AN EXPERIMENTAL STUDY ON THE EFFECT OF PERMEABLE GROYNE ON FLOW CHARACTERISTICS IN A MEANDERING CHANNEL

AFLAH ORNIMA

DEPARTMENT OF WATER RESOURCES ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY (BUET), DHAKA-1000, BANGLADESH

DECEMBER 2018

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BY

AFLAH ORNIMA

Student No. 0412162080

In partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE IN WATER RESOURCES ENGINEERING

DEPARTMENT OF WATER RESOURCES ENGINEERING BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY (BUET), DHAKA-1000

DECEMBER 2018

DECLARATION

This is to certify that the thesis on "An Experimental Study on the Effect of Permeable Groyne on Flow Characteristics in a Meandering Channel." has been performed by me and neither this thesis nor any part there of has been submitted elsewhere for the award of any other degree or diploma.

(Dr. Md. Sabbir Mostafa Khan)

Countersigned by the Supervisor

(Aflah Ornima)

Signature of the Candidate

CERTIFICATE OF APPROVAL

The thesis titled "**An Experimental Study on the Effect of Permeable Groyne on Flow Characteristics in a Meandering Channel**" submitted by Aflah Ornima, Roll No. 0412162080P, Session: April 2012, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Science in Water Resources Engineering on 18th December, 2018.

Dr. Md. Sabbir Mostafa Khan Professor Department of WRE, BUET, Dhaka.	**Chairman** (Supervisor)
Dr. Md. Mostafa Ali Professor and Head Department of WRE, BUET, Dhaka.	**Member** (Ex-officio)
Dr. Umme Kulsum Navera Professor Department of WRE, BUET, Dhaka.	**Member**
Dr. Nasreen Jahan Associate Professor Department of WRE, BUET, Dhaka.	**Member**
Mr. Abu Saleh Khan (M. Sc.) Deputy Executive Director (DED) Institute of water Modeling (IWM) House-496, Road-32, New DOHS Mohakhali, Dhaka-1206.	**Member** (External)

ACKNOWLEDGEMENT

At first, I would like to praise almighty Allah for his support in all aspect of my life. I wish to express profound gratitude and sincerest appreciation to my supervisor Dr. Md. Sabbir Mostafa khan, Professor Department of Water Resources Engineering, Bangladesh University of Engineering and Technology, Dhaka for inspiring me to conduct this thesis work and to provide me dexterous guide which help me to reach at culmination of the work successfully. The author is really grateful to the supervisor for his cordial supervision, intellectual guidance, valuable suggestions, constant support and encouragement at every stage of this study. Without coordination and help this study would have been incomplete.

I am also grateful to Dr. Md. Mostafa Ali, Professor and Head, Department of Water Resources Engineering, BUET, Dhaka, for providing all library facilities and laboratory facilities for accomplishing this study in a comprehensive manner. Who introduced the author to the interesting field of meandering channels.

I also would like to thank the assistants of Hydraulic and IWFM Laboratory of BUET for their physical help to complete my laboratory experiment efficiently. The author is also indebted to the members of the examination committee Dr. Umme Kulsum Navera, Professor Department of Water Resources Engineering, BUET, Dr. Nasreen Jahan, Associate Professor, Department of Water Resources Engineering, BUET and Md. Abu Saleh Khan, DED (Deputy Executive Director), IWM for their valuable comments and constructive suggestions regarding this study.

The author is also thankful to lab assistant Mr. Mostafa for providing the velocity measurement current meter during the experiments.

Finally the author expresses profound thanks to her family members for supporting and inspiring to conduct the study. Especially my mother for her mental support to complete my study carefully and sincerely and friends and well-wisher for supporting and inspiring me to complete my M.Sc. Engg. Degree.

Aflah Ornima

Std. ID: 0412162080P

ABSTRACT

Groynes are hydraulic structures that protect against bank erosion, maintain water level by deflecting flow direction, and ensure navigation safety. They can be used for flood control, land reclamation, and provision of navigable depth. In addition, their functions can be changed along with the goals of river works and the nature of the stream. Groynes are flow diversion structures, commonly used in river engineering especially at river bends to prevent bank erosion and control river meandering. Today, various types of groynes have been installed as pilot projects encouraging competent authorities proceed with such option in the wake of pertinent needs. One is impermeable another one is permeable. In this study, permeable groynes in meandering channel are used.

The experimental study has been conducted in the open air facility of Water Resources Engineering Department, Bangladesh University of Engineering and Technology (BUET), Dhaka. Required data have been collected from 10 experimental runs in five different setups of the compound meandering channel. In each of those runs, velocities are measured at four cross-sections, and within each cross-section at four zones. Two depths of water (i.e. 20 cm and 15 cm) are considered in this study. Analyses are done for velocity distribution profile, velocity distribution coefficients (i.e. energy and momentum coefficients) and shear stress distribution.

In the present study, studies are carried out on velocity distribution profiles, velocity distribution coefficients and shear stress distribution. For zone-wise distribution of mean velocity, 20 cm and 15 cm depths, set-up 2 (i.e. 3 groynes at L spacing, L = length of the groyne) is the best option among all the set- ups. For zones 2, 3 and 4, set-up 2 produces minimum velocities throughout the cross-sections although zone1 produced minimum velocities for set-up 4 (i.e. 3 groynes at 3L spacing) for 20 cm depth case. For cross-section-wise distribution for both 20 cm and 15 depths, set-up 2 is the best option among all the set- ups. Regarding energy coefficient, for 20 cm depth, hence set-ups 1 (single groyne), 3 (i.e. 3 groynes at 2L spacing) and 4 seem to be the preferred options. For 15 cm depth, set-ups 2 and 4 seem to be the preferred options regarding energy coefficient. Regarding momentum coefficient, for 20 cm depth, set-ups 1, 2, 3 and 4 seem to be the preferred options. For 15 cm depth, set-ups 2 and 4 seem to be the preferred options regarding momentum coefficient. Regarding shear stress distribution, set-up 2 seems to be the best option with the lowest values among all the zones for both 20 cm and 15 cm depths.

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Symbol	Meaning
A	Area of channel cross section
B	Width of the meandering channel
C	Chezy's roughness coefficient
D	Depth ratio
L	Length of meandering channel
P	Wetted perimeter of the channel section
U	Mean velocity
U*	The friction velocity
k	Von Karman's constant
Z	Height above bed
Zo	Height of hydraulic roughness.
N	No of Blows
a	Coefficient of values
b	Coefficient of values
Q	Discharge
τ	Shear stress
g	Gravitational acceleration,
ρ	Density of flowing fluid,
R	Hydraulic radius of the channel cross-section
S_o	Channel bottom slope
α	Energy Coefficient
β	Momentum Coefficient

LIST OF ABBREVIATIONS

Symbol	Meaning
BUET	Bangladesh University of Engineering and Technology
COR	Correlation coefficient
LF	Left Floodplain
MC	Main Channel
RF	Right Floodplain

Sl	Run No	Meaning of Run No
1	C1S1Z1R1	Cross Section1,Setup1, Zone 1 Run1 (D=20 cm)
2	C1S1Z2R1	Cross Section1,Setup1, Zone 2 Run1 (D=20 cm)
3	C1S1Z3R1	Cross Section1,Setup1, Zone 3 Run1 (D=20 cm)
4	C1S1Z4R1	Cross Section1,Setup1, Zone 4 Run1 (D=20 cm)
5	C1S2Z1R1	Cross Section1,Setup2, Zone 1 Run1 (D=20 cm)
6	C1S2Z2R1	Cross Section1,Setup2, Zone 2 Run1 (D=20 cm)
7	C1S2Z3R1	Cross Section1,Setup2, Zone 3 Run1 (D=20 cm)
8	C1S2Z4R1	Cross Section1,Setup2, Zone 4 Run1 (D=20 cm)
9	C1S3Z1R1	Cross Section1,Setup3, Zone 1 Run1 (D=20 cm)
10	C1S3Z2R1	Cross Section1,Setup3, Zone 2 Run1 (D=20 cm)
11	C1S3Z3R1	Cross Section1,Setup3, Zone 3 Run1 (D=20 cm)
12	C1S3Z4R1	Cross Section1,Setup3, Zone 4 Run1 (D=20 cm)
13	C1S4Z1R1	Cross Section1,Setup4, Zone 1 Run1 (D=20 cm)
12	C1S3Z4R1	Cross Section1,Setup3, Zone 4 Run1 (D=20 cm)
13	C1S4Z1R1	Cross Section1,Setup4, Zone 1 Run1 (D=20 cm)
14	C1S4Z2R1	Cross Section1,Setup4, Zone 2 Run1 (D=20 cm)
15	C1S4Z3R1	Cross Section1,Setup4, Zone 3 Run1 (D=20 cm)
16	C1S4Z4R1	Cross Section1,Setup4, Zone 4 Run1 (D=20 cm)
17	C2S1Z1R1	Cross Section2,Setup1, Zone 1 Run1 (D=20 cm)
18	C2S1Z2R1	Cross Section2,Setup1, Zone 2 Run1 (D=20 cm)
19	C2S1Z3R1	Cross Section2,Setup1,Zone 3 Run1 (D=20 cm)
20	C2S1Z4R1	Cross Section2,Setup1, Zone 4 Run1 (D=20 cm)
21	C2S2Z1R1	Cross Section2,Setup2, Zone 1 Run1 (D=20 cm)
22	C2S2Z2R1	Cross Section2,Setup2, Zone 2 Run1 (D=20 cm)
23	C2S2Z3R1	Cross Section2,Setup2, Zone 3 Run1 (D=20 cm)
24	C2S2Z4R1	Cross Section2,Setup2, Zone 4 Run1 (D=20 cm)
25	C2S3Z1R1	Cross Section2,Setup3, Zone 1 Run1 (D=20 cm)

Sl	Run No	Meaning of Run No
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28	C2S3Z4R1	Cross Section2,Setup3, Zone 4 Run1 (D=20 cm)
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32	C2S4Z4R1	Cross Section2,Setup 4, Zone 4 Run1 (D=20 cm)
33	C3S1Z1R1	Cross Section3,Setup 1, Zone 1 Run1 (D=20 cm)
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42	C3S3Z2R1	Cross Section3,Setup 3 , Zone 2 Run1 (D=20 cm)
43	C3S3Z3R1	Cross Section3,Setup 3, Zone 3 Run1 (D=20 cm)
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45	C3S4Z1R1	Cross Section3,Setup 4, Zone 1 Run1 (D=20 cm)
46	C3S4Z2R1	Cross Section3,Setup 4, Zone 2 Run1 (D=20 cm)
47	C3S4Z3R1	Cross Section3,Setup 4, Zone 3 Run1 (D=20 cm)
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53	C4S2Z1R1	Cross Section4,Setup 2, Zone 1 Run1 (D=20 cm)
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56	C4S2Z4R1	Cross Section4,Setup 2, Zone 4 Run1 (D=20 cm)
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62	C4S4Z2R1	Cross Section4,Setup 4, Zone 2 Run1 (D=20 cm)
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66	C5S1Z2R1	Cross Section5,Setup 1, Zone 2 Run1 (D=20 cm)
67	C5S1Z3R1	Cross Section5,Setup 1, Zone 3 Run1 (D=20 cm)
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75	C5S3Z3R1	Cross Section5,Setup 3, Zone 3 Run1 (D=20 cm)
76	C5S3Z4R1	Cross Section5,Setup 3, Zone 4 Run1 (D=20 cm)
77	C5S4Z1R1	Cross Section5,Setup 4, Zone 1 Run1 (D=20 cm)
78	C5S4Z2R1	Cross Section5,Setup 4, Zone 2 Run1 (D=20 cm)
79	C5S4Z3R1	Cross Section5,Setup 4, Zone 3 Run1 (D=20 cm)
80	C5S4Z4R1	Cross Section5,Setup 4, Zone 4 Run1 (D=20 cm)

CHAPTER ONE

INTRODUCTION

1.1 General

Groynes are hydraulic structures that protect against bank erosion, maintain water level by deflecting flow direction, and ensure navigation safety. They can be defined as shore protection structures (usually perpendicular to the shoreline) built to trap littoral drift or retard erosion of the shore, as structures installed on the front side of the bank, or as revetment to protect the bank or the levee against erosion. They can be used for flood control, land reclamation, and provision of navigable depth. In addition, their functions can be changed along with the goals of river works and the nature of the stream.

Thus Natural rivers stream and man-made surface drainage channels often overflow their banks during episodes of high flooding resulting in a huge potential damage to life and property as well as erosion and depositions of sediments. Many rivers have meandering compound channels possessing a main channel, which always carries flow and one or two floodplains, which only carry flow at above bank full stages. It has been established that a strong interaction between the faster moving main channel flow and slower moving floodplain flow takes place in a compound channel. Groynes are flow diversion structures, commonly used in river engineering especially at river bends to prevent bank erosion and control river meandering. Recently, groynes have gathered potential to attract attention again because the natural bank form made by groynes is found sustainable at an extent serving better than others considering river ecosystem as well .

Today, various types of groynes have been installed as pilot projects encouraging competent authorities proceed with such option in the wake of pertinent needs. One is impermeable another one is permeable. In case of impermeable groynes local scours are concentrated in front edges of groyne. The effect of flow characteristics of a meandering channel with the varying spacing and deflection angle of groyne. The other side in cases of permeable groynes local scours with similar values are occurred around groynes. In this paper, we will introduce the re-appraisal of permeable groynes as nature-friendly river training structure both to retain lands adjacent to the river banks and improve ecosystem. Such problematic situation has influenced and convinced to crop up the issue and find a way-out. After facing a bunch of tussle, ‘Permeable Groynes’ have found as best suited pertinent solution. The below figures (1.1) IS indicated nature and classification of Permeable gryones. They permit the flow of water through them. They dampen the velocity and reduce the erosive action of the stream. The permeability of the groyne helps in avoiding abrupt offset in a shore. A part of materials and littoral drift pass through the groyne. This results in sand deposition on both sides of groyne.

As know that A groyne is a rigid hydraulic structure built from an ocean shore (in coastal engineering) or from a bank (in rivers) that interrupts water flow and limits the movement of sediment. It is usually made out of wood, concrete or stone. In the ocean, groynes create beaches or prevent them being washed away by long shore drift. In a river, groins prevent erosion and ice-jamming, which in turn aids navigation. Ocean groynes run generally perpendicular to the shore, extending from the upper foreshore or beach into the water. All of a groyne may be under water, in which case it is a submerged groyne. The areas between groups of groynes are groyne fields. Groynes are generally placed in groups. They are often used in tandem with seawalls. Groynes, however, may cause a shoreline to be perceived as unnatural.

Figure 1.1 : Nature of Gryone

The epilogue of the proposal puts emphasis on the congruence of permeable groynes as river training structures to protect concave banks of rivers categorized as medium and small in nature. Considering the pattern of construction and activities supposed to be seen while functioning, it is projected that it will be environmentally fit, economically feasible and socially acceptable as well leading such an option to be a sustainable one. In that case permeable groynes as bank protection measures at some distinct locations with remarkable yields in performance and still functioning passionately guarding protected banks from engulfment The flow characteristics in a compound meandering channel, with the various spacing of permeable gryones should be illustrate the effect of such type of structure on the local hydraulic phenomena with following characteristics. Economical and cost-effective river training option, lessened pressure of current towards noses, enough alternative to Geo-bag protection, less construction period, low maintenance Cost, seasonal maintenance would lead such structure to be constituted as an Impermeable one. Engineers, planners and researchers are highly interested in predicting accurately as well as reliably the quantitative estimates of flow parameters in a compound meandering channel. As a result, an adequate knowledge of the hydraulics of compound meandering channel flow is required for the proper design and management of rivers, drainage and irrigation canals.

Types of groynes:

1. According to the materials used: Permeable groyne and Impermeable groyne (solid).
2. According to its height below high water: Submerged groyne and Non submerged groyne.
3. According to the function it serves: Attracting groyne, Deflecting groyne, Repeting groyne and Sedimenting groyne.
4. Special types of groyne: Denehy's T headed groyne, Hocky type groyne and Burma type groyne.

1.2 Meandering Channel

River meandering is a complicated process involving a large number of channel and flow parameters. Ingles' (1947) define meandering and it states as "where however, banks are not tough enough to withstand the excess turbulent energy developed during floods, the banks erode and the river widens and shoals. In channels with widely fluctuating discharges and silt charges, there is a tendency for silt to deposit at one bank and for the river to move to the other bank. This is the origin of meandering. Figure 1.4 and 1.5 are formation of meandering channel in below.

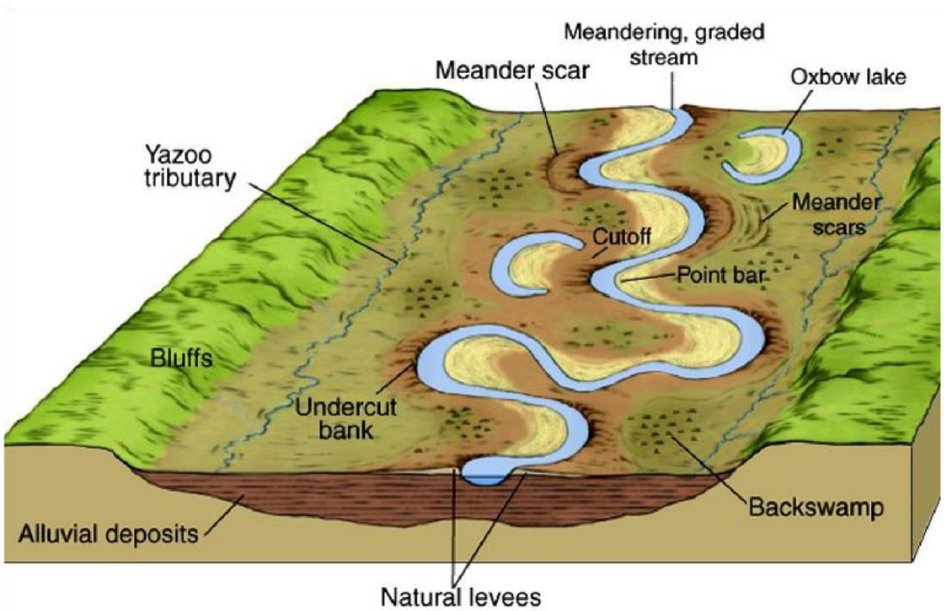

Figure 1.2: Simple illustration of Formation of Meandering Channel Reach

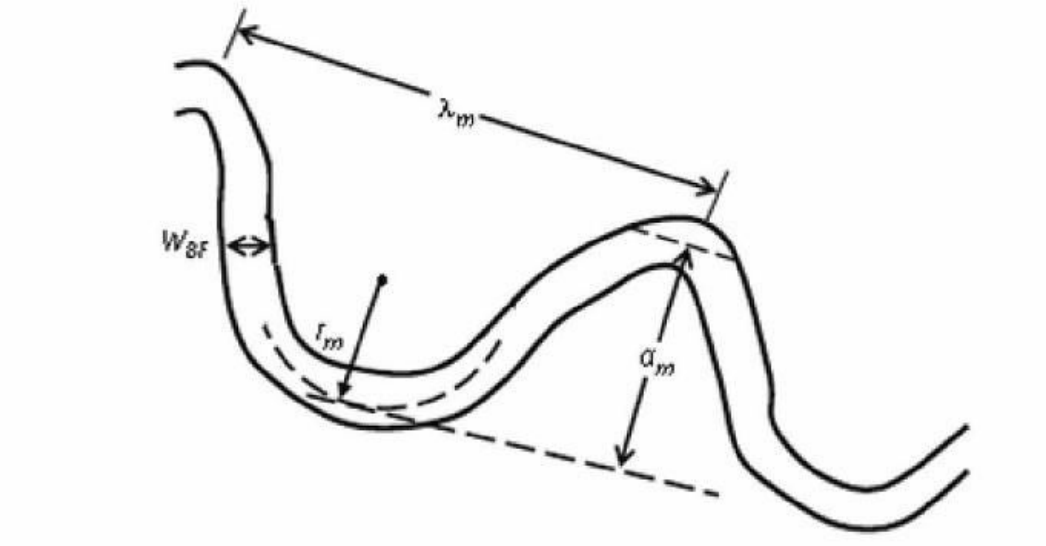

Figure 1.5: Schematic diagram of Meandering Channel Reach

Some degree of sinuosity is required before a channel is called meandering. The meander ratio or sinuosity index is a means of quantifying how much a river or stream meanders (how much its course deviates from the shortest possible path). It is calculated as the length of the stream divided by the length of the valley. A perfectly straight river would have a meander ratio of 1. Sinuosity ratio more than 1.05 is classified as sinuous and meandering. As bed width is related to discharge, meander wavelength also is related to discharge. The quasi-regular alternating bend of stream meanders are described in terms of their wavelength λm, their radius of curvature rm and their amplitude αm.

