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ABSTRACT

This report dwells upon the design development of RCC jack jetty and Porcupines as cost effective and relatively environmental friendly river training structures. Implementation of conventional river training structures like marginal embankment or levees, guide banks, groynes or spurs, cut offs, pitching of banks, pitched islands, sills, closing dykes and longitudinal dykes are becoming unaffordable and relatively less efficient due to various factors. In the current scenario, it has become priority for the river experts to consider not only the effectiveness of the structure but also to be deeply involved in the aspects like construction cost, environmental impact and aesthetics.

With the increase in steel prices and other construction materials, RCC Jack jetty may be used as a cost-effective and workable river training structure. Also, porcupine system is one of the most economical and efficient river training measures for channelization of river and protection of embankments including highways and bridge abutments. Behaving as permeable structures, they also produce positive impacts on the ecology.

New design indices and performance parameters were evolved in this R&D study which provides primary guidelines for developing design of a RCC jetty field and Porcupines based on the desired design objectives of erosion control, moderate reclaim and heavy reclaim. Threshold values of these parameters were obtained from the analytical study of the laboratory data to categorize the desired design objectives for field condition. The field evidence and analytical results of the prototype study support the laboratory findings of RCC jetty field.

Furthermore, as a complementary measure to enhance the positive effects of Jack Jetty system especially in erosion control and sedimentation, it has been attempted in this study to investigate the impact of combined applications of Jack Jetty and Trail Dykes. On the basis of laboratory experiments and field prototype studies, the results of the above combined applications have been found to be quite encouraging and positive in extracting enhanced effects as desired.

Since research is an unending ongoing process, the outcome of present R&D scheme may be considered as the curtain raiser in the present theme. Obviously, there is an imperative need to undertake studies in future to develop further the design methodology by gaining an insight into the hydraulics of complex flow mechanism involving expenditure of turbulent kinetic energy in and around jacks and porcupines. Further field application of the jack jetty and porcupines are required for fine tuning the laboratory results.

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CHAPTER – 1
INTRODUCTION

1.1 Background

River use has long been an important element in human activities and socioeconomic development. Water is used for domestic, industrial, and agricultural purposes. Hydropower is exploited to engine the industry, the river channel is used for navigation, and the fresh water fishery is a traditional resource. Moreover, rivers and the riparian waters are also used for recreation and leisure. To achieve the economic benefits and meet other demands of humans the rivers have been dammed and channelized. The natural fluvial processes and ecological systems within the river and riparian areas have thus been disturbed to a great extent. River regulation and river training have been performed for various purposes. (Wang et al. 2007)

River plays a complex role in the geomorphological processes of sedimentation and erosion. At lower discharge there is the problem of sedimentation and at higher discharges the erosion of bank occurs. River training works refers to the structural measures for improving the rivers and its banks. For the prevention and mitigation of flash floods and general flood control ensuring the safe passage of floods, river training work is the important component. River training works are the structures which are constructed to control the natural processes i.e. sedimentation & erosion and to train the river as per the requirement of mankind.

Many river training structures are implemented for river training works along with the bioengineering techniques to minimize the negative effects on environment and landscape. There are number of conventional methods of river training works such as marginal embankments or levees, guide banks, spurs or groynes, submerged vanes, cut offs, pitching of banks, pitched islands, sills, closing dykes, longitudinal dykes etc. Some of the measures are less expensive than the others.

Sediment management particularly the control of sediment movement, scour, and deposition is one of the difficult problem encountered by river engineers (Odgaard and Wang 1991). Undermining of the banks and loss of soil is frequently caused by bed scour along the outer bank of river curves. Deposition of sediment often reduces flood conveyance capacity of rivers and interferes with navigation. Effective, affordable measures to control the sediment movement is the main difficulty in the engineering treatment.

The increasing demands of bank protection work in many reaches of rivers have focused attention on an imperative need to develop cost effective and eco-friendly river training measures like jack jetty and porcupines on sound scientific basis to tackle the twin burning problems of flood and erosion along with facilitating navigation. This report focuses on the

"Experimental Study on Jack Jetty & Porcupine Systems of River Training". However, the actual prototype study on Jack Jetty has also been included in this report.

1.2 River Training Works

River is dynamic and continuously changes its position, shape and other characteristics with variation in distance and time. Due to changing behaviour of river following problems can be seen:

- Bank erosion
- Channel course change
- Flood protection
- Aggradations and degradation of channel bed
- Maintaining navigable channel

Every year we face the problem of bank erosion due to flood. This phenomenon induces several impact on the vital infrastructures of the nation such as roadways, houses, loss of agricultural land, irrigation and drinking facilities, loss of properties and human lives. It poses a severe threat to the sustainable development of the nation.

To cope with the problems caused by floods we need river training works. These are often required to stabilize the river channel along a certain alignment and/or with a certain cross section. The river training work is aimed to prevent damage to the land or property adjacent to the river. The other goals of river training works are:

The river training works are used to:

- Protect the river banks from excessive meandering
- Prevent shifting in its course
- Maintain navigability
- Train the river as per the requirement of mankind
- Safe passage of the flood
- Efficient transport of the sediment load
- Provide sufficient depth for navigation channel
- Make river course stable and prevent bank erosion
- Prevent outflanking of the structures

1.2.1 Some Conventional River Training Works

Traditional structures such as groins, revetments, etc., are used to maintain a suitable channel for the purpose of flood control, protect river banks, enhance navigation conditions and also restore the natural habitat of river environment. However, the construction and maintenance of these structures represent an undesirable cost and time consuming in actual days (Awal et al. 2011). Some Conventional river training works are:

1.2.1.1 Marginal embankments

Marginal embankments also known as levees are earthen embankments which are constructed in the flood plains of a river parallel to the river banks. These type of embankment confines the river flood water within the cross section available between the embankments. It does not allow flood water to be spilled over to the flood plains. They are generally constructed for long stretches along a river in low lying areas with an extended floodplain.

1.2.1.2 Guide bunds

Also called Bell's bund. It is constructed at the site of a barrage, weir, bridge, etc. to guide the river flow through the confined waterway without causing damage to the structure and its approaches. The guide banks are usually provided in pairs, symmetrical in plan and may either be parallel or converge slightly towards the structure, extending a little downstream but largely on the upstream of the structure and curved inlands on both ends to provide a bell mouth entry and smooth exit.

1.2.1.3 Spur

Spur dikes are the hydraulic structures used for river training and bank protection works. Spur dike is fixed perpendicular or at an angle to the flow direction in the channels. The two important functions of spur dike are; to reduce the flow velocity and to protect the channel banks. It is known as one of the best types of hydro-engineering structures to deflect or divert the water flow. Historically, spur dikes are provided to prevent the River bed and bank erosion.(Pandey, Ahmad, and Sharma 2017)

A spur, spur dyke or groyne is a structure constructed transverse to the river flow extending from the bank into the river. This type of structure is used for river training and bank protection of certain reach of the river by

- Guiding or diverting the flow direction
- Inducing reformation of river bank by deposition of sediment carried by the stream

The spur creates the zone of slack flow which encourages siltation in the region of the spur to create a natural bank. The spurs can be constructed with many materials such as stones, bamboo, tree trunks and branches, concrete or any other material which are not easily detached by the river and is strong enough to withstand the flow and the impacts of debris.

The spurs may be classified on the basis of

a. Submergence
   (i) Submerged
   (ii) Non submerged

When water flows over the spur dike, it is known as submerged spur dike and the dikes which are not fully submerged in water or where water passes through any length of spur dikes are known as non-submerged spur dikes

b. Permeability
   (i) Permeable
   (ii) Non permeable

Generally, permeable spur dikes consist of steel, timber, bamboo, or RCC piles and these piles are in one or several rows. Permeable spur dikes are generally cheaper and used as a temporary work. Impermeable spur dikes are usually built of stones, gravels, local soils, rocks, and easily available local materials. An impermeable spur dike blocks and deflects the approach flow. However, permeable spur dike permits water to pass through it at a decreased velocity

c. Orientation
   (i) Deflecting
   (ii) Repelling
   (iii) Attracting

An attracting spur dike inclines in a downstream way and diverts the flow away from itself but a repelling spur dike inclines the flow in upstream direction itself. When a spur dike is fixed perpendicularly to the flow, it is a deflecting spur dike.

1.2.1.4 Bank revetment

Revetment refers to a continuous artificial surface on a river bank or embankment slope and part of the river bed which is designed to absorb the energy of the incoming water and protect against erosion by the river current. Revetments are usually placed along the concave side of a river bend where river velocities are high.

1.2.2 Some Low Cost Methods of River Training Works

Nowadays, the increasing demand of low cost river training structures which can be friendly to the environment reminds the necessity of different types of structures. The construction and maintenance of conventional type of river training structures represent an undesirable cost and time consuming in actual days.(Awal et al. 2011)

These types of structures are expensive both in terms of capital cost and maintenance cost. There are some problems to construct such types of river training works:

(i) high cost of construction materials - boulders, wire nets

(ii) unavailability of boulders

(iii) unavailability of construction labors and their high cost

(iv) practically unaffordable for large river networks

For the construction of these types of conventional river training works huge amount of boulders are required. The over extraction of boulders cause erosion and due to it river plain becomes much more vulnerable to flooding because it allows loose landmass to be washed downstream especially during monsoons.

1.2.2.1 Sandbagging

Sandbags can be used to reinforce structures and to build (emergency) dikes. They are widely used to control or reduce the devastating effects of floods particularly in plain areas. Sandbags can also be stacked to make a barrier against rising flood water as well as in areas where flash floods are likely to occur (Hellevang 2011). Bags can be made from various materials and in different sizes but woven polypropylene is the most common. Bags with a filled weight of no more than 30–40 pounds (14–18 kg) are easier to handle. Sand is the easiest and most available material for filling and shaping the bags. Silt and clay can also be used, but working with these materials is more difficult

1.2.2.2 Bandalling

Bandals or bandallings are commonly applied to improve or maintain the flow depths for navigation during low water periods in alluvial rivers of Indian sub-continent. Recently, these are also used for closing off secondary channels in the large rivers like the Ganges to ensure stable single course (Rahman et al. 2003). The essential characteristics of bandals are that they are positioned at an angle with main current and there is an opening below it while the upper portion is blocked. As a empirical rule the blockage of the flow section should be about 50% in order to maintain the flow acceleration. The surface current is being forced to the upstream face creating significant pressure difference between the upstream and downstream side of bandal. The flow near the bed is directed perpendicular to the bandal resulting near bed sediment transport along the same direction. Therefore, much sediment is supplied to the one side of channel and relatively much water is transported to the other side. The reduced flow passing through the opening of bandals are not sufficient to transport all the sediment coming towards this direction, resulting sedimentation over there. On the other side, more water flows with little sediment, resulting bed erosion of the channel on that side

1.2.2.3 Porcupines

Porcupine systems are one of the novel techniques which have been adopted as a cost-effective method of river training (Aamir and Sharma 2015). Porcupine Systems have also been deployed in big rivers in India like Brahmaputra and Ganga with fairly good results. A Porcupine is a unit of the system which comprises six members of RCC which are joined together with the help of iron nuts and bolts to form a tetrahedral frame. Each member is 2–4 m in length, depending upon the requirements. At the time of concreting of members, holes are kept in the RCC poles for the bolts. Generally, RCC poles of 3 m length are used having a cross section of 15 cm × 15 cm (Kakran and Keshri 2012). Reinforcement is given using 4 Nos. of MS bars of 6 mm diameter, with stirrups at 15 cm c/c. Larger porcupines may also be used with greater cross section and heavier reinforcement as per the requirements. Bolts are normally 12–15 mm diameter. Check nuts are to be provided for better grip. Washers are required at both ends for better grip with the RCC members. RCC porcupines should be connected together by wire rope and properly placed on the ground to avoid any disturbance caused by the intensity of flow. The basic principle of porcupine protecting river bank is the decelerating effect of member bars (Yu et al. 2011), which offer resistance to flow and hence cause reduction in velocity.

1.2.2.4 Submerged vanes

Submerged vane is a technique which is used for sediment management in alluvial rivers. Submerged vanes are vertical small flow-training structures (foils), designed to modify the near-bed flow pattern and redistribute flow and sediment transport within the channel cross section (Odgaard and Spoljaric 1986). The vanes are vertical, small-aspect ratio foils (with a height-length ratio, *H/L,* ranging from 0.1-0.5) installed on the channel bed at angles of attack between 5 and 20°. (At angles greater than 20°, the vanes affect the overall roughness characteristics of the stream flow; and flow separation becomes important producing unacceptable scour holes near the upstream ends of the vanes.) The vane height-water depth ratio ranges from 0.2-0.5. In the presence of such a vane, the near-bed fluid downstream from the vane attains a transverse (or secondary) velocity component, *vb,* which persists for some distance downstream. With constant pressure head in the transverse direction, *vh* is compensated by a near-surface component, *vs,* in the opposite direction. The ensuing helical motion of the flow downstream from the vane generates a predictable pattern of aggradation and degradation downstream.

1.2.2.5 Jack Jetty

Jack Jetty is a low cost and effective river training work on which experiment has been carried out through experimental work (Shriwastava and Sharma 2014). H.F. Kellner is responsible for the invention of Jack Jetty (Grassel 2002). He made his first jack with three willow poles tied together at the mid-point. To keep the willow poles extended, he laced them with wire. He replaced the willows with the steel angle design that is the standard today and has changed very little since these. Instead of steel jetty, a modified version of a jack constructed from Reinforced Cement Concrete with cables (RCC Jack) was used (Anupama Nayak, Nayan Sharma, Kerry Anne Mazurek 2016).

1.2.2.6 Trail Dyke

L-head dikes are dikes with a section extending downstream from the channel ends generally about parallel to the channel line. The addition of the L-head section can be used to increase the spacing between dikes, to reduce scour on the stream end of the dike, or to extend the effects of the dike system farther downstream. The L-head portion of the dike takes the energy at the stream end of the dike and spreads it over a larger area, L-heads tend to block the movement of sediment behind the dike by reducing the formation of eddies (recirculation) in the lee/downstream of the dike

1.3 Overall Objective of the Study

i) Objective design methodology on scientific basis for cost effective river training structures - Jack Jetty and modified Porcupine systems will be developed with the help of intensive experimentation in lab and some limited study in field environment depending on actual feasibility for the same. This will contribute towards effective application of the above more affordable river training measures in India and elsewhere.

ii) The above research output is expected to contribute towards evolving designs for cost effective river training measures supported by systematic scientific investigation. This will do away the existing conjectural practice for deciding their design configuration.

iii) The above end-products of this R & D project will considerably contribute towards their advantageous potential field applications for Inland navigation channel development, stream-bank protection, sediment control, channel improvement and in other related areas of Water Resources Engineering.

iv) From a preliminary analysis made by the present investigators in IIT Roorkee, prima facie it had emerged that the required cost per kilometre of stream bank protection by using the above relatively newer techniques comes to only about 20 to 25% of the cost being incurred for the case of conventional bank protection measures. Thus, the relatively low-cost river training techniques of Jack Jetty system will enable the water resources engineers to bring much greater length of erosion affected stream bank under the ambit of protective cover.

CHAPTER – 2

LITERATURE REVIEW

2.1 Jack Jetty

Jack Jetty is a cost effective river training measure on which study has been carried out through experimental work. Jetty jack which was invented by H. F. Kellner in the early 1920's. This was a permeable form of bank protection and did the job at a lower cost than the non-permeable types of bank protection then in use. He made his first jack with three willow poles tied together at the mid-point. To keep the willow poles extended, he laced them with wire. Afterwards, he replaced the willows with steel angles.

2.2 Historical use of Jack Jetty

Grassel (2002) reported that H.F. Kellner founded first jack jetty named "Kellner Jack" in 1920 which was a permeable form of bank protection performed at a lower cost than the non-permeable type. Kellner started his experiments on a small stream neat his home in Topeka, Kansas. The first jack by Kellner was made with three willow poles tied together at the mid-point. He laced them with wire to keep the willow poles extended. Later on he replaced the willow poles with the steel angles. The structural unit of the system called Jack was composed of 4.88 m long 0.1m*0.1m*0.006m steel angles bolted together at their mid-points. Later on Sharma (2012) used RCC Jack Jetty in the Ganga River at Nakhwa site located at 11 Km downstream of Varanasi to inhibit stream bank erosion.

2.3 Literature Review on Application of Jack Jetty

- Grassel (2002) describes that the Arkanas River saw the first installations of jetty systems by the Albuquerque District of the U.S. Corps of Engineers, with five on the Arkanas and two on the Rio Grande which were completed in the early 1950s. By 1953 seven additional jetty systems were installed on the Rio Grande. Soon after installation of Jetty systems high flows were experienced by two of the completed projects – one on the Purgatorie River in Higbee, Colorado and the other on the Arkanas River in Manzanola, Colorado. In the both cases there was no damage to the permeable jetty systems and bank protection was resolved so the efficiency of those systems were verified.
- In Kansas, the jetties were installed by the State Highway Department to protect the bridge across the Cimarron River at Sitka. Before the jetty installation in 1950, the bridge abutment washed twice and both times the bridge was extended. After the installation, the Department was able to remove the extension. (Grassel 2002)

- In Nebraska, the Santa Fe Railway bridge protection project in 1947 demonstrated how jetties were used to establish a new bank on a curve that matched the natural curve of the river. The project used 980 units of jacks consisting 12.2 m of retards, 550m of double diversion lines and 14 backup retard lines to achieve a new bank. (Grassel 2002)
- In Oklahoma, the railroad company in 1942 installed jetty system to achieve a high bank in a deep channel, a deviation from the recommended use of the system for low to moderate height banks. At first, they graded the slope to 1:2 and then placed the jetty system in usual pattern except for tightly spaced retard lines to form a gridiron of resistance. (Grassel 2002)
- Grassel (2002) has again said that in New Mexico, the Santa Fe Railroad used jetty system with success from 1936. The embankments situated next to the banks of the Rio Galisteo had been protected by heavy riprap that was consistently washed out during floods. To build up an auxiliary bank a jetty field was installed and later another row of jacks were installed where the attack of the river was directly against the embankment.
- The flexible jack jetty system conforms to channel scour and allows sediment-laden water to penetrate an area of low kinetic energy where sediment drops out thereby building a bank (Carlson and Enger 1956, Lagasse 1980). Successfully installed jetty system makes sediment beds at a rate of 1 foot per year which makes new ground for vegetation growth. Vegetation increases the protective value of the jetty system. Figure 2.1 describes the reach of the Rio Grande before jetty jack installation, Figure 2.2 shows how the field appeared in the river before vegetation and Figure 2.3 illustrates how the area is appeared after vegetation such as cottonwood, willow and grass. (Grassel 2002)

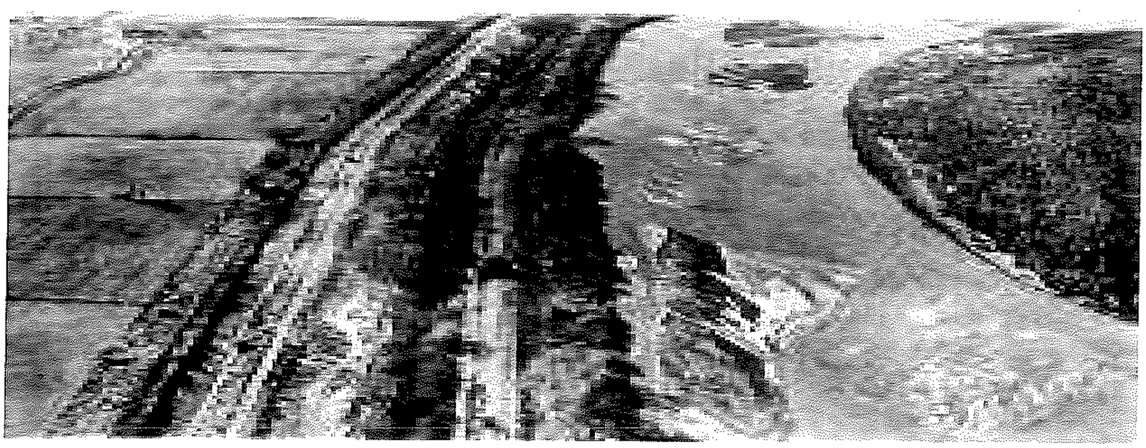


Figure 2.1 : Location of Jack Jetty Installation (Photo: Dec 12, 1952) on the Rio Grande near Bernallillo, NM, Aerial photo by the Corps of Engineers

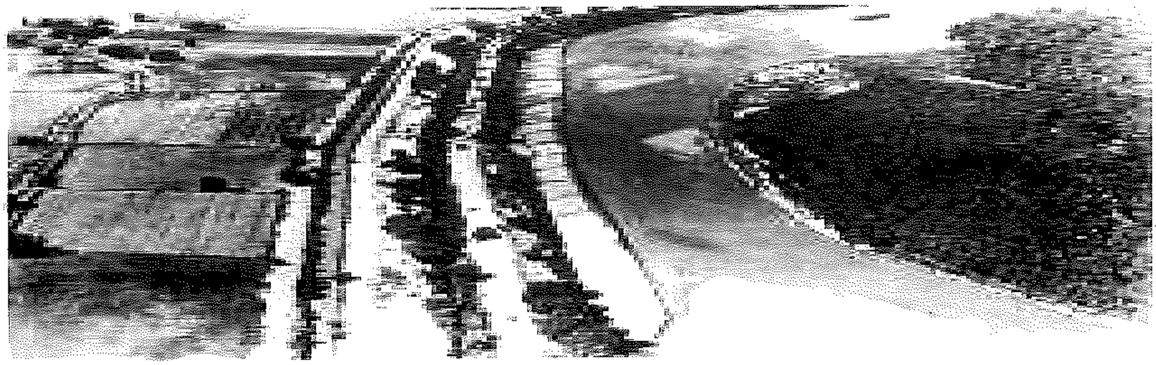


Figure 2.2 : Jetty Field Installed (Photo: Aug 12, 1953)

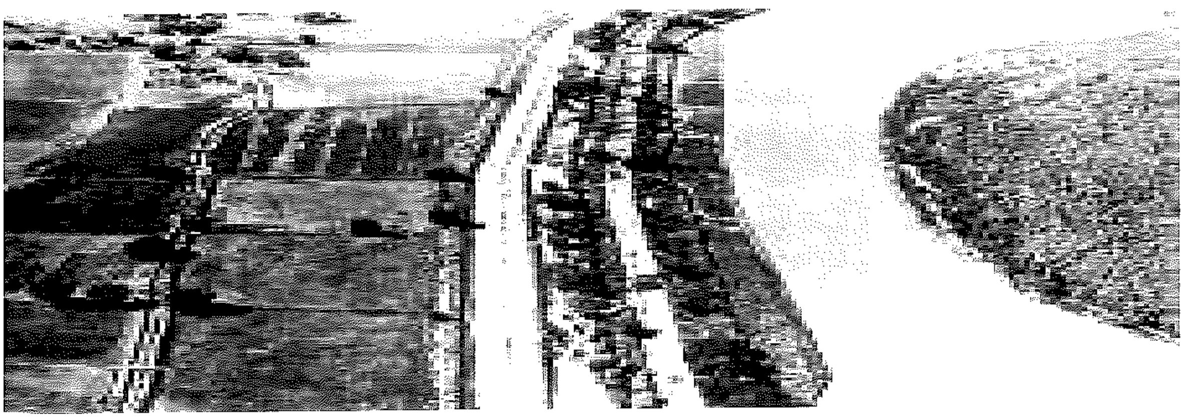


Figure 2.3 : Vegetation dominates in the mature Jetty Field, photo Sept. 12, 1955 on the Rio Grande near Bernallillo, NM, Aerial photo by the Corps of Engineers

- The Middle Rio Grande Conservancy District (MRGCD) formed in 1925 had constructed five diversion dams, miles of drainage canals and levees. The Bureau of Reclamation was a part of the Rio Grande Channelization Project and was engaged in rehabilitating the MRGCD's irrigation and drainage systems installing jack jetty fields which covered 100 miles of the reach below Cochiti (U.S. Arny Corps of Engineers and Bureau of Reclamation 2002, Crawford et al. 1993, Lagasse 1980, Najmi 2001). After completion of these works the Rio Grande was converted into highly modified water storage and water conveyance system having extensive flood control structures. The Espanola floodway also experienced extensive levee rehabilitation and channel straightening with jetty fields.

2.4 Review on Turbulent Bursting

2.4.1 Concept of two Dimensional Bursting

The bursting process is one of the typical characteristics of turbulent flow and the bursting events play the main role in sediment transport. The concept of bursting phenomenon was introduced by Kline et al. (1967) for describing transfer of momentum between the turbulent and laminar region near the boundary. The rate of sediment entrainment depends on quadrant events (Kline et al. 1967). The two dimensional bursting process comprises four types of events. (Keshavarzy and Ball 1997) On the basis of the sign of velocity fluctuation, they are classified as:

i) Outward Interaction or Quadrant I (upward front) in which $u'>0$, $w'>0$
ii) Ejection event or Quadrant II (upward back) in which $u'<0$, $w'>0$
iii) Inward Interaction or Quadrant III (downward back) in which $u'<0$, $w'<0$
iv) Sweep event or Quadrant IV (downward front) in which $u'>0$, $w'>0$

Algebraically they are defined by:

$$u' = u - \bar{u}$$

and

$$w' = w - \bar{w}$$

where u and w are the instantaneous velocities in the longitudinal and vertical direction respectively. $\bar{u}$ and $\bar{w}$ are the temporal mean velocities in the longitudinal and vertical directions. These temporal mean velocities are given by:

$$\bar{u} = \frac{1}{N} \sum_{i=1}^{N} u_i$$

and

$$\bar{w} = \frac{1}{N} \sum_{i=1}^{N} w_i$$

Where, N is the number of instantaneous velocity samples.

The Figure 2.4 below shows the phase diagram with the quadrant of each event class indicated.

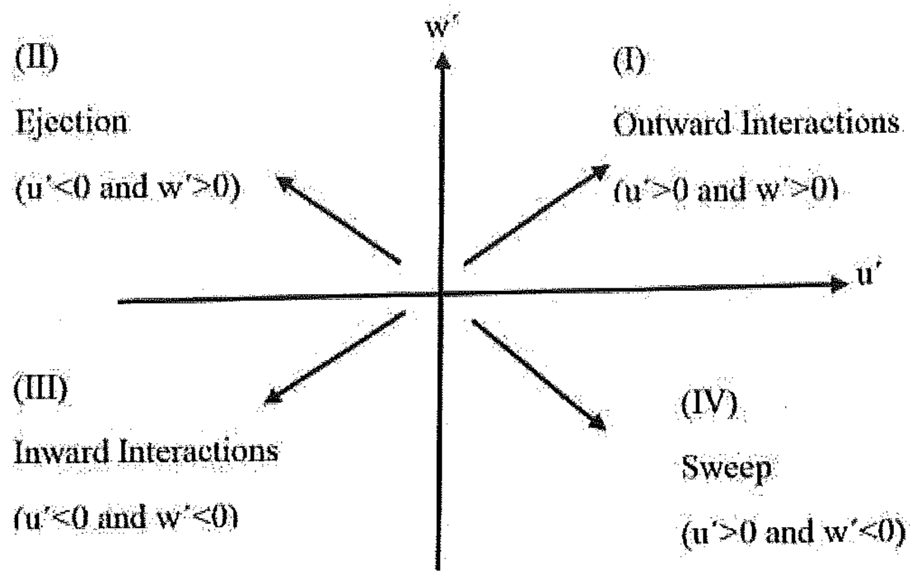


Figure 2.4 : Phase diagram with the quadrant of each event class

Wallace et al. (1972) and Willmarth and Lu (1972) have applied a conditional sampling and averaging technique to quantify the contribution to the Reynolds shear stress during a cycle of events observed in the bed region of the turbulent boundary layer. Lu and Willmarth (1973) introduced the quadrant analysis for studying the structure of the bursting phenomenon. The quadrant analysis was employed to determine the frequency of occurrence of each individual event within a bursting process, i.e. outward interactions, ejections, inward interactions, and sweeps.(Izadinia, Heidarpour, and Schleiss 2013).

2.4.2 Concept of three Dimensional Bursting

A new method three-dimensional quadrant analyses proposed by Keshavarzi and Gheisi (2006) has been used in this study to define the turbulent flow structure in the vicinity of jack jetty and trail dikes. It enables to take the effect of secondary flow. Natural stream flow is mostly three dimensional, thus the 3D analysis of laboratory experiment will provide greater details regarding the bursting phenomenon. It will provide greater insight of the flow structure in the vicinity of jack jetty and trail dikes. The bursting process consists of four events in Class A and four events in Class B, which are defined as follows.

Class A1: internal outward interaction ($u' > 0$, $v' > 0$, $w' > 0$)
Class A2: internal ejection ($u' < 0$, $v' < 0$, $w' > 0$)
Class A3: internal inward interaction ($u' < 0$, $v' < 0$, $w' < 0$)
Class A4: internal sweep ($u' > 0$, $v' > 0$, $w' < 0$)
Class B1: external outward interaction ($u' > 0$, $v' < 0$, $w' > 0$)

Class B2: external ejection ($u' < 0$, $v' > 0$, $w' > 0$)

Class B3: external inward interaction ($u' < 0$, $v' > 0$, $w' < 0$)

Class B4: external sweep ($u' > 0$, $v' < 0$, $w' < 0$)

where u', v' and w' are the velocity fluctuations in streamwise, transverse and vertical directions.

These eight classes of the bursting process indicate the momentum transfer between the horizontal adjacent water flow layers, and moreover, produce the instantaneous turbulent shear stress along the streamwise and transverse directions. (Hongwei, Xuehua, and Bao'an 2009) Algebraically they are defined by:

$$u' = u - \bar{u}$$

$$v' = v - \bar{v}$$

$$w' = w - \bar{w}$$

where u, v and w are the instantaneous velocities in the longitudinal, transverse and vertical direction respectively. $\bar{u}$, $\bar{v}$ and $\bar{w}$ are the temporal mean velocities in the longitudinal, transverse and vertical directions. These temporal mean velocities are given by:

$$\bar{u} = \frac{1}{N}\sum_{i=1}^{N} u_i\,, \qquad \bar{v} = \frac{1}{N}\sum_{i=1}^{N} v_i \text{ and } \qquad \bar{w} = \frac{1}{N}\sum_{i=1}^{N} w_i$$

Where, N is the number of instantaneous velocity samples

2.4.3 Concept of Reynolds Stress

When turbulence measurements are available, local shear stress can be found out from Reynolds stress as in the equation below. Where u', v' and w' are the velocity fluctuations of longitudinal, lateral and vertical components respectively.

$$\tau_{zx} = -\rho\overline{u'w'}$$

$$\tau_{zy} = -\rho\overline{v'w'}$$

Where τ_{zx} = Reynolds stress in streamwise direction

τ_{zy} = Reynolds stress in transverse direction

CHAPTER – 3

EXPERIMENTS, OBSERVATIONS AND RESULTS FOR RCC JACK JETTY TESTING (FINDING SOME DESIGN INDICES)

3.1 Experimental Programme

From the preceding chapter it is apparent that the steel frame jack jetty systems have come into existence in the 50's of last century. It is obvious that certain preliminary studies on the performance of modified RCC jack jetties is necessary in order to develop rational design methodology which will enable it to be used as an affordable cost effective river training measure. To study and analyse the effect of jack jetty on the flow domain and pertinent fluvial parameters, the experimental programme of the present research was divided into three phases namely– the 'micro', the 'macro' and the field prototype study in the river Ganges at Nakhwa site in India. In the first phase of experiments, i.e., micro level, the effect of jack jetty on the fluvial parameters was studied. This phase of experiment was carried out partly in the River Engineering laboratory, Department of WRD&M, IIT Roorkee, India and partly in the Hydraulics laboratory, Civil and Geological Engineering Department, University of Saskatchewan, Canada. In the macro level phase of study, the effect of various combinations of jack jetties on the sediment laden flow of water was investigated to come up with the optimum combination of jetty field to meet with the required objective of erosion control, moderate reclaim or high reclaim. This chapter describes the experimental set up in both the laboratories and the various configurations of the jack jetty tested. The chapter also illustrates the observations made and the equipment and instruments used to record the observations. In the present study the experiments were focused on developing rational design approach and methodology of the jack jetty system with systematic scientific investigation to study the flow behaviour behind the structures. The test conditions and data collection procedures are also detailed in this chapter.

3.2 Laboratory Flume for First Part of Micro Level Study

All the experiments of the first part of micro level study were performed in a masonry recirculating flume in the River Engineering Laboratory of WRD&M, IIT Roorkee. The masonry open channel flume is 22.5 m long, 1.2 m wide and 0.6 m high. Recirculating flow of water is supplied to the channel with the help of a centrifugal pump with a 10 hp electric motor with 0.1 m diameter delivery and suction pipe from a masonry underground water storage tank of size 12.5 m x 2 m x 2 m. Two rails are fitted on the walls of the flume on both sides. Two 0.15 m dia axial flow pumps are used for recirculating the water, when more discharge is required in the flume. A steel bridge or trolley spans the width of the flume and is mounted on rails of the flume side walls. The bridge or trolley is moved by rope or can be pulled manually. It is equipped with a point gauge which can read to 0.001 m for measuring elevations of the sand surface and water surface. For velocity measurement, Micro ADV was also mounted on the trolley. Horizontally graduated scales which can read to 0.001 m are there along the length of the flume. The flume was filled to a depth of 0.40 m with a poorly sorted medium sand having d50 of 0.25 mm. The slope of the channel bed of the experimental flume was maintained with the help of dumpy level. Bed level measurements were taken with the help of dumpy level to find out the slope 35 and thereby maintaining the slope required for the study purpose. A direct discharge meter was connected to the delivery pipe. From the meter or delivery pipe the water flows into a stilling basin and then through three honeycombed walls for suppressing the turbulence.

3.3 Laboratory Flume for Macro Level Study

All the experiments for the Macro level study were carried out in a 0.5 m wide flume. A Sketch of tilting flume (in plan) and its components used in macro study of experiments shown in Figure 3.1. An overflowing tank was installed at the upstream end (that served as a head tank) to ensure the supply of steady discharge into the experimental flume. The flume used was made of mild steel with side walls made of transparent perspex sheet. The flume has an in-built upstream tank of 0.4 m x 0.9 m x 1.15 m dimensions. Figure 3.2 gives a sketch of the approaches. Figure 3.3 shows the upstream end of the flume with plastic perforated sheet used as a flow conditioner and Figure 3.4 tail gate used to control flow depth at downstream end of flume. The bed of the flume is supported on angle iron sections, the lower ends of which are connected to a shaft that is placed length wise parallel to the central portion of flume below it. The shaft is movable horizontally backward and forward with the help of a gear box and electric motor such that if the shaft moves towards the direction of flow the front portion of flume moves upward and the lower portion moves downward and vice versa. This is the 37 mechanism of adjusting the flume to required slope. The water flowing in the flume falls into a downstream tank installed with v-notch weir to measure flow, which is connected to storage tank. From the downstream storage tank, water is lifted with the help of two 10 hp pumps. Pipes of 0.1 m diameter carry water from the storage tank to the upstream constant head tank. The discharge was regulated with the help of a gate valve placed after the constant head tank. In the upstream end of the flume a brick wall was constructed with staggered holes and two rows of plastic perforated plastic sheet walls following were provided to dampen the surface disturbances /

destroy the excess energy of inflow and distribute the flow uniformly through the entire width of the flume. Figure 3.3 and 3.4 shows the upstream and downstream ends of the flume.

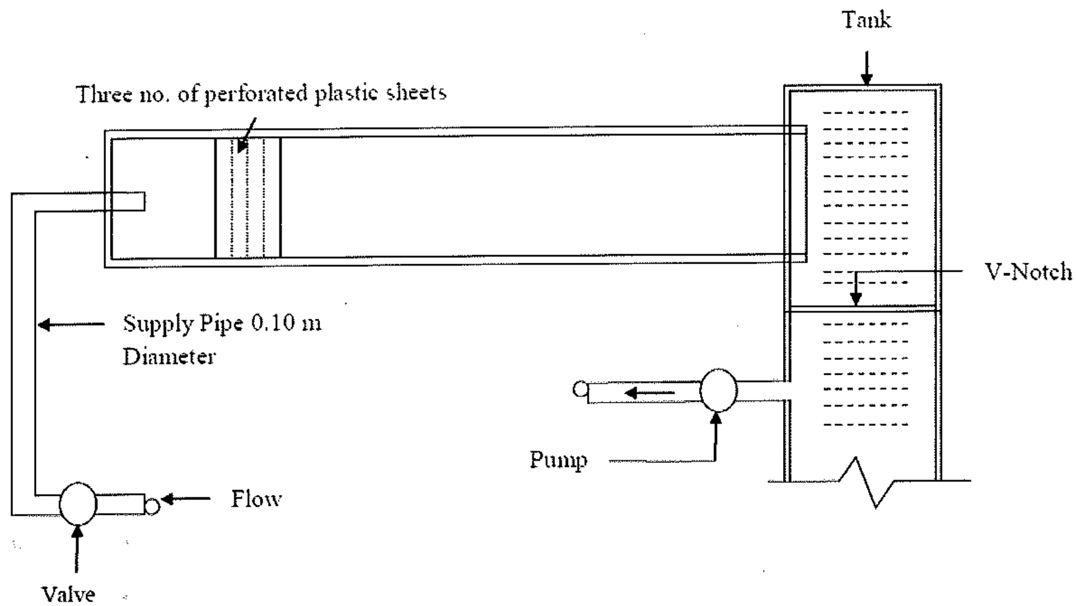


Figure 3.1 : Sketch of tilting flume (in plan) and its components used in macro study of experiments

Figure 3.2 : Upstream end of the flume with plastic perforated sheet used as a flow conditioner

Figure 3.3 : Tail Gate used to Control Flow Depth at Downstream end of Flume

3.4 Details of Measurement Equipment

3.4.1 Acoustic Doppler Velocimeter

The Acoustic Doppler Velocimeter (ADV) was used to measure the 3- Dimensional velocity components of the flow. It is a remote sensing 3-D velocity sensor which transmits acoustic pulses into water. These pulses are then scattered by the particles present in water. The echo is received by the receivers of the ADV and the Doppler shift is calculated from the segments of the echo. The echo is Doppler shifted in proportion to the particle velocity. There are four types of ADV probes: (i) 3-D down looking probe (ii) 3-D up looking probe (iii) 3-D side looking probe and (iv) 2-D side-looking probe. Among these four types of probes, only 3-D down looking probe was employed for this study.

For the sign convention with respect to the flow direction, a positive 'x' denotes a vector streamline longitudinally along the flow direction; a positive 'y' denotes the transverse direction (across the flume width) perpendicular to the streamlines. The flow depth is measured in a direction perpendicular to the bed, denoted by the z axis.

According to the user's manual, the velocity range is to be set before starting the data collection. The range is a nominal value and the exact maximum velocity is different along the vertical axis (i.e., toward the transmitter) and in the horizontal plane. As a general rule, the velocity range should always be set as small as possible. If, for example, the maximum expected velocity is 0.08 m/sec, the velocity range should be set to 0.10 m/sec. The reason for this is that the noise in the data increases with increasing velocity range and hence lose precision at high sampling rates. In the present study, the sampling rate used was 25 Hz. If the conditions are not known in advance, the velocity range must be set high enough to cover the whole deployment period. The ADV can measure the undisturbed 3-D flow at velocity range of 0.25 m/sec. The technique employed in ADV is superior to the other conventional methods, since the actual sampling volume is located at a lower depth (0.05 m below the probe, in the present case) than the probe and hence is less distributed.

There should be a reasonable amount of suspended particles in the water for the successful operation of the ADV, user manual was used for reference. For the present study baby powder was used as the seeding material to generate sufficient amount of suspended particles to facilitate measurement of the Doppler shift. It was found that the ADV recorded the data with a signal correlation less than 70 when there were not any seeding materials in the flume water. The seeding materials generating the suspended particles help to obtain better sound wave reflections which eventually increased the amplitude of the instrument and the correlation. Moreover, the velocity measurements with signal correlations greater than 70 were increased significantly. Figure 3.4 is a photograph of the ADV mounted on a trolley in the flume. The three dimensional velocity data obtained with the Micro ADV were analysed using the software, WinADV, Version 1.845 (Wahl, 2000a). The velocity measurements in the experiments were analysed with the correlation filter set to 70% and the velocities were kept for points for which there were at least 70% data retained. For points with less than 70% data retained, the analysis was repeated with the filter set to 40% correlation, and again the average velocities were kept, providing that there were more than 70% data retained. This made it possible to have velocity values closer to the bed, determining velocity profiles.

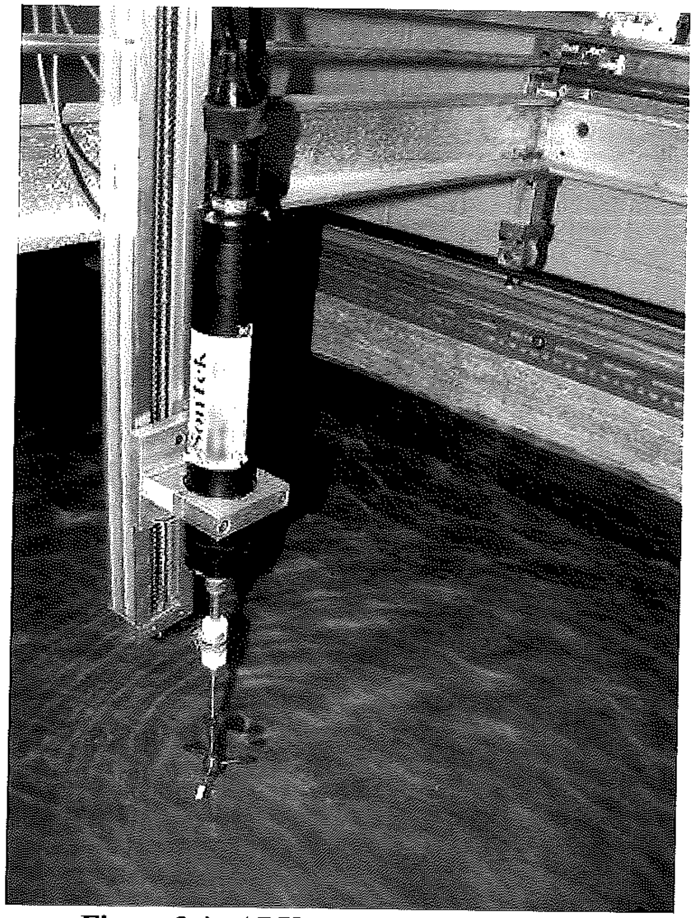


Figure 3.4 : ADV mounted on the trolley

3.5 Sediments Used

Experiments were performed with two types of sediments having median diameter as 0.248 mm (as shown in the Figure 3.5) and 0.59 mm (as shown in the Figure 3.6). The relative densities of all sands were 2.65. The macro level study is done with the median size of sediment 0.248 mm and the micro level study is done with the median size of sediment 0.59 mm.

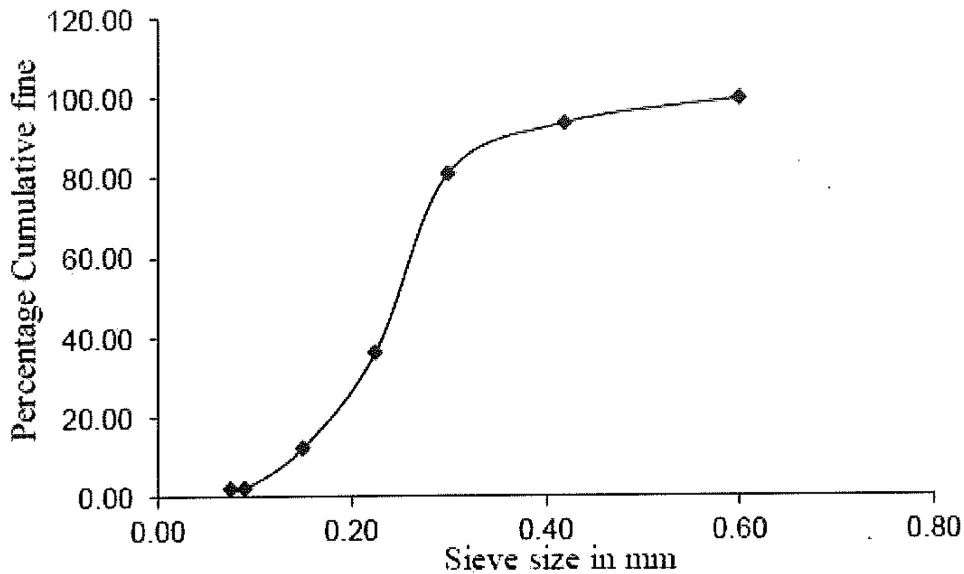


Figure 3.5 : Grain size distribution curve for sand, d50=0.248 mm

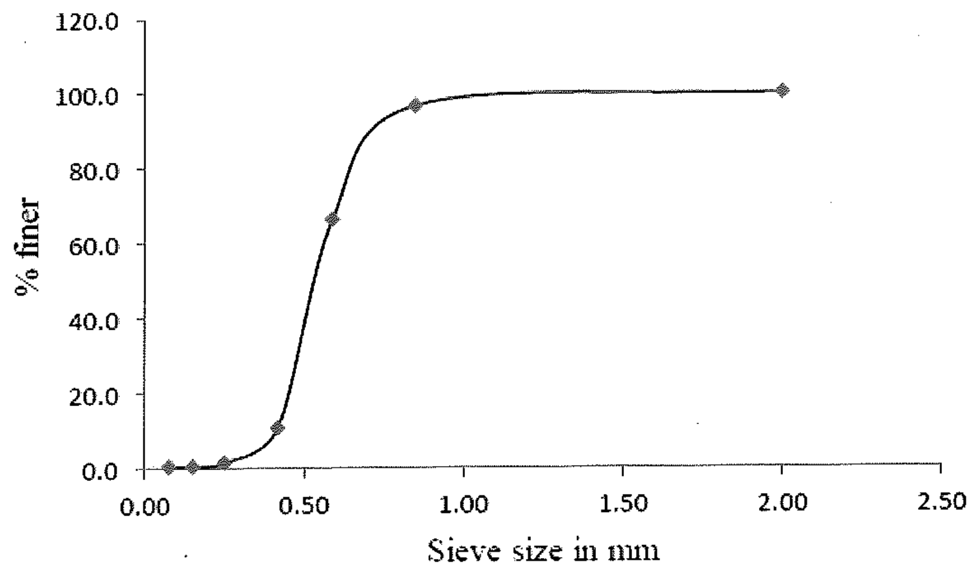


Figure 3.6 : Grain size distribution curve for sand, d50=0.59 mm

3.6 Experimental Procedure

3.6.1 Experimental Procedure for Micro Level Study

Experiments were conducted in the following steps:

i) Before starting the experiments the side rails of the flume were adjusted and were kept parallel to each other and parallel to the bottom of the channel. This was kept parallel to the ground to maintain the correct slope.

ii) The depth of sediment bed layer of the test section was fixed at 0.15 m by filling sand.

iii) Before placement of jack jetty model the sediment bed of flume was levelled and the bed level readings were taken with the help of pointer gauge.

iv) After placement of the jack jetty model, the sediment bed of flume was again leveled around the jack jetty.

v) The water was supplied to the flume from constant head tank to upstream tank and upstream tank to flume. The supply pipe connected to the pump and the discharge was controlled by a regulating valve.

vi) Flow was introduced in the flume very slowly by closing the tail gate so that no scouring occurred around the jetty.

vii) Uniform flow without sediment motion corresponding to a selected discharge was established with the help of tailgate.

viii) The water which discharges into the tail box was allowed to flow over 900 V-notch. After flowing over the notch the water was discharged into the sump from where it was recirculated by pump.

ix) For the measurement of water depth the pointer gauge was fixed to a vertical graduated rod. This pointer gauge and the ADV for velocity measurement was mounted on a electrically driven trolley which could move to and fro and helped in taking the readings and measurements. The difference of water level reading and sand bed reading gives the water depth.

x) All the components of the velocities were measured by ADV in a grid pattern.

3.6.2 Experimental Procedure for The Macro Level Study

Experiments were conducted in the following steps:

i) Before starting the experiments the side rails of the flume were adjusted and were kept parallel to each other and parallel to the bottom of the channel. This was kept parallel to the ground to maintain the correct slope.

ii) The depth of sediment bed layer of the test section was fixed at 0.15 m by filling sand.

iii) Before placement of the jetty Field the sediment bed of flume was leveled and the bed level readings were taken with the help of pointer gauge.

iv) After placement of the jetty Field, the sediment bed of flume was again leveled around the jetty field.

v) The water was supplied to the flume from constant head tank to upstream tank and upstream tank to flume. Supply pipe connected to the pump and the discharge was controlled by a regulating valve.

vi) Flow was introduced in the flume very slowly by closing the tail gate so that no scouring occurred around the jetty due to operation.

vii) Uniform flow without sediment motion corresponding to a selected discharge was established with the help of tailgate.

viii) The water which discharges into the tail box was allowed to flow over 900 V-notch. After flowing over the notch the water was discharged into the sump from where it was recirculated by pump.

ix) This clear water run continued for half an hour. Then the motor was shut and water was discharged gradually with the operation of tail gate such as not to disturb the sand bed. The valves which control the regulation of flow into the flume were not altered so as to maintain the same discharge into the flume for the flowing sediment run. After the water is drained sand bed levels were measured with the help of pointer gauge.

x) After the bed profile is measured for clear water run the flume is again filled with water and run for the discharge for which it was run for the clear water condition. Water level was maintained with the help of downstream tail gate. Once the flow comes into a steady state condition sediment of specific concentration was injected into the flume at a section 0.5 m upstream of the jetty Field. When the sediment injection into the flume is done the flume was ran for 4 hours.

xi) This sediment water run continued for 4 hours. Then the motor was shut and water was discharged gradually with the operation of tail gate such as not to disturb the sand bed. After the water is drained sand bed levels were measured with the help of point gauge.

3.7 Objectives

The goal of the experimental studies on the jack jetty described herein was to develop potential design indices and performance parameters to assess sediment deposition in the jetty fields (lines of jack jetty). The work was accomplished in the laboratory, with some verification of the results in a field test of a jetty system. The work summarized here is presented in more detail in Nayak (2012). The specific objectives of the experiments were as follows:

- To develop design indices and performance parameters to represent different alternative jetty field layouts to optimize performance in capturing sediment for berm formation;
- To investigate the effect of submergence level of the jetty field on sediment deposition within the field;
- To develop thresholds for achievement of various design objectives for erosion control and reclamation using a jetty field; and
- To gain an insight into the effect of various jetty field configurations on channel bed

Table 3.1 : Details of experimental conditions in phase – 1 of the study

	Expt. No.	Bed slope	Water Depth (m)	Discharge (m3/s)	Froude Number (Fr)	D50 of sediment (mm)	Layout of jacks on the flume bed
SERIES-I	1	0.000133	10	0.013	0.113	0.2481	One 0.08 m model
	2	0.000133	10	0.013	0.113	0.2481	One 0.10 m model
	3	0.000133	10	0.013	0.113	0.2481	Four 0.10 m model
	4	0.000133	10	0.013	0.113	0.2481	Three 0.10 m model
	5	0.000133	10	0.013	0.113	0.2481	Two 0.10 m model
	6	0.000133	20	0.039	0.116	0.2481	Four 0.10 m model
SERIES-I	7	0.000133	20	0.039	0.116	0.2481	Three 0.10 m model
	8	0.000133	20	0.039	0.116	0.2481	Two 0.10 m model
	9	0.000133	20	0.039	0.116	0.2481	4 rows 0.10 m models, 2 in each row
	10	0.000133	20	0.039	0.116	0.2481	3 rows 0.10 m models, 2 in each row
	11	0.000133	20	0.039	0.116	0.2481	2 rows 0.10 m models, 2 in each row
	12	0.000133	20	0.039	0.116	0.2481	4 rows 0.08 m models, 2 in each row
	13	0.000133	20	0.039	0.116	0.2481	3 rows 0.08 m models, 2 in each row
	14	0.000133	20	0.039	0.116	0.2481	2 rows 0.08 m models, 2 in each row
SERIES-II	15	0.000133	30	0.071	0.115	0.59	0.20 m model
	16	0.000133	40	0.107	0.112	0.59	one 0.30 m model
	17	0.000133	40	0.107	0.112	0.59	Two 0.20 m models
	18	0.000133	40	0.107	0.112	0.59	Three 0.20 m models

Table 3.2 : Details of experimental conditions in Phase – 2 of the study

Expt. No.	Bed slope	qs (ppm)	D50 of sediment (mm)	Lr/Ls	Discharge (m3/s)	Froude Number (Fr)	Water Depth (m)	Submeregence Ratio
1	0.000133	500	0.2481	0.5	0.0225	0.11	0.25	0.53
2	0.000133	500	0.2481	1	0.0225	0.11	0.25	0.53
3	0.000133	500	0.2481	1.5	0.0225	0.11	0.25	0.53
4	0.000133	500	0.2481	2	0.0225	0.11	0.25	0.53
5	0.000133	500	0.2481	0.5	0.018	0.13	0.20	0.41
6	0.000133	500	0.2481	1	0.018	0.13	0.20	0.41
7	0.000133	500	0.2481	1.5	0.018	0.13	0.20	0.41
8	0.000133	500	0.2481	2	0.018	0.13	0.20	0.41
9	0.000133	500	0.2481	0.5	0.013	0.15	0.15	0.22
10	0.000133	500	0.2481	1	0.013	0.15	0.15	0.22
11	0.000133	500	0.2481	1.5	0.013	0.15	0.15	0.22
12	0.000133	500	0.2481	2	0.013	0.15	0.15	0.22
13	0.000133	250	0.2481	0.5	0.013	0.15	0.15	0.22
14	0.000133	250	0.2481	1	0.013	0.15	0.15	0.22
15	0.000133	250	0.2481	1.5	0.013	0.15	0.15	0.22
16	0.000133	250	0.2481	2	0.013	0.15	0.15	0.22
17	0.000133	750	0.2481	0.5	0.013	0.15	0.15	0.22
18	0.000133	750	0.2481	1	0.013	0.15	0.15	0.22
19	0.000133	750	0.2481	1.5	0.013	0.15	0.15	0.22
20	0.000133	750	0.2481	2	0.013	0.15	0.15	0.22
21	0.000133	1000	0.2481	0.5	0.013	0.15	0.15	0.22
22	0.000133	1000	0.2481	1	0.013	0.15	0.15	0.22
23	0.000133	1000	0.2481	1.5	0.013	0.15	0.15	0.22
24	0.000133	1000	0.2481	2	0.013	0.15	0.15	0.22

3.8 Observation Result and Analysis

To analyse the experimental data, terminologies need to be introduced to describe the jetty field and these are summarized below. A single or stand unit of the model is called a jack, as shown in Figure 3.7, and when the jacks are connected together in a line with a cable, they form a jetty.

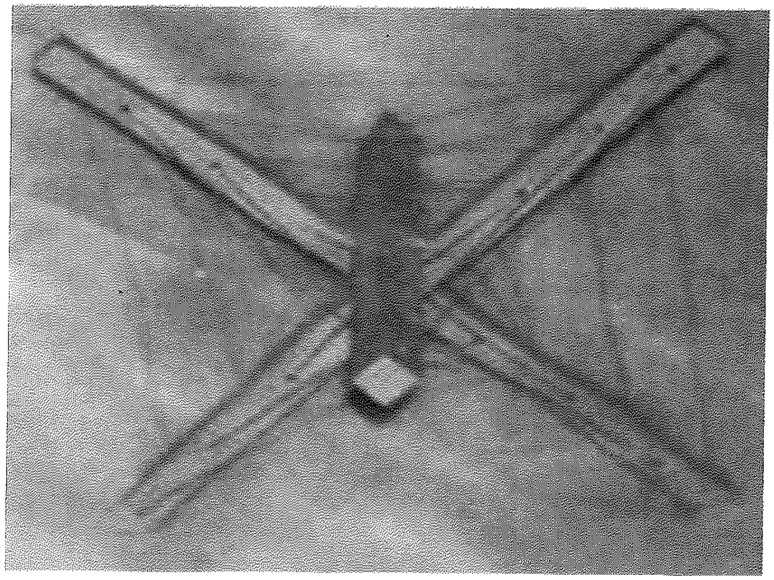


Figure 3.7 : Photograph of the jack used in the laboratory experiments

When lines of jetty are laid parallel to the bank of the channel, they are called 'diversion lines', and when the jetty are projected into the river at a certain angle with the bank, they are called 'retards'. Combinations of retard and diversion lines form a jetty field. Figure 3.8 shows schematic diagram in plan of a jetty field showing retards and a diversion line, where Lr is the length of the retards and Ls is the centre-to-centre spacing of retards. Figure 3.9 shows a sketch representing the elevation of a jack in water, where h is the height of jack and H is the depth of flow. Additionally new design indices and performance parameters for the jack system were developed: the Jetty Field Density Index (JFDI), the Jetty Field Submergence Index (JFSI), the Bed Deposit Factor (BDF) and the Jetty Field Length Factor (JFLF). These are defined as follows

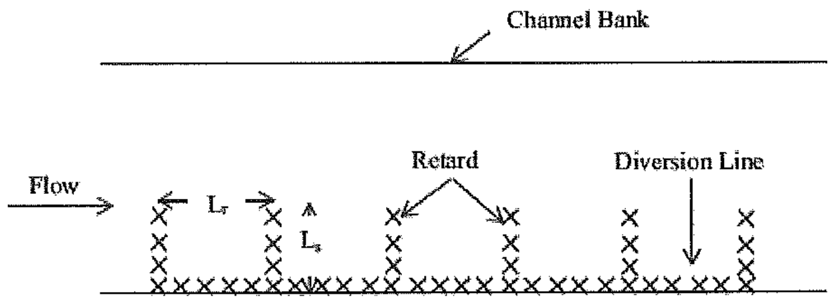


Figure 3.8 : Layout (in plan) of a jetty field showing a diversion line and retards

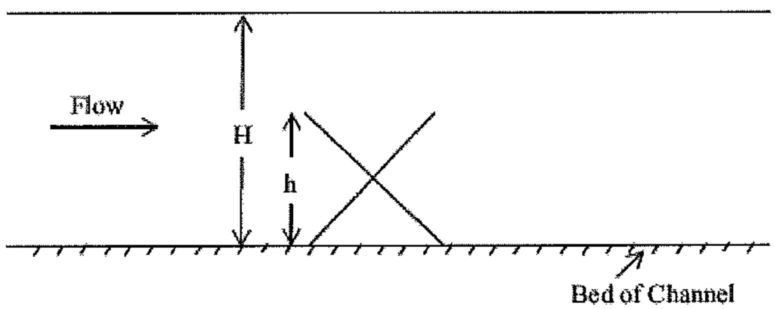


Figure 3.9 : Elevation of a jack in water

Jetty Field Density Index : the length of retard to the centre-to-centre spacing of the retards or (Lr/Ls). Smaller values of the Jetty Field Density Index correspond to sparse jetty fields, and higher values represent densely configured fields.

Jetty Field Submergence Index : the ratio of the depth of water above the top of the jack to the total depth of water or (H-h)/H. Smaller values of the Jetty Field Submergence Index represent smaller submergences.

Bed Deposit Factor : the depth of sand deposited on the sand channel bed to the total depth of water. Larger values of the Bed Deposit Factor suggest larger amounts of sedimentation in the jetty field.

Jetty Field Length Factor : the length of one compartment (the area enclosed by two adjacent retard lines) of the jetty field to the total cumulative length of jetty field compartments.

Threshold values for the Bed Deposit Factor for various combinations of the Jetty Field Density Index, Jetty Field Submergence Index and sediment concentrations of the bed load and suspended in flow were developed to aid in developing guidelines for the design of the jack jetty systems. To determine these thresholds, the jack jetty systems were tested with various

Jetty Field Density Indices for four sediment concentration values of the bed load and suspended load in flow and three Jetty Field Submergence Indexes to ascertain the efficiency of the jetty field in creating sedimentation in the channel bed. Sand deposition in the jetty field was monitored and measured for all experiments and analysed in terms of Bed Deposit Factor. It was also found that the efficiency of the jetty field in providing sedimentation is enhanced at smaller submergence and for higher sediment concentrations in the flow.

