OUT IN ABROAD

For finalizing the design of some projects, model studies were performed outside Bangladesh. Among them some model studies are discussed here.

1. Movable bed model of Jamuna bridge corridor (NEDECO, 1987).

The movable bed model was constructed in the Netherlands at the consultants "De-voorst" Laboratory to study the channel pattern of the braided Jamuna river and to test the various concepts and layouts of the river training works for the Jamuna bridge at Sirajgonj. The dimensions of the model are: length 55 m, width 20 m. It has a bed of sand of dia 0.2 mm under a 0.7 percent slope. The scale value of the model is 0.01. A scaling method was developed to design the physical scale model of the Jamuna river in Bangladesh (Klaassen 1987). Initially exploring tests were carried out with constant discharge, having recirculation of water and sediment . Water and sediment were introduced into the model at a number of points in the upstream boundary in order to vary the channel pattern. The following measurements were carried out:

1. Aerial photographs from over head rails.
2. Measurements of transverse cross-section.
3. Water and sediment discharge and their distribution over the inlet points.
4. Water levels, to determine the slope in the model.

Tests were carried out with various constant discharges after which the resulting channel pattern was compared to the actual observed patterns. The scale of the model was thus finally established as to be 1:1000 horizontally and 1:200 vertically, implying a less serious distortion than initially estimated. Fig. 3.1 shows a vertical view of movable bed model with river training structure.

During the last weaks of september, 1987 the fixed bank, were introduced into the model to represent the bank protection works at Sirajgonj and the Bhuapur ferry site. The resulting changes in the channel pattern are being studied. As a next step the bridge and appurtenant river training works will be introduced in the model and final recommendations for the layout and concept of training works will be made.

2. Studies of hydrothermal conditions of water supply source, Ghorasal power station, Bangladesh (Technopromexport, 1987).

By the present time two 55 mw and one 210 mw units have been put into services at the Ghorasal Thermal power station. The fourth unit of 210 mw is under construction, the fifth one of the same capacity is in the design stage. It is contemplated to install another 210 mw units. Unit 5 and 6 are designed for higher cooling water temperature with the rated capacity at the inlet being maintained at 38^{o}c whereas that of units 3 and 4 at 36^{o}c.

Hydrothermal investigations of the TPS water supply source were started in 1984. To this end a model of the Lakhya river reach was constructed at the experimental ground of the B.E. vedeneev VNIIG. The principal results of the model tests were used in TPS extension project contemplating installation of three other 210 mw units: the 4th, 5th and 6th ones.

The dimensionless temperature number governs the thermal conditions of the model and the formula for scalling water temperatures. Froude Number determines the velocity and discharge scales, Reynolds Number determines the geometric scales and Stroughal Number determines the time scale of the model. The scales of width 1:50 and depth 1:20 determined the scales of the water discharges and time 1:4160 and 1:12 respectively, rounded off to some degree for experimental purposes. The flume was 50 m long and 3 m wide. The pump operation control and data acquisition were carried out automatically. 22 float mounted resistance thermometers for recording the surface water temperatures were installed at equal spacings along the model length. Five thermometers were used for recording the water temperatures at the model boundaries. The reading were taken every 10 minutes in the tidal cycles, altogether six times.

Model experiments showed that when installing units 5 and 6, it was necessary either to considerably extend the length of the discharge channel or to provide units 3 & 4 with mechanical draft cooling towers which run in dry season only.

3. Model study of the confluence of the Lakhya and Dhaleswari River (Interconsult, 1983).

In order to investigate the heavy siltation problems in the confluence area between Lakhya and Dhaleswari a physical model study was carried out at the Norwegian Hydrodynamic Laboratory (NHL), Trondheim, Norway, in 1983. NHL was assigned by Interconsult A/S on behalf of Bangladesh Inland Water Transport Authority, Dhaka. The model study had two main purposes: (a) to give flow directions and velocities for use in the computations (b) to assist in evaluation of alternative designs, from the view point of bed load transport. In the model the river was reproduced in a length of 6000 m. The dimensions of the model are shown in Fig. 3.2. The chosen model length scales were vertical = 1:33⅓, horizontal = 1:200. The time and velocity scales are in agreement with Froude's model Law. Polysterol 2710 which has a density of 1.05 g/cm^3 and a representative diameter of approximate 2.5 mm was used to model the bed sediments. Water was used as a model fluid. The velocities in the model were measured with an ultasonic current meter giving three velocity components seperately. The model was run for three different situations regarding water level, discharge, etc. The model was calibrated for one high water situation and one low water situation. Model studies had been conducted on the present channel and four other alternative channel alignment.

CHAPTER FOUR

REVIEW OF MODELLING TECHNIQUES FOLLOWED BY THE RIVER RESEARCH INSTITUTE

4.1 INTRODUCTION

In conducting a mdoel study the following steps known as modelling techniques, have to be performed systematically,

i) design of the model

ii) construction of the model

iii) calibration and validation of the model

iv) operation and collection of data from the model, and

v) interpretation of model results.

To review the modelling techniques followed at the River Research Institute, indepth study of three selected model study has been made. The selected model studies are: model study of silt excluder tunnel of Teesta Barrage project, model study of Kushtia town protection from erosion of river Gorai and model study for protection of right flood embankment of the Brahmaputra Jamuna river. The steps followed and technique adopted in various stages of the actual model run are discussed in the following sections.

4.2 MODEL STUDY OF SILT EXCLUDER TUNNEL OF TEESTA BARRAGE PROJECT

4.2.1 Introduction

The Bangladesh Water Development Board has taken up the construction of barrage accross the river Teesta near Dalia in the district of Rangpur for supplying irrigation water to the Teesta project which comprises a total command area of 18,50,000 acres of land in the district of Dinajpur, Rangpur and Bogra (Binnie & Partners, 1969). The main barrage consists of 7 bays of undersluice and 37 bays in the weir portion. The divide wall divides the undersluice and weir bays, the details of which may be available elsewhere (BRTC-BWDB, 1987; Progress report, 1987).

The Teesta river carries a huge amount of sediment load both in suspended and bed materials (BRTC-BWDB, 1987). After completion of barrage construction silt will enter into the irrigation canal with the diverted water through the canal head regulator (CHR). The sediment cause serious problems in operating the gates of the regulator and also deteriorates irrigation water quality. To overcome this situation, silt excluder tunnels are being provided in the three undersluice bays adjacent to the canal head regulator. Silt excluder is a device by which silt is excluded from water entering the canal. It is constructed in the river bed in front of head regulator. There were 4 tunnels in each bay totalling 12 tunnels and the internal dimensions were 1x10'-0"x7'-6", 3x7'-0"x7'-6" and 8x7'-9"x7'-6". Fig. 4.1 presents detailed dimensions of the silt excluder tunnels. The transported bed materials to be deposited in the river bed would be flushed through the excluder tunnels, thereby the irrigation water to be withdrawn from the river u/s of the barrage will contain only suspended sediment of smaller size.

The objectives of the model study were to see the design efficiency and hydraulic performance of the silt excluder tunnel system having reference to the discharge in the canal and for exclusion of sand to the canal and to determine the most suitable alignment of the CHR in relation to the axis of the barrage. A model study was conducted in a distorted scale model with horizontal scale of 1:100 and vertical scale of 1:48 in September, 1981. It was recommended to modify (1) the axis of canal head regulator to 112^{o} in relation to the axis of barrage, (2) the approach of right guide bank infront of canal head regulator was modified (3) the silt excluder tunnel system was slightly extended. Finally in order to verify further the result of model study an undistorted model of sediment excluder tunnel together with canal head regulator, undersluice and a portion of barrage was constructed and experiments were carried out in June, 1982, the detail of which is given in the following articles.

4.2.2 <u>Design Procedure of the Silt Excluder</u>

All data, drawings and information of the prototype, needed for designing a model, were supplied by the design circle of BWDB. The design circle received the data from the field offices of the project circle and also from the hydrology directorate. River Research Institute has no field staffs of its own to collect data directly. But the officials of River Research Institute visit the prototype site occasionally during model design to observe the prototype situation.

Directorate of design, Teesta Head Works designed various components of the barrage including the sediment excluder tunnels. Various design parameters like discharge, stage, flow, sediment load, cross-section of the river etc. were collected by the technical personnels of BWDB. The model of silt excluder tunnel together with canal head regulator, undersluice and a portion of barrage was designed according to Froudian Law of similitude. The model was constructed in an undistorted scale of 1:48.

4.2.3 Construction of Model

The model was constructed at the premises of River Research Institute at Dhaka. All the linear dimensions of the prototype were converted to model dimension according to the chosen scales. The alignment of canal head regulator with 8 bays, the silt excluder tunnels cover 3 bays out of 7 bays of undersluice and 6 bays of barrage with divide wall had been reproduced in the model. Only a portion of river infront of undersluice and by the side of right guide bank had been reproduced. Fig. 4.2 shows all the detail dimensions of the model of silt excluder tunnel of Teesta barrage. Total length of river reproduced in the model was about 5000 feet and the width of the river was about 3000 feet. A 3 feet rectangular sharp-crested weir and a 1'-6" rectangular sharp-crested weir were installed respectively for measuring discharge through the barrage and the canal head regulator. Three gauges were installed for measuring the water surface elevation in the model at three different sites -- one about 21 feet (about 1000 feet in the prototype) u/s of the crest of barrage, one at 8 feet (about 400 feet in prototype) downstream from crest of barrage and one at 6 feet (about 300 feet in prototype) u/s of the crest of the CHR in the canal.

The river portion of model was constructed according to original plan with fine sand. Silt excluder tunnels were constructed with teak wood. The angle of bend, height, width and thickness of wall of respective tunnels were made as per plan. Six piezometers were installed to measure pressure in tunnels no. 1,3 & 5 (counting from canal head regulator). The barrage, undersluice and canal head regulator were constructed with cement mortar. The gates were constructed with thin mild steel (m.s) sheet of 16 s.w.g. thick.

4.2.4 Operation Technique

Water was used as model liquid and arrangement for required water was made through pumping water from a nearby pond. No material was mixed with or introduced to water for meeting the requirement of sediment load in the model; rather velocity method was exersized instead of introducing any sediment load. As reported by the personnels of River Research Institute, velocity method may be defined as the technique in which velocity measures whether a particle will move or settle down. During test run velocity of water was the deciding factor which ensured whether deposition of sediment load would occur or not. Test runs were made initially without installing the excluder tunnel system for the discharges 30000, 40,000 60,000, 52,000 cfs (prototype).

The u/s elevation was maintained at 170' ft. R.L. which is the pond level for drawing discharge in the canal. The undersluice and barrage gates were kept partially open to maintain upstream level. The canal gates were also kept open partially to pass the required discharge of 12,500 cfs (prototype) through the canal. It was not necessary to open all the gates fully for allowing the above discharge to pass in the canal. The downstream level in the canal was maintained at 168.0' feet R.L.

The sediment which resulted from scouring of bed materials entered in the canal and also passed through the barrage. The amount of sediment deposited in the canal and also at the d/s of barrage were measured at the end of each experiment. This is presented in Table 4.1. The model was run for one hour approximately.

Erosion took place at the nose of divide wall. As more discharge passed along the undersluice there was unsymmetrical flow and erosion and deposition took place towards the undersluice pockets. The model study revealed that the influence of divide wall (length 310 feet from the centre of barrage axis) was extended upto 4 bays of undersluice counted from divide wall side and the bed material did not move beyond the above 4 bays.

The excluder tunnel system was then fixed up in the model and the model was then run for the above discharges. The u/s pond level was maintained at the retrogressed level as given in Table 4.2. The sediment deposited in the canal as well as in the downstream of tunnel system was collected and measured. It was found that scouring took place at the nose of divide wall for high discharge.

4.2.5 Calibration and Validation

No model, hydraulic or otherwise, is of any value unless it can safely be used to predict prototype phenomena. Following construction it is therefore necessary to check the model to determine if known prototype phenomena can be reproduced (validation) and to modify it as necessary (calibration) if discrepancies are noted. In the case of sediment excluder tunnel of Teesta barrage, it is reported that the model was constructed to a relatively large scale (1:48) with no geometric distortion for which scale effect was minimum and the model reproduced prototype behaviour accurately. Moreover, discharge and water levels were controlled in the model and as a result no modification of the model was necessary.