1.3 Background of the Study

Most of the river flow can be characterized as compound meandering channel flow i.e. consisting of a meandering main channel flanked by one or two side load plains. In fact, Bangladesh is one of the biggest Deltas in the world which is composed in the world of three major compound river systems, namely the Ganges, the Brahmaputra-Jamuna and the Meghna. Proper quantification of the flow parameters for the main channel and flood plain flow of such rivers still has been a subject of considerable research. A systematic study is of utmost 2 importance from the view point of better understanding of the flow phenomena in a meandering channel. Though Bangladesh is crisscrossed by so many rivers having meandering mechanism i.e. erosion in the outer bend and deposition in the inner bend but unfortunately research documents related to this are hard to come by. Considering the importance and scope for research, the present study is undertaken.

At first ADV Flow Tracker should be used for velocity data collection which is named 3-D flow velocity meter. Due to machine error of ADV meter I had to shift to current meter for Velocity pattern and 1-D flow direction will be observed using dye/paper float around the groyne area. The various flow parameters such as discharge, cross-sectional mean velocity, point velocities (V), shear stress (τ), energy co-efficient and momentum co-efficient should be calculated. Permeable groynes as bank protection measures at some distinct locations with remarkable yields in performance and still functioning passionately guarding protected banks from engulfment.

The shear stress can be calculated by the equation,

Shear stress, $\tau = \gamma R S_o$

Where, γ = unit weight of water

R= hydraulic radius

S_o= channel bottom slope

1.4 Objectives of the Study

The objective of the research is to understand the physics of flow phenomenon in the meandering channel with varying spacing of permeable gryones. The specific objectives of the research are as follows:

- Flow field
- Energy and Momentum co-efficient
- Shear Stress

in a meandering channel for different flow conditions with varying spacing of permeable groynes.

1.5 Organization of the Thesis

This thesis comprises of five chapters. General description is given in Chapter 1, Literature review is presented in Chapter 2, Experimental works are focused in Chapter 3, Results and Discussions of the research work is described in Chapter 4 and finally the Conclusions are in the Chapter 5. The first chapter of the study gives a brief description of the flow characteristics in a meandering channel effect of permeable gryones. It also includes the main objectives of the present study. The second chapter gives a short account of previous studies and literature available for the present study. The chapter three describes the experimental work as a whole. This chapter discusses about the experimental set up, construction of the channel, data collection procedures and methodology. The chapter four describes the experimental results concerning flow parameters such as distribution of discharge, velocity, shear stress, energy coefficient and momentum coefficient. The chapter five summarizes the conclusions drawn from the present research. A guideline for the future work is also outlined in this chapter. In the concluding part of the thesis, results in the form of figures (graphs), tables and photographic view of a meandering channel are presented in the Appendix-A and Appendix-B. References are provided to take a look at the relevant literatures that were consulted.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

A main channel flanked with one or two shallow flood plains is usually referred to as a compound channel system. The most obvious aspect of a compound channel is that the flow depths on the flood plain are often significantly smaller than the depths in the main channel especially during small floods and channel flow is known to have a distorted 3-dimensional nature mainly due to the velocity difference between the main channel and the flood plain. A shear layer is formed at the junction of the main channel and the flood plain, and fluid exchange takes place through this junction region. In case of meandering channel such flow structure is more complex. When the flow goes over bank in the compound meandering channel, the 3-dimensional (3D) flow mechanisms in the bend of a main channel are further enhanced by the interaction that may occur between the main channel and flood plain flow. An illustration of the flow field, stream wise components of main channel and flood plain flow in meandering compound channels

2.2 Preview of the Past Studies

In this section, as part of literature review a brief summary of the relevant papers are introduced. The materials reviewed may be categorized as experimental investigations of compound channel in straight reaches and compound meandering channel.

2.2.1 Compound Channels in Straight Reaches

Khatua et al. (2012) investigated the stage-discharge prediction for straight and smooth compound channels width wide floodplains and proposed a new method i.e. Modified Divided Channel Method (MDCM) for calculating the discharge in compound channels. An equation for interaction length of interface is developed for the calculation of momentum transfer between the main channel and floodplain. They found that MDCM gave satisfactory discharge results for both small-scale and large-scale experimental data. Considering all the data sets, the standard error is found to be minimum when compared with all other approaches and also compares favorably with that estimated using Conveyance.

Mohaghegh and Kouchakzadeh (2007) in a paper entitled “Evolution of Stage-Discharge relationship in Compound Channels.” compared the experimental results with the computed results obtained from the nine most well-known methods for computation of discharge in a compound channel. The results demonstrate a high accuracy of the divided channel method with the horizontal division lines, while the length of division line is included within the calculation of the wetted perimeter. In addition, as relative depth increases, the results of the all methods converge to each other and also in case of steeper slopes in lower relative depths, more agreements between different calculated methods and experimental results were observed.

Furthermore, the results show the effects of the maximum momentum transfer on the horizontal interface between the main channel and floodplains, while further angular distance from the horizontal interface toward the vertical interface between main channel and floodplains causes gradual decrease of momentum transfer effects.

Proust et al. (2006) investigated experimentally the flow in an asymmetrically compound channel transition reach in an abrupt floodplain contraction (mean angle 22°). They compared three 1D models and one 2D simulation to their experimental data to know whether the models, developed for straight and lightly converging channels, are equally valid to their geometry. They showed that the error on the level of water is moderated due to lateral mass transfer but increased error of discharge distribution in the sub-areas. They suggested for further work to understand the phenomena of severe mass transfers in non-prismatic compound channels.

Taming and Knight (2004) conducted numerical simulation to understand the secondary flow effect on the lateral momentum transfer with a standard k-model linked artificially with a given secondary flow. This simulation reproduced the typical linear distribution of momentum transfer term. The simulated secondary flow decreased the bed shear in main channel and increased the flood plain shear.

Ozbek et al. (2003) used limited experimental results from the FCF at Wallingford, for computing apparent shear stress and discharge in symmetrical compound channels with varying floodplain widths. They considered three assumed interface planes (vertical, horizontal, and diagonal) between the main channel and the floodplain sub-sections for computation of apparent shear stresses across the interfaces. They evaluated the discharge values for each sub section and for the whole cross-section. They showed that the performance of these computation methods depend on their ability to accurately predict apparent shear stress. The diagonal and horizontal division methods provided better results than the vertical division method, with the diagonal method giving the most satisfactory results.

Atabay and Knight (2002) presented some stage discharge relationship of symmetrical compound channel section using the experimental results of the Flood Channel Facility (FCF). They examined the influence of flood plain width and main channel aspect ratio to the stage discharge relationship. They derived simple empirical relationships between stage and total discharge, and stage and zonal discharge for uniform roughness and varying flood plain width ratio. The broad effects on the stage-discharge relationship due to flood plain width ratio were examined.

Myers et al. (2001) presented the experimental results of both fixed and mobile main channel boundaries together with two types of flood plain roughness compound channel using FCF data. On the basis of mathematical modeling, they proposed the velocity and discharge ratio relationships which was helpful for discharge assessment in over-bank flows and compared their results well with the data from a prototype natural compound river channel. They found that the ratios of main channel to floodplain average velocities and discharge plot logarithmically for the laboratory data, and linearity with the natural river data. The "divided channel method"(DCM) of discharge estimation overestimated the discharge in all cases and exhibited reasonable accuracy when applied to laboratory data with smooth floodplains, but showed significant errors up to 35% for rough floodplain data, and up to 27% for river data. The single channel method (SCM) significantly underestimated compound discharge for all cases for low flow depths, but became more accurate at larger depths for the smooth boundary laboratory data as well as the river data.

Thornton et al. (2000) performed series of eight experiments in a physical model of a compound channel to quantify the apparent shear stress at the interface between main channel and both vegetated and non-vegetated floodplain. They analyzed the data by using a turbulence-based method to calculate the apparent shear stress as a function of the fluctuation in channel velocities. They presented an empirical relationship for the estimation of the apparent shear stress at the main channel-floodplain interface which was found to be the function of the bed shear stress, average velocity, flow depth, and the blockage caused by floodplain vegetation. They also presented an empirical relationship to incorporate a quantitative measure of the density of vegetation within a floodplain.

Bousmar and Zech (1999) presented a theoretical 1D model of compound channel flow known as the exchange-discharge model (EDM) which is suitable for stage-discharge computation as well as practical water-profile simulations. The momentum transfer is estimated as the product of velocity gradient at the interface by the mass discharge exchanged through this interface resulting from the turbulence. Similarly, the turbulent exchange discharge is estimated by a model analogous to the mixing length model including a proportionality factor ψ that is found to be reasonably constant. They summarized that the model predicts well the stage-discharge both for the experimental data and natural data. They applied their models successfully for flow prediction in a prototype River Sambre in Belgium. Khan (1999) in a paper entitled "A study of flow characteristics in a compound channel." described the total discharge increases with the increase in depth and width of the compound section. The discharge decreases with the increase of flood plain roughness for the same depth ratio. Discharge in both the flood plain and main channel decreases with the increase in flood plain roughness.

Pang (1998) conducted experiments on compound channel in straight reaches under isolated and interacting conditions. It was found that the distribution of discharge between the main channel and floodplain was in accordance with the flow energy loss, which can be expressed in the form of flow resistance coefficient. In general, Manning's roughness coefficient not only denoted the characteristics of channel roughness, but also influenced the energy loss in the flow. The value of with the same surface in the main channel and floodplain possessed different values when the water depth in the section varied.

Myers and Lines (1997) studied the behavior of two key discharge ratios, namely total to bank full discharge and main channel to floodplain discharge in compound channels for smooth and homogeneously roughened channels of various scales. The total to bank full discharge ratio was shown to be independent of bed slope and scale and was function of cross section geometry only. The other ratio was also independent of bed slope and scale but was influenced by the lateral floodplain bed slope. They evaluated the coefficients and exponents in the equations relating to flow ratios to flow depths. Acers (1993) deduced a design formula for straight two stage channels by taking into account the interaction effects between floodplain and main channel. A parameter representing the coherence between the hydraulic condition of floodplain and main channel zones was proposed. The formulations were tested in large-scale experimental channels covering a wide range of geometry.

Stephenson and Kolov opoulos (1990) in a paper entitled “Effects of Momentum Transfer in Compound Channels” discussed four different methods of subdivision of compound channels on the basis of consideration of shear stress between floodplain and main channel to evaluate a method of discharge calculation. Based on the published data, they concluded that their 'area method' was the most promising alternative of discharge computation and that Prions-Townsend (1984) equation gave better results for apparent shear stress at floodplain and main channel interface. They incorporated channels with fairly wide range of bed roughness and floodplain widths in their computations.

Myers (1987) presented theoretical considerations of ratios of main channel velocity and discharge to the floodplain values in compound channel. These ratios followed a straight-line relationship with flow depth and were independent of bed slope but dependent on channel geometry only. Equations describing these relationships for smooth compound channel geometry were presented. The findings showed that at low depths, the conventional methods always overestimated the full cross sectional carrying capacity and underestimated at large depths, while floodplain flow capacity was always underestimated at all depths. He underlined the need for methods of compound channel analysis that accurately model proportions of flow in floodplain and main channel as well as full cross-sectional discharge capacity.

Wormleaton and Hadjipanos (1985) studied flow distribution in compound channels and showed that even though a calculation method may give satisfactory results of overall discharge in a compound channel, the distribution of flow between floodplain and main channel may be badly modeled. In general, the floodplain flow was found to be underestimated and the main channel flow overestimated. Knight and Hamed (1984) extended the work of Knightand Demetriou (1983) to rough floodplains. The floodplains were roughened progressively in six steps to study the influence of different roughness between floodplain and main channel to the process of lateral momentum transfer. Using four dimensionless channel parameters, they presented equations for the shear force percentages carried by floodplains and the apparent shear force in vertical, horizontal, diagonal, and bisector interface plains. The apparent shear force results and discharge data provided the strength and weakness of these four commonly adopted design methods used to predict the discharge capacity of the compound channel.

Knight and Demetrious (1983) conducted experiments in straight symmetrical compound channels to understand the discharge characteristics, boundary shear stress and boundary shear force distributions in the section. They presented equations for calculating the percentage of shear force carried by floodplain and also the proportions of total flow in various sub-areas of compound section in terms of two dimensionless channel parameters. For vertical interface between main channel and floodplain the apparent shear force was found to be more at low depths of flow and also for high floodplain widths. On account of interaction of flow between floodplain and main channel, it was found that the division of flow between the subareas of the compound channel did not follow the simple linear proportion to their respective areas.

Wormleaton et al. (1982) undertook a series of laboratory tests in straight channels with symmetrical floodplains and used "divide channel" method for the assessment of discharge. From the measurement of boundary shear, apparent shear stress at the vertical, horizontal, and diagonal interface plains originating from the main channel-floodplain junction could be evaluated. An apparent shear stress ratio was proposed which was found to be a useful yardstick in selecting the best method of dividing the channel for calculating discharge. It was found that under general circumstances, the horizontal and diagonal interface method of channel separation gave better discharge results than the vertical interface plain of division at low depths of flow in the floodplains.

Rajaratnam and Ahmadi (1981) in a paper entitled “Hydraulics of channels with floodplains.” studied the interaction of the flow in a main channel and a wide floodplain experimentally. They observed that because of the interaction the bed shear stress of the floodplain is increased and the bed shear stress of the main channel is decreased and that depth ratio of the flow in the main channel and floodplain determines the level of interaction. They also found that the apparent shear stress is also a function of depth ratio. They noticed that the eddy viscosity varies strongly across the flow. They defined the total width of the mixing region as: Bt = 5.97(H-d); where H and d are the depths in the main channel and floodplain respectively. This width starts in the main channel where U begins to decrease with lateral distance (y) to the section in the floodplain where U reaches the steady floodplain value of U.

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Rajaratnam and Ahmadi (1979) studied the flow interaction between straight main channel and symmetrical floodplain with smooth boundaries. The results demonstrated the transport of longitudinal momentum from main channel to flood plain. Due to flow interaction, the bed shearing floodplain near the junction with main channel increased considerably and that in the main channel decreased. The effect of interaction reduced as the flow depth in the floodplain increased.

Myers and Elswy (1975) studied the effect of interaction mechanism and shear stress distribution in channels of complex sections. In comparison to the values under isolated condition, the results showed a decrease up to 22 percent in channel shear and increase up to 260 percent in floodplain shear. This indicated the possible regions of erosion and scour of the channel and flow distribution in alluvial compound sections.

Compound Meandering Channel Prabir et al. (2012) in a paper entitled “Flow Investigations in a Wide Meandering Compound Channel” investigated the flow characteristics in a meandering compound channel that were conducted in a smooth meandering compound channel having width ratio (Wr≈12) under different values of relative depth (Dr) and velocity contours were shown. It is seen that with increased relative depth the primary velocity gradient decreases in both sides of bend apex in a meandering compound channel. However the velocity magnitude remains higher in inside of bend and adjacent floodplain than in outside zone of the bend.

Jing (2010) presented a three-dimensional (3D) numerical model to investigate the turbulent flow in meandering compound open channels with trapezoidal cross-sections. The velocity magnitude, tangential velocity, transverse velocity and Reynolds stress are calculated for various flow conditions. Good agreement between the simulated and available laboratory measurements was obtained. Comparison of the calculated secondary currents off our cases(one being in bank flow and other three being overbank flow) with different water depths reveals that the in bank flow exhibits different flow behaviors from that of the overbank flow does and the water depth has significant effects on the magnitude and direction of secondary currents.

Afzalimehr and Singh (2009) carried out field experiments on five reaches of the meandering cobble-bed Beheshtabad River in central Iran and showed that the position of the maximum velocity was independent of the relative submergence (h/d50 less or more than 4) and relative curvature (R/W), where h is the flow depth, d50 is the median diameter of sediment, R is the radius of curvature, and W is the river width. A new method, called the boundary-layer characteristic method, was employed for the determination of shear velocity. The shear velocity values estimated with this method were in agreement with those obtained using the parabolic law. The law of the wall was valid for low and high relative curvatures in the inner, outer, and central zones of the meandering reaches.

However, this law was not suitable for determining the shear velocity for the relative submergence range of $2.7 < h/d50 < 9.6$ due to its high sensitivity to near bed velocities.

Shiono, Chan, Rameshwaran and Chandler (2008) investigated the flow characteristics in meandering channels with non-mobile and mobile beds for overbank flows measuring flow rates, velocities, turbulent kinetic energies, bed forms and sediment transport rates at overbank flows condition. The behavior of bed form in meandering channels with overbank flows was observed using digital photogrammetry, with velocity measurements taken with a Laser Doppler Anemometer. The bed form structure and velocity distributions along the meandering channel were obtained for bank full flow and three overbank flow depths. Important interactions between the flow structure and bed form were observed along the meandering channel. The sediment transport rates collected during the experiment showed three phases; an increase in the sediment transport rate up to the bank full level, a small decrease as the flow goes overbank up to a relative depth ratio of 0.3 and then an increase again for higher flow depths. The regions of higher turbulent kinetic energy were identified. The total energy losses due to friction, secondary flow and interfacial turbulence in the lower layer flow of the main channel were compared in both the non-mobile and mobile bed cases.

Patra K.C. (2005) in a paper entitled ”Discharge Assessment for Two Stage Meandering and Straight Compound Channels.” analyzed the discharge characteristics of compound sections composed of a rectangular main channel and one or two floodplains disposed off to its sides. A set of smooth and rough sections is studied with aspect ratio varying between 2 and 5. The assumed vertical, diagonal, and horizontal interface plains are used to separate the compound channel section to subsections, the discharge for each subsection are calculated using Manning's equation. These subsection discharges are then added to give the total discharge carried by the meandering and straight compound channels. However, all these interface planes give results that are different from the observed values. A variable-inclined interface is proposed for which apparent shear force is calculated as close to zero. Equations are presented giving proportion of discharge carried by the main channel and floodplain. The equations agree well with experimental and river discharge data. Using a variable-inclined interface, the error between the measured and calculated discharges for the meandering compound sections is found to be the minimum when compared to that using other interfaces.

Wormleaton et al. (2005) investigated velocity distributions, depth variation and sediment transport under bank full and overbank flow conditions in meandering channels with a graded sand bed using the large-scale U.K. Flood Channel Facility. They concluded that the influence of overbank flow on the morphology of the bend depended upon the roughness of the floodplain, which determined the intensity of the interaction circulation generated around the crossover. This counteracted the centrifugal circulation around the bend which in the case of both smooth and rough floodplains led to erosion of the inner point bar. However, in the case of smooth floodplain the interaction circulation was strong enough through the bend to cause deposition around the outside bank. With the rough floodplain, the net circulation around the bend was not strong enough either to maintain the point bar or cause deposition around the outside of the bend. This led to increased net erosion of bed material around the apex which was deposited downstream to form an enhanced point bar.

Patra et al. (2004) in a paper entitled “Flow and Velocity Distribution in Meandering Compound Channels.” investigated the flow and velocity distribution in meandering compound channels with over bank flow. Using power law they presented equations concerning the three-dimensional variation of longitudinal, transverse, and vertical velocity in the main channel and floodplain of meandering compound sections in terms of channel parameters. The results of formulations compared well with their respective experimental channel data obtained from a series of symmetrical and unsymmetrical test channels with smooth and rough surfaces. They also verified the formulations against the natural river and other meandering compound channel data.

Morvan et al. (2003) in a paper entitled “Three-Dimensional Hydrodynamics of Meandering Compound Channels.” investigated the velocity field in meandering compound channels with over bank flow using the Flood Channel Facility (FCF) data, and simulated the flow field using computational fluid dynamics. They predicted the velocities, secondary velocities and the helical motion of the water flowing within the main channel and compared their results with the experimental data.

Patra and Kar (2000) in a paper entitled. Flow Interaction of Meandering River with Floodplains.” reported the test results concerning the boundary shear stress, shear force, and discharge characteristics of compound meandering river sections composed of a rectangular main channel and one or two floodplains disposed off to its sides. They used five dimensionless channel parameters to form equations representing the total shear force percentage carried by floodplains. A set of smooth and rough sections were studied with aspect ratio varying from 2 to 5. Apparent shear forces on the assumed vertical, diagonal, and horizontal interface plains were found to be different from zero at low depths of flow and changed sign with increase in depth over floodplain. They proposed a variable-inclined interface for which apparent shear force was calculated as zero. They presented empirical equations predicting proportion of discharge carried by the main channel and floodplain.