For each experimental run, the Jetty Field Length Factor was plotted against the Bed Deposit factor. The trend line followed a second-order polynomial trend with high correlation coefficient. From this plot average and maximum Bed Deposit Factor values were determined. The thresholds later were discretized from these values. Based on the thresholds, the design guidelines were developed.

Table 3.3 shows the average and maximum Bed Deposit Factor developed from the bed profile plots for a suspended sediment concentration of 500 ppm for various layouts of the jetty field with varying Jetty Field Density Index for various Jetty Field Submergence Indices. Similarly Table 3.4 illustrates and presents the average and maximum Bed Deposit Factor evaluated from the bed profile measurements with fixed submergence and varying layout of the jetty field with varying Jetty Field Density Index and varying sediment concentrations. The results were categorized into three bed deposit levels, erosion control, and moderate reclaim and heavy reclaim. If the average Bed Deposit Factor is less than 0.1, then one can expect for erosion control. If it is between 0.1 and 0.2, moderate reclaim can be expected. If the bed deposit factor is more than 0.2, then heavy reclaim might be expected.

It was evident that the efficiency of the jetty field performs better with lower submergences than higher submergences and with higher sediment concentrations in the flow as seen in Table 3.3 and Table 3.4. The average Bed Deposit Factor values vary in the range of 0.05–0.08, and for medium submergences and a moderate concentration around 500 ppm, that overall vary in the range of 0.1–0.19. Similarly for low submergence and high sediment concentration, it varies between 0.2 and 0.3.

Table 3. 3 : Bed deposit factors for various jetty field submergence indices for a fixed sediment concentration in the flow of qs ¼ 500 ppm

JFSI	Average Bed Deposit Factor		Maximum Bed Deposit Factor	
0.53	0.05	Erosion Control	0.07	Erosion Control
0.53	0.07	Erosion Control	0.08	Erosion Control
0.53	0.08	Erosion Control	0.08	Erosion Control
0.53	0.08	Erosion Control	0.2	Moderate Reclaim
0.41	0.11	Moderate Reclaim	0.15	Moderate Reclaim
0.41	0.1	Erosion Control	0.12	Moderate Reclaim
0.41	0.1	Erosion Control	0.11	Moderate Reclaim
0.41	0.09	Erosion Control	0.19	Moderate Reclaim
0.22	0.11	Moderate Reclaim	0.16	Moderate Reclaim
0.22	0.11	Moderate Reclaim	0.14	Moderate Reclaim
0.22	0.17	Moderate Reclaim	0.21	Heavy Reclaim
0.22	0.12	Moderate Reclaim	0.2	Moderate Reclaim

Table 3.4 : Threshold values for various jetty field density indices for fixed jetty field submergence index ¼ 0.22 and varied sediment concentration

qs	JFDI	Average	Maximum		
250	0.5	0.08	0.11	Erosion Control	Moderate Reclaim
500	0.5	0.12	0.16	Moderate Reclaim	Moderate Reclaim
750	0.5	0.14	0.19	Moderate Reclaim	Moderate Reclaim
1000	0.5	0.18	0.23	Moderate Reclaim	Heavy Reclaim
250	1	0.1	0.13	Erosion Control	Moderate Reclaim
500	1	0.1	0.14	Erosion Control	Moderate Reclaim
750	1	0.14	0.19	Moderate Reclaim	Moderate Reclaim
1000	1	0.16	0.24	Moderate Reclaim	Heavy Reclaim
250	1.5	0.11	0.15	Moderate Reclaim	Moderate Reclaim
500	1.5	0.17	0.21	Moderate Reclaim	Heavy Reclaim

750	1.5	0.18	0.22	Moderate Reclaim	Heavy Reclaim
1000	1.5	0.21	0.25	Heavy Reclaim	Heavy Reclaim
250	2	0.09	0.15	Erosion Control	Moderate Reclaim
500	2	0.12	0.16	Moderate Reclaim	Moderate Reclaim
750	2	0.18	0.25	Moderate Reclaim	Heavy Reclaim
1000	2	0.19	0.24	Moderate Reclaim	Heavy Reclaim

3.9 Design Methodology for Jetty Field

In this section, the goal is to provide design guidelines for the Jetty Field Density Index, which would provide the designer basic information of what configuration and layout of the jetty field should be adopted for achievement of desired goals for sedimentation in the field. Table 3.5 provides information about JFDI to be adopted for various sets of experiments with fixed sediment concentration and varying JFSI. Table 3.6 provides information about JFDI to be adopted for various sets of experiments with fixed JFSI and varying sediment concentration.

Table 3.5 : Guidelines for jetty field design with a fixed sediment concentration

qs	JFSI	Requirement	Bed Deposit Factor	JFDI
500	0.22	Erosion Control	<0.1	<0.5
		Moderate Reclaim	Between 0.1 to 0.2	0.5 to 1
		High Reclaim	>0.2	1.5 to 2
	0.41	Erosion Control	<0.1	<0.5
		Moderate Reclaim	Between 0.1 to 0.2	0.5 to 2
		High Reclaim	>0.2	-
	0.53	Erosion Control	<0.1	0.5
		Moderate Reclaim	Between 0.1 to 0.2	2
		High Reclaim	>0.2	-

Table 3.6 : Guidelines for jetty field design with a fixed JFSI

JFSI	qs	Requirement	Bed Deposit Factor	JFDI
0.22	250	Erosion Control	<0.1	0.5
		Moderate Reclaim	Between 0.1 to 0.2	0.5 to 1
		High Reclaim	>0.2	-
	500	Erosion Control	<0.1	<0.5
		Moderate Reclaim	Between 0.1 to 0.2	0.5 to 1
		High Reclaim	>0.2	>1.5
	750	Erosion Control	<0.1	<0.5
		Moderate Reclaim	Between 0.1 to 0.2	0.5 to 1
		High Reclaim	>0.2	1.5 to 2
	1000	Erosion Control	<0.1	<0.5
		Moderate Reclaim	Between 0.1 to 0.2	0.5
		High Reclaim	>0.2	1 to 2

CHAPTER – 4
PERFORMANCE EVALUATION WITH FIELD APPLICATION IN A LARGE ALLUVIAL RIVER

4.1 Background

The prior chapters have provided us with sound knowledge and understanding of effect of submerged jacks on the fluvial behaviour of the flow by reduction in velocity, shear stress and sediment transport capacity of the flow and effectiveness of the jetty field in sediment laden flow in creating sedimentation. The laboratory study was tried to be validated with prototype field study in the Ganga river at Nakhwa site.

Ganga, the 2,525 km river rises in the western Himalayas in the Indian state of Uttarakhand, and flows south and east through the Gangetic Plain of North India into Bangladesh, where it empties into the Bay of Bengal. By discharge it ranks among the world's top 20 rivers and the 2nd largest in the South Asia and the longest in India. The water depth in the Ganga varies 8 to 10 meters in low flow and 20 to 21 meters in high flows.

This is the first time modified RCC Jack Jetty systems are used in India in the river Ganga at Nakhwa. This site is located 11Km downstream of Varanasi. The problem at this site was insufficient navigation draught. Presence of secondary channel on the left side used to divert part of the flow and leave the right channel with insufficient navigation draught. The remedial action could be to explore ways and means to increase the depth in the right channel to reduce the velocity so that flow conditions conducive for navigation could be induced. It was tried to develop the right channel to facilitate navigation. This could be achieved by minimising the flow in the secondary or left channel to divert the concentrated flow in the main or right channel. One more expected conjunctive issue could be, after channel closure when the flow gets diverted towards the right channel then the concentrated flow might cause erosion on the immediate concave right bank of the right channel so the right bank needed to be provided with bank protection or erosion control measures.

The problem at Nakhwa Site on the Ganga River was proposed to be tackled in two stages separately in two locations (A) and (B) as shown in Figure 4.1. In the first stage the left channel was tried to be plugged or partially closed by inducing sediment with jetty screens and in the second stage the right bank of the river was provided with river training measures in terms of jetty fields for erosion control. The location (A) was provided with jetty screen which consists of continuous lines of RCC jack jetties laid together across the total width of the river. The purpose of having these jetty screens on the left channel is to partially close the channel which will consequently divert the flow towards the main right channel and thereby the right bank channel is expected to deepen due to flow diversion. These three rows of 300 m long RCC jack jetty were proposed to be positioned about 100m downstream of the channel bifurcation. The right channel on location (B) is provided with two rows of diversion lines and 6 retards to protect 300m length stretch of the river.

4.2 Analysis with Satellite Image

The Ganga river at Nakhwa site was monitored with the help of satellite imageries of 2005 and October 2011. The morphological changes in the river verified by comparing the pre Jack Jetty installation PAN image of 2005 and post Jack Jetty installation October 2011 image along with GIS based measurements. The GIS measurements are tabulated in Table 4.1 shows the width of the left channel which was 246m has significantly reduced to 50m and the width of the right channel has broadened to 341m from 180m. The river has narrowed down on the left channel to almost 200m and has broadened to almost 160m on the right channel post Jack Jetty installation.

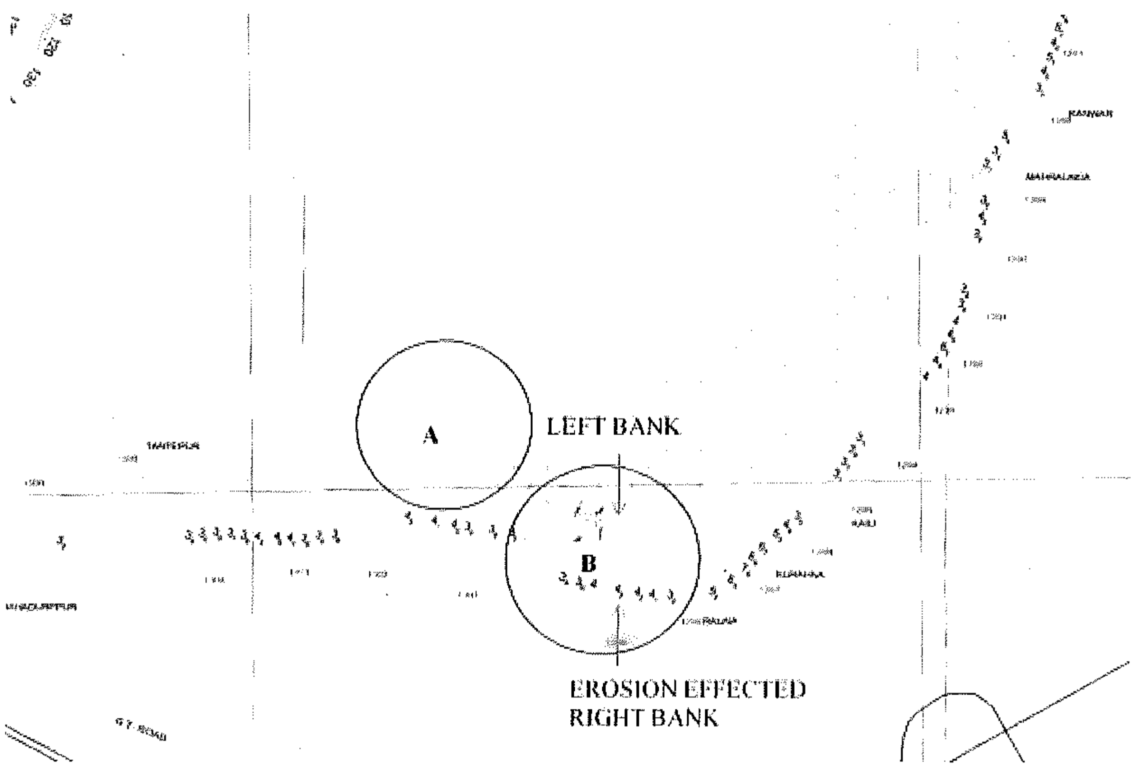


Figure 4.1 : Plan view of Nakhwa Site in the Ganga river showing location (A) and (B)

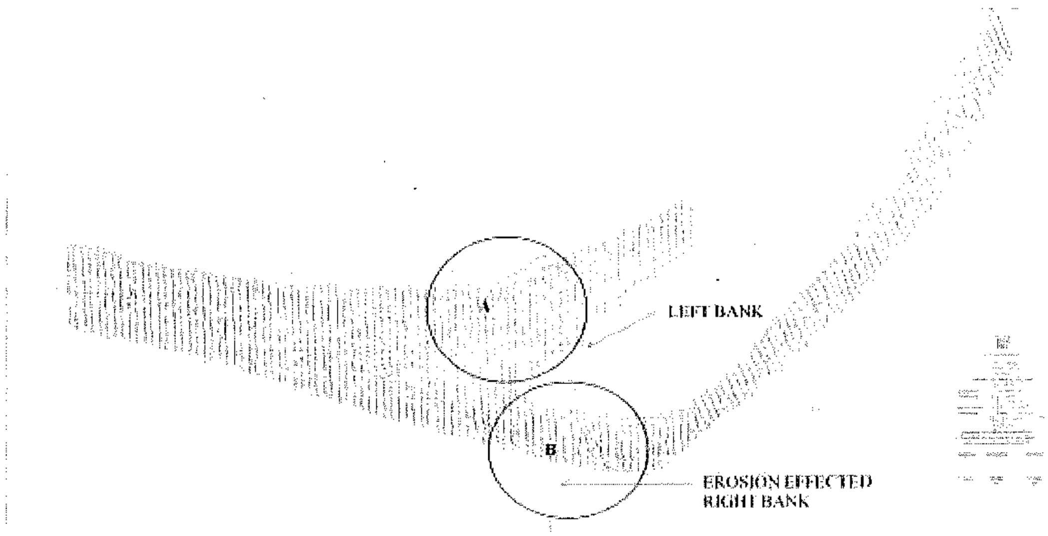


Figure 4.2 : Pre River Training survey map

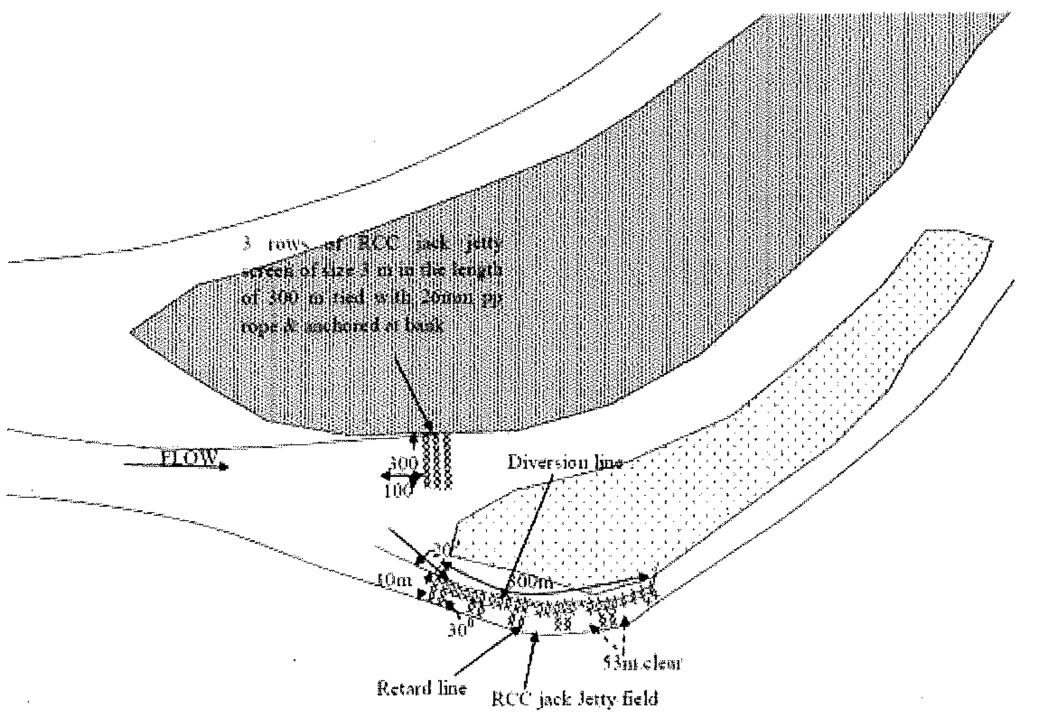


Figure 4.3 : Detail arrangement of RCC jetty screen and RCC jetty field in Location (A) and (B) at Nakhwa site

Figure 4.4 : Satellite Image 2005

Figure 4.5 : Satellite Image October 2011

Table 4.1 : GIS Measurements

Channel Location	2005 Image	October 2011 Image
Left channel	246 m	50m
Right Channel	180m	341m

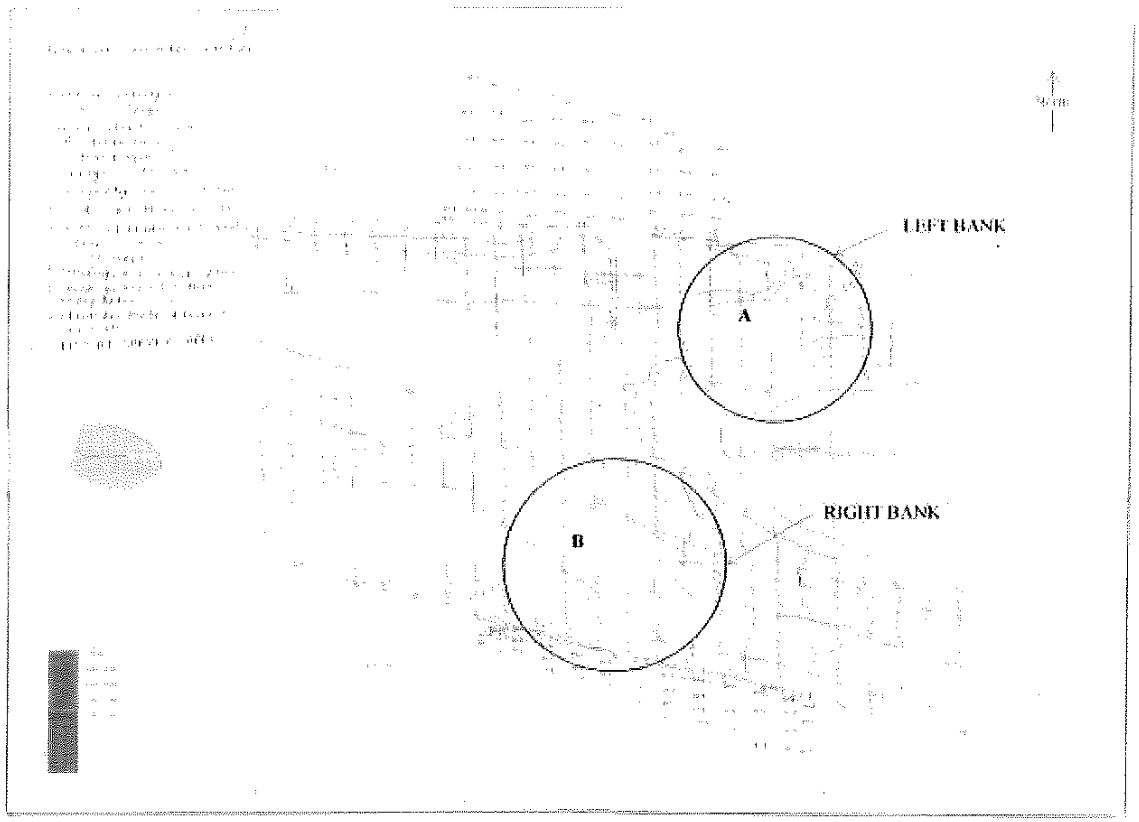


Figure 4.6 : Post River Training survey map

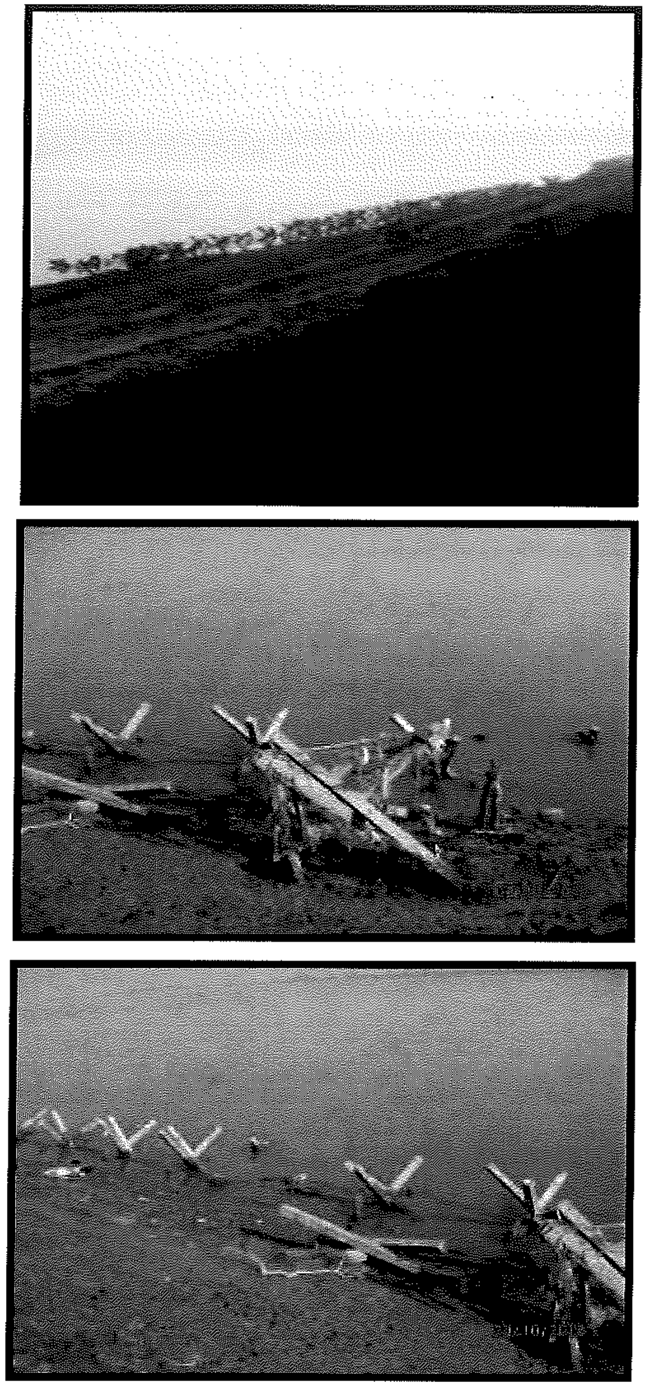


Figure 4.7 : Silting with the RCC Jack Jetties

4.3 Analysis with Survey Data

Topographical river bed level survey of the study area at Nakhwa site was conducted for pre and post flood season to monitor the stream bed changes post Jack Jetty installation in right channel. The protected stretch of the right channel was delineated into 22 cross sections to quantify the bed level changes post jetty installation. After analysing the pre and post survey data the stream bed changes post Jack Jetty installation is plotted for all the 22 sections and shown from Figure 4.8 to Figure 4.29. Plots are shown in terms of stream bed changes to Cross sectional length. Cross sectional length is a term derived to represent the width of the river in the protected stretch to plot the stream bed changes for all the cross sections with cross sectional distance in the scale where 0 denotes the left bank and 1 denotes the right bank.. The stream bed changes are calculated in terms of BDF, depth of sand deposited to the depth of water.

Close examination of these plots show after installing the river training measure there is sedimentation on the right bank of the right channel and erosion is stopped. The depth of the river in the middle of the channel has increased which can now provide sufficient navigation draught to cargo ships.

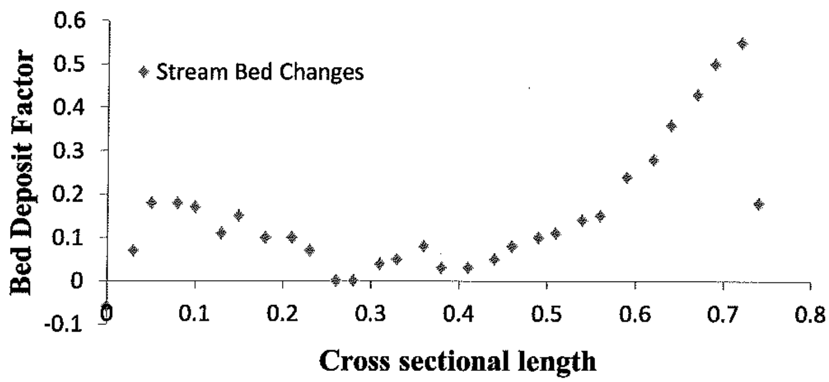


Figure 4.8 : 1st Cross Section

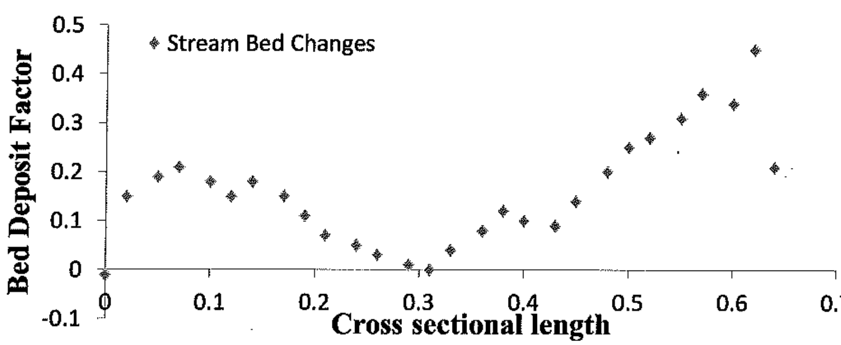


Figure 4.9 : 2nd Cross Section

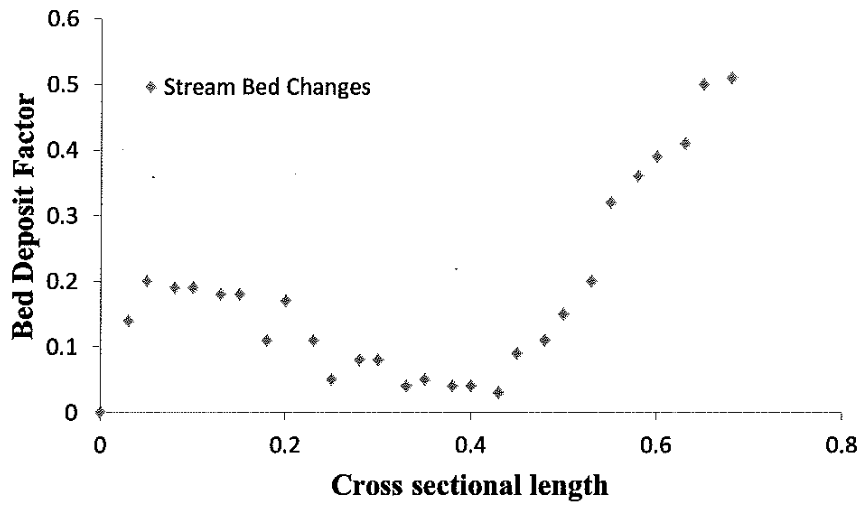


Figure 4.10 : 3rd Cross Section

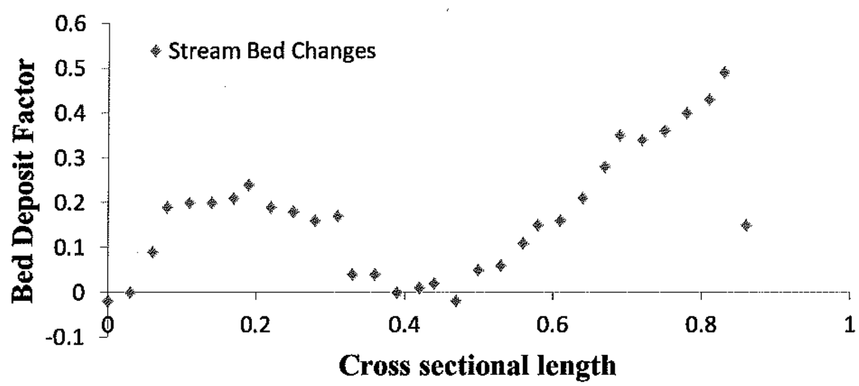


Figure 4.11 : 4th Cross Section

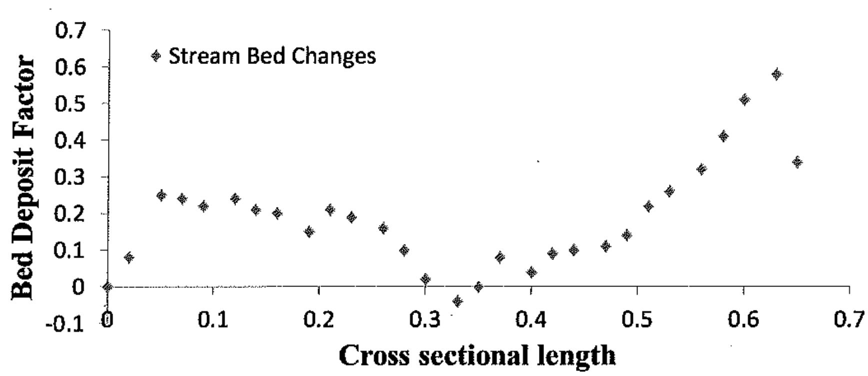


Figure 4.12 : 5th Cross Section

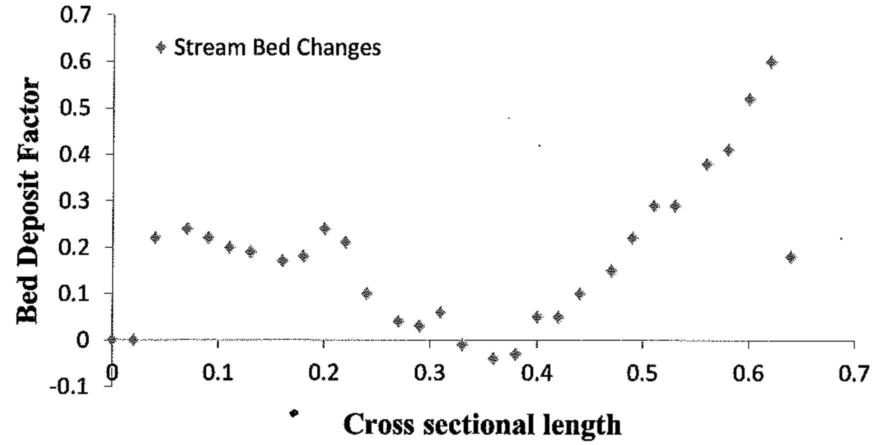


Figure 4.13 : 6th Cross Section

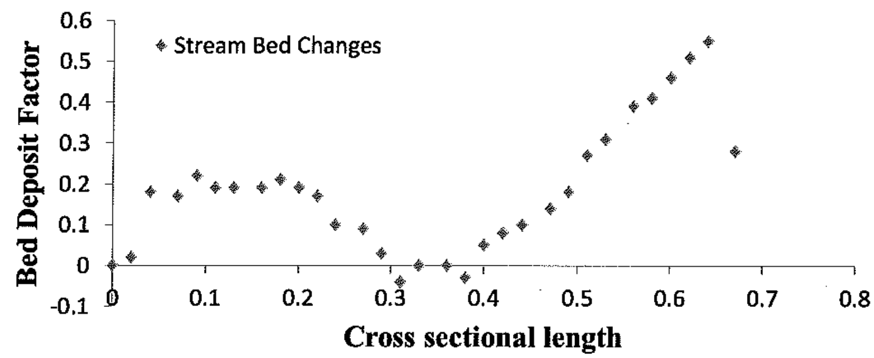


Figure 4.14 : 7th Cross Section

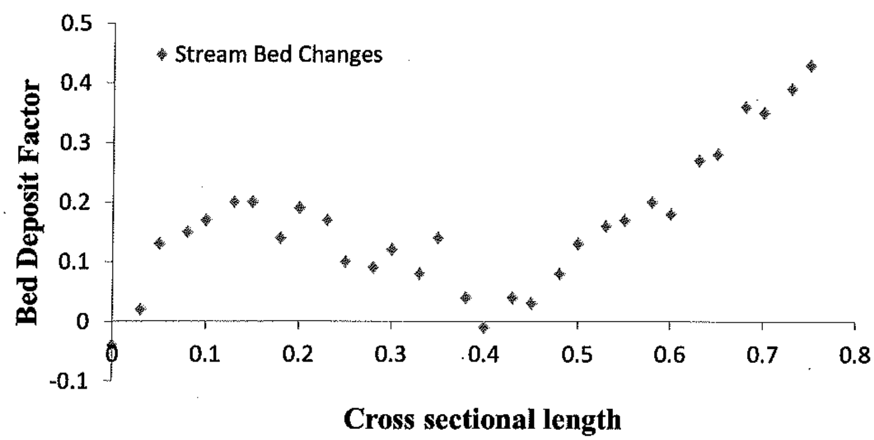


Figure 4.15 : 8th Cross Section

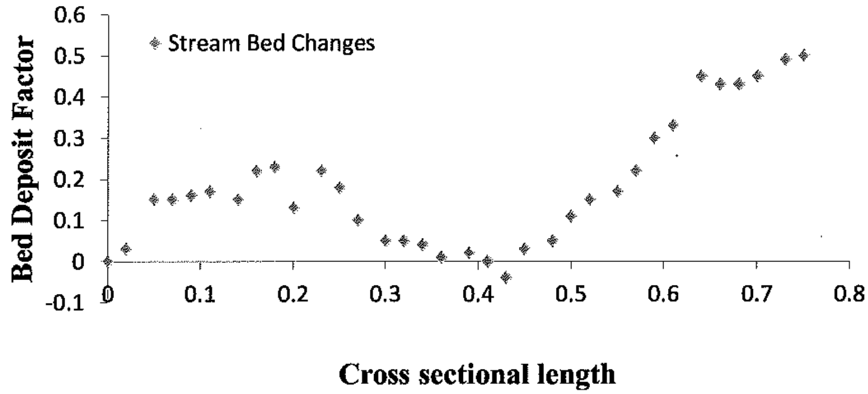


Figure 4.16 : 9th Cross Section

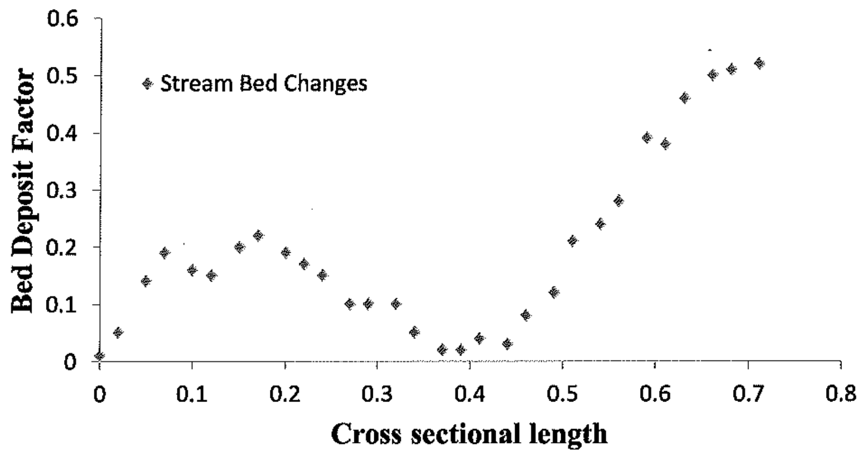


Figure 4.17 : 10th Cross Section

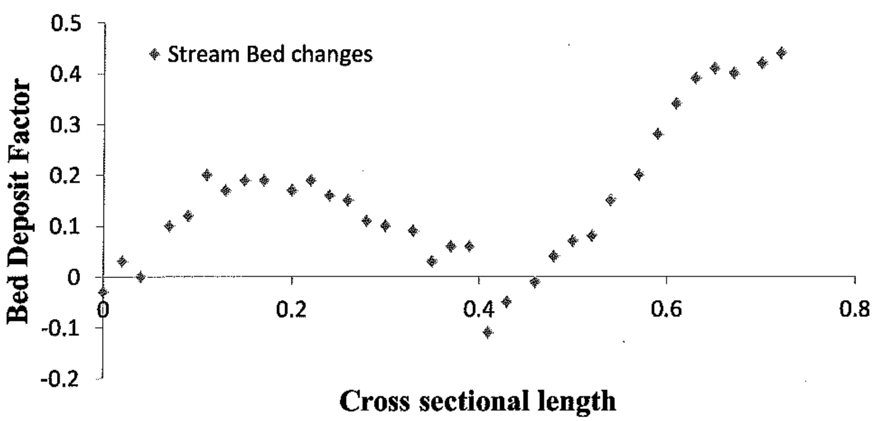


Figure 4.18 : 11th Cross Section

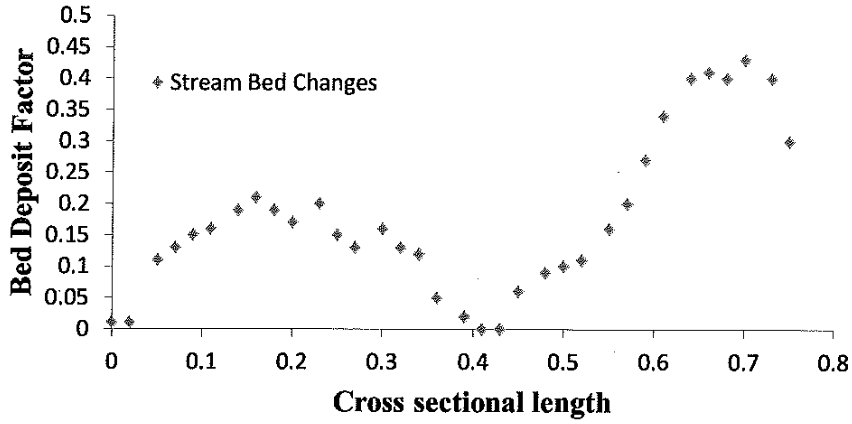


Figure 4.19 : 12th Cross Section

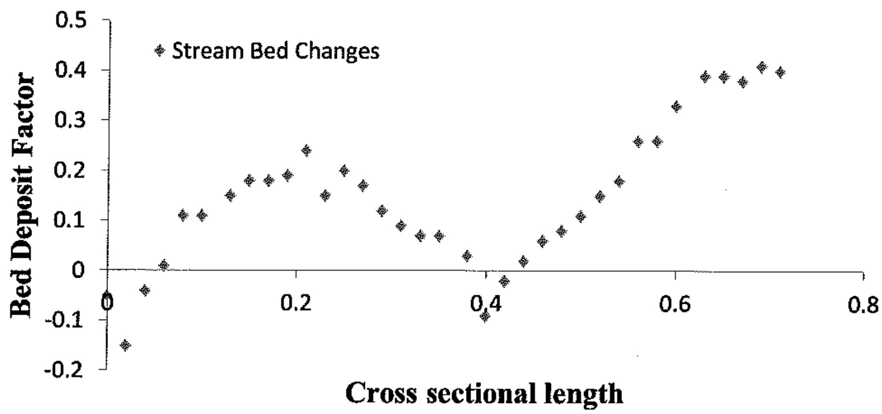


Figure 4.20 : 13th Cross Section

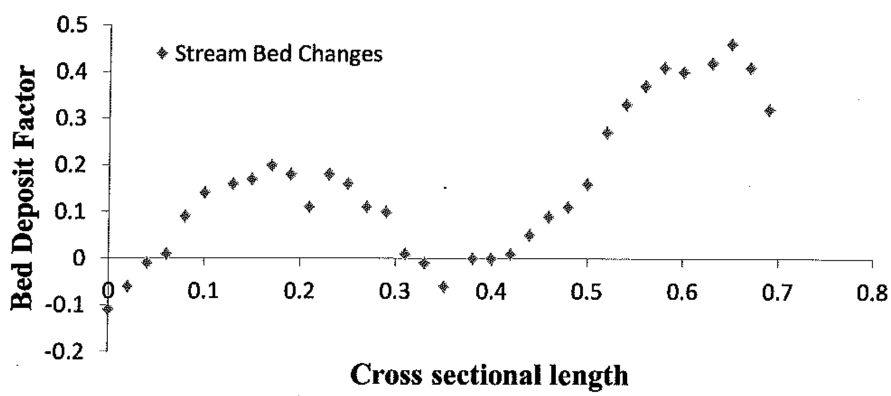


Figure 4.21 : 14th Cross Section

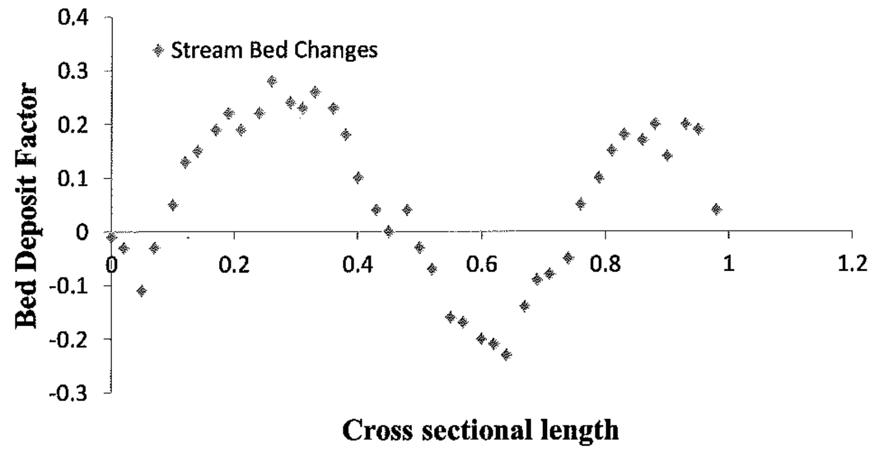


Figure 4. 22 : 15th Cross Section

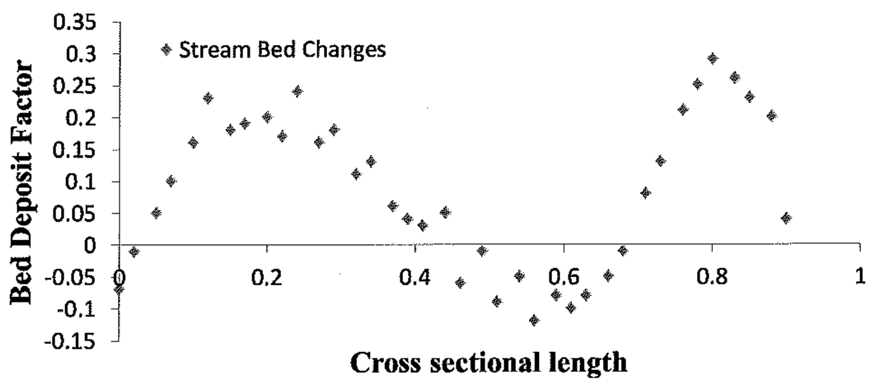


Figure 4.23 : 16th Cross Section

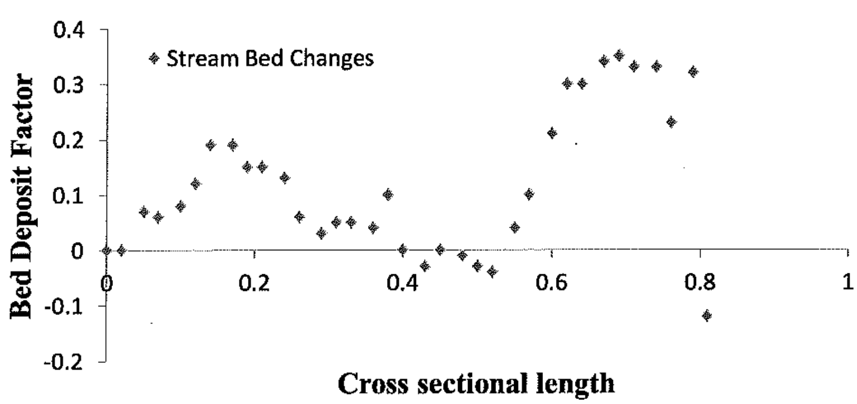
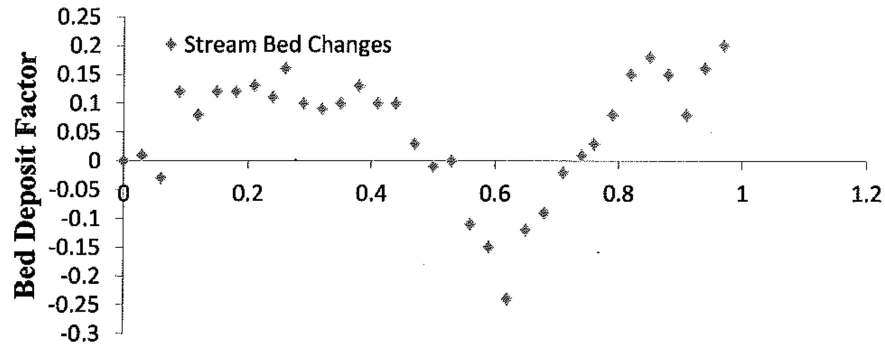
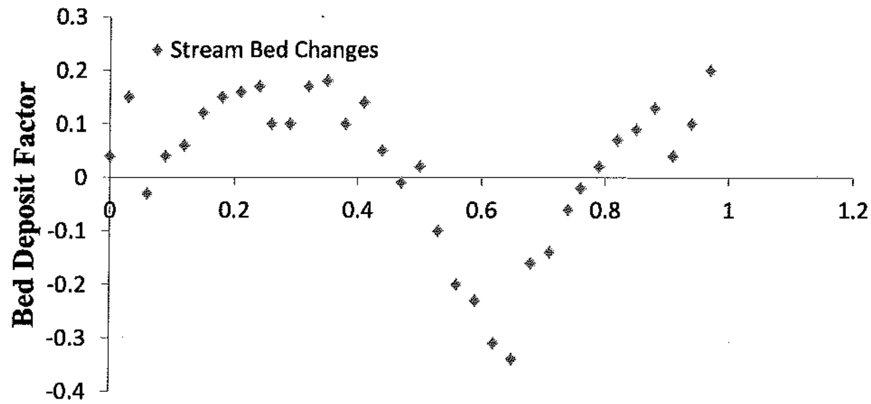


Figure 4.24 : 17th Cross Section



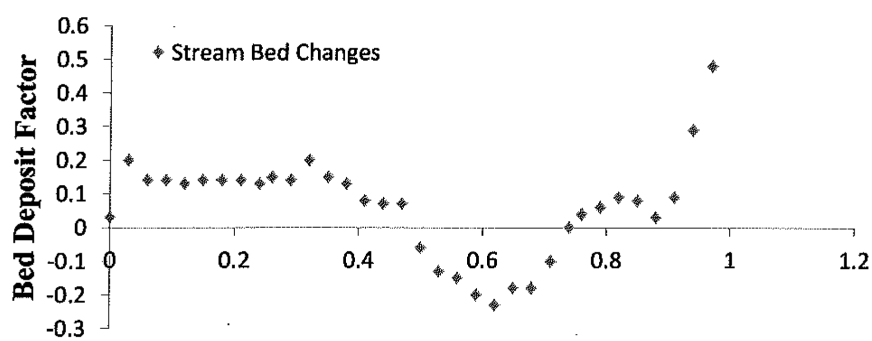
Cross sectional length

Figure 4.25 : 18th Cross Section



Cross sectional length

Figure 4.26 : 19th Cross Section



Cross sectional length

Figure 4.27 : 20th Cross Section

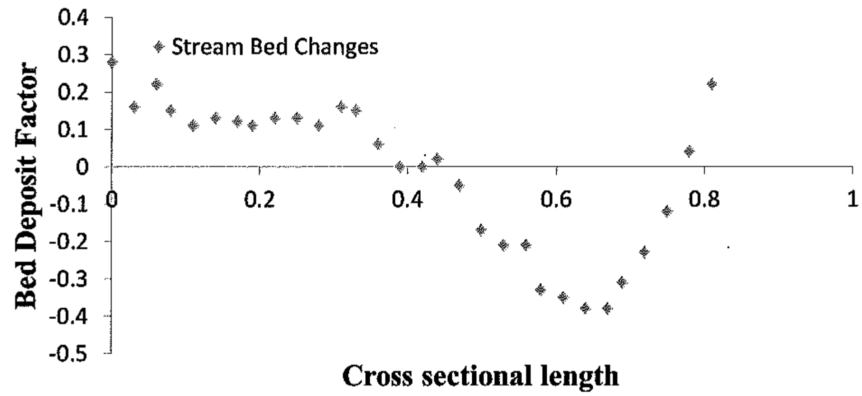


Figure 4.28 : 21st Cross Section

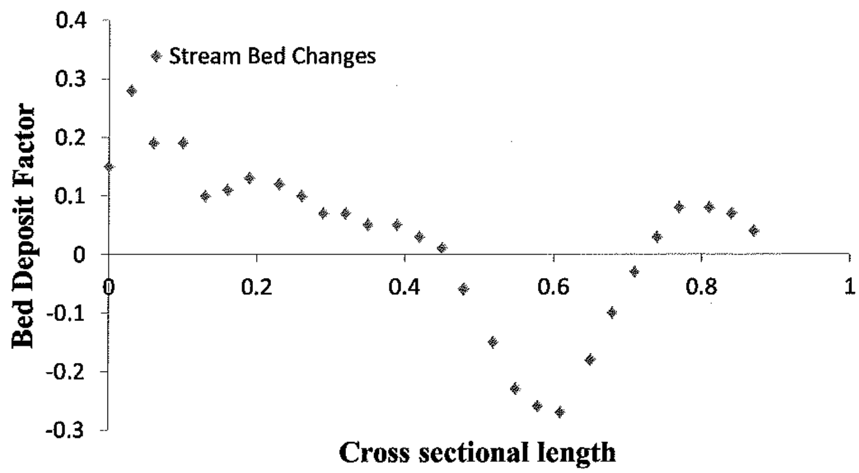


Figure 4.29 : 22nd Cross Section

Analysing the BDFs in a similar manner as explained in the previous chapter average and maximum BDFs are calculated for validating the laboratory experimental results. Comparison of the BDFs show the analysed BDFs of the field study are compatible with the laboratory results and the design methodology as suggested with the help of thresholds holds good with the field data.

4.4 Conclusion

This field study has been conducted in the Ganga river at Nakhwa site for validation of the laboratory data. Analysis of the satellite images and the pre and post RT survey data has provided with sufficient information of the partial closure of the left channel and erosion being stopped on the right bank of the right channel. Now this channel can be further used for navigation. The field study has helped in validating the laboratory data.

CHAPTER – 5

STUDY ON PORCUPINE

5.1 General

A Porcupine is a unit of the system which comprises 6 members of RCC rectangular beam members which are joined together with the help of iron nuts and bolts to form a tetrahedral frame. Each member is 2 m to 4 m in length, depending upon the field requirements. At the time of concreting of members, holes are kept in the RCC poles for the bolts. Generally, RCC poles of 3 m length are used having a cross section of 15 cm × 15 cm. Reinforcement is given using 4 nos. of MS bars of 6 mm diameter; with stirrups at 15 cm c/c. Larger porcupines may also be used with greater cross section and heavier reinforcement as per the requirements. Bolts are normally 12 mm to 15 mm diameter. Check nuts are to be provided for better grip. Washers are required at both ends for better grip with the RCC members. RCC porcupines should be connected together by wire rope and properly anchored to the ground to avoid any disturbance caused by the intensity of flow. Figure 5.1 shows a three dimensional sketch of a typical RCC Porcupine unit.

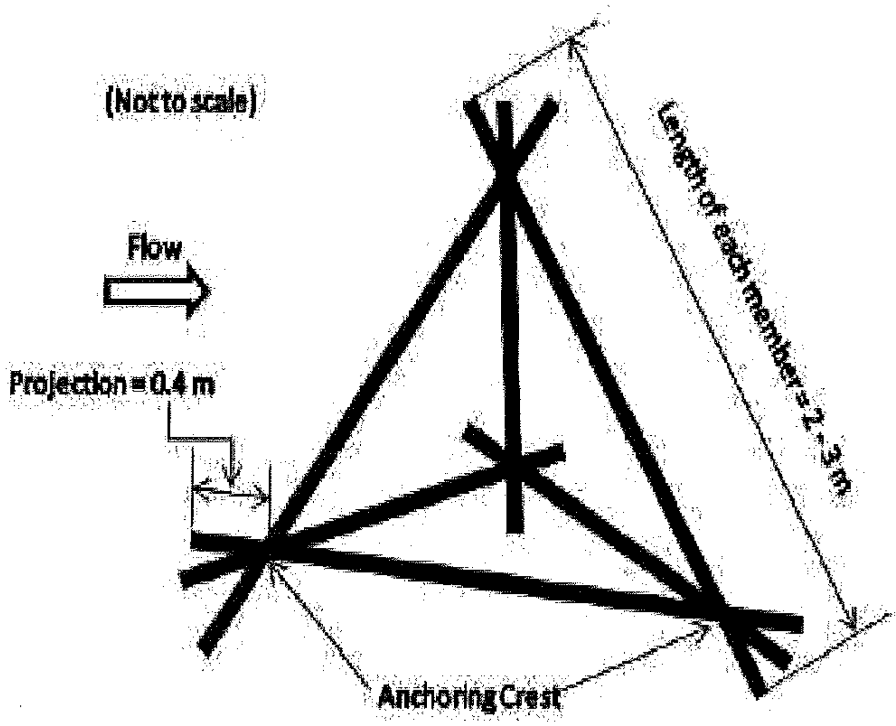


Figure 5.1 : Porcupine

The basic principle of porcupine protecting river bank is the decelerating effect of member bars, which offer resistance to flow and hence cause reduction in velocity.

5.2 Experimental Set-Up, Observations and Results Analysis for Porcupines

5.2.1 Objectives

The main objectives of the experimental study are described as follows:

i) To investigate the change in velocity field induced by the porcupine.

ii) To gain an insight into the effect of various porcupine field configurations on channel bed changes.

iii) To evolve new suitable indices and parameters to represent alternative porcupine field layout to optimize performance in capturing sediment.

iv) To investigate the effect of various submergence level of the porcupine field on inducing bed deposition.

v) To develop threshold of design parameters for achievement of alternative design objectives of porcupine field layout and configuration for erosion control and reclamation.

vi) To plan for validation of the proposed design of the porcupine system with field application on an alluvial river with respect to stream bed changes and bank protection or erosion control.

5.2.2 Laboratory Flume Set-Up & Experimental Procedure

To study and analyse the effect of porcupines on the flow and relevant fluvial parameters, the experimental program of the current research was allocated into two phases, namely 'Phase – 1' and 'Phase – 2'. The experiments were carried out in the Outdoor River Engineering Laboratory of Department of WRD&M, IIT Roorkee, situated near Toda Kalyanpur village, Roorkee.

In the first phase of experiments, the effect of porcupines on the fluvial parameters was studied. In the second phase of study, the effect of various arrangements of porcupines on the sediment laden flow of water was investigated to come up with the optimal combination of porcupine field to be suitable for the requisite objective of erosion control, moderate reclaim or high reclaim.

This section gives a description of the experimental set up in the laboratory and the various configurations of porcupines tested. The observations made and the equipment's & instruments used to record the observations have also been illustrated. The experiments in the present study were focused primarily on developing rational design methodology for porcupine system with systematic scientific investigation to study the behaviour of flow behind the structures. The test conditions and procedures used for data collection are also described in this section.

The experiments for the present study were carried out in the Outdoor River Engineering Laboratory of the Department of WRD&M, IIT Roorkee near Toda Kalyanpur village. An experimental flume 6 m long, 0.86 m wide and 0.54 m deep was used with 0.15 m thickness of sand bed, giving effective depth of 0.39 m. Porcupine models were fabricated in the workshop using 4 mm MS rods. 6 pieces of MS rods, each of 0.10 m length, were welded together to get the desired shape. Figure 5.2 shows a model of porcupine placed in the flume. The effective height of the model is 0.09 m when they are placed in the flume.

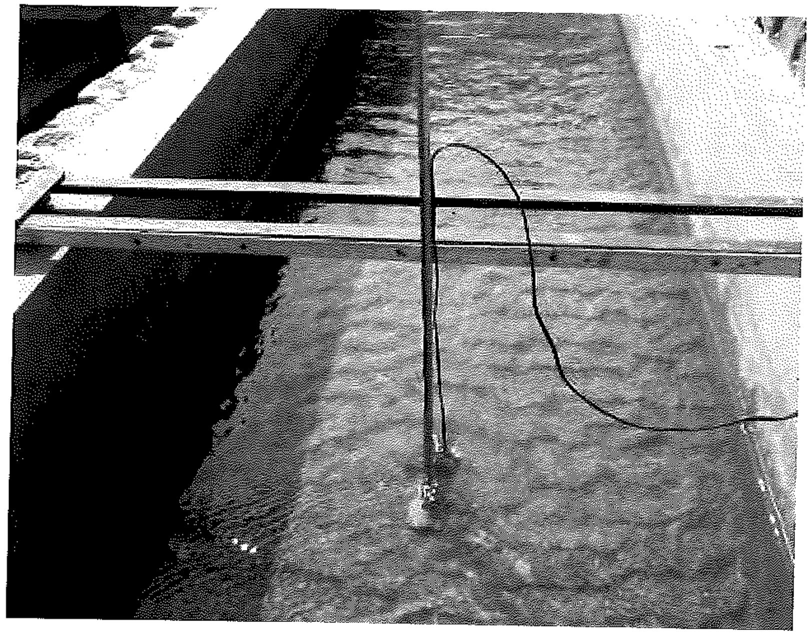


Figure 5.2 : Experimental flume with current meter

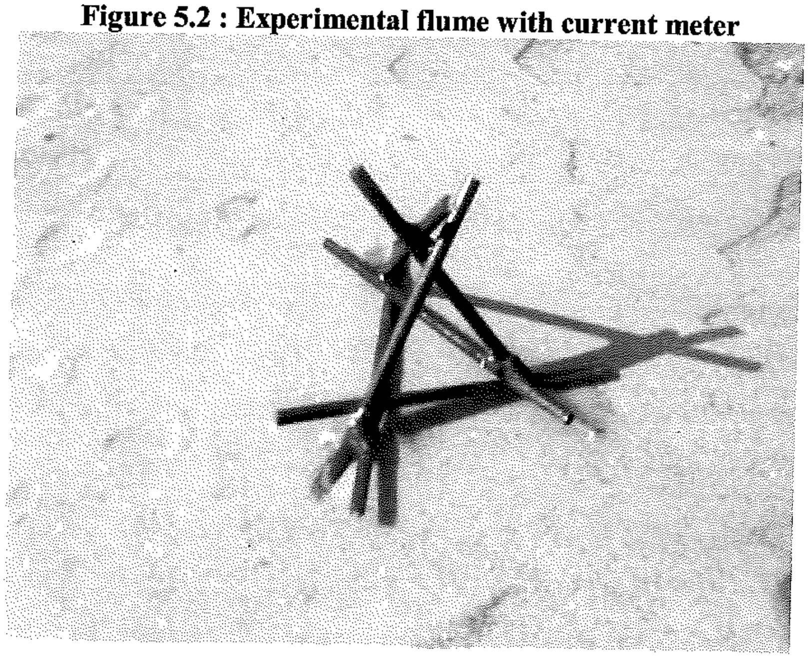


Figure 5.3 : MS model of porcupine

Figure 5.4 presents a sketch of layout plan of the experimental setup, which includes a sump tank from where the water is pumped into the overhead tank using a feed pump. Dotted lines with arrow heads represent the direction of flow. When the overhead tank is full, water passes over the V-notch into the stilling tank, which contains a perforated wall which is used to create a still pocket of water before it enters into the experimental flume; hence a steady flow is obtained into the flume. An outlet valve is connected to the overhead tank, which controls the rate of flow into the stilling tank from the overhead tank by removing excess quantity of flow from the overhead tank. The base of the experimental flume is kept higher than the stilling tank to enable entry of steady flow into the flume. At the exit of the flume, a collection tank collects the water and re-circulates it into the sump tank.