4.2.6 Data Collection and Interpretation of Prototype Data

Discharges through the barrage and that of canal was measured by sharp crested rectangular weir. Water surface elevation at u/s and d/s of river and also at canal head regulator was recorded by three gauges which was installed earlier. Sediment which had been deposited in the canal and at the d/s of the excluder tunnel were measured by weighing at the end of every run. Data collected from the model were converted to prototype data by using the model scale ratio and by similitude method. Data collected from the model are furnished with respect to prototype data in table-4.1. Besides, some physical behaviour of the model was observed carefully to assess the prototype behaviour and its successful functioning. They are summerised below briefly.

1. The canal as designed would be able to draw 125oo cfs (prototype) discharge.
2. The length and location of divide wall is sufficient to prevent cross-current infront of excluder tunnel system.
3. For high discharges the nose of the divide wall has to be protected. Protection need be confined to 30 feet (prototype) radius around the nose.
4. Infront of the mouth of the tunnel there would be erosion and the protection as provided in the design would be sufficient.
5. The flow through the extreme right side bays of canal would be significantly less as the discharge increases. When the discharge in the river would be low the flow through canal bays would be more or less uniform.
6. During high discharges, the barrage and undersluice gates should be opened uniformely.

7. Flow condition in the canal head regulator indicated that 12 tunnels in 3 bays of undersluice would be necessary for exclusion of bed materials entering the canal head regulator.
8. Movement of bed materials in the canal beyond the toe of canal head regulator would depend on the hydraulic condition of the canal. Model study indicated that bed material did not move significantly far away from the toe of stilling basin of canal head regulator.

Finally it was recommeded that the canal head regulator with tunnels in three bays with approach guide bank and divide wall would function satisfactorily and would satisfy the design consideration. There would be a little chance of clogging of tunnels. Plate 1,2 and 3 shows some nature of model feature during model study.

4.2.7 Comparison and Discussion

4.2.7.1 <u>Comparison</u>

1. It is reported that the model test was performed by velocity method i.e., sediment exclusion would be depended on flow condition in the model and no sediment was fed during experiment. But modelling of sediment transport is the standard practice. Theoretical consideration and comparison with experiment showed that the sediment transport is dependent upon the dimensionless parameter θ (Shield's parameter) and R (the grain Reynold Number).

$$\theta = \frac{\tau_o}{d\gamma(S-1)} = \frac{U_f^2}{(S-1)gd}$$

$$R = \frac{U_f d}{\nu}$$

where, τ_o = botom shear stress

γ = density of water

d = grain diameter

s = relative density of sediment = $\frac{\gamma_s}{\gamma}$

U_f = shear velocity

ν = Kinamatic viscosity

θ and R must have the same value in model and prototype (Mortensen 1984). Further the Froude Law shall exist for hydraulic process.

2) Fine sand was used in the model bed and rugosity coefficient to the model bed was nearly equal to that of prototype bed i.e. $n_r = 1$. Rugosity coefficient is a measure of roughness of the sides and bottom of the channel which depends upon the channel condition and discharge. It is denoted by 'n' and when used in Manning's formula it is called Mannings roughness coefficient or simply Manning's 'n'. It is reported that surface fall in model was kept equal to that of prototype. But in a geometrically similar model where surface fall in model is equal to that in the prototype, $n_r = (L_r)^{1/6}$ where suffix indicates the model prototype ratio and L is the characteristics length. The model scale was adopted as $L_r = 1:48$. So $n_r = (\frac{1}{48})^{1/6}$ or $n_r = 1:1.90$ i.e. rugosity coefficient of model bed should keep $\frac{1}{1.90}$ times as that of the prototype bed.

3) A portion of river, only 5000 feet in length and 3000 feet width with respect to prototype had been reproduced in the model. It seems that actual prototype approach condition could not be reproduced as the length width ratio is very small. River approach condition play an important role in deciding the location of the mouth of excluder tunnels.

4) No time scale was maintained for a particular run. It is evident from Einstein and Ning Chien formula that time scale ratio is inversely proportional to sediment load ratio i.e. $t_r \alpha \frac{1}{Q_{tr}}$. No account for sediment load ratio and corresponding sliding time scale had been considered. Any increase or decrease of time scale from the selected value (by froudian approach) give the scale of a sliding effect.

5) To reproduce actual bed configuration tampletes are used as a standard practice. But in this model study no tampletes were used during construction of the model.

6) Tunnel performance was observed visually and comments were made qualitatively. As for example no comments had been made about the efficiency of the excluder tunnels and no quantative measurement about sediment load with respect to prototype that may be deposited in the canal or how much sediment would pass through excluder tunnels in a particular period of time had been evaluated. No comment about the flushing velocity, head required for easy operation and escape discharge of the prototype tunnels was given.

7) Test runs were performed for discharges varying from 20,000 cfs. to 54,000 cfs in the prototype. Design flood for Teesta barrage is 450,000 cfs through main barrage and 1000,000 cfs through the by pass. No study had been made with this design flood discharge.

8) Head loss in different tunnels should be same in the prototype. It was necessary to check it through model experiment. But no such checking were made during the operation of the model.

9) Discharge through silt excluder tunnel should be 15 to 20% of the canal discharge and a minimum of 0.5 to 0.75 m of working head is required for sediment excluders. But no comment about escape discharge and head required for flushing velocity had been made during the model study.

10) No comment had been made about the position of the excluder tunnels with respect to depth of water. The excluder should cover 1/3 water depth of heavy sediment concentration.

11) It was recommended from the result of the model test that the canal head regulator with silt excluder tunnels in three bays of undersluice would function satisfactorily and would satisfy the design criteria. But a recent study shows that Teesta barrage project facing acute sediment disposal problem from the Teesta canal. It is estimated that huge quantity of suspended sediment to an amount of 934 acre ft. of suspended sediment will enter into the Teesta canal through the canal head regulator (Huq 1987). Without calculating the efficiency of the excluder tunnels such recommendation cannot be made.

4.2.7.2 Discussion

The above comparison shows that there is a need for modifications in the methodology and technique that were adopted in the model study with the standard practice. Sediment control in a barrage is one of the most difficult as well as very important aspect of a barrage project. A precize model study of the sediment exclusion devices covering all standard aspects and very accurate estimate of sediment load are essential before final design and construction of the Teesta barrage.

Model experiment had been done on the excluder tunnels of same size i.e., all tunnels are of 8'-6"x7'-6". But the prototype tunnels are: one 10'-0"x7'-6", three 7'-0"x7'-6" and eight 7'-9"x7'-6". For standard practice, the number of tunnels usually provided are 4 to 6; size of the tunnel 1.8x2.1 m and self cleaning velocity of flow 3m/sec are generally adopted for alluvial river. A header tank with constant head and a flow spliter may be included in the existing recirculating system to provide accurate flow control with gravity feed. An ineffective sediment exclusion system may even jeopardize the entire barrage project. Study of the sediment exclusion devices of some existing barrage in India shows that most of the sediment exclusion devices are not functioning properly very few are however functioning very well. Before the design and construction of a barrage an experience in this respect from similar project is also essential.

4.3 MODEL STUDY FOR PROTECTION OF RIGHT FLOOD EMBANKMENT OF THE BRAHMAPUTRA-JAMUNA RIVER.

4.3.1 Introduction

Jamuna a part of Brahmaputra river, rises on the northern slope of the Himalayas. It then flows through Asam and finally enters into Bangladesh. It is joined by Dharla and Teesta in its path while flowing through southerly direction. It takes the name of Jamuna river until its confluence with the Ganges river near Aricha. There are 135 miles of embankment along the right bank of Teesta and Brahmaputra-Jamuna strarting from Kaunia and ending at Bera. The position of the embankment is very much precarious at number of places. Active erosion is also prevailing at the engulfed position of the embankment. Sometimes embankment has been retired perpendicularly. Cross embankments have been constructed to check the erosion but to no effect. Presently it is felt that the flow of the river should be diverted away from the right bank so that the embankment will remain safe from erosion, slip, settlement, breaches etc.

River Research Institute carried out a model study in 1987 to find out method for protecting the Brahmaputra Jamuna right flood embankment from bank erosion of the Brahmaputra-Jamuna river.

4.3.2 Design Procedure of the Model

Plan and cross sections of the river needed for designing the model, were supplied by the Executive Engineer, Brahmaputra Survey Divn.-II, BWDB, Mymensingh. Water level and discharge data were collected from the Directorate of Surface Water Hydrology-I, Water Development Board, Dhaka. A distorted movable bed model was chosen with horizontal scale of 1:500 and vertical scale of 1:100 with a natural distortion of 5. The dimension and physical quantities of the model were based on the Froudian similitude relationship, some of which are listed below:

Horizontal scale ratio : $L_r = 1:500$

Vertical scale ratio : $D_r = 1:100$

Distortion scale ratio : $S_r = \frac{L_r}{D_r} = 1:5$

Velocity scale ratio : $V_r = \sqrt{D_r} = 1:10$

Discharge scale ratio : $Q_r = L_r D_r V_r = 1:500,000$

Where the subscript 'r' represent the ratio of model to prototype.

Rating curve was prepared for Brahmaputra Jamuna River with the help of the water level and discharge data observed at Bahadurabad for the year 1985. The upstream gauge at Dhutichara 250' upstream of cross-section J ≠ 15-6 (Fig. 4.9) was collected on the basis of average slope of water level 0.0001 between the stage at Bahadurabad and the corresponding stage at Chilmari.

The following discharges were selected with their upstream and downstream water elevation for model experiment. All dimensions are presented in prototype unless otherwise stated.

Sl. No.	Discharge in cfs.	Water surface elevation at Bahadurabad in ft from rating curve	Water surface elevation at Dhuti-chara in ft.	Remarks
1.	500,000	51.75	57.05	Dhutichara W.L. was calculated on the basis of average slope
2.	10,00,000	57.25	62.55	
3.	15,00,000	60.90	66.20	
4.	20,00,000	63.60	68.90	
5.	25,00,000	66.30	71.60	

4.3.3 Construction of the Model

The model was constructed in an existing flume of 270'x100' at the River Research Institute. About 18 miles of the river Brahmaputra from cross-section No. J ≠ 16-5 to cross-section No. J ≠ 14-7-1 was reproduced in the model as shown in fig. 4.9. The mean diameter of the sand used in the model was .222 mm. The plan of the river was reduced to model scale and river was laid in the flume. The cross section were reduced to model scale and with the help of bamboo pegs and levelling instrument, these sections were reproduced in the model and the model was moulded with above sand. Two metallic Gauges were fixed on the bed of the river; One at 250' upstream of cross-section J ≠ 15-6 and the other at 2000' upstream of cross-section No. J ≠ 14-7 to measure the water surface elevation of the river. Four tilting gates were placed at the end of the model to reproduced the tail water elevations. A six feet wide rectangular weir was placed at the front of the model to measure the discharges. The cross-bars and closures in the model were constructed of cement concrete.

4.3.4 Calibration and Validation

The model test was first conducted to obtain a correspondance in behaviour between the model and the actual field condition. In this case the verifications were made by comparing the prototype stage--discharge relation at Bahadurabad and stage at Dhutichara with those obtained in model. The model was run with existing cross-bars for the discharge corresponding to 5,00,000; 10,00,000; 15,00,000; 20,00,000; 25,00,000 cfs. in prototype with corresponding water levels at Bahadurabad and water levels at Dhutichara were recorded as shown in Table 4.3.

It was observed from Table 4.3 that water levels at prototype and those observed in the model were more or less same. So it was considered that model behaved similar to prototype.

4.3.5 Operation Technique

Water was used as model liquid and arrangement for required water was made through pumping water by recirculation method.

No material was mixed with or introduced to water for meeting the requirement of sediment load in the model. Four test run were made including proving test for calibration and validation. In test No.2 the model was moulded with existing cross-bars and the head of the cross bars were extended into the river from 20% to 30% of the width of the channel. The model was run for discharges corresponding to 10,00,000; 15,00,000; 20,00,000; 25,00,000 cfs. Surface flow lines were observed by dropping ball for each discharge. Velocities were measured for different discharges at each cross-section at a distance of 500' from the right bank. In test No.3, the model was moulded with existing cross bars. The new cross bars and two closures were constructed; One cross bar was constructed at 1500' downstream of cross section No. J ≠ 16-7 and the other one was construction at cross section No. J ≠ 14-6. Noongola cross bar was demolished and a new closure was constructed in place of Noongola cross bar. The other was constructed at cross-section J ≠ 14-1. The model was run for discharges corresponding to 10,00,000; 15,00,000; 20,00,000 and 25,00,000 cfs in prototype. Surface flow lines were observed for different discharges. Velocities were measured for each discharge at each cross section at a distance of 500' from the right bank of the river. In test run No. 4, the model was moulded as per model scale. Sripur cross-bar was extended 500' more with an angle of 15°. The proposed closure No.1 & 2 were also extended 500' each. One new closure of 8000' length was constructed at a distance of 875' downstream of c.s. No. J ≠ 14-4. Katlamari cross bar was demolished. The model was run for discharge corresponding to 10,00,000; 15,00,000; 20,00,000 & 25,00,000 cfs in prototype. Flow lines were observed for each discharge as done earlier. Velocities were measured for each discharge at each cross section at a distance of 500' from the right bank of the river.