Ervine et al. (2000) presented a practical method to predict depth-averaged velocity and shear stress for straight and meandering over bank flows. They also presented an analytical solution to the depth-integrated turbulent form of the Navier-Stokes equation that includes lateral shear and secondary flows in addition to bed friction. They applied this analytical solution to a number of channels, at model, and field scales, and compared with other available methods such as that of Shiono and Knight and the lateral distribution method (LDM). Shiono et al. (1999) in a paper entitled “Stage-Discharge Assessment in Compound Meandering Channels.” reported the effect of bed slope and sinuosity on discharge of two stage meandering channel. Basing on dimensional analysis, an equation for the conveyance capacity was derived which was subsequently used to obtain the stage-discharge relationship for meandering channel with over bank flow. It was found that the channel discharge increased with an increase in bed slope and it decreased with increase in sinuosity for the same channel. An error of 10% in discharge estimation was reported for relative depths exceeding 0.01. Shiono et al. (1999) in a paper entitled “Bed shear stress in meandering channels for overbank flows” investigated boundary shear stress in meandering channels for overbank flow using a Preston tube and a heated thin film sensor. Measurements of secondary flow were also carried out using a Laser Doppler Anemometer. The distributions of the boundary stress and secondary flow along the meandering channels for over bank flow show that locations of peak and dip on the boundary shear stress distribution well correspond to those of the secondary flow downwards and upwards motion respectively.

Shiono et al. (1999) in a paper entitled “Energy Losses due to Secondary Flow and Turbulence in Meandering Channels with Over bank Flow.” presented the secondary flow and turbulence data using two components Laser- Doppler anemometer. They developed the turbulence models, and studied the behavior of secondary flow for both in bank and over bank flow conditions. They divided the channel into three sub areas, namely (i) the main channel below the horizontal interface (ii) the meander belt above the interfaces and (iii) the area outside the meander belt of the flood plain. They investigated the energy losses for compound meandering channels resulting from boundary friction, secondary flow, turbulence, expansion and contraction. They reported that the energy loss at the horizontal interface due to shear layer, the energy loss due to bed friction and energy loss due to secondary flow in lower main channel have the significant contribution to the shallow over-bank flow. They also concluded that the energy loss due to expansion and contraction in meander belt have the significant contribution to the high over-bank flow.
Shiono and Muto (1998) in a paper entitled “Complex flow mechanisms in compound meandering channels with overbank flow” investigated the most important feature of the compound meandering channel flow as the behavior of the secondary flow. Turbulence and secondary flow measurements were undertaken using a two component laser-Doppler anemometer in meander channels with straight flood plain banks. The difference in direction of rotation of the flow before and after inundation at a bend section was confirmed by the detailed velocity measurements. In addition, by performing the measurements over a half wavelength of meander, the originating and developing processes of the secondary flow were also clarified. In contrast to the centrifugal force for in bank flow, the interaction between the main channel flow and the flood plain flow in the cross-over region was found to play an important role in developing a shear produced secondary flow in the overbank cases. In such channels, large interfacial shear stresses were induced at around the bank full level, especially in the cross-over region, and were found to be larger than the bed shear stress in magnitude. The influence of secondary flow on eddy viscosity was found also to be significant.

Fares (1995) in a paper entitled “Boundary Shear in Curved Channel with Side Overflow.” investigated the characteristic changes in the boundary shear stress field of a channel bend at the intersection with a side overflow. On the basis of a field survey on bottom topography changes of the meandering river Allan Water at the cut-off section, a detailed study of boundary shear stresses in an idealized rigid bed model was undertaken. Both mathematical and experimental approaches were employed in the idealized model study.

The analysis of results showed that continual reductions in shear stresses occurred in the bend at the side overflow region. The maximum reduction of shear stresses was 37% in cases of low side overflows and 82% in cases of high side overflows. These reductions were attributed to the development of stagnation and separation zones at the intersection associated with strong lateral outward currents. Based on the idealized model study, the features observed in the bed topography of Allan Water at the cutoff section are most likely to develop in cases of combined bend and high side overflows.

Wark and James (1994) developed a procedure to calculate conveyance in meandering channels with over bank flow based on the horizontal division of the cross section. It represented a significant change to the current practice of using vertical division of separating the floodplain from main channel. The non-friction energy losses were shown to be less important as the floodplain was roughened. The bed friction remained the most significant source of energy loss in the channels with over bank flow. The work was tested against the field data collected from the river Roding at Abridge in Essex and found to predict the measured stage-discharge relations reasonably well.

Sellin et al. (1993) in a paper entitled "Behavior of Meandering Two Stage Channels." studied the influence of channel geometry, floodplain widths and roughness on the stage-discharge relationship. They found that the interaction mechanism associated with over bank flow in straight channels had very little influence on meandering two stage channels. For compound channel with smooth boundary, the loss of energy at various flow depths was expressed in terms of the variation of Manning's and Darcy-Weisbach friction factor. They suggested that considerably more work is needed to establish a sufficiently robust calculation method to reflect adequately the range of circumstances found in the field. The influence of floodplain roughness, main channel cross section, and sinuosity on the flow structures required further studies.

Ervine et al. (1993) reported the influence of parameters like sinuosity, boundary roughness, main channel aspect ratio, width of meander belt, flow depth above bank full level, and cross sectional shape of main channel affecting the conveyance in the meandering channel. They quantified the effect of each parameter through a non-dimensional discharge coefficient F* and reported the possible scale effects in modeling such flows.

Willetts and Hardwick (1993) in a paper entitled "Stage Dependency for Over Bank Flow in Meandering Channels." studied the measurement of stage-discharge relationship and observation of velocity fields in small laboratory two stage channels. It was found that the zones of interaction between the channel and floodplain flows occupied the whole or at least very large portion of the main channel. The water, which approached the channel by way of floodplain, penetrated to its full depth and there was a vigorous exchange of water between the inner channel and floodplain in and beyond the downstream half of each bend. This led to consequent circulation in the channel in the whole section. The energy dissipation mechanism of the trapezoidal section was found to be quite different from the rectangular section and they suggested for further study in this respect. They also suggested for further investigation to quantify the influence of floodplain roughness on flow parameters.

Mekeogh and Kiely (1989) in a paper entitled "Experimental study of the
Mechanisms of flood flow in meandering channels" discussed the flow mechanism and derived the following conclusions:

1) Conveyance of a meandering channel floodplain is greater than that of a straight channel floodplains
2) Boundary shear is higher in meandering flood flow than straight channel flood flow.
3) The flow mechanisms of expansion and contraction are shown to occur in meandering flood flow.
4) At high depth ratio, the direction of flood flow over the meandering channel is essentially parallel with the flood plain flow.
5) The longitudinal turbulence intensities were higher n magnitude for meandering channels than straight channels.
6) The maximum turbulence intensity was observed to occur on the floodplains, adjacent to the downstream interface of the crossover sections and at the inner bend of the main channel,
7) Turbulence transfer from the floodplain to the main channel was observed in straight and meandering channels.

Johannesson and Parker (1989) in a paper entitled "Velocity Distribution in Meandering Rivers." presented an analytical model for calculating lateral distribution of depth averaged primary flow velocity in meandering rivers. Using an approximate "moment method" they accounted for the secondary flow in the convective transport of primary flow momentum, yielding satisfactory results of the redistribution of primary flow velocity. Ervine and Ellis (1987) carried out experimental investigation for the different sources of losses of energy in the meandering compound channel. They divided the compound channel into three sub areas, namely (i) the main channel below the horizontal interface from the junction, (ii) the meander belt above the interface, and (iii) the area outside the meander belt of the flood plain. They identified the different sources of losses of energy in each sub-area and proposed a discharge estimation method.

Ghosh and Kar (1975) in a paper entitled "River Flood Plain Interaction and Distribution of Boundary Shear in a Meander Channel with Flood Plain." presented the evaluation of interaction effect and the distribution of boundary shear stress in meander channel with floodplain. Using the relationship proposed by Toebes and Sooky (1967) they evaluated the interaction effect by a parameter (W). The interaction loss increased up to a certain floodplain depth and there after it decreased. They concluded that the channel geometry and roughness distribution did not have any influence on the interaction loss.

Toebes and Sooky (1967) in a paper entitled "Hydraulics of Meandering Rivers with Floodplains." investigate the hydraulics of meandering rivers with floodplains under laboratory conditions. They attempted to relate the energy loss of the observed internal flow structure associated with interaction between main channel and floodplain flows. The significance of helicoidally channel flow and shear at the horizontal interface between main channel and floodplain flows were investigated. It was found that energy loss in compound meandering channel was more than the sum of simple meandering and uniform channel carrying the same total discharge and same wetted perimeter. The interaction loss increased with decreasing mean velocities and exhibited a maximum when the depth of flow over the floodplain was less. For the purpose of analysis, a horizontal fluid boundary located at the level of main channel bank full stage was proposed as the best alternative to divide the compound channel into hydraulic homogeneous sections. Helicoidal currents in meander flood plain geometry were observed to be different and more pronounced than those occurring in a meander channel carrying in bank flow. It was reported that Reynold's number (R) and Froude number (F) had significant influence on the meandering channel flow.

2.3 Comments on the Literature Review

From the literature review it is apparent that most of the research in a compound meandering channel concentrated on the different methods of discharge and shear stress estimation for different width and depth ratio. But research documents related to flow characteristics i.e. velocity distribution, stage-discharge curve, flow distribution, shear stress distribution and velocity distribution coefficients in a compound meandering channel are rare not only in Bangladesh but also in the world. Velocity distribution as well as stage-discharge curve, shear stress distribution is essential for the design, operation and maintenance of a compound meandering channel and more importantly for the prediction of flood and flood protection measures. So the study of flow characteristics in a compound meandering channel is an important issue now-a-days.

Most of the rivers have their cross sectional geometry in the form of a compound section where a deep main channel is often flanked by one or two shallow adjacent floodplains. The main channel flow is usually faster and the floodplain flow is slower comparatively. When the flow goes over bank, such a combination generates considerable momentum and mass transfer between floodplain flow and main channel flow rendering the flow analysis an extremely complex task. Additionally if the plan form or the path of the channel is sinuous or meandering instead of straight one which is the case more often than not, further complex mechanisms occur in the channel flow such as large sets of coherent vertical structures due to presence of secondary flow of Prandtl's 1st kind as well as due to anisotropic turbulence arising out of complex geometry of the channel and uneven bottom topography. The determination of suitable stage discharge relationship and the associated flow variables such as depth averaged velocity and boundary shear are often hard to achieve due to strong three dimensional nature of the flow where no complete theoretical analysis is possible. River flow can be schematized as compound meandering channel in which the mechanism of erosion in the outer bank and deposition in the inner bank. Naturally, River overflow their banks during the episodes of high flooding resulting in a huge potential damage to life and property as well as erosion and depositions of sediments. In a compound meandering channel there is an intense interaction between the faster moving main channel flow and slower moving floodplain flow resulting in a lateral transfer of a significant amount of longitudinal momentum which affects the shear stress distribution in a channel flow.

Shear stress in a compound meandering channel is strongly governed by interaction between flow in the main channel and that in the floodplain due to prevailing of different hydraulic conditions in the main channel and floodplain flow, the shape of the cross-section, the longitudinal variation in plan form geometry, the sediment concentration and the lateral and longitudinal distribution of boundary roughness. The flow structure of a compound channel is a complicated process due to the transfer of momentum between the deep main channel and the adjoining shallow floodplains.

Experiments are carried out to measure the shear stress around the wetted perimeter of a two-stage compound channel and to quantify the momentum transfer in terms of shear stress along the assumed interfaces originating from the junction between main channel and flood plain. This is further helpful for deciding appropriate interface plains for evaluation of accurate stage-discharge relationship for a compound channel of all geometry. The lateral momentum transfers are found to magnificently affect the shear stress distribution in flood plain and main channel sub sections [1]. Knowledge of momentum transfer to different interfaces can be acquired from the distribution of boundary shear in the sub sections. In the present work, commonly used equations of shear stress distributions across assumed interface plane are analyzed and tested for various types of compound channels and their flow conditions using published data.

Furthermore, a modified expression to predict the boundary shear distribution in compound channels that is good for all width ratios is derived and is found to provide significant improved results [1]. The shear stress distribution in the straight compound channel and the compound meandering channel have been investigated by a number of authors[1],[2],[3], [4], [5], [6],[7],[8],[9],[10],[11],[12] and [13]. Most of hydraulic formulae derived by the author assuming that the shear stress distribution is uniform over the wetted perimeter. Distribution of shear stress mainly depends upon the shape of the cross section and the structure of the secondary flow cells. However, for meandering channel there is a wide variation in the local shear stress distribution from point to point in the wetted perimeter. Also the magnitude of shear in a meandering channel is significantly different from that of straight channel having the same geometry, shape and cross sectional area. For the meandering compound channels the important parameters effecting the shear stress distribution are sinuosity (Sr), the amplitude (a), relative depth (Dr), width ratio (Wr) and the aspect ratio (Ar) [13]. Information regarding the shear stress distribution is crucial in controlling floods, solving a variety of river hydraulics and engineering problems, designing stable channels, revetments and artificial waterways. Considering the importance of shear stress distribution in a channel flow, there is a need to evaluate the shear stress carried by the main channel and floodplain boundary in a compound meandering channel at various locations of meander path. The aim of this study is to describe the effect of the interaction mechanism on the basis of shear stress distribution in compound meandering channel sections with varying floodplain width and depth ratio.

2.4 Shear Stress Distribution in Meandering Compound Channel

Field measurements of velocity and turbulence have been carried out by Koopaei et al. (2003), in a study reach of the River Severn (U.K.) during overbank flows. He calculated shear velocity using different methods; (a) the reach averaged

$U^* = \sqrt{gfRS}$……………………………….(2.1)

Where g = gravitational acceleration; S f = energy slope; and R = hydraulic radius (reach-averaged values).

b) For logarithmic velocity profile according to (Nikora and Smart, 1997): the velocity distribution can be written as

$u^* = u'/((1/k)*\ln(z/z_\circ)))$……………………(2.2)

Shear stress is derived as

$\tau_1 = \rho {u^*_1}^2$……………………………………...(2.3)

Where Zo describes the roughness length, u is the time-averaged stream wise velocity at distance z.

He observed that there is a discrepancy between the calculated values of the shear velocities due to different methods. He also calculated Ks and Zo but no co-relation with ks and Zo was found.

Afzalimeh and Singh (2009), carried out field experiments on five reaches of the meandering cobble-bed Beheshtabad river in central Iran and showed that the position of the maximum velocity was independent of the relative submergence h / d where h is the flow depth, and relative curvature R / W, d is the median diameter of sediment, R is the radius of curvature, and W is the river width. A new method, called the boundary-layer characteristic method, was employed for the determination of shear velocity.

Shiono et al. (1999) measured boundary shear stress in meandering channels for overbank flow using a Preston tube and a heated thin-film sensor. Measurements of secondary flow were also carried out using a laser Doppler anemometer. The distributions of the boundary stress and secondary flow along the meandering channels for over bank flow show that locations of peak and dip on the boundary shear stress distribution well correspond to those of the secondary flow downwards and upwards motion respectively.

Knight et al. (1979) and Ishigaki et al. (1996) measured the boundary shear stress using a Preston tube and investigated its distribution with respect to an aspect ratio in straight open channels. Knight et al.(1984) measured the boundary shear stress in strong secondary flow regions in a relatively large meandering channel. Their results indicate that an undulation of the boundary shear stress distribution is closely related to the secondary flow structure. The downwards motion of secondary flow is generally related to larger boundary shear stress, on the other hand, the upwards motion is related to smaller boundary shear stress. Khatua and Patra (2007) investigated the distribution of shear stress in the main channel and floodplain of meandering and straight compound channels. Based on the experimental results of boundary shear, they predict the distribution of boundary shear carried by main channel and floodplain sub sections. Five dimensionless parameters are used to form equations representing the total shear force percentage carried by floodplains. A set of smooth and rough sections was studied with aspect ratio varying from 2 to 5.

CHAPTER THREE

METHODOLOGY

3.1 General

The experimental study has been conducted in the open air facility of Water Resources Engineering Department, Bangladesh University of Engineering and Technology (BUET), Dhaka. Required data have been collected from 10 experimental runs in five different setups of the compound meandering channel. The details of the experimental setup as well as the measuring techniques are described in the following articles. The experimental setup consists of two parts, the permanent part and the temporary part. The permanent part is the experimental facility necessary for the storage and regulation of water circulating through the experimental reach.

The temporary part is mainly brick walls which are used to vary the floodplain width for different setups.

3.2 Theory of Meandering Channel

3.2.1 Introduction

The flow in the bend of a meandering channel is of the free-vortex type where the velocity varies inversely with the radius of curvature. Because of secondary current in a bend, the flow is of helical-screw type and since the secondary current near the bed is from the outer to the inner bank, the outer bank is constant erosion and the eroded materials are deposited at the inner bank. This process causes increasing curvature of the outer bank, leading to horse shoe type loop formation. Deep channel is maintained at the outer bank and the inner bank gets shallower. In meandering channel, large interfacial shear stresses were induced at around the bank full level, especially in the cross-over region.

3.2.2 Geometry of Meandering Channel

In general a meander is a bend in a sinuous watercourse or river. The geometry of a meandering channel (Fig 3.1) is usually described by the meander length

(ML) and meander width (MB). Various parameters that are used to define the characteristics of the meanders are as follows:

Meander Length (ML): The meander length is the axial length of one meander, i.e. the tangential distance between the two consecutive corresponding points of a meander. Meander Width (MB): The meander width is the distance between the outer edges of the one clockwise loop and the adjacent anti-clockwise loop of the meander.

Meander Ratio (Mr): The meander ratio is the ratio of the meander width to the meander length. Sinuosity (Sr): The sinuosity is the ratio of the thalweg length to the valley length. The thalweg length is the length of the river along the line of the maximum depth.

Figure 3.1: Geometry of a Meandering Channel Normal river width (W) Meandering width (MB) Meandering Length (ML)

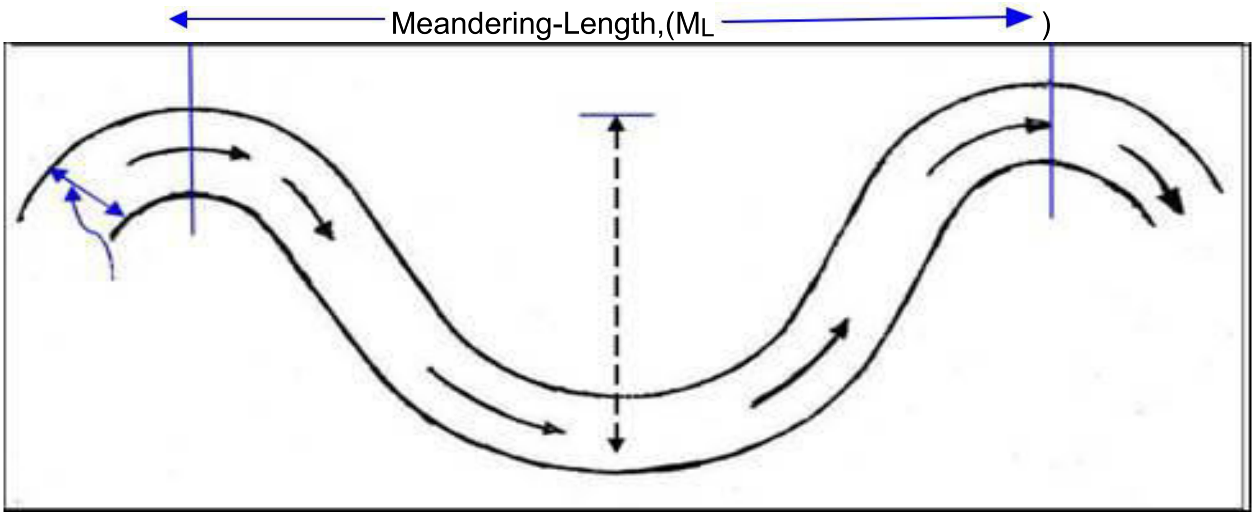


Figure 3.1: Geometry of a Meandering Channel

A schematic diagram of the experimental reach is presented in figure 3.1 and figure 3.1(a) represents the schematic diagram of the experimental set-up.

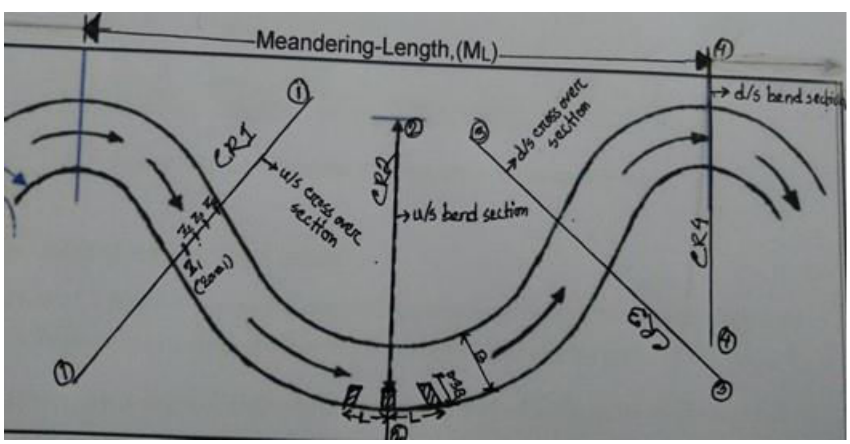


Figure 3.1(a): A schematic diagram of the experimental reach

1. Sand Filling	2. Brick Flat soling Meandering channel	3. Net Finishing of channel

4. Drawing of Meandering Channel	5. Construction of Meandering channel	6. Net Finishing of Meandering channel

Figure 3.1(b).A schematic diagram of the experimental reach

3.2.3 Mechanism of Meander Development

Development of a meander is a highly complex phenomenon. Various investigators studied the problem in the past and gave their own theories. Some of these theories are explained below.