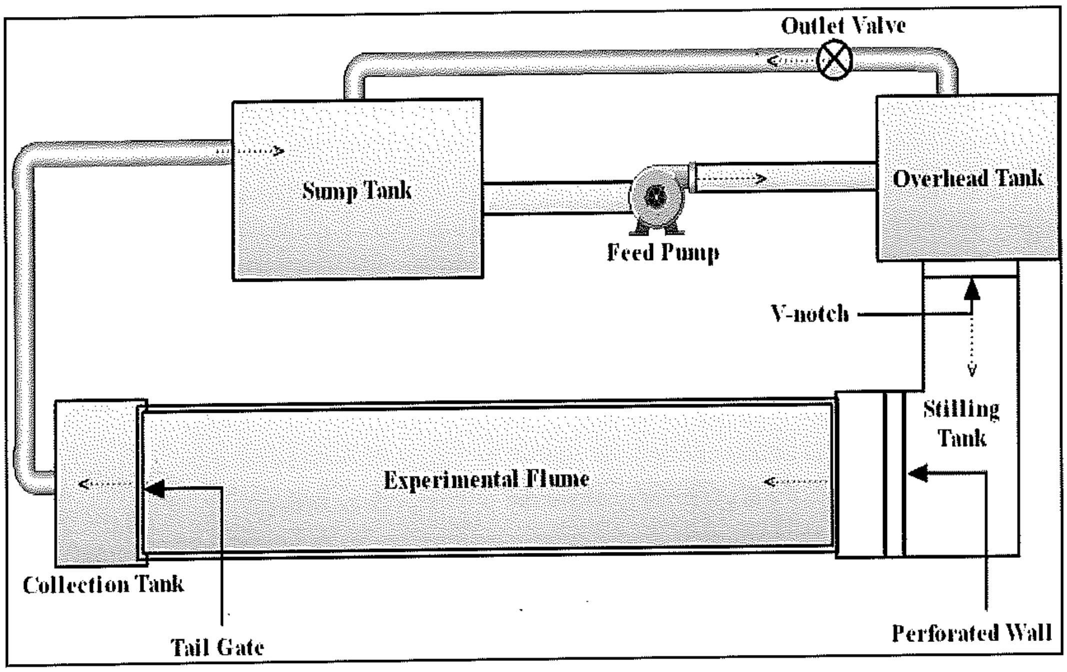


Figure 5.4 : Sketch of Layout Plan of the experimental setup

Flow was passed over a 90° V-notch (Figure 5.5) to measure the flow rate. Head over the V-notch was measured by a point gauge and the flow rate passing over it was calculated by the V-notch equation [Eq. (5.1)].

$$Q = \frac{8}{15} C_d \sqrt{2g} \tan\frac{\theta}{2} h^{5/2} \quad 5.1$$

Where,

Q = Flow Rate

C_d = Coefficient of Discharge

θ = Angle of V-Notch

g = Acceleration due to gravity

h = Head over V-Notch

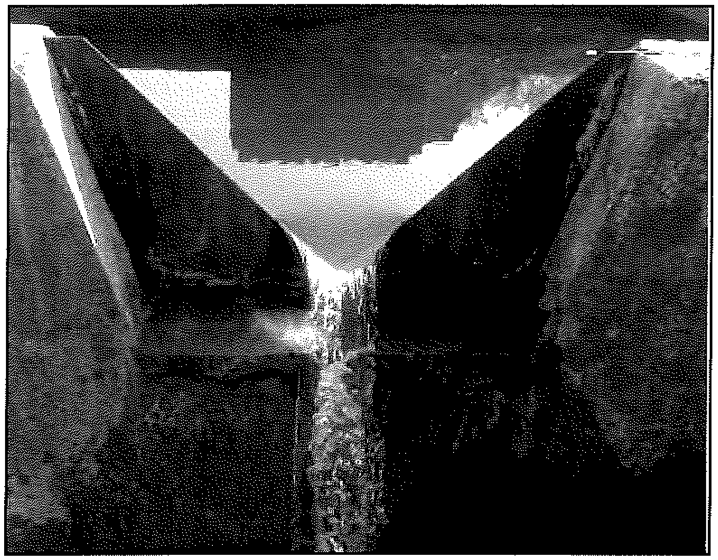


Figure 5.5 : V-notch used to measure flow rate

Figure 5. 6 : Tail gate at downstream end of flume used to control flow depth

The experimental flume had a graduated scale on its side walls having a least count of 0.01 m. These graduations helped in placing the models in the exact position inside the flume and also in taking velocity readings at intended points. Tail gate was used at the downstream end of the flume to control the depth of flow inside the flume (Figure 5.6).

5.2.3 Details of Measuring Instruments – Current-meter

Measurement of velocity was done by using a current meter which directly gives the reading of velocity of flow in the attached indicator correct up to 0.01 m/s. The indicator shown in Figure 5.7 is connected with the rotating fins of the current meter with the help of two wires, which records the number of rotations made by the fins and continuously gives the reading of velocity at every 20 second intervals.

To measure the depth of sand deposition in the second phase of the experiments, a point gauge was used having a least count of 0.01 cm. It consists of a main scale which reads correct up to 0.1 cm and a vernier scale for reading up to 0.01 cm.

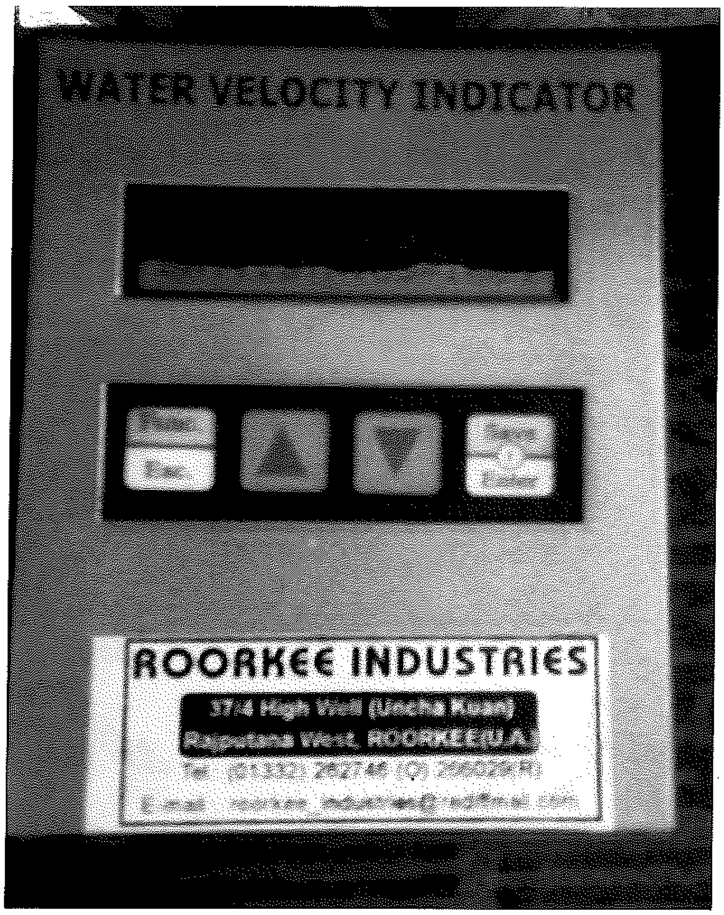


Figure 5. 7 : Velocity indicator which is connected with current meter

5.2.4 Sediments Used

Experiments were performed using sediments with median diameter as 0.2281 mm (as shown in Figure 5.8. The relative density of the sand was 2.65.

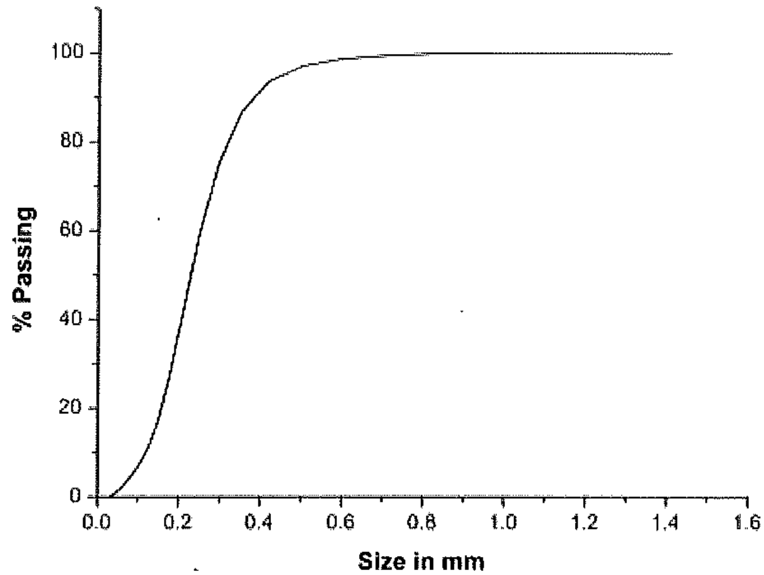


Figure 5. 8 : Grain size distribution curve, d50 = 0.2281 mm

5.2.5 Experimental Procedures

5.2.5.1 Phase – 1 Experiment

Phase – 1 experiments were conducted in the following steps:

i. Before starting the experiments, the depth of sediment bed layer of the test section was fixed at 0.15 m by filling sand.

ii. Before placement of porcupine model the sediment bed of flume was leveled and the bed level readings were taken with the help of point gauge.

iii. After placement of the porcupine model, the sediment bed of flume was again leveled around the porcupine.

iv. The water was supplied to the flume from constant head tank to upstream tank and upstream tank to flume. The supply pipe was connected to the pump and the discharge was controlled by a regulating valve.

v. Flow was introduced in the flume very slowly by closing the tail gate so that no scouring occurred around the porcupine.

vi. Uniform flow without sediment motion corresponding to a selected discharge was established with the help of tailgate.

vii. The water which discharges into the tail box was allowed to flow over 90° V-notch. After flowing over the notch the water was discharged into the sump from where it was recirculated by pump.

viii. For the measurement of water depth the point gauge was fixed to a vertical graduated rod. The difference of water level reading and sand bed reading gives the water depth.

ix. The velocity of flow was measured by current meter in a grid pattern.

Table 5.1 : Phase – 1 Study Experiments

Experiment No.	Water Depth (m)	Discharge (m^3/s)	Layout of Porcupines
1	0.10	0.025	One 0.10 m model
2	0.10	0.025	Two 0.10 m models in a row
3	0.10	0.025	Three 0.10 m models in a row
4	0.10	0.025	Four 0.10 m models in a row
5	0.20	0.0406	Two 0.10 m models in a row
6	0.20	0.0406	Three 0.10 m models in a row
7	0.20	0.0406	Four 0.10 m models in a row
8	0.24	0.0583	Two 0.10 m models in a row
9	0.24	0.0583	Three 0.10 m models in a row
10	0.24	0.0583	Four 0.10 m models in a row

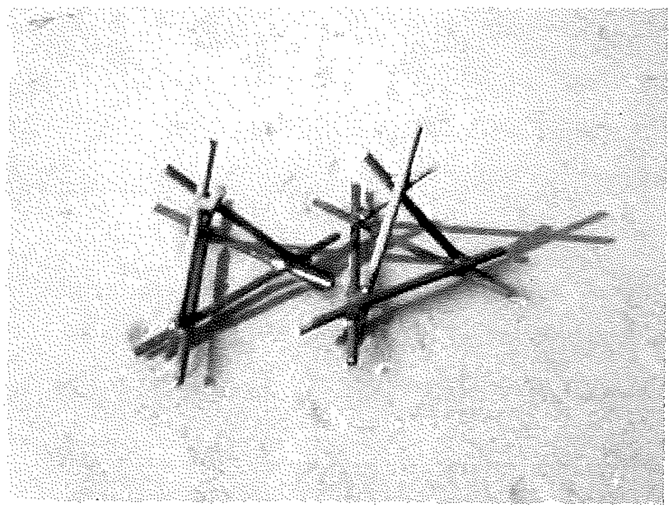


Figure 5.9 : Two models in row

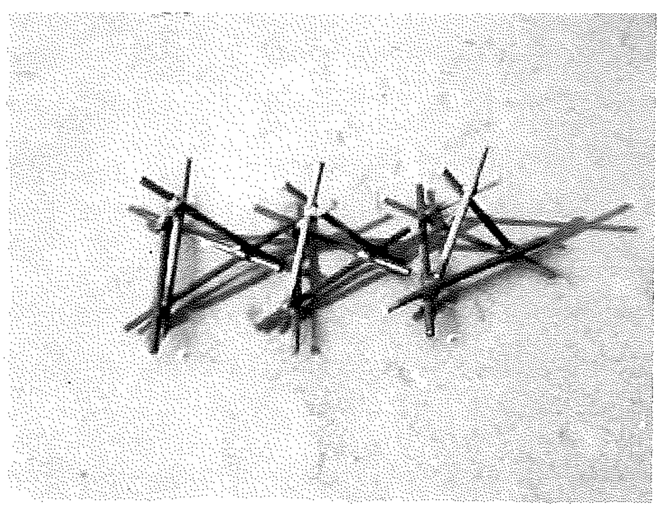


Figure 5. 10 : Three models in row

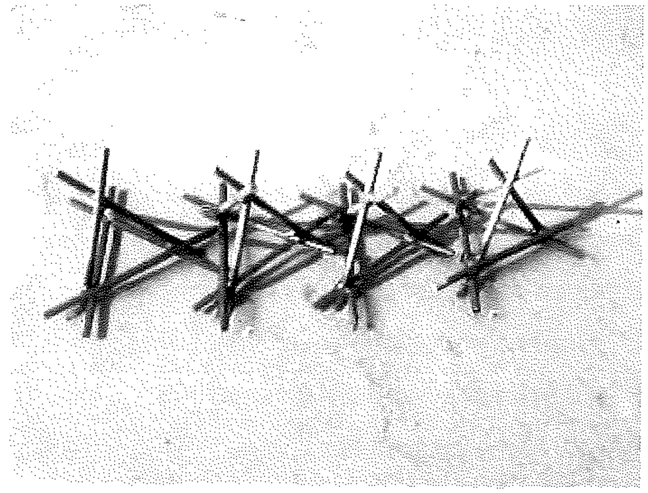


Figure 5.11 : Four models in row

Figure 5.9 to Figure 5.11 are the photographs of the different arrangement of models for first phase study presented in Table 5.1.

5.2.5.2 Phase – 2 Experiment

Phase – 2 experiments were conducted in the following steps:

i. Before starting the experiments, the depth of sediment bed layer of the test section was fixed at 0.15 m by filling sand.

ii. Before placement of porcupine field the sediment bed of flume was leveled and the bed level readings were taken with the help of point gauge.

iii. After placement of the porcupine field, the sediment bed of flume was again leveled around the porcupine field.

iv. The water was supplied to the flume from constant head tank to upstream tank and upstream tank to flume. The supply pipe was connected to the pump and the discharge was controlled by a regulating valve.

v. Flow was introduced in the flume very slowly by closing the tail gate so that no scouring occurred around the porcupine.

vi. Uniform flow without sediment motion corresponding to a selected discharge was established with the help of tailgate.

vii. The water which discharges into the tail box was allowed to flow over 90° V-notch. After flowing over the notch the water was discharged into the sump from where it was recirculated by pump.

viii. This clear water run continued for half an hour. Then the motor was shut and water was discharged gradually with the operation of tail gate such as not to disturb the sand bed. The valves which control the regulation of flow into the flume were not altered so as to maintain the same discharge into the flume for the flowing sediment run. After the water is drained sand bed levels were measured with the help of pointer gauge.

ix. After the bed profile is measured for clear water run the flume is again filled with water and run for the discharge for which it was run for the clear water condition. Water level was maintained with the help of downstream tail gate. Once the flow comes into steady state condition sediment of specific concentration was injected into the flume at a section 0.5 m upstream of the porcupine field. When the sediment injection into the flume is done the flume was ran for 2 hours.

x. This sediment water run continued for 2 hours. Then the motor was shut and water was discharged gradually with the operation of tail gate such as not to disturb the sand bed. After the water is drained sand bed levels were measured with the help of point gauge.

Table 5.2 : Phase – 2 Study Experiments

Experiment No.	q_s (ppm)	L_T/L_s	Discharge (m^3/s)	Water Depth (m)	Submergence Ratio
1	500	1.0	0.030	0.24	0.625
2	500	1.5	0.030	0.24	0.625
3	500	2.0	0.030	0.24	0.625
4	500	1.0	0.025	0.20	0.550
5	500	1.5	0.025	0.20	0.550
6	500	2.0	0.025	0.20	0.550
7	500	1.0	0.017	0.15	0.400
8	500	1.5	0.017	0.15	0.400
9	500	2.0	0.017	0.15	0.400
10	750	1.0	0.017	0.15	0.400
11	750	1.5	0.017	0.15	0.400
12	750	2.0	0.017	0.15	0.400
13	1000	1.0	0.017	0.15	0.400
14	1000	1.5	0.017	0.15	0.400
15	1000	2.0	0.017	0.15	0.400

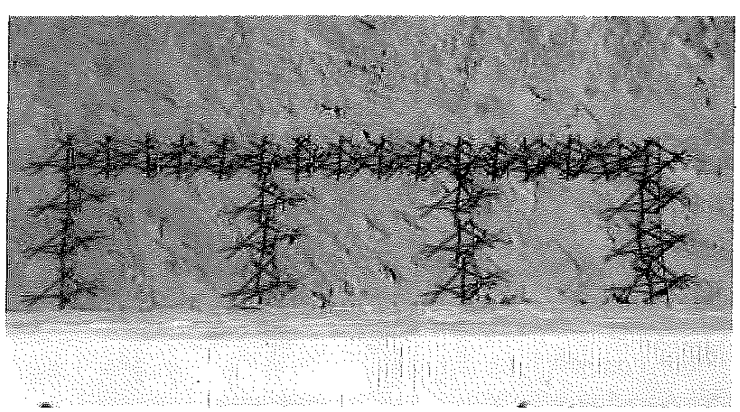


Figure 5.12 : One diversion line with 4 retards

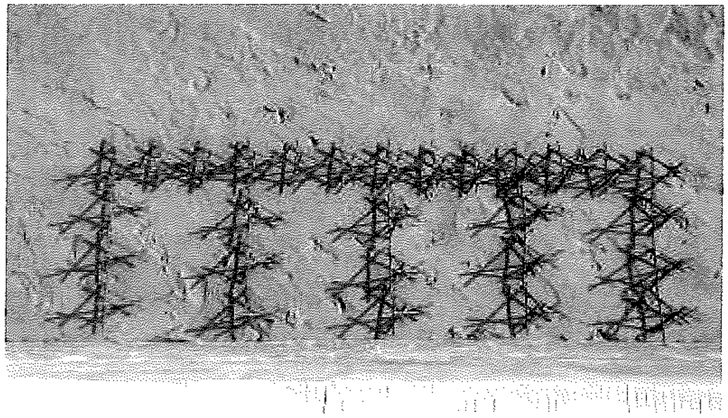


Figure 5. 13 : One diversion line with 5 retards

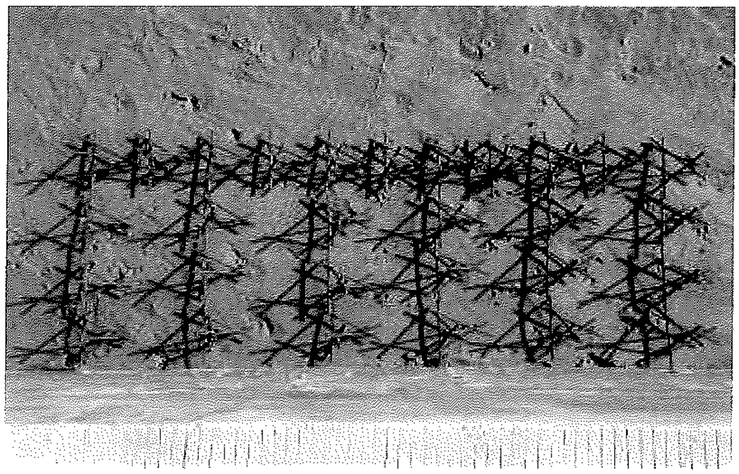


Figure 5. 14 : One diversion line with 6 retards

Figure 5.12 to Figure 5.14 are the photographs of the different arrangement of models for second phase study presented in Table 5.2.

5.3 Observation, Result and Analysis

5.3.1 Phase – 1 Study Results

5.3.1.1 Background

The objective of the first phase study was to study the effect of the porcupine on the behaviour of flow. Uniform flow conditions were established for each test and velocity measurements were carried out to measure the velocity field before installation of porcupine. Then the porcupine was placed at the centre of the flume, midway along its length (i.e., at x = 3 m) and the velocity field was measured again. For each discharge tested, depth of flow at a location about 0.5 m upstream of the porcupine was measured in the centreline of the flume. These measurements were taken in a grid pattern around the porcupine field. The first cross section was taken just upstream of the porcupine where the velocity distribution of the flow was not changed due to presence of the porcupine.

This testing was carried out for different configurations of the porcupines. The objective behind these sets of experiments was to investigate the change in velocity due to the porcupines. The present research is proposed to design and develop the porcupine structure as a river training measure by arresting the bed load sediment in the lower depths of flow. In this study the main concern is on the bed load of the sediment carried by the stream.

All the experiments were conducted for the incipient motion condition keeping the average bed shear stress just below the critical shear stress by fixing the Shields' parameter to 0.045 as per Yalin-Karahan (Pope et al. 2006; Shields 1936; Yalin and Karahan 1979).

Clear water condition was maintained by avoiding incipient motion condition in the present part of the study. This was done by maintaining the average bed shear stress less than critical shear stress to avoid movement of bed. Average bed shear stress ($\tau_{\circ}$) and critical bed shear stress (τc) are given by eqn. 5.2 and 5.3 respectively.

$$\tau_{\circ} = \gamma_f RS \quad (5.2)$$

$$\tau c = \tau ci \times (\gamma s - \gamma_f) \cdot d \quad (5.3)$$

Where,

τci = dimensionless critical shear stress

γ_s = unit weight of sand

γ_f = unit weight of water

R = hydraulic mean depth

S = water surface slope

d = mean diameter of sediment particles

Incipient motion condition was achieved by fixing the bed slope in such a way that the average bed shear stress remains less than the critical shear stress taking into consideration the Shields' parameter.

5.3.1.2 Study of Velocity Plots

To get an understanding into the velocity field in and around the porcupine, plots of the vertical velocity profiles were drawn (Figure 5.15 to Figure 5.17). The x-axis in these plots shows distance in meter from upstream end of flume along the centre line of the channel and y-axis represents velocity of flow in m/s at different depths.

It can be briefed that the presence of porcupines has appreciable effect on the flow velocity. The velocity gets reduced to much lower values in the bottom layers than in the top layers of flow. It is observed that for the same values of depth of flow and discharge intensity, the flow velocity reduces more in case of more than one models placed in a row than in case of a single model, which shows that using more number of porcupines in a series causes a greater reduction in velocity of flow. Further, it is observed that a series of models has not only larger effect on velocity, but also the effect continues up to a greater distance on the downstream side of the models.

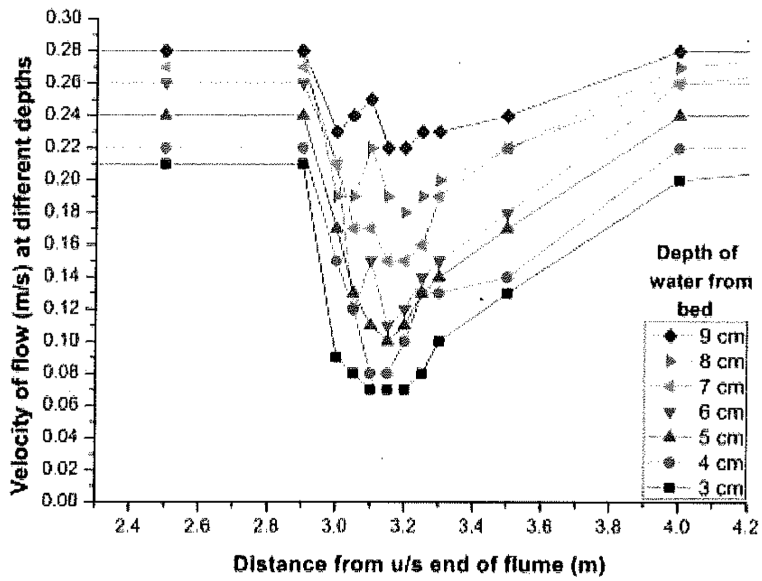


Figure 5.15 : Velocity of flow along centre line with 1 model in 0.1 m water

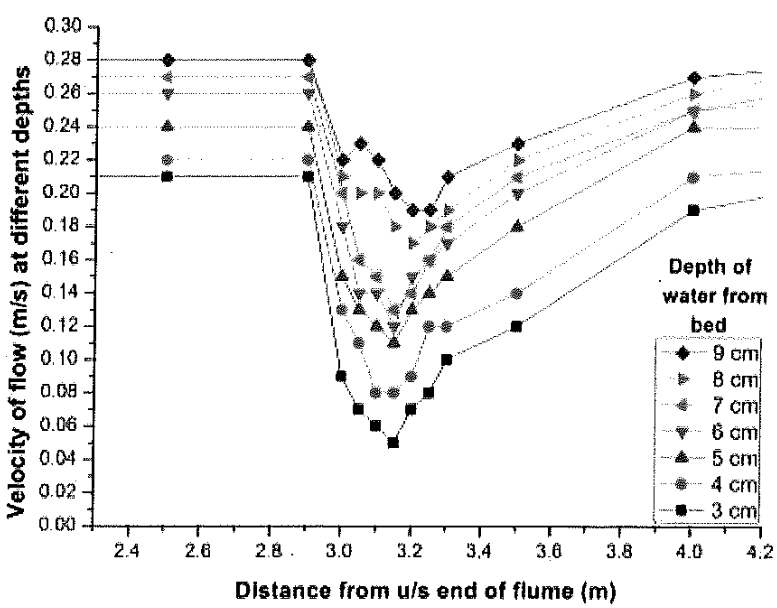


Figure 5.16 : Velocity of flow along centre line with 2 model in 0.1 m water

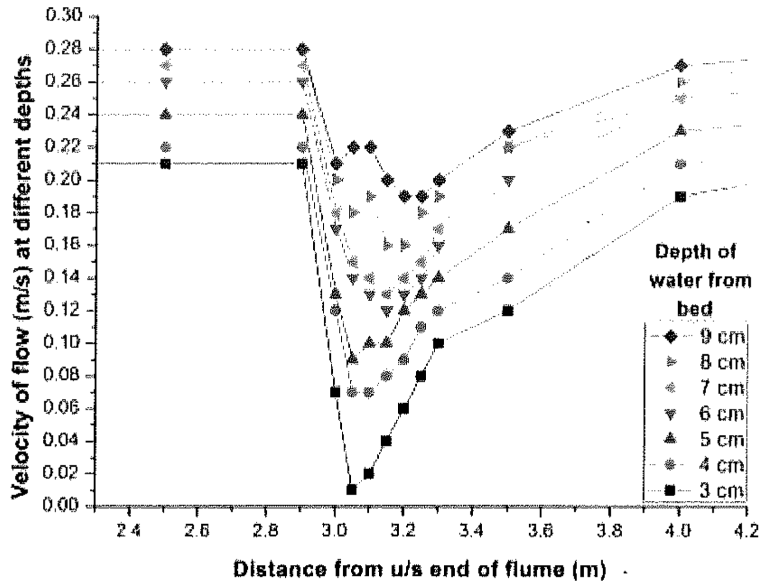


Figure 5. 17 : Velocity of flow along centre line with 4 model in 0.1 m water

Conclusions of Phase – 1 Study:

Noticeable reduction in velocity is observed behind the submerged porcupine than the non-porcupine case which varies from 60% to 70% on an average in the bottom layers of the flow along the centre line.

5.3.2 Phase – 2 Study Results

5.3.2.1 Background

Significant reduction in velocity and thereby sediment transport capacity of the flow is clearly shown by the analysis and the results presented in the previous section. It signifies positive influence of the submerged porcupine towards inducing sedimentation in the flow which calls for advance investigation of the efficiency of porcupine field in producing sedimentation or berm formation in response to a sediment laden flow. In the second phase of this work, the efficiency of the porcupine field performance in the sediment laden flow environment is investigated experimentally.

A review of the literature brought forth that there is hardly any scientific design methodology available for the porcupine which had been in extensive use. Its use has been purely based on experience and conjecture. It was thus envisioned in this present research to develop rational design methodology for the structures on a rational scientific basis. The goal has been to develop design indices and performance parameters to provide guidelines for a rational design methodology. The second phase study therefore has been planned and postulated to achieve the following objectives:

i. To evolve new suitable design indices and performance parameters to represent different alternative porcupine field layouts to optimize performance in capturing sediment for berm formation.

ii. To investigate the effect of various submergence level of the porcupine field on inducing bed deposition.

iii. To develop thresholds for achievement of various design objectives of erosion control and reclamation.

iv. To gain an insight into the effect of various porcupine field configurations on channel bed changes.

To fulfil the required objective for the present part of study, laboratory experiments were carefully framed to logically attain the desired goal of developing a rational design methodology for the porcupine structures. To facilitate in the experimental program, certain new terminologies have been evolved which are briefed below with schematic diagrams as shown in Figure 5.18 and Figure 5.19.

It is to be noted that a single or stand unit of the model is called a porcupine and when they are connected together with a cable they form a porcupine line. When lines of porcupines are laid parallel to the bank of the channel they are called as diversion lines and when the porcupines are projected into the river at certain angle with the bank they are called as retards. Combination of retard and diversion lines forms a porcupine field. Figure 5.18 shows schematic diagram of the plan of proposed porcupine field showing retards and diversion line. The term retard is known from the literatures, we are introducing Lr as the length of the retards and Ls as the centre to centre spacing of retards. Figure 5.19 is a sketch showing the elevation of a porcupine in water where h is the height of model and H is the depth of water in the flume.

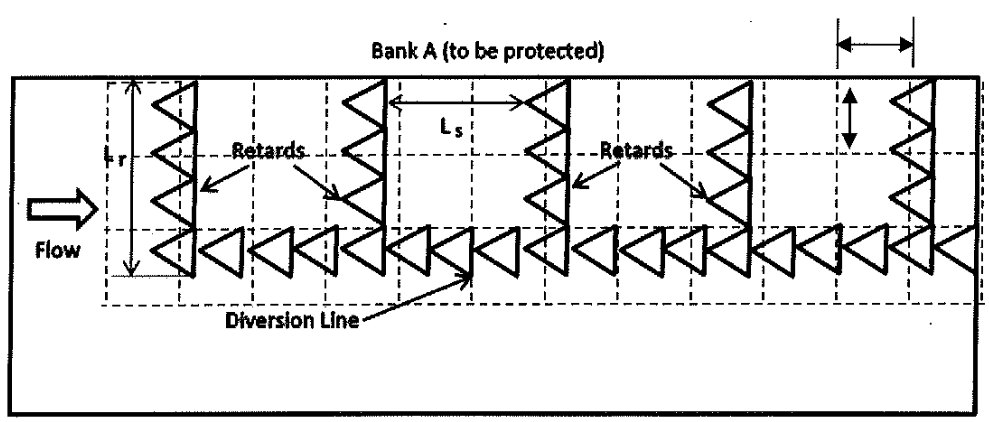


Figure 5.18 : Layout Plan of porcupine field in flume showing diversion line and retards

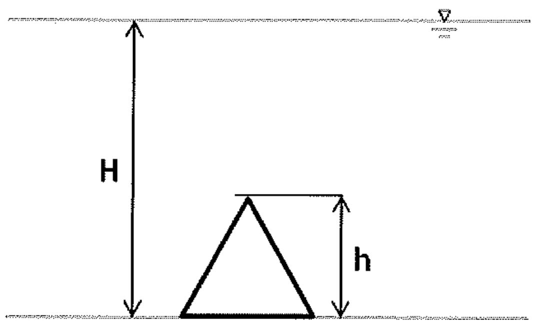


Figure 5.19 : Elevation of a porcupine in water

Certain new appropriate design indices and performance parameters are developed in the perspective of developing a rational design methodology, viz. Porcupine Field Density Index (PFDI), Porcupine Field Submergence Index (PFSI), Bed Deposit Factor (BDF) and Porcupine Field Length Factor (PFLF) to represent the characteristics of different alternative porcupine field layout.

Porcupine Field Density Index is defined as the ratio of length of retard to centre to centre spacing of retards, which can be written as (Lr/Ls). Lesser values of Porcupine Field Density Index represent sparsely configured porcupine field whereas high values represent densely arranged porcupine field.

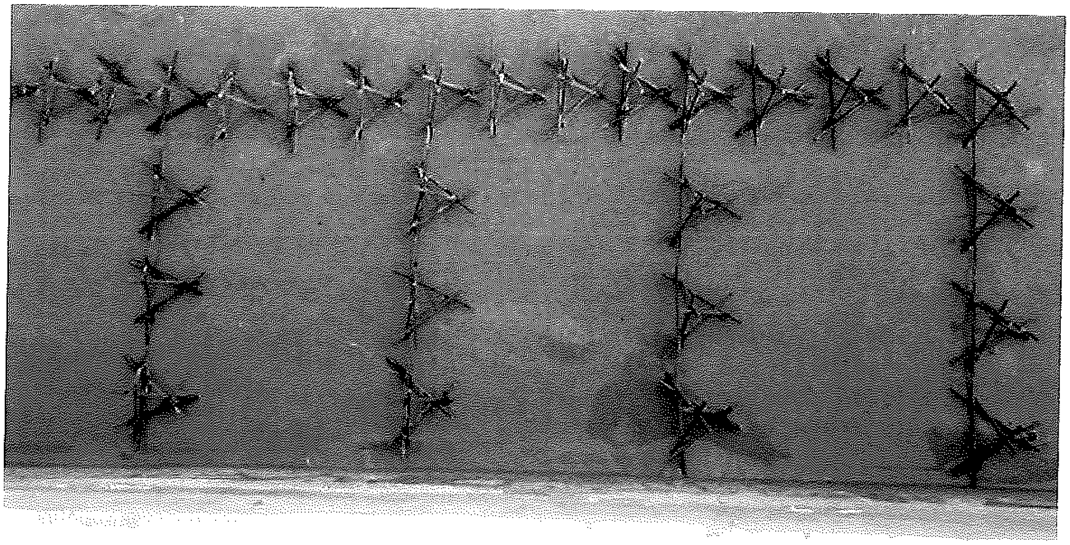
Porcupine Field Submergence Index is defined as the ratio of depth of water above the top of porcupine height to the total depth of water, which can be written as [(H-h)/H].

Lower values of Porcupine Field Submergence Index represent lower submergence and higher values represent higher submergence.

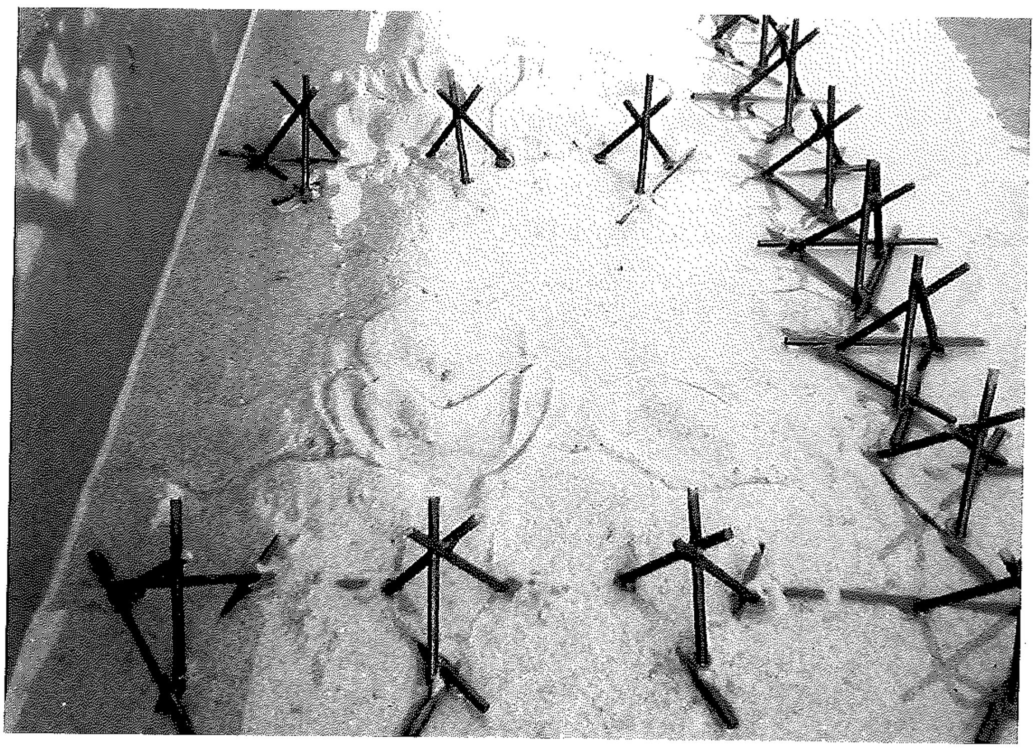
Bed Deposit Factor is defined as the ratio of depth of sand deposited in the sand bed to the total depth of water, where higher values of Bed Deposit Factor signify good amount of sediment deposition in the bed and vice versa.

Porcupine Field Length Factor is defined as the ratio of length of one compartment of the porcupine field to the total cumulative length of porcupine field compartments.

Laboratory experiments were planned and implemented with different porcupine field layouts with three values of Porcupine Field Density Index, three values of Porcupine Field Submergence Index and three sediment concentrations, which have been detailed in the previous chapters. All the experiments were carried out with clear water condition for sediment laden flow. At the end of every experimental run, bed profile was examined and measurements were taken to obtain the amount of sand berm formation or sediment deposition in the porcupine field. Figure 5.20 to Figure 5.22 show the photographs of the layout of various porcupine fields investigated in flume for changing Porcupine Field Density Index after clear water and sediment runs. Prominent sedimentation is visibly noticed in the porcupine field.

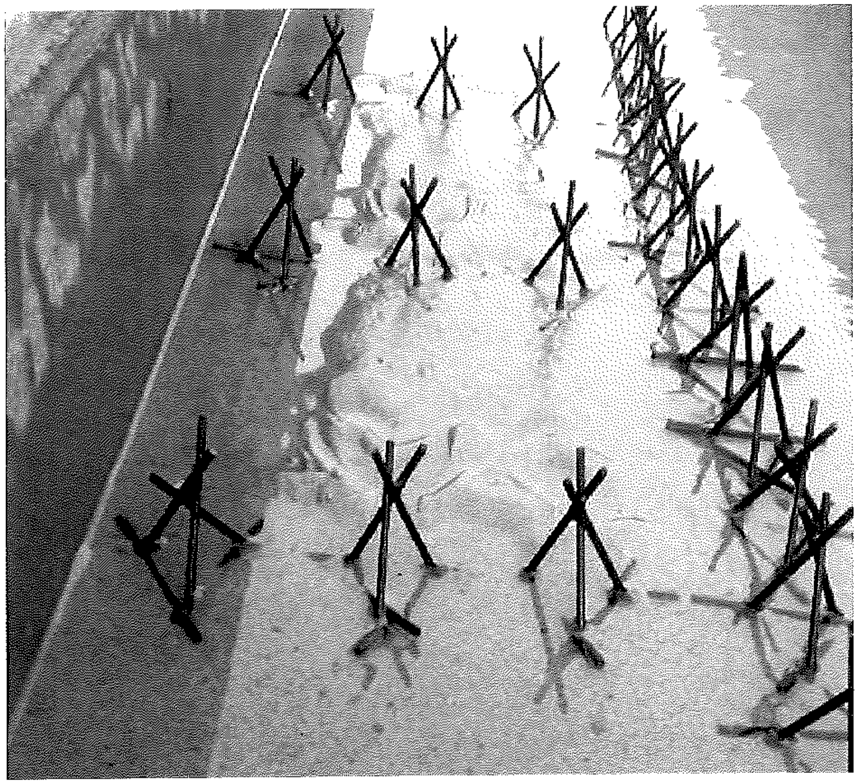


(a)

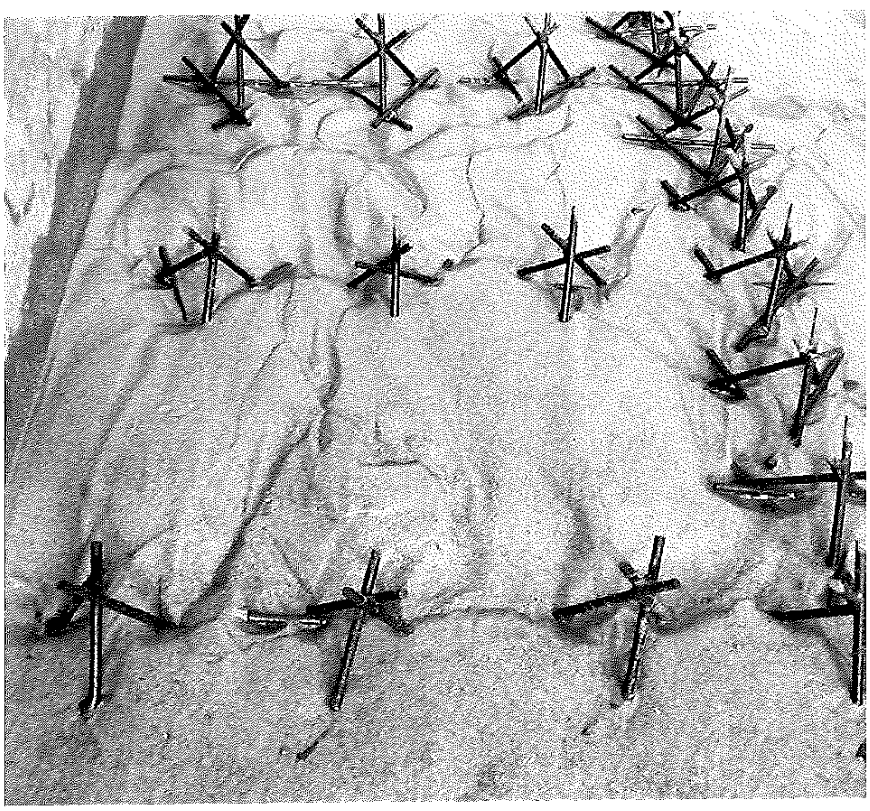


(b)

Figure 5.20 : Porcupine field with PFDI = 1.0 (a) clear water run (b) sediment run

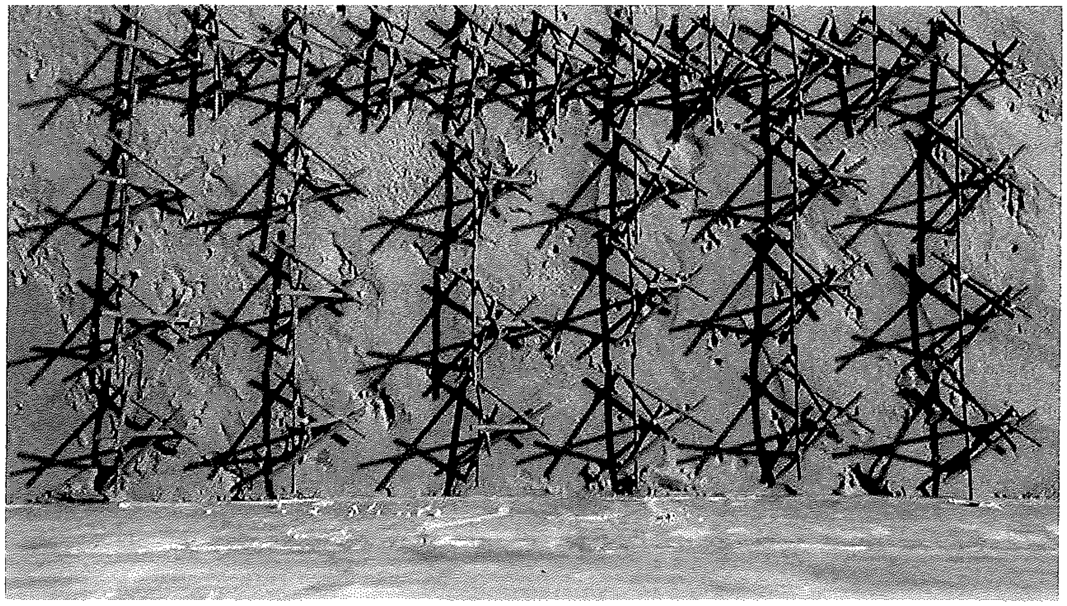


(a)

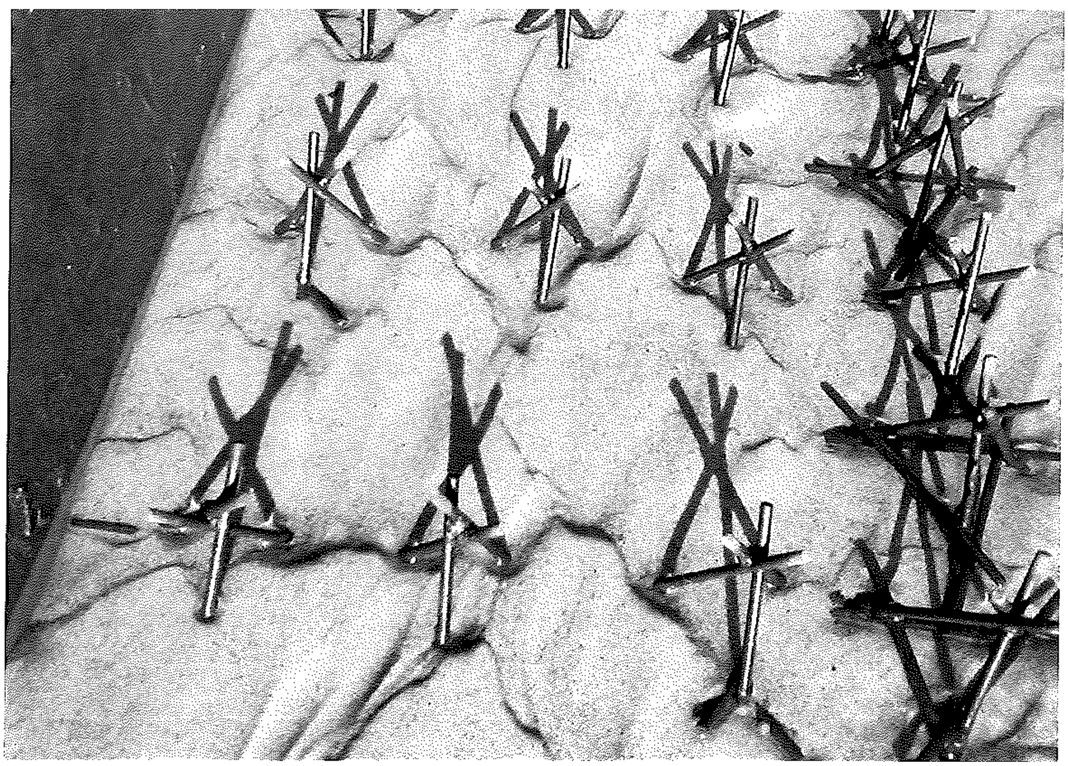


(b)

Figure 5.21 : Porcupine field with PFDI = 1.5 (a) clear water run (b) sediment run



(a)



(b)

Figure 5.22 : Porcupine field with PFDI = 2 (a) clear water run (b) sediment run

Conclusions of Phase – 2 study:

- Pronounced bed deposition is observed in the porcupine field behind the porcupines with sediment laden flow, the depth and extent of which is maximum in the initial to central portions of the porcupine field and gradually reduces towards the tail end.
- Submergence inversely impacts the performance of the porcupine field in terms of sedimentation.
- Sediment concentration poses positive impact on enhanced performance of porcupine field.

5.3.3 Quantification of Trap Efficiency

The preceding sections presented the pattern of sediment deposition in the porcupine field which was quantified in terms of the amount of sediment deposited in the field. Trap efficiency of sediment was calculated to record the efficiency of porcupine field in absolute terms. It was tried to check the mass balance in the porcupine field for each experimental run. Trap efficiency of the porcupine field is calculated taking into consideration porosity of lightly compacted sand and angle of repose of wet soil.

Table 5.3 presents calculation of trap efficiency for a particular set of run with PFDI = 1.0, PFSI= 0.625 and sediment concentration = 500 ppm. First column is the distance along the length of the channel; second to fourth columns represent the sand deposition height at each cross section along the three longitudinal sections. The sections 'A', 'B', and 'C' are the sections along the length of flume at 0.10 m, 0.20 m and 0.30 m respectively from the wall. Fifth column calculates the radius of the sand deposition taking into consideration the angle of repose of soil as 32° for wet sand and the depth of deposition. Sixth column calculates the volume of sand deposited and seventh column is the volume of sand after consideration of porosity which is taken as 35% for lightly compacted sand. Eighth column represents the weight of sand deposited taking into account the unit specific weight of sand which is 2650 kg/m3. Fifth to eighth columns show the calculation of sand deposited along the diversion line of the porcupine field at 0.30 m from flume side wall. Similar procedure has been adopted for the evaluation of sand deposition along the other two longitudinal sections inside the porcupine field.

Table 5.4 is a compilation of mass balance for all the sets of second phase experimental runs. This table gives an account of the trap efficiency of the porcupine field. First to fourth columns are the various combinations of parameters for the runs. Fifth column is weight of the sand deposited in the porcupine field and sixth column is the quantity of sand injected in the flow. Seventh column calculates the trap efficiency of the porcupine field.

Close inspection of the trap efficiency reveals that trap efficiency of the porcupine field increases to significant percentage with the increase in sediment concentration. Also, it is observed that when the submergence level goes down and the sediment concentration increases, the trap efficiency also records increase. Trap efficiency directly implies the efficiency of the porcupine field in inducing sedimentation which means with less submergence and high sediment concentration, the efficiency of the porcupine field gets enhanced.

Table 5.3 : Estimation of sand deposition in the porcupine field

Distance along the length of flume (m)	**Berm height with sediment laden water (cm)**			**Radius of cone**	**Total volume of sand (m3)**	**Volume of sand taking porosity into consideration (m3)**	**Weight of sand (kg)**
	at C	**at B**	**at A**	**at C**			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0.1	0.8	1.0	1.3	0.012102764	0.000001	0.00000080	0.002
0.2	1.0	1.3	1.5	0.015128455	0.000002	0.00000156	0.004
0.3	1.3	1.5	1.6	0.019666991	0.000005	0.00000342	0.009
0.4	1.5	1.6	1.7	0.022692682	0.000008	0.00000526	0.014
0.5	1.7	2.1	2.3	0.025718373	0.000012	0.00000765	0.020
0.6	1.6	1.9	2.1	0.024205528	0.000010	0.00000638	0.017
0.7	1.5	1.8	2.0	0.022692682	0.000008	0.00000526	0.014
0.8	1.3	1.6	1.9	0.019666991	0.000005	0.00000342	0.009
0.9	1.3	1.5	1.7	0.019666991	0.000005	0.00000342	0.009
1.0	1.2	1.4	1.6	0.018154146	0.000004	0.00000269	0.007
1.1	1.1	1.2	1.4	0.0166413	0.000003	0.00000207	0.005
1.2	0.9	1.3	1.5	0.013615609	0.000002	0.00000114	0.003
1.3	1.1	1.3	1.4	0.0166413	0.000003	0.00000207	0.005
1.4	0.9	1.1	1.3	0.013615609	0.000002	0.00000114	0.003
1.5	0.7	1.1	1.2	0.010589918	0.000001	0.00000053	0.001
						Total weight =	**0.124**

Table 5.4 : Trap efficiency calculation

Lr/Ls	Discharge (l/s)	Water Depth (cm)	qs (ppm)	Weight of sand deposited (kg)	Weight of sand injected (kg)	Trap Efficiency (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.0	30	24	500	0.637	5.0	12.74
1.5	30	24	500	0.986	5.0	19.72
2.0	30	24	500	1.763	5.0	35.26
1.0	25	20	500	0.804	5.0	16.08
1.5	25	20	500	1.115	5.0	22.30
2.0	25	20	500	2.869	5.0	57.38
1.0	17	15	500	0.704	5.0	14.08
1.5	17	15	500	1.336	5.0	26.72
2.0	17	15	500	3.473	5.0	69.46
1.0	17	15	750	1.859	5.0	37.18
1.5	17	15	750	2.123	5.0	42.46
2.0	17	15	750	3.602	5.0	72.04
1.0	17	15	1000	2.695	5.0	53.90
1.5	17	15	1000	3.713	5.0	74.26
2.0	17	15	1000	4.100	5.0	82.00

5.3.4 Performance of Porcupine Field

The bed profile data collected for each set of combination of porcupine field layout and configurations after every experimental run are plotted in terms of PFLF and Bed Deposit Factor. These plots are presented here to demonstrate the comparison of effect of various parameters on the efficiency of the porcupine field in terms of Bed Deposit Factor. The various parameters to be compared are the Porcupine Field Density Index, Porcupine Field Submergence Index and sediment concentration.

Figure 5.23 to Figure 5.25 show the BDF vs. PFLF plots for three sets of Porcupine Field Density Index with three combinations of Porcupine Field Submergence Index. These plots were drawn with fixed sediment concentrations. Each plot illustrates the performance of fixed layout of the porcupine field with various values of Porcupine Field Submergence Index. Figure 5.23 is a plot with PFDI = 1.0 and three Porcupine Field Submergence Index values. This plot depicts that Bed Deposit Factor is in lower range for maximum submergence and goes on increasing as the submergence goes down. Similarly, Figure 5.26 to Figure 5.28 represent the effect of submergence on porcupine fields with layout as PFDI = 1.0, 1.5 and 2.0 respectively. Close inspection of the plots indicates that the trend is better observed with improved results in smaller values of Porcupine Field Submergence Index for all sets of Porcupine Field Density Index. We can generalize saying that the efficiency of porcupine field to sediment laden water varies inversely with Porcupine Field Submergence Index.

Similarly, Figure 5.29 compares deposition values for different sediment concentrations. It can be noticed that for higher concentration, deposition is more than for lower concentrations.

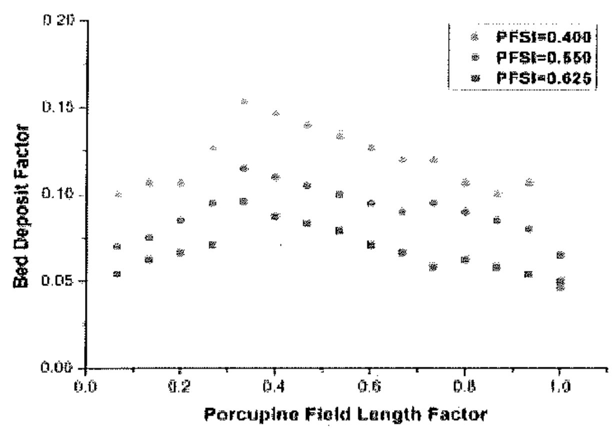


Figure 5.23 : Plot with PFDI = 1.0 and qs = 500 ppm

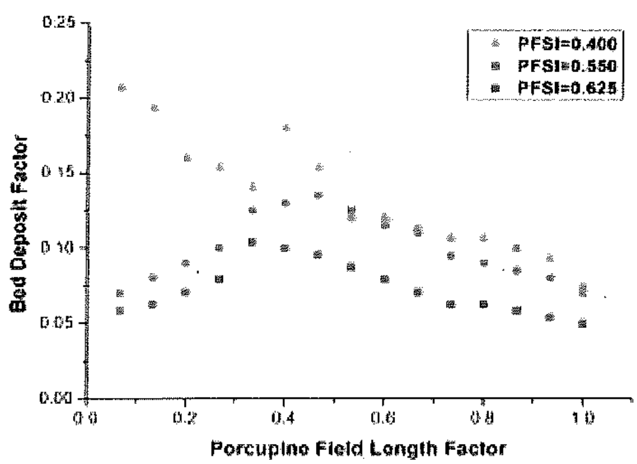


Figure 5.24 : Plot with PFDI = 1.5 and qs = 500 ppm

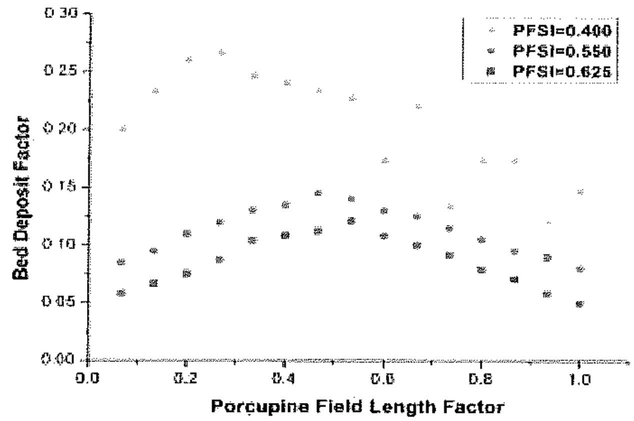


Figure 5.25 : Plot with PFDI = 2.0 and qs = 500 ppm

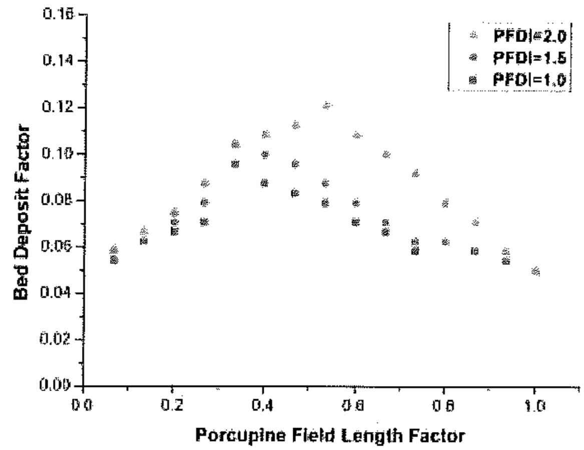


Figure 5. 26 : Plot with PFDI = 0.625 and qs = 500 ppm

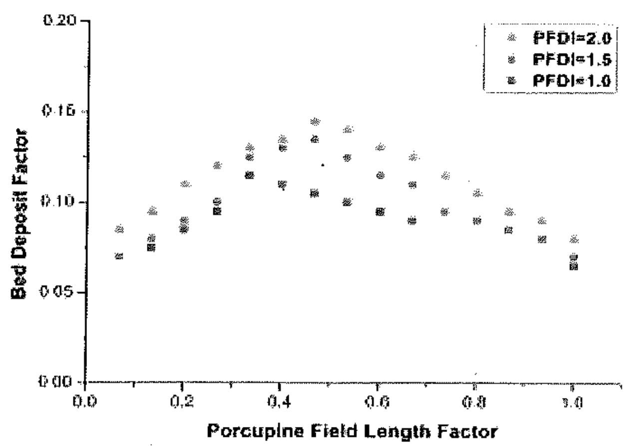


Figure 5. 27 : Plot with PFDI = 0.550 and qs = 500 ppm

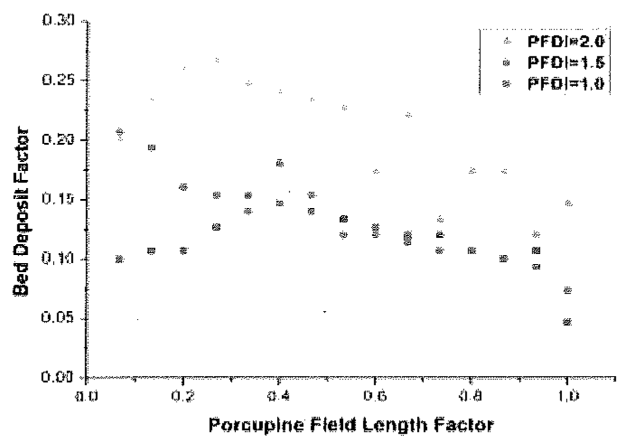


Figure 5. 28 : Plot with PFDI = 0.40 and qs = 500 ppm

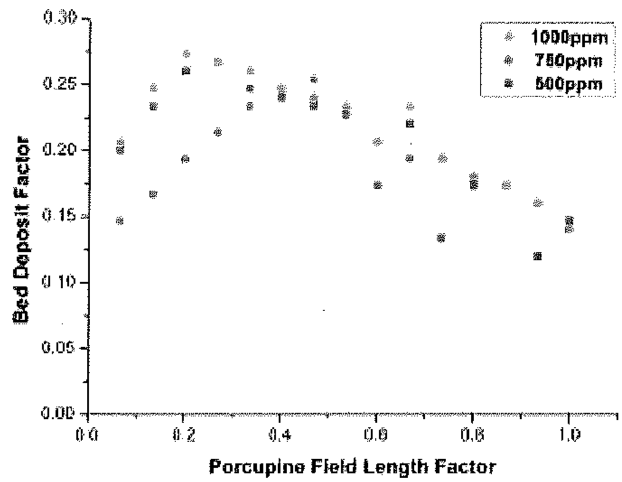


Figure 5.29 : Plot with PFDI =2.0 and PFSI = 0.4

5.3.5 Evolving Thresholds

As noted earlier, threshold values of Bed Deposit Factor for various combinations of Porcupine Field Density Index, Porcupine Field Submergence Index and sediment concentration are envisioned to develop rational guiding principles for the design of the porcupine systems. The porcupine systems are investigated for various values of Porcupine Field Density Index with three sediment concentration values and three values of Porcupine Field Submergence Index to determine the efficiency of the porcupine field in causing sediment deposition and its performance for various degrees of submergence and various levels of sediment concentrations. Sand deposition in the porcupine field was observed and measured for all the sets of experiments and assessed in terms of Bed Deposit Factor for all the data sets. These Bed Deposit Factors follow specific trend and it was also found that the efficiency of the porcupines field is enhanced with lesser degrees of submergence and higher levels of sediment concentrations in the flow.