4.3.6 Data Collection and Interpretation to Prototype Data

Discharges through the model were measured by a calibrated rectangular weir. Water surface elevations were measured at 250' u/s of C.S. J ≠ 15-6 and 2000' u/s of C.S. J ≠ 14-7 by two metallic gauges installed earlier. Velocities for different discharges at each run were measured. Data collected from the model were converted to prototype data by using the model scale ratio and by similitude method. It revealed from the result of test No.1 that eroding velocities exist along the right bank of the river and flow hit the bank directly. Test No.2 show that eroding velocities exist along the whole length of the right bank and flow passes very close to the right bank. Test No. 3 show that non eroding velocity except at few places occured along the whole length of right bank and flow lines shifted to a considerable distance away from the right bank. Scour whole occured the toe of nose of all cross bars and closures. Test No. 4 gave a better performance and it showed taht flow lines shifted to a more considerable distance away from the right bank than in test No.3.

Finally it was concluded that 7 Nos. of cross bar and 3 nos. of closure as shown in Fig. 4.6 may prevent erosion of right bank of the river and thesemay protect the right flood embankment of Brahmaputra Jamuna river. The position and length of the cross-bars and closures were mentioned below:

CROSS-BAR

Sl. No.	Name of cross-bar	Position	Total length
1.	Sripur	Existing	3250'
2.	Proposed cross-bar No.1	1500' d/s of C.S. J = 16-7 and parallel to c.s. J ≠ 15-1.	2250'
3.	Kamarjani C.B.	Existing	2750'
4.	Managh C.B.	"	500'
5.	Rasulpur C.B.	"	1500'
6.	Proposed C.B. No.2	Along the C.S. of J ≠ 14-6	3250'
7.	Gazaria C.B.	Existing	3000'

CLOSURE

1.	Proposed closure No.1	at Noongola	3000'
2.	Proposed closure No.2	at the bank at an angle 45° with c.s. J ≠ 14-1	6000'
3.	Proposed closure No.3	875' d/s from c.s. J ≠ 14-4 at an angle 65° with embankment	8000'

4.3.7 Comparison and Discussion

1. Rating curve of Brahmaputra Jamuna river at Bahadurabad had been made for only one year (1985), on the basis of which stages at different discharges had been calculated and used in the model study. Rating curve based on one year data may not be representative. At least 20 to 25 years data should be analysed and an average rating curve may be made for using in the experiment. Water surface elevation at Dhutichara was calculated on the basis of average water surface slope of .0001 but no comment had been made about the basis of accepting this slope.

2. The river Jamuna is an alluvial river and carries a huge amount of sediment load. But no sediment was fed during experiment. Modelling of sediment transport is the standard practice. Sediment transport affects the slope and flow of the river.

3. Sand of mean diameter of 0.222 mm had been used to mould the bed of the model but no comment had been made about the size of the bed materials of the prototype. Roughness affects the velocity and should be modelled.

4. Jamuna is a braided river. For reproduction of channel pattern scaling procedure (Klaassen, 1987) may be followed.

5. Comparing water surface elevation in the model and that in the prototype, it was considered that model behaved similar to prototype. But for accurate validation of the model all the phenomena like sediment load, channel pattern, etc should be reproduced.

6. Time scale had not been followed during model study and experiment had not been made to confirm the river course after a long period of time.

4.4 MODEL STUDY FOR PROTECTION OF KUSTIA TOWN FROM RIGHT BANK EROSION OF GORAI RIVER

4.4.1 Introduction

Kustia town was threatened by the right bank erosion of the river Gorai. River flow directly hit the right bank near kustia town causing severe erosion. To protect the town from erosion, decission was taken to divert the river flow from right bank to the middle by constructing Groynes . It was also decided to conduct a model test at the River Research Institute to find out the most effective and economical measure for protection of Kustia town by constructing groyne/spurs and to determine their location, length, angle alignment, etc. of the proposed structure. Accordingly River Research Institute conducted a model experiment in the year 1971 and it was recommeded for construction of two nos. of T-head gorynes for the protection of kustia town (HRL R-34, 1971). Out of the two only one T-head groyne (Groyne no.2) was constructed in 1973 by which a big char was developed downstream of it but the problems of erosion upstream of the groyne deteriorated day by day. Again, according to the authority decission, River Research Institute conducted model experiments on the problem in the year 1979 and it was recommeded for construction of 3 Nos. of T-head Groynes instead of two (RRI R-55, 1979).

Bangladesh Water Development Board taken up the construction work of Groyne No. 1 in January 1985 and the Project Director, Irrigation and Rehabilitation project, requested River Research Institute to take up the model study on emergency basis to suggest whether the size and location of the proposed groyne no.1 is still effective or is to be modified. It was also requested to study whether the proposed Groyne no. 3 is still required or not as the thalweg has been changed and a big char was developed at its proposed location. Accordingly a distorted movable bed model was constructed at the River Research Institute and experiments were carried out in April, 1985, the detail of which is given in the following articles.

4.4.2 Design Procedure of the Model

Survey maps and some cross-section of the problem area of the river Gorai starting from its offtake point from the river Padma to the Gorai Railway bridge, needed for designing the model were supplied by the project Director, Irrigation and Rehabilitation project, BWDB. Relevant water level and discharge data were collected from the Hydrology Directorate BWDB, Dhaka. The model was designed based on the Froudian law of similitude. The adopted model scales were as follows:

Horizontal scale ratio, $X_r = 1:200$

Vertical scale ratio, $Y_r = 1:36$

Slope distortion scale ratio $S_r = \frac{X_r}{Y_r} = 1:5.55$

Velocity scale ratio, $V_r = \sqrt{Y_r} = 1:6$

Discharge scale ratio $Q_r = (X_r Y_r)\ V_r = 1:43200$

where suffix r indicates the model to prototype ratio.

4.4.3 Construction of the Model

The model was constructed at the premises of the River Research Institute. All the linear dimension of the prototype were converted to model dimension according to the chosen scales. About four miles of the river had been reproduced in the model from the offtake upto the Gorai Railway bridge. The model had been moulded with fine sand of d_m = .237 mm. Two metallic gauge were fixed in the river model bed, one at the offtake of the river and one at the Gorai Railway bridge. A 10 cusec pump was installed to supply water to the model. A rectangular weir was installed upstream of the model for measuring the discharges. The T-head groynes and Bell month Spur were made of cement concrete and the permeable groyne was made of bamboo chips. The length of T-head of groyne no. 2 was 400 feet and the shank was 250 feet and the angle between them was 100^{o} (d/s side). The length of the permeable spur and beel mouth spur were 800 feet and 400 feet respectively.

4.4.4 Operation Technique

Water was used as model liquid and arrangement for required water was made through pumping water from a near-by pond and by recirculation of water by a pump 10 cusec capacity. No material was mixed with or introduced to water for meeting the requirement of sediment load in the model. Four test run were made during model experiment with prototype discharges of 20,000; 50,000; 100,000; 150,000 and 250000 cusec respectively for each test run. First test run was made with existing T-head groyne no.2 only and water level at Gorai Railway bridge and at cross-section 1 were recorded for the above discharges (Fig. 4.19). Second test run was made with the existing groyne No.2 and the proposed groyne No.1 in the right bank at cross-section no.2 about 2400 feet upstream from the existing groyne no.2, 3rd test run was made with groyne no. 1 & 2 in position and with a permeable spur of 800 feet long which was placed making 45° with the bank (Fig. 4.10) at upstream of groyne no.1 and about 400 feet downstream of cross-section 6(u/s) and 4th test run were made with groyne no.1 and groyne no.2 in position and with a Bell mouth spur of 400 feet long making right 1100 feet downstream of cross-section 4 (u/s) (Fig. 4.11) and this removing the permeable spur. Discharges were measured by a calibrable rectangular weir which was installed at upstream of the model and water surface elevation at different section were measured from the installed gauge. The river model was moulded before every test run.

4.4.5 Calibration and Validation

The model test was conducted first to obtain the hydraulic similitude between the model and prototype (calibration test). The first test run with different discharges as per table 4.4.

were made for calibration purpose. Water level at Gorai Railway bridge and at cross section No.1 were recorded for each discharge and are furnished on table 4.4 . It was observed from the table that the water level at prototype and those observed in the model are more or less same. So it was considered that the model behaved similar to prototype and no calibration was required.

4.4.6 Data Collection and Interpretation to Prototype Data

Discharges through the model were measured by a calibrated weir. Water surface elevation at Gorai Railway bridge and at cross-section-1 were measured for different discharges by two gauges which were installed earlier. Data collected from the model were converted to prototype data by using the model scale ratio and similitude method. No other quntitative measurement or data were collected but some physical behaviour of the model was observed carefully to assess the prototype behaviour and its successful functioning. They were summerised below:

1. During test run No.2 with Groyne No.1 & 2, the flow lines, velocity profiles and scour were observed for different discharges. It revealed from the result that the flow may be diverted from right bank to middle of the river. The existing char upstream of Groyne No.1 would be eroded heavily during highest flood.

2. In test run No.3 with Groyne No.1 & 2 and permeable groyne velocity distribution and nature of flow was observed for different discharges. During higher discharges the flow would divert from right bank to mid-channel upstream of Groyne No.1 and about 1/3 portion of char was cut resulting an uniform flow along the river. The velocity became nil along the right bank upto cross-section No.2 adverse effect was seen at the left bank.

3. In test run no. 4 with the Groyne no. 1 & 2 and the bell mouth spur, velocity distribution and nature of flow was observed for different discharges. It was found from the test that the region of char upstream of Groyne no.1 would be checked and no adverse effect was seen at the bank.

Finally it was recommended that the proposed size and location of groyne no. 1 as suggested earlier would be quite effective and no modification was necessary. In order to retain the newly formed char at the right bank either the permeable spur made of Salbollah or the bell mouth spur would be constructed.

4.4.7 Comparison and Discussion

Comparison and discussion made in serial number 1,6 and 7 of article 4.3.7 are also applicable for model study for protection of Kustia town from erosion of Gorai river. Moreover the following comments may be made on the model experiment.

1. Experiment had been conducted for the discharges varing from 20,000 to 250,000 cfs. (prototype) but no information was available about the design or peak discharge of the river Gorai. Atleast one test run should be made to see its effect on the river boundary and also on the proposed protective measures (Groynes) using the design discharge.

2. Investigation should be made on scour depth which may be formed at the nose of the groynes and on different design criteria of the groynes as it may withstand at worst situation.

3. The river Gorai is also an alluvial river and carries a huge amount of sediment load. But no sediment was fed during experiments. Modelling of a sediment transport is the standard practice. Sediment transport affects the flow and slope of the river.

4. Sand of mean diameter of 0.237 mm was used to mould the river model. But no information about the bed materials and bed roughness had been furnished. Similitude of bed materials is of great importance. Otherwise scaling effects would be more and should be considered for model validation.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Based on the study as delineated in the previous chapters, the following conclusions may be drawn.

1. A survey of the physical model studies carried out in Bangladesh at River Research Institute has been conducted till March 1988. It is found that about 97 numbers of model studies had been conducted at River Research Institute since its creations. Four models are being carried out at present.

2. Out of these 97 model studies 67 are mobile bed and 30 are fixed bed models, considering distortion 47 are distorted modles and 50 are undistorted models. From another basis of classification it was found that 66 are river models, 14 are canal models and 17 are other than river and canal models, such as drainage regulator model, demonstration models etc.

3. Three model studies had been critically reviewed to have an overall idea about the model techniques that are practiced at the River Research Institute, Dhaka. These include model study of silt excluder tunnels of Teesta Barrage Project, model study of protection of Kustia town from erosion of Gorai river and model study for protection of Right Flood Embankment of Brahmaputra-Jamuna river.