1. Inglis theory: According to Inglis, when there is heavy load of bed material in the river, excess turbulent energy is developed due to unevenness of the bed. The flow does not remain axial and it it tends to concentrate towards one of the banks. When the flow concentrates at a bank that bank resists the component of velocity causing flow towards it and a part of the velocity energy is converted into pressure energy. This results in an increase in the water surface near that bank. This increased pressure causes a cross-current of the bottom water towards the other bank and there is deposition of the material at the inner bank.

2. Friedkin,s Theory: According to Friedkin, meandering occurs because of local bank erosion and consequent overloading and deposition by the river of the heavier sediments which move along the bed. In other words, a bank is locally scoured which results in the excess silt charge. This excess silt charge is deposited on the same bank a little further downstream because it cannot be carried by the river. Meandering occurs because of this deposition.

3. Joglekar,s Theory: According to Joglekar and his associates, the primary cause of meandering is excess of sediments in river during floods. This sediment load being in excess of the load-carrying capacity of the river is deposited on the bed. Consequently, the river tends to build up a steeper slope which causes a reduction in the depth of water. There is a corresponding increase in the width of the river banks o not resist erosion. Even when there is a slight deviation from uniform axial flow, more flow occurs towards one bank than the other. Additional flow is immediately attracted towards that bank. It leads to shoal formation at the other bank. This accentuates the curvature of flow and finally a meander is formed.

3.3 Description of Different Components

3.3.1 Outline of the Experimental Reach

The experimental reach consists of a 670 cm long symmetric meandering channel, set at a constant bed slope 0.001845 with fixed bed and banks. The total length of the channel is 975cm of which 670cm is meandering channel. The entire reach is constructed by brick, cement and sand. The experimental reach of this meandering channel has wavelength, λ=365.70cm, bed width, B=137.2 cm. The length of the groyne, L = 0.3B with spacing of the groyne, S =L, 2L,3L and 4L,where B (137.2 cm) is bed width of the main channel. Here, experimental permeable groyne is wooden and length is 41.4 cm (0.3B) and width is 5.75 cm including 8 numbers of cross bracing which spacing is 4.6 cm. Also the depth of this groyne is 25 cm which is greater than experimental water level 20 cm and 15 cm.

A schematic diagram of the experimental reach and experimental setup are presented in the figure 3.1(a), 3.1(b), 3.1 (c) and 3.1 (d) respectively.

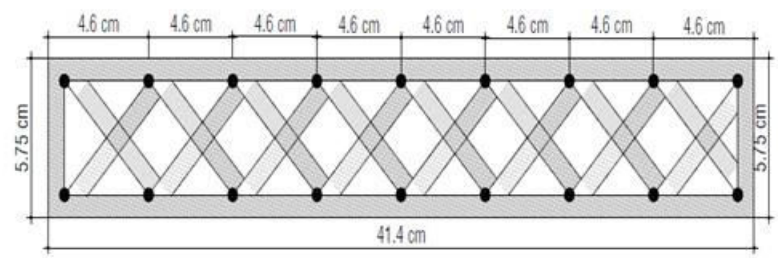


Fig: Plan of permeable groyne

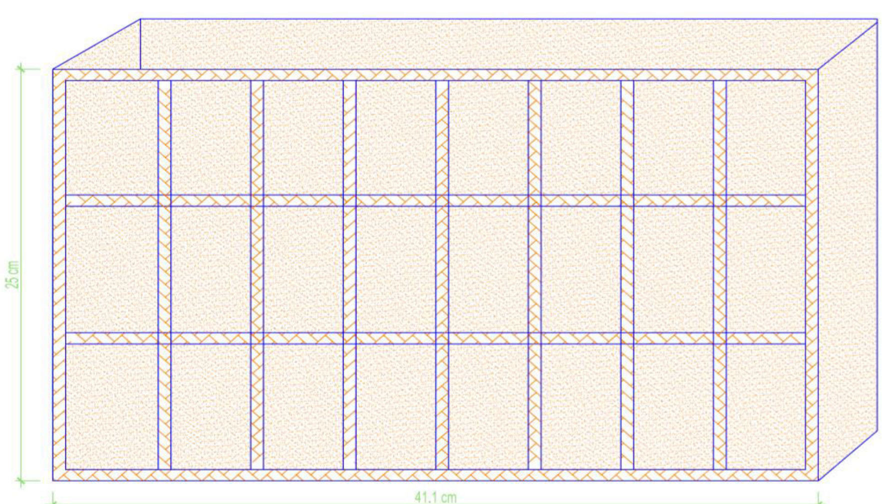


Fig: Elevation of Gryone

Figure 3.1 (c): A Schematic Diagram of the Experimental Setup

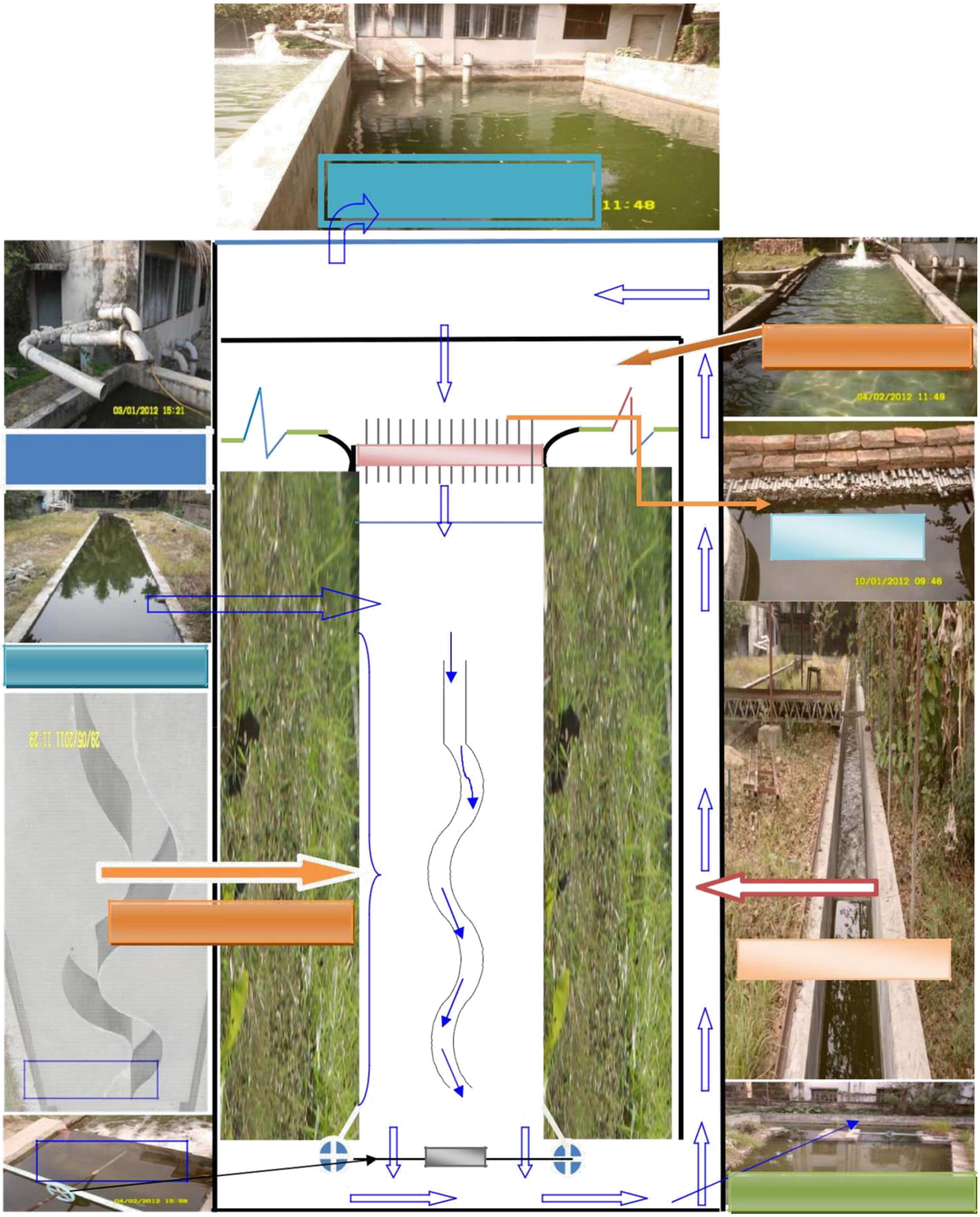


Figure 3.1 (d): A Schematic Diagram of the Experimental Setup

3.3.2 The Water Supply System

The upstream reservoir

The upstream reservoir is near the pump house, located between the storage pool and the approach channel, where water is storage from direct supply of the pump. The reservoir has 11m length and width 3 m and has a vertical depth of 10 m, so it can store a huge amount of water. Water from the upstream reservoir passes through a wall made up PVC pipes into the approach channel. This is done to ensure undisturbed and uniform flow in the experimental reach.

The approach channel

The approach channel conveys water to the experimental channel, it is 242 cm in width and length is 30m. The walls of the channel are made of bricks, sand and cement. This approach channel carries water as a uniform flow. The sharp-crested weir is located in the upstream of the channel. Figure 3.2 shows the upstream reservoir, the approach channel including the measuring weir and rail.

Figure 3.2: Upstream reservoirs, the approach channel including the sharp crested weir

Storage Reservoir

The total capacity of reservoir is about 1152 m^3. From the storage reservoir water is intake by the pump and discharge to the upstream reservoir. The valve attached to the reservoir is used to empty the reservoir for cleaning or repairing purpose.

Downstream Reservoir

The downstream reservoir serves as the transition reservoir. At the entrance of the reservoir there is a tail gate and a spillway is used to remove excess water at the end.

Figure 3.3: The storage reservoir

The Guide Vanes and Tubes

To ensure a more smooth flow toward the approach channel, guide vanes are placed between the transition flume and the approach channel which are at right angle to each other. In order to prevent turbulence in the approach channel, PVC pipe (diffuser) is used. Figure 3.4 shows the guide vanes and tubes.

Figure 3.4: Guide vanes and tubes

Centrifugal Pump

The centrifugal pump draws water from the storage reservoir and supplies to the upstream reservoir. The capacity of the pump is 80 l/s. Figure 3.5 shows the water supply system from the centrifugal pump.

The tail gate

The regulating function of the downstream end is provided by tail gate. The tail gate rotates around a horizontal axis. It is operated to maintain desired water level in the experimental reach. Another function of tail gates is to close the experimental part during non-running periods. At the end of the experimental channel, water is allowed to flow freely so that backwater has no effect in the experimental reach. Figure 3.6 shows the hand operated tail gate.

3.4 Measuring Equipment

3.4.1 Measuring line and measuring bridge

To indicate the co-ordinate system and the location of various measurements, both side walls are equipped with parallel measuring lines, indicating the X direction. As the experimental reach is a meandering channel, so actual X direction for main channel is taken as the flow direction and by using a set-squire, the perpendicular direction is determined. During data collection, the measuring bridge is to be moved to the predefined location along the channel manually. A small wooden trolley is fitted on the bridge and is operated manually. A base plate is fitted on this trolley which can be adjusted at any distance across the channel. The measuring instrument is kept fixed on this plate. Figure 3.9 shows the measuring bridge at cross section location.

3.4.2 The Point Gauge and Reference Point

The point gauge is used to measure water level in the approach channel. The gauge is installed at the approach channel that helps to maintain water level in the experimental reach for different runs in a setup.

3.4.3 The stilling basin and transition flume

Behind the tail gate the water falls into a stilling basin there is a transition flume, which allows water for recirculation.

Figure 3.5: Water supply system from the centrifugal pump

Figure 3.6: Hand operated tail gate

Figure 3.7: Transition flume

3.4.4 The Current Meter

A current meter is oceanographic device for flow measurement by mechanical (rotor current meter), tilt (Tilt Current Meter), acoustical (ADCP) or electrical means. Mechanical current meters are mostly based on counting the rotations of a propeller and are thus rotor Current meters. A mid-20th-century realization is the Ekman current meter which drops balls into a Container to count the number of rotations. The Roberts radio current meter is a device mounted on a moored buoy and transmits its findings via radio to a servicing vessel. Savories current meters rotate around a vertical axis in order to minimize error introduced by vertical motion. A built-in clock triggers the instrument at preset intervals and a total of six channels are sampled in sequence. The first channel is a fixed reference reading for control purposes and data identification. Channels 2, 3 and 4 represent measurement of temperature, conductivity and depth respectively. Channels 5 and 6 represent the vector averaged current speed and direction since the previous triggering of the instrument. The data is sequentially fed to the Data Storage Unit (DSU) 2990 or 2990E.The flow direction is detected by a magnetic compass, a needle clamped onto a potentiometer. This design becomes problematic for instruments in the Arctic Ocean since the North Magnetic Pole moves relative to the geographic North Pole and this (time-depended) magnetic declination cannot be neglected any more. These values only hold for medium currents between 0.02 and 2.95 m/s. Small velocities are difficult to detect because the vane shows a lot of inertia and the rotor needs to overcome friction before starting to rotate. The company calls the acoustical single-point instruments recording **current meter** which allows to keep the abbreviation RCM.

Figure 3.8: Current meter

3.4.5 Construction of the Meandering Channel

An extensive works has been done for the construction of the compound meandering channel in the open air laboratory of Water Resources Engineering Department, BUET. At the initial stage the channel bed was prepared by brick flat soling and then neat finishing was done by cement layer. The required drawing was set-up by a handmade large compass with a permanent marker. Figure 3.10 shows the drawing set-up of the channel. The construction phase of the channel is shown in figure 3.19. At every steps of construction, the required dimensions were checked thoroughly and from starting to end, the entire construction process was under regular supervision.

Figure 3.9: Construction Stage of Meandering Channel

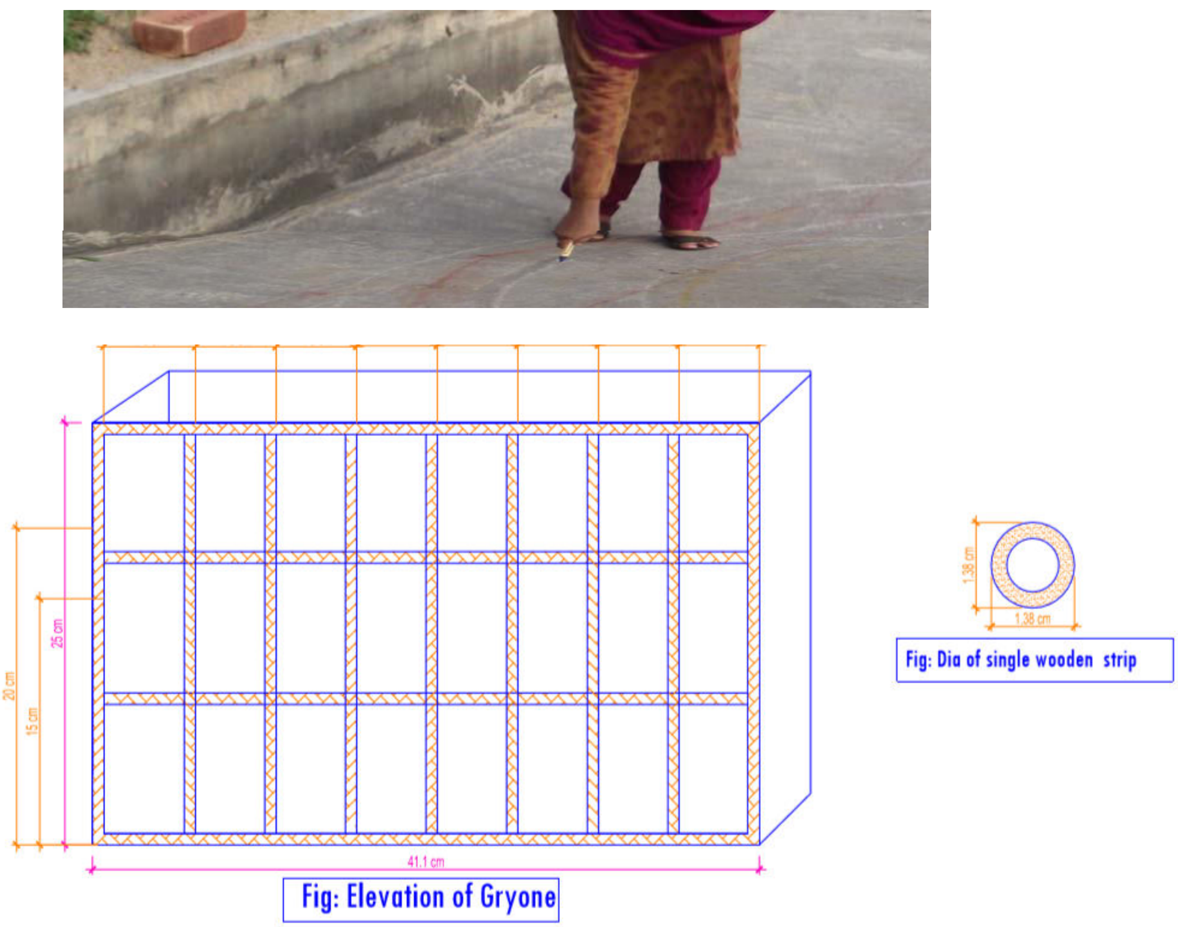


Figure 3.10 : Drawing set-up in the field with Permeable Groyne

3.5 Data Collection and Processing

3.5.1 Process of Experiment

The following flow of tasks are to be followed up during the study period:

(i) Preparation of the Experimental Setup:

The proposed study will be carry out in the open-air facility of Water Resources Engineering Department, BUET. The experimental setup for meandering channel will consist of a main channel. The groynes are considered to be permeable for this experiment. The locations of the groyne will changed at main channel for each setup with varying spacing at various flow conditions. The conditions are (i) a single groyne at concave bend and (ii) Series of groyne with varying spacing. The total length of the channel is 975cm of which 670cm is meandering channel. The length of the groyne, L = 0.3B with spacing of the groyne, S =L, 2L,3L and 4L,where B (137.2 cm) is bed width of the main channel.

The length of groyne is governed by the shape of the cross-section of the river and the extent of protection of the bank required. General practice is to relate the spacing of groynes to their length. But the spacing also depends on the orientation to the flow velocity, the bank curvature and purpose of the groynes. Usually the spacing considered about 2 to 3 times the length of groynes. This rule includes some safety for the bank erosion and protection. An Indian guideline suggests a spacing of the groynes by 0.1 to 0.15 of the meander length of an outflanking channel. If the meander length is 15 to 30 times the channel width and length of the groyne is 30% of the channel width, then the spacing is 0.6 to 0.15 times the length of the gryone. (Bureau of research testing and consultancy: Guidelines for river bank protection)

For the first set-up, a single Groyne should be place perpendicularly in concave bend. Then for second, third, fourth and fifth set-up consider series of groyne with spacing “S=L”, “S=2L”, “S=3L” and “S=4L in same bend. For every set-up, there will be two different run for two different water depths (D1 and D2).

(ii) Measurement of Experimental Data:

Two different run will be completed for two different water depths (D1 and D2) in the laboratory experiment. Velocity readings for each set-up should be taken at 40 (forty) different points including five different set-up. The velocity data collection will be measured by a flow velocity meter named Current Meter. The dye/paper float should be used for velocity pattern and flow direction around the groyne area. The various flow parameters such as discharge, cross-sectional mean velocity, point velocities, isovel, energy co-efficient and momentum co-efficient, shear stress (τ) should be calculated. Here, H is the water level at main channel. The shear stress can be calculated by the equation, $\boldsymbol{\tau = \gamma R S_o}$

Where, γ is the unit weight of water, R is the hydraulic radius and S_o is the channel bottom slope.