The procedure for development of the rational design methodology has been followed by analysing the results of the extensive experimental runs. Bed profile is plotted for each experimental run separately and these were analysed to follow a second order polynomial trend with high correlation coefficient. Figure 5.30 shows a bed profile plot when PFDI = 1.0, PFSI = 0.625 and sediment concentration was 500 ppm. This plot follows the equation y = -0.12734x2 + 0.11864x + 0.05157 with R^2 = 0.62518. Average and maximum Bed Deposit Factor values are discretized from these plots to form a range of thresholds based on which the design guidelines have been developed. The presence of some outliers can be attributed to the formation of vortex near the porcupines. However, removal of such outliers does not have considerable effect on the trend of the plot and correlation coefficient. Therefore, their presence can be neglected for the purpose of analysis.

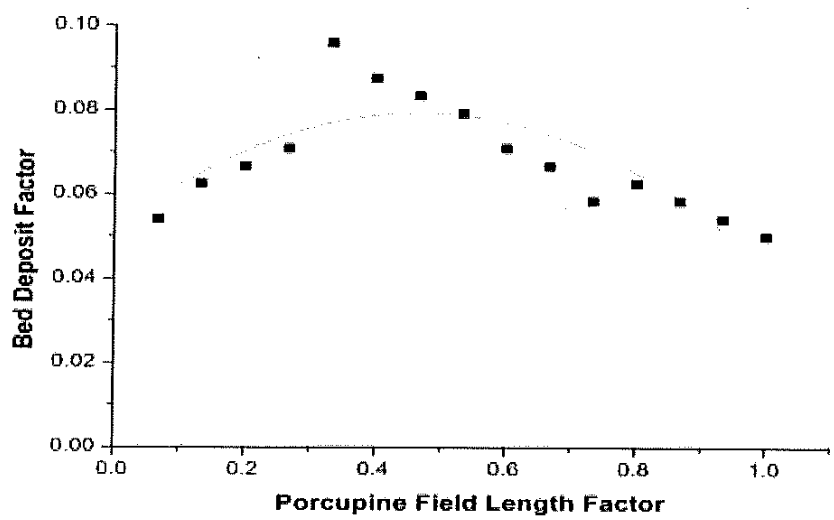


Figure 5. 30 : Plot with PFDI =1.0 and PFSI = 0.625 and qs = 500 ppm

Table 5.5 and Table 5.6 are logically developed for evolving threshold values from the experimental runs. Table 5.5 illustrates the average and maximum Bed Deposit Factor extracted from the bed profile plots with fixed sediment concentration for various layouts of the porcupine field with varying Porcupine Field Density Index for various Porcupine Field Submergence Index. Similarly, Table 5.6 illustrates and presents the average and maximum Bed Deposit Factor evaluated from the bed profile measurements with fixed submergence and varying layout of the porcupine field with varying Porcupine Field Density Index and varying sediment concentrations. Thresholds are evolved after in depth analyses of these average and maximum Bed Deposit Factors.

The design guidelines are rationally scheduled by classifying the desired objective into three levels namely, erosion control, moderate reclaim and heavy reclaim. The various design levels were reasonably fixed by allocating certain range of Bed Deposit Factors for each level as, if average Bed Deposit Factor is less than 0.1 then one can expect for erosion control, if it is between 0.1 to 0.2 it is for moderate reclaim and if it is more than 0.2 then heavy reclaim might be expected.

Bed profile contour plots have provided with enough information and statistics of the extent and depth of sedimentation in the porcupine field for various sets of Porcupine

Field Submergence Index, Porcupine Field Density Index and sediment concentration. This processed information formed the basis for fixing thresholds for various combinations. It was manifest that the efficiency of the porcupine field is superior in lower submergence to higher submergence and higher sediment concentration to lower. Average and maximum Bed Deposit Factors in Table 5.5 and Table 5.6 also demonstrate the same behaviour. Close examination of the values of average and maximum Bed Deposit Factor suggests that for high submergence and low sediment concentration, the average Bed Deposit Factor values vary in the range of 0.05 to 0.15, and for medium concentration and submergence these vary in the range of 0.1 to 0.2. Similarly for low submergence and high sediment concentration it varies from 0.2 to 0.3. These values have directed to fixing thresholds for the three design objectives of erosion control, moderate reclaim and high reclaim, and accordingly, threshold for erosion control is fixed for Bed Deposit Factor < 0.1 and Bed Deposit Factor within 0.1 to 0.2 suggests moderate reclaim. Similarly, Bed Deposit Factor > 0.2 indicates heavy reclaim.

Table 5.5 : Threshold values for various PFSI for fixed concentration = 500 ppm

PFSI	PFDI	Average BDF	Purpose	Maximum BDF	Purpose
0.625	1.0	0.068	Erosion Control	0.096	Erosion Control
0.625	1.5	0.073	Erosion Control	0.104	Moderate Reclaim
0.625	2.0	0.086	Erosion Control	0.121	Moderate Reclaim
0.550	1.0	0.090	Erosion Control	0.115	Moderate Reclaim
0.550	1.5	0.100	Erosion Control	0.135	Moderate Reclaim
0.550	2.0	0.113	Moderate Reclaim	0.145	Moderate Reclaim
0.400	1.0	0.116	Moderate Reclaim	0.153	Moderate Reclaim
0.400	1.5	0.135	Moderate Reclaim	0.207	Heavy Reclaim
0.400	2.0	0.203	Heavy Reclaim	0.267	Heavy Reclaim

Table 5.6 : Threshold values for various PFDI for fixed PFSI = 0.4

qs	PFDI	Average BDF	Purpose	Maximum BDF	Purpose
500	1.0	0.116	Moderate Reclaim	0.153	Moderate Reclaim
750	1.0	0.162	Moderate Reclaim	0.200	Moderate Reclaim
1000	1.0	0.188	Moderate Reclaim	0.253	Heavy Reclaim
500	1.5	0.135	Moderate Reclaim	0.207	Heavy Reclaim
750	1.5	0.167	Moderate Reclaim	0.207	Heavy Reclaim
1000	1.5	0.208	Heavy Reclaim	0.260	Heavy Reclaim
500	2.0	0.203	Heavy Reclaim	0.267	Heavy Reclaim
750	2.0	0.196	Moderate Reclaim	0.253	Heavy Reclaim
1000	2.0	0.217	Heavy Reclaim	0.273	Heavy Reclaim

5.4 Development of Design Methodology

Two sets of threshold values were delineated, one for a particular sediment concentration and in other case it was studied for a fixed Porcupine Field Submergence Index. As noted, these thresholds are developed to provide guidelines for the development of design methodology, on a rational basis.

As defined in the previous section, the design objective has been divided into three stages: erosion control, moderate reclaim and heavy reclaim. The design methodology is given in terms of Porcupine Field Density Index which would provide the designer basic information of what configuration and layout of the porcupine field should be adopted for achievement of desired objectives. Table 5.7 and Table 5.8 provide information about the range of Bed Deposit Factor for various sets of experiments. Information of these ranges and thresholds has enabled the development of the design approach, on an objective foundation.

Table 5.7 and Table 5.8 reproduce the design approach developed in this work for the desired objectives. Table 5.7 shows, if Porcupine Field Submergence Index is in a specific range (as mentioned in Table 5.5) and the objective is only erosion control then the required value of Porcupine Field Density Index can be adopted from the Table 5.7. Similarly Table 5.8 illustrates that if the sediment concentration is in a particular range (as mentioned in Table 5.6) then for the three design objectives defined above, Porcupine Field Density Index should be fixed. This forms the rational design basis, to substitute the present day conjectural approach.

Table 5.7 : Design Template for fixed sediment concentration (qs = 500)

PFSI	Requirement	BDF	PFDI
0.400	Erosion Control	< 0.1	< 1.0
0.400	Moderate Reclaim	Between 0.1 & 0.2	1.0 – 1.5
0.400	Heavy Reclaim	> 0.2	> 1.5
0.550	Erosion Control	< 0.1	< 1.5
0.550	Moderate Reclaim	Between 0.1 & 0.2	1.5 – 2.0
0.550	Heavy Reclaim	> 0.2	> 2.0
0.625	Erosion Control	< 0.1	< 2.0
0.625	Moderate Reclaim	Between 0.1 & 0.2	> 2.0
0.625	Heavy Reclaim	> 0.2	-

Table 5.8 : Design Template for fixed PFSI (PFSI = 0.40)

qs	Requirement	BDF	PFDI
500	Erosion Control	< 0.1	< 1.0
500	Moderate Reclaim	Between 0.1 & 0.2	1.0 – 1.5
500	Heavy Reclaim	> 0.2	> 1.5
750	Erosion Control	< 0.1	< 1.0
750	Moderate Reclaim	Between 0.1 & 0.2	1.0 – 1.5
750	Heavy Reclaim	> 0.2	1.5 – 2.0
1000	Erosion Control	< 0.1	< 1.0
1000	Moderate Reclaim	Between 0.1 & 0.2	1.0 – 1.5
1000	Heavy Reclaim	> 0.2	> 1.5

CHAPTER – 6
EXPERIMENT ON JACK JETTY FOR ANGLE OF DIVERSION

6.1 Objectives

The objective of study described are as follows:-

i) To investigate the effect of jack jetty on flow with regard to local sediment transport capacity bed profile analysis.

ii) To investigate the velocity effect pre and post installation of jetty field.

iii) To gain information on its effect on channel bed changes.

iv) To introduce parameter for various angles of incidence of attack configurations.

v) To investigate the velocity changes at different angles of incidence and determine the best configuration of Jetty field.

6.2 Experimental Procedure

Models are placed in the 0.50 m wide laboratory flume with height 0.4 m and bed material of sand with d50 = 0.25 mm and σg = 1.29. Sand layer on the bed has a height of 0.12 m. Slope of the flume is set at 0.0001875 and has maintained the condition of clear water flow. Flume is attached with other instruments that have flow recirculation system to provide steady uniform flow to the flume. Illustration of the flume and the recirculation system.

The Jack Jetty field functions by trapping sediment and debris during flood events to essentially build up its own levee to confine the river channel. It has been described that a jetty system is designed to conform to the existing regime of the river. The system appears to work best if it was placed in concave bank of a meandering channel. However a key issue for the successful use of the system was sediment

6.2.1 Jack Jetty Submergence Index

Jetty Field Submergence Index is defined as the depth of water above the top of jack height to the total depth of water which can be written as ((H-h)/H). Lower values of Jetty Field Submergence Index represent lower submergence and higher values represent higher submergence (JFSI).

6.2.2 Jack Jetty Density Index

Jetty Field Density Index is defined as the length of retard to centre to centre spacing of retards which can be written as (Lr/Ls). Lesser values of Jetty Field Density Index represents lightly configured jetty field and height values represent densely configured jetty field (JFDI).

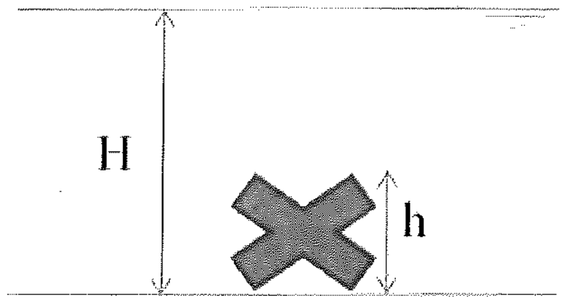


Figure 6.1 : Represents JFSI

From that is apparent that the steel frame jack jetty systems have come into existence in the 50's of last century. It is obvious that certain preliminary studies on the performance of modified RCC jack jetties is necessary in order to develop rational design methodology which will enable it to be used as an affordable cost effective river training measure. To study and analyse the effect of jack jetty on the flow domain and pertinent fluvial parameters, the experimental programme of the present research was divided into three phases namely for angle of diversion at 00,200 and 300 respectively with low jetty field density index and high jetty field density index.

Figure 6.2 : Represents Jetty Field at 00

6.3 Laboratory Result

It is learnt that a single or stand unit of the model is called a jack and when they are connected together with a cable they form a jetty. When lines of jetties are laid parallel to the bank of the channel they are called as diversion lines and when the jetties are projected into the river at certain angle with the bank they are called as retards. Combination of retard and diversion lines forms a jetty field.

6.3.1 Effect on Bed Profile

Bed profile contours were drawn with the data collected after each experimental run. Deposition in the jetty field follows similar trend, it is predominant in the initial portions and gradually reduces towards the tail end of the jetty field. When the jetty field is densely configured or with higher sediment concentrations or for lower submergence ratios, it could be noticed that the contours are longitudinal and being semi-circular or semi ellipsoidal. It might be inferred from these observations that when the jetty field efficiency is higher, then sediment deposition is predominant in the jetty field and the pattern of the deposition is not like small heap of sand around the base of the jacks but more of layered deposition.

The below plot is of JFDI=3, with angle of incidence of attack as 200 .similar plots are there which is sufficient enough to draw the conclusions

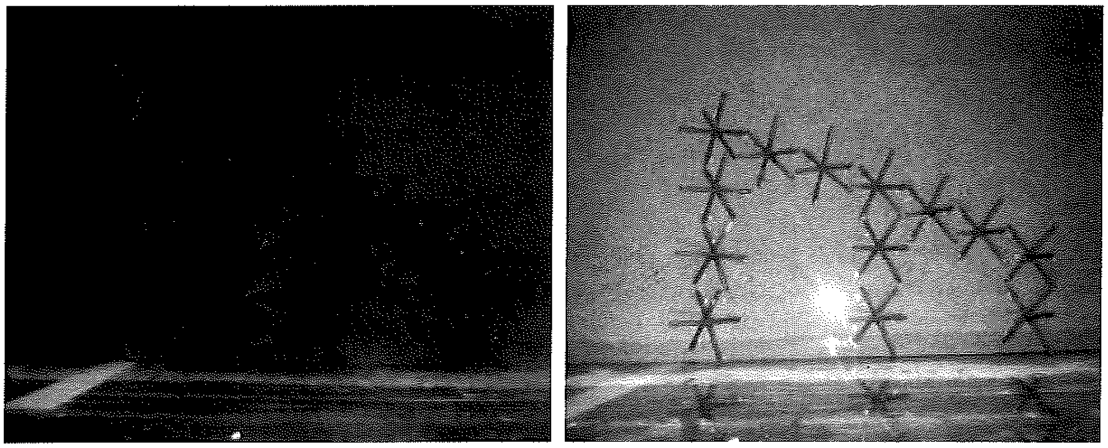


Figure 6.3 : Represents Jetty field at 200 and Jetty field at 300

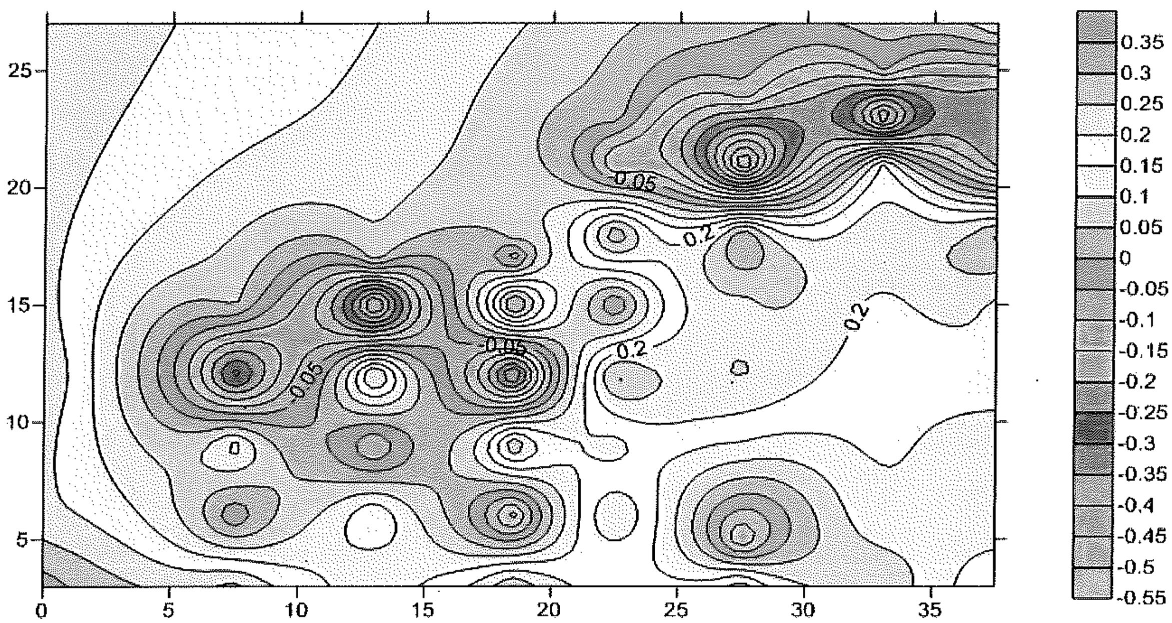


Figure 6.4 : Represents Bed Profile Data

Table 6.1 : Experimental plan for various parameters

Exp no	Bed Slope	water depth(m)	Discharge (m3/s)	Froude no	Arrangement of jetty field		Submergence ratio	vel of flow m/s
					L_R/L_S	Angle of dev		
1	0.0001875	0.1	0.005	0.101	1.53	**30 degree**	0.36	0.1
2	0.0001875	0.13	0.0065	0.088	1.53	30 degree	0.52	0.1
3	0.0001875	0.17	0.0085	0.077	1.53	30 degree	0.61	0.1
4	0.0001875	0.2	0.01	0.071	1.53	30 degree	0.68	0.1
5	0.0001875	0.1	0.005	0.101	3.33	30 degree	0.36	0.1
6	0.0001875	0.13	0.0065	0.088	3.33	30 degree	0.52	0.1
7	0.0001875	0.17	0.0085	0.077	3.33	30 degree	0.61	0.1
8	0.0001875	0.2	0.01	0.071	3.33	30 degree	0.68	0.1
9	0.0001875	0.1	0.005	0.101	1.38	**20 degree**	0.36	0.1
10	0.0001875	0.13	0.0065	0.088	1.38	20 degree	0.52	0.1
11	0.0001875	0.17	0.0085	0.077	1.38	20 degree	0.61	0.1
12	0.0001875	0.2	0.01	0.071	1.38	20 degree	0.68	0.1
13	0.0001875	0.1	0.005	0.101	3	20 degree	0.36	0.1
14	0.0001875	0.13	0.0065	0.088	3	20 degree	0.52	0.1
15	0.0001875	0.17	0.0085	0.077	3	20 degree	0.61	0.1
16	0.0001875	0.2	0.01	0.071	3	20 degree	0.68	0.1
17	0.0001875	0.1	0.005	0.101	1.6	**0degree**	0.36	0.1
18	0.0001875	0.13	0.0065	0.088	1.6	0 degree	0.52	0.1
19	0.0001875	0.17	0.0085	0.077	1.6	0 degree	0.61	0.1
20	0.0001875	0.2	0.01	0.071	1.6	0 degree	0.68	0.1
21	0.0001875	0.1	0.005	0.101	4	0 degree	0.36	0.1
22	0.0001875	0.13	0.0065	0.088	4	0 degree	0.52	0.1
23	0.0001875	0.17	0.0085	0.077	4	0 degree	0.61	0.1
24	0.0001875	0.2	0.01	0.071	4	0 degree	0.68	0.1

6.3.2 Quantification of Velocity Reduction

Contour plots above suggested prominent effect of submerged jacks on the flow field which is more pronounced with the bigger size jacks than the smaller ones. It also suggested, submergence has an effect on the performance of the jack as well which varies inversely with each other. Furthermore, it could be observed that multiple units of jacks perform in an enhanced way than single units of jacks. The contour plots have given a general idea and presented pictorial representation of the same. In the present section of the study, it has been attempted to quantify the reduction in velocity due to the presence of submerged jacks than the non-jack case in percentage terms.

The percentage reduction in velocity is calculated by comparing the velocity with and without jacks at same positions. This comparison is done at a particular depth above sand bed. The percentage reduction in the shows is 70 to 95% with an average reduction of 70%.

All these plots show a particular trend which shows higher percentage reduction in the initial portion of the plot and which gradually goes on decreasing towards the tail end. As it is known, the initial portion of the plot represents the cross sections just downstream of the jack up to almost 0.8 m and the tail end of the plot is cross sections beyond that. This particular plot shows maximum reduction of 95% and 70% in average till 0.8 m downstream of the jack which then decreases to 60% and then gradually goes down.

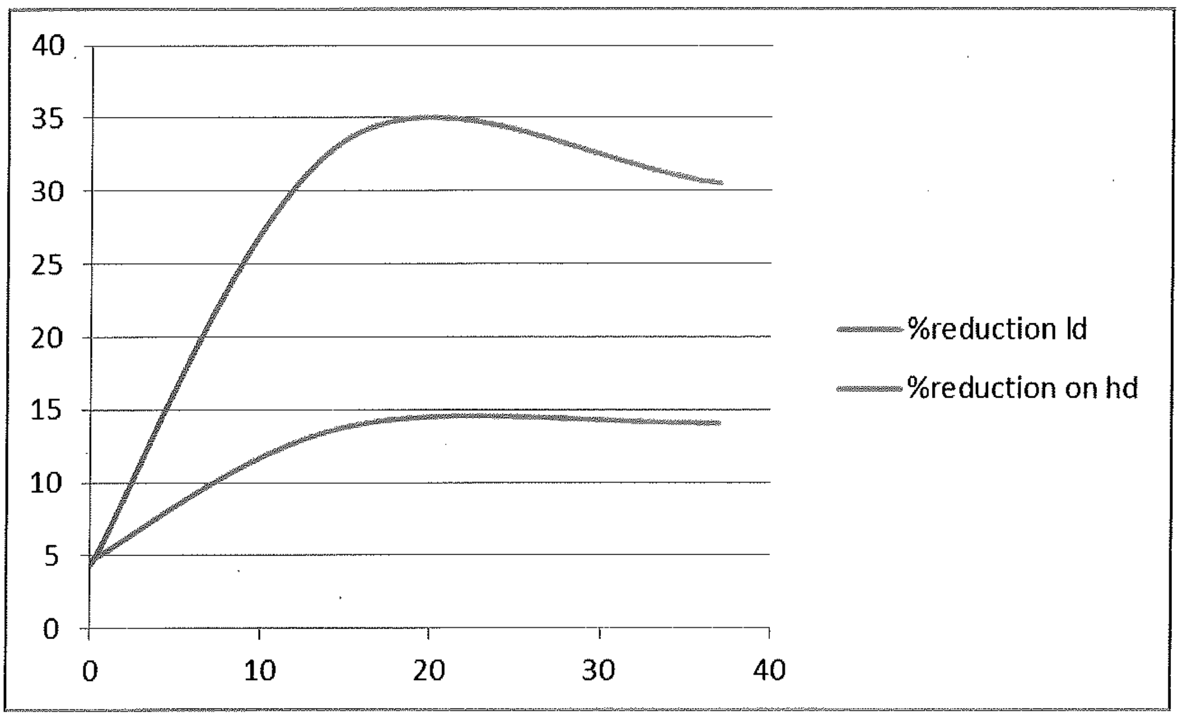


Figure 6. 5 : Represents X axis as the distance in longitudinal direction and y axis the % reduction with ld for low density and hd for high density values being 1.38 and 3. With 0.06 m above the bed.

6.4 Conclusion

Experimental data processing in the present chapter suggests significant reduction in flow velocity due to the presence of submerged jacks which depends on variety of situations such as, reduction in velocity with bigger jacks than smaller ones. Reduction in velocity is pronounced and is more enhanced in the initial stretch which then tapers off to minimize further downstream of the jack. Effect of submergence could be faintly observed. The work describes that effect is more prominent for when the arrangement is for 20 degree at angle of incidence of attack then at 30 degree.

Analysis of the bed profile data has facilitated helped in summarizing, that jetty field performed better with lower Jetty Field Submergence Index and high sediment concentration in densely configured jetty fields. New suitable design indices and performance parameters have been developed with threshold values for various design objectives namely erosion control, moderate reclaim and heavy reclaim and design methodology could be developed with rational scientific basis. New design indices and performance parameters are evolved in this work which provides primary guidelines for developing design of a RCC jetty field based on desired design objective of erosion control.

CHAPTER – 7
EXPERIMENT ON TRAIL DYKE

7.1 Objectives

The main objectives of the experimental study are described as follows:

- To investigate the effect of different spacing, configuration and submergence ratio on the performance of trail dyke by plotting velocity contours;
- To investigate the variation in velocity fields by the trail dyke from the non-trail dyke case;
- To investigate the effect of different submergence ratios on the bed scour pattern in the vicinity of dykes;
- To investigate the joint performance of trail dyke and jack jetty; and
- To evolve a rationale design approach of trail dyke after comparing laboratory study with the field result.

7.2 Laboratory Flume Set Up

All the experiments have been conducted out in a lab flume made of mild steel with side walls made of transparent Perspex sheet having 0.50 M width and 0.70 M depth. In order to supply the steady discharge into the flume, an overflow tank was installed at the upstream end. A tank of dimension 0.4 m x 0.9 x 1.15 m was in built at the upstream end of flume. Upstream end of the flume was associated with plastic perforated sheet acting as flow conditioner (Figure 7.2) and an adjustable tail gate at the downstream end of the flume was used to maintain flow depth in the flume (Figure 7.3). The bed of the flume is connected to the movable shaft. In order to maintain the required slope of flume, the front portion of the flume moves upward and lower portion moves downward as shaft moves in the direction of flow and vice versa.

The water in the flume falls into a downstream tank which is installed with V-Notch weir and connected to storage tank. The incoming discharge of 5 litres/sec was controlled by using the said valve gate and measured by means of V-Notch weir. Water is lifted from the downstream tank to the upstream constant head tank by 0.1 m dia pipes. After this constant head tank, a gate valve was placed to control the discharge. A brick wall with staggered holes and two rows of plastic perforated sheet walls were also provided at the upstream end of the flume to make the uniform distribution of flow through the width of flume. A sketch of the arrangement of flume set up is shown in Figure 7.1

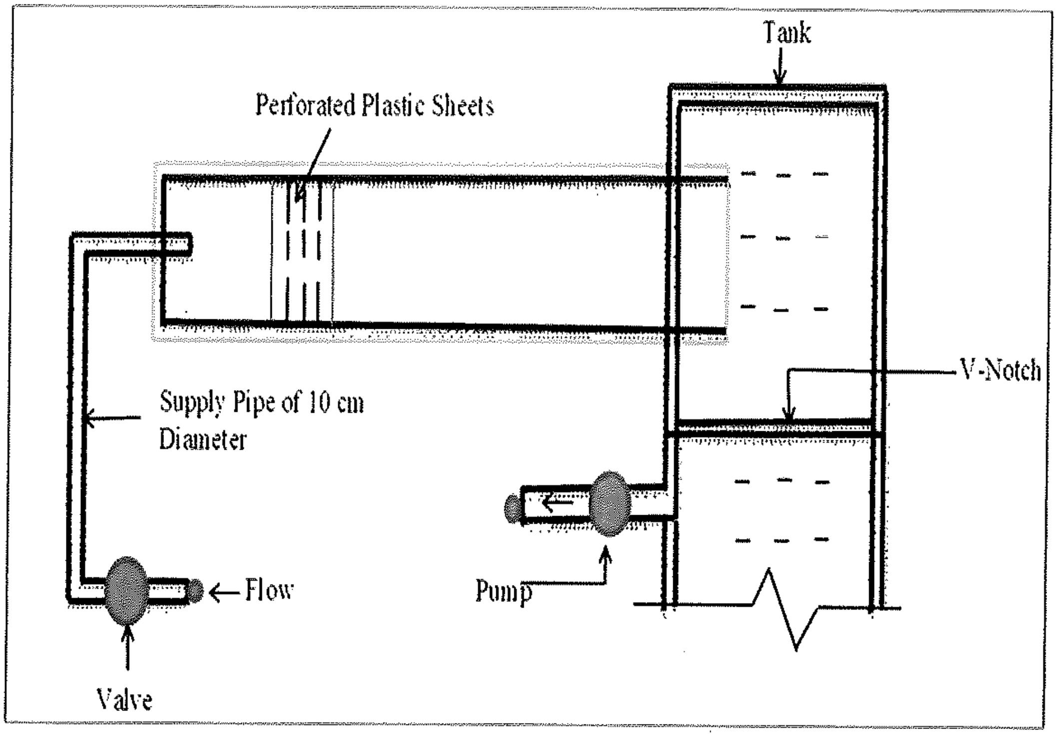


Figure 7.1 : Plan of Tilting Flume set up in River Engineering. Laboratory of WRD&M Department

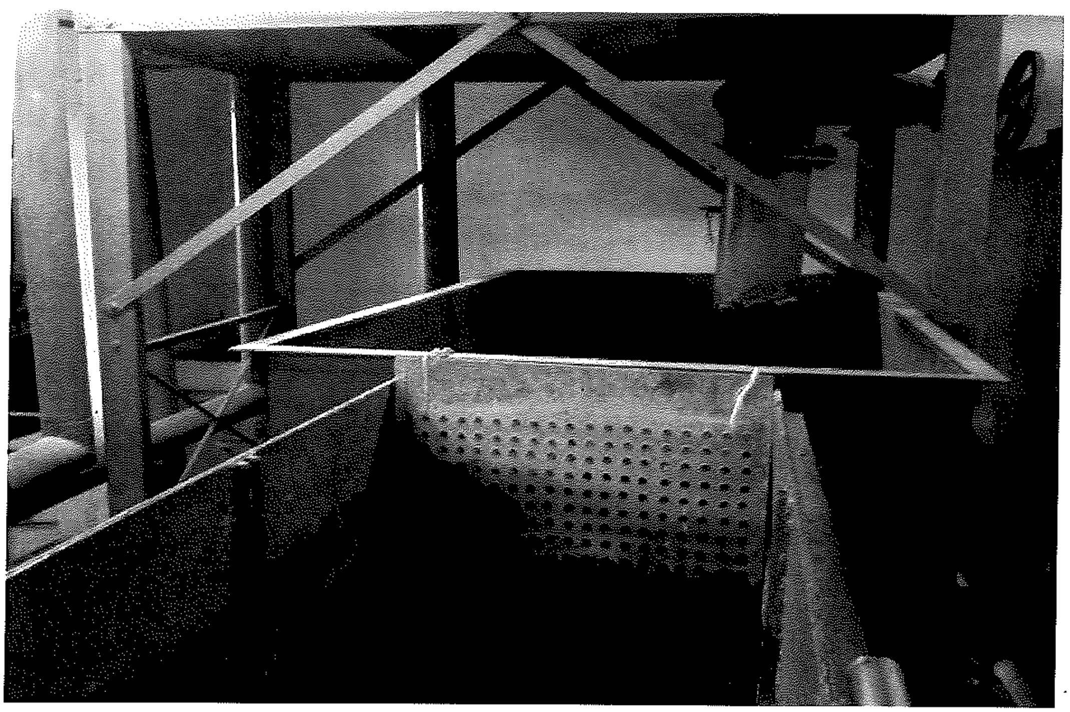


Figure 7.2 : Upstream end of the flume attached with plastic perforated sheet

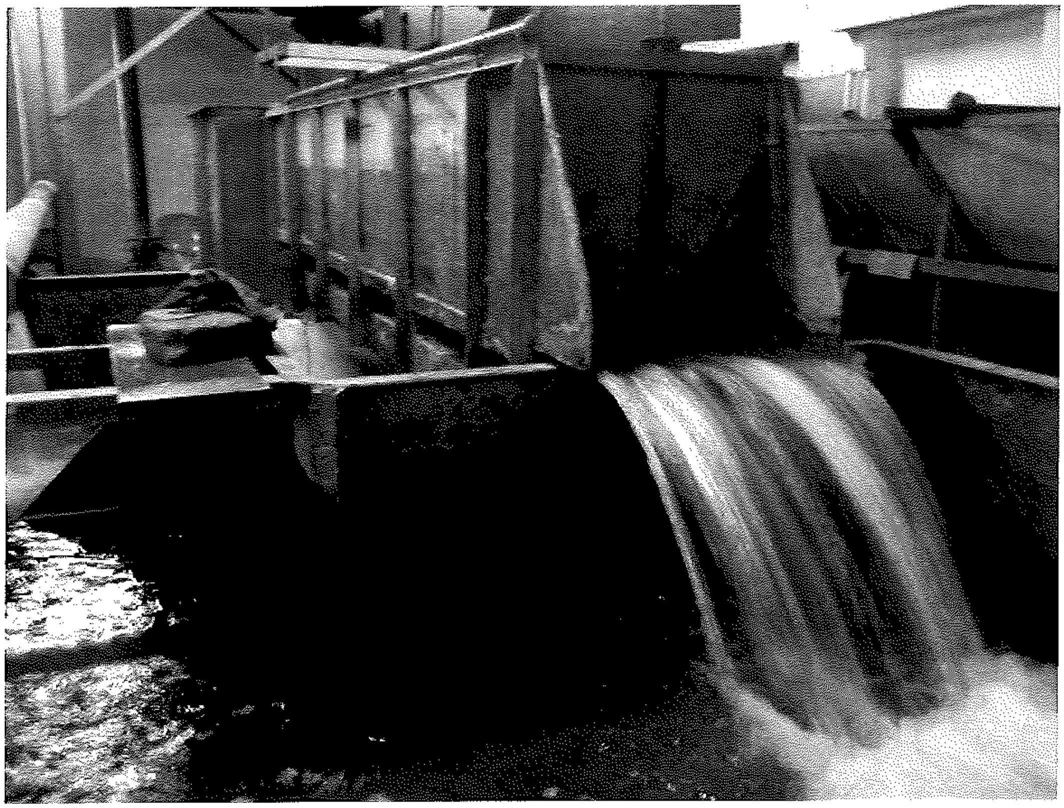


Figure 7.3 : Downstream end of the flume attached with adjustable tail gate

Measurement of flow rate was calculated by 90°-V-Notch (*Figure 7.4*) equation as given by the equation 7.1.

$$Q = \frac{8}{15} C_d \sqrt{2g} \tan\frac{\theta}{2} h^{5/2} \quad 7.1$$

Where,

Q = Flow Rate

C_d= Coefficient of Discharge

θ = Angle of V-Notch

g = Acceleration due to gravity

h = Head over V-Notch

Perspective view of the complete set up for conducting experiment in River Engg. Lab is shown in *Figure 7.5*.

Figure 7.4 : 90 Degree-V-Notch to measure flow rate

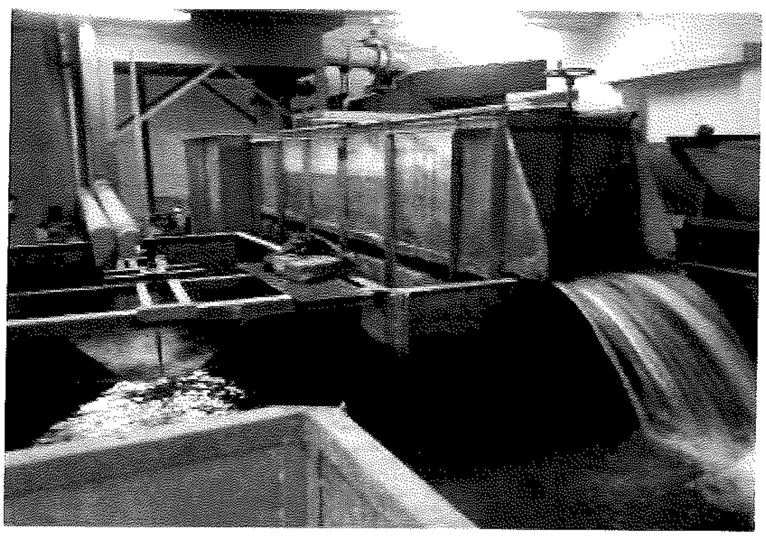


Figure 7.5 : Perspective view of the complete set up for conducting experiment in River Engg. Lab

7.3 Experimental Procedure

The areas surrounding the dikes in the flume were divided into grids of size 5 cm in the direction of flow as well as transverse to the flow. The trail dikes used in the experiments were made up of 3 mm thick Perspex sheet and indicated by T.D-A, T.D-B and T.D-C in the direction of flow. The length of each trail dike transverse to the flow (L1) was fixed to 10 cm and varied in the direction of flow (L2) as per the requirement of experiment. The velocity at each nodal points of the grid in the plane of middle depth of dike was measured using Acoustic Doppler

Velocimetre. For all the experiments, the initial bed surface was levelled to horizontal. Pointer gauge was used to measure the bed level before and after the run of each experiment to measure the bed scour patterns.

A series of clear water experiments were conducted by changing the spacing, configuration and submergence ratios in order to investigate the effects of hydraulic parameters on the performance of trail dike system as per Figure 7.6. Trail Dikes T.D-A, T.D-B and T.D-C installed for an experiment is shown in Figure 7.7.

As per the result achieved for the trail dike system, the experiment of the trail dike and jack jetty system were conducted to evaluate the conjunctive use of the joint system.

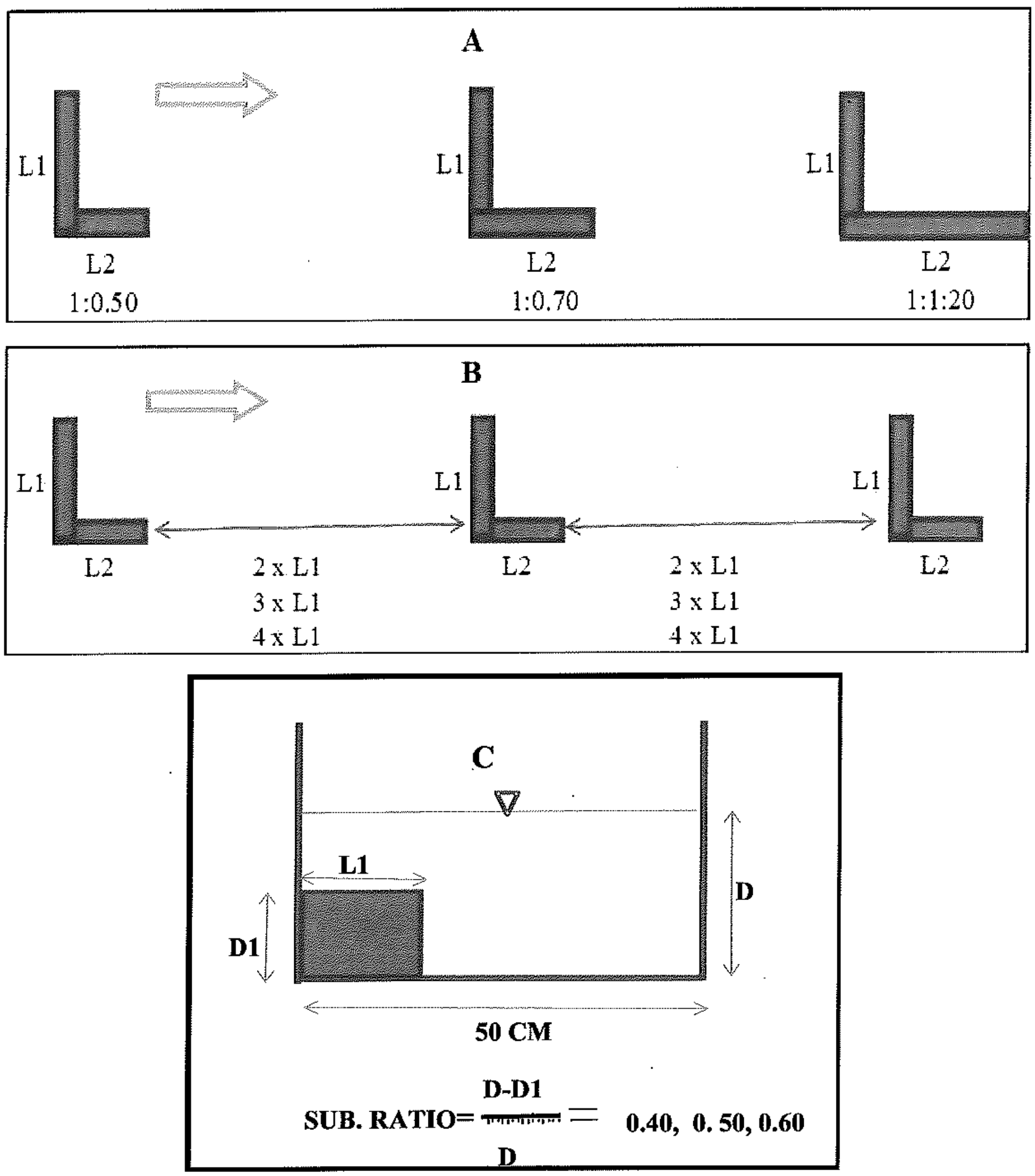


Figure 7.6 : Experimental set up conducted for configuration (A), spacing (B) and submergence ratio (C) in flume

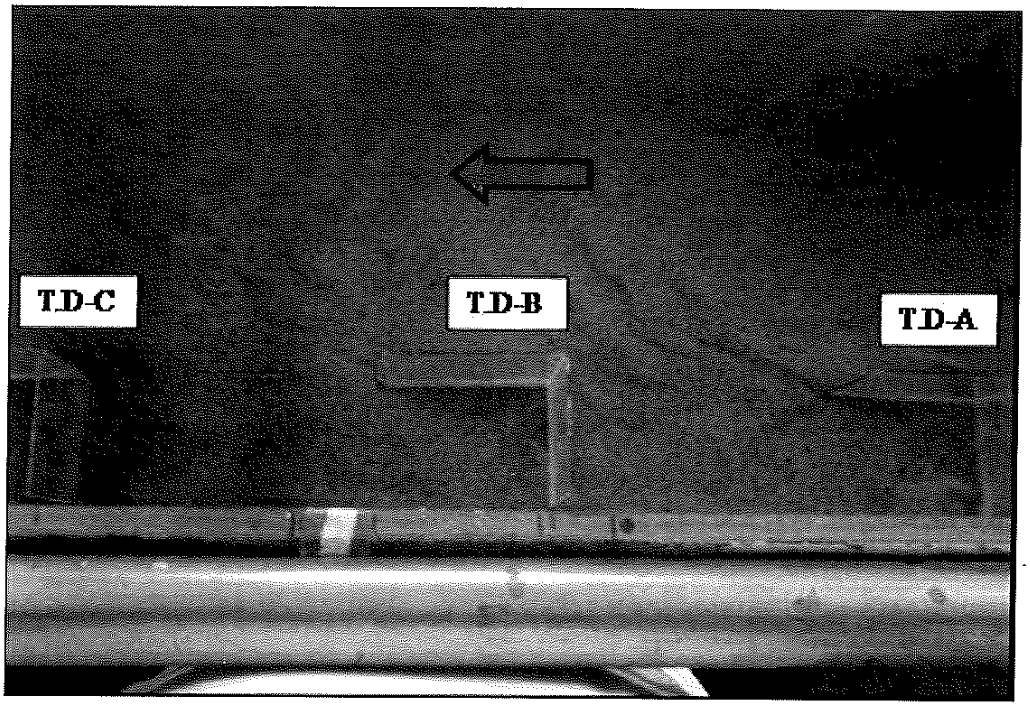


Figure 7.7 : T.D-A, T.D-B and T.D-C installed in the flume

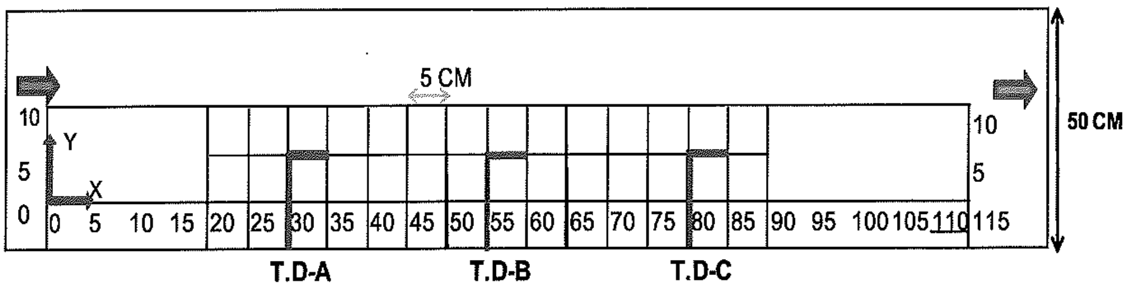
7.4 Experimental Results and Analysis

7.4.1 Effect of Spacing on the Performance of Trail Dikes

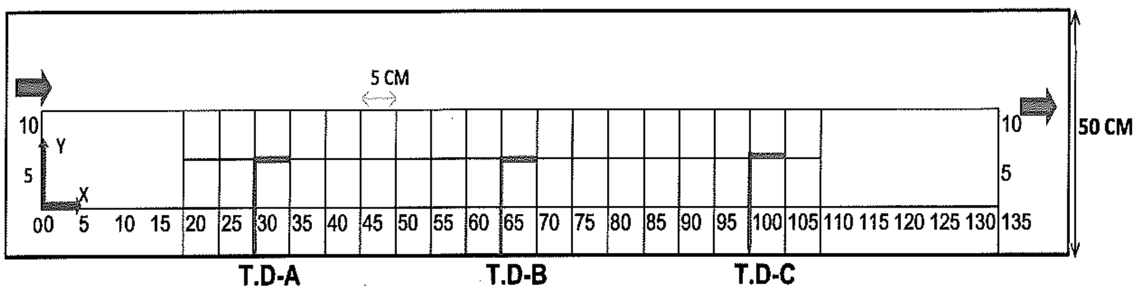
Experiments were carried out to investigate the influence of spacing on the performance of dikes by plotting the velocity contours indicating the change in the velocity profile. With the same dimension (L1:L2:: 1:0.5) and submergence ratios (0.50) of the three numbers of dike T.D-A, T.D-B and T.D-C placed in the series in the flume, the spacing between each dike was varied as two, three and four times of the length (L1) of the dike in three consecutive sets of experiment represented by grid-1a, 1b and 1c respectively (Figure 7.8).

Under the same discharge condition, conceptually it may be observed from Figure 7.9, Figure 7.10 and Figure 7.11 that the grid-1b with spacing as three times of the dike length possesses the significant reduction of velocity throughout the grid. Grid-1c is indicating the least reduction of velocity while in case of grid-1a, velocity reduces but not to the extent as compared to grid-1b. In spite of less spacing between the dikes in grid-1a as compared to grid-1b, the reason for the less effectiveness of grid-1a may be understood in such a way that the eddies generated due to the spiral flow downstream of dike in grid-1a are intercepting and overlapping each other due to much closer spacing so as to make the dike unable to spread the energy of flow over a larger area resulting in less efficiency for the reduction of velocity. Also the increase of space to length ratio in case of grid-1c may lead to highly influenced turbulent eddies resulting least reduction of velocity.

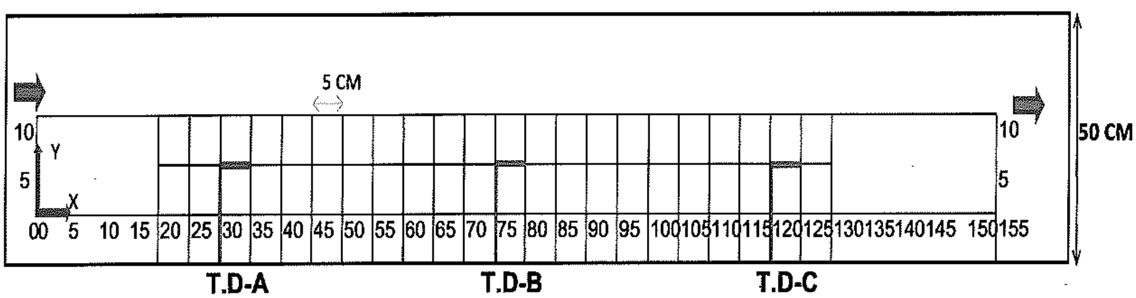
Graphical comparisons (Figure 7.13, Figure 7.14 and Figure 7.15) of ambient velocity distribution with the velocity after installation of dikes was done as per the grid 2a, 2b and 2c (Figure 7.12). It has been observed that the grid-2b with spacing three times of the dike length shows the most uniform pattern of reduction of velocity throughout the grid, thus justifies the velocity contour above.



Grid-1a: Grid with spacing as two times of length of dike (L1)



Grid-1b: Grid with spacing as three times of length of dike (L1)



Grid-1c: Grid with spacing as four times of length of dike (L1)

Figure 7.8 : Experimental set up for different combination of spacing in flume (To compare velocity contour)

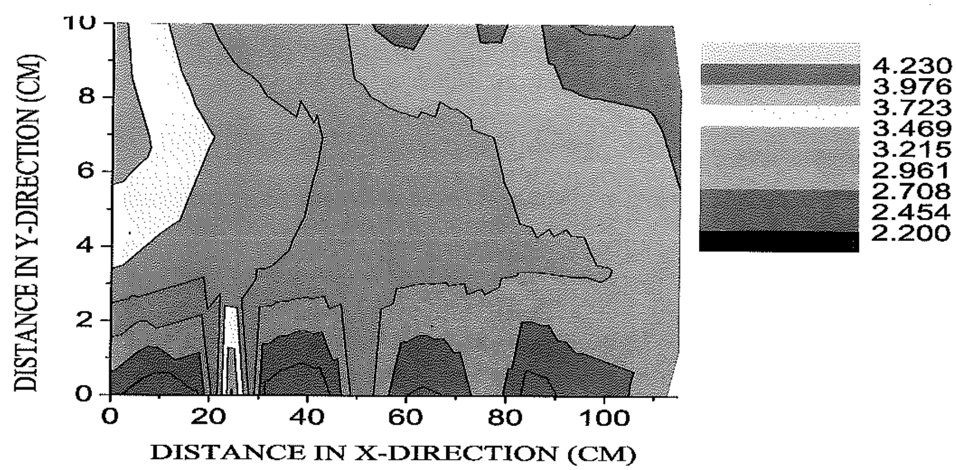


Figure 7.9 : Variation of Velocity in grid-1a (Spacing with two times of L1)

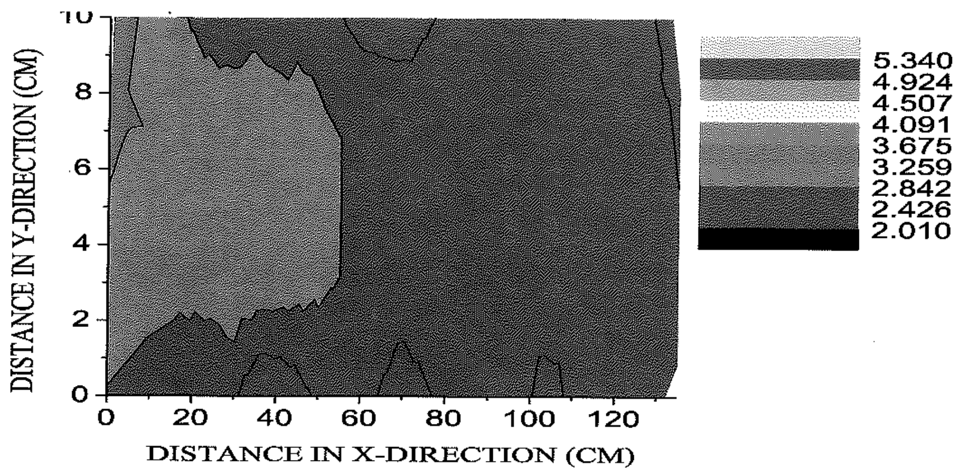


Figure 7.10 : Variation of Velocity in grid-1b (Spacing with three times of L1)

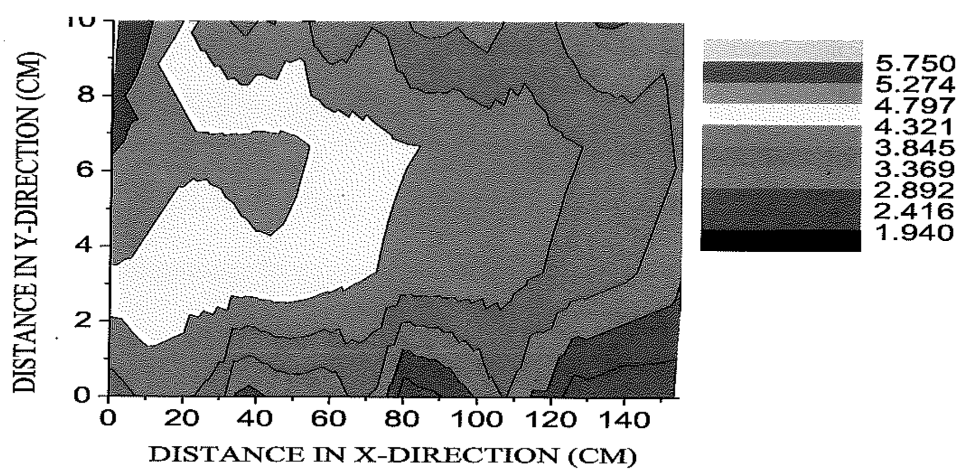
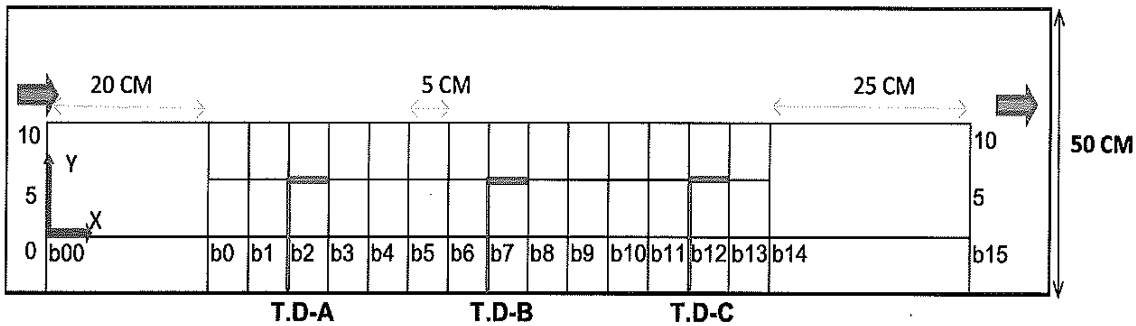
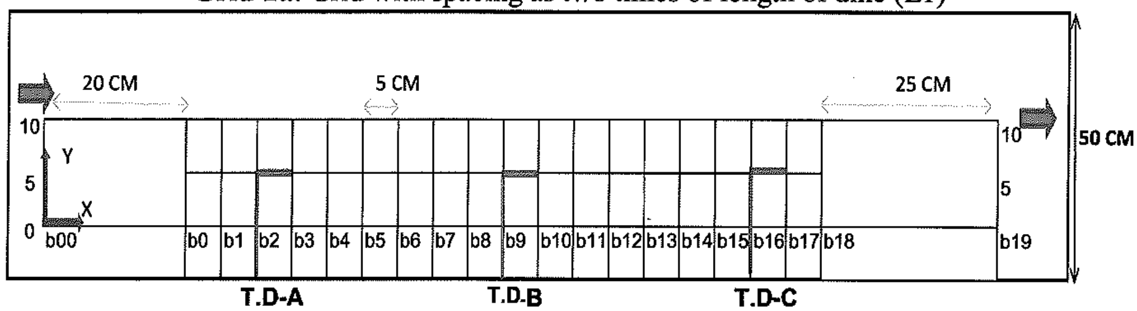


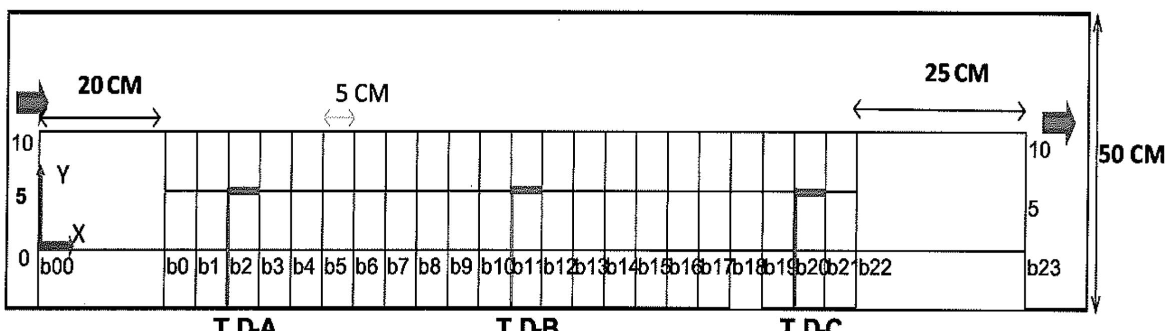
Figure 7.11 : Variation of Velocity in grid-1c (Spacing with four times of L1)



Grid-2a: Grid with spacing as two times of length of dike (L1)



Grid-2b: Grid with spacing as three times of length of dike (L1)



Grid-2c: Grid with spacing as four times of length of dike (L1)

Figure 7.12 : Experimental set up for different combination of spacing in flume (To compare pre and post installation velocity)

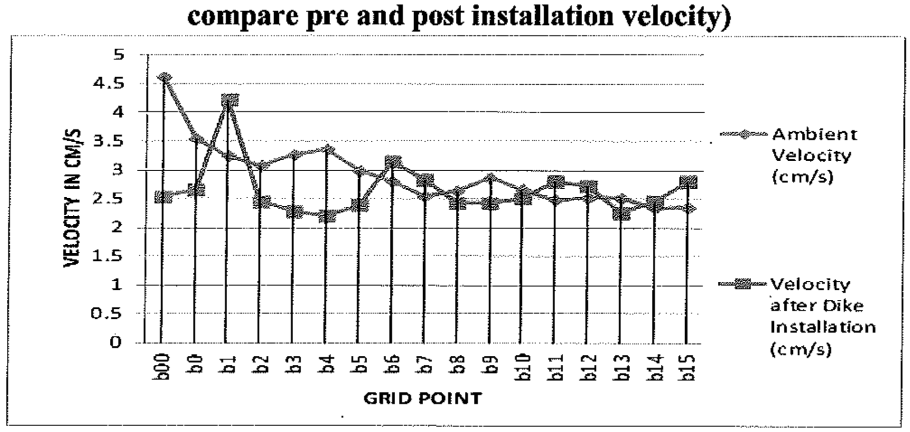


Figure 7.13 : Comparison of velocity in grid-2a (Spacing with two times of L1)

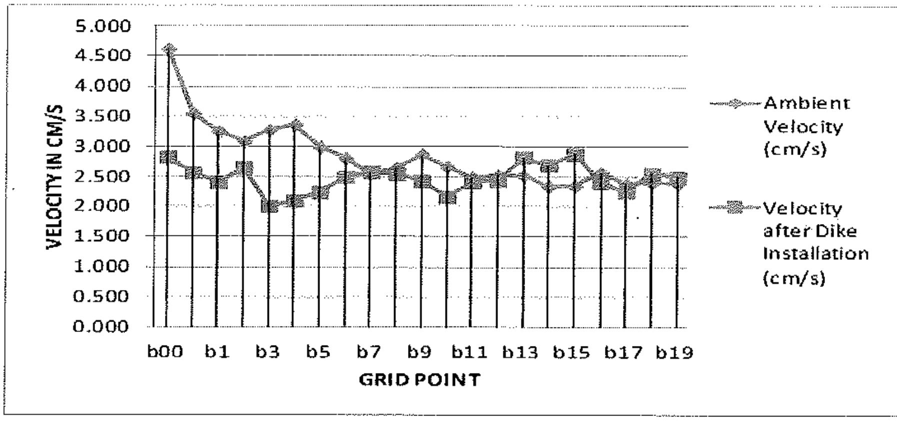


Figure 7.14 : Comparison of velocity in grid-2b (Spacing with three times of L1)

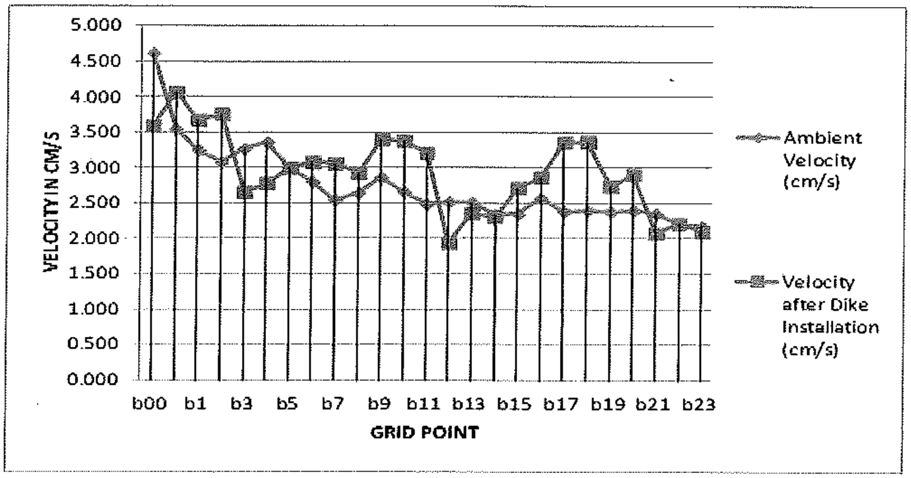
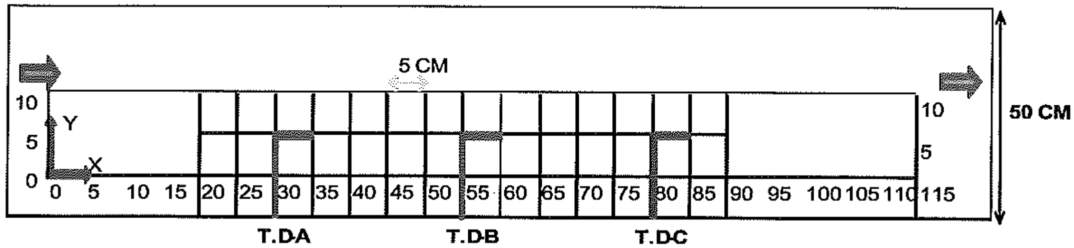


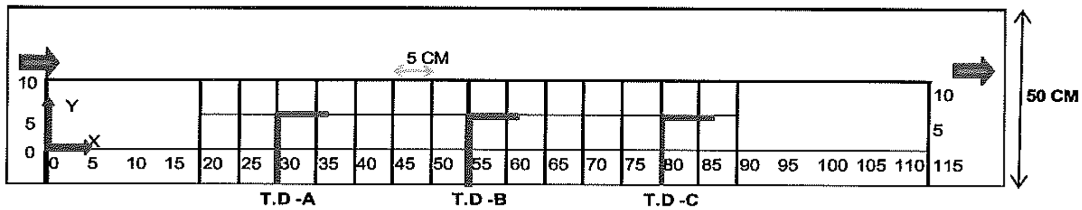
Figure 7.15 : Comparison of velocity in grid-2c (Spacing with four times of L1)

7.4.2 Effect of Dike Length Configuration Ratio on the Performance of Trail Dikes

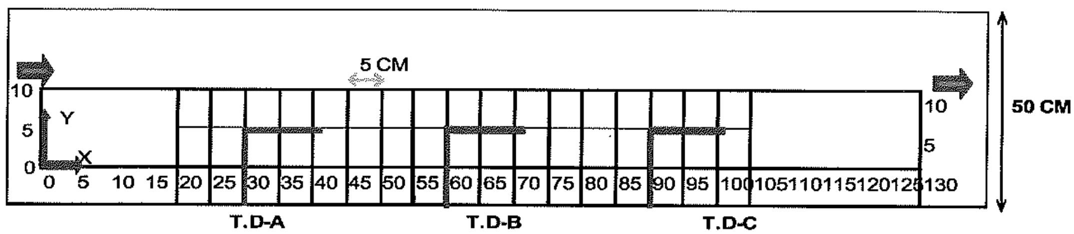
To investigate the impact of dike length configuration on the performance of trail dikes, three sets of experiment with three dikes in series each were carried out with configuration ratio of L1:L2 as 1:0.5, 1:0.7 and 1:1.20 under same spacing (two times of L1) and submergence ratios (0.50) for each of the dikes, represented by grid-3a, 3b and 3c respectively (Figure 7.16). Under the same discharge condition, as the configuration ratio increases, the velocity reduction efficiency also increases (Figure 7.17, Figure 7.18 and Figure 7.19). So, Grid -3b with series of trail dikes having configuration ratio 1:1.20 is producing better result in reduction of velocity. Graphical comparisons (Figure 7.21, Figure 7.22 and Figure 7.23) of ambient velocity distribution with the velocity after installation of dikes as per the grid 4a, 4b, 4c (Figure 7.20) indicates that the experiment with configuration ratio 1:1.20 is producing better and consistent performance throughout the grid in reducing the velocity as compared to experiments with other configuration ratios and thus justifies the comparisons of velocity contours.