4. It is found that techniques of model studies conducted at the River Research Institute in many instances do not comply fully with the standard practices. For instance the velocity method used in the model experiment of silt excluder tunnel of Teesta Barrage Project had not introduced the sediment feed for observing the characteristics of sediment transport.

5. It is reported from the model experiment of silt excluder tunnel that all the twelve tunnels in three bays would be required for silt exclusion. Without modelling the sediment transport phenomena such inference needs clarification.

6. Comparing water surface elevation in the model and the prototype for the model study of Kustia Town Protection as well as the protection of right flood embankment of Brahmaputra-Jamuna river, model-prototype conformity had been validated. But for accurate validation of the model sediment load, channel pattern, etc. should be reproduced.

7. Time scale and distortion of time scale should be considered in all the model experiments.

8. Results obtained from each of the model studies of the above three models as reported by the River Research Institute seems to be highly optimistic. But these studies reveal that the prediction of prototype behaviour obtained from the model studies does not reflect the actual condition. Thus the results obtained from these model studies are very prone to scale effects.

9. It is found that difficulties in modellings are selection of appropriate similarity criteria; selection of model scale or scales; the calibration of model and the application of model results to prototype conditions including the necessary re-adjustments.

10. It is also found that after a model studies has been completed, little effort is given to investigate the accuracies of the model results using high values of prototype data.

5.2 RECOMMENDATION FOR FUTURE STUDY

The scope of this study may further be extended by incorporating the followings:

1. Investigation of the details of model techniques by constructing a model ideally suited to the prototype circumstances.

2. The data of unsuccessful model studies may be collected and critically reviewed to evaluate the causes of failures and make recommendations for further improvement.

3. Field data of projects completed based on recommendations of model studies at River Research Institute may be collected for comparing the prototype and model results for obtaining better insight into the analytical considerations in modelling technique.

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A P P E N D I X - A

T A B L E S

TABLE 2.1 : TYPE OF ACTIVE FORCE AND CORRESPONDING NON-DIMENSIONAL GROUP

Type of active force	Measure	Ratio	Non-dimensional group	Name associated with non-dimensional group
Gravity	γL^3	$\frac{\rho L^2 v^2}{\gamma L^3}$	$\frac{v^2}{gL}$	Froude
Viscosity	$\mu v L$	$\frac{\rho L^2 v^2}{\mu v L}$	$\frac{vL}{\nu}$	Reynolds
Surface tension	σL	$\frac{\rho L^2 v^2}{\sigma L}$	$\frac{v^2 \rho}{\sigma / L}$	Weber
Pressure	pL^2	$\frac{\rho L^2 v^2}{pL^2}$	$\frac{v^2}{p/\rho}$	Euler
Elastic force	EL^2	$\frac{\rho L^2 v^2}{EL^2}$	$\frac{v^2}{E/\rho}$	Cauchy*

L indicates a representative length

*The square root of Cauchy number is the Mach number.

TABLE 2.2: FLOW CHARACTERISTICS AND SIMILITUDE RATIOS

Characteristics	Dimension	Froude	Reynolds	Weber	Euler	Mach
Velocity	LT^{-1}	$L_r^{1/2}$	$\nu_r L_r^{-1}$	$\sigma_r^{1/2}(L_r \rho_r)^{-1/2}$	$P_r^{1/2} \rho_r^{-1/2}$	$E_r^{1/2} \rho_r^{-1/2}$
Time	T	$L_r^{1/2}$	$L_r^2 \nu_r^{-1}$	$L_r^{3/2} \rho_r^{1/2} \sigma_r^{-1/2}$	$L_r \rho_r^{1/2} P_r^{-1/2}$	$L_r \rho_r^{1/2} E_r^{-1/2}$
Discharge	$L^3 T^{-1}$	$L_r^{5/2}$	$L_r \nu_r$	$L_r^{3/2} \sigma_r^{1/2} \rho_r^{-1/2}$	$L_r^2 P_r^{1/2} \rho_r^{-1/2}$	$L_r^2 E_r^{1/2} \rho_r^{-1/2}$
Force	MLT^{-2}	$\rho_r L_r^3$	$\rho_r \nu_r^2$	$L_r \sigma_r$	$L_r^2 P_r$	$L_r^2 E_r$

Table 3.1 : Classification of Model Studies on the Basis of the Nature of Boundary of the Models

Nature of boundary	Serial number of model experiment as given in art 3.2.
Mobile bed	3,5,6,7,9,12,13,14,18,23,24,25,28,30,32,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,66,67,68,70,72,73,74,75,76,78,79,80,81,82,86,87,89,91,92,93,95,96,97.
Fixed bed	1,2,4,8,10,11,15,16,17,19,20,21,22,26,27,29,31,33,34,35,65,69,71,77,83,84,85,88,90,94.

Table 3.2 : Classification of Model Studies on the Basis of the Nature of Scales of the Model

Nature of scales	Serial number of model studies as given in art. 3.2
Distorted scale model	3,9,12,14,18,28,35,36,38,40,42,43,44,45,46,48,49,50,52,53,54,55,57,61,64, 62 66,67,68,70,73,74,75,76,78,79,80,81,82,86,89,91,92,93,95,96,97, 87, 89
Undistorted scale model	1,2, 4,5,6,7,8,10,11,13,15,16,17,19,20,21,22,23,24,25,26,27,29,30,31,32,33, 34,37,39, 47,51,56,58,59,60,63,65, 71,72,77,83,84,85,88,90, 41, 94

Table 3.3 : Classification of Model Studies on the Basis of Purpose of the Study

Purposes	Serial number of model studies as given in art 3.2
Irrigation	7,11,12,14,15,16,19,25,26,27,28,29,32,33,36,41,42,43,44,47,51,52,56,58,59, 60,64,65,67,68,69,70,71,72,73,74,75,76,79.
Flood control	2,4,6,8,10,27,77.
Drainage	13,27,30,31,37,39,40,87.
Power development	1,5,21,26,28,83,84.
Navigation	20,22,28.
Town protection/ Bank erosion	3,9,18,34,38,45,46,48,49,50,53,54,55,57,61,62,66,78,80,82,89,91,93,95,96,97.
Constal development	17,20,23,24,31,39.
Misc	35,88.

Table 4.1: Showing the gauge and sediment deposition for different discharges without excluder tunnel and with tunnel system

Sl. No.	Discharge in cfs		Gange in ft. P.W.D. datum, at			Wt. of Sediment		Remarks
	River	Canal	U/S in River	D/S in River	Canal Head of Regulator	Canal	D/S of excluder tunnel	
				Without Excluder Tunnel system				
1.	30,000	12500	170.00	164.90	168.00	-	-	not measured
2.	40,000	12500	170.00	165.00	168.00	31 lbs		
3.	51,875	12500	170.00	166.00	168.00	25 lbs		
				With Excluder tunnel				
1.	20,000	12500	170.00	164.35	168.00			
	30,000	12500	170.00	165.00	168.00	¼ lb	3 lbs	
2.	40,000	12500	170.00	165.40	168.00	2 lbs	10 lbs	
3.	54,000	12500	170.00	166.00	168.00	6 lbs	65 lbs	

Table 4.2: Stage discharge and retrogressed level for different discharge of river Teesta at Dalia

Sl. No.	Discharge in cfs	Stage in ft PWD datum curve 5 mean	Retrogressed level in ft PWD datum	Remarks
1	10,000	167.25	163.17	
2	20,000	168.20	164.34	
3	30,000	168.40	164.90	
4	40,000	168.70	165.40	
5	60,000	169.20	166.10	
6	100,000	169.80	166.79	

TABLE - 4.3

Stages at Bahadurabad and Dhutichara for different discharges of river Teesta of Dalia.

Sl. No.	Prototype discharge in cfs at Bahadurabad.	Water level at Bahadurabad from rating curve (in ft)	Corresponding water level at Dhutichara		Remarks
			Prototype in ft.	Observed in model (in ft)	
1.	5,00,000	51.75	57.05	57.00	
2.	10,00,000	57.25	62.55	62.50	
3.	15,00,000	60.90	66.20	66.50	
4.	20,00,000	63.60	68.90	68.85	
5.	25,00,000	66.30	71.60	71.80	

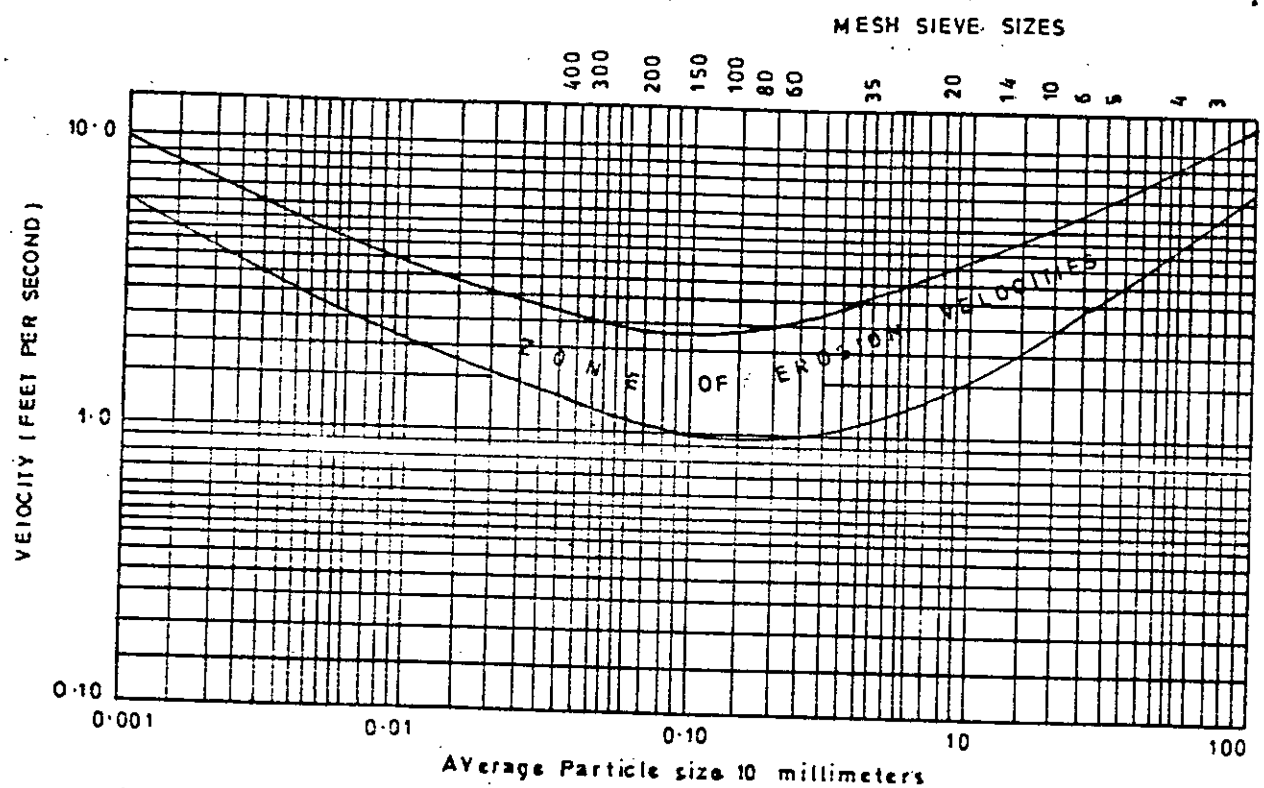
TABLE - 4.4

Gauge reading at Gorai Rly-bridge for different discharges of the river Gorai.