(iii) Laboratory Test Scenarios:

Run No.	Groyne Condition	Water Depth (D)	Location of reading (Distance from the surface water)
1.	Single Groyne at one side of main channel at Bend	D1 And D2	Velocity readings at the 0.2H, 0.4H, 0.6H, 0.8H of the total depth
2.	Series of Groyne (three groyne) at one side of main channel at S = L spacing at Bend		
3.	Series of Groyne (three groyne) at one side of main channel at S = 2L spacing at Bend		
4.	Series of Groyne (three groyne) at one side of main channel at S = 3L spacing at Bend		
5.	Series of Groyne (three groyne) at one side of main channel at S = 4L spacing at Bend		

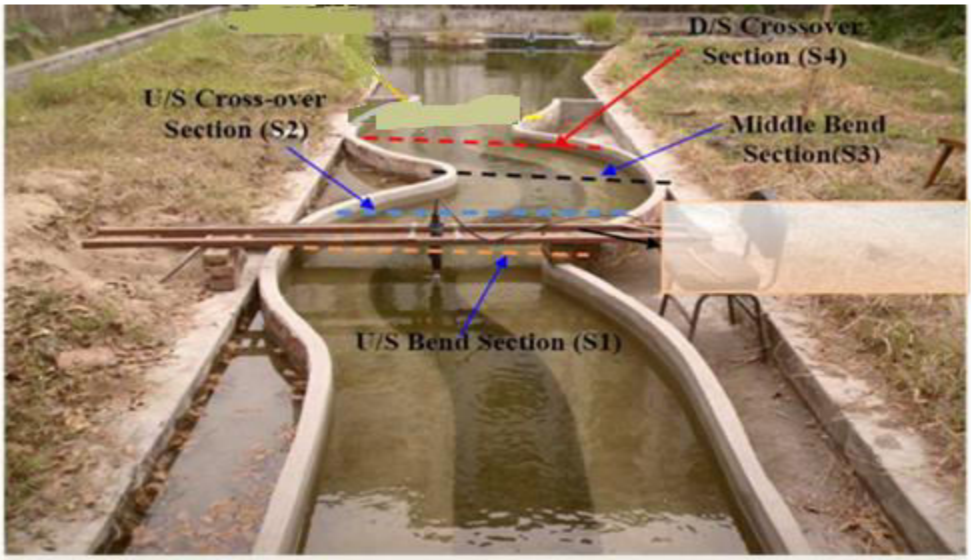
3.5.2 Laboratory Test and Processing

The entire experiment consists of five setups for different depth ratio i.e velocity readings at the 0.2H, 0.4H, 0.6H, 0.8H and each setup has two runs i.e. depth D1=20 cm & D2=15 cm. Each run consists of four cross sections. Each cross section (CR) is divided into 4 zones starting from left floodplain to right floodplain. The main channel is equally divided into four zones (zone Z1 to zone Z4). Thus Velocity readings for each set-up should be taken at 40 (forty) different points including five different set-up by the using of current meter. Table 3.1 shows the laboratory test scenarios and cross-sectional location for data collection is shown in the figure 3.11 represents the layout of Bend Section.

Table 3.1 Laboratory Test Scenarios

Sl	Run No	Meaning of Run No
1	C1S1Z1R1	Cross Section1,Setup1, Zone 1 Run1 (D=20 cm)
2	C1S1Z2R1	Cross Section1,Setup1, Zone 2 Run1 (D=20 cm)
3	C1S1Z3R1	Cross Section1,Setup1, Zone 3 Run1 (D=20 cm)
4	C1S1Z4R1	Cross Section1,Setup1, Zone 4 Run1 (D=20 cm)
5	C1S2Z1R1	Cross Section1,Setup2, Zone 1 Run1 (D=20 cm)
6	C1S2Z2R1	Cross Section1,Setup2, Zone 2 Run1 (D=20 cm)
7	C1S2Z3R1	Cross Section1,Setup2, Zone 3 Run1 (D=20 cm)
8	C1S2Z4R1	Cross Section1,Setup2, Zone 4 Run1 (D=20 cm)
9	C1S3Z1R1	Cross Section1,Setup3, Zone 1 Run1 (D=20 cm)
10	C1S3Z2R1	Cross Section1,Setup3, Zone 2 Run1 (D=20 cm)
11	C1S3Z3R1	Cross Section1,Setup3, Zone 3 Run1 (D=20 cm)
12	C1S3Z4R1	Cross Section1,Setup3, Zone 4 Run1 (D=20 cm)
13	C1S4Z1R1	Cross Section1,Setup4, Zone 1 Run1 (D=20 cm)
12	C1S3Z4R1	Cross Section1,Setup3, Zone 4 Run1 (D=20 cm)
13	C1S4Z1R1	Cross Section1,Setup4, Zone 1 Run1 (D=20 cm)
14	C1S4Z2R1	Cross Section1,Setup4, Zone 2 Run1 (D=20 cm)
15	C1S4Z3R1	Cross Section1,Setup4, Zone 3 Run1 (D=20 cm)
16	C1S4Z4R1	Cross Section1,Setup4, Zone 4 Run1 (D=20 cm)
17	C2S1Z1R1	Cross Section2,Setup1, Zone 1 Run1 (D=20 cm)
18	C2S1Z2R1	Cross Section2,Setup1, Zone 2 Run1 (D=20 cm)
19	C2S1Z3R1	Cross Section2,Setup1,Zone 3 Run1 (D=20 cm)
20	C2S1Z4R1	Cross Section2,Setup1, Zone 4 Run1 (D=20 cm)
21	C2S2Z1R1	Cross Section2,Setup2, Zone 1 Run1 (D=20 cm)
22	C2S2Z2R1	Cross Section2,Setup2, Zone 2 Run1 (D=20 cm)
23	C2S2Z3R1	Cross Section2,Setup2, Zone 3 Run1 (D=20 cm)
24	C2S2Z4R1	Cross Section2,Setup2, Zone 4 Run1 (D=20 cm)
25	C2S3Z1R1	Cross Section2,Setup3, Zone 1 Run1 (D=20 cm)

Sl	Run No	Meaning of Run No
26	C2S3Z2R1	Cross Section2,Setup3, Zone 2 Run1 (D=20 cm)
27	C2S3Z3R1	Cross Section2,Setup3, Zone 3 Run1 (D=20 cm)
28	C2S3Z4R1	Cross Section2,Setup3, Zone 4 Run1 (D=20 cm)
29	C2S4Z1R1	Cross Section2,Setup 4, Zone 1 Run1 (D=20 cm)
30	C2S4Z2R1	Cross Section2,Setup 4, Zone 2 Run1 (D=20 cm)
31	C2S4Z3R1	Cross Section2,Setup 4, Zone 3 Run1 (D=20 cm)
32	C2S4Z4R1	Cross Section2,Setup 4, Zone 4 Run1 (D=20 cm)
33	C3S1Z1R1	Cross Section3,Setup 1, Zone 1 Run1 (D=20 cm)
34	C3S1Z2R1	Cross Section3,Setup 1, Zone 2 Run1 (D=20 cm)
35	C3S1Z3R1	Cross Section3,Setup 1, Zone 3 Run1 (D=20 cm)
36	C3S1Z4R1	Cross Section3,Setup 1, Zone 4 Run1 (D=20 cm)
37	C3S2Z1R1	Cross Section3,Setup 2, Zone 1 Run1 (D=20 cm)
38	C3S2Z2R1	Cross Section3,Setup 2, Zone 2 Run1 (D=20 cm)
39	C3S2Z3R1	Cross Section3,Setup 2, Zone 3 Run1 (D=20 cm)
40	C3S2Z4R1	Cross Section3,Setup 2, Zone 4 Run1 (D=20 cm)
41	C3S3Z1R1	Cross Section3,Setup 3 , Zone 1 Run1 (D=20 cm)
42	C3S3Z2R1	Cross Section3,Setup 3 , Zone 2 Run1 (D=20 cm)
43	C3S3Z3R1	Cross Section3,Setup 3, Zone 3 Run1 (D=20 cm)
44	C3S3Z4R1	Cross Section3,Setup 3, Zone 4 Run1 (D=20 cm)
45	C3S4Z1R1	Cross Section3,Setup 4, Zone 1 Run1 (D=20 cm)
46	C3S4Z2R1	Cross Section3,Setup 4, Zone 2 Run1 (D=20 cm)
47	C3S4Z3R1	Cross Section3,Setup 4, Zone 3 Run1 (D=20 cm)
48	C3S4Z4R1	Cross Section3,Setup 4, Zone 4 Run1 (D=20 cm)
49	C4S1Z1R1	Cross Section4,Setup 1, Zone 1 Run1 (D=20 cm)
50	C4S1Z2R1	Cross Section4,Setup 1, Zone 2 Run1 (D=20 cm)
51	C4S1Z3R1	Cross Section4,Setup 1, Zone 3 Run1 (D=20 cm)
52	C4S2Z4R1	Cross Section4,Setup 1, Zone 4 Run1 (D=20 cm)
53	C4S2Z1R1	Cross Section4,Setup 2, Zone 1 Run1 (D=20 cm)
54	C4S2Z2R1	Cross Section4,Setup 2, Zone 2 Run1 (D=20 cm)
55	C4S2Z3R1	Cross Section4,Setup 2, Zone 3 Run1 (D=20 cm)
56	C4S2Z4R1	Cross Section4,Setup 2, Zone 4 Run1 (D=20 cm)
57	C4S3Z1R1	Cross Section3,Setup 3, Zone 1 Run1 (D=20 cm)
58	C4S3Z2R1	Cross Section3,Setup 3, Zone 2 Run1 (D=20 cm)
59	C4S3Z3R1	Cross Section3,Setup 3, Zone 3 Run1 (D=20 cm)
60	C4S3Z4R1	Cross Section3,Setup 3, Zone 4 Run1 (D=20 cm)
61	C4S4Z1R1	Cross Section4,Setup 4, Zone 1 Run1 (D=20 cm)
62	C4S4Z2R1	Cross Section4,Setup 4, Zone 2 Run1 (D=20 cm)
63	C4S4Z3R1	Cross Section4,Setup 4, Zone 3 Run1 (D=20 cm)
64	C4S4Z4R1	Cross Section4,Setup 4, Zone 4 Run1 (D=20 cm)
65	C5S1Z1R1	Cross Section5,Setup 1, Zone 1 Run1 (D=20 cm)
66	C5S1Z2R1	Cross Section5,Setup 1, Zone 2 Run1 (D=20 cm)
67	C5S1Z3R1	Cross Section5,Setup 1, Zone 3 Run1 (D=20 cm)
68	C5S1Z4R1	Cross Section5,Setup 1, Zone 4 Run1 (D=20 cm)
69	C5S2Z1R1	Cross Section5,Setup 2, Zone 1 Run1 (D=20 cm)
70	C5S2Z2R1	Cross Section5,Setup 2, Zone 2 Run1 (D=20 cm)
71	C5S2Z3R1	Cross Section5,Setup 2, Zone 3 Run1 (D=20 cm)
72	C5S2Z4R1	Cross Section5,Setup 2, Zone 4 Run1 (D=20 cm)
73	C5S3Z1R1	Cross Section5,Setup 3, Zone 1 Run1 (D=20 cm)
74	C5S3Z2R1	Cross Section5,Setup 3, Zone 2 Run1 (D=20 cm)
75	C5S3Z3R1	Cross Section5,Setup 3, Zone 3 Run1 (D=20 cm)
76	C5S3Z4R1	Cross Section5,Setup 3, Zone 4 Run1 (D=20 cm)
77	C5S4Z1R1	Cross Section5,Setup 4, Zone 1 Run1 (D=20 cm)
78	C5S4Z2R1	Cross Section5,Setup 4, Zone 2 Run1 (D=20 cm)
79	C5S4Z3R1	Cross Section5,Setup 4, Zone 3 Run1 (D=20 cm)
80	C5S4Z4R1	Cross Section5,Setup 4, Zone 4 Run1 (D=20 cm)



Similarly for this 5 setup/case/condition and 4 cross section, Run 2 has been done for water depth of 15 cm

Figure 3.11: The Cross-sectional location for data collection

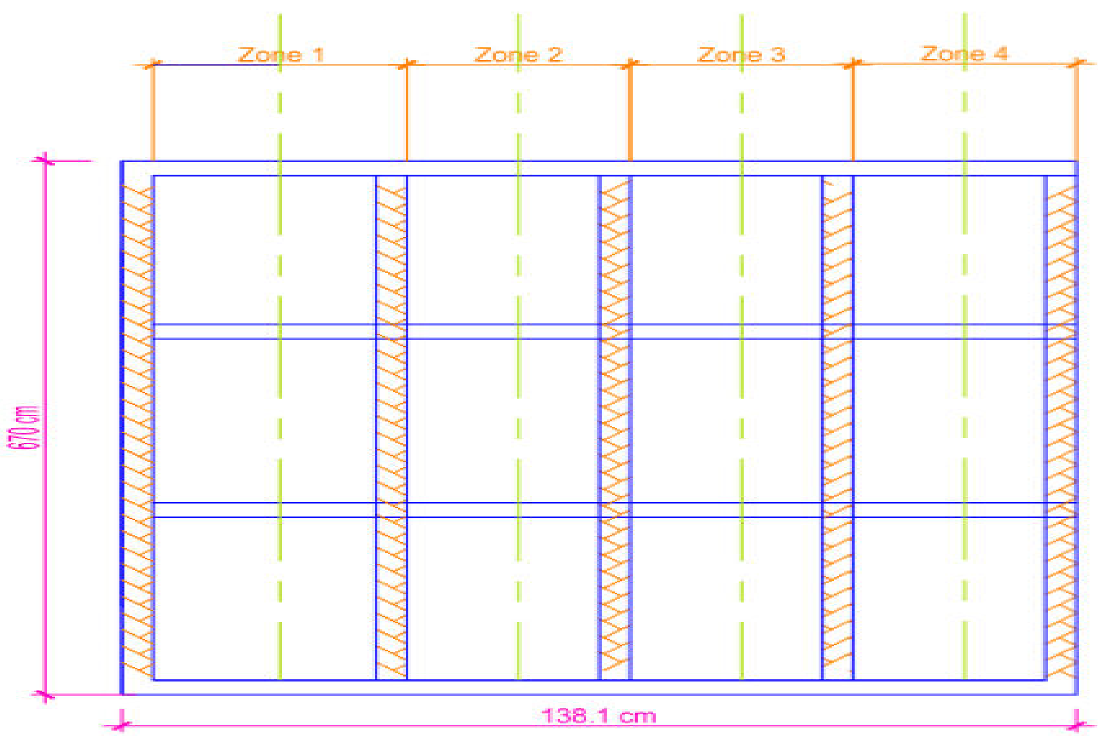


Figure 3.12: Zone wise experimental setup of permeable groyne in a meandering channel

In each zone point velocity readings are taken by Current meter at three vertical points i.e. 0.4H, 0.6H, 0.8H for meandering channels which consist of main channel for five condition and each condition has four cross section.

3.5.3 Measurement of Velocity

Owing to the presence of the free surface and the friction over the channel bed and banks, the velocities are not uniformly distributed in an open channel flow section. The velocity along a vertical varies from zero at the stream bed and maximum at or near the surface. The average velocity along a vertical is determined by measuring the velocities at 0.4H, 0.6H and 0.8H of the depth below the free surface when the depth is more than 0.61m or at 0.6 of the depth when the depth is less than 0.61m, i.e.

$$\ddot{U} = (0.2U+0.8U)/2 = 0.6U \qquad 3.1$$

Practically, we found velocities from velocity profile for different depth using current meter and applied the following formula

$$V=aN+b \qquad 3.2$$

Where a,b are coefficients of values 0.1334 and 0.029 respectively.

N= no of Blows.

3.5.4 Measurement of Discharge

Different methods are available for the measurement of discharge in an open channel flow and of them area velocity method is the familiar one. In this method a channel section is subdivided into a number of segments by a number of successive intervals. Then by using the average velocity determined according to the previous article, the discharge of the segment is calculated as follows

$$Qi = Ai.Ui \qquad 3.3$$

Where Qi the discharge in the ith segment, Ai is the cross-sectional area of the ith segment and Ui is the average velocity at the ith vertical.

The total discharge is computed as

$$Q=\Sigma Qi \qquad 3.4$$

The cross-sectional mean velocity of a stream is equal to the discharge divided by the area, i.e.

$$U= Q/\Sigma\Delta A \qquad 3.5$$

3.5.5 Estimation of Bed Shear Stress

Shear Stress is a measure of the force of friction from a fluid acting on a body in the path of that fluid .In the case of open channel flow; it is the force of moving water against the bed of the channel. Estimation of bottom shear stress is important because it controls the erosion and deposition of sediments at the bed as well as their diffusion in the water column. For simple ideal conditions, bottom shear stress could be measured directly using a Floating Plate element or a Preston tube. In turbulent flows the estimation of bed shear stress may be linked to the first moment statistics (mean) or second moment statistics of the turbulence. Different methods available are Logarithmic velocity profile method, Covariance or Reynolds stress method, Turbulent kinetic energy method and Inertial dissipation method. The bed shear stress can be calculated by the following equation

$$\tau = \rho g R S0 \qquad 3.6$$

Where, g=gravitational acceleration,

ρ= density of flowing fluid,

R= hydraulic radius of the channel cross-section

S0=channel bottom slope.

Velocity profiles are often used as an indirect method to determine mean boundary shear stress in natural rivers (Wilcock 1996).While several methods are available to determine the time-averaged local boundary shear stress(e.g. Biron et al.2004,Dietrich & Whiting 1989), this study employs the theoretical log-law, given as:

$$U/U^* = (1/k)\ln(Z/Zo) \qquad 3.7$$

Where U is the mean velocity, U* is the friction velocity, k is von Karman's constant (k=0.4), Z is the height above bed, Zo is the height of hydraulic roughness.

The above equation applies within a near bed region that is both well below the free surface and above the local influence of individual bed roughness element. For steady uniform sub critical flow in a wide straight channel with roughness dominated by grains on the bed surface, a log profile is found to closely approximate velocity throughout the flow depth.

3.5.6 Velocity Distribution Coefficients

Due to non-uniform velocity distribution in a channel section, the kinetic energy and the momentum of flow computed from the cross-sectional mean velocity are generally less than their actual values. To get the actual kinetic energy of flow, the kinetic energy based on the mean velocity is multiplied by the coefficient,α known as the kinetic energy coefficient or the coriolis coefficient. Similarly to get the actual momentum, the momentum based on the mean velocity is multiplied by the coefficient,β known as the momentum coefficient or the boussinesq coefficient. The energy and momentum coefficients α and β together are known as the velocity distribution coefficients. The energy and momentum coefficients are always positive and never less than unity. For uniform velocity distribution in the channel section, α= β=1. From the experimental results the value of α varies from 1.13 to 1.51 and β varies from 1.06 to 1.15 for fairly straight prismatic channel, but it changes due to many factors such as meander parameters and roughness criteria of the channel. In channels of complex cross-section, the coefficient for energy and momentum can easily be as great as 1.6 and 1.2 and can vary quite rapidly from section to section in case of irregular alignment. In regular channels, flumes, spillways the average value of energy and momentum coefficient are 1.31 and 1.11. On the other hand in the river valley over flooded condition the average value of energy and momentum coefficient are 1.75 and 1.2 (After Chow, 1958).

Energy Coefficient (α) and Momentum Coefficient (β) can be expressed as:

$$\alpha = U^3A/ \Sigma U^3\Delta A \quad 3.8$$

$$\beta = U^2A/ \Sigma U^2\Delta A \quad 3.9$$

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 General

A detailed analysis of experimental data are presented in this chapter.
This experimental Studies will be carried out to compute,

- Flow field
- Energy and Momentum co-efficient
- Shear Stress

in a meandering channel for different flow conditions with varying spacing for permeable groynes.

4.2 Velocity Distribution

Velocity distribution in a meandering channel is affected by many factors such as permeable groynes at varying spacing. Here zone wise velocity distributions at different cross-sections are analyzed for two depth ratios. Results of velocity distribution in the meandering channel are discussed in the following articles.

4.2.1 Individual Velocity Profiles

In this study, one dimensional point velocities in four different zones at several cross sections for different depth ratios are measured. Mean velocities for different cross sections, depth ratios for various set-ups are presented in Appendix A-1 to A-10.

4.2.2 Illustrations of Velocity Distribution

4.2.2.1 Zone-wise comparison of mean velocity among different set-ups and cross-sections for various depth ratios:

Table 4.1: Mean Velocity

(Set-ups 1-5, Cross-sections 1-4, Depth 20 cm) for Zone 1:

Scope	Depth (cm)	Mean Velocity (m/s)
Set up :1_C1	20	0.24
Set up :1_C2	20	0.03
Set up :1_C3	20	0.17
Set up :1_C4	20	0.25
Set up :2_C1	20	0.17
Set up :2_C2	20	0.03
Set up :2_C3	20	0.09
Set up :2_C4	20	0.17
Set up :3_C1	20	0.28
Set up :3_C2	20	0.03
Set up :3_C3	20	0.29
Set up :3_C4	20	0.03
Set up :4_C1	20	0.03
Set up :4_C2	20	0.03
Set up :4_C3	20	0.09
Set up :4_C4	20	0.03
Set up :5_C1	20	0.12
Set up :5_C2	20	0.03
Set up :5_C3	20	0.06
Set up :5_C4	20	0.18

Setup 1: Single groyne:

The mean velocities for cross section (CR)1 , CR2, CR3 and CR4 in zone 1 are 0.24 m/s, 0.03 m/s, 0.17 m/s and 0.25 m/s respectively. Velocity is the least in CR2 where the groyne is located. From CR1 to CR2 velocity decreases and after CR2 it again increases and finally in CR4 it becomes almost same as CR1.