Grid-3a: Grid with Configuration ratio L1:L2 as 1:0.50



Grid-3b: Grid with Configuration ratio L1:L2 as 1:0.70



Grid-3c: Grid with Configuration ratio L1:L2 as 1:1.20

Figure 7.16 : Experimental set up for different combinations of Configuration (To compare velocity contour)

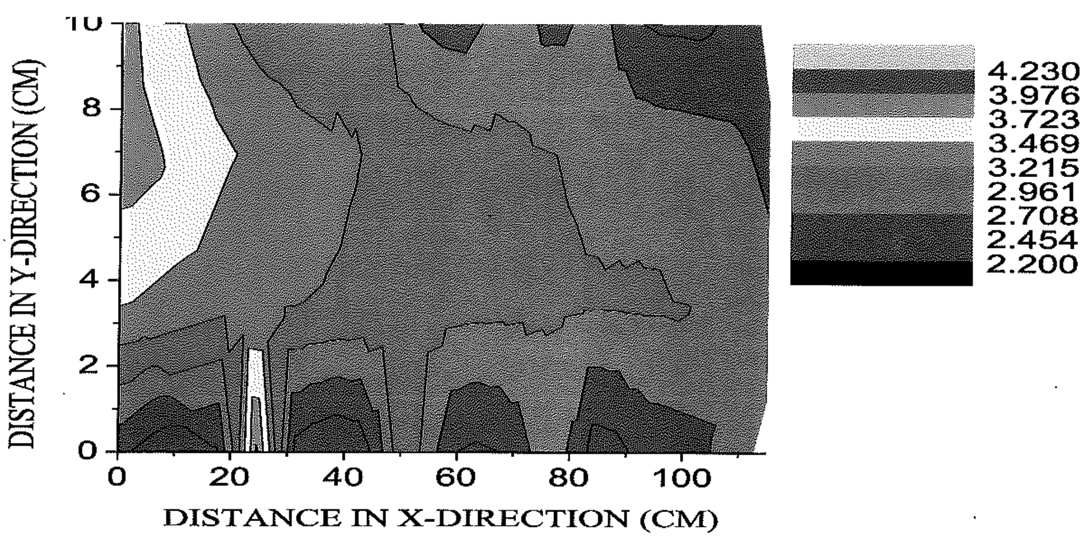


Figure 7.17 : Variation of Velocity in grid-3a (Configuration ratio 1:0.50)

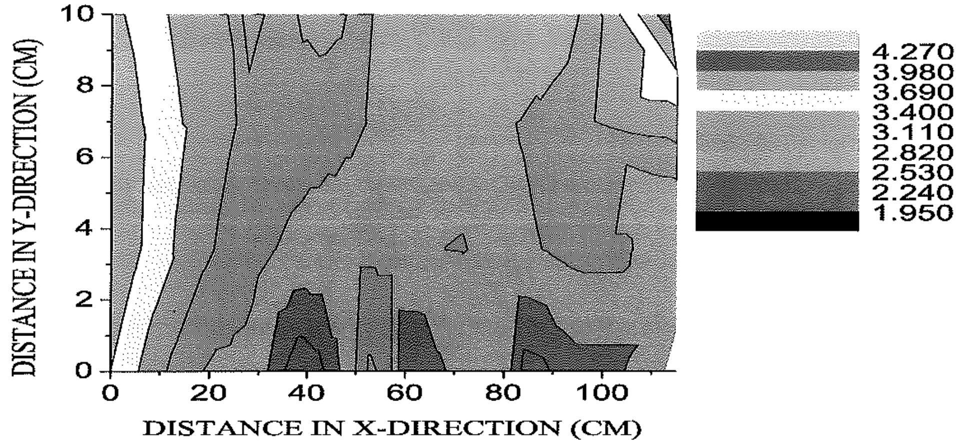


Figure 7.18 : Variation of velocity in grid-3b (Configuration ratio 1:0.70)

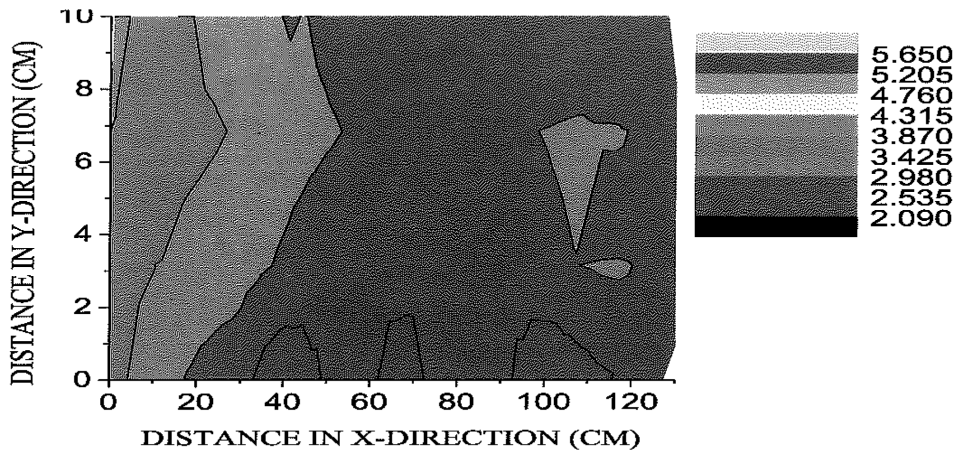
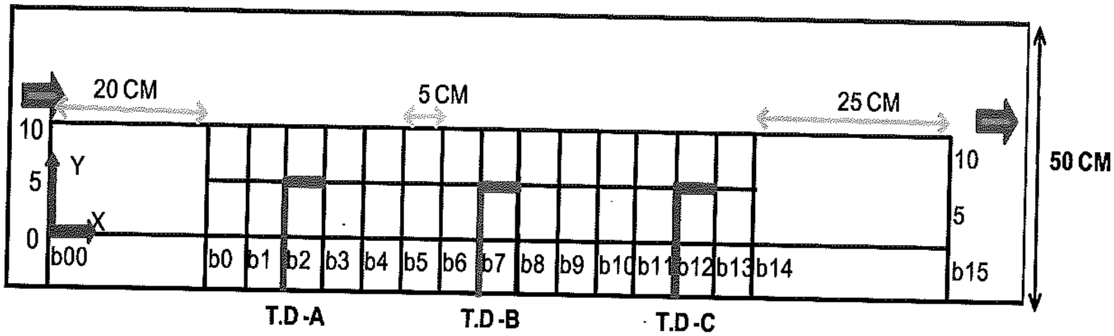
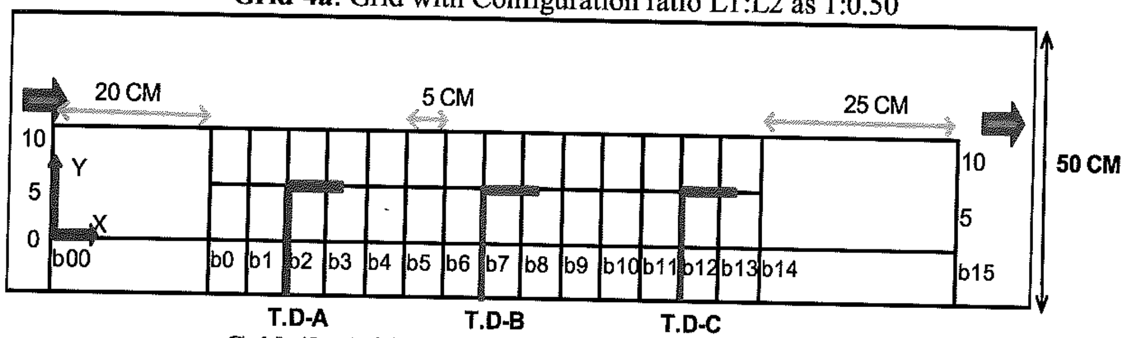


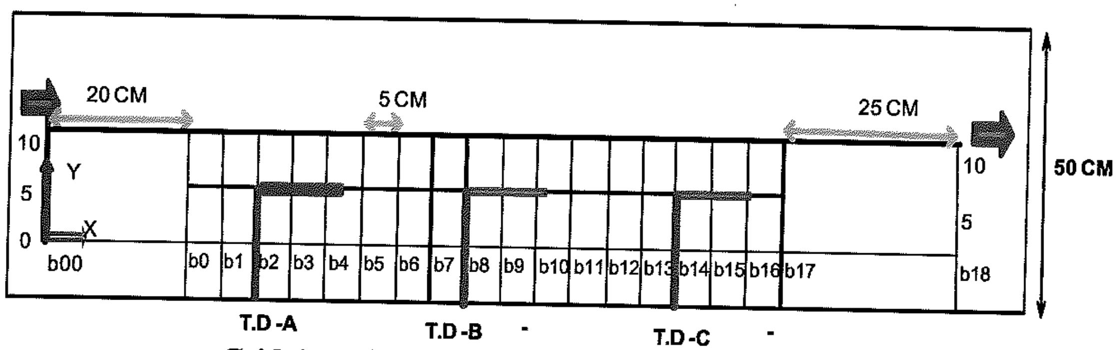
Figure 7.19 : Variation of Velocity in grid-3c (Configuration ratio 1:1.20)



Grid-4a: Grid with Configuration ratio L1:L2 as 1:0.50



Grid-4b: Grid with Configuration ratio L1:L2 as 1:0.70



Grid-4c: Grid with Configuration ratio L1:L2 as 1:1.20

Figure 7.20 : Experimental set up for different combination of Configuration in flume (To compare pre and post installation velocity)

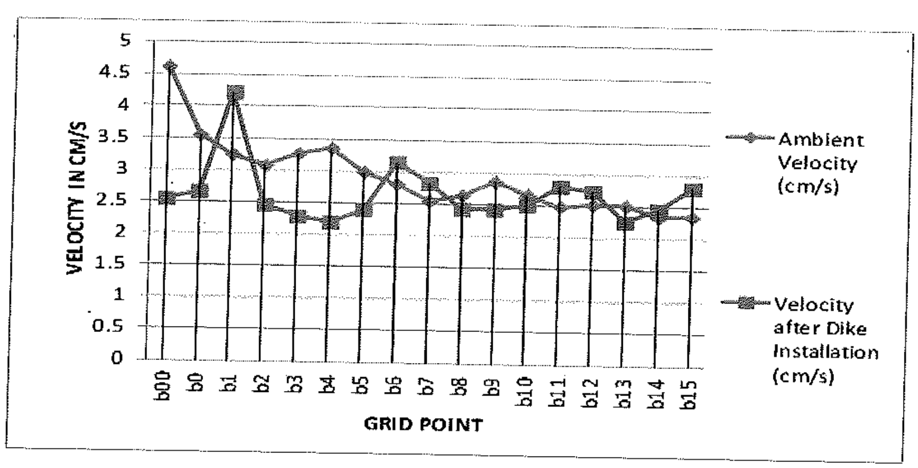


Figure 7.21 : Comparison of velocity in grid-4a (Configuration ratio as 1:0.50)

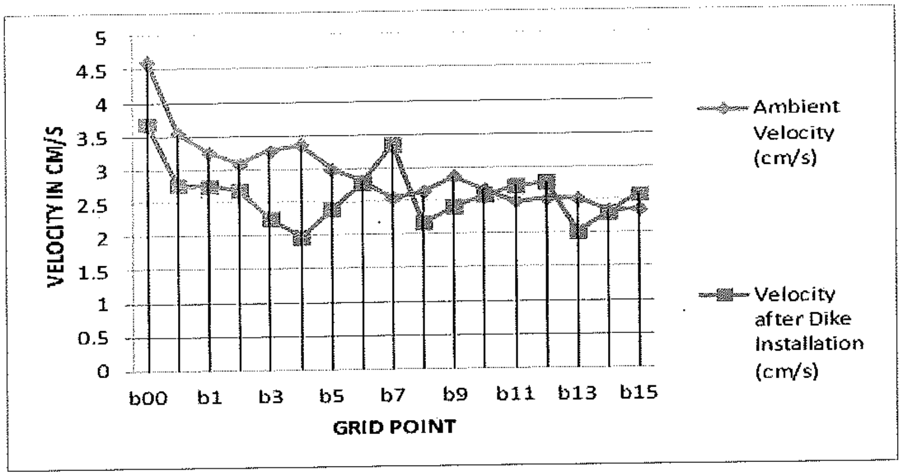


Figure 7.22 : Comparison of velocity in grid-4b (Configuration ratio as 1:0.70)

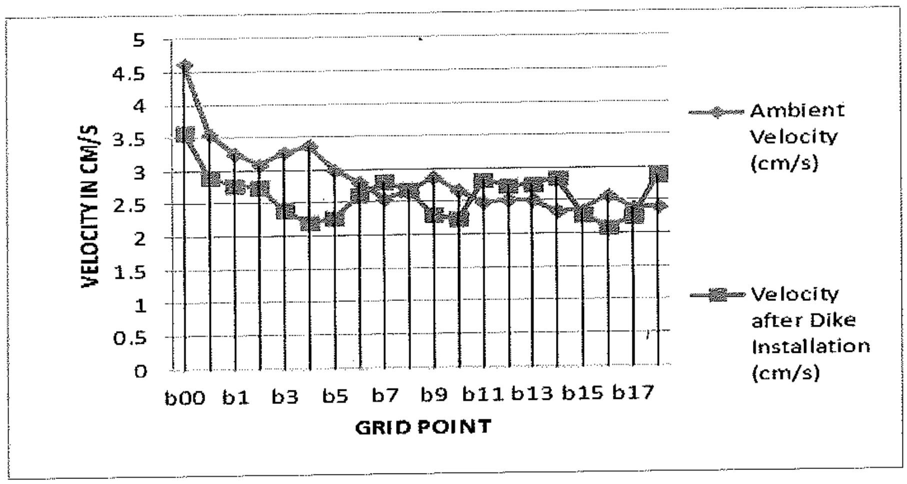


Figure 7.23 : Comparison of velocity in grid-4c (Configuration ratio as 1:1.20)

7.4.3 Effect of Submergence Ratio on the Performance of Trail Dikes

Submergence ratio is defined as the ratio of clearance depth of flow above dike to the depth of flow in flume (Figure 7.24). Three sets of experiments with three dikes in series each were also done with submergence ratio as 0.40, 0.50, 0.60 respectively under the same spacing (two times of L1) and dike length configuration (L1:L2 :: 10 cm: 5 cm) for each of the dikes represented by grid 5 (Figure 7.25). It has been observed from plotting the velocity contour that with the increase in submergence ratio, the effectiveness of the dike systems decreases in terms of reducing the velocity (Figure 7.27, Figure 7.28 and Figure 7.29). So, the experiment with series of trail dikes having submergence ratio 0.40 are indicating the better performance of dike systems. Similarly the graphical comparisons (Figure 7.30, Figure 7.31 and Figure 7.32) of ambient velocity with the velocity after installation of dikes based on the experimental set up of grid 6 (Figure 7.26) indicates that the experiment with submergence ratio of 0.40 produces the most uniform reduction of velocity specially around the first dike. This is generally treated as the most critical region to be protected in the field.

The sudden increase in the velocity after the installation of dikes at the points just near to the trail dike is mainly due to the formation of strong eddies causing heavier scour mostly around the additional structural features L2.

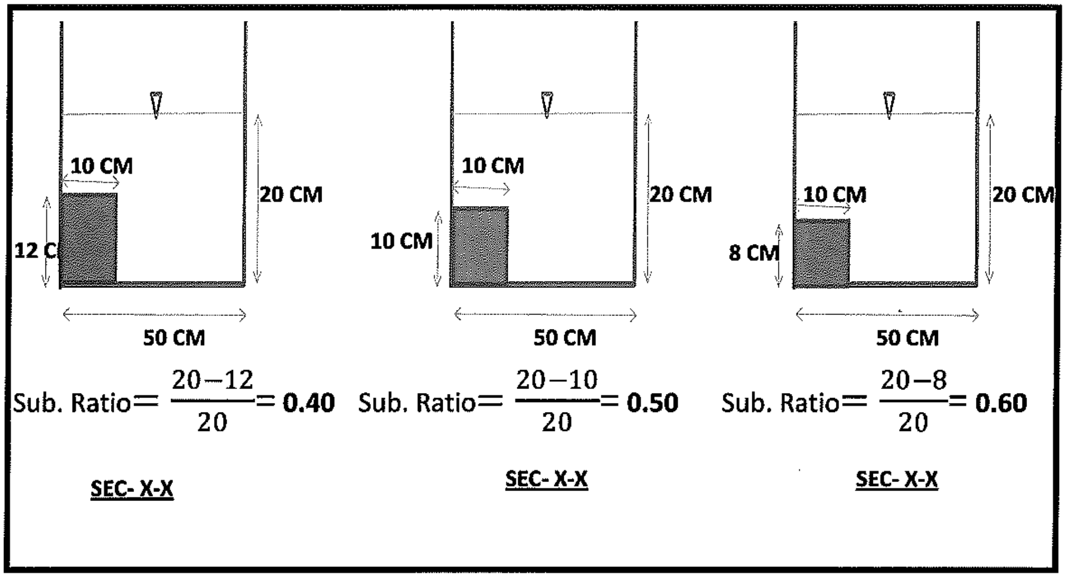
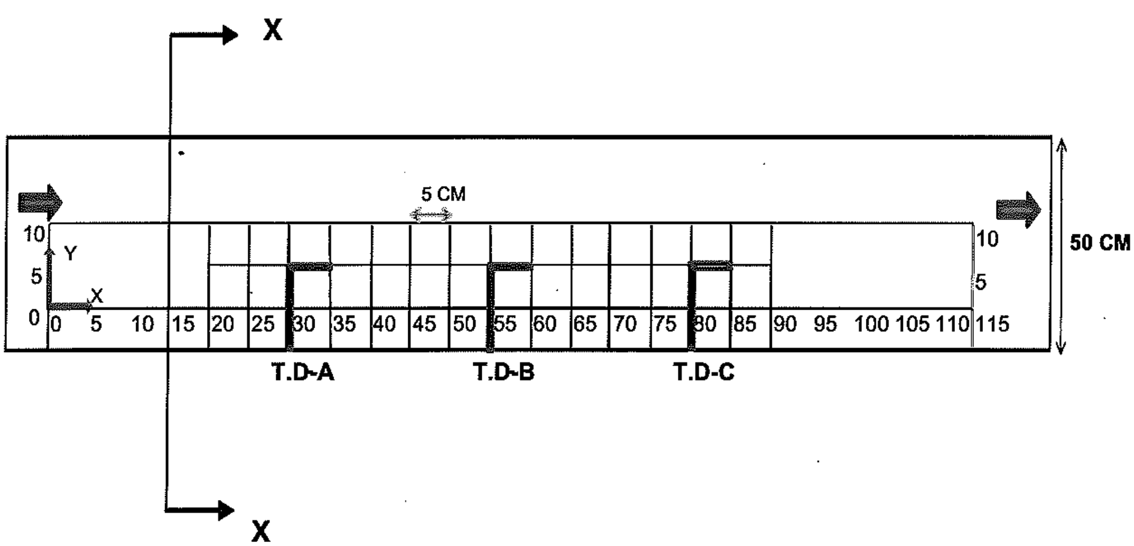
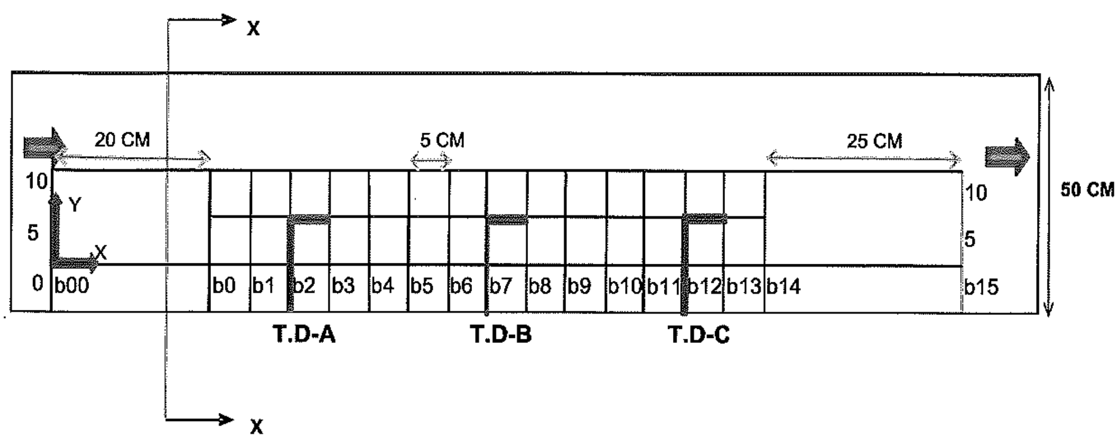


Figure 7.24 : Flume set up for submergence ratio 0.40, 0.50 and 0.60



Grid-5: Grid with submergence ratio as 0.40, 0.50 and 0.60

Figure 7.25 : Experimental set up for different submergence ratios in flume (To compare velocity contour)



Grid-6: Grid with submergence ratio as 0.40, 0.50 and 0.60

Figure 7.26 : Experimental set up for different submergence ratio in flume (To compare pre and post installation velocity)

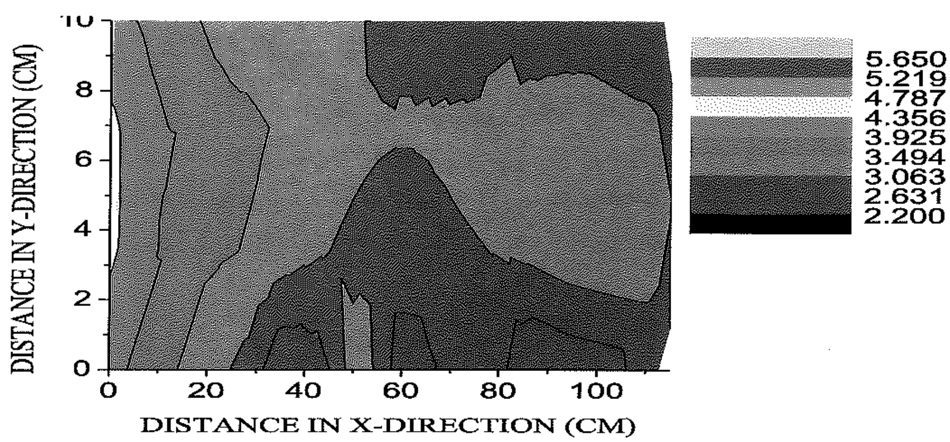


Figure 7.27 : Variation of Velocity in grid-5 (Submergence ratio 0.40)

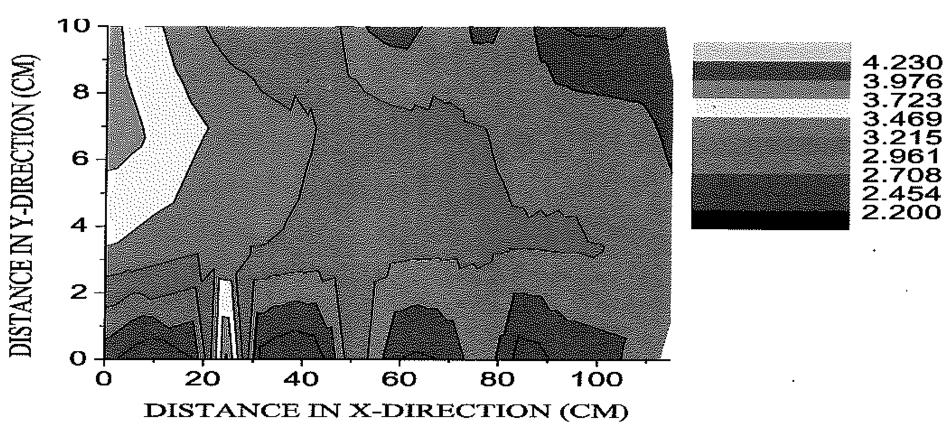


Figure 7.28 : Variation of Velocity in grid-5 (Submergence ratio 0.50)

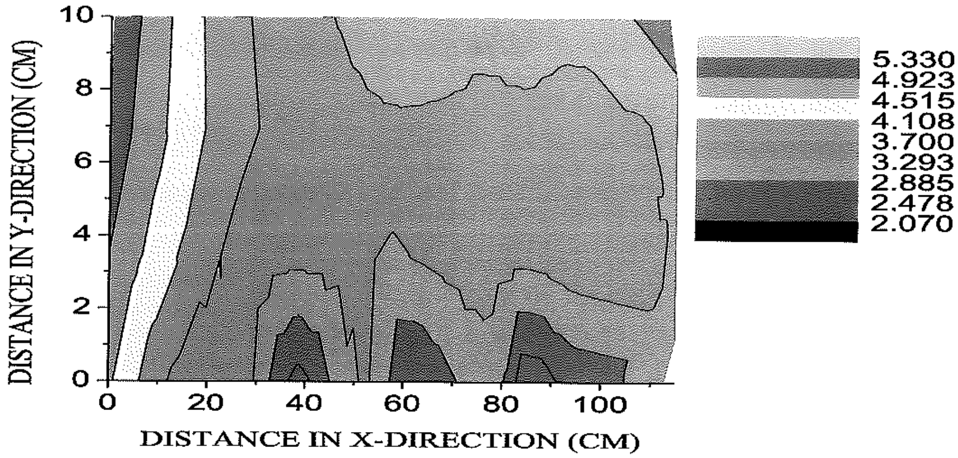


Figure 7.29 : Variation of Velocity in grid-5 (Submergence ratio 0.60)

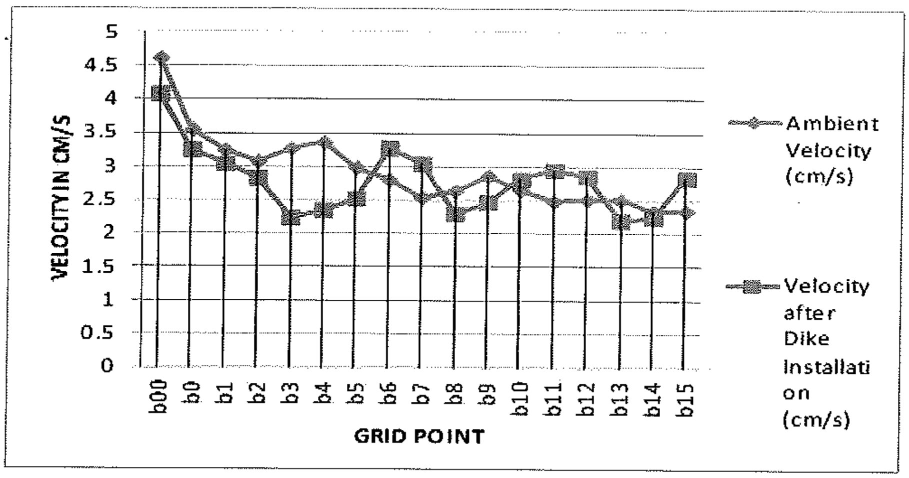


Figure 7.30 : Comparison of velocity in grid-6 (Submergence ratio as 0.40)

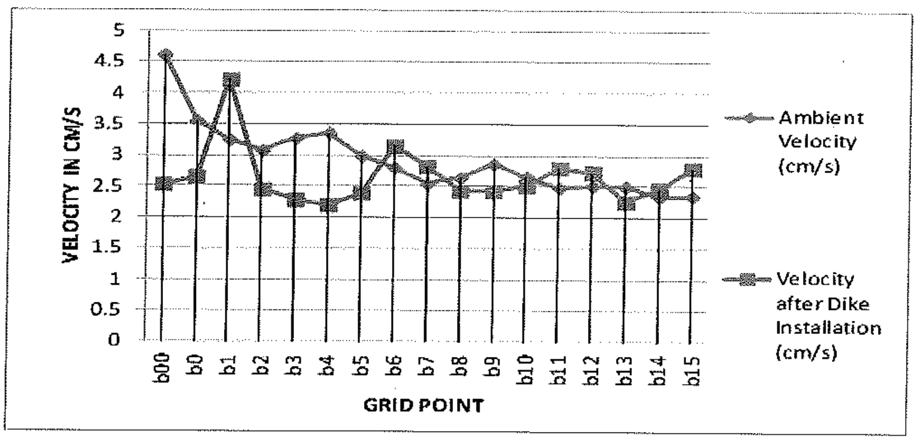


Figure 7.31 : Comparison of velocity in grid-6 (Submergence ratio as 0.50)

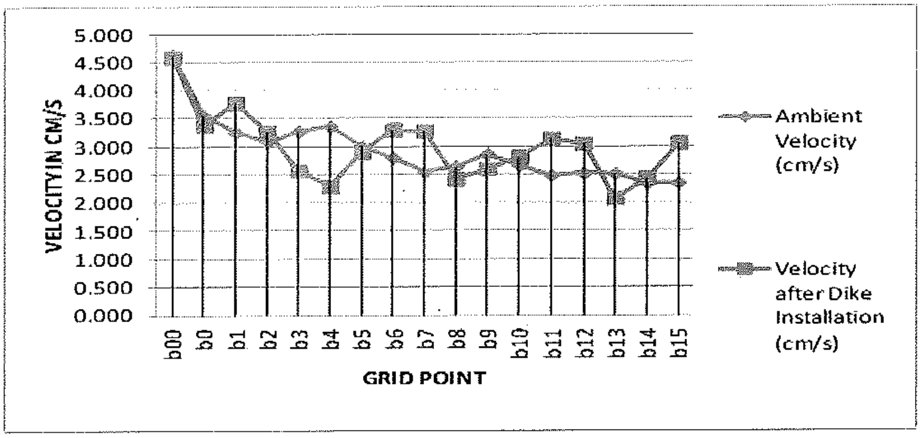
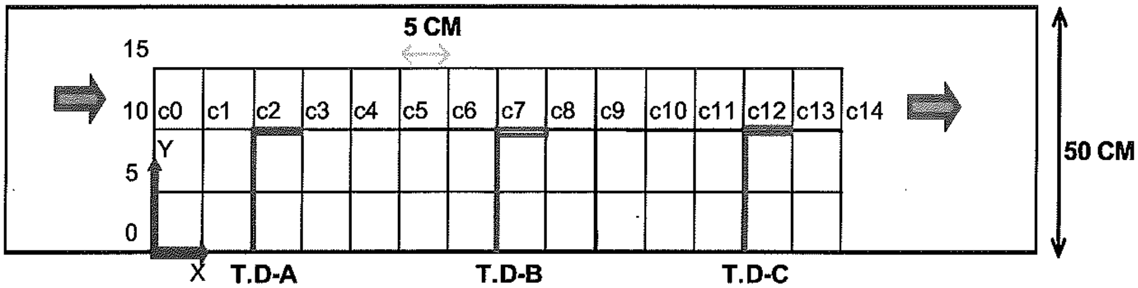


Figure 7.32 : Comparison of velocity in grid-6 (Submergence ratio as 0.60)

7.4.4 Effect of Submergence Ratio on the Scour Pattern in the Vicinity of Trail Dikes

Experimental analysis shows that bed deformation pattern is very complicated in the vicinity of dikes as it depends upon many hydraulic parameters like dike configuration, submergence ratios, Froude number, properties of bed materials. However this thesis emphasizes on the effect of different submergence ratios on the bed scour pattern in the vicinity of dikes. Bed level measurements with pointer gauge were taken at each nodal point along the line of L2 before the run of each experiment with submergence ratio 0.40, 0.50 and 0.60 respectively as per the grid 7 (Figure 7.33). After the installation of dikes, experiments were carried out and again bed levels were observed after each run. The reason for selecting the line of L2 was due to the creation of heavy scour zone especially at the junction of L1 and L2 due to the formation of strong turbulent eddies (Figure 7.34).

From Figure 7.35, representing the variation of difference of bed level against the respective grid points, it has been observed that with the increase in submergence ratio or decrease in the blockage to flow, the scour depth also decreases accordingly. So the experiment with submergence ratio 0.60 shows the least scour depth in the vicinity of dikes. But as the experiment with lower submergence ratio produces the highest reduction of velocity as described in section 4.5.3, so it is recommended to use adequate stone apron or other protective measures to counteract the local scour in the vicinity of dikes in case the protection is to be done with dikes having lower submergence ratios.



Grid-7: Grid with submergence ratio as 0.40, 0.50 and 0.60

Figure 7.33 : Experimental set up for different submergence ratios in flume (To compare bed scour pattern)

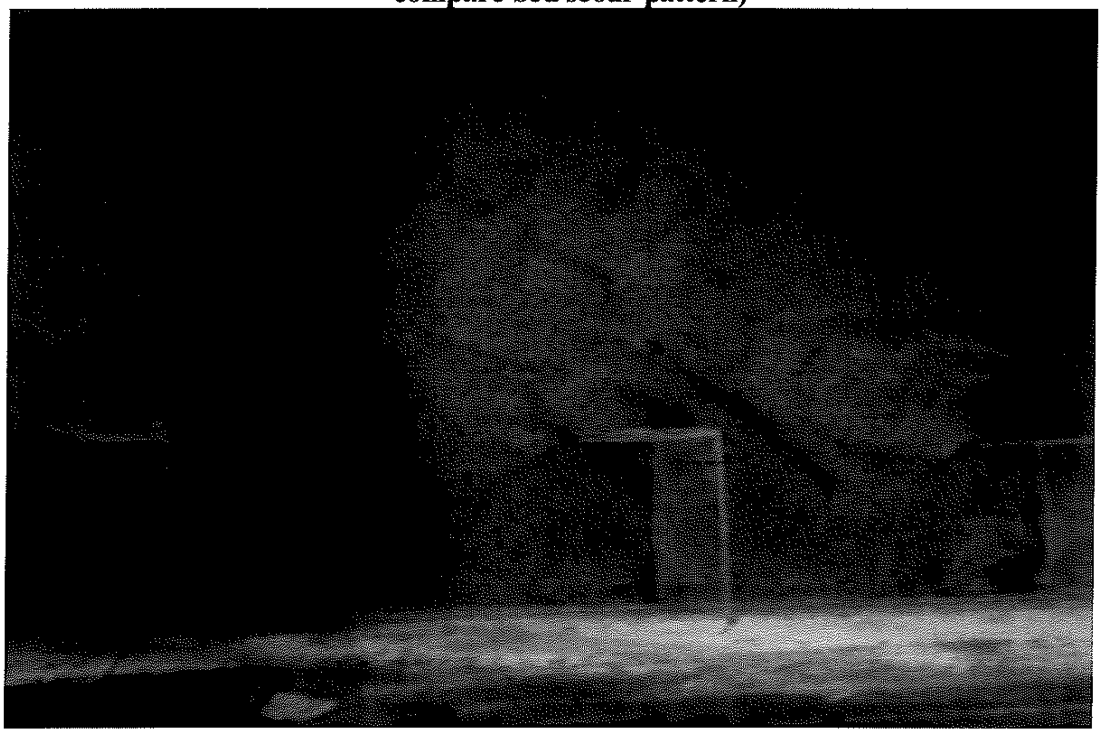


Figure 7.34 : Formation of scour hole at the junction of L1 and L2 in flume

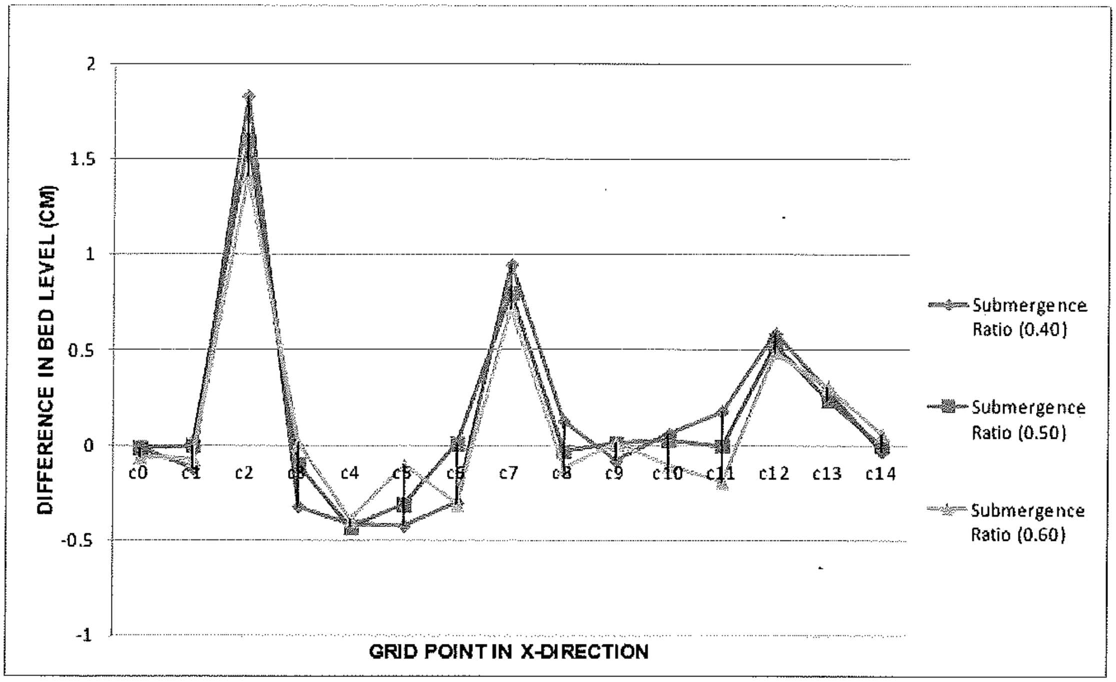


Figure 7.35 : Comparison of bed scour pattern in the vicinity of dikes (Submergence ratio 0.40, 0.50, 0.60) (Scouring and Deposition indicated by positive and negative values respectively)

CHAPTER – 8
APPLICATION OF JACK JETTY IN SOLANI RIVER PHASE – 1

8.1 Study Area

Solani River, an important tributary of River Ganga, flows in south easterly direction with a considerable discharge of around 1,30,000 cusecs. This river is basically having the tendency of causing significant damages to the lowland area nearby its bank by eroding the bank soil and shifting of the river course. River catchment along with the Dhanori escape contributes the runoff, which is having a potential of causing disaster of approx. 9860 hectare of farming land. Flooding in the river affects around 60 villages of Hardwar and Muzaffarnagar districts in Uttarakhand state of India. 2 MW Solar Power Plant is situated near the left bank of Solani River at Bhagwanpur site (lowland area) near Roorkee in Uttarakhand state of India. The height of the channel banks are varying from 3 to 4 meters and the slope of the bank is 1H: 1V. The Solani River is having tendency of bulging along the left bank and causing threat to the Power Plant.

8.2 Methodology

Before the monsoon season of year 2012, six numbers of trail dykes were constructed. Keeping in view of the damages occurred to some portions of the bank nearby area of the plant during monsoon season of year 2012 and 2013, the banks were supplemented by two additional trail dykes one T.D-1U with L1: L2 as 15 m: 7.5 m and the other T.D-1D with L1: L2 as 20 m: 10 m before the monsoon season of 2014.

Length of the dyke in transverse and parallel to the direction of flow are indicated by L1 and L2. The submergence ratios as 0.40 were kept for both T.D-1U and T.D-1D. An initial flood with discharge around 1, 30, 000 cusecs shifted the bank about 30 meters towards the plant. RCC Jack-Jetty Systems of size 1.5 m x 0.1 m x 0.1 m with one row of diversion and retard lines in one tier each were also installed hurriedly between the trail dyke T.D-1D and the T.D-1 in 2014 especially for the purpose of restricting further shifting of river towards the plant in successive floods. However, no jetties were installed in the portion between T.D-1U and T.D-1. The purpose was to assess and compare the behaviour of trail dyke with and without the supplementation of jack jetty. Layout of bank protection works adopted in Solani River is sketched in Figure 8.1**Error! Reference source not found.**.

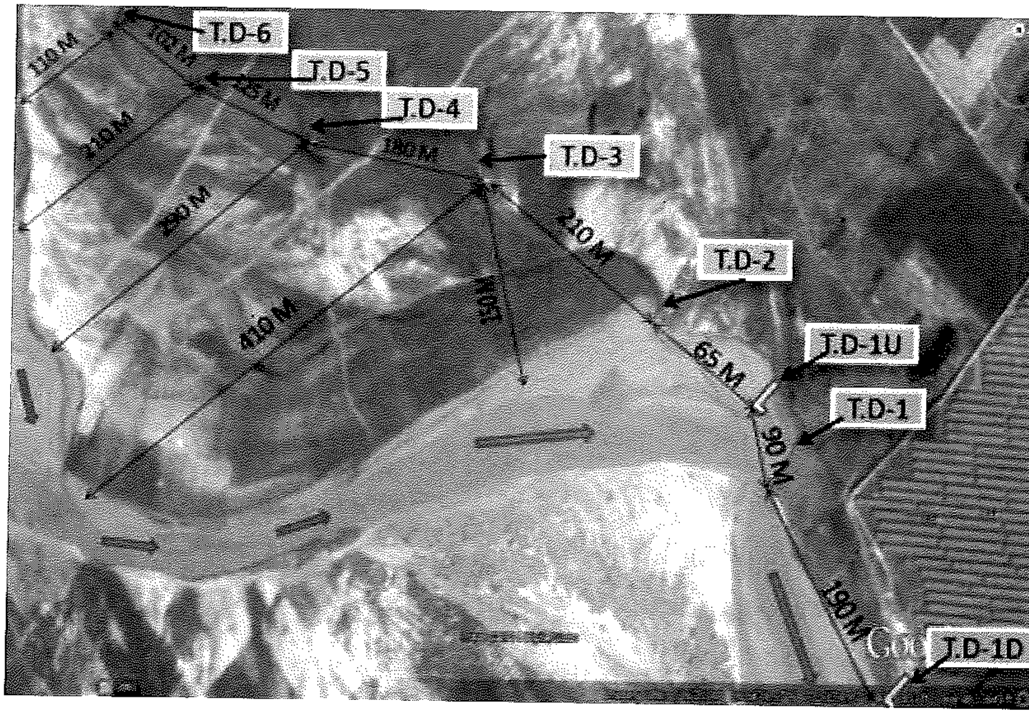


Figure 8.1 : Layout of Trail Dikes on the Solani River

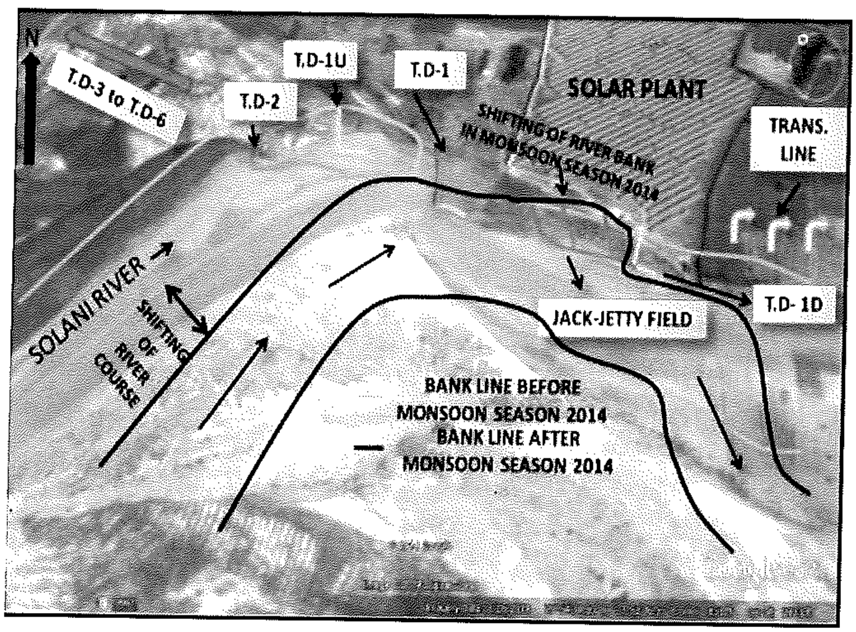


Figure 8.2 : Layout of bank protection works adopted in Solani River

8.3 Results and Analysis

To emphasize the effectiveness of trail dyke T.D-1U, T.D-1D and the combined performance of T.D-1 & T.D-1D with RCC Jack Jetty, topographical survey was conducted before and after the monsoon season of year 2014. From the survey result it was found that an average deposition of around 0.75 feet up to a length of 45 M downstream of the dyke T.D-1U (Trail dyke without jetty field) has been occurred. Also, It has been observed that deposition of sediment decreases as we move beyond 45 m downstream of the dyke which is basically the 3 times of the effective length of the dyke (L1= 15 M).

Similarly at the site of Jack Jetty installation between T.D-1 and T.D-1D, it has been observed that accretion of land occurred with a significant average deposition of 1 feet mainly around the line of 10 m distance parallel to the bank. The discussed line was basically the line of diversion for Jack Jetty. As these jetty fields were installed hurriedly during monsoon season, so their implementation was not executed according to the design criteria available. In spite of that the achieved result in this portion concludes that the implementations of these Jack Jetty with trail dyke are successfully contributing for the effective sedimentation of land. Capturing of small trees and bushes in the jetty field are shown in the Figure 8.3.

The conjunctive field application of trail dyke T.D-1 & T.D-1D along with RCC jack jetty systems in Solani River shifted the erosive channel currents away from the bank. In spite of occurrence of most of the devastating flood in between T.D-1 and T.D-1D, further bank erosion was inhibited in this region. As from the Figure 8.4 and Figure 8.5; it can be clearly observed that the repetition of high intensity flood in between the period from 31/08/2014 and 15/09/2014 could not be able to shift the river bank further towards the plant. It was a big relief as otherwise this might be damaging the plant causing immense loss of property.

Similarly average deposition of sediments around 1.5 feet up to the length of 60 M downstream of the dyke T.D-1D has been observed. Accretion of land up to 60 M downstream of the dyke T.D-1D was measured as 3 times the effective length of the dyke (L1= 20 M). It was also observed that the pre bed levels are higher than the post bed level as we move beyond 20 m towards the centre of the river. This has happened due to fact that the effective length of the dyke T.D-1D was 20 m and scouring tendency of the bed generally occurs beyond this effective length due to the formation of strong turbulent eddies generated by high velocity. The installation of jetty field upstream of the trail dyke T.D-1D was also a key factor towards the significant deposition of sediment downstream to the dyke T.D-1D.

The performance of these structures also afforded protection to the transmission line of power plant in downstream of T.D-1D. The protection of these transmission lines was a huge success as the supply of electricity was supposed to be stopped to the grid before the implementation of these structures.

Figure 8.3 : Capturing of small trees and bushes in the jetty field in Solani River

Figure 8.4 : Implementation of RCC Jack Jetty to inhibit further erosion between T.D-1 & T.D-1D

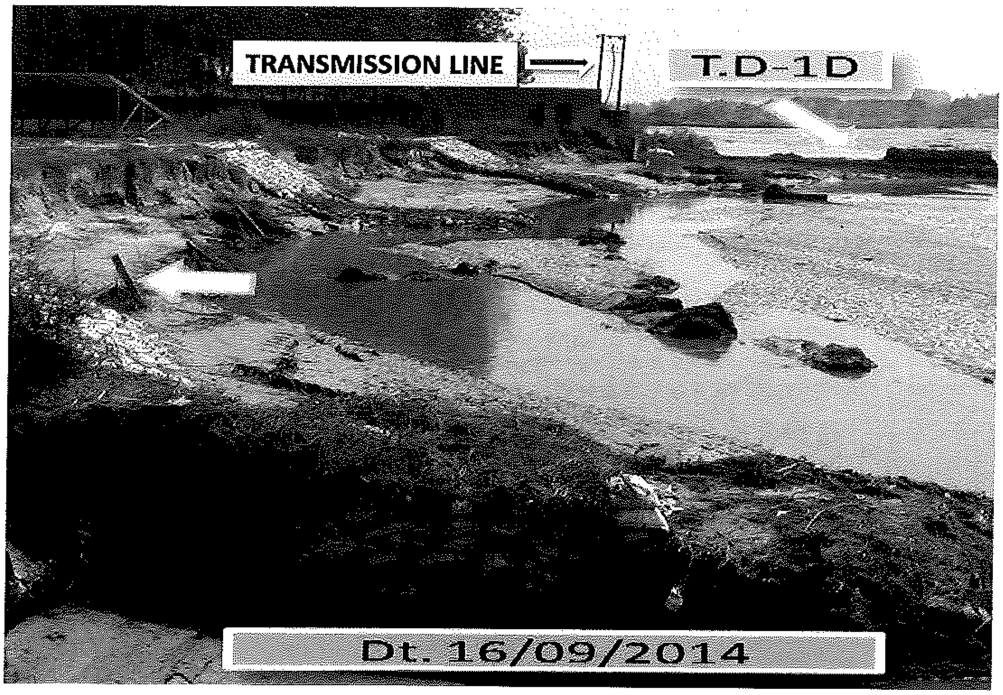


Figure 8.5 : Siltation, Inhibition of bank erosion between T.D-1 & T.D-1D & Protection of Transmission Line

CHAPTER – 9
TURBULENT BEHAVIOUR IN THE VICINITY OF JACK JETTY AND TRAIL DYKE

9.1 Laboratory Flume Set Up

All the laboratory experiments on were conducted in the River Engineering Lab of WRD&M Department, IIT Roorkee. The flume set up was maintained as in the experiment carried out on Trail Dyke described in Chapter 7.

9.2 Experimental Plan

To study the performance of combined system of Jack Jetty & Trail Dyke (Objective II) and turbulent behaviour in the vicinity of Jack Jetty & Trail Dyke, lab experiment has been conducted. The experiment was carried for four conditions

i. Experiment for plain condition
ii. Experiment for Trail Dyke model only
iii. Experiment for Jack Jetty model only
iv. Experiment for Combined system of Jack Jetty and Trail Dyke

Constant discharge (Q = 10 lps) and water depth was maintained for all four experiments.

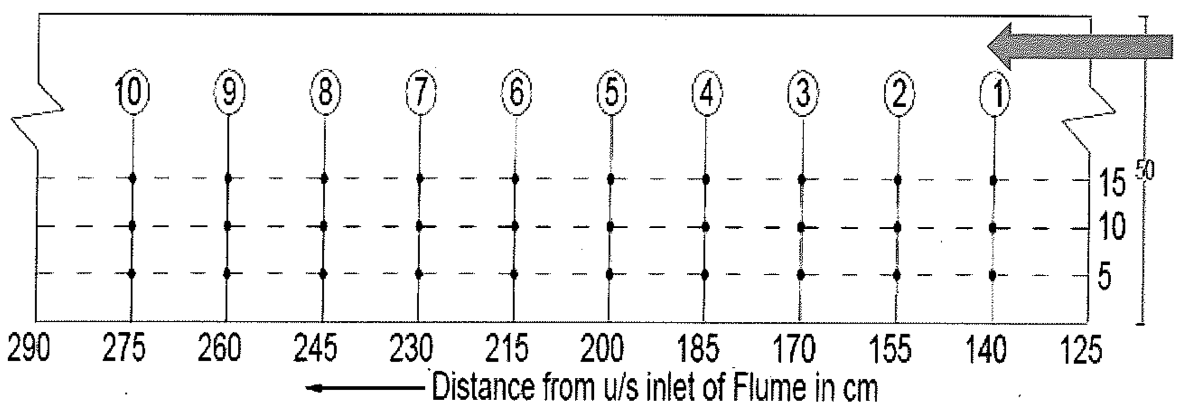


Figure 9.1 : Experimental Plan for Plain Condition (No Model)

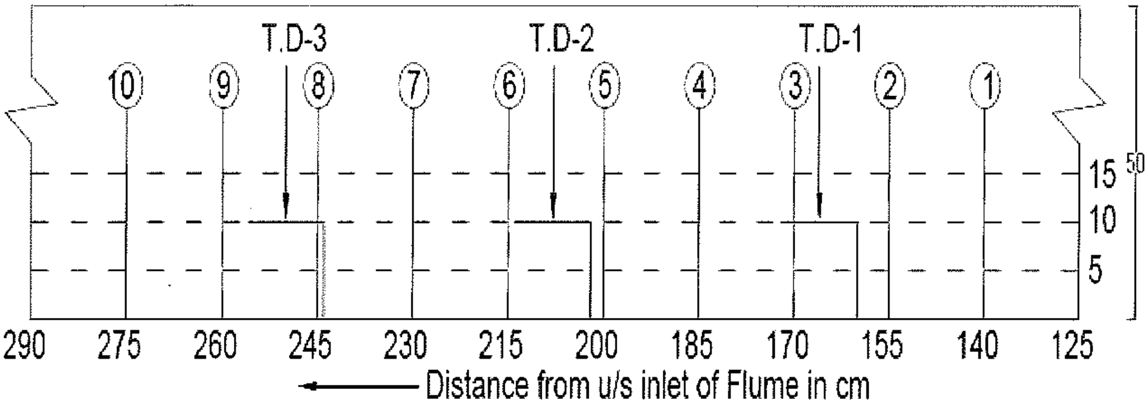


Figure 9.2 : Experimental Plan Trail Dyke only

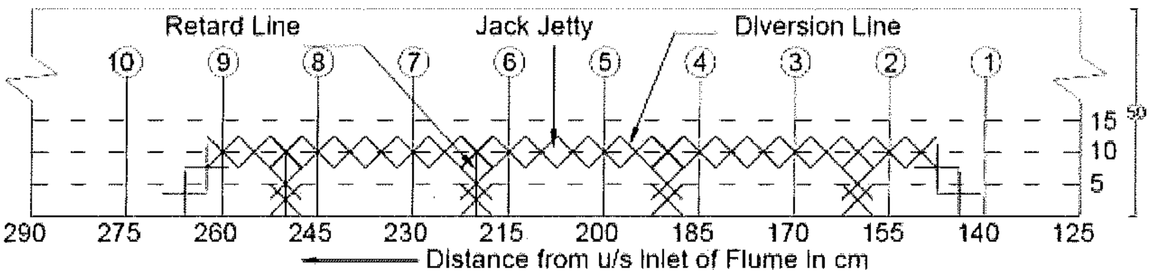


Figure 9.3 : Experimental Plan for Jack Jetty only

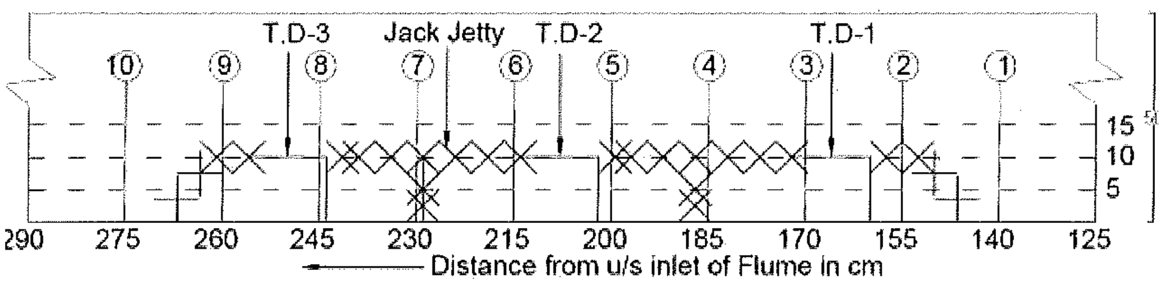


Figure 9.4 : Experimental Plan for combined system of Jack Jetty and Trail Dyke

The velocity were measured in 10 sections (in the interval of 15 cm) in longitudinal direction and 3 sections in lateral direction (in the interval of 5 cm). Number of velocity measurements in one horizontal plane was 30 (10*3). The velocity were measured in various four depths i.e. near bed, 4 cm above bed, 7 cm above bed and 10 cm above bed. Thus no of velocity measured for each experiment was 120 (10*3*4). The sediment bed layer for the test section was fixed to 0.15 m depth by filling sand.