Sl. No.	Prototype discharge in cfs at Gorai Railway Bridge	Gauge Reading at Gorai Rly. Bridge from Rating curve, ft.	Corresponding Gauge reading at c.s.No.1 ft. R.L.	
			Prototype	Observed in model
1.	20,000	22.00	23.08	23.00
2.	50,00	28.20	29.28	29.00
3.	100,000	34.80	35.83	36.00
4.	150,000	40.00	40.28	41.00
5.	250,000	43.50	44.58	45.00

APPENDIX - B

FIGURES



Clay	Fine Silt	Coarse Silt	Very Fine Sand	Fine Sand	Medium Sand	Coarse Sand	Very Fine gravel	Fine gravel

BUREAU OF SOILS, U.S. DePT. AGR CLASSIFICATION

FIGURE -2.1 : Showing erosion veloeities for various particle sizes

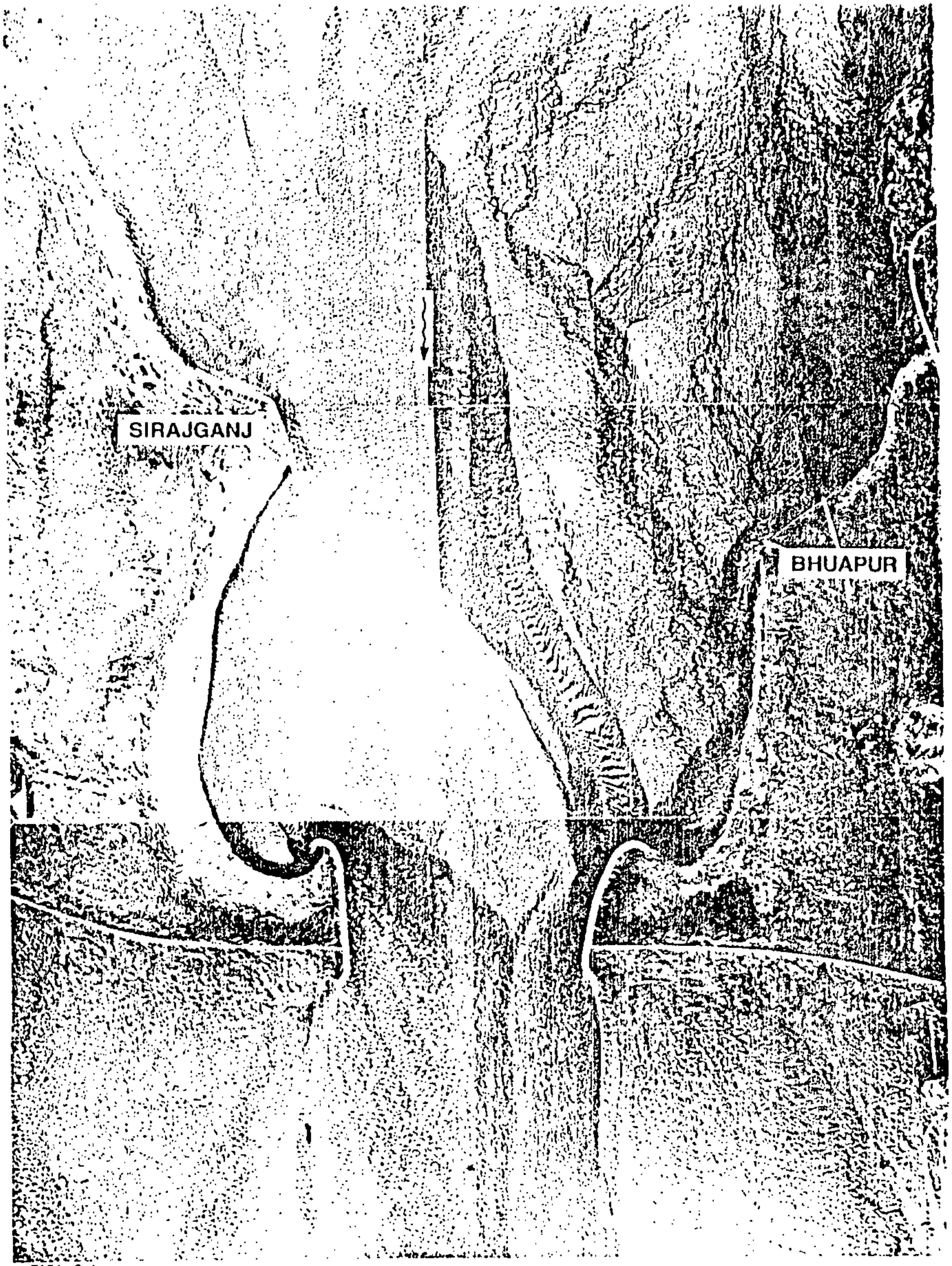
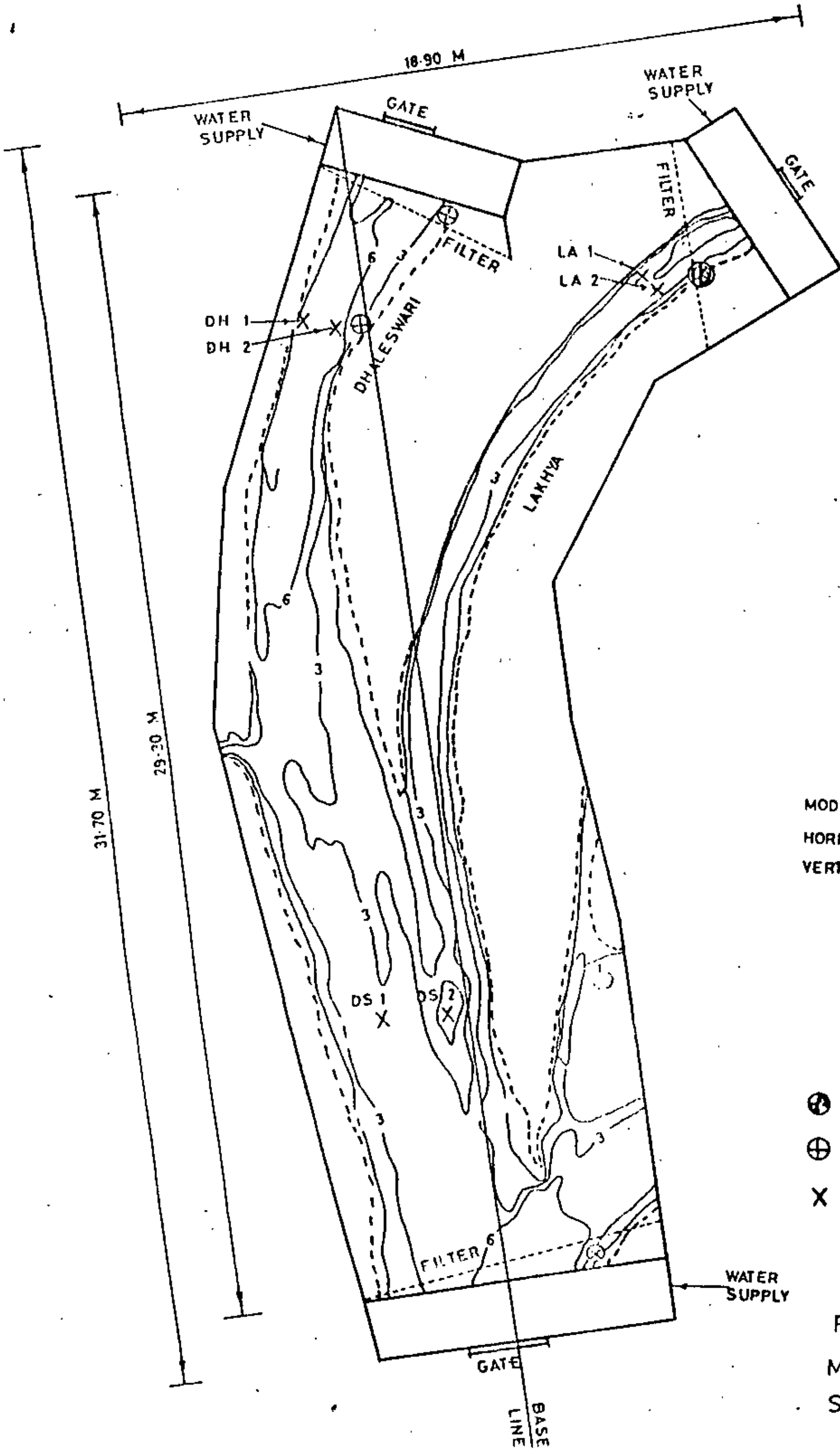


FIG.- 3·1
Vertical view of movable bed model with river training structures for Jamuna bridge.



MODEL SCALE
HORIZONTAL : 1:200
VERTICAL : 1: 331/3

WATER GAUGE MODEL
⊕ WATER GAUGE PROTOTYPE
X SAMPLING POINT PROTOTYPE

FIG:— 3.2
MODEL PLAN OF DSALESWARI-SITALKHYA CONFLUENCE.

MODEL PLAN

DHALESWARI / SITALAKHYA CONFLUENCE STUDY	
NORGES HYDRODYNAMISKE LABORATORIES NORWEGIAN HYDRODYNAMIC LABORATORIES	602855 JULY-83