The groyne is located in CR2 which results in a decrease in velocity at the location (i.e.0.03 m/s).The effect of groyne is evident d/s of the groyne with a relatively less velocitin CR3 (i.e.0.17 m/s).

Setup 2: Groynes at L distance:

In zone1 in CR1, velocity is 0.17 m/s which is less than that of CR1 of set-up 1. In CR2 velocity is 0.03 m/s which remains same as the velocity in CR2 of set-up 1. In CR3 it is 0.09 m/s and in CR4 it is 0.17 m/s. The velocity is the least in CR2, where the groyne is located. From CR1 to CR2, velocity decreases and after CR2, it again increases and finally in CR4 it becomes almost same as CR1.

Three groynes at L spacing are reducing velocities u/sin CR1 (i.e.0.17 m/s) and d/s in CR3 (i.e.0.09 m/s). This reduction in velocities specially at groyne bank on the d/s side will trigger sedimentation which in turn is the main purpose of placing the gryones.

Setup 3: Groynes at 2L distance:

In zone1 in CR1, velocity is 0.28 m/s which is higher than previous two set-ups. In CR2 velocity is 0.03 m/s, in CR3 it is 0.29 m/s and in CR4 it is 0.03 m/s. From CR1 to CR2, velocity decreases and after CR2, it again increases and finally at CR4 it decreases.

This setup produces an unusual result in CR3 with an increase in velocity (i.e.0.29 m/s) yet the velocity is being reduced at further d/s at CR4 (i.e.0.03 m/s). So there is a chance of sedimentation not immediately after the groyne section but further d/s at groyne bank.

Setup 4: Groynes at 3L distance:

In zone1 CR1 and CR2, velocities are the same (i.e. 0.03 m/s). In CR3 it is 0.09 m/s and in the CR4 it is again 0.03 m/s. velocity is the least in CR2, where the groyne is located. From CR1 to CR2, velocity remains the same and after CR2, it again increases and finally at CR4 it becomes same as CR1.

Set-up 4 produces the least velocities in various cross-sections at the groyne bank and hence can be a preferred option for permeable groyne construction.

Setup 5: Groynes at 4L distance:

In zone1 CR1, velocity is 0.12 m/s, in CR2 velocity is 0.03 m/s, in CR3 it is 0.06 m/s and in CR4 it is 0.18 m/s. Velocity is the least in CR2, where the groyne is located. From CR1 to CR2, velocity decreases and after CR2, it again increases in CR3 and further increases in CR4.

Set-up 4 can be a viable option as there are significant reduction in velocities at the groyne bank.

For set-ups 4 and 5, it shows a reduction of velocities at d/s sections of groyne with set-up 4 (i.e. 3 gryones at 3L spacing) producing the most reduction at d/s section and hence the preferred option.

Table 4.2: Mean Velocity

(Setup 1-5, Cross-section 1-4, Depth 20 cm) for Zone 2:

Scope	Depth (cm)	Mean Velocity (m/s)
Set up :1_C1	20	0.24
Set up :1_C2	20	0.26
Set up :1_C3	20	0.25
Set up :1_C4	20	0.27
Set up :2_C1	20	0.13
Set up :2_C2	20	0.15
Set up :2_C3	20	0.14
Set up :2_C4	20	0.18
Set up :3_C1	20	0.27
Set up :3_C2	20	0.28
Set up :3_C3	20	0.34
Set up :3_C4	20	0.29
Set up :4_C1	20	0.27
Set up :4_C2	20	0.25
Set up :4_C3	20	0.29
Set up :4_C4	20	0.28
Set up :5_C1	20	0.29
Set up :5_C2	20	0.15
Set up :5_C3	20	0.23
Set up :5_C4	20	0.32

Setup 1: Single groyne:

The mean velocities for CR1, CR2, CR3 and CR4 in zone2 are 0.24 m/s, 0.26 m/s, 0.25 m/s and 0.27 m/s respectively. Velocities remain the same throughout various cross-sections in zone2.

Setup 2: Groynes at L distance:

In zone2 CR1, velocity is 0.13 m/s which is less than that of CR1 of set-up 1. In CR2 velocity is 0.15 m/s which decreases from CR2 of set-up 1. In CR3 it is 0.14 m/s and in CR4 it is 0.18 m/s. From CR1 to CR2, velocity increases and after CR2 it again decreases in CR3 and finally in CR4 it becomes maximum.

Set-up 2 seems to be the preferred option with minimum velocities throughout the cross-sections.

Setup 3: Groynes at 2L distance:

In zone2 CR1, velocity is 0.27 m/s, in CR2 velocity is 0.28 m/s, in CR3 it is 0.33 m/s and CR4 it is 0.29 m/s. From CR 1 to CR 2, velocity increases and after CR2, it again increases in CR3 which is maximum and finally in CR4 it decreases.

Setup 4: Groynes at 3L distance:

In zone2 in CR1 and CR2, velocities are 0.27 m/s and 0.25 m/s respectively. In CR3 it is 0.29 m/s and in CR4 it is 0.28 m/s. Velocity is the least in CR2, where the groyne is located. From CR 1 to CR 2, velocity decreases and after CR2, it again increases and finally at CR4 it becomes almost same as CR3.

Setup 5: Groynes at 4L distance:

The mean velocity for CR1, CR2, CR3 and CR4 in zone2 are 0.29 m/s, 0.15 m/s, 0.23 m/s and 0.32 m/s respectively. Velocity is the least in CR2, where the groyne is located. From CR1 to CR2, velocity decreases and after CR2, it again increases and finally in CR4 it becomes maximum.

There is no significant change in velocities along the reaches for each set-up. Overall, set-up 2 (i.e. this groyne located at L spacing) produces minimum velocities along the reach among all the set-ups.

Table 4.3: Mean Velocity

(Setup 1-5, Cross-section 1-4, Depth 20 cm) for Zone 3:

Scope	Depth (cm)	Mean Velocity (m/s)
Set up :1_C1	20	0.25
Set up :1_C2	20	0.33
Set up :1_C3	20	0.30
Set up :1_C4	20	0.27
Set up :2_C1	20	0.13
Set up :2_C2	20	0.19
Set up :2_C3	20	0.16
Set up :2_C4	20	0.20
Set up :3_C1	20	0.27
Set up :3_C2	20	0.36
Set up :3_C3	20	0.35
Set up :3_C4	20	0.33
Set up :4_C1	20	0.26
Set up :4_C2	20	0.35
Set up :4_C3	20	0.34
Set up :4_C4	20	0.33
Set up :5_C1	20	0.31
Set up :5_C2	20	0.37
Set up :5_C3	20	0.36
Set up :5_C4	20	0.38

Setup 1: Single groyne:

The mean velocity for CR1, CR2, CR3 and CR4 in zone3 are 0.25 m/s, 0.33 m/s, 0.30 m/s and 0.27 m/s respectively. Velocity is the least in CR1 and maximum in CR2, where the groyne is located. From CR1 to CR2, velocity increases and after CR2, it again decreases and finally in CR4 it becomes close to CR1.

Setup 2: Groynes at L distance:

In zone3 CR1, velocity is 0.13 m/s which is less than that of CR1 of set-up 1. In CR2 velocity is 0.19 m/s which is also less than CR2 of set-up 1. In CR3 it is 0.16 m/s and in CR4 it is 0.20 m/s. Again velocity is the least in CR1 and maximum in CR2 where the groynes located. From CR1 to CR2, velocity increases and after CR2, it again decreases and finally in CR4 it is the highest and becomes almost same as CR2.

Setup3: Groynes at 2L distance:

In zone3 CR1, velocity is 0.27 m/s which is higher than previous two set-ups. In CR2 velocity is 0.36 m/s, in CR3 it is 0.35 m/s and in CR4 it is 0.33 m/s. From CR1 to CR2, velocity increases and after CR2, it remains about the same as CR2 and finally in CR4 it decreases.

Setup 4: Groynes at 3L distance:

The mean velocity for CR1, CR2, CR3 and CR4 in zone3 are 0.26 m/s, 0.35 m/s, 0.34 m/s and 0.33 m/s respectively. Velocity is the least in CR1 and maximum in CR2 where the groyne is located. From CR1 to CR2, velocity increases and after CR2, the velocities remain about the same.

Setup 5: Groynes at 4L distance:

The mean velocity for CR1, CR2, CR3 and CR4 in zone3 are 0.31 m/s, 0.37 m/s, 0.36 m/s and 0.38 m/s respectively. Velocity is the least in CR1 and maximum in CR4. Velocities remain about the same in all the cross-sections.

There is significant increase in velocities in zone3 for set-ups 3, 4 and 5. Set-up 2 (i.e. 3 groynes at L spacing) seems to be the preferred option.

Table 4.4: Mean Velocity

(Setup 1-5, Cross-section 1-4, Depth 20 cm) for Zone 4:

Scope	Depth (cm)	Mean Velocity (m/s)
Set up :1_C1	20	0.20
Set up :1_C2	20	0.40
Set up :1_C3	20	0.32
Set up :1_C4	20	0.04
Set up :2_C1	20	0.10
Set up :2_C2	20	0.24
Set up :2_C3	20	0.15
Set up :2_C4	20	0.03
Set up :3_C1	20	0.21
Set up :3_C2	20	0.41
Set up :3_C3	20	0.03
Set up :3_C4	20	0.39
Set up :4_C1	20	0.20
Set up :4_C2	20	0.46
Set up :4_C3	20	0.33
Set up :4_C4	20	0.22
Set up :5_C1	20	0.24
Set up :5_C2	20	0.46
Set up :5_C3	20	0.39
Set up :5_C4	20	0.09

Setup 1: Single groyne:

The mean velocity for CR1, CR2, CR3 and CR4 in zone4 are 0.20 m/s, 0.40 m/s, 0.32 m/s and 0.04 m/s respectively. Velocity is the least in CR4 and maximum in CR2, where the groyne is located. From CR1 to CR 2, velocity increases and after CR2, it again decreases and finally in CR4 it becomes minimum. **Setup 2: Groynes at L distance:**

In zone4 CR1, velocity is 0.10 m/s which is less than that of CR1 of set-up 1. In CR2 velocity is 0.24 m/s, in CR3 it is 0.15 m/s and in CR4 it is 0.03 m/s. Again velocity is the least in CR1 and maximum in CR2 where the groyne is located. From CR1 to CR2, velocity increases and after CR2, it again decreases and finally in CR4 it is minimum.

Setup3: Groynes at 2L distance:

The mean velocity for CR1, CR2, CR3 and CR4 in zone4 are 0.21 m/s, 0.41 m/s, 0.03 m/s and 0.39 m/s respectively. From CR1 to CR2, velocity increases. After CR2, it abruptly decreases in CR3. Finally in CR4 it increases significantly.

Setup 4: Groynes at 3L distance:

The mean velocity for CR1, CR2, CR3 and CR4 in zone4 are 0.20 m/s, 0.46 m/s, 0.33 m/s and 0.22 m/s respectively. Velocity is the least in CR1 and maximum in CR2 where the groyne is located. From CR1 to CR2, velocity increases and after CR2, it again decreases.

Setup 5:Groynes at 4L distance:

The mean velocity for CR1, CR2, CR3 and CR4 in zone4 are 0.24 m/s, 0.46 m/s, 0.39 m/s and 0.09 m/s respectively. Velocity is the least in CR4 and maximum in CR2. From CR1 to CR2, velocity increases and after CR2, it again decreases and finally in CR4 it again significantly decreases to a minimum value.

Set-up 2 (i.e. 3 groynes at L spacing) seems to be the preferred option.

For 20 cm depth, set-up 2 (i.e. 3 gryones at L spacing) is the safest option among all the set-ups. For zones 2, 3 and 4, set-up 2 produces minimum velocities throughout the cross-sections although zone1 produced minimum velocities for set-up 4 for 20 cm depth case.

Table 4.5: Mean Velocity

(Setup 1-5, Cross-section 1-4, Depth 15 cm) for Zone 1:

Scope	Depth (cm)	Mean Velocity (m/s)
Set up :1_C1	15	0.33
Set up :1_C2	15	0.03
Set up :1_C3	15	0.23
Set up :1_C4	15	0.31
Set up :2_C1	15	0.17
Set up :2_C2	15	0.03
Set up :2_C3	15	0.11
Set up :2_C4	15	0.16
Set up :3_C1	15	0.36
Set up :3_C2	15	0.03
Set up :3_C3	15	0.03
Set up :3_C4	15	0.42
Set up :4_C1	15	0.03
Set up :4_C2	15	0.03
Set up :4_C3	15	0.12
Set up :4_C4	15	0.03
Set up :5_C1	15	0.14
Set up :5_C2	15	0.03
Set up :5_C3	15	0.14
Set up :5_C4	15	0.20

Setup 1: Single groyne:

The mean velocity for CR1 , CR2, CR3 and CR4 in zone1 are 0.33 m/s, 0.03 m/s, 0.23 m/s and 0.31 m/s respectively. Velocity is the least in CR2 where the gryone is located. From CR1 to CR2 velocity decreases and after CR2 it again increases abruptly and finally in CR4 it becomes almost same as CR1.

The groyne is located at CR2 which results in a decrease in velocity at the location (i.e.0.03 m/s).

Setup 2: Groynes at L distance:

In zone1 CR1, velocity is 0.17 m/s which is less than that of CR1 of set-up 1. In CR2 velocity is 0.03 m/s which remains same as CR2 of set-up 1. In CR 3 it is 0.11 m/s and in CR4 it is 0.16 m/s. The velocity is the least in CR2, where the groyne is located. From CR1 to CR2, velocity decreases and after CR2, it again increases and finally at CR4 it becomes almost same as CR1.

Setup 3: Groynes at 2L distance:

In zone1 CR1, velocity is 0.36 m/s which is higher than previous two set-ups. In CR2 velocity is 0.03 m/s, in CR3 it is 0.03 m/s and in CR4 it is 0.42 m/s. From CR1 to CR2, velocity decreases significantly and after CR3, it again increases abruptly in CR4.

This set-up produces minimum velocities at and d/s of groyne section (i.e.0.03 m/s). This set-up produced high velocities at CR1 and CR4.

Setup 4: Groynes at 3L distance:

In zone1 in CR1 and CR2, velocities are 0.03 m/s. In CR3 it is 0.12 m/s and in the CR4 it is again 0.03 m/s. From CR1 to CR2, velocity remains same, and after CR2, it again increases and finally increases in CR4.

Setup 5: Groynes at 4L distance:

In zone1 CR1, velocity is 0.14 m/s, in CR2 velocity is 0.03 m/s, in CR3 it is 0.14 m/s and in CR4 it is 0.20 m/s. Velocity is the least in CR2, where the groyne is located. From CR1 to CR2, velocity decreases and after CR2, it again increases in CR3 and finally in CR4 it is maximum.

For set-up 4 produces the minimum velocities throughout the cross-sections and hence is the preferred option.

Table 4.6: Mean Velocity

(Setup 1-5, Cross-section 1-4, Depth 15 cm) for Zone 2:

Scope	Depth (cm)	Mean Velocity (m/s)
Set up :1_C1	15	0.34
Set up :1_C2	15	0.32
Set up :1_C3	15	0.33
Set up :1_C4	15	0.35
Set up :2_C1	15	0.17
Set up :2_C2	15	0.18
Set up :2_C3	15	0.18
Set up :2_C4	15	0.19
Set up :3_C1	15	0.42
Set up :3_C2	15	0.40
Set up :3_C3	15	0.39
Set up :3_C4	15	0.45
Set up :4_C1	15	0.37
Set up :4_C2	15	0.36
Set up :4_C3	15	0.40
Set up :4_C4	15	0.41
Set up :5_C1	15	0.39
Set up :5_C2	15	0.15
Set up :5_C3	15	0.29
Set up :5_C4	15	0.38

Setup 1: Single groyne:

The mean velocity for CR1, CR2, CR3 and CR4 in zone2 are 0.34 m/s, 0.32 m/s, 0.33 m/s and 0.35 m/s respectively. Velocity is the least in CR2 where the gryone is located. Velocities throughout the cross-sections remain about the same.

Setup 2: Groynes at L distance:

In zone2 in CR1, velocity is 0.17 m/s which is less than that of CR1 of set-up 1. In CR2 velocity is 0.18 m/s which decreases from CR2 of set-up 1. In CR3 it is 0.18 m/s and in CR4 it is 0.19 m/s. The velocities are about the same four cross-sections.

Setup 3: Groynes at 2L distance:

In zone2 in CR1, velocity is 0.42 m/s which is higher than previous two set-ups. In CR2 velocity is 0.40 m/s, in CR3 it is 0.39 m/s and CR4 it is 0.45 m/s. From CR 1 to CR 2, velocity decreases and after CR2, it again decreases which is the least and finally in CR4 it becomes maximum.

Setup 4: Groynes at 3L distance:

In zone2 CR1 and CR2, velocities are 0.37 m/s and 0.36 m/s respectively. In CR3 it is 0.40 m/s and in CR4 it is 0.41 m/s. Velocity is the least in CR2, where the groyne is located. From CR 1 to CR 2, velocity decreases and after CR2, it again increases and finally at CR4 it becomes almost same as CR3.

Setup 5: Groynes at 4L distance:

The mean velocity for CR1, CR2, CR3 and CR4 in zone2 are 0.39 m/s, 0.15 m/s, 0.29 m/s and 0.38 m/s respectively. Velocity is the least in CR2, where the groyne is located. From CR1 to CR2, velocity decreases and after CR2, it again increases and finally in CR4 it becomes maximum.

There is no significant change in velocities along the reaches for each set-up. Overall, set-up 2 (i.e. this groyne located at L spacing) produces minimum velocities along the reach among all the set-ups.

Table 4.7: Mean Velocity

(Setup 1-5, Cross-section 1-4, Depth 15 cm) for Zone 3:

Scope	Depth (cm)	Mean Velocity (m/s)
Set up :1_C1	15	0.33
Set up :1_C2	15	0.41
Set up :1_C3	15	0.38
Set up :1_C4	15	0.35
Set up :2_C1	15	0.17
Set up :2_C2	15	0.22
Set up :2_C3	15	0.20
Set up :2_C4	15	0.20
Set up :3_C1	15	0.41
Set up :3_C2	15	0.47
Set up :3_C3	15	0.44
Set up :3_C4	15	0.47
Set up :4_C1	15	0.36
Set up :4_C2	15	0.48
Set up :4_C3	15	0.45
Set up :4_C4	15	0.45
Set up :5_C1	15	0.40
Set up :5_C2	15	0.50
Set up :5_C3	15	0.50
Set up :5_C4	15	0.51

Setup 1: Single groyne:

The mean velocity for CR1, CR2, CR3 and CR4 in zone3 are 0.33 m/s, 0.41 m/s, 0.38 m/s and 0.35 m/s respectively. Velocity is the least in CR1 and maximum in CR2, where the groyne is located. From CR1 to CR2, velocity increases and after CR2, it again decreases and finally in CR4 it becomes close to CR1.

Setup 2: Groynes at L distance:

In zone3 CR1, velocity is 0.17 m/s which is less than that of CR1 of set-up 1. In CR2 velocity is 0.22 m/s which is also less than CR2 of set-up 1. In CR3 it is 0.20 m/s and in CR4 it is 0.20 m/s. Again velocity is the least in CR1 and maximum in CR2 where the groynes located. From CR1 to CR2, velocity increases and after CR2, it again decreases and finally in CR3 and CR4, the velocities are equal.

Setup3: Groynes at 2L distance:

In zone3 in CR1, velocity is 0.41 m/s which is higher than previous two set-ups. In CR2 velocity is 0.47 m/s, in CR3 it is 0.44 m/s and in CR4 it is 0.47 m/s. From CR1 to CR2, velocity increases and after CR2, it decreases in CR3 and finally in CR4 it again increases.

Setup 4: Groynes at 3L distance:

The mean velocity for CR1, CR2, CR3 and CR4 in zone3 are 0.36 m/s, 0.48 m/s, 0.35 m/s and 0.35 m/s respectively. Velocities are the least in CR3 and CR4, maximum in CR2 where the groyne is located. From CR1 to CR2, velocity increases and after CR2, it again decreases and finally in CR4 it becomes same as CR3.

Setup 5: Groynes at 4L distance:

The mean velocity for CR1, CR2, CR3 and CR4 in zone3 are 0.40 m/s, 0.50 m/s, 0.50 m/s and 0.51 m/s respectively. Velocity is the least in CR1 and maximum in CR4. In CR2 velocity is almost similar of CR4. From CR1 to CR2, velocity increases and after CR2 the velocities remain about the same.