The Trail dyke used in this experiment was made up of 3mm thick Perspex sheet and indicated as T.D.-1, T.D. - 2 and T.D. – 3. The spacing between the Trail dyke was taken as 30 cm, 3 times the effective length of the dike (L1). The configuration of the Trail dike was be taken as L1:L2 =1:1.2 and the submergence ration of Trail Dyke is taken as 0.4. The jack Jetty was made of mild steel of 10 cm length. Three units of Jacks were welded together at their midpoints. The vertical height of Jack Jetty was 7 cm. For the experiment with Jack Jetty only, one row of diversion line and four straight retard lines (in the interval of 30 cm) were used. The first retard line u/s of T.D. – 1 and the last retard line ds of TD. – 3 are laid out at an angle of 45 and 135 with the bank line respectively. Similarly for the experiment with combined system of Jack Jetty and Trail Dyke, one diversion line, four retard lines of Jack Jetty, three no of Trail Dykes were used. The retard lines in between the two Trawl Dykes were placed at their mid points. The submergence ratio of Jack Jetty was 0.58.

The focus of this experiment was to evaluate the performance of combined system of Jack Jetty & Trail Dyke in the velocity reduction and bed deposition pattern and to investigate the turbulent behaviour and bursting characteristics in the vicinity of Jack Jetty and Trail Dyke by quadrant and octant methods.

9.3 Study of Velocity Contour

Velocity contour plots are drawn to certify the findings of the velocity profiles drawn in the precious section. These contours are drawn for different conditions of the experiment. These were drawn at different layers of flow to see the extent of jack jetty and trail dyke in that particular layer. These plots are drawn at different layers of the velocity profile where each layer represents different water depths in the flow. In the contour plots x-axis represents the longitudinal distance (cm) and y –axis represents lateral distance (cm).Velocity measurements are in cm/sec.

Figure 9.5, 9.6, 9.7 and 9.8 represent contour plots in near bed, 4 cm above bed, 7 cm above bed and 10 cm respectively above bed in plain condition. The average velocity in near bed condition, 4 cm above bed, 7 cm above bed and 10 cm above bed are 2.72 cm/sec, 13.13 cm/sec, 14.14 cm/sec, 14.12 cm/sec.

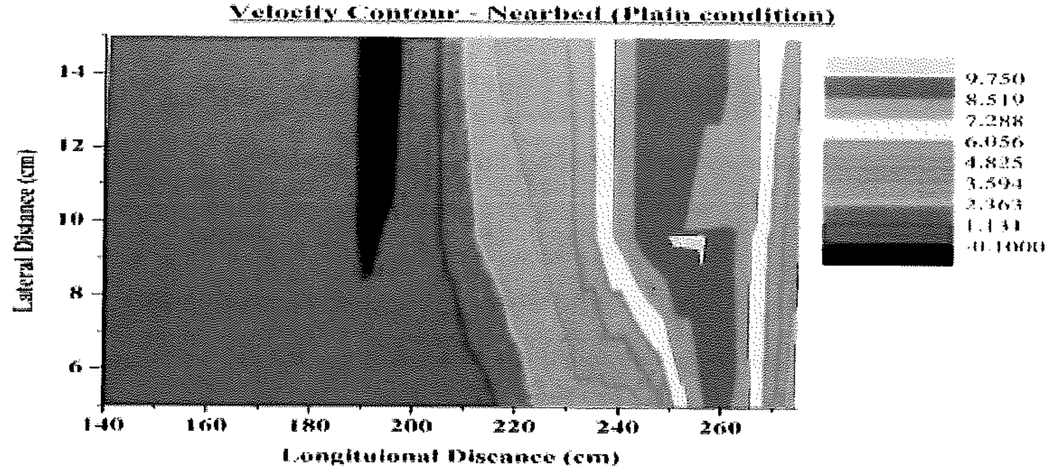


Figure 9.5 : Velocity Contour Near bed – Plain Condition

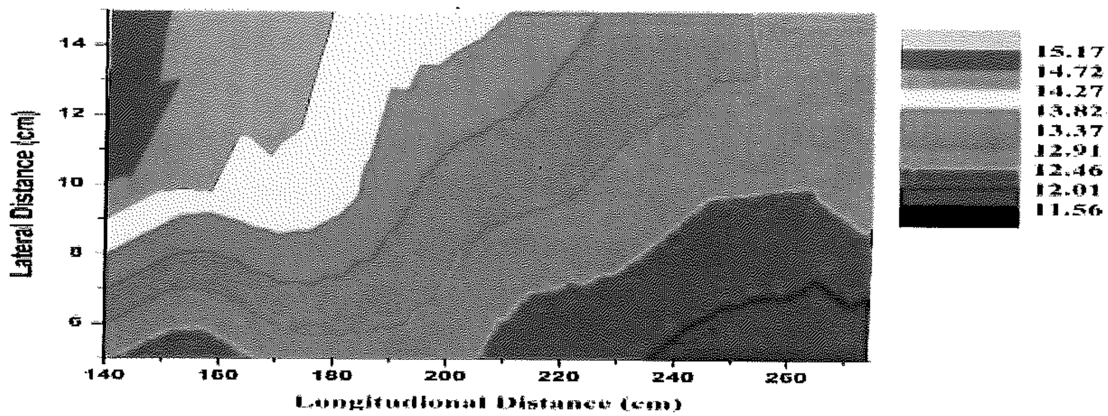


Figure 9.6 : Velocity Contour 4 cm above bed – Plain Condition

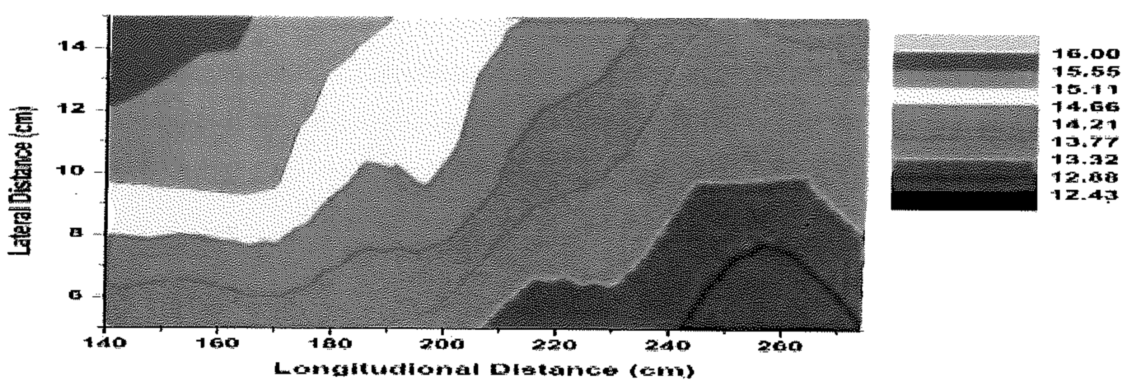


Figure 9.7 : Velocity Contour 7 cm above bed – Plain Condition

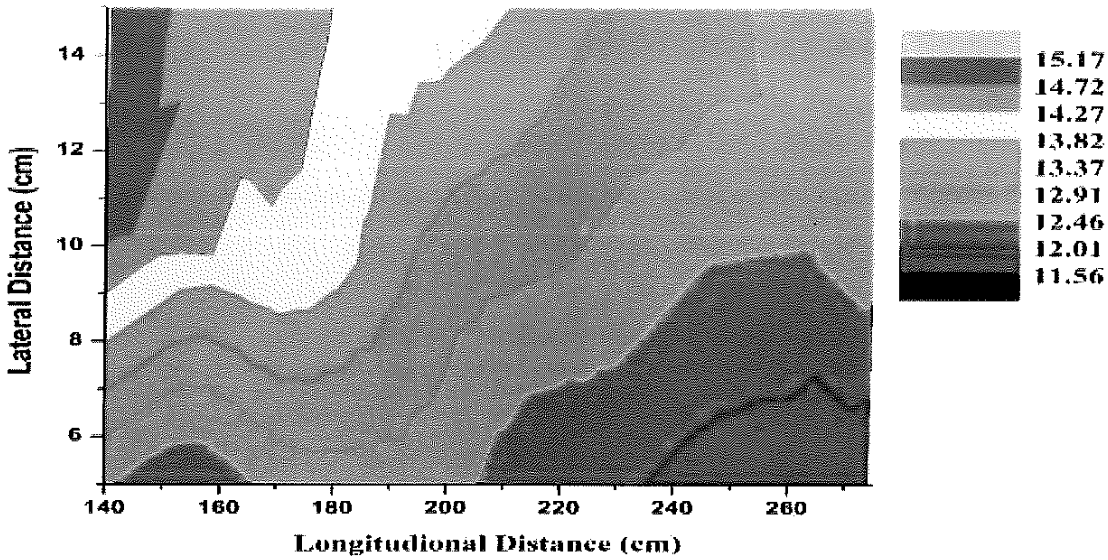


Figure 9.8 : Velocity Contour 10 cm above bed – Plain Condition

Figure 9.9, 9.10, 9.11 and 9.12 represent contour plots in near bed, 4 cm above bed, 7 cm above bed and 10 cm respectively above bed with Trail Dyke model only. The average velocity in near bed condition, 4 cm above bed, 7 cm above bed & 10 cm above bed are 0.08 cm/sec, 5.15 cm/sec, 6.13 cm/sec & 6.11 cm/sec respectively.

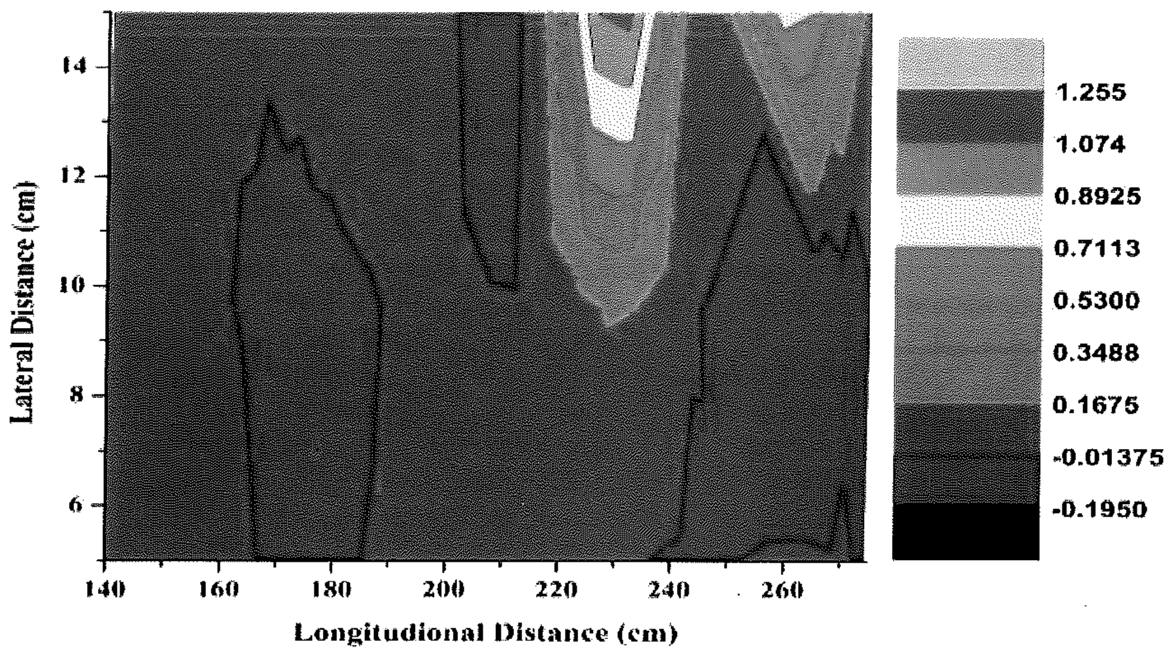


Figure 9.9 : Velocity Contour near bed – with Trail Dyke model

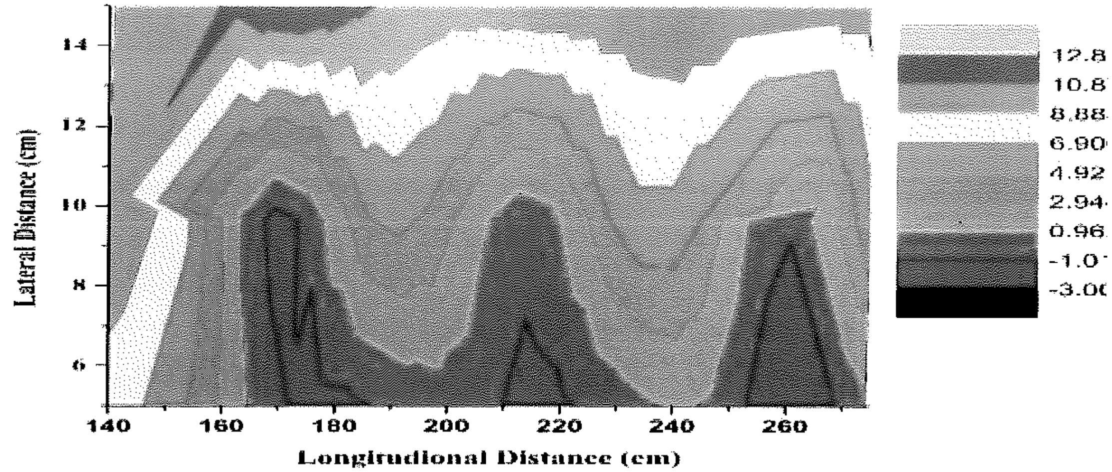


Figure 9.10 : Velocity Contour 4 cm above bed – with Trail Dyke model

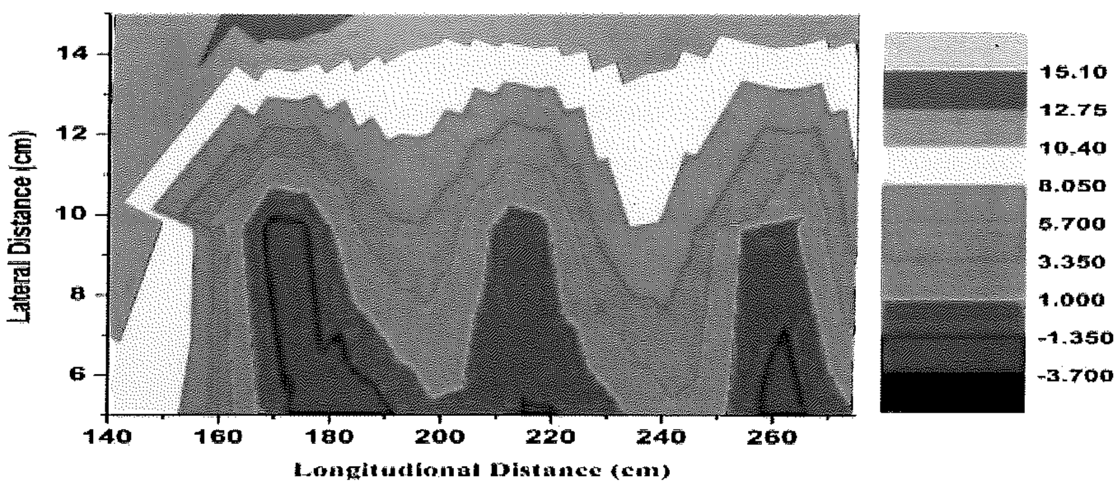


Figure 9.11 : Velocity Contour 7 cm above bed – with Trail Dyke model

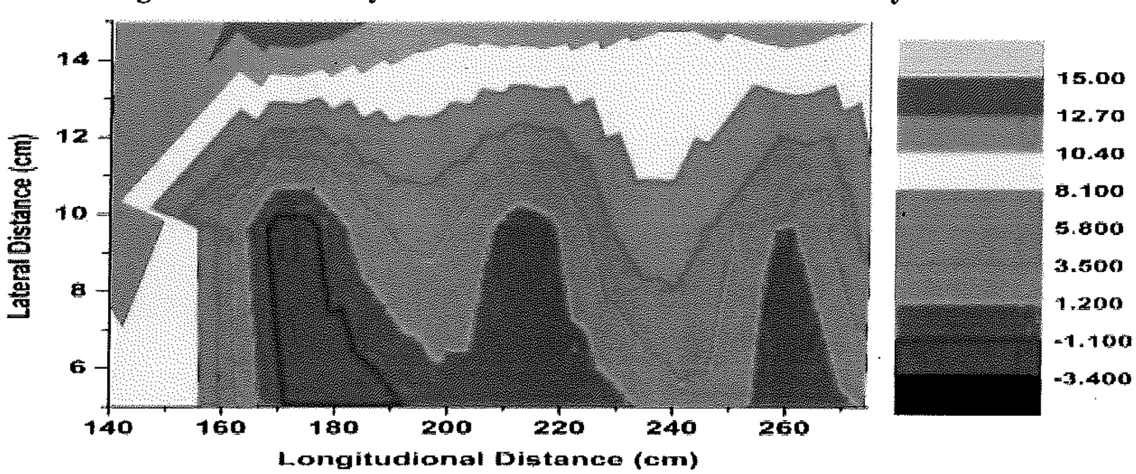


Figure 9.12 : Velocity Contour 10 cm above bed – with Trail Dyke model

Figure 9.13, 9.14, 9.15 and 9.16 represent contour plots in near bed, 4 cm above bed, 7 cm above bed and 10 cm respectively above bed with Jack Jetty model only. The average velocity in near bed condition, 4 cm above bed, 7 cm above bed & 10 cm above bed are 0.017 cm/sec, 6.54 cm/sec, 8.72 cm/sec & 11.37 cm/sec respectively.

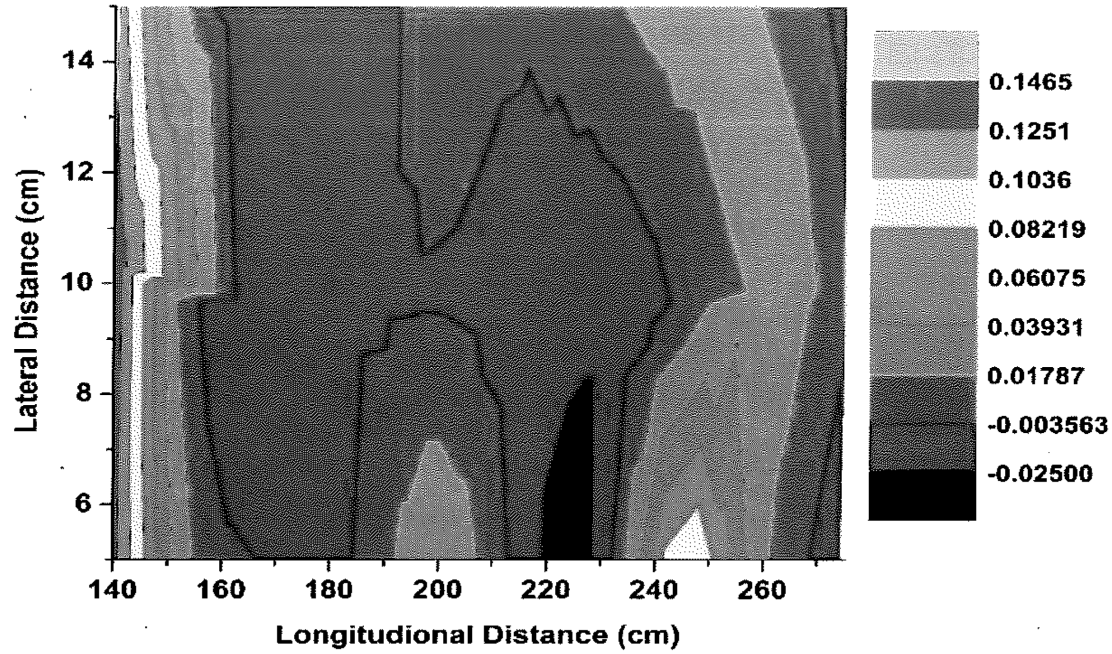


Figure 9.13 : Velocity Contour near bed – with Jack Jetty model

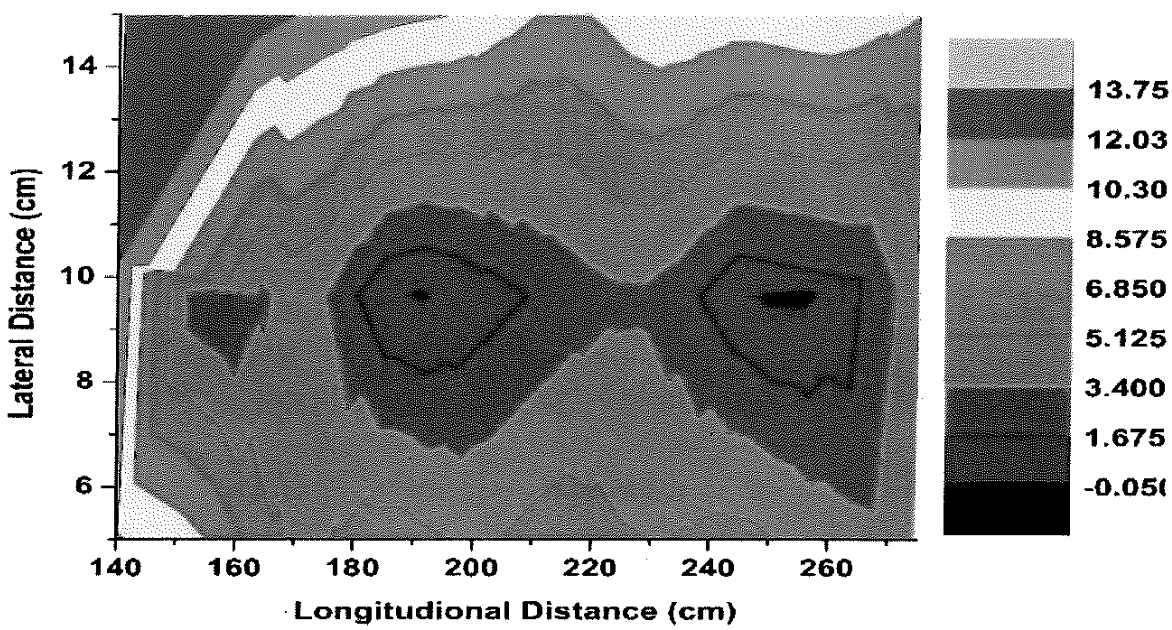


Figure 9.14 : Velocity Contour 4 cm above bed – with Jack Jetty model

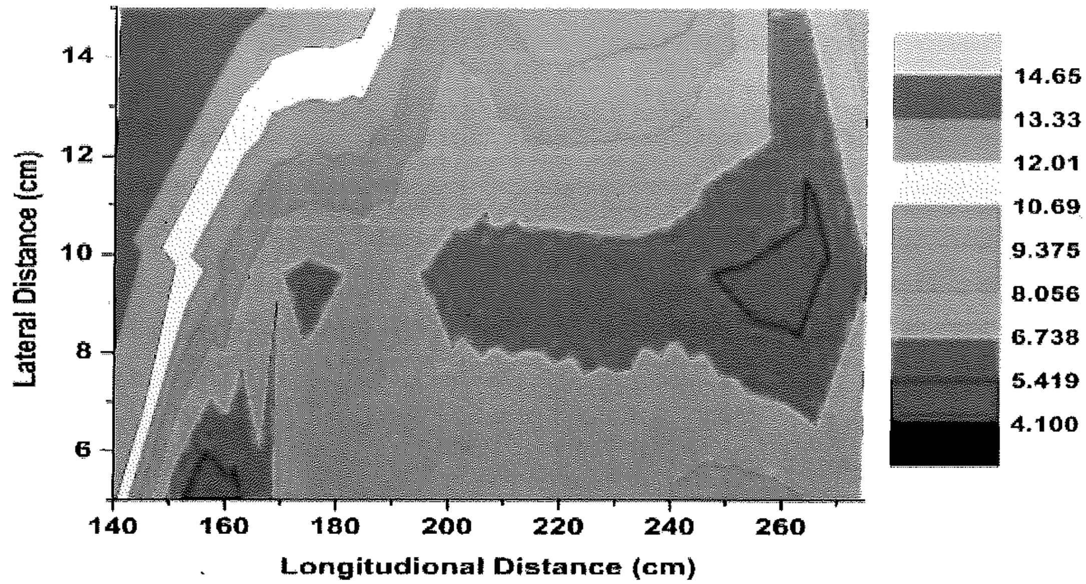


Figure 9.15 : Velocity Contour 7 cm above bed – with Jack Jetty model

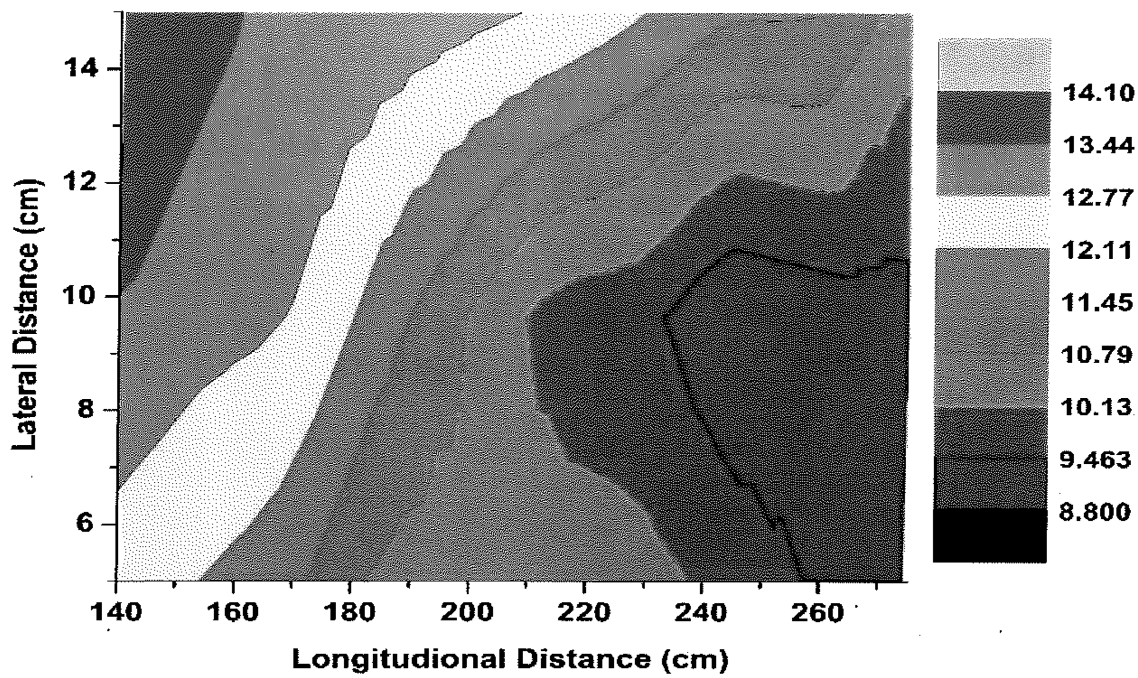


Figure 9.16 : Velocity Contour 10 cm above bed – with Jack Jetty model

Figure 9.17, 9.18, 9.19 and 9.20 represent contour plots in near bed, 4 cm above bed, 7 cm above bed and 10 cm respectively above bed with combined system of Jack Jetty and Trail Dyke. The average velocity in near bed condition, 4 cm above bed, 7 cm above bed & 10 cm above bed are 0.0037 cm/sec, 2.75 cm/sec, 4.16 cm/sec & 5.36 cm/sec respectively.

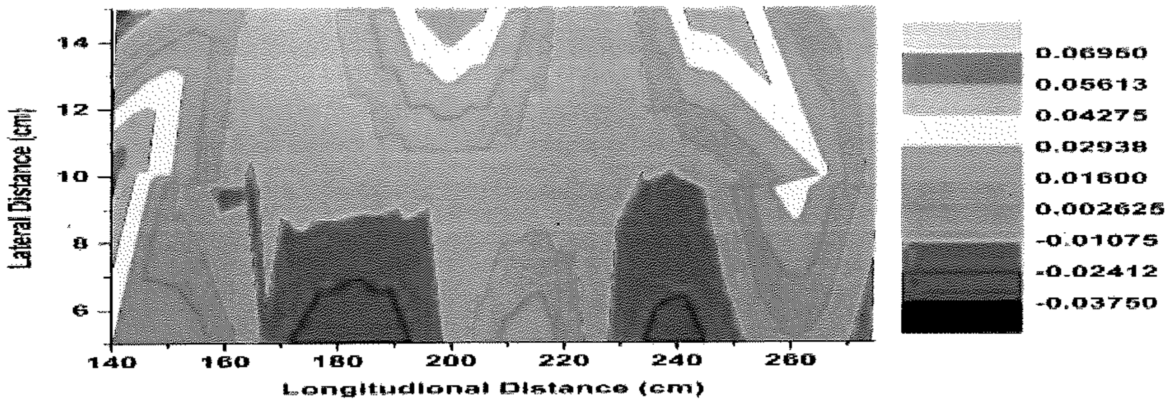


Figure 9.17 : Velocity Contour near bed – with combined system Jack Jetty & Trail Dyke

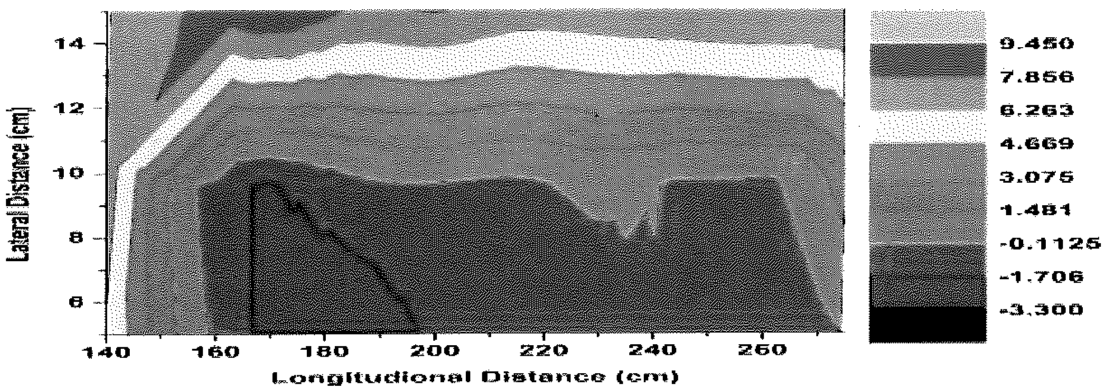


Figure 9.18 : Velocity Contour 4 cm above bed – with combined system Jack Jetty & Trail Dyke

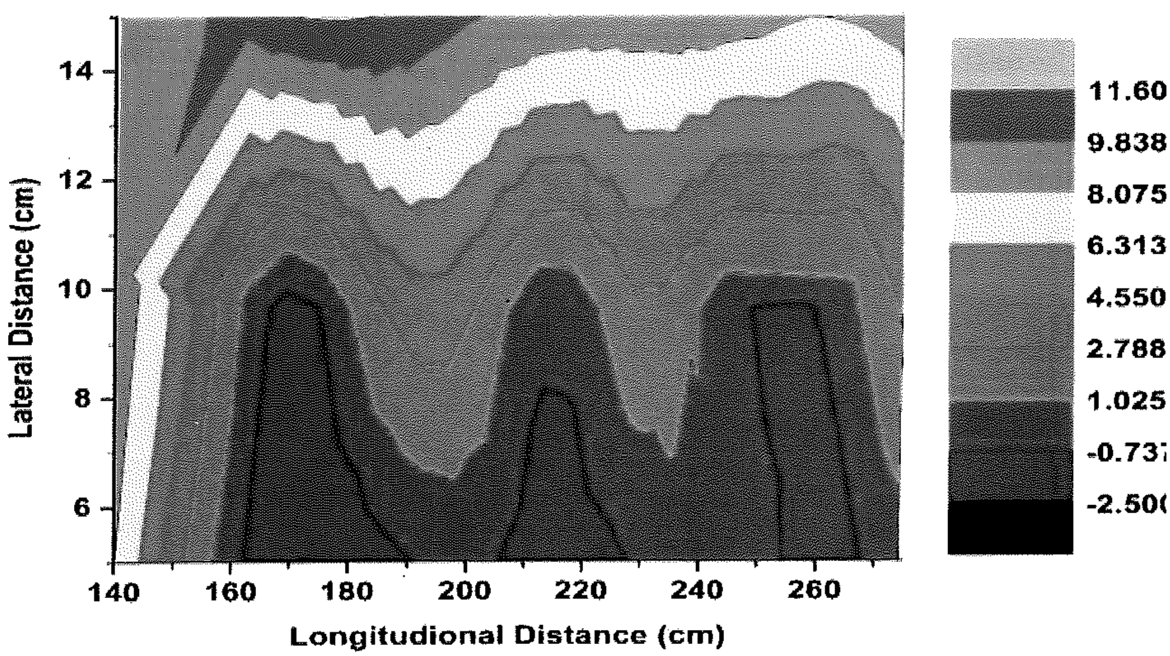


Figure 9.19 : Velocity Contour 7 cm above bed – with combined system Jack Jetty & Trail Dyke

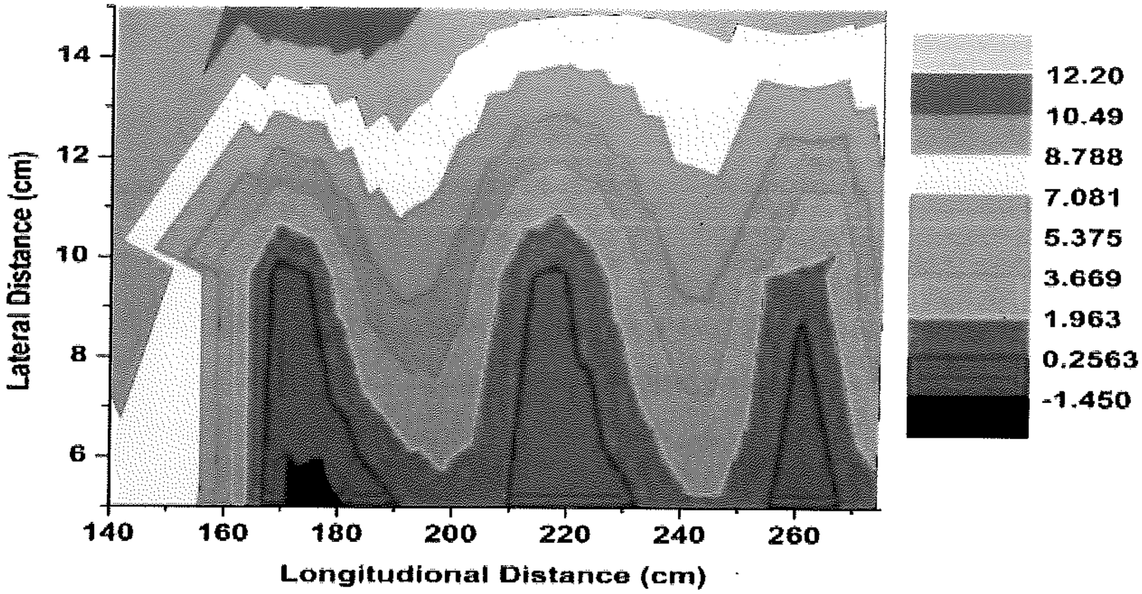


Figure 9.20 : Velocity Contour 10 cm above bed – with combined system Jack Jetty & Trail Dyke

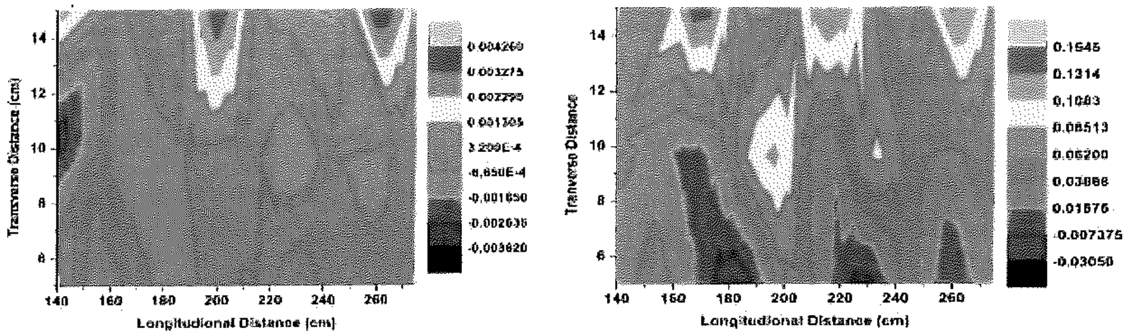
From the contour plots it can be ascertained that velocity flow field gets affected due to the presence of submerged Jacks and Trail Dykes in the vicinity of Jack Jetty and Trail Dyke. It can be observed that lesser velocity along the line of Jack & Trail Dyke and which increases gradually across the sides towards the side of the flume. Under the same discharge conditions, velocity is less in the combined system of Jack Jetty and Trail Dyke.

Table 9.1 : Percentage Reduction in velocity at various depth of flow

Depth of measurement	% Reduction in velocity		
	With Trail Dyke	With Jack Jetty	With Combined system
Near bed	97.07	99.38	99.86
4 cm above bed	60.76	50.17	79.06
7 cm above bed	56.62	38.30	70.57
10 cm above bed	56.72	19.47	62.04

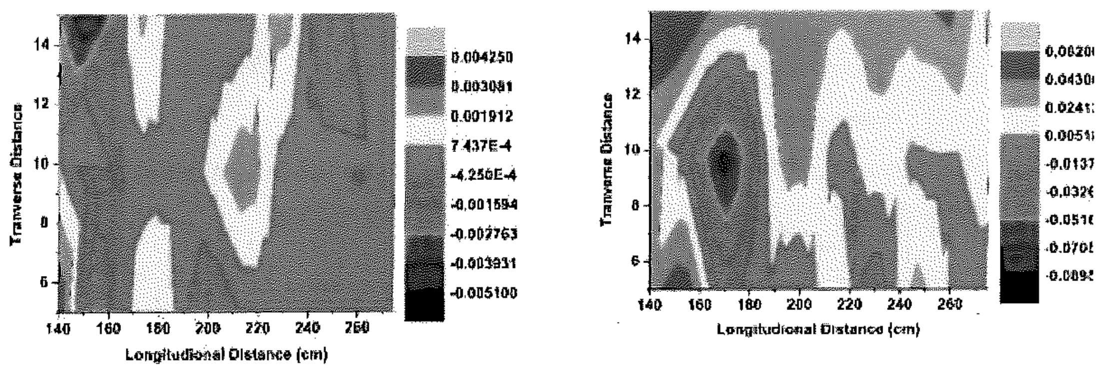
9.4 Study of Reynolds Stress

Figure 9.21, 9.22 and 9.23 represent the distribution of Reynolds stress in horizontal plane near bed and 4 cm above bed with Trail Dyke model only, with Jack Jetty model only and with combined system of Jack Jetty & Trail Dyke respectively. The x-axis denoting the length along the line of flow and y-axis denoting the transverse distance across the flow. The legends of the contours represent the values of Reynolds Stress (N/mm^2). It is seen from the plots that values of Reynolds stress are reduced after installation of jack Jetty & Trail Dyke. All these plots show a particular trend which shows lesser values of Reynolds stress in the line nearby distance from boundary and which gradually goes on decreasing across the sides towards the flume. The Jack Jetty and Trail Dyke are installed up to the distance of 10 cm from boundary. In the periphery of the structure value of Reynolds stress are less.



(a) (b)

Figure 9.21 : Reynolds Stress Contour with Trail Dyke model (a) near bed (b) 4 cm above bed



(a) (b)

Figure 9.22 : Reynolds Stress Contour with Jack Jetty model (a) near bed (b) 4 cm above bed

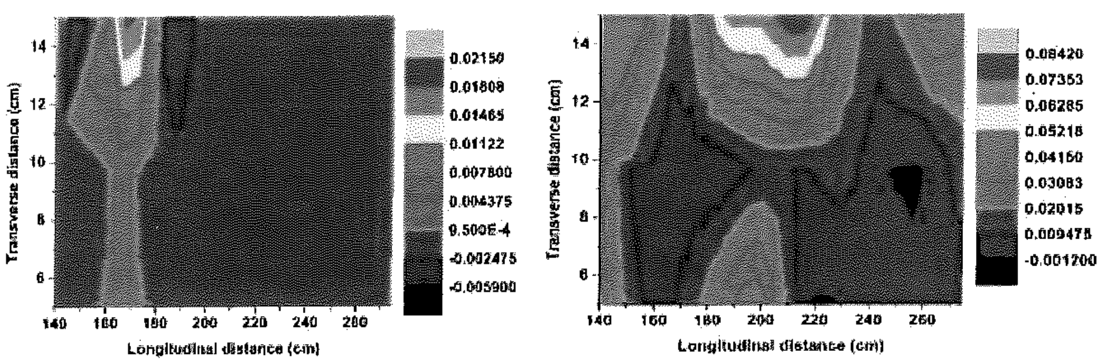


Figure 9.23 : Reynolds Stress Contour with combined system of Jack Jetty and Trail Dyke (a) near bed (b) 4 cm above bed

It was tried to quantify the percentage reduction in Reynolds stress post installation of Jack Jetty & Trail Dyke. Figure 9.24, 9.25 and 9.26 show distribution of percentage reduction in Reynolds stress with Trail Dyke only, Jack Jetty only and combined system of Jack Jetty & Trail Dyke. The contour plots have ascertained that Reynolds stress post installation of structure has been reduced remarkably. The average reduction in Reynolds with Trail Dyke, Jack Jetty and combined system are 8%, 73% and 58% respectively at 4 cm above bed. Similarly in near bed condition percentage reduction are 96%, 98% and 95% with Trail Dyke, jack Jetty and combined system respectively. It is noticed, the reduction in Reynolds stress also follow similar trend as reduction in velocity. This also goes on decreasing across the flow as the effect of Jack Jetty and Trail Dyke diminishes.

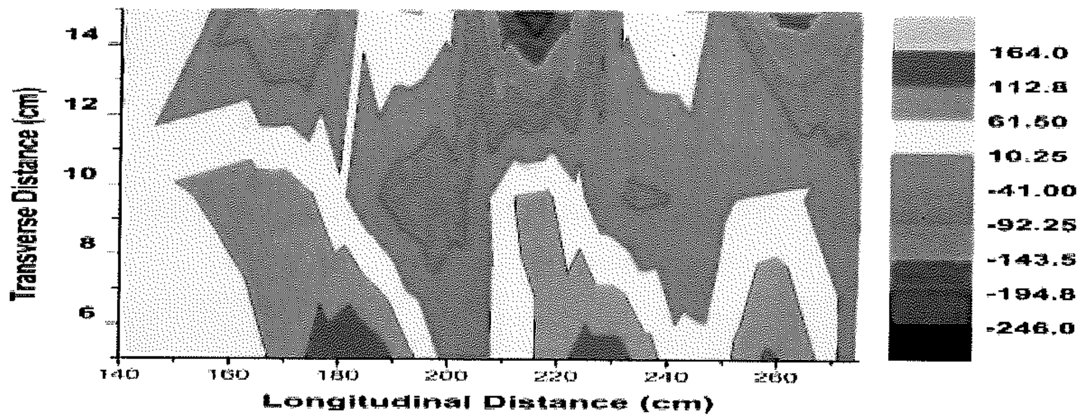


Figure 9.24 : Reynolds stress reduction contour with Trail Dyke model – 4 cm above bed

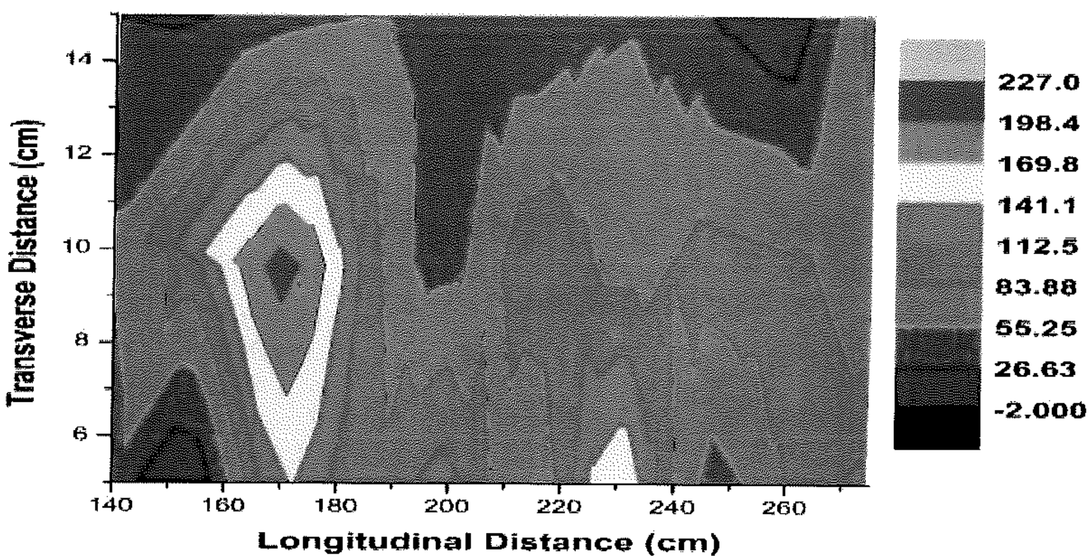


Figure 9.25 : Reynolds stress reduction contour with Jack Jetty model – 4 cm above bed

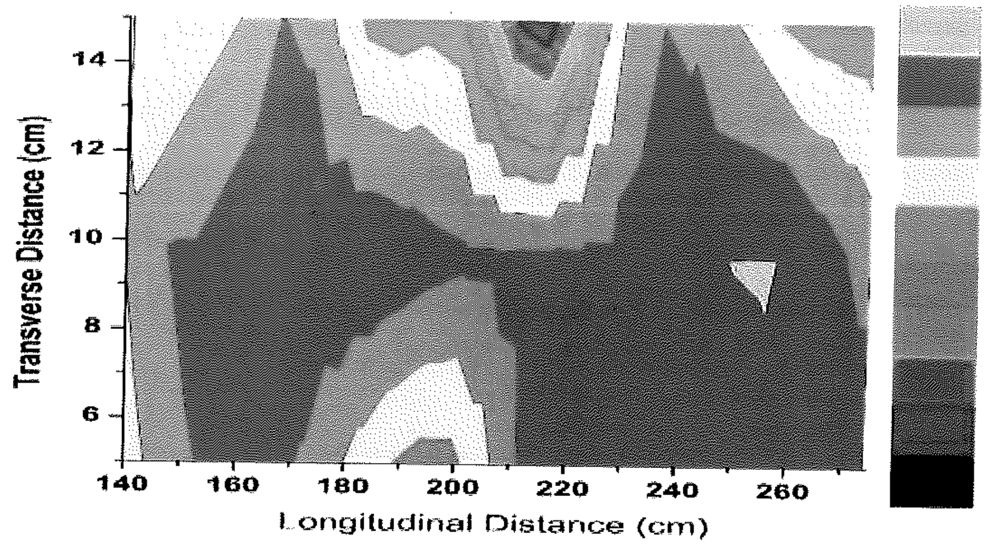


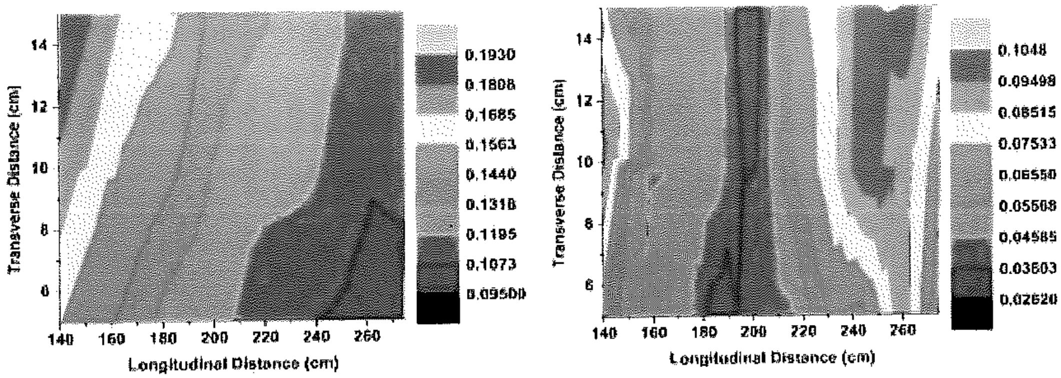
Figure 9.26 : Reynolds Stress Reduction contour with combined system – 4 cm above bed

Table 9.2 : Percentage Reduction of Reynolds Stress

Depth flow	**% Reduction in Reynolds Stress**		
	With Trail Dyke	**With Jack Jetty**	**With Combined system**
Near bed	96	98	95
4 cm above bed	8	73	58

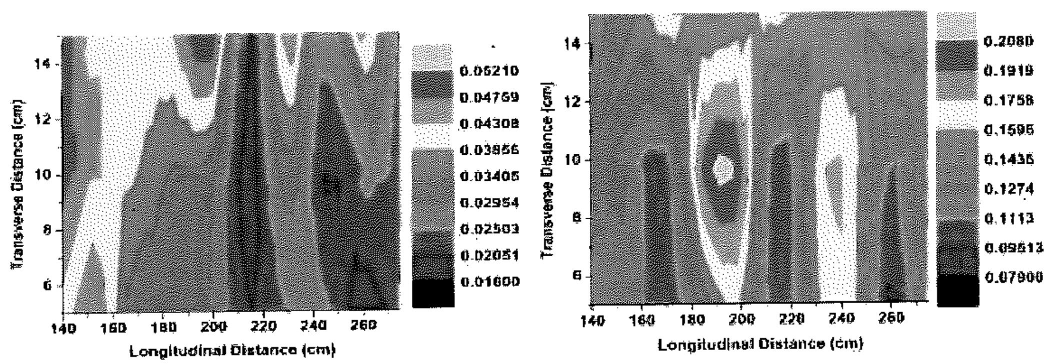
9.5 Study of Turbulent Kinetic Energy

Figure 9.27, 9.28, 9.29 and 9.30 represent the distribution of Reynolds stress in horizontal plane near bed and 4 cm above bed without model (plain condition), with Trail Dyke model only, with Jack Jetty model only and with combined system of Jack Jetty & Trail Dyke respectively. The x-axis denoting the length along the line of flow and y-axis denoting the transverse distance across the flow. The legends of the contours represent the values of Turbulent Kinetic Energy (N/mm^2). It is seen from the plots that values of TKE are reduced after installation of jack Jetty & Trail Dyke. The Jack Jetty and Trail Dyke are installed up to the distance of 10 cm from boundary. In the periphery of the structure values of TKE are less.



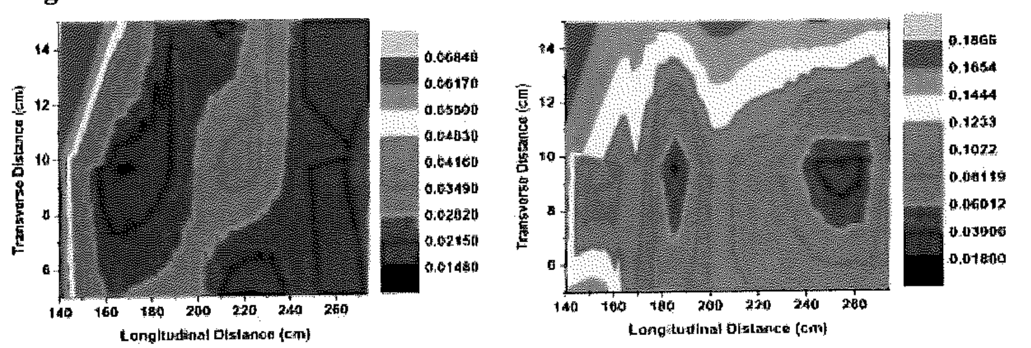
(a) (b)

Figure 9.27 : Distribution of TKE (a) near bed (b) 4 cm above bed with no model (plain condition)



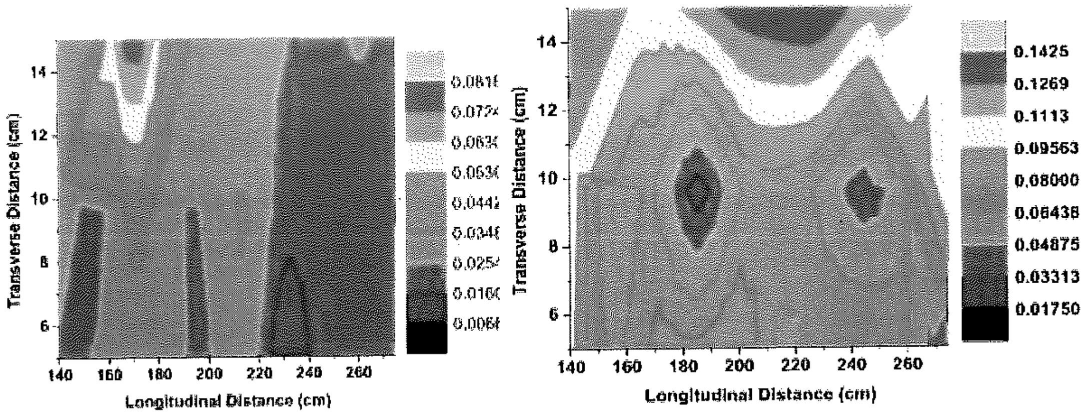
(a) (b)

Figure 9.28 : Distribution of TKE (a) near bed (b) 4 cm above bed with Trail Dyke only



(a) (b)

Figure 9.29 : Distribution of TKE (a) near bed (b) 4 cm above bed with Jack Jetty only



(a) (b)

Figure 9.30 : Distribution of TKE (a) near bed (b) 4 cm above bed with combined system

It was tried to quantify the percentage reduction in TKE post installation of Jack Jetty & Trail Dyke. Figure 9.31, 9.32 and 9.33 show distribution of percentage reduction in TKE with Trail Dyke only, Jack Jetty only and combined system of Jack Jetty & Trail Dyke. The contour plots have ascertained that TKE post installation of structure has been reduced remarkably. The average reduction in TKE with Trail Dyke, Jack Jetty and combined system are 49%, 53% and 57% respectively at 2 cm above bed. Similarly at 4 cm above bed, percentage reduction are -6%, 12% and 34% with Trail Dyke, jack Jetty and combined system respectively. The value of TKE has been increased at 4 cm above bed with Trail Dyke model only. This also goes on decreasing across the flow as the effect of Jack Jetty and Trail Dyke diminishes.

Figure 9.31 : Distribution of Percentage reduction in TKE near bed with Trail Dyke only

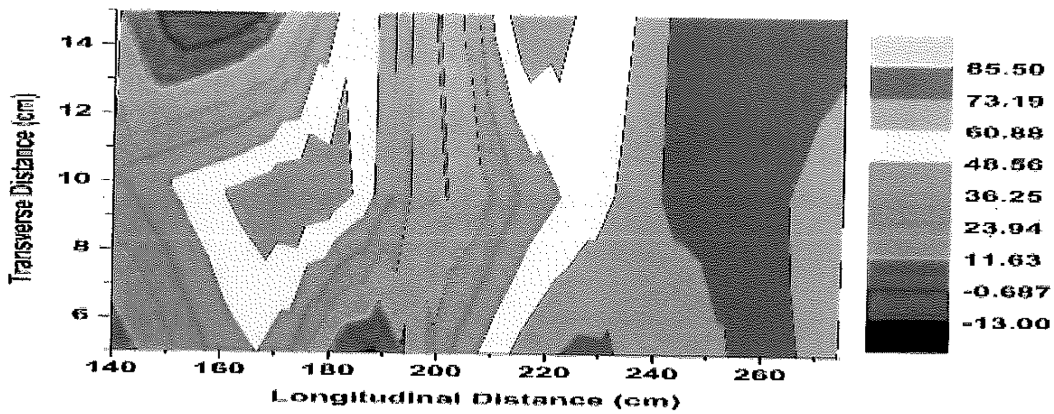


Figure 9.32 : Distribution of Percentage reduction in TKE near bed– with Jack Jetty only

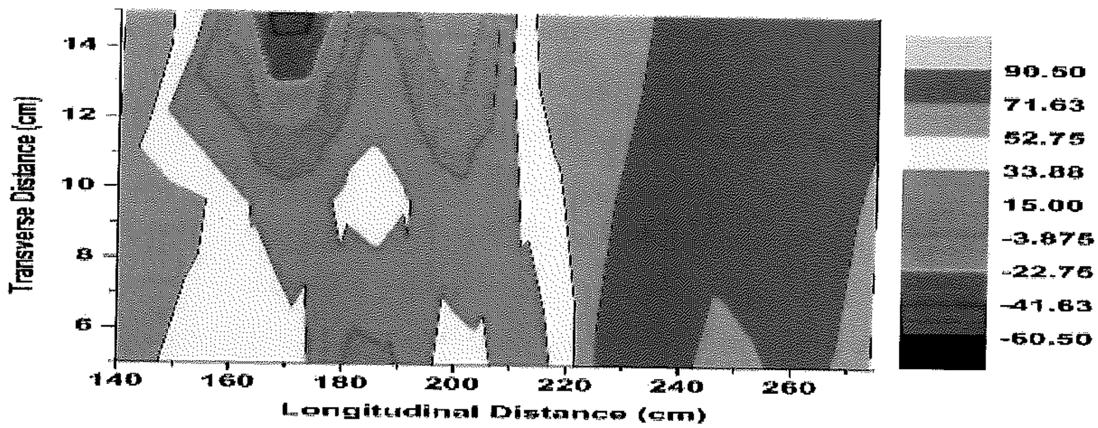


Figure 9.33 : Distribution of TKE near bed –with combined system

9.6 Study of Bursting Ratio and Deposition/Scouring

The conditional probability of occurrence of sweep and ejection quadrant events are calculated at 10 different points at the distance of 2 cm from the bed. The plot between bursting ratio and scouring/deposition are plotted for 10 different points located 15 cm from the boundary for four different conditions for same discharge and depth of flow. The bursting ratio values are shown in primary axis and scouring/deposition values are shown in secondary axis. The negative values in secondary axis show deposition whereas positive values represent scouring. The bursting ratio is high at the point of scouring and low at point of deposition.