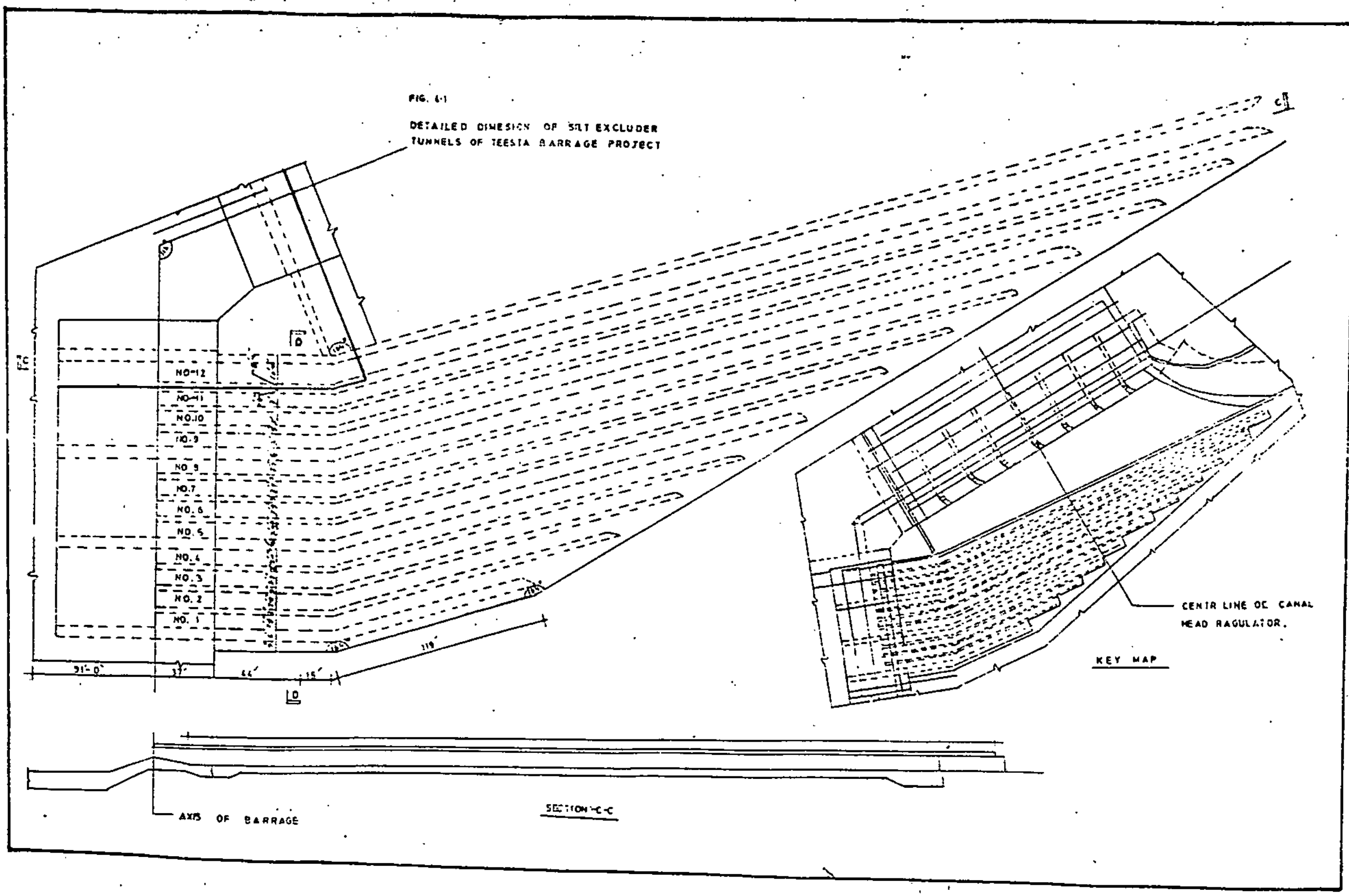


FIG. 6-1

DETAILED DIMESION OF SILT EXCLUDER TUNNELS OF TEESTA BARRAGE PROJECT

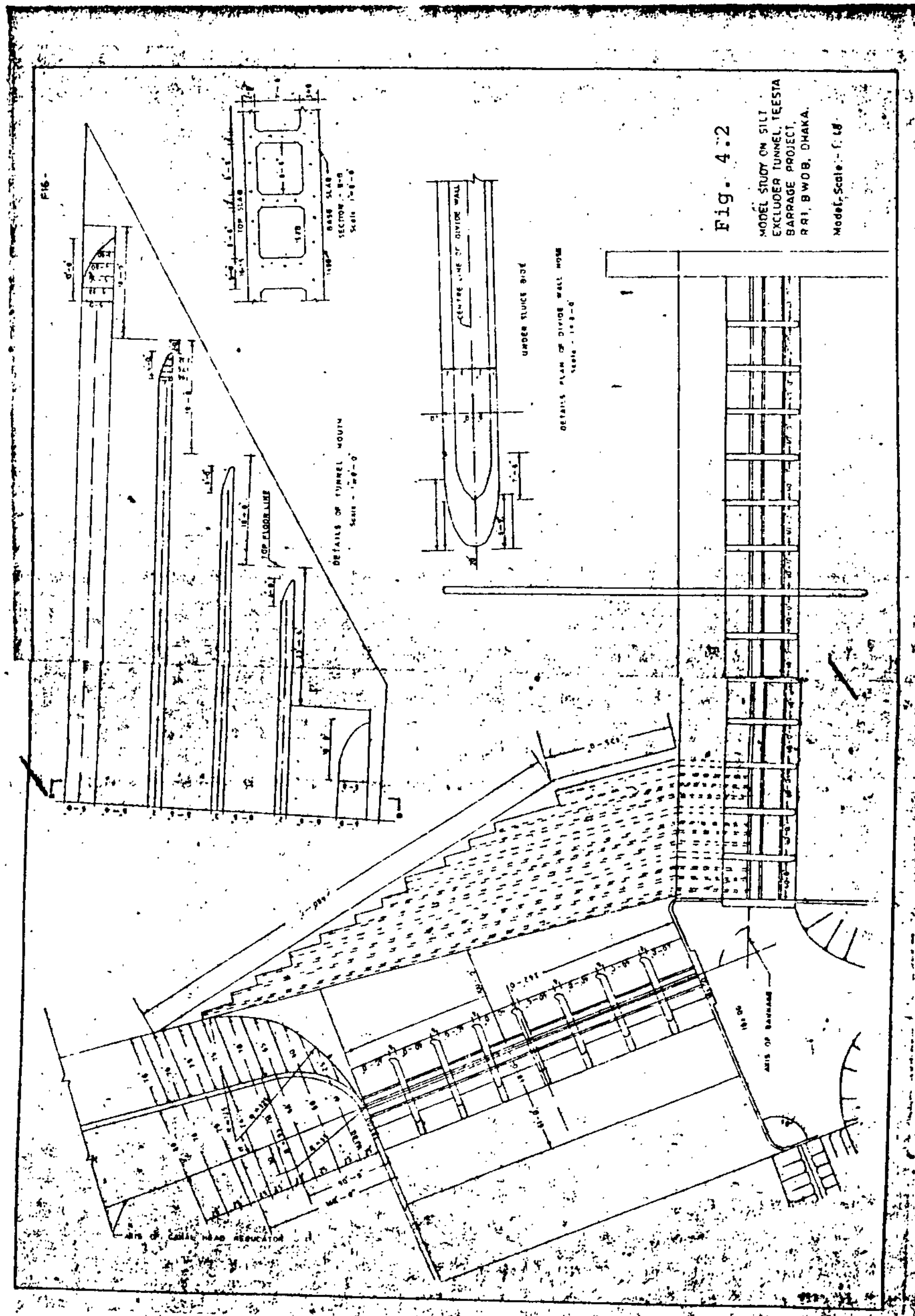


Fig. 4.2

MODEL STUDY ON SILT EXCLUDER TUNNEL, TEESTA BARRAGE PROJECT, RRI, BWDB, DHAKA.

Model Scale :- 1:48

Plate-1

Figure 4.3: Model plan showing nature of flow in the cannel with sediment excluder tunnel(discharge 40,000 cfs).

Figure 4.4: Model plan showing nature of flow in the cannel with sediment excluder tunnel(discharge 20,000 cfs).

Plate-2

Figure 4.5: Model plan showing the nature of dry-bed after model run, Teesta barrage project.

Figure 4.6: Model plan showing nature of scour around the nose of divide wall of Teesta barrage project.

Plate-3

Figure 4.7: Model plan showing nature of scour infront of undersluice of Teesta barrage project.

Figure 4.8: Model study showing the nature of sediment entry and deposition in-the cannel head Regulator of Teesta barrage project.

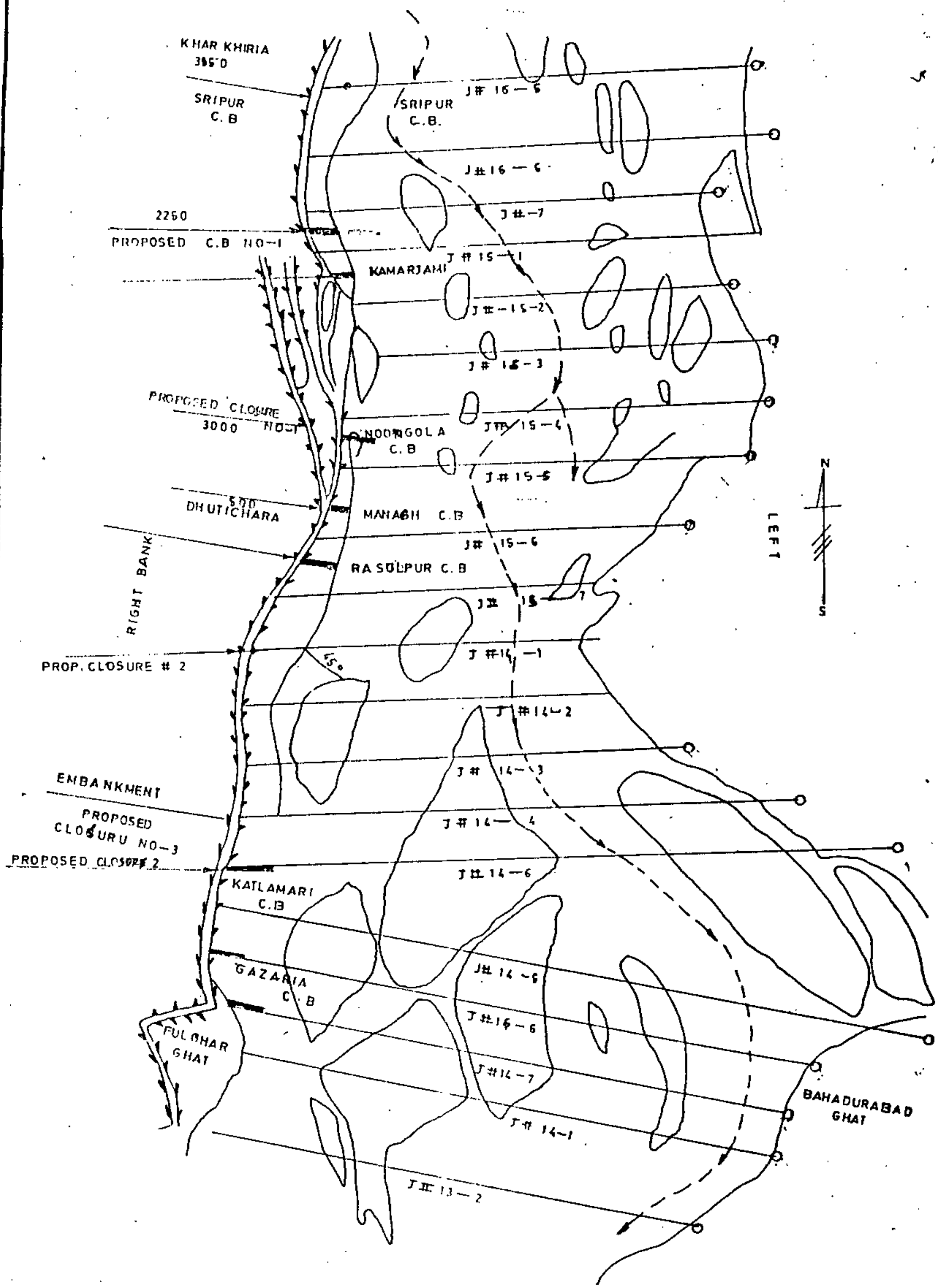


FIG:- 4·9

MAP OF BRAMPUTRA-JAMUNA RIVER, SHOWING PRESENT COURSE, LOCATION OF CROSS-SECTIONS AND EMBANKMNT, ETC. year ?

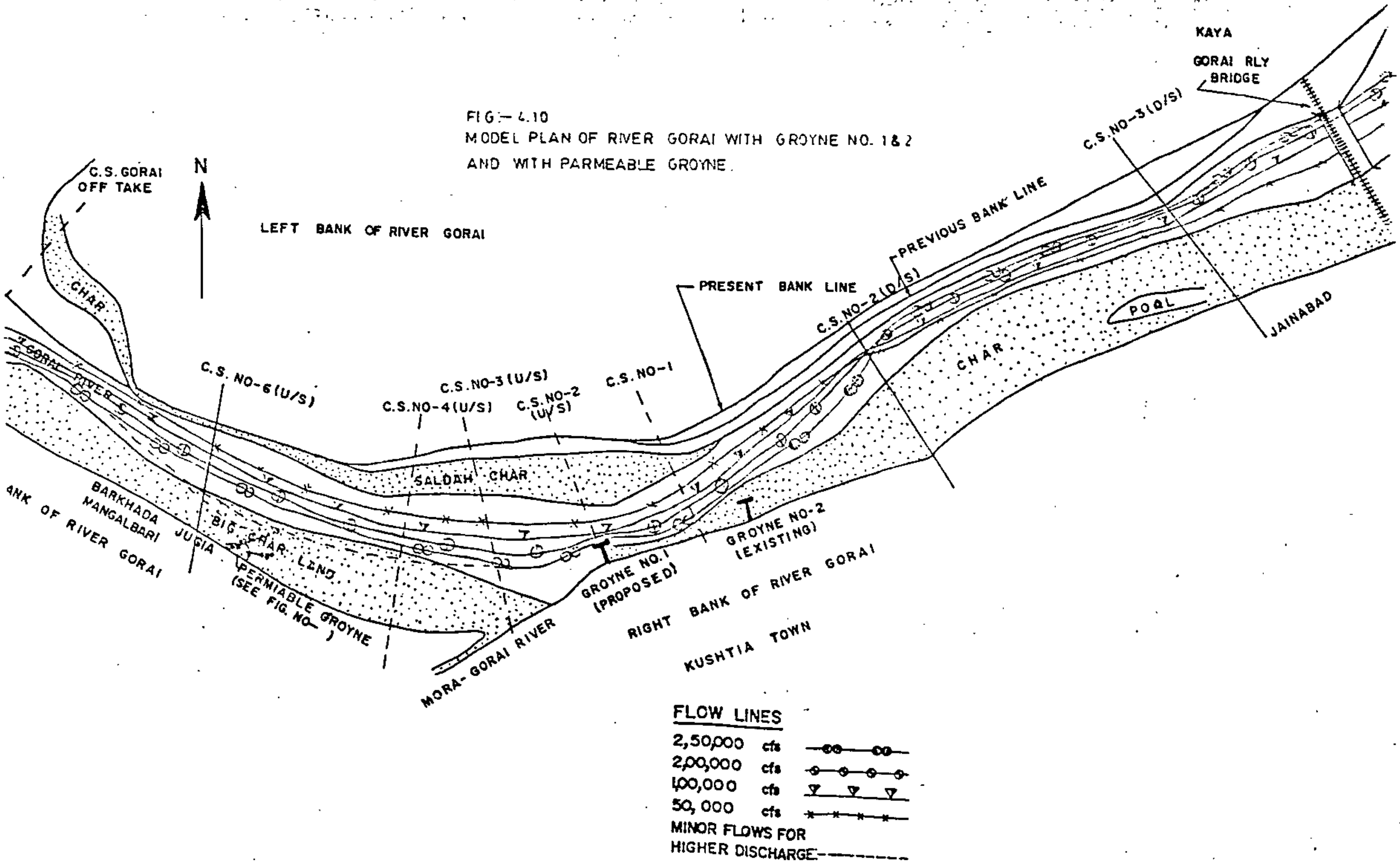


FIG:— 4.10
MODEL PLAN OF RIVER GORAI WITH GROYNE NO. 1 & 2 AND WITH PARMEABLE GROYNE.