There is a significant increase in velocity in CR2 where the groyne is located in the all the set-ups along all reaches. Yet set-up2 (i.e. 3 groynes at L spacings) seems to be the most viable option.

Table 4.8: Mean Velocity

(Setup 1-5, Cross-section 1-4, Depth 15 cm) for Zone 4:

Scope	Depth (cm)	Mean Velocity (m/s)
Set up :1_C1	15	0.24
Set up :1_C2	15	0.47
Set up :1_C3	15	0.40
Set up :1_C4	15	0.06
Set up :2_C1	15	0.10
Set up :2_C2	15	0.27
Set up :2_C3	15	0.18
Set up :2_C4	15	0.03
Set up :3_C1	15	0.31
Set up :3_C2	15	0.60
Set up :3_C3	15	0.49
Set up :3_C4	15	0.13
Set up :4_C1	15	0.28
Set up :4_C2	15	0.51
Set up :4_C3	15	0.35
Set up :4_C4	15	0.06
Set up :5_C1	15	0.31
Set up :5_C2	15	0.64
Set up :5_C3	15	0.54
Set up :5_C4	15	0.07

Setup 1: Single groyne:

The mean velocity for CR1, CR2, CR3 and CR4 in zone4 are 0.24 m/s, 0.47 m/s, 0.40 m/s and 0.06 m/s respectively. Velocity is the least in CR4 and maximum in CR2, where the groyne is located. From CR1 to CR 2, velocity increases and after CR2, it again decreases and finally in CR4 it becomes minimum.

Setup 2: Groynes at L distance:

In zone4 in CR1, velocity is 0.10 m/s which is less than that of CR1 of set-up 1. In CR2 velocity is 0.27 m/s which is also less than CR2 of set-up 1, in CR3 it is 0.18 m/s and in CR4 it is 0.03 m/s. Again velocity is the least in CR4 and maximum in CR2 where the groyne is located. From CR1 to CR2, velocity increases and after CR2, it again decreases and finally in CR4 it is minimum and becomes close to CR1.

Setup3: Groynes at 2L distance:

The mean velocity for CR1, CR2, CR3 and CR4 in zone4 are 0.31 m/s, 0.60 m/s, 0.49 m/s and 0.13 m/s respectively. From CR1 to CR2, velocity increases. After CR2, it decreases in CR3. Finally in CR4 it decreases significantly.

Setup 4: Groynes at 3L distance:

The mean velocity for CR1, CR2, CR3 and CR4 in zone4 are 0.28 m/s, 0.51 m/s, 0.35 m/s and 0.06 m/s respectively. Velocity is the least in CR4 and maximum in CR2 where the groyne is located. From CR1 to CR2, velocity increases and after CR2, it decreases and in CR4 it again decreases significantly.

Setup 5:Groynes at 4L distance:

The mean velocity for CR1, CR2, CR3 and CR4 in zone4 are 0.31 m/s, 0.64 m/s, 0.54 m/s and 0.07 m/s respectively. Velocity is the least in CR4 and maximum in CR2. From CR1 to CR2, velocity increases and after CR2, it again decreases and finally in CR4 it again significantly decreases to a minimum value.

Set-up 2 produces the best results in terms of reduction of velocities, and hence considered to be the most viable option.

Overall, for 15 cm depth, set-up 2 (i.e. 3 gryones at L spacing) is the safest option among all the set-ups. For zones 2, 3 and 4, set-up 2 produces minimum velocities throughout the cross-sections although zone1 produced minimum velocities for set-up 4 for 15 cm depth case.

4.2.2.2 Cross-section-wise comparison among 5 different set-ups and 4 zones:

Table 4.9: For 20 cm WL (Horizontal CR1:)

Scope	Depth (cm)	Mean Velocity (m/s)			
		Zone 1	Zone 2	Zone 3	Zone 4
Set up :1_C1	20	0.24	0.24	0.25	0.20
Set up :2_C1	20	0.17	0.13	0.13	0.10
Set up :3_C1	20	0.28	0.27	0.27	0.21
Set up :4_C1	20	0.03	0.27	0.26	0.20
Set up :5_C1	20	0.12	0.29	0.31	0.24

Setup1: Single groyne:

Zone1 and zone2 have the same velocities of 0.24 m/s, In zone 3 velocity becomes 0.25 m/s and finally in zone 4 it decreases to 0.20 m/s.

Setup 2: Groynes at L distance:

In zone1, velocity is 0.17 m/s which is less than that of zone1 of set-up 1. In zone2 and zone3 velocities are the same (i.e. 0.13 m/s) and in zone4 it becomes 0.10 m/s. So it is seen that there are relative reduction in velocities from zone1 to zone4 in case of groynes located at L spacings as compared to set-up 1.

Setup 3: Groynes at 2L distance:

In zone1 in velocity is 0.28 m/s. The velocities are same at zone2 and zone3 (i.e. 0.27 m/s). Then velocity reduces to 0.21 m/s in zone4.

Setup 4: Groynes at 3L distance:

The mean velocities for zone1, zone 2, zone3 and zone4 are 0.03 m/s, 0.27 m/s, 0.26 m/s and 0.20 m/s respectively. In zone1, velocity is very low, but in zone2 it becomes 0.27 m/s and it reduces to 0.20 m/s in zone4.

Setup 5: Groynes at 4L distance:

This case is almost same as setup 4. The mean velocities for zone1, zone2, zone3 and zone4 are 0.12 m/s, 0.29 m/s, 0.31 m/s and 0.24 m/s respectively. In zone1, velocity is the least, but in zone2 velocity becomes equal to 0.29 m/s and it reduces to 0.24 m/s in zone4.

Apart from zone1 (i.e. in which set-up 4 produces the minimum velocities), the other zones (i.e. zone2, zone3 and zone4) produce minimum velocities for set-up 2 in cross-section 1.

Table 4.10: For 20 cm WL (Horizontal CR2)

Scope	Depth (cm)	Mean Velocity (m/s)			
		Zone 1	Zone 2	Zone 3	Zone 4
Set up :1_C2	20	0.03	0.26	0.33	0.40
Set up :2_C2	20	0.03	0.15	0.19	0.24
Set up :3_C2	20	0.03	0.28	0.36	0.41
Set up :4_C2	20	0.03	0.25	0.35	0.46
Set up :5_C2	20	0.03	0.15	0.37	0.46

Setup 1: Single groyne:

In zone1, velocity is 0.03 m/s which is less than that of CR1 of set-up 1. In zone2 and zone3 velocities are 0.26 m/s and 0.33 m/s. In zone4 it becomes 0.40 m/s. So it is seen that velocity increases abruptly from zone1 to zone2 and gradually increases from zone3 to zone4 in case of single groyne.

Setup 2: Groynes at L distance:

In zone1, velocity is 0.03 m/s which is same as zone1 of set-up 1. In zone2 and zone3 velocities are 0.15 m/s and 0.19 m/s respectively. In zone4 the velocity becomes 0.24 m/s. So it is seen that velocity increases abruptly from zone1 to zone2 and gradually increases from zone3 to zone4 in case of groynes located at L distance.

Setup 3: Groynes at 2L distance:

The mean velocities for zone1, zone 2, zone3 and zone4 are 0.03 m/s, 0.28 m/s, 0.36 m/s and 0.41 m/s respectively. So it is seen that velocity increases abruptly from zone1 to zone2 and gradually increases from zone3 to zone4 in setup of groynes located at 2L distance.

Setup 4:Groynes at 3L distance:

The mean velocities for zone1, zone 2, zone3 and zone4 are 0.03 m/s, 0.25 m/s, 0.35 m/s and 0.46 m/s respectively. In zone 1, velocity is very low, but in zone2 velocity becomes 0.25 m/s and it becomes 0.46 m/s in zone4.

Setup 5: Groynes at 4L distance:

The mean velocities for zone1, zone 2, zone3 and zone4 are 0.03 m/s 0.15 m/s, 0.37 m/s and 0.46 m/s respectively. In zone1, velocity is very low, but in zone2 velocity becomes 0.15 m/s and it again increases to 0.46 m/s in zone4.

Set-up 2 (i.e. groynes located at L spacing) shows minimum velocities in all the zones and hence it is the preferred option for the bank for cross-section 2.

Table 4.11: For 20 cm WL (Horizontal CR3)

Scope	Depth (cm)	Mean Velocity (m/s)			
		Zone 1	Zone 2	Zone 3	Zone 4
Set up :1_C3	20	0.17	0.25	0.30	0.32
Set up :2_C3	20	0.09	0.14	0.16	0.15
Set up :3_C3	20	0.29	0.34	0.35	0.03
Set up :4_C3	20	0.09	0.29	0.34	0.33
Set up :5_C3	20	0.06	0.23	0.36	0.39

Setup 1: Single groyne:

In zone1, velocity is 0.17 m/s. Also in zone2 and zone3 velocities are 0.25 m/s and 0.30 m/s respectively. In zone4 it becomes 0.32 m/s. So it is seen that velocity increases from zone1 to zone2 and gradually increases from zone3 to zone4 in case of single groyne.

Setup 2: Groynes at L distance:

In zone1, velocity is 0.09 m/s. In zone2 and zone3 velocities are 0.14 m/s and 0.16 m/s respectively. In zone4 the velocity becomes 0.15 m/s. So it is seen that velocity increases significantly from zone1 to zone2 and gradually increases from zone3 to zone4 in case of groynes located at L distance.

Setup 3: Groynes at 2L distance:

The mean velocities for zone1, zone 2, zone3 and zone4 are 0.29 m/s, 0.34 m/s, 0.35 m/s and 0.03 m/s respectively. So it is seen that velocity increases from zone1 to zone2 and decreases abruptly from zone3 to zone4 in setup of groynes located at 2L distance.

Setup 4:Groynes at 3L distance:

The mean velocities for zone1, zone 2, zone3 and zone4 are 0.09 m/s, 0.29 m/s, 0.34 m/s and 0.33 m/s respectively. In zone 1, velocity is very low, but in zone2 velocity becomes 0.29 m/s and it becomes 0.33 m/s in zone4.

Setup 5:Groynes at 4L distance:

The mean velocities for zone1, zone 2, zone3 and zone4 are 0.06 m/s 0.23 m/s, 0.36 m/s and 0.39 m/s respectively. In zone1, velocity is very low, but in zone2 velocity becomes 0.23 m/s and it again increases to 0.39 m/s in zone4.

Set-up 2 (i.e. groynes located at L spacing) shows minimum velocities in all the zones and hence it is the preferred option for cross-section 3.

Table 4.12: For 20 cm WL (Horizontal CR4)

Scope	Depth (cm)	Mean Velocity (m/s)			
		Zone 1	Zone 2	Zone 3	Zone 4
Set up :1_C4	20	0.25	0.27	0.27	0.04
Set up :2_C4	20	0.17	0.18	0.20	0.03
Set up :3_C4	20	0.03	0.29	0.33	0.39
Set up :4_C4	20	0.03	0.28	0.33	0.22
Set up :5_C4	20	0.18	0.32	0.38	0.09

Setup 1: Single groyne:

In zone1, zone2 and zone3 velocities are almost same which are 0.25 m/s, 0.27 m/s and 0.27 m/s respectively and finally in zone 4 it decreases significantly to 0.04 cm/s.

Setup 2: Groynes at L distance:

In zone1, velocity is 0.17 m/s. In zone2 and zone3 velocities are 0.18 m/s and 0.20 m/s respectively. In zone4 the velocity becomes 0.03 m/s. So it is seen that velocity increases gradually from zone1 to zone3 and decreases abruptly from zone3 to zone4 in case of groynes located at L distance.

Setup 3: Groynes at 2L distance:

The mean velocities for zone1, zone 2, zone3 and zone4 are 0.03 m/s, 0.29 m/s, 0.33 m/s and 0.39 m/s respectively. So it is seen that velocity increases abruptly from zone1 to zone2 and it again increases from zone3 to zone4 in setup for groynes located at 2L distance.

Setup 4:Groynes at 3L distance:

The mean velocities for zone1, zone 2, zone3 and zone4 are 0.03 m/s, 0.28 m/s, 0.33 m/s and 0.22 m/s respectively. In zone 1, velocity is very low, but in zone2 velocity becomes 0.28 m/s and it becomes 0.22m/s in zone4.

Setup 5:Groynes at 4L distance:

The mean velocities for zone1, zone 2, zone3 and zone4 are 0.18 m/s 0.32 m/s, 0.38 m/s and 0.09 m/s respectively. In zone4, velocity is the least, but from zone1 to zone2 velocity increases from 0.32 m/s to 0.38 m/s and it again decreases to 0.09 m/s in zone4.

Apart from zone1 (i.e. in which set-ups 3 and 4 produces the minimum velocities), the other zones (i.e. zone2, zone3 and zone4) produce minimum velocities in cross-section 4.

Set-up 2 (i.e. groynes located at L spacing) shows minimum velocities in all the zones and hence it is the preferred option for the bank for a depth of 20 cm.

Table 4.13: For 15 cm WL (Horizontal CR1:)

Scope	Depth (cm)	Mean Velocity (m/s)			
		Zone 1	Zone 2	Zone 3	Zone 4
Set up :1_C1	15	0.33	0.34	0.33	0.24
Set up :2_C1	15	0.17	0.17	0.17	0.10
Set up :3_C1	15	0.36	0.42	0.41	0.31
Set up :4_C1	15	0.03	0.37	0.36	0.28
Set up :5_C1	15	0.14	0.39	0.40	0.31

Setup 1: Single groyne:

In zone 1, zone2 and zone3 velocities are 0.33 m/s, 0.34 m/s and 0.33 m/s and finally in zone 4 it decreases to 0.24 m/s.

Setup 2: Groynes at L distance:

In zone 1, the velocity is 0.17 cm/s which is less than that of zone 1 of set-up 1. In zones 2 and 3 velocities are 0.17 m/s and in the last zone it became 0.10 m/s.

Setup 3: Groynes at 2L distance:

In this set-up, high velocities are found (i.e. 0.42 m/s and 0.41m/s respectively) in zone2 and zone3. Th velocity reduces to 0.31 m/s in zone 4.

Setup 4: Groynes at 3L distance:

In zone1 velocity is 0.03 cm/s. In zones 2, 3 and 4 velocities are 0.37 m/s, 0.36 m/s and 0.28 m/s respectively. In zone1, velocity is very low, but in zone 2 velocity became 0.37 m/s and it reduces to 0.28 m/s in zone4.

Setup 5: Groynes at 4L distance:

In zone 1, the velocity is 0.14 m/s. In zones 2, 3, 4 the velocities are 0.39 m/s, 0.40 m/s and 0.31 m/s respectively. In zone 1, velocity is low which was higher than setup 4, but in zone 2 velocity became 0.39 m/s and it reduces to 0.31 m/s in zone 4.

Minimum velocities are observed in all the zones for se-up 2 apart from zone1 for set-up 4 and hence set-up 2 is the safest option for the bank for cross-section 1.

Table 4.14: For 15 cm WL (Horizontal CR2:)

Scope	Depth (cm)	Mean Velocity (m/s)			
		Zone 1	Zone 2	Zone 3	Zone 4
Set up :1_C2	15	0.03	0.32	0.41	0.47
Set up :2_C2	15	0.03	0.18	0.22	0.27
Set up :3_C2	15	0.03	0.40	0.47	0.60
Set up :4_C2	15	0.03	0.36	0.48	0.51
Set up :5_C2	15	0.03	0.15	0.50	0.64

Setup 1: Single groyne:

In zone1, zone2 and zone3 velocities are 0.03 m/s, 0.32 m/s and 0.41 m/s and finally in zone 4 it increases to 0.47 m/s.

Setup 2: Groynes at L distance:

In zone1, velocity is 0.03 m/s which is same that of zone1 of set-up 1. In zone2 and zone3 velocities are 0.18 m/s and 0.22 m/s respectively. In zone4 it becomes 0.27 m/s.

Setup 3: Groynes at 2L distance:

In zone1, velocity is 0.03 m/s. The velocities in other zones show significant higher values.

Setup 4: Groynes at 3L distance:

The mean velocities for zone1, zone 2, zone3 and zone4 are 0.03 m/s, 0.36 m/s, 0.48 m/s and 0.51 m/s respectively. In zone1, velocity is the least, but in zone2 it becomes 0.36 m/s and it further increases to 0.51 m/s in zone4.

Setup 5: Groynes at 4L distance:

The mean velocities for zone1, zone2, zone3 and zone4 are 0.03 m/s, 0.15 m/s, 0.50 m/s and 0.64 m/s respectively. In zone1, velocity is the least, but in zone2 velocity becomes 0.15 m/s and it further increases to 0.64 m/s in zone4.

Set-up 2 (i.e. groynes located at 'L' spacing) shows minimum velocities in all the zones and hence it is the preferred option for the bank for cross-section 2.

Table 4.15: For 15 cm WL (Horizontal CR3:)

Scope	Depth (cm)	Mean Velocity (m/s)			
		Zone 1	Zone 2	Zone 3	Zone 4
Set up :1_C3	15	0.23	0.33	0.38	0.40
Set up :2_C3	15	0.11	0.18	0.20	0.18
Set up :3_C3	15	0.03	0.39	0.44	0.49
Set up :4_C3	15	0.12	0.40	0.45	0.35
Set up :5_C3	15	0.14	0.29	0.50	0.54

Setup 1: Single groyne:

In zone 1, zone2 and zone3 velocities are 0.23 m/s, 0.33 m/s and 0.38 m/s and finally in zone 4 it increases to 0.40 m/s.

Setup 2: Groynes at L distance:

In zone1, velocity is 0.11 m/s which is less than that of zone1 of set-up 1. In zone2 and zone3 velocities are the almost same (i.e. 0.18 m/s and 0.20 m/s respectively). In zone4 it becomes 0.18 m/s.

Setup 3: Groynes at 2L distance:

In zone1, velocity is 0.03 m/s. The velocities are 0.39 m/s and 0.44 m/s in zone2 and zone3 respectively. Then velocity increases to 0.49 m/s in zone4.

Setup 4: Groynes at 3L distance:

The mean velocities for zone1, zone 2, zone3 and zone4 are 0.12 m/s, 0.40 m/s, 0.45 m/s and 0.35 m/s respectively. In zone1, velocity is the least, but in zone2 it becomes 0.40 m/s and it reduces to 0.35 m/s in zone4.

Setup 5: Groynes at 4L distance:

The mean velocities for zone1, zone2, zone3 and zone4 are 0.14 m/s, 0.29 m/s, 0.50 m/s and 0.54 m/s respectively. In zone1, velocity is the least, but in zone2 velocity becomes 0.29 m/s and it further increases to 0.54 m/s in zone4.

Set-up 2 (i.e. groynes located at 'L' spacing) shows minimum velocities in all the zones and hence it is the preferred option for the bank for cross-section 3.

Table 4.16: For 15 cm WL (Horizontal CR4:)

Scope	Depth (cm)	Mean Velocity (m/s)			
		Zone 1	Zone 2	Zone 3	Zone 4
Set up :1_C4	**15**	**0.31**	**0.35**	**0.35**	**0.06**
Set up :2_C4	**15**	**0.16**	**0.19**	**0.20**	**0.03**
Set up :3_C4	**15**	**0.42**	**0.45**	**0.47**	**0.13**
Set up :4_C4	**15**	**0.03**	**0.41**	**0.45**	**0.06**
Set up :5_C4	**15**	**0.20**	**0.38**	**0.51**	**0.07**

Setup1: Single groyne:

In zone1 velocity is 0.31 m/s. Zone2 and zone3 have the same velocities of 0.35 m/s, and finally in zone 4 it decreases significantly to 0.06 m/s.

Setup 2: Groynes at L distance:

In zone1, velocity is 0.16 m/s which is less than that of zone1 of set-up 1. In zone2 and zone3 velocities are almost the same (i.e. 0.19 m/s and 0.20 m/s respectively). In zone4 it becomes 0.03 m/s.

Setup 3: Groynes at 2L distance:

In zone1, velocity is 0.42 m/s. The velocities are almost same at zone2 and zone3 (i.e. 0.45 m/s and 0.47 m/s respectively). Then velocity reduces to 0.13 m/s in zone4.

Setup 4: Groynes at 3L distance:

The mean velocities for zone1, zone 2, zone3 and zone4 are 0.03 m/s, 0.41 m/s, 0.45 m/s and 0.06 m/s respectively. In zone1, velocity is very low, but in zone2 it becomes 0.41 m/s and it again reduces to 0.06 m/s in zone4.

Setup 5: Groynes at 4L distance:

The mean velocities for zone1, zone2, zone3 and zone4 are 0.20 m/s, 0.38 m/s, 0.51 m/s and 0.07 m/s respectively. In zone4, velocity is the least (i.e. 0.07 m/s), but in zone2 velocity becomes 0.38 m/s and it again increases to 0.51 m/s in zone3. After which the velocity decreases abruptly to 0.07 m/s in zone4.