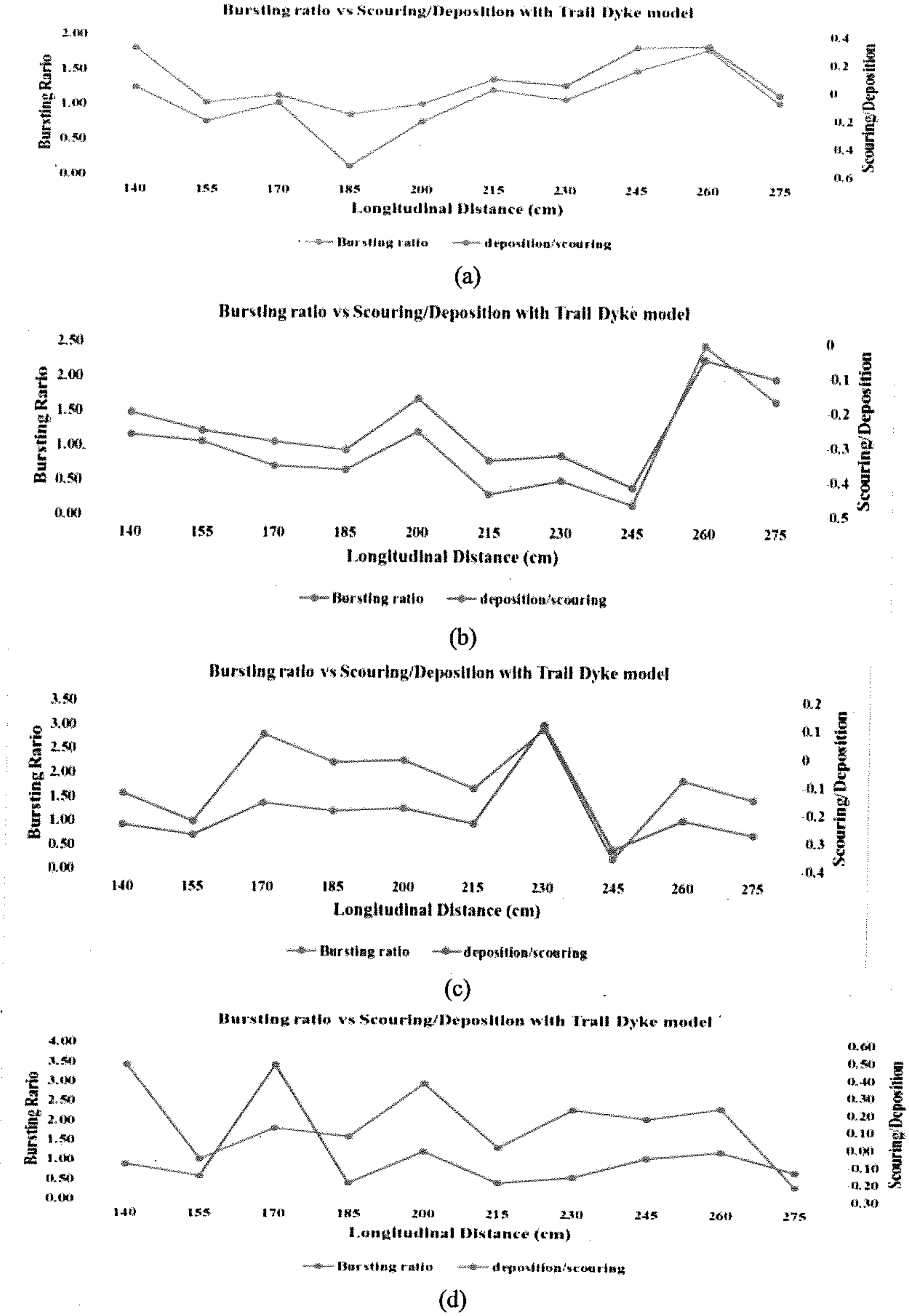


Figure 9.34 : Shows relation between bursting ratio and scouring/deposition (a) without model (b) with Trail Dyke (c) with Jack Jetty (d) with combined system

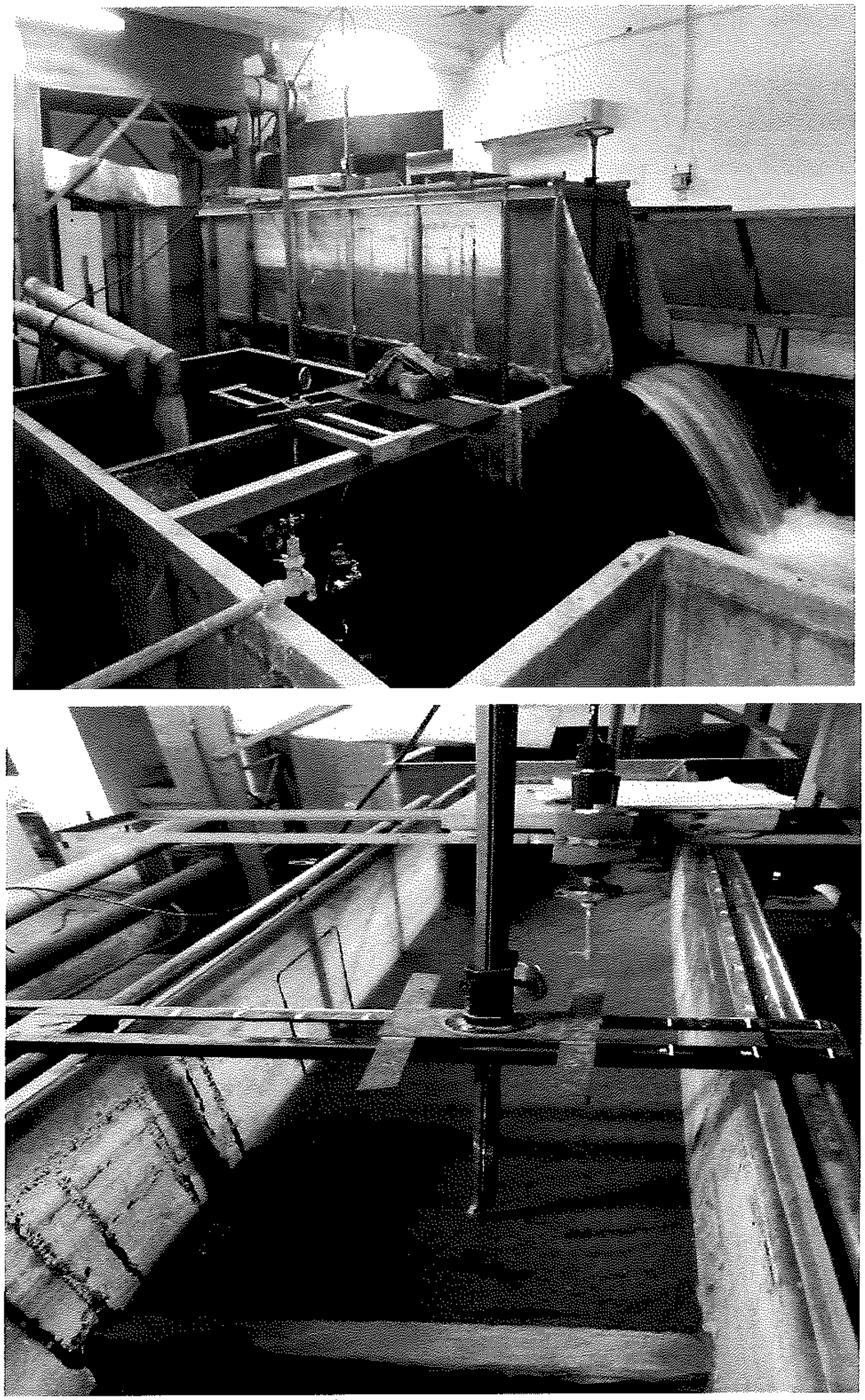


Figure 9.35 : Experiment in Plain Condition (with no model)

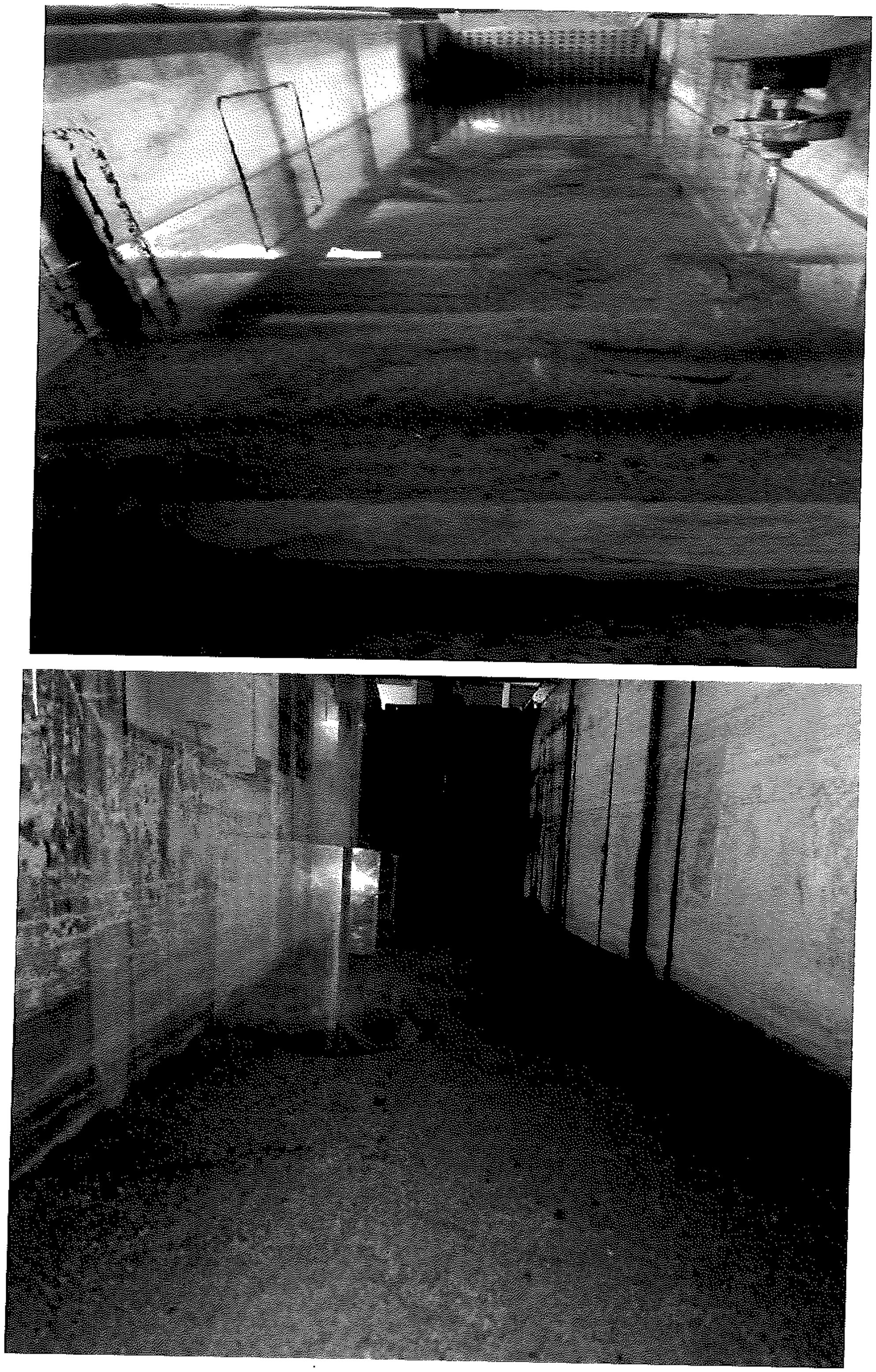


Figure 9.36 : Experiment with Trail Dyke model only

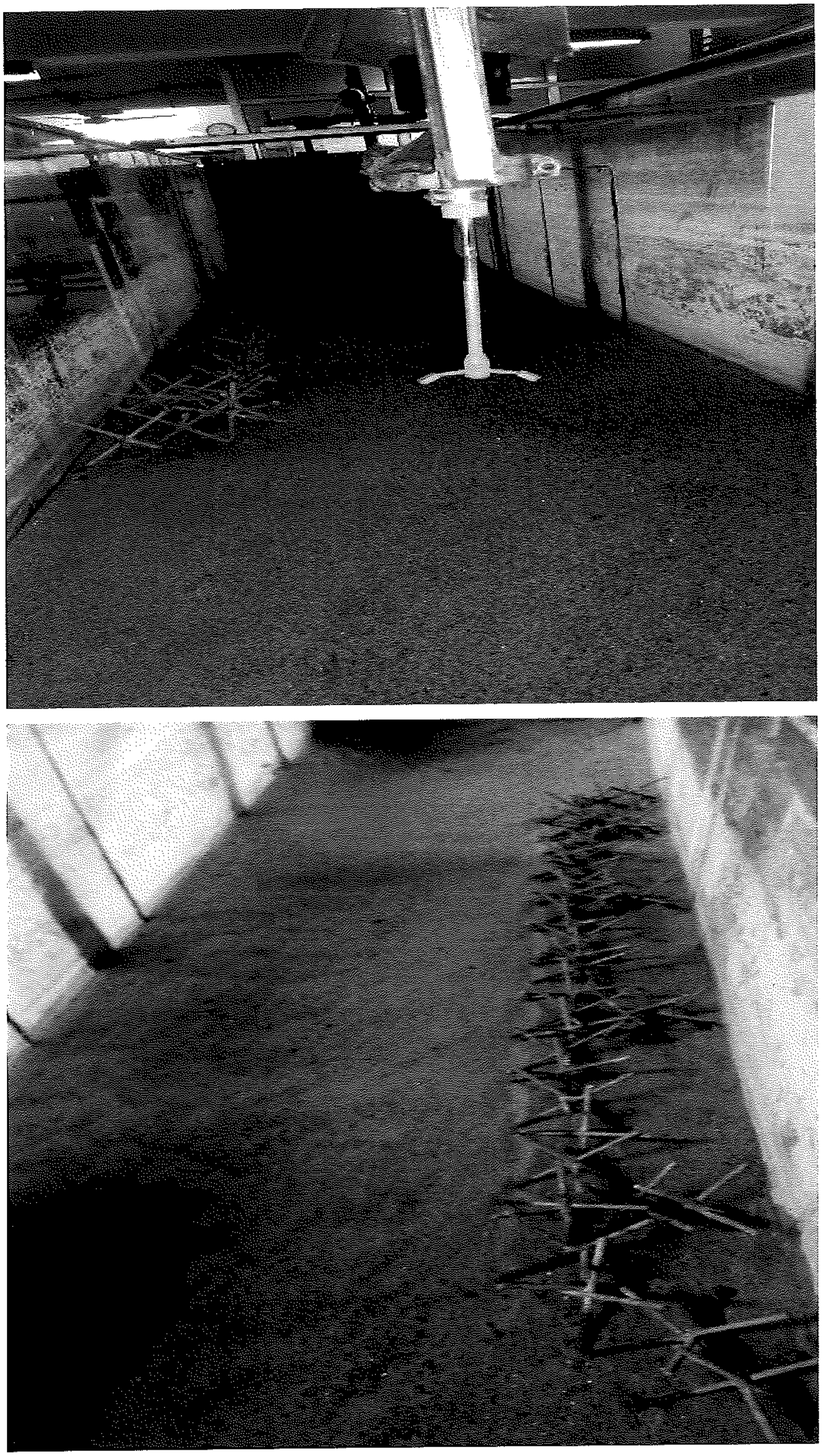


Figure 9.37 : Experiment with Jack Jetty model only

Figure 9.38 : Experiment with combined system

9.7 Study of Multi-Tiered Jack Jetty System

In the big river having more depth like Koshi River, multi-tiered Jack Jetty will be appropriate for better sedimentation. To study the performance of multi-tiered Jack Jetty system (Objective IV), lab experiment has been conducted. The experiment was carried for three following conditions

i) Experiment in without model Figure 9.39.

ii) Experiment with single-tiered Jack Jetty Figure 9.40. **Error! Reference source not found.**

iii) Experiment with multi-tiered Jack Jetty Figure 9.41.

Constant discharge and water depth was maintained for all three experiments.

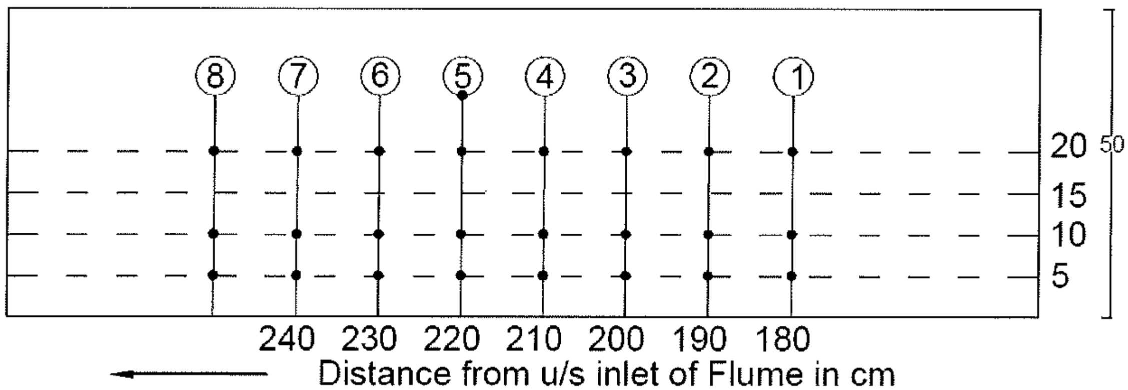


Figure 9.39 : Experimental Plan without model

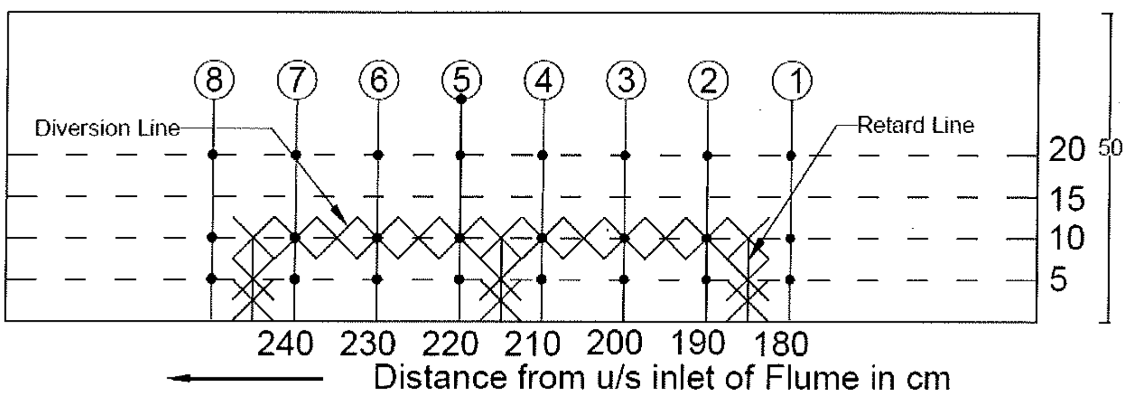


Figure 9.40 : Experimental Plan with Single Tiered Jack Jetty

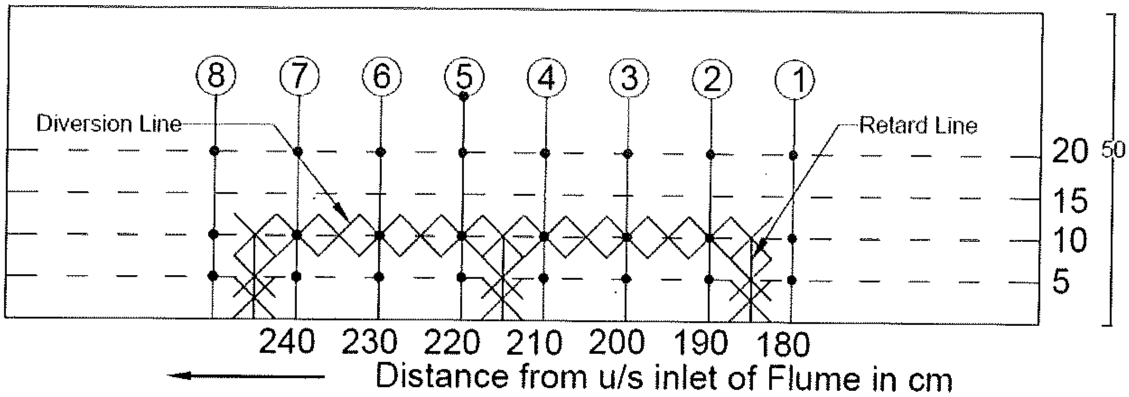
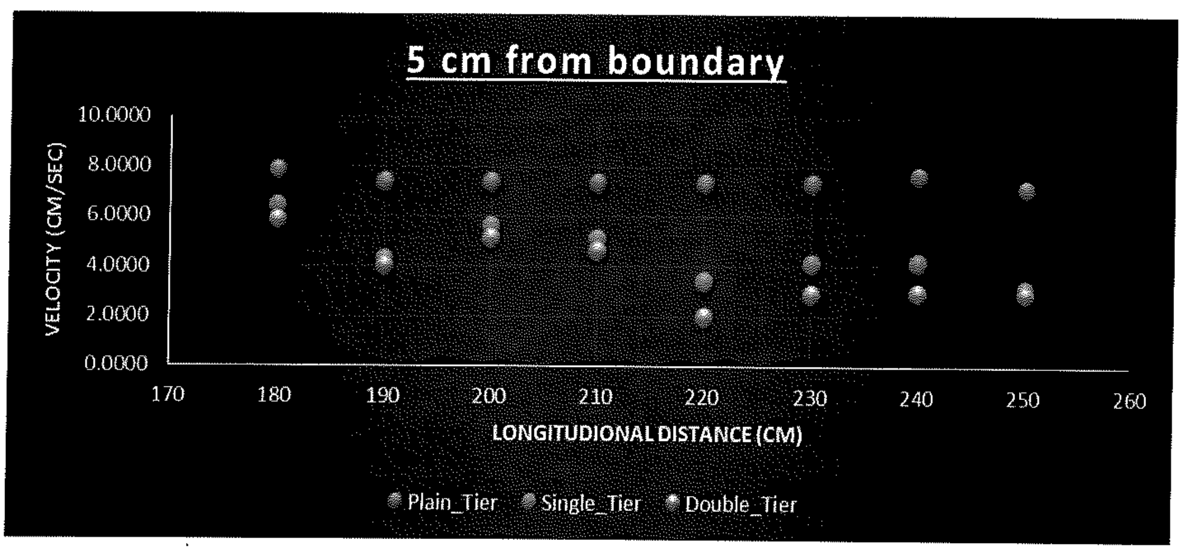


Figure 9.41 : Experimental Plan with Double Tiered Jack Jetty

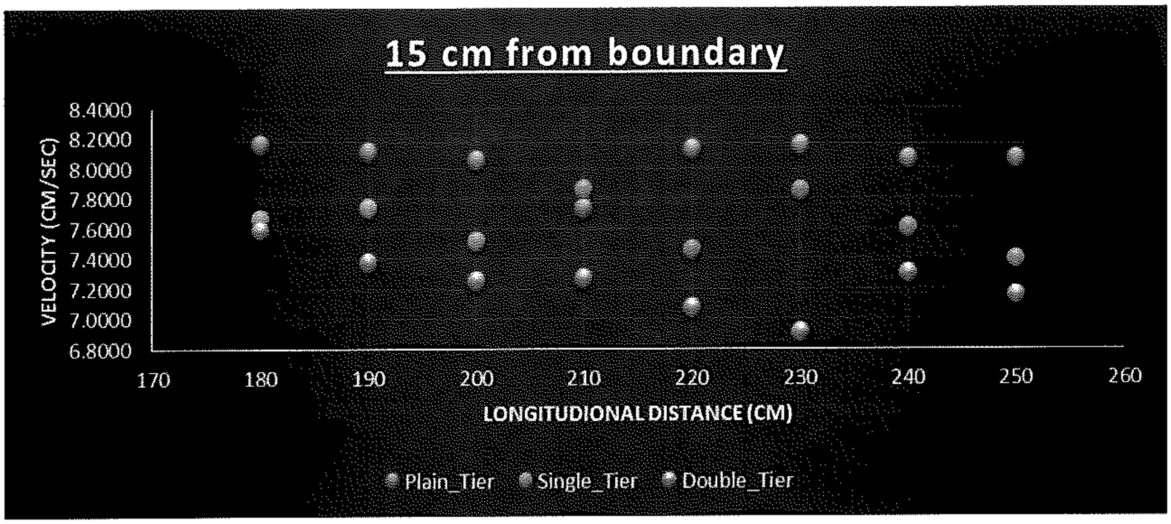
To observe the spatial and temporal velocity data, flow domain is divided into 72 grid points (8*3*3). The experimental set up is as shown in figures above. The sampling rate by ADV was 25 Hz. The instantaneous velocities in the longitudinal direction (u), transverse direction (v) and in vertical direction (w) were recorded for each nodal points. The velocity measurements were taken in three different depths near bed, 5.5 cm above bed and 8.5 cm above bed. The constant discharge and constant water depth (25 cm) were maintained throughout the experiment.

9.7.1 Study of Velocity Profile

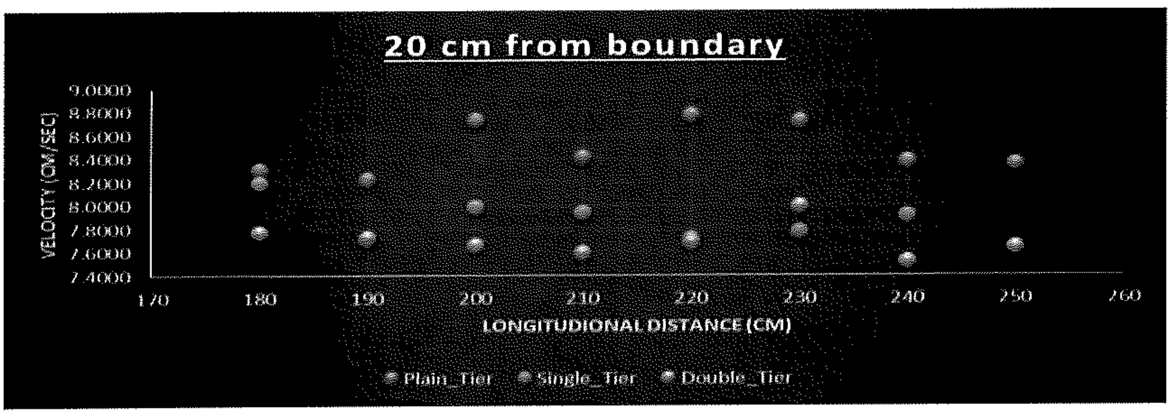
To evaluate the performance of multi-tiered jack jetty system, velocity profile has been drawn. The velocity data measured for each experiment were compared from the plots.



(a)



(b)



(c)

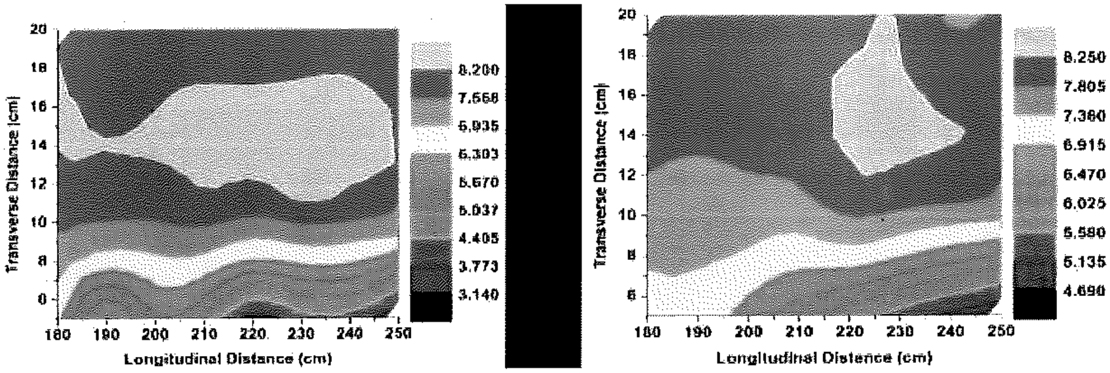
Figure 9.42 : Velocity Profile (a) 5 cm (b) 15 cm (c) 20 cm from boundary – 5.5 cm above bed

The above figure shows that velocities are decreased with the installation of Jack Jetty. The velocity is less in double tiered jack jetty system.

9.7.2 Study of Velocity Contour

Similarly velocity contours are plotted to certify the findings of velocity profiles. Velocity contours are drawn for the experiment without model, single-tiered and double tiered jack jetty system. These were plotted for different depths of flow 5.5cm and 8.5 cm above bed. In the contour plots x-axis represents the longitudinal distance (cm) and y –axis represents lateral distance (cm). Velocity measurements are in cm/sec.

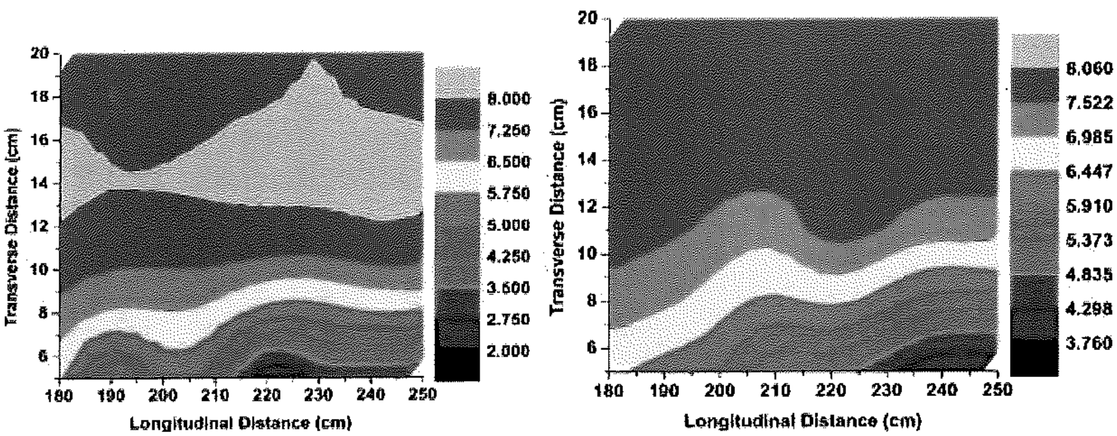
Figure 9.43 represents contour plots in 5.5cm and 8.5 cm above bed single-tiered jack jetty system. The average velocity at 5.5 cm and 8.5 cm above bed are 6.68 cm/sec and 7.23 cm/sec respectively.



(a) (b)

Figure 9.43 : Velocity contour (a) 5.5 cm above bed (b) 8.5 cm above bed – Single Tiered

Figure 9.44 represents contour plots in 5.5cm and 8.5 cm above bed with double-tiered jack jetty system. The average velocity at 5.5 cm and 8.5 cm above bed are 6.26cm/sec and 6.73 cm/sec respectively.



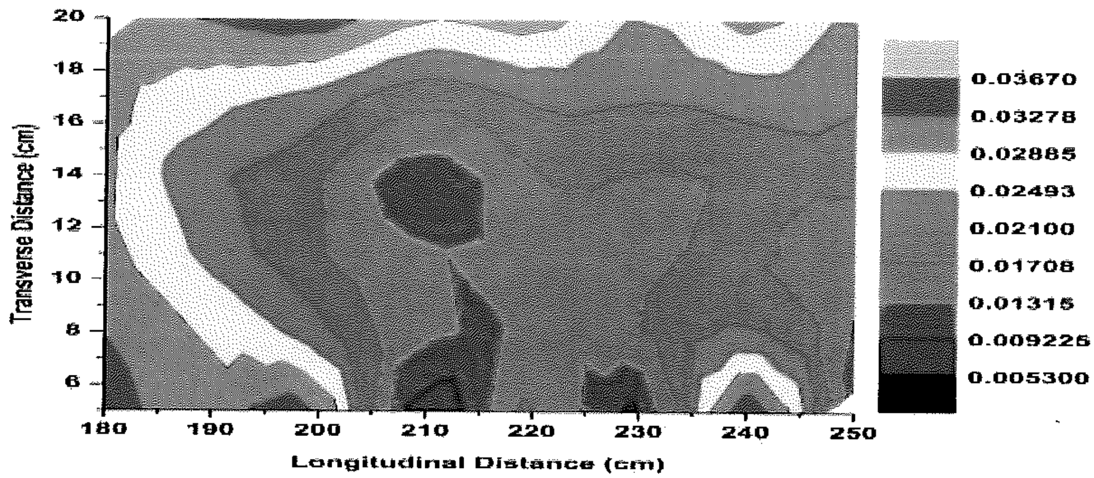
(a) (b)

Figure 9.44 : Velocity Contour (a) 5.5 cm above bed (b) 8.5 cm above bed – Double Tiered

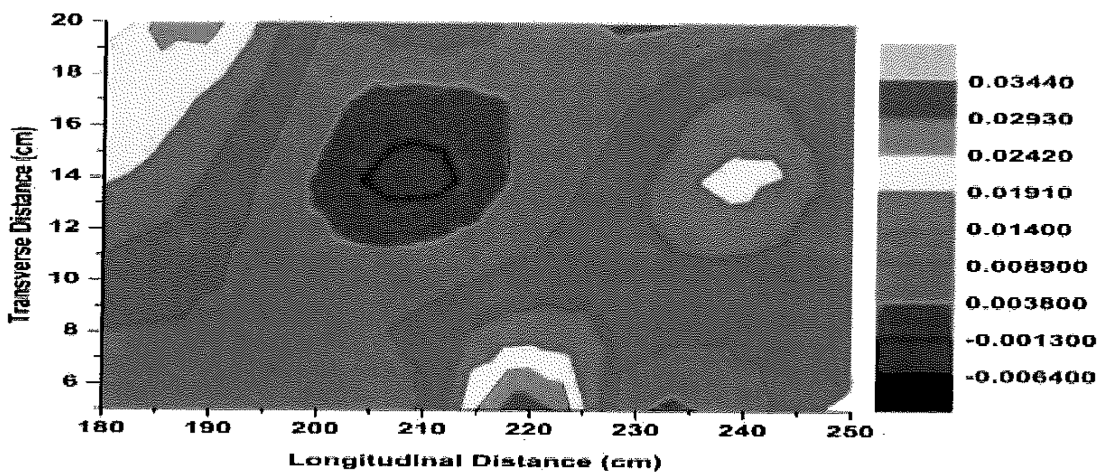
From the contour plots it can be ascertained that velocity flow field gets affected due to the presence of submerged Jacks in the vicinity of Jack Jetty field. It can be observed that lesser velocity along the line of Jack and which increases gradually across the sides towards the side of the flume. Under the same discharge conditions, velocity is less in the double-tiered system of Jack Jetty.

9.7.3 Study of Reynolds Stress

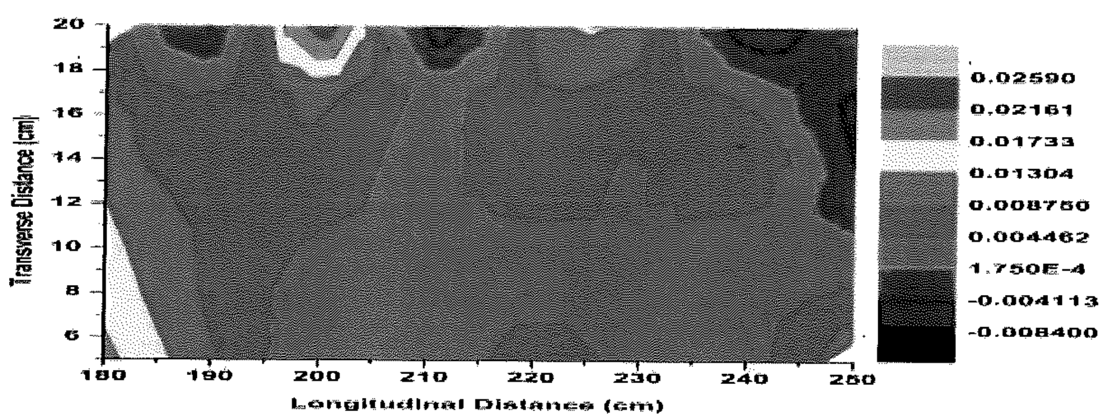
Figure 9.45 (a), (b) (c) represent the distribution of Reynolds stress in horizontal plane without model, with single-tiered and double-tiered jack jetty system respectively. The x-axis denoting the length along the line of flow and y-axis denoting the transverse distance across the flow. The legends of the contours represent the values of Reynolds Stress (N/mm^2). It is seen from the plots that values of Reynolds stress are reduced after installation of jack Jetty. The Jack Jetty are installed up to the distance of 10 cm from boundary. In the periphery of the structure value of Reynolds stress are less.



(a)

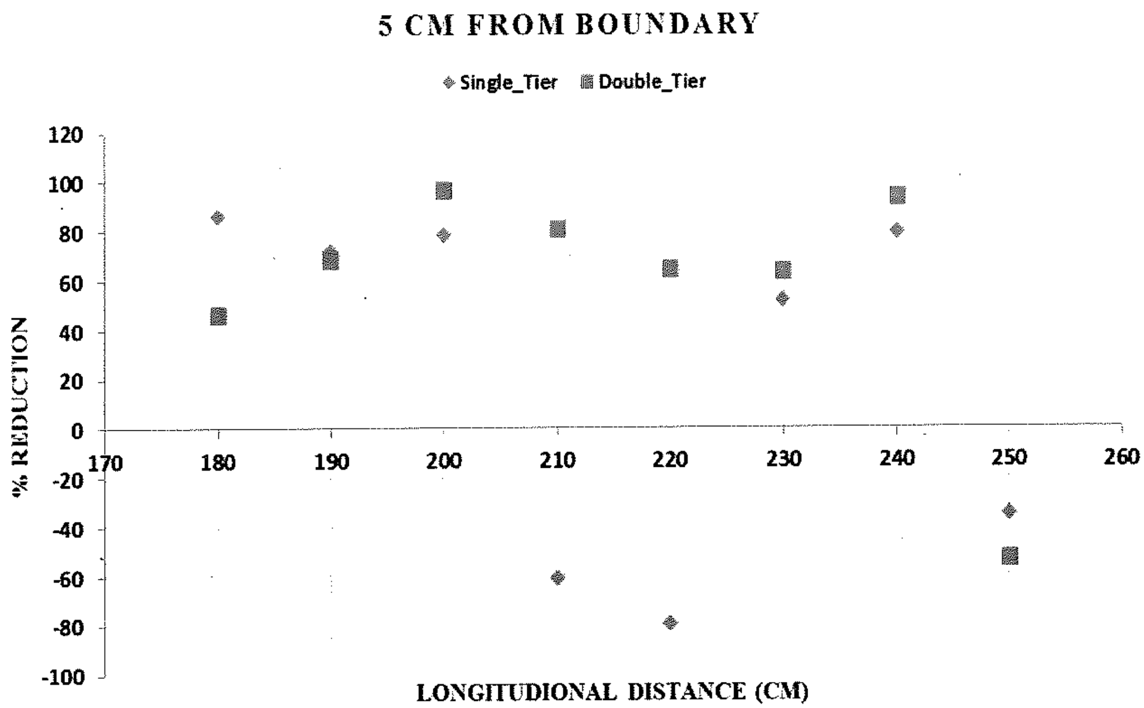


(b)

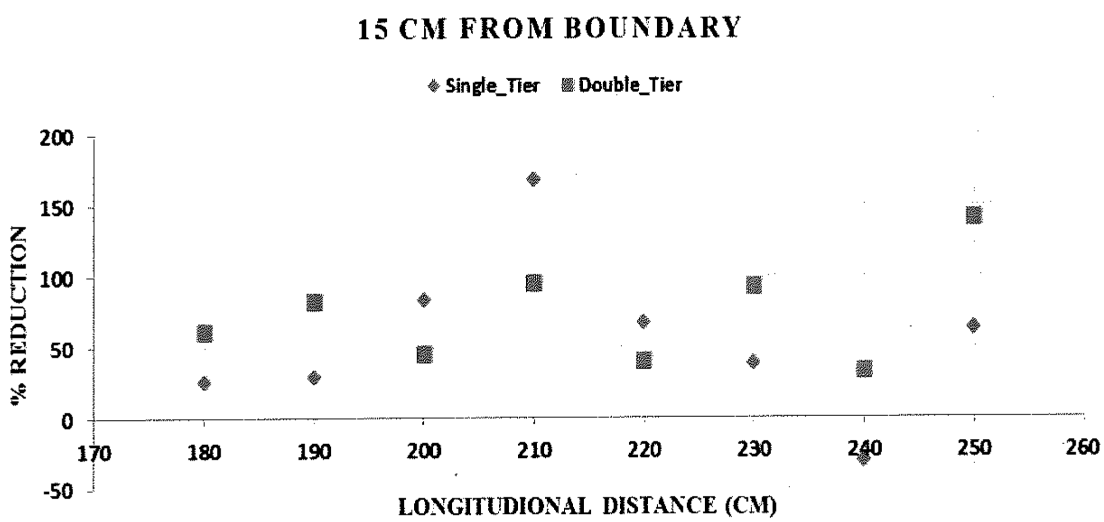


(c)

Figure 9.45 : Distribution of Reynolds Stress (a) without model (b) with Single Tiered Jack Jetty (c) with Double Tiered Jack Jetty


5 CM FROM BOUNDARY
Single_Tier
Double_Tier
% REDUCTION
LONGITUDIONAL DISTANCE (CM)
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
170
180
190
200
210
220
230
240
250
260

(a)


15 CM FROM BOUNDARY
Single_Tier
Double_Tier
% REDUCTION
LONGITUDIONAL DISTANCE (CM)
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100
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170
180
190
200
210
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240
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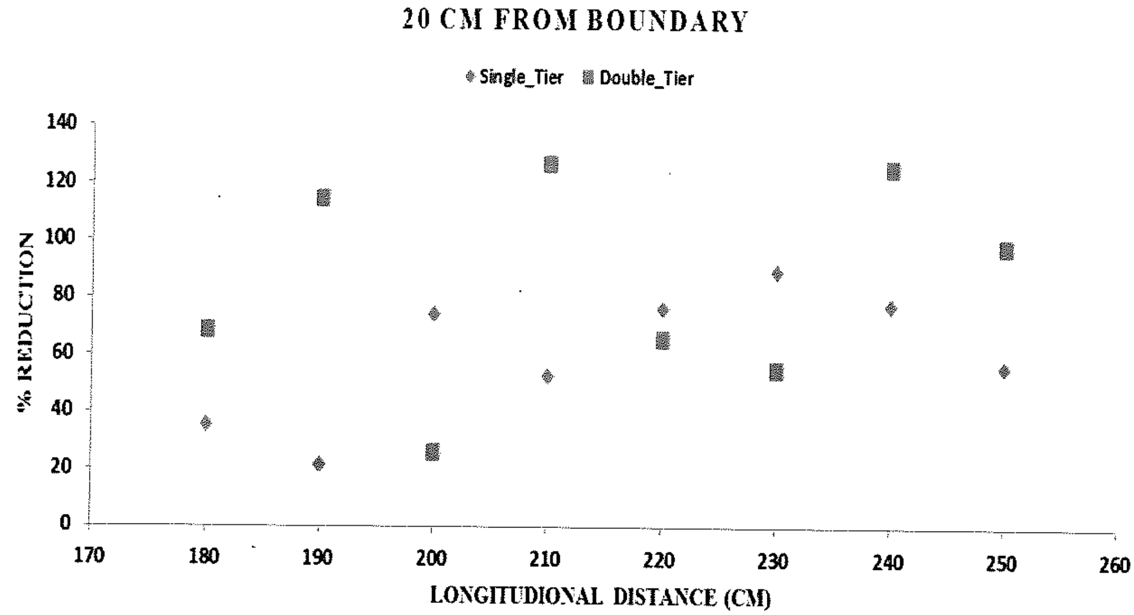
(b)



(c)

Figure 9.46 : Reduction of Reynolds Stress in percentage (a) 5 cm (b) 15 cm (c) 20 cm from boundary

It was tried to calculate the percentage reduction in Reynolds stress post installation of multi-tiered jack jetty system. Figure 9.46 shows the comparison of Reynolds stress reduction by single tiered and double tiered system in different longitudinal sections i.e. 5cm, 15 cm and 20 cm from boundary. The average reduction in Reynolds stress with single tiered system at 5cm, 15cm and 20 cm from the boundary are 24.14%, 55.73% and 60.38% respectively. Similarly the Reynolds stress reduction with double tiered system in three longitudinal sections are 57.71%, 74.13% and 85.12% respectively.

Table 9.3 : Percentage Reduction of Reynolds Stress with multi-tiered system

Distance from boundary	**% Reduction in Reynolds stress**	
	With single tiered	**With double tiered**
5 cm	24.14	57.71
10 cm	55.73	74.13
20 cm	60.38	85.12

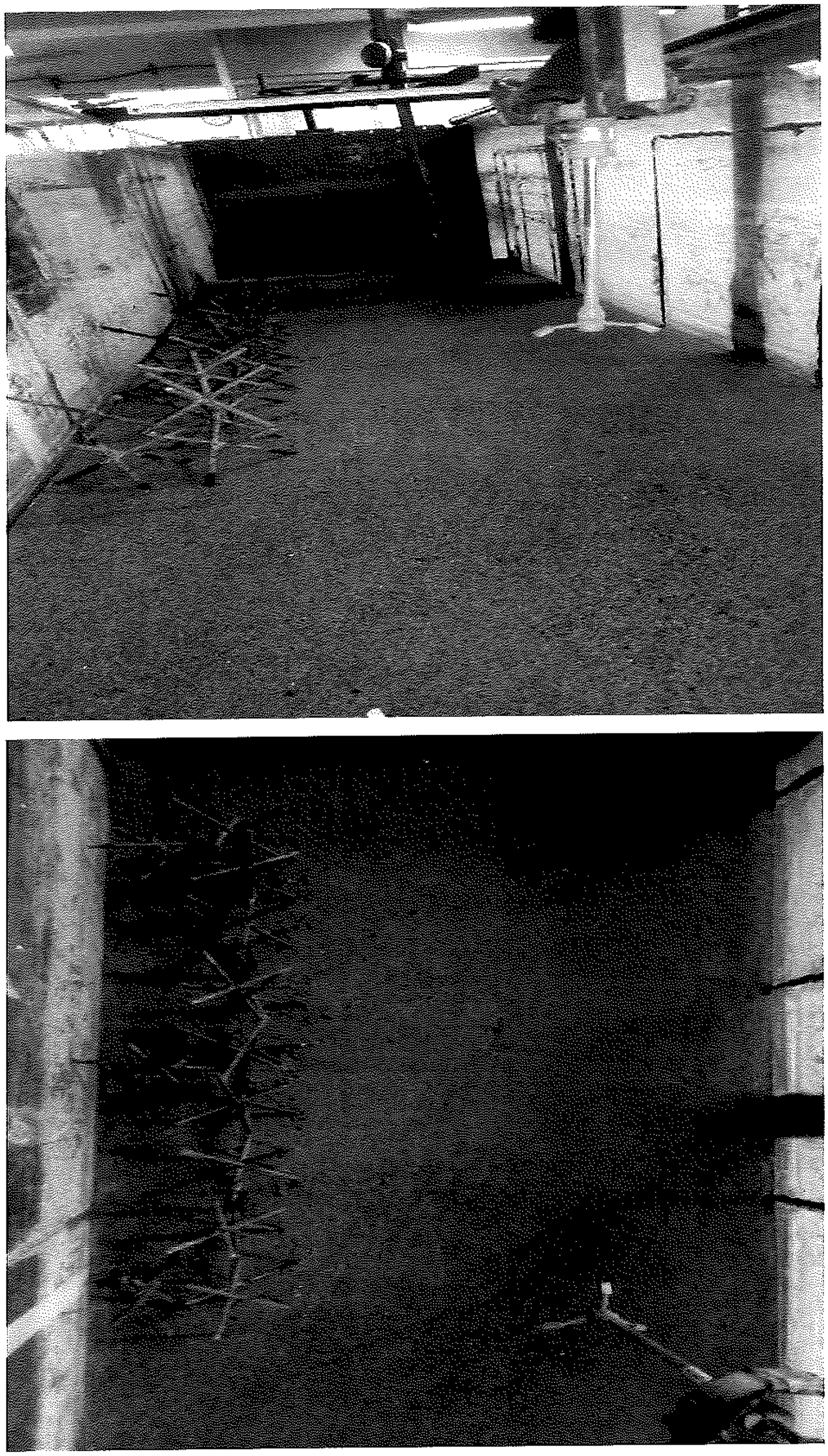


Figure 9.47 : Experiment on multi-tiered Jack Jetty system

CHAPTER – 10
APPLICATION OF JACK JETTY IN SOLANI RIVER PHASE – 2

10.1 Data Collection (Topographical Survey)

Before installation of the jack jetty system, a topographical survey was carried out pre - monsoon. The bed level data were taken before monsoon with the help of dumpy level. For this, the line joining the edge of two existing trail dikes (TD1-U & TD-1D) was made straight. With reference to the straight line cross section data in between the two trail dikes were taken in the interval of 10 m. The distance between two existing trail dykes was 175m. The cross section was taken for the entire distance. The pre-monsoon survey was conducted in the month of June, 2017.

To evaluate the performance of the jack jetty system, post-monsoon topographical survey after implementation of Jetty system was also carried out. The post monsoon survey was conducted in the month of February, 2018. Level data were taken at the same points as that of pre-monsoon survey. The level data were compared for the performance of the system.

Figure 10.1 : Dumpy Level with Tripod stand and Staff

Figure 10.2 : Study area pre monsoon

Figure 10.3 : Study area during post-monsoon survey

10.2 Materials and Method

10.2.1 RCC Jack Jetty

The size of RCC jack jetty used was 1.5m*0.1m*0.1m. Initially monolithic RCC Jack Jetty system was planned to install in the river because of its strength. But the time was short and monsoon was going to start, so individual RCC frames were casted in the site. The individual frames were tied together at the mid points with GI wire.

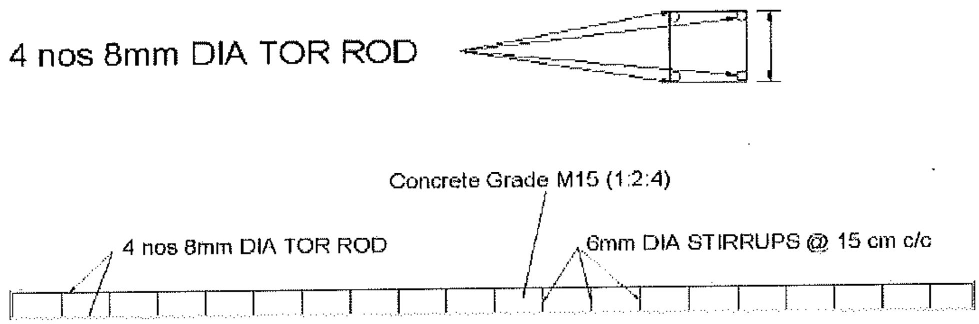


Figure 10.4 : Details of Longitudinal reinforcement of RCC Jack Jetty

Figure 10.5 : Casting of RCC Jack

10.2.2 Layout Plan of Jack Jetty

As described in previous chapter, the RCC Jack Jetty was proposed to place in between two existing trail dykes (TD-1U and TD-1D) near the 2 MW Solar Power Plant to prevent the bank from erosion and to reclaim the eroded land. The proposed length of the diversion line (along the flow of river) was 150 m and the length of the retards (across the flow of river) designed was 9 m. The spacing of the retard lines was designed in the interval of 30 m as shown in Figure 10.6.

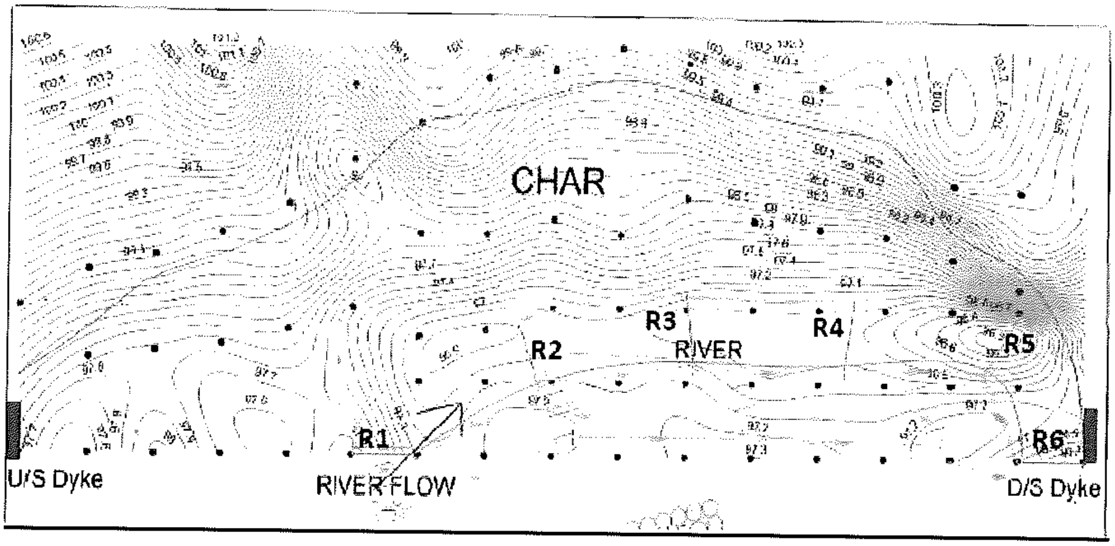


Figure 10.6 : Layout Plan of Jack Jetty

As 70 m diversion line was completed, there was a heavy flood in the river in 11th July, 2017. The further extension of diversion line was difficult due to presence of water in the river and swampy land in that area. Extension of diversion line was stopped.

Figure 10.7 : Study area before implementation of Jetty system

10.2.3 Implementation of Jack Jetty

The RCC Jack Jetty system was started to install from 6th July, 2017.

Figure 10.8 : Study area during implementation of Jetty system

The land of that area was so swampy so implementation was difficult. First 9m retard line, from u/s side and 60 m diversion line were completed up to 10th July, 2017.

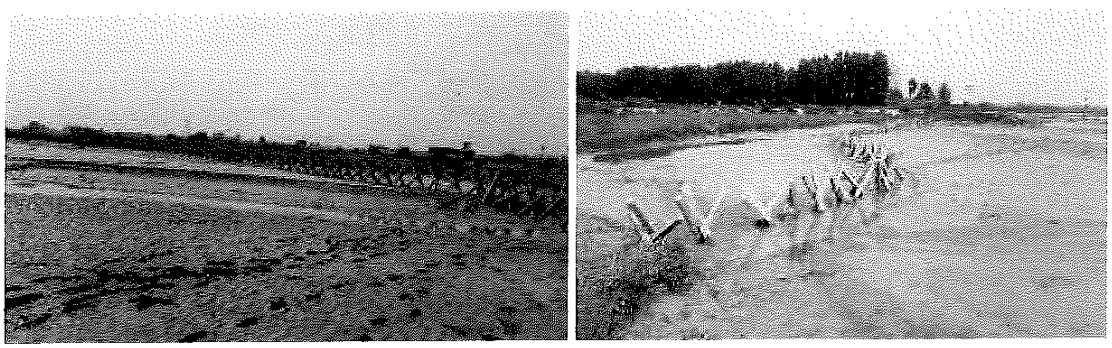


Figure 10.9 : Study area during implementation of Jetty system

Just after completion of the 70 m diversion line and one retard line (9 m), there was a flood in the river. There was sufficient deposition around the periphery the Jack Jetty. However a small channel of about 3 - 5 m was formed due to flood. The channel was formed in the inner side of the diversion line. Up to that time retard lines were not completed, so channel was developed. This was a threat in the implementation of Jetty system.

Figure 10.10 : Silt deposition and Formation of Channel

Due to continuous rainfall, water in the river and swampy land further extension of diversion line was difficult so jack jetty in diversion line was not extended. Two retard lines (R2 & R3) were installed hurriedly. Also one extra retard line (R1') in the u/s side of the channel was constructed during the monsoon to close the channel.

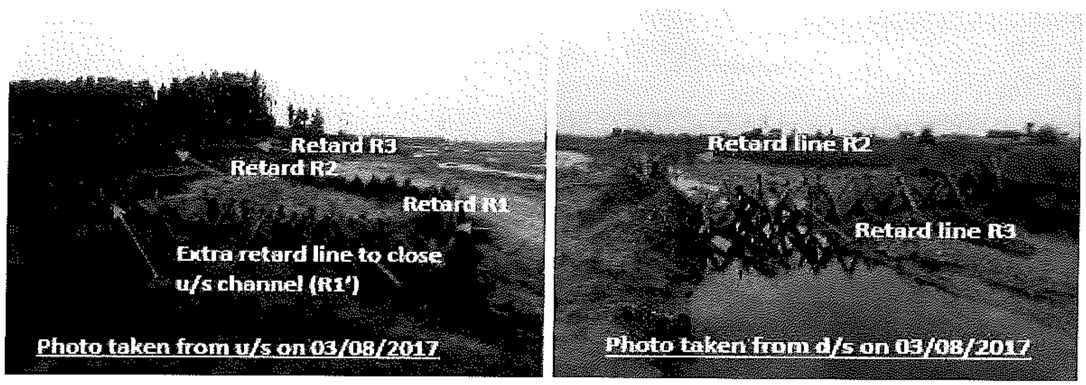


Figure 10.11 : Construction of Retard lines after channel formation

After construction of retard lines including extra retard line (R1') in the u/s side, the channel was continuously deposited and subsequently closed.

Figure 10.12 : Photo taken from u/s on 20/8/2017

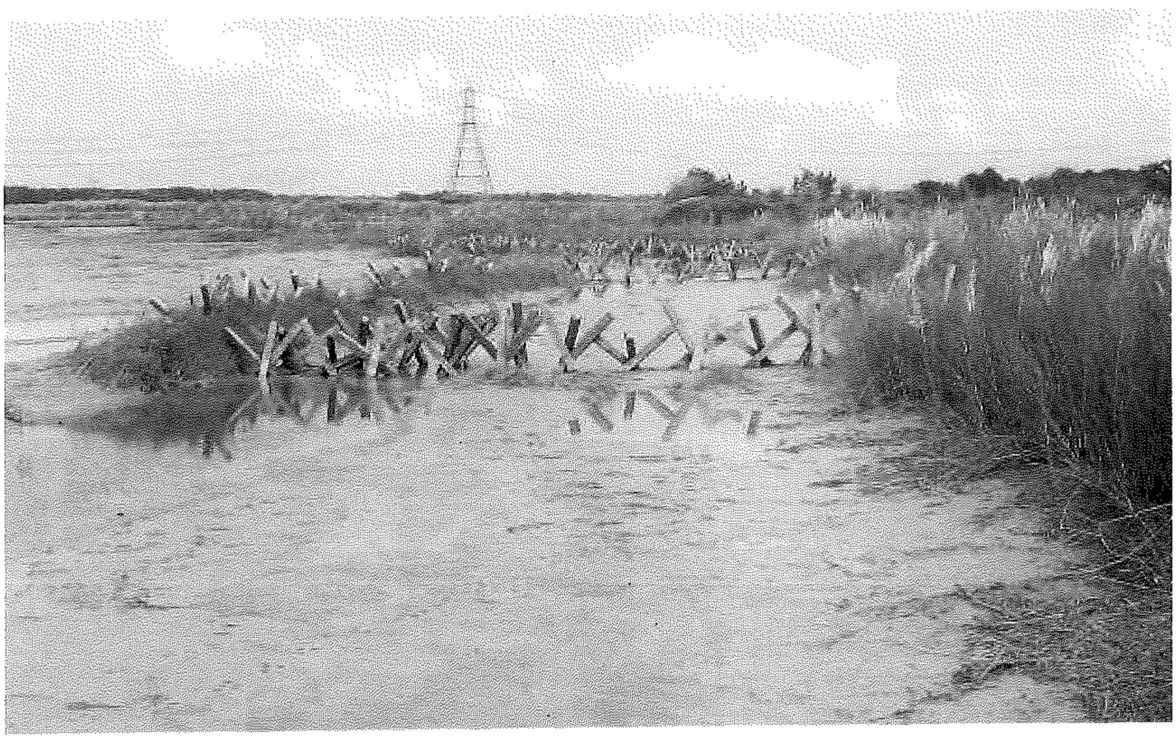


Figure 10. 13 : Photo taken from d/s on 20/8/2017

Figure 10.14 : Photo taken from u/s on 15/9/2017

Figure 10.15 : Photo taken from d/s on 15/9/2017

Figure 10.16 : Photo taken from u/s on 6/10/2017

Figure 10.17 : Photo taken from d/s on 6/10/2017

Figure 10.18 : Photo taken from u/s on 27/02/2018

Figure 10.19 : Photo taken from d/s on 27/02/2018

10.3 Result and Analysis

10.3.1 General

The field application of RCC Jack Jetty systems in Solani river yielded good results, as the erosive channel currents were deflected away from the bank. The portion of the land implemented with RCC Jack Jetty in front of the Solar Power Plant in between TD 1 –U and TD 1-D area witnessed about the accretion of land. Also the wheat farming in the bank in front of the Plant is proof for the reclamation of the land.