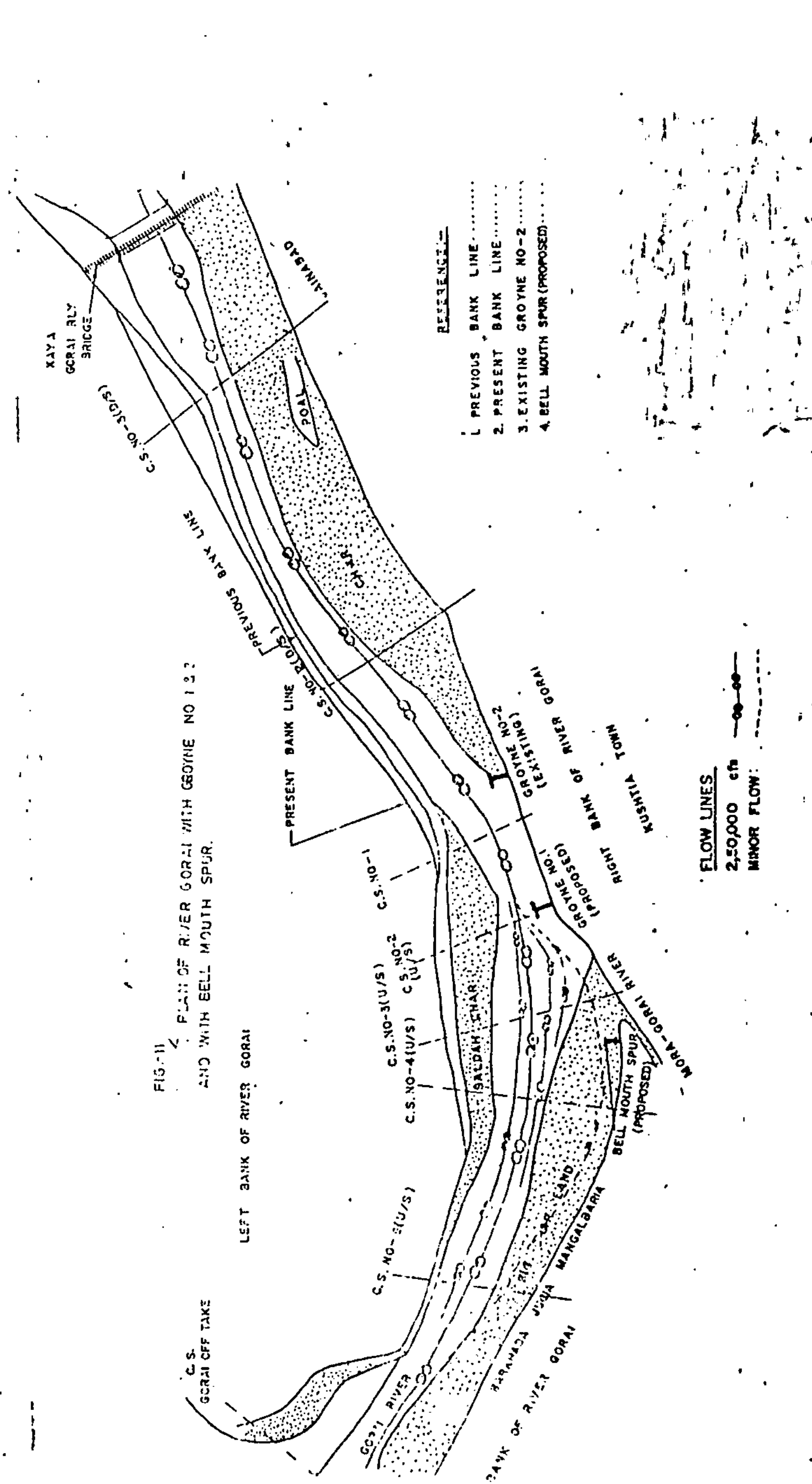


FIG-11 PLAN OF RIVER GORAI WITH GROYNE NO 1 & 2 AND WITH BELL MOUTH SPUR.

APPENDIX - C: A short list of river models undertaken at the River Research Institute, Dhaka.

1. Model of the river Teesta at Gadamari, Rangpur.
2. Model of the river Teesta at Tambulpur, Rangpur.
3. Model of the river Karnafuli at Kaptai, Chittagong.
4. Model of the river Shog at Dinajpur.
5. Model of the river Jamuna at Sirajgonj.
6. Model of the river Dharla at Kurigram.
7. Model of the river Little Feni at Feni.
8. Model of the river Muhuri at Feni.
9. Model of the river Dakatia at Chandpur.
10. Model of the river Nabaganga at Magura.
11. Model of the river Gumti at Comilla.
12. Model of the river Brahmaputra at Badalpur, Mymensingh.
13. Model of the river Brahmaputra at Samvogonj, Mymensingh.
14. Model of the river Chuner at Khulna.
15. Model of the river Kobadak-Khulpetua at Khulna.
16. Model of the river Gorai at Kustia.
17. Model of the river Gorai at Kumarkhali.
18. Model of the river Khowai at Shaistagong, Sylhet.
19. Model of the river Khowai at Ballah, Sylhet.
20. Model of the river Manu at Moulavibazar.
21. Model of the river Ganges at Rajshahi.
22. Model of the river Meghna at Mohonpur.

APPENDIX - D : DESCRIPTION OF SELECTED MODEL STUDIES UNDERTAKEN AT RIVER RESEARCH INSTITUTE, DHAKA.

1. Model Investigation of Spillway Design of Dam at Kaptai in Karnafuli River (HRL ,1953)

Model study of the section of spillway of the dam at Kaptai in the Karnafuli river, which was proposed for the control of flood in the river and the production of Hydro-electric power, were conducted on a 1:24 scale model to determine the performance of spillway apron that would function satisfactorily and would be able to dessipated spillway discharges without undermining the toe of spillway. The experiments were conducted in the Hydraulic Research Laboratory of Irrigation Directorate, Dhaka in February 1953.

2. Model Experiment for the Prevention of Erosion at Sirajgonj by the River Jamuna (HRL - 1953)

The river Jamuna had been eroding the upstream of the right bank of the loap channel, which was protected by existing brickmatress work near Sirajgonj town. A portion of brickmatress had already been eroded above the protruding nose of the revetment. There was likely danger of further eroding completely the protective revetment work if measures were not taken to arrest the erosion. In order to determine the effectiveness and location of spur to stop erosion and to test any other arrangement for prevention of erosion, the problem was refered to the Hydraulic Research Laboratory for model experiment. A moveable bed model was constructed in the Laboratory in July 1953 and experiment on the length, position and type of spur were made. The scale of the model adopted was horizontal 1:200, and vertical 1:50.

3. Model Experiment of the Design of Diversion Channel of the Dam at Kaptai in the Karnafuli River (Rahman, 1954)

The diversion channel was being constructed to carry the discharge of river Karnafuli during the period of construction of dam at Kaptai. The diversion channel was designed to carry the maximum flood discharge of 200,000 cusecs. Model experiment was conducted (i) to find out the afflux at the upstream level for passing the flood discharge through the diversion channel, (ii) to determine the effectiveness of the protective apron for prevention of erosion at the downstream end of the diversion channel. The model was constructed to 1:90 geometrically similar scale in the Hydraulic Research Laboratory in March 1953 and experiments were performed. The section and bottom level of the diversion channel was modified after completing the model experiment of the diversion channel and Chief Engineer, (Irrigation) directed to take up the model experiment on the modified bed level and side slope. Accordingly a modified model of the diversion channel was constructed in March 1954 and experiments were performed.

4. Model Studies on the Design of Buri Teesta Flood Spillway (HRL - 1956)

The Buri Teesta flood spillway was designed to pass the expected flood discharge of 3600 cusecs of Buri Teesta River. The general purpose of the model study was to investigate the hydraulic performance of the spillway apron as originally designed with a view toward developing such design modification as might be necessary to assure the hydraulic safety of the structure. The model of the spillway as designed was constructed in brick flume to a linear scale ratio of 1:24 in the Hydraulic Research Laboratory in June 1956 and experiments were performed.

5. Model Experiment for the Prevention of Erosion at Kurigram by River Dharla (HRL-1956).

A mobile bed model with a horizontal scale of 1:300 and vertical scale of 1:40 as constructed in the Hydraulic Research Laboratory in July 1956, and experiments were conducted on the length, position and type of spur to stop the erosion of the right bank of the river Dharla at Kurigram.

6. Model Studies of Little Feni Regulator in Connection with Coastal Embankment Project (HRL - 1962).

A comprehensive programme for the protection of Little Feni catchment area in the district of Noakhali from the inundation of saline water had been considered. The project consisted of construction of dikes, regulators, sluice, etc. The model study was made to check the performance of the stilling basin and the effectiveness of the flexible paving downstream. The model was constructed to a scale of 1:24 in the Hydraulic Research Laboratory,Dhaka and tests were started in June, 1961 and were completed by the end of August, 1961.

7. Model Studies for the Checking of Erosion of Right Bank of Feni River Upstream of Sovapur Bridge (HRL-1962)

Upstream of Sovapur bridge, the Little Feni river takes a sharp turn, then runs parallel to the Dhaka-Chittagong trunk Road for about three fourth of a mile and passes under the bridge at an angle. The river was fast eroding its right embankment endangering the trunk road. To protect the trunk road and arrest erosion it was suggested to put up a series of triangular spurs on the eroding bank as an immediate measure and to carry out model tests to find a permanent solution of the problem. Model studies were carried on whether the protective measure already undertaken were adequate and to find more effective and economical measures for protection of a more permanent nature, in H.R. Laboratory during June, 1961 to December,1961. Tests were done in a distorted model with horizontal scale of 1:100, a vertical scale of 1:20 with a natural slope distortion of 5.

8. Sectional Model Studies of Magura Barrage (HRL-1962)

The then East Pakistan WAPDA was considering a scheme to construct a barrage accross the river Nabagonga below the confluence of Rivers Nabagonga and Kumar at Magura in the district of Jessore for the purpose of raising the water table to improve agricultural production. The main features and dimensions of the barrage were designed by consultants, and proposed to make arrangements for model studies to ascertain some design features. A sectional model of the Barrage was constructed to a scale of 1:24 and experiment were done during Oct. 1961 to July, 1962.

9. Model Experiment of Intake Channel of Ganges-Kobadak Project (HRL 1958)

The first problem was to study the flow condition at the offtake in order to ensure that the supply canal communicates with the Ganges in all seasons. The other problem related to the up keep of the supply canal. It was necessary that the supply at offtake should enter the canal in a uniform way and the bottom sand should move along the river bed without entering the supply canal. A moveable bed model with a horizontal scale of 1:1000 and vertical scale of 1:100 was constructed in the H.R. Laboratory Dhaka in November, 1958.

10. Hydraulic Model Study of Cofferdam for Barrage Teesta Project (HRL - 1961).

The Teesta Project comprises a barrage accross the Teesta River and a system of canals for irrigation of portions of the

Rangpur, Dinajpur and Bogra districts. It is proposed to construct the barrage near Gaddamari in the district of Rangpur. To protect the barrange during construction an extensive earth cofferdam is proposed to encircle the entire barrage. The consultants, Massers High Zinn and Associates (London) requested that a model be constructed to study methods of protection for the cofferdam during construction of the barrage i.e. general location of the barrage and cofferdam; effect of clossing the east channel and best arrangement of armored spurs to protect the main cofferdam. The model studies at the Hydraulic Research Laboratory were conducted during the period January, 1960 to February,1961. The model was a distorted model with a horizontal scale of 1:300 and vertical scale 1:60 with natural slope distortion of 5.

11. Model Study on Ganges-Kobadak Regulator R2-S4/K(HRL- 1967)

Ganges-Kobadak project is the first biggest irrigation project in Bangladesh which started in 1953 with a comprehensive plan to supply irrigation water to the plains of Kustia and Jessore by pumping water from the river Ganges under a head difference of about 30 ft. During the site visit it was noticed that the stilling basin of the regulators could not effectively dissipate the energy of the flowing water and consequantly there was considerable scour downstream of the structure. According to the decission a model experiment on one of such regulators,

R_2-S_4/K of G.K. project was performed in the Hydraulic Research Laboratory, Dhaka in March 1967. The model was constructed to an undistorted scale of 1:6.