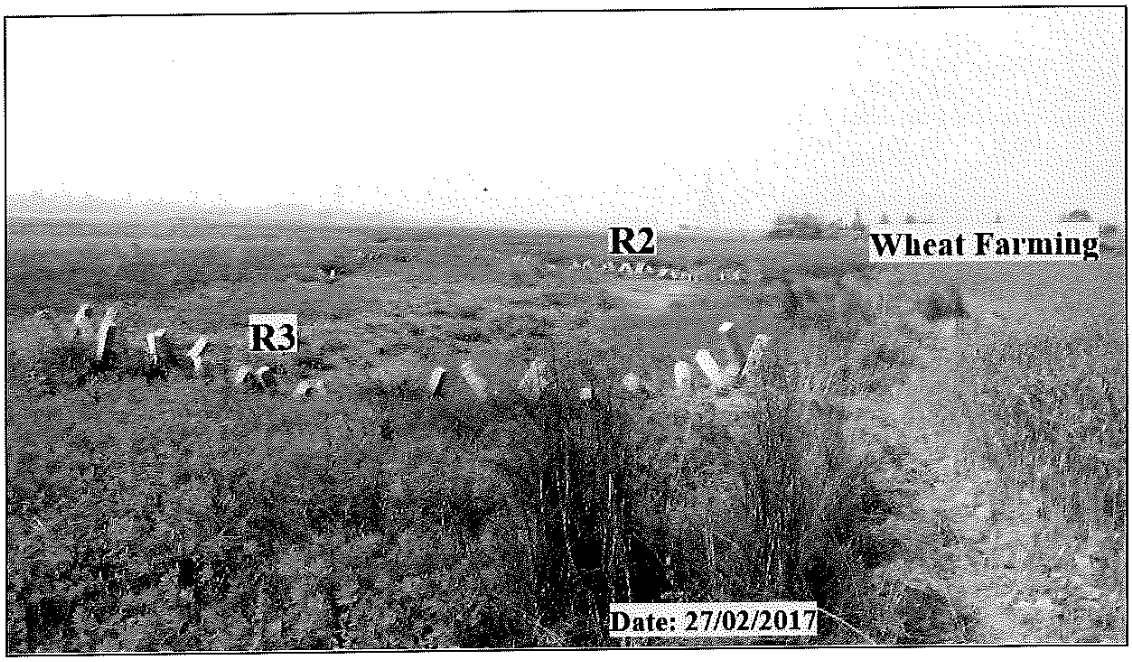


Figure 10.20 : Study area post monsoon showing land reclamation

10.3.2 Analysis with Survey Results

To evaluate the performance of the Jack Jetty systems, sixteen cross sections of the river bed downstream of the existing Trail Dyke (TD 1 –U) were plotted in the interval of 10 m. The plotted cross sections show the significance deposition of the sediment. The maximum deposition is in the periphery of Jetty Field. The Jack Jetty was installed from 65 m d/s of the u/s existing Trail Dyke. The deposition of sediment is up to 1.5 m. Though implementation of Jack Jetty was stopped at 70 m of diversion line, the deposition beyond that point is also quite remarkable.

As already stated, the Jetty systems were installed hurriedly during monsoon season, so the implementation was not executed according to the standard design criteria available. In spite of that the achieved result in this portion concludes that the implementation of the Jack Jetty system is highly satisfactory for the effective sedimentation of land. It can be clearly stated that there will be some more deposition of sand after next flood which will magnify the achieved result.

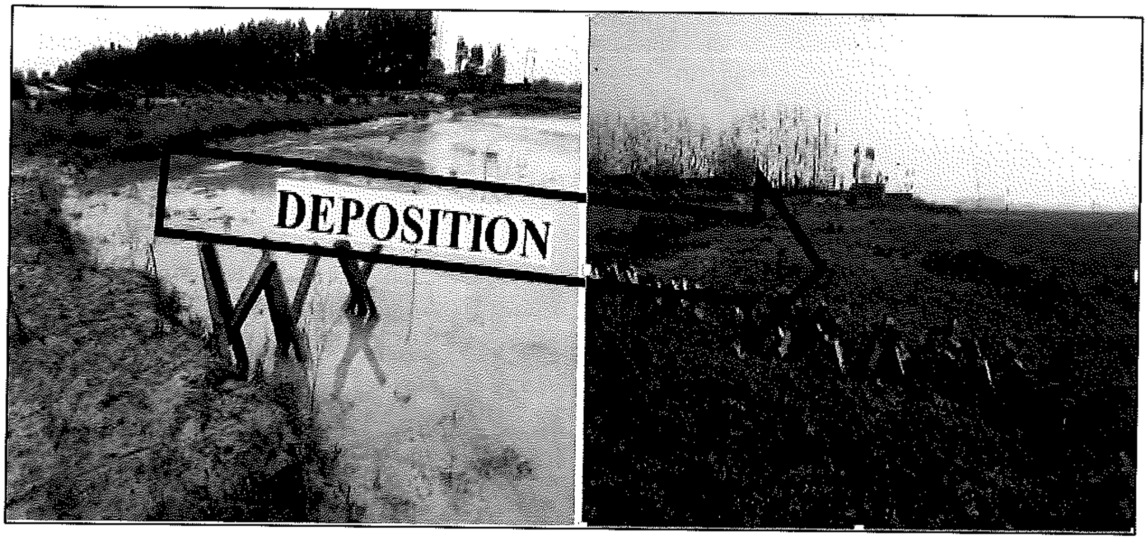


Figure 10. 21 : Comparison of study area between pre monsoon and post monsoon

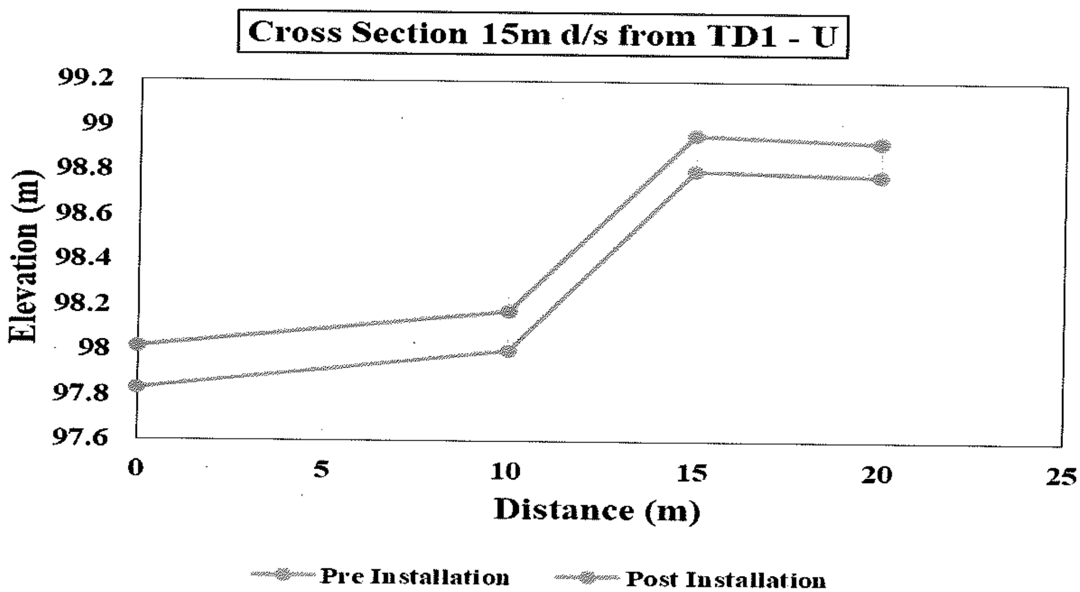


Figure 10.22 : Cross Section 1 : 15 m d/s from TD1 -U

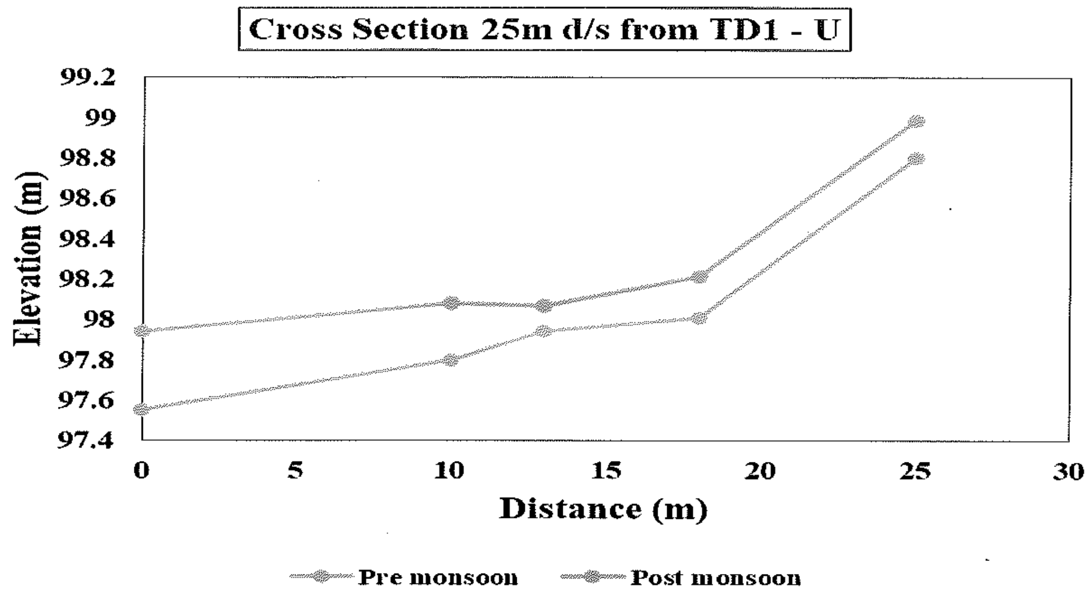


Figure 10.23 : Cross Section 2 : 25 m d/s from TD1 -U

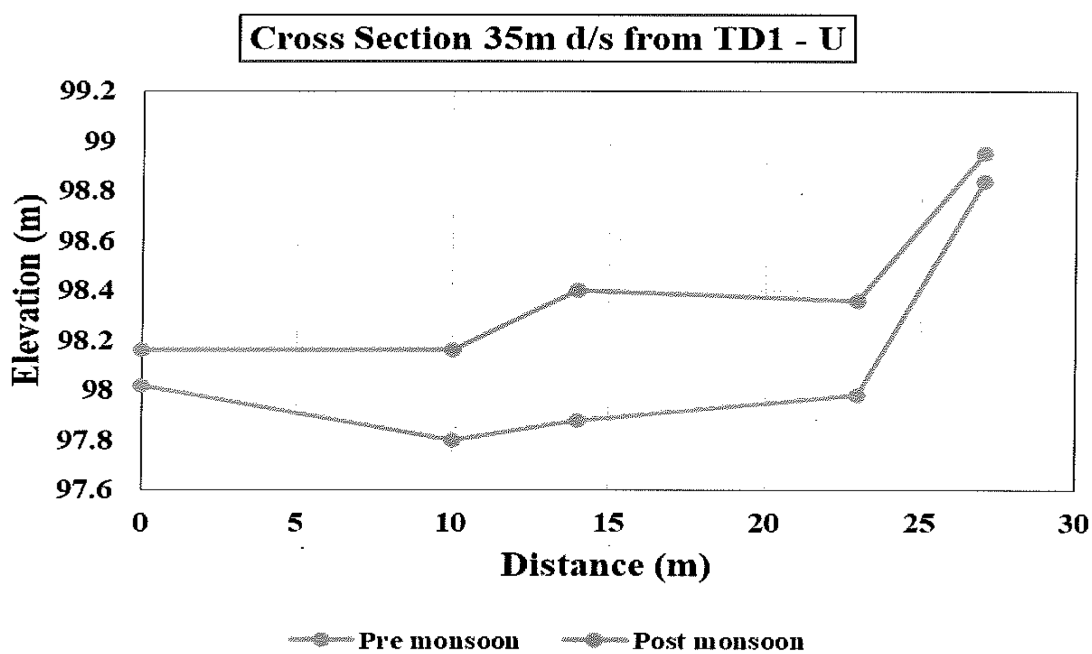


Figure 10.24 : Cross Section 3 : 35 m d/s from TD1 -U

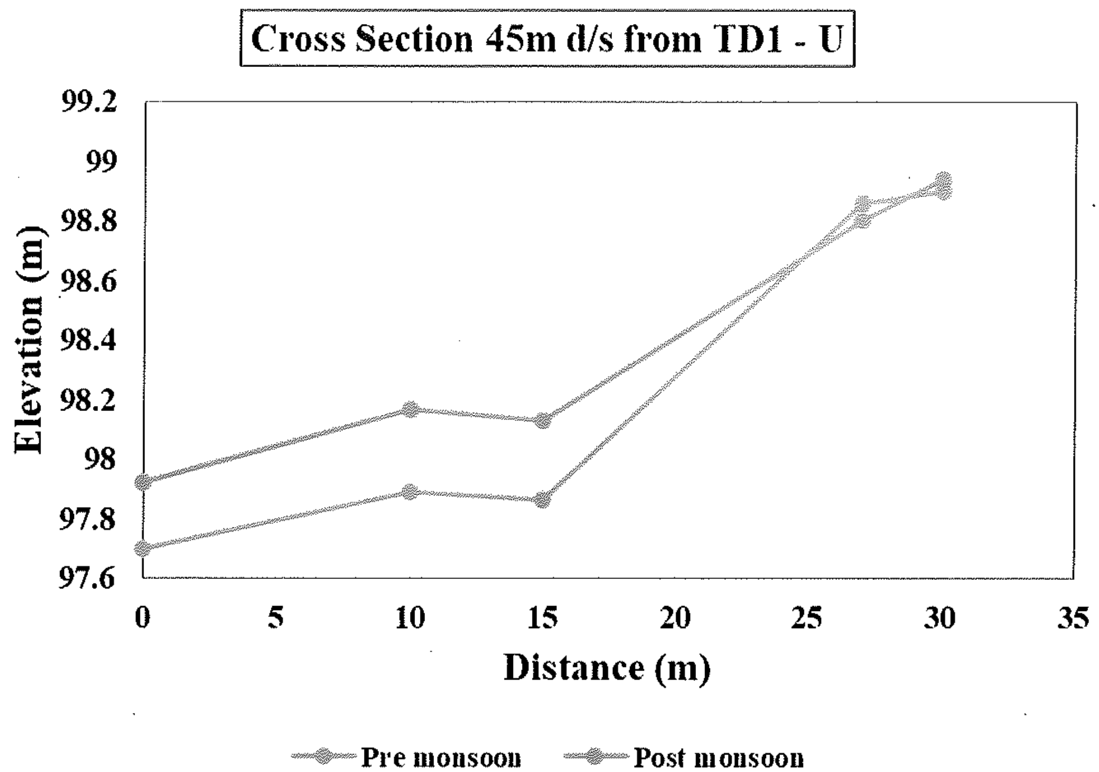


Figure 10.25 : Cross Section 4 : 45 m d/s from TD1 -U

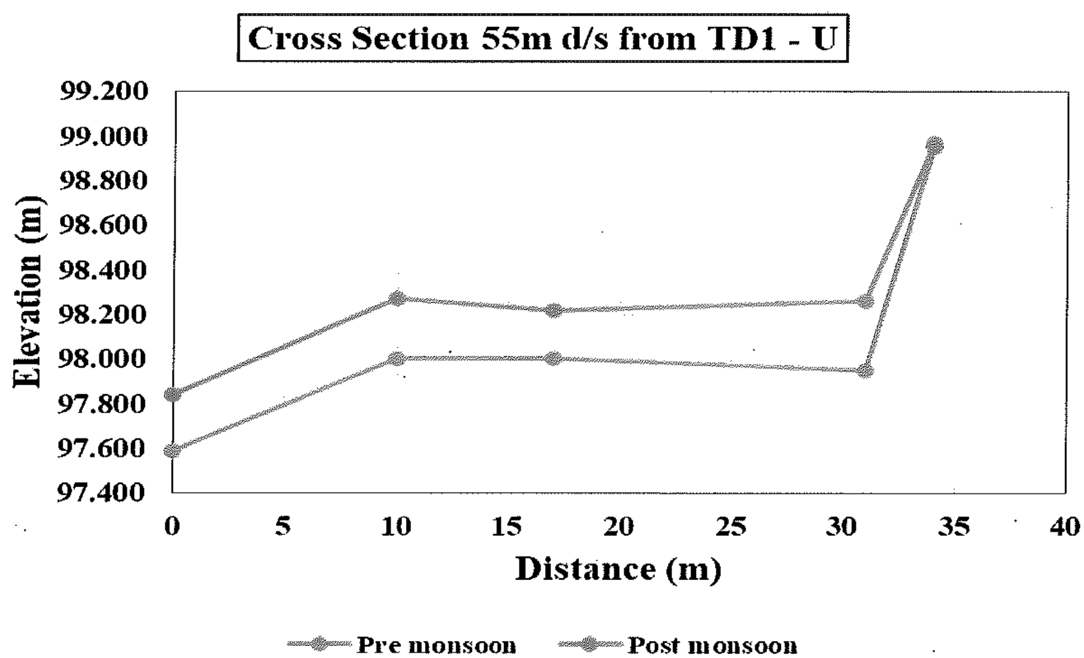


Figure 10.26 : Cross Section 5 : 55 m d/s from TD1 -U

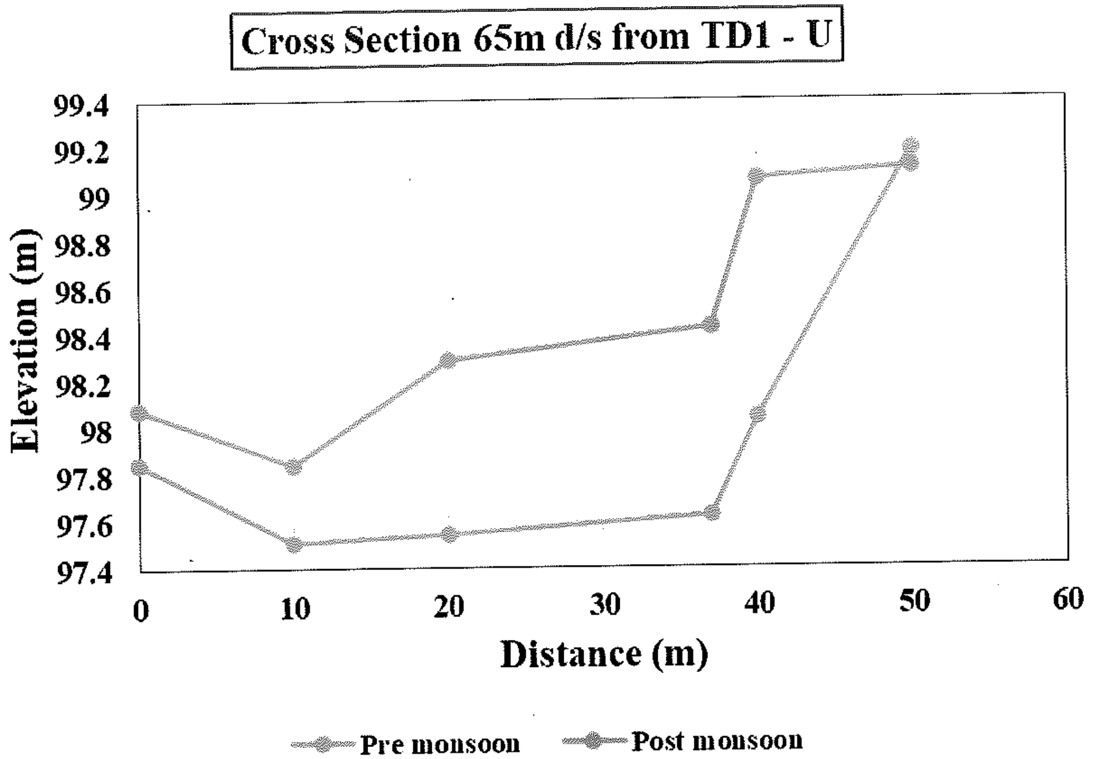


Figure 10.27 : Cross Section 6 : 65 m d/s from TD1 -U

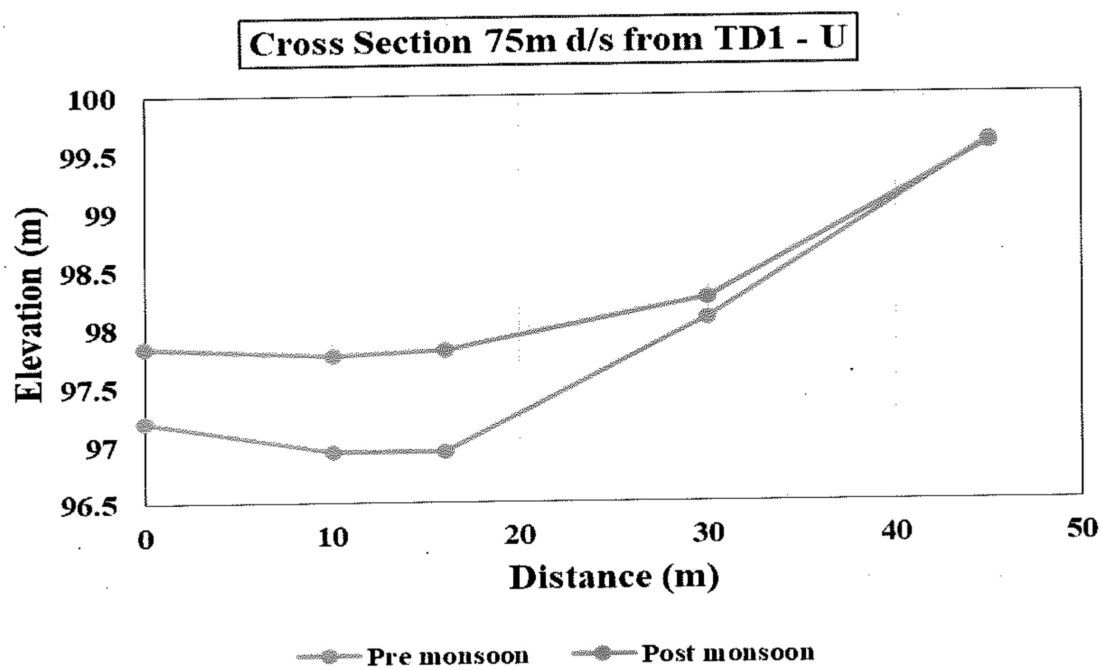


Figure 10.28 : Cross Section 7 : 75 m d/s from TD1 -U

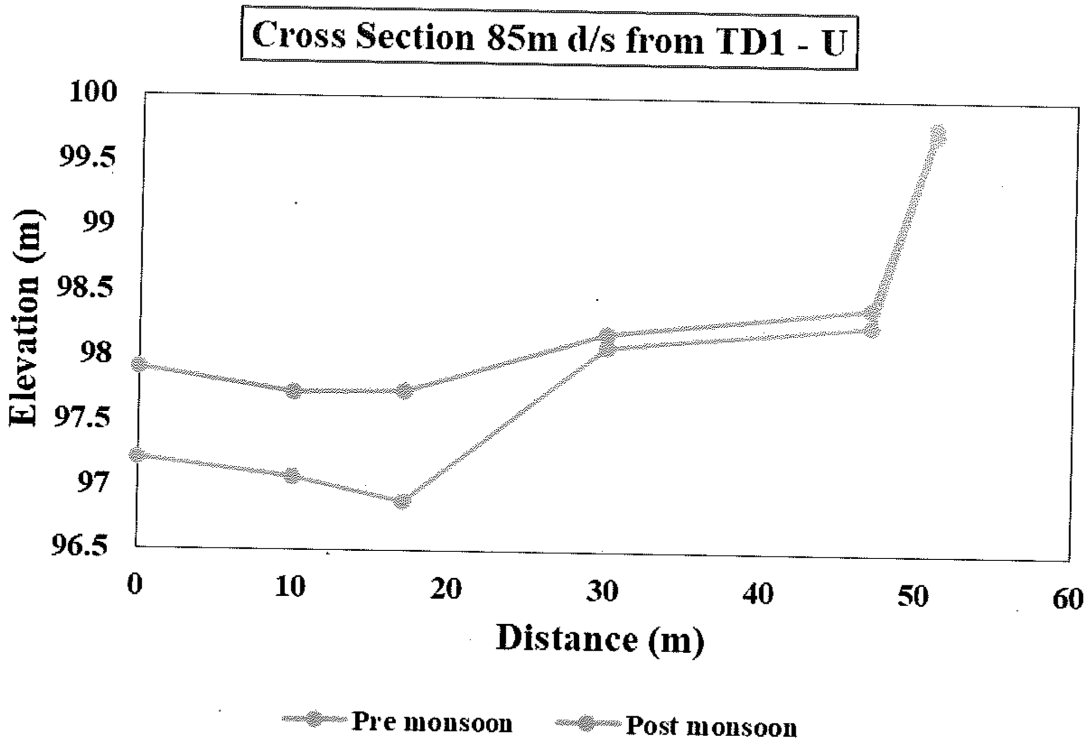


Figure 10.29 : Cross Section 8 : 85 m d/s from TD1 –U

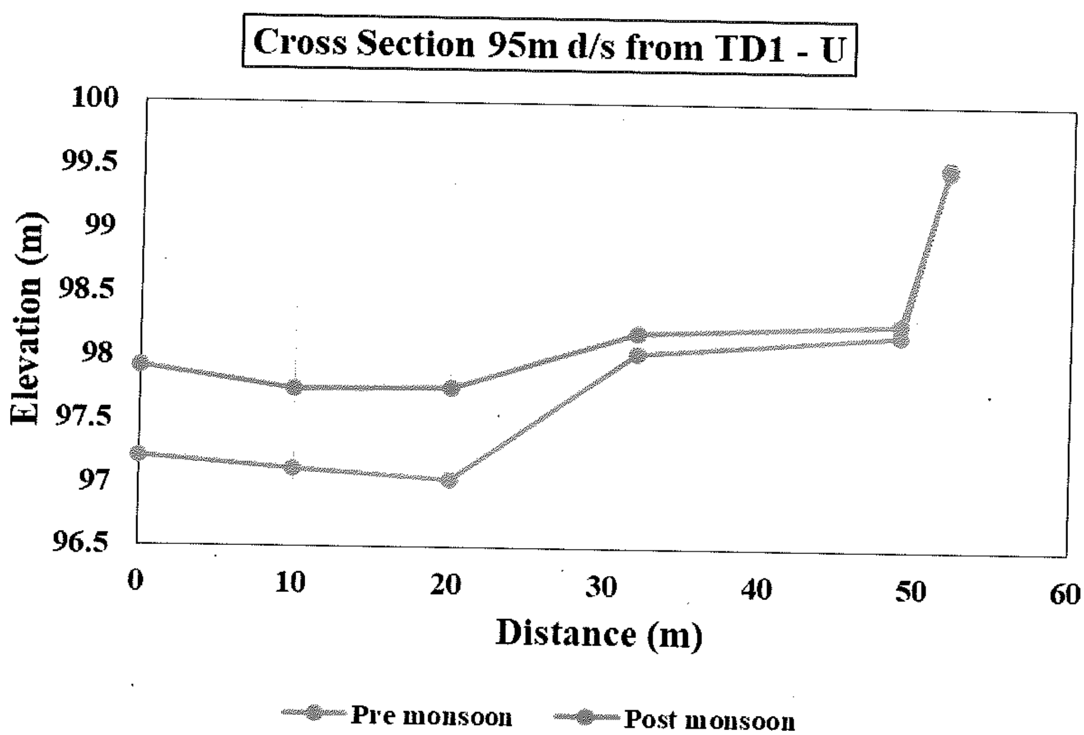


Figure 10.30 : Cross Section 9 : 95 m d/s from TD1 -U

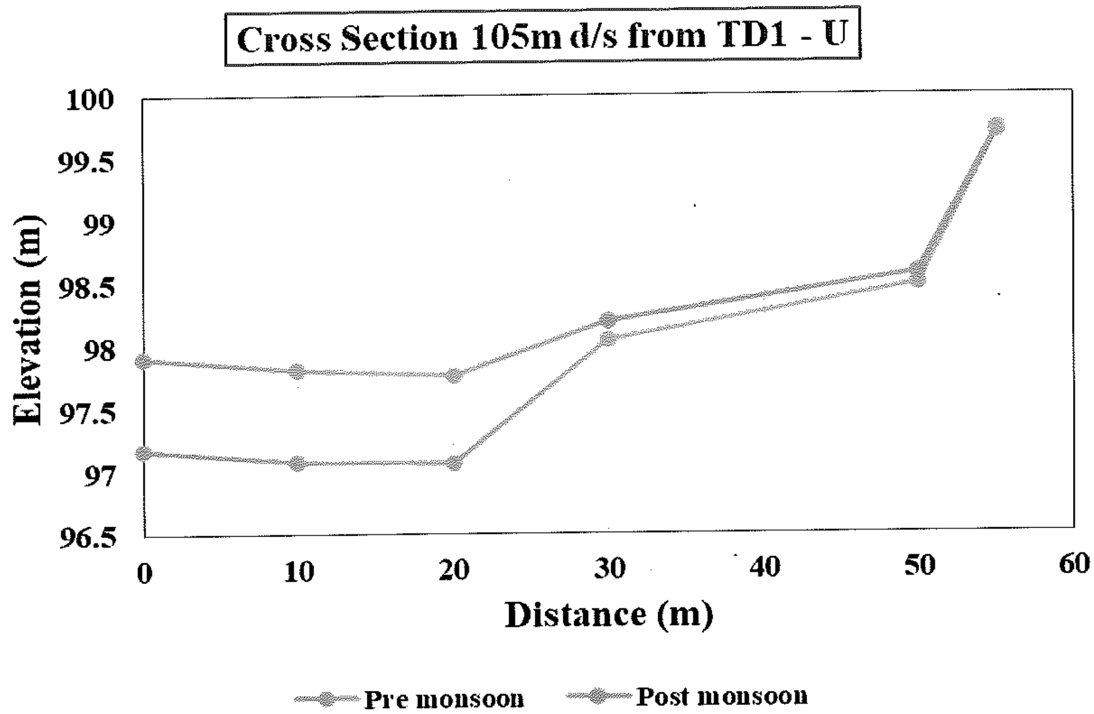


Figure 10.31 : Cross Section 10 : 105 m d/s from TD1 -U

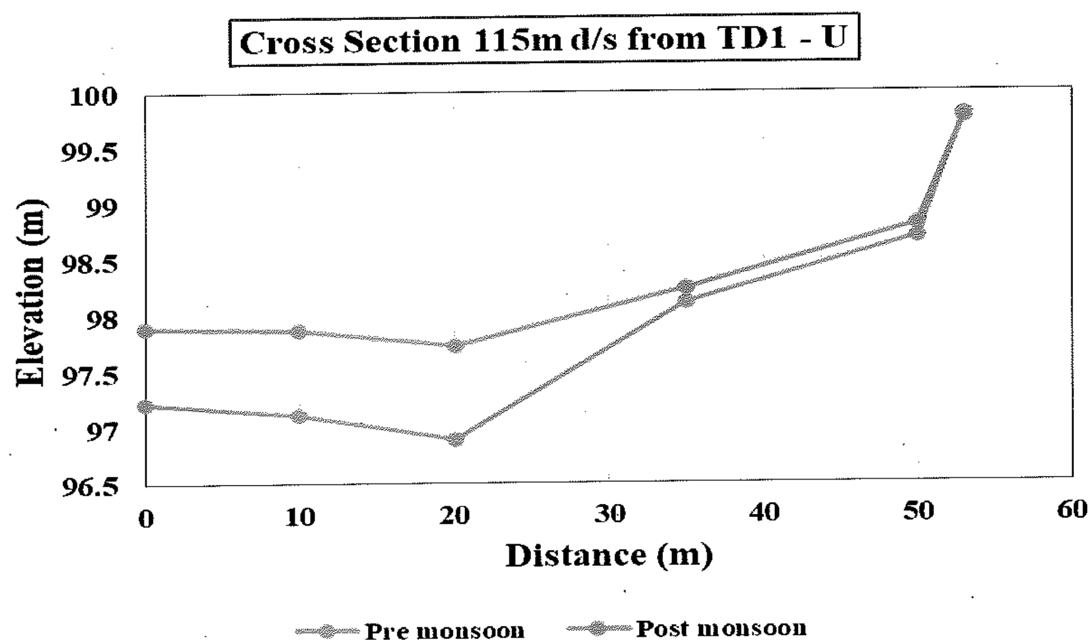


Figure 10.32 : Cross Section 11 : 115 m d/s from TD1 -U

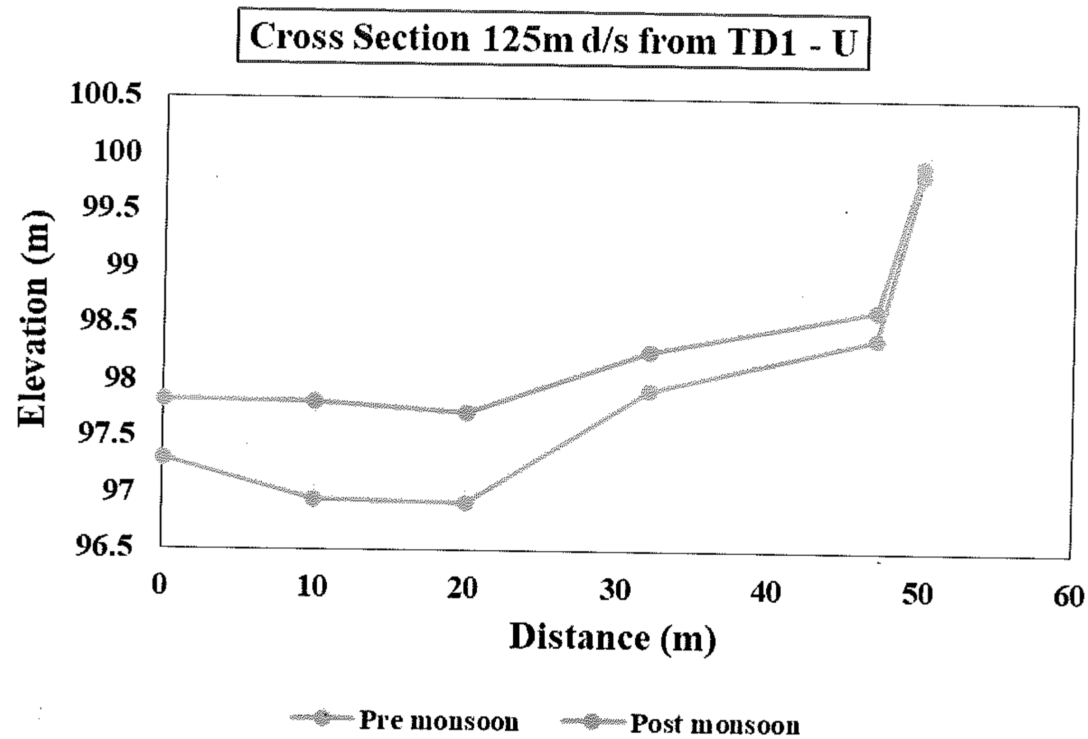


Figure 10.33 : Cross Section 12 : 125 m d/s from TD1 -U

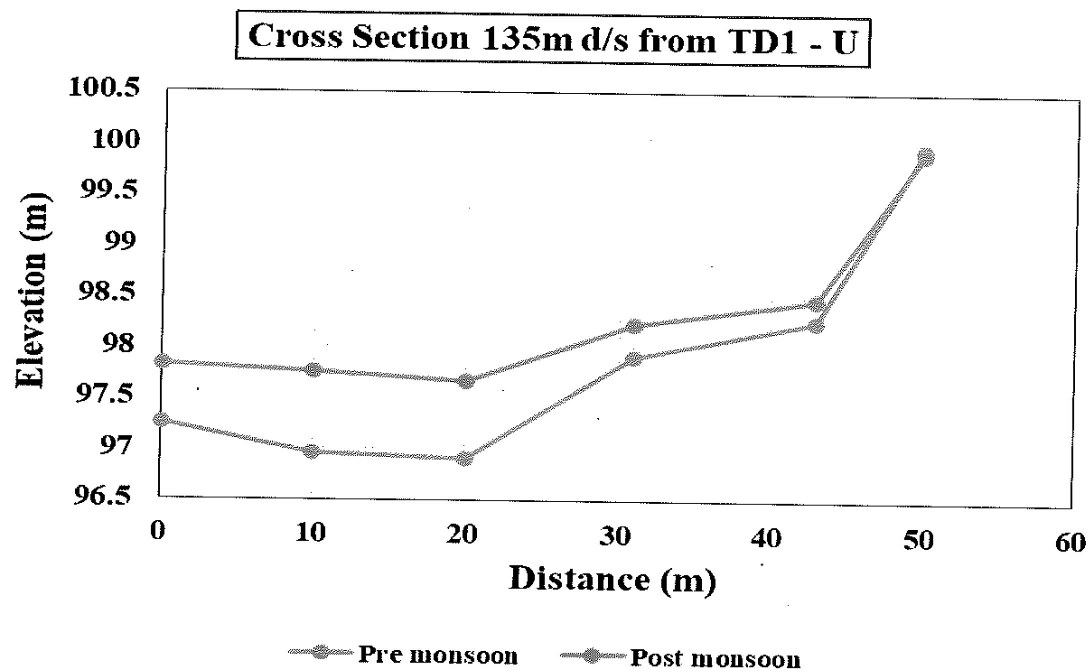


Figure 10.34 : Cross Section 13 : 135 m d/s from TD1 -U

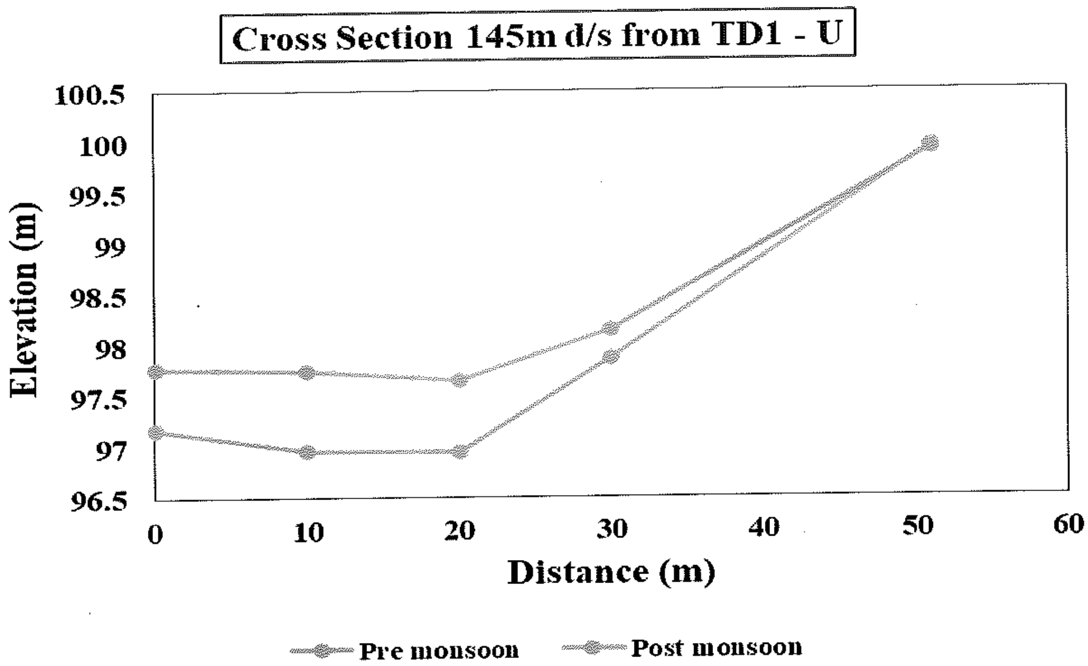


Figure 10.35 : Cross Section 14 : 145 m d/s from TD1 -U

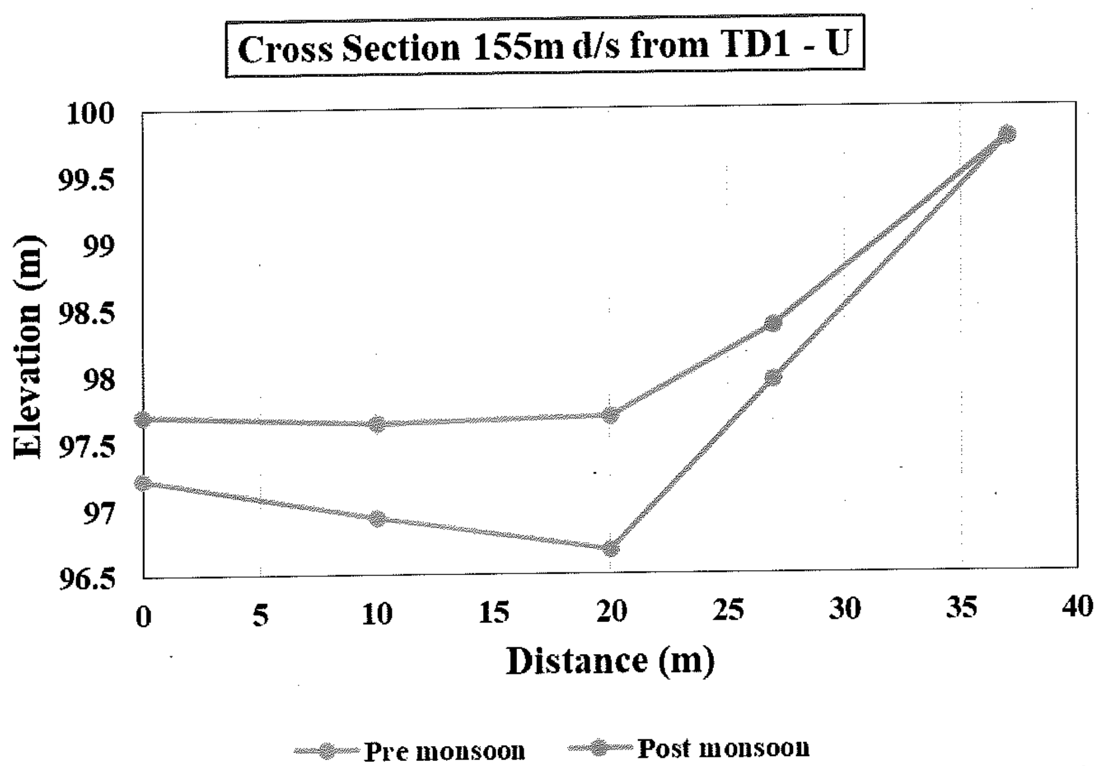


Figure 10.36 : Cross Section 15 : 155 m d/s from TD1 -U

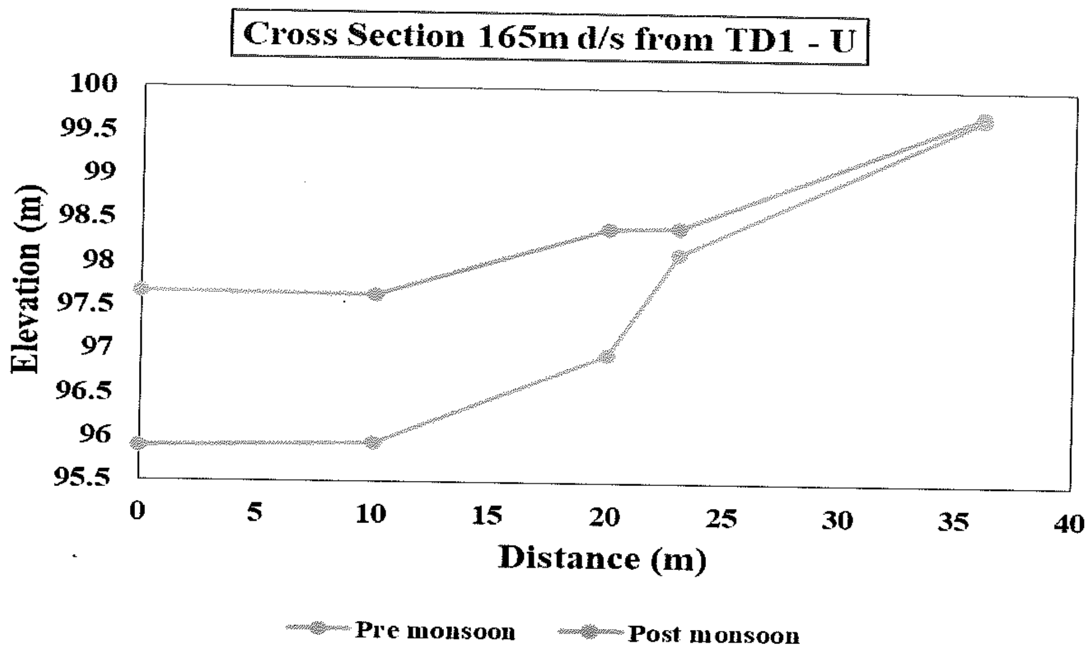


Figure 10.37 : Cross Section 16 : 165 m d/s from TD1 -U

CHAPTER – 11
SUMMARY OF FINAL REPORT OF R&D SCHEME

This report dwells upon the design development of RCC jack jetty and Porcupines as cost effective and relatively environmental friendly river training structures. Implementation of conventional river training structures like marginal embankment or levees, guide banks, groynes or spurs, cut offs, pitching of banks, pitched islands, sills, closing dykes and longitudinal dykes are becoming unaffordable and relatively less efficient due to various factors. In the current scenario, it has become priority for the river experts to consider not only the effectiveness of the structure but also to be deeply involved in the aspects like construction cost, environmental impact and aesthetics.

With the increase in steel prices and other construction materials, RCC Jack jetty may be used as a cost-effective and workable river training structure. Also, porcupine system is one of the most economical and efficient river training measures for channelization of river and protection of embankments including highways and bridge abutments. Behaving as permeable structures, they also produce positive impacts on the ecology.

New design indices and performance parameters were evolved in this R&D study which provides primary guidelines for developing design of a RCC jetty field and Porcupines based on the desired design objectives of erosion control, moderate reclaim and heavy reclaim. Threshold values of these parameters were obtained from the analytical study of the laboratory data to categorize the desired design objectives for field condition. The field evidence and analytical results of the prototype study support the laboratory findings of RCC jetty field.

Furthermore, as a complementary measure to enhance the positive effects of Jack Jetty system especially in erosion control and sedimentation, it has been attempted in this study to investigate the impact of combined applications of Jack Jetty and Trail Dykes. On the basis of laboratory experiments and field prototype studies, the results of the above combined applications have been found to be quite encouraging and positive in extracting enhanced effects as desired.

Since research is an unending ongoing process, the outcome of present R&D scheme may be considered as the curtain raiser in the present theme. Obviously, there is an imperative need to undertake studies in future to develop further the design methodology by gaining an insight into the hydraulics of complex flow mechanism involving expenditure of turbulent kinetic energy in and around jacks and porcupines. Further field application of the jack jetty and porcupines are required for fine tuning the laboratory results.

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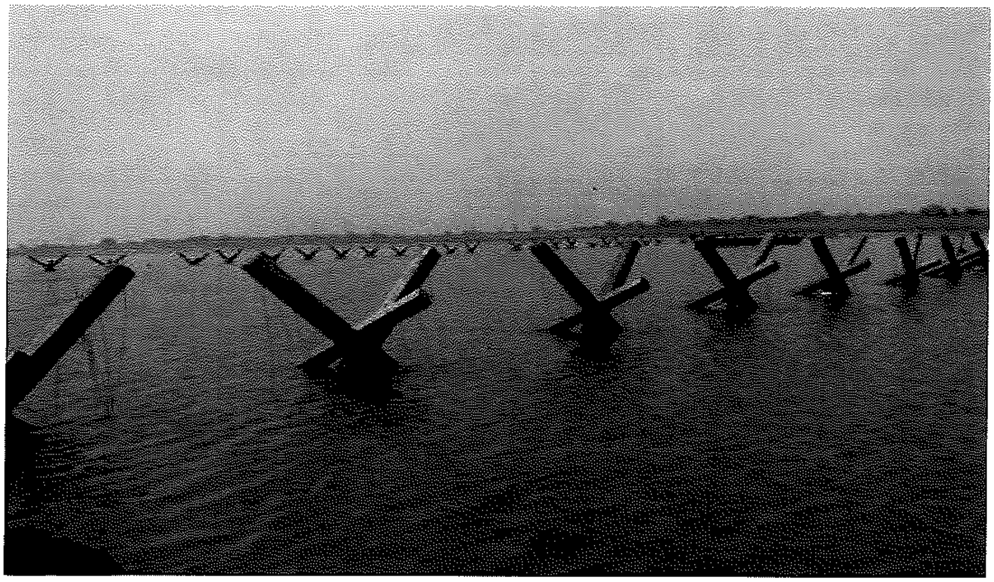
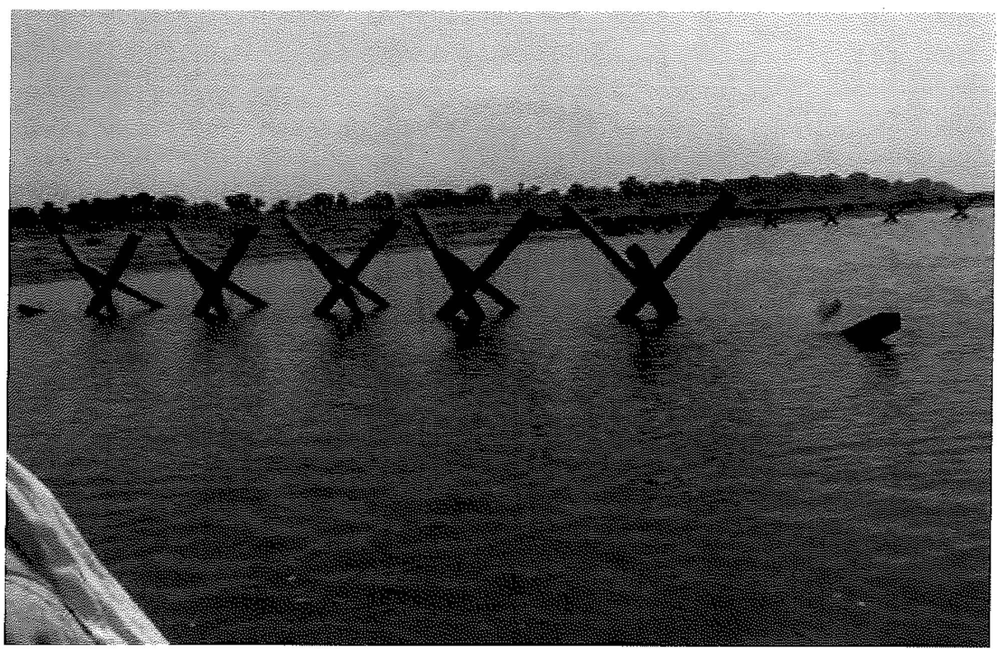
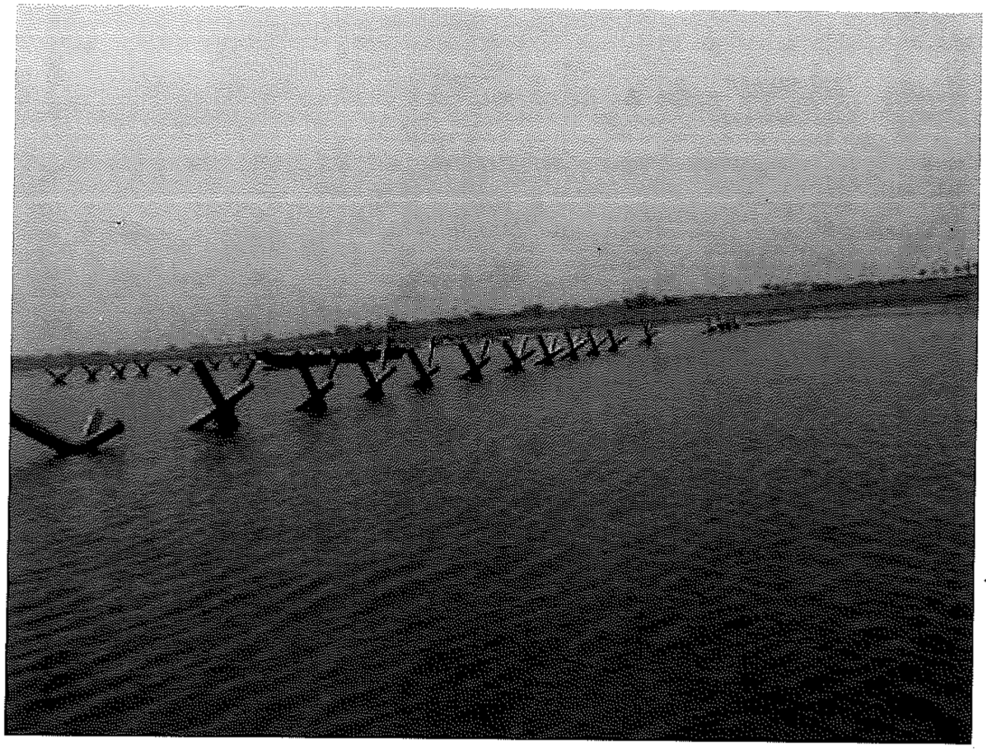
ANNEXURE – 1
SOME PRACTICAL APPLICATION OF JACK JETTY

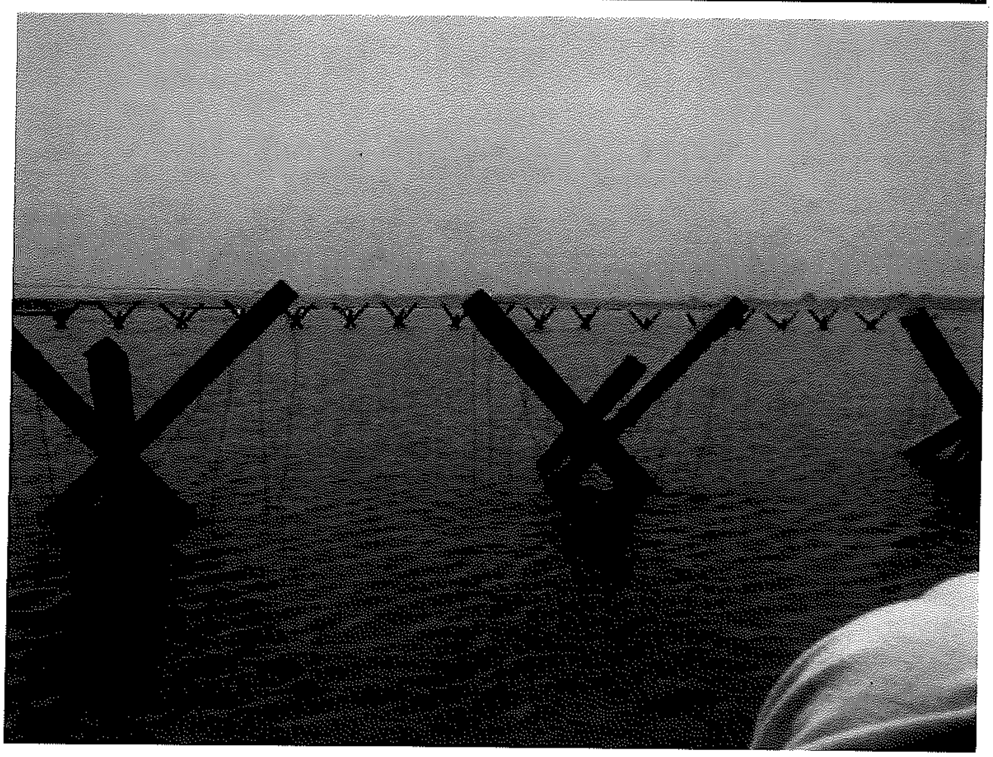
On the basis of intensive lab and prototype experiment Jack Jetty system has been installed in big rivers like Ganga and Brahmaputra. Successful implementation of the system shows the significance of the Jack Jetty system.

Application of Jack Jetty in Ganga River (D/S of Varanasi)



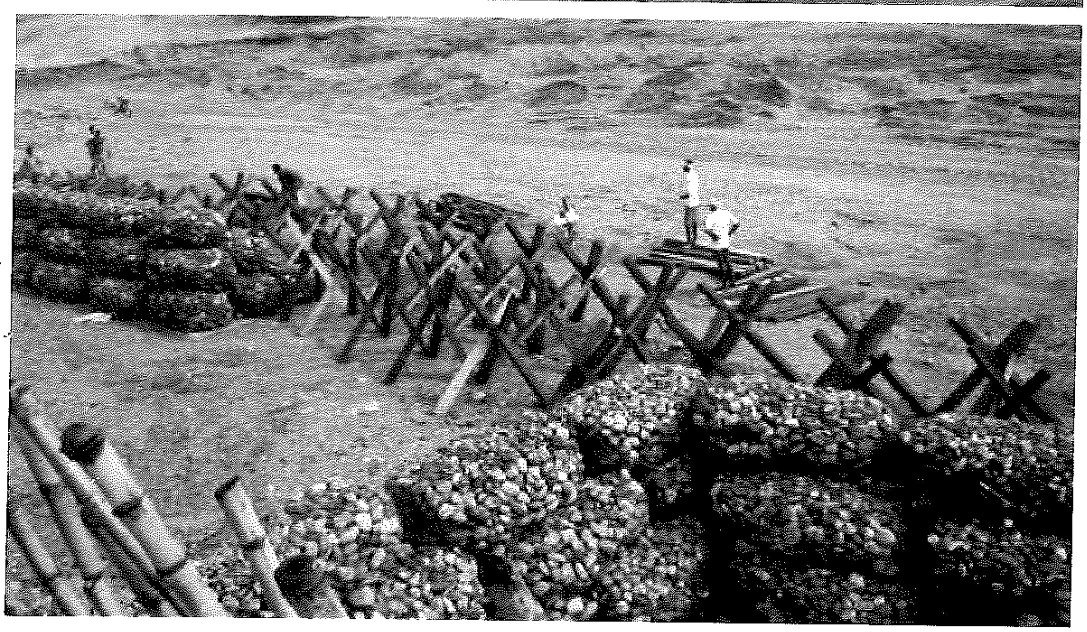


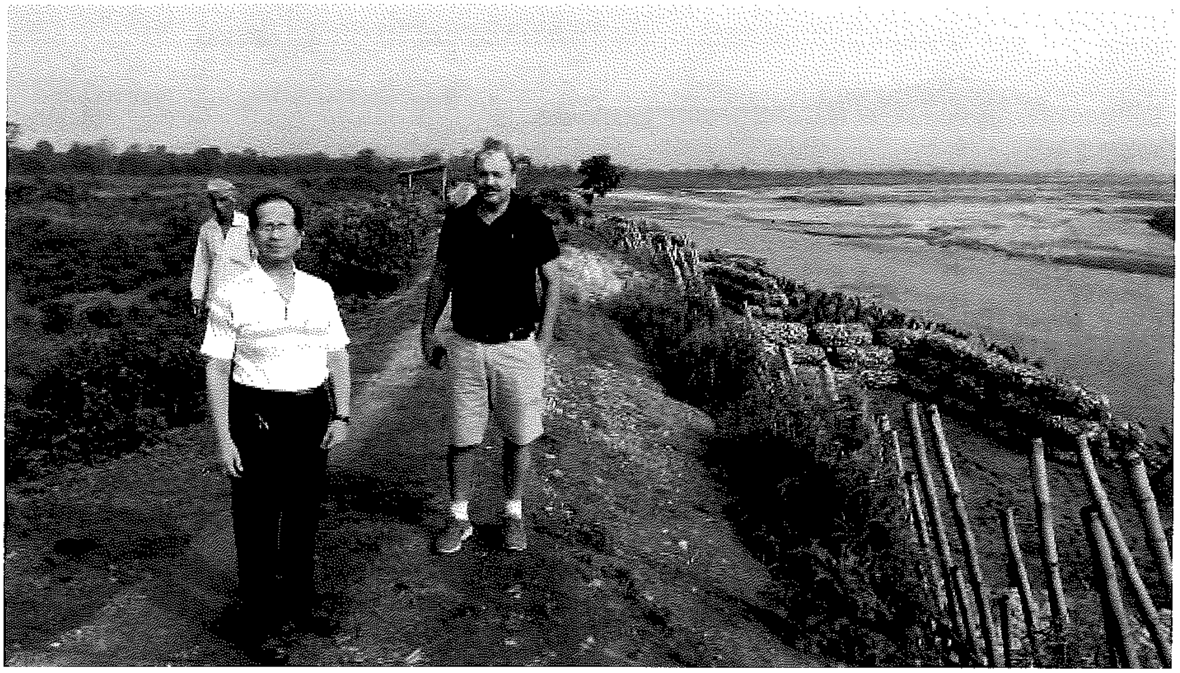




Application of Jack Jetty In Barnadi River (Assam)

Conjunctive use of Jack Jetty and Trail Dyke was applied to inhibit the bank erosion in Barnadi River a tributary of Brahmaputra River. The bank of the river near the Tea State was eroded and threatened the Tea Company. So Jack Jetty with Trail Dyke was mainly designed to protect Nagrijuli Tea State in Asam. After implementation of this system siltation took place remarkably. The Tea Company is safe after implementation of the system. After silt deposition, vegetation growth took place providing additional flow resistance. Sufficient sediment has been accumulated to form a new bank.





Application of Jack Jetty In Subansiri River (Assam)

Emergency use of RCC Jack Jetty was done in Subansiri river for erosion control in 2015