12. Model Study on Badalpur Intake Structure in Connection with Old Brahmaputra Multipurpose Project (HRL-1965).

The Old Brahmaputra Multipurpose project aims at the utilization of water from Brahmaputra river for irrigation, hydro-power and navigation in the district of Mymensingh and some parts of the district of Dhaka. The project envisages diversion of water from the Brahmaputra river by an intake channel and then past scouring sluice and through diversion regulator near Badalpur into the old Brahmaputra channel to utilise for irrigation, navigation and hydro-power. It was decided that a model be constructed of the intake structure and a comprehensive series of tests to be performed. A fixed bed model of Badalpur Intake structure had been constructed to a scale of 1:72 in the H.R.Laboratory and experiments were carried out from December 1964 to September 1965.

13. Model Study on Drainage Regulator, Chandpur Irrigation Project (HRL - 1967).

The Chandpur Irrigation project is located in the South Eastern part of Bangladesh which covers an area of about 137269 acres in the district of Comilla and Noakhali. The three fold purposes of the project was to supply irrigation water to the land, to protect land from flood by high embankments and to drain out the area during rainy season through drainage regulator. It was decided to take up a model experiment of the drainage regulator in connection with the project. The model was constructed in an undistorted scale of 1:24 in the open field of the Hydraulic Research Laboratory, Dhaka and experiments were carried out in June, 1967.

14. Model Studies on Main Pumps Outlet Stilling Basin of Ganges-Kobadak Project (HRL - 1968)

A model study of transition section of Ganges-Kobadak project main pump outlet stilling basin and the movable bed of main supply canal was taken up in 1968. The construction of main pump house, setting of three big pumps and outlet structure were nearing completion and some doubts were expressed about the adequate of the transition section of outlet stilling basin of pumps and the moveable bed of main supply canal. The model of the G.K. main pump outlet stilling basin and main supply canal had been constructed in an undistorted scale of 1:22 in the HR Laboratory and experiments were carried out.

15. Model Study on the Location of Teesta Barrage (HRL R-27,1969).

A model study was under consideration for the construction of barrage accross the Teesta river near Gaddimari in the district of Rangpur and a system of canals for irrigation in some portions of Dinajpur, Rangpur and Bogra district. A distorted moveable bed model was constructed to a horizontal scale of 1:250 and vertical scale of 1:48 with natural slope distortion of 5.2 and study on the barrage had been performed at the H.R. Laboratory to determine the most suitable location and orientation of the barrage; study of features of barrage design, location and type of permanent training works upstream; and construction arrangements of diversion, cofferdams and temporary training works in April, 1968.

16. Model Study of Typical R.C. Box Sluice for Coastal Embankment Project (HRL-1969)

It was proposed to carry out a model study on an R.C. Box sluice designed for coastal embankment projects to evaluate downstream erosion characteristics of the sluice and to determine whether erosion could be reduced by using different arrangements of energy-dissipating devices. An undistorted model of scale 1:12 was constructed and tests in this connection were carried out in the H.R. Laboratory in December, 1969.

17. Model Study on Protection of Right Bank Embankment Downstream of Kazirhat Regulator in Little Feni River (HRL-1973)

The right bank embankment of little Feni river was eroded between sluice S-1 sluice S-8 in polder no.59/IA at two location downstream of Kazirhat regulator. Bangladesh Water Development Board proposed to build some protective structure, to protect the embankment from erosion. The model study was carried out to findout the number of protective structures to be required and also the best location and size of the structures at H.R. Laboratory in October, 1972. The horizontal and vertical scale of the model were 1:150 and 1:25 respectively with a distortion of 6.

18. Model Study on Erosion Problem in Khowai River (HRL-1975)

A moveable bed model study was performed on the erosion problem in the river Khowai at Ballah in the district of Sylhet and Khowai town in Tripura state of India. The study was taken up in the month of March, 1974 at H.R. Laboratory, Dhaka on request by the Director Indo-Bangladesh Joint River Commission, Bangladesh. The vertical and horizontal scales of the model were 1:30 and 1:100 respectively.

19. Model Study on Manu River in Connection with Manu Barrage Project (HRL - 1976).

BWDB had taken up a scheme for construction of a barrage accross the river Manu near Matharkapon under Moulvibazar district, to store and raise the river level to a suitable elevation, to feed the gravity irrigation canal system during dry period. A distorted moveable bed model of the river Manu in connection with Manu Barrage project was taken up with horizontal scale of 1:120 and vertical scale 1:48 with distortion of 2.5 in the Hydraulic Research Laboratory, Dhaka in the month of November, 1975. Experiments and observations were made for alignment of Barrage, general flow characteristics and training of the river upstream of the barrage.

20. Model Study of Old Brahmaputra River in Connection with the Protection work of Mymensingh Jute Mills at Shamvugonj (HRL - 1977, HRL-1978).

Mymensingh Jute Mills at Shamvugonj on the left bank of old Brahmaputra river was threatened by bank erosion of the river. To protect the serious scouring, temporary measures were taken by the mill authority. It was decided that before taking permanent protection measures model test might be performed to study the effectiveness of the probable measures for the protection work. A distorted moveable bed model was constructed with horizontal scale 1:200 and vertical scale 1:48 at the H.R. Laboratory, Dhaka in June ,1977 and experiments were carried out accordingly.

21. Model Study on Tengapara Weir-cum-Regulator (HRL - 1978).

In April 1977, a model study was carried out on Tengapara weir-cum-regulator with a linear scale 1:14 both horizontal and vertical in H.R. Laboratory. The main purpose of study was to evaluate the downstream scour of the bed and erosion characteristics of the banks and to determine whether scouring and erosion could be reduced by different arrangements of energy dissipating devices. Tests were carried out on the model accordingly in February, 1978.

22. Model Study on Feni Regulator (RRI-1979).

A model study of Feni regulator in connection with Muhuri Irrigation project in the district of Feni was run on the request of the consulting Engineer of BWDB M/S IECO and the model was constructed in the existing flume with a linear scale of 1:36 at the laboratory of RRI in the month of April 1979.

23. Model Study on Hazimara Regulator to Protect it from the Erosion of Meghna River (RRI-1979)

It was proposed that hydraulic model experiment might be done to find out the suitable measure to be taken to save the regulator from the bank erosion of the Meghna River. A distated moveable bed model study were carried out with a horizontal scale of 1:400 and vertical scale of 1:60 with a distortion of 6.66 in the River Research Institute in August, 1979, accordingly.

24. Model Study on Hazimara Regulator (RRI-1978)

Hazimara Regulator had been constructed on the outfall of the south Dakatia river under Chandpur Irrigation project. After opening of the cofferdam from upstream and downstream of the regulator heavy scour was observed on the downstream of stilling basin. Model study was carried out to find the cause of scouring and to suggest a remedy thereof at the RRI, Dhaka in December, 1978. The linear scale of the model was 1:36.

25. Model Study on Erosion Problem of Khowai River (RRI - 1979)

In the year 1975, the Indo-Bangladesh Joint River Commission, requested the H.R. Laboratory BWDB, Dhaka to study the problem in a model and to suggest a lasting solution. Accordingly the H.R. Laboratory submitted its recommendation to the joint River Commission vide H.R. Laboratory Report No. 40,41 and 42 but no permanent protective work had been constructed. As a result, further erosion took place on the left bank upstream of Ballah Railway on Bangladesh side and at Durganagar on the right bank downstream of Khowai town on Indian side. So, the Indo-Bangladesh Joint Rivers Commission discussed this problem of erosion again and suggested that hydraulic model study might be done to find out a permanent solution of the problem. It was further decided that Indian and Bangladeshi proposals would be tested in that model and more effective and economical measure might be evolved. Accordingly River Research Institute, Dhaka set up the hydraulic model of Khowai River in March, 1979 and experiments were carried out. The model was constructed to a horizontal scale 1:100 and vertical scale 1:24 in a 100'x60' flume.

26. Model Study on Rajshahi Town Protection Scheme, RRI-1980)

Rajshahi Town and its adjoining areas were threatened from severe erosion of the river Ganges. BWDB had taken up the scheme for construction of T-head groyne or spur on the left bank of river Ganges to protect the Rajshahi Town. A distorted moveable bed model study was taken up with horizontal scale 1:300 and vertical scale 1:72 at the River Research Institute in the month of December, 1979 and it conducted the tests on emergency basis from January, 1980.

27. Model Studies on Siltation Problem in the G.K. Intake Channel (RRI - 1980)

During the last few years, the main flow of the river Ganges remained on the left bank near Hardinge Bridge resulting in heavy siltation on the mouth of the G.K. Intake channel at right bank of the river. This resulted in heavy expenditure for dredging purpose to keep clear the mouth of the intake channel of the G.K. Irrigation project pumping plant. It was proposed that hydraulic model experiment would be conducted to find out the suitable measures to be taken so that the main flow of the river always remains along the right bank near Intake channel. A distorted moveable bed model was constructed with horizontal scale of 1:400 and vertical scale of 1:72 with distortion of 5:55 in River Research Institute, Dhaka in November, 1980.

28. Model Studies on the First Proposed Site of Barrage for the Ganges Barrage Project (RRI 1981).

The BWDB had under consideration of construction of a barrage accross the Ganges River. The main purpose of the Ganges

Barrage was to create a pond from which river water can be diverted, by gravity into a system of canals for irrigation of lands in the district of Kustia, Jessore, Khulna, Barisal, Faridpur, Pabna and Rajshahi. It was decided that the scale model study of the Ganges Barrage would be conducted at the premises of River Research Institute, Dhaka to find out the best location and orientation of the barrage out of the three locations. Accordingly a distorted moveable bed model experiment was carried out from December, 1980. The horizontal and vertical scales of the model were 1:300 and 1:50 respectively.

29. Model Study on Canal Head Regulator of Teesta Barrage Project (RRI - 1982).

The model study was carried out on a sectional model constructed at River Research Institute, Dhaka in February 1982 for testing discharge coefficient, length and elevation of stilling basin for thecanal, shape, size and location of friction blocks and end sill, scour in downstream, hydraulic performance of the stilling basin, etc. The model was constructed to an undistorted geometrically similar scale of 1:24.

30. Model Study on the Closure of Dalia Channel of Teesta River (RRI - 1982).

During construction period of Teesta barrage the Dalia channel was closed and a road was constructed upto the right bank of Doani channel for transport of construction material. Model studies were taken up in connection with stabilisation of main course through left Doani channel and to close the right Dalia channel, so that flow passes along the Doani channel, in December, 1982 at River Research Institute, Dhaka. The horizontal and vertical scales of the model were 1:250 and 1:48 respectively.

31. Model Study on Loop-cutting and Protection of Right Bank Embankment Downstream of Kazirhat Regulator in Little Feni River (RRI - 1983)

The right bank embankment of Little Feni river was eroded at two locations downstream of Kazirhat regulator. As per request of Design Directorate, River Research Institute took up a physical model to study and suggest measure on the problem. A movable bed model was constructed with horizontal scale 1:100 and vertical scale 1:20 at River Research Institute and experiments were carried out in 1983.

32. Model Study on Bifurcation of Bogra -Rangpur Canal Regulators for Teesta Barrage Project (RRI - 1985).

The main object of model study was to determine the critical bifurcation angles of Bogra & Rangpur regulators with respect to Teesta canal axis as well as to see the hydraulic performance of respective canal regulators in relation to effective distribution of the upstream main canal discharges through each of the regulators as desired. The model study was performed to an undistorted scale of 1:18 at the River Research Institute, Dhaka in March, 1985.

33. Model Study on Sirajgonj Town Protection Works (RRI - 1986).

The main object of the model study was to find out the most effective and economical measure for protection of Sirajgonj Town by constructing groynes/spurs/cross-bars and to determine their location, length angle, alignment etc. of the proposed structure. A distorted moveable bed model study with length ratio 1:500 and depth ratio 1:100 was conducted at River Research Institute during the period from February to July 1986.

34. Model Study of the Barisal Harbour (Interconsultant,1984)

A physical fixed bed model of 1:200 horizontal and 1:50 vertical scale was constructed at the premises of River Research Institute (RRI), BWDB, for Barisal harbour area to find out a probable solution of erosion and siltation in the area of investigation. The study has been carried out jointly by the Department of Water Resources Engineering (WRE) BUET, Dhaka and the River Research Institute (RRI), BWDB. The model study has been assigned to the Deptt. of WRE by interconsultant A/S on behalf of the BIWTA, Dhaka.