Set-up 2 (i.e. groynes located at 'L' spacing) shows minimum velocities in all the zones and hence it is the preferred option for the bank for cross-section 4.

Overall, for 15 cm depth, set-up 2 (i.e. 3 gryones at L spacing) is the safest option among all the set-ups.

4.3 Velocity Distribution Co-efficient:

4.3.1 Calculating α & β:

Due to non-uniform velocity distribution in a channel section, the kinetic energy and the momentum of flow computed from the cross-sectional mean velocity are usually less than their actual values. To get the actual kinetic energy of flow, the kinetic energy based on the mean velocity is multiplied by the coefficient,α known as the kinetic energy coefficient or the Coriolis coefficient. Similarly to get the actual momentum, the momentum based on the mean velocity is multiplied by the coefficient,β known as the momentum coefficient or the Boussinesq coefficient. The energy and momentum coefficients α and β together are known as the velocity distribution coefficients. The energy and momentum coefficients are always positive and never less than unity. For uniform velocity distribution in the channel section, α= β=1.

From the experimental results the value of α varies from1.03 to 1.36 and β varies from 1.01 to 1.12 for fairly straight prismatic channel, but in practically it changes due to many factors such as meander parameters and rough ness criteria of the channel.

4.3.2 Comparison among 5 different set-ups and 4 cross-sections

4.3.2.1 Zone-wise comparison of α among 5 set-ups and 4 cross-sections:

Table 4.17: 20 cm: α comparison for Zone 1:

Scope	α
S1 CR1 Z1 R1	1.35
S1 CR1 Z2 R1	1.44
S1 CR1 Z3 R1	1.44
S1 CR1 Z4 R1	1.35
S1 CR2 Z1 R1	1.34
S1 CR2 Z2 R1	1.33
S1 CR2 Z3 R1	1.39
S1 CR2 Z4 R1	1.36
S1 CR3 Z1 R1	1.28
S1 CR3 Z2 R1	1.40
S1 CR3 Z3 R1	1.40
S1 CR3 Z4 R1	1.33
S1 CR4 Z1 R1	1.34
S1 CR4 Z2 R1	1.41
S1 CR4 Z3 R1	1.36
S1 CR4 Z4 R1	1.34

Setup 1: Single groyne:

Values of α for set-up 1 in CR1, CR2, CR3 and CR4 are 1.35, 1.34, 1.28 and 1.34 respectively. CR1 shows the maximum value of α (i.e. 1.35) and CR3 shows the minimum value α (i.e. 1.28).

Setup 2: Groynes at L distance:

Values of α for set-up 2 in CR1, CR2, CR3 and CR4 are 1.74, 1.34, 1.33 and 1.37 respectively. CR1 shows the maximum value of α (i.e. 1.74) and CR3 shows the minimum value α (i.e. 1.33).

Setup 3: Groynes at 2L distance:

Values of α for set-up 3 in CR1, CR2, CR3 and CR4 are 1.32, 1.34, 1.37 and 1.34 respectively. CR3 shows the maximum value of α (i.e. 1.37) and CR1 shows the minimum value α (i.e. 1.32).

Setup 4: Groynes at 3L distance:

Values of α for set-up 4 in CR1, CR2, CR3 and CR4 are 1.34, 1.34, 1.54 and 1.34 respectively. CR3 shows the maximum value of α (i.e. 1.54) and CR1, CR2 and CR4 show the minimum value α (i.e. 1.34).

Setup 5: Groynes at 4L distance:

Values of α for set-up 5 in CR1, CR2, CR3 and CR4 are 1.86, 1.34, 1.77 and 1.34 respectively. CR1 shows the maximum value of α (i.e. 1.86) and CR2 and CR4 show the minimum value α (i.e. 1.34).

Set-ups 1, 3 and 4 seem to produce minimum values of α and hence are the preferred options for zone 1.

Table 4.18: 20 cm: α comparison for Zone 2:

Scope	α
S1 CR1 Z2 R1	1.44
S1 CR2 Z2 R1	1.33
S1 CR3 Z2 R1	1.40
S1 CR4 Z2 R1	1.41
S2 CR1 Z2 R1	1.44
S2 CR2 Z2 R1	1.35
S2 CR3 Z2 R1	1.38
S2 CR4 Z2 R1	1.39
S3 CR1 Z2 R1	1.46
S3 CR2 Z2 R1	1.35
S3 CR3 Z2 R1	1.39
S3 CR4 Z2 R1	1.38
S4 CR1 Z2 R1	1.38
S4 CR2 Z2 R1	1.33
S4 CR3 Z2 R1	1.37
S4 CR4 Z2 R1	1.34
S5 CR1 Z2 R1	1.40
S5 CR2 Z2 R1	1.46
S5 CR3 Z2 R1	1.35
S5 CR4 Z2 R1	1.45

Setup 1: Single groyne:

Values of α for set-up 1 in CR1, CR2, CR3 and CR4 are 1.44, 1.33, 1.40 and 1.41 respectively. α in CR1 shows the maximum value of α (i.e. 1.44) and CR2 shows the minimum value α (i.e. 1.33).

Setup 2: Groynes at L distance:

Values of α for set-up 2 in CR1, CR2, CR3 and CR4 are 1.44, 1.35, 1.38 and 1.39 respectively. α in CR1 shows the maximum value of α (i.e. 1.44) and CR2 shows the minimum value α (i.e. 1.35).

Setup 3: Groynes at 2L distance:

Values of α for set-up 3 in CR1, CR2, CR3 and CR4 are 1.46, 1.35, 1.39 and 1.38 respectively. α in CR1 shows the maximum value of α (i.e. 1.46) and CR2 shows the minimum value α (i.e. 1.35).

Setup 4: Groynes at 3L distance:

Values of α for set-up 4 in CR1, CR2, CR3 and CR4 are 1.38, 1.33, 1.37 and 1.34. α in CR1 shows the maximum value of α (i.e. 1.38) and CR2 shows the minimum value α (i.e. 1.33).

Setup 5: Groynes at 4L distance:

Values of α for set-up 5 in CR1, CR2, CR3 and CR4 are 1.40, 1.46, 1.35 and 1.45 respectively. α in CR4 shows the maximum value of α (i.e. 1.45) and CR3 shows the minimum value α (i.e. 1.35).

All the set-ups seem to produce similar values of α and hence there is no preferred option for zone 2.

Table 4.19: 20 cm: α comparison for Zone 3:

Scope	α
S1 CR1 Z3 R1	1.44
S1 CR2 Z3 R1	1.39
S1 CR3 Z3 R1	1.40
S1 CR4 Z3 R1	1.36
S2 CR1 Z3 R1	1.40
S2 CR2 Z3 R1	1.38
S2 CR3 Z3 R1	1.36
S2 CR4 Z3 R1	1.40
S3 CR1 Z3 R1	1.39
S3 CR2 Z3 R1	1.34
S3 CR3 Z3 R1	1.36
S3 CR4 Z3 R1	1.39
S4 CR1 Z3 R1	1.42
S4 CR2 Z3 R1	1.38
S4 CR3 Z3 R1	1.42
S4 CR4 Z3 R1	1.35
S5 CR1 Z3 R1	1.40
S5 CR2 Z3 R1	1.40
S5 CR3 Z3 R1	1.37
S5 CR4 Z3 R1	1.34

Setup 1: Single groyne:

Values of α for set-up 1 in CR1, CR2, CR3 and CR4 are 1.44, 1.39, 1.40 and 1.36 respectively. α in CR1 shows the maximum value of α (i.e. 1.44) and CR4 shows the minimum value α (i.e. 1.36).

Setup 2: Groynes at L distance:

Values of α for set-up 2 in CR1, CR2, CR3 and CR4 are 1.40, 1.38, 1.36 and 1.40 respectively. α in CR1 and CR4 shows the maximum value of α (i.e. 1.40) and CR3 shows the minimum value α (i.e. 1.36).

Setup 3: Groynes at 2L distance:

Values of α for set-up 3 in CR1, CR2, CR3 and CR4 are 1.39, 1.36, 1.34 and 1.39 respectively. α in CR1 and CR4 shows the maximum value of α (i.e. 1.39) and CR3 shows the minimum value α (i.e. 1.34).

Setup 4: Groynes at 3L distance:

Values of α for set-up 4 in CR1, CR2, CR3 and CR4 are 1.42, 1.38, 1.42 and 1.35 respectively. α in CR1 and CR3 show the maximum value of α (i.e. 1.42) and CR4 shows the minimum value α (i.e. 1.35).

Setup 5: Groynes at 4L distance:

Values of α for set-up 5 in CR1, CR2, CR3 and CR4 are 1.40, 1.40, 1.37 and 1.34 respectively. α in CR1 and CR2 shows the maximum value of α (i.e. 1.40) and CR4 shows the minimum value α (i.e. 1.34).

All the set-ups seem to produce similar values of α and hence there is no preferred option for zone 3.

Table 4.20: 20 cm: α comparison for Zone 4:

Scope	α
S1 CR1 Z4 R1	1.35
S1 CR2 Z4 R1	1.36
S1 CR3 Z4 R1	1.33
S1 CR4 Z4 R1	1.34
S2 CR1 Z4 R1	1.45
S2 CR2 Z4 R1	1.31
S2 CR3 Z4 R1	1.34
S2 CR4 Z4 R1	1.36
S3 CR1 Z4 R1	1.37
S3 CR2 Z4 R1	1.35
S3 CR3 Z4 R1	1.34
S3 CR4 Z4 R1	1.33
S4 CR1 Z4 R1	1.36
S4 CR2 Z4 R1	1.37
S4 CR3 Z4 R1	1.31
S4 CR4 Z4 R1	1.35
S5 CR1 Z4 R1	1.34
S5 CR2 Z4 R1	1.33
S5 CR3 Z4 R1	1.34
S5 CR4 Z4 R1	1.62

Setup 1: Single groyne:

Values of α for set-up 1 in CR1, CR2, CR3 and CR4 are 1.35, 1.36, 1.33 and 1.34 respectively. α in CR2 shows the maximum value of α (i.e. 1.36) and CR3 shows the minimum value α (i.e. 1.33).

Setup 2: Groynes at L distance:

Values of α for set-up 2 in CR1, CR2, CR3 and CR4 are 1.45, 1.31, 1.34 and 1.36 respectively. α in CR1 shows the maximum value of α (i.e. 1.45) and CR2 shows the minimum value α (i.e. 1.31).

Setup 3: Groynes at 2L distance:

Values of α for set-up 3 in CR1, CR2, CR3 and CR4 are 1.37, 1.35, 1.34 and 1.33 respectively. α in CR1 shows the maximum value of α (i.e. 1.37) and CR4 shows the minimum value α (i.e. 1.33).

Setup 4: Groynes at 3L distance:

Values of α for set-up 4 in CR1, CR2, CR3 and CR4 are 1.36, 1.37, 1.31 and 1.35 respectively. α in CR2 shows the maximum value of α (i.e. 1.37) and CR3 shows the minimum value α (i.e. 1.31).

Setup 5: Groynes at 4L distance:

Values of α for set-up 5 in CR1, CR2, CR3 and CR4 are 1.34, 1.33, 1.34 and 1.62 respectively. α in CR4 shows the maximum value of α (i.e. 1.62) and CR2 shows the minimum value (1.33).

All the set-ups seem to produce similar values of α and hence there is no preferred option for zone 4.

Table 4.21: 15 cm: α comparison for Zone 1:

Scope	α
S1 CR1 Z1 R2	1.41
S1 CR2 Z1 R2	1.34
S1 CR3 Z1 R2	1.32
S1 CR4 Z1 R2	1.35
S2 CR1 Z1 R2	1.34
S2 CR2 Z1 R2	1.33
S2 CR3 Z1 R2	1.38
S2 CR4 Z1 R2	1.33
S3 CR1 Z1 R2	1.36
S3 CR2 Z1 R2	1.34
S3 CR3 Z1 R2	1.34
S3 CR4 Z1 R2	1.35
S4 CR1 Z1 R2	1.34
S4 CR2 Z1 R2	1.34
S4 CR3 Z1 R2	1.31
S4 CR4 Z1 R2	1.34
S5 CR1 Z1 R2	1.37
S5 CR2 Z1 R2	1.34
S5 CR3 Z1 R2	2.10
S5 CR4 Z1 R2	1.35

Setup 1: Single groyne:

Values of α for set-up 1 in CR1, CR2, CR3 and CR4 are 1.41, 1.34, 1.32 and 1.35 respectively. α in CR1 shows the maximum value of α (i.e. 1.41) and CR3 shows the minimum value of α (i.e. 1.32).

Setup 2: Groynes at L distance:

Values of α for set-up 2 in CR1, CR2, CR3 and CR4 are 1.34, 1.33, 1.38 and 1.33 respectively. α in CR3 shows the maximum value of α (i.e. 1.38) and CR2 and CR4 show the minimum value of α (i.e. 1.33).

Setup 3: Groynes at 2L distance:

Values of α for set-up 3 in CR1, CR2, CR3 and CR4 are 1.36, 1.34, 1.34 and 1.35 respectively. α in CR1 shows the maximum value of α (i.e. 1.36) and CR2 and CR3 show the minimum value of α (i.e. 1.34).

Setup 4: Groynes at 3L distance:

Values of α for set-up 4 in CR1, CR2, CR3 and CR4 are 1.34, 1.34, 1.31 and 1.34 respectively. α in CR1,CR2 and CR4 show the maximum value of α (i.e. 1.34) and CR3 shows the minimum value of α (i.e. 1.31).

Setup 5: Groynes at 4L distance:

Values of α for set-up 5 in CR1, CR2, CR3 and CR4 are 1.37, 1.34, 2.10 and 1.35 respectively. α in CR3 shows the maximum value of α (i.e. 2.10) and CR2 show the minimum value of α (i.e. 1.34).

Set-ups 2, 3 and 4 seem to produce minimum values of α and hence are the preferred options for zone 1.

Table 4.22: 15 cm: α comparison for Zone 2:

Scope	α
S1 CR1 Z2 R2	1.45
S1 CR2 Z2 R2	1.35
S1 CR3 Z2 R2	1.35
S1 CR4 Z2 R2	1.35
S2 CR1 Z2 R2	1.35
S2 CR2 Z2 R2	1.34
S2 CR3 Z2 R2	1.37
S2 CR4 Z2 R2	1.40
S3 CR1 Z2 R2	1.38
S3 CR2 Z2 R2	1.35
S3 CR3 Z2 R2	1.35
S3 CR4 Z2 R2	1.37
S4 CR1 Z2 R2	1.37
S4 CR2 Z2 R2	1.36
S4 CR3 Z2 R2	1.35
S4 CR4 Z2 R2	1.36
S5 CR1 Z2 R2	1.36
S5 CR2 Z2 R2	1.31
S5 CR3 Z2 R2	1.35
S5 CR4 Z2 R2	1.52

Setup 1: Single groyne:

Values of α for set-up 1 in CR1, CR2, CR3 and CR4 are 1.45, 1.35, 1.35 and 1.35 respectively. α in CR1 shows the maximum value (i.e. 1.45) and CR2, CR3 and CR4 show the minimum value of α (i.e. 1.35).

Setup 2: Groynes at L distance:

Values of α for set-up 2 in CR1, CR2, CR3 and CR4 are 1.35, 1.34, 1.37 and 1.40 respectively. α in CR4 shows the maximum value (i.e. 1.40) and CR2 shows the minimum value (i.e. 1.34).

Setup 3: Groynes at 2L distance:

Values of α for set-up 3 in CR1, CR2, CR3 and CR4 are 1.38, 1.35, 1.35 and 1.37 respectively. α in CR1 shows the maximum value (i.e. 1.38) and CR2 and CR3 show the minimum value (i.e. 1.35).

Setup 4: Groynes at 3L distance:

Values of α for set-up 4 in CR1, CR2, CR3 and CR4 are 1.37, 1.36, 1.35 and 1.36 respectively. α in CR1 shows the maximum value (i.e. 1.37) and CR3 shows the minimum value (i.e. 1.35).

Setup 5: Groynes at 4L distance:

Values of α for set-up 5 in CR1, CR2, CR3 and CR4 are 1.36, 1.31, 1.35 and 1.52 respectively. α in CR4 shows the maximum value (i.e. 1.52) and CR2 shows the minimum value (i.e. 1.31).

Set-ups 2, 3 and 4 seem to produce minimum values of α and hence are the preferred options for zone 2.

Table 4.23: 15 cm: α comparison for Zone 3:

Scope	α
S1 CR1 Z3 R2	1.40
S1 CR2 Z3 R2	1.36
S1 CR3 Z3 R2	1.34
S1 CR4 Z3 R2	1.34
S2 CR1 Z3 R2	1.34
S2 CR2 Z3 R2	1.37
S2 CR3 Z3 R2	1.36
S2 CR4 Z3 R2	1.36
S3 CR1 Z3 R2	1.38
S3 CR2 Z3 R2	1.36
S3 CR3 Z3 R2	1.34
S3 CR4 Z3 R2	1.35
S4 CR1 Z3 R2	1.38
S4 CR2 Z3 R2	1.37
S4 CR3 Z3 R2	1.35
S4 CR4 Z3 R2	1.34
S5 CR1 Z3 R2	1.36
S5 CR2 Z3 R2	1.35
S5 CR3 Z3 R2	1.35
S5 CR4 Z3 R2	1.36

Setup 1: Single groyne:

Values of α for set-up 1 in CR1, CR2, CR3 and CR4 are 1.40, 1.36, 1.34 and 1.34 respectively. α in CR1 shows the maximum value (i.e. 1.40) and CR3 and CR4 show the minimum value of α (i.e. 1.34).

Setup 2: Groynes at L distance:

Values of α for set-up 2 in CR1, CR2, CR3 and CR4 are 1.34, 1.37, 1.36 and 1.36 respectively. α in CR2 shows the maximum value (i.e. 1.37) and CR1 shows the minimum value of α (i.e. 1.34).

Setup 3: Groynes at 2L distance:

Values of α for set-up 3 in CR1, CR2, CR3 and CR4 are 1.38, 1.36, 1.34 and 1.35 respectively. α in CR1 shows the maximum value (i.e. 1.38) and CR3 shows the minimum value of α (i.e. 1.34).

Setup 4: Groynes at 3L distance:

Values of α for set-up 4 in CR1, CR2, CR3 and CR4 are 1.38, 1.37, 1.35 and 1.34 respectively. α in CR1 shows the maximum value (i.e. 1.38) and CR4 shows the minimum value of α (i.e. 1.34).

Setup 5: Groynes at 4L distance:

Values of α for set-up 5 in CR1, CR2, CR3 and CR4 are 1.36, 1.35, 1.35 and 1.36 respectively. α in CR1 and CR4 show the maximum value (i.e. 1.36) and CR2 and CR3 show the minimum value of α (i.e. 1.35).

All the set-ups seem to produce similar values of α and hence there is no preferred option for zone 3.

Table: 4.24: 15 cm: α comparison for Zone 4:

Scope	α
S1 CR1 Z4 R2	1.36
S1 CR2 Z4 R2	1.36
S1 CR3 Z4 R2	1.35
S1 CR4 Z4 R2	2.43
S2 CR1 Z4 R2	1.34
S2 CR2 Z4 R2	1.35
S2 CR3 Z4 R2	1.34
S2 CR4 Z4 R2	1.38
S3 CR1 Z4 R2	1.35
S3 CR2 Z4 R2	1.35
S3 CR3 Z4 R2	1.36
S3CR4 Z4 R2	1.54
S4 CR1 Z4 R2	1.35
S4 CR2 Z4 R2	1.34
S4 CR3 Z4 R2	1.35
S4 CR4 Z4 R2	1.41
S5 CR1 Z4 R2	1.35
S5 CR2 Z4 R2	1.35
S5 CR3 Z4 R2	1.35
S5 CR4 Z4 R2	1.47

Setup 1: Single groyne:

Values of α for set-up 1 in CR1, CR2, CR3 and CR4 are 1.36, 1.36, 1.35 and 2.43 respectively. α in CR4 shows the maximum value (i.e. 2.43) and CR3 shows the minimum value of α (i.e. 1.35).

Setup 2: Groynes at L distance:

Values of α for set-up 2 in CR1, CR2, CR3 and CR4 are 1.45, 1.31, 1.34 and 1.36 respectively. α in CR1 shows the maximum value (i.e. 1.45) and CR2 shows the minimum value of α (i.e. 1.31).

Setup 3: Groynes at 2L distance:

Values of α for set-up 3 in CR1, CR2, CR3 and CR4 are 1.35, 1.35, 1.36 and 1.54 respectively. α in CR4 shows the maximum value (i.e.1.54) and CR1 and CR2 show the minimum α (i.e.1.35).

Setup 4: Groynes at 3L distance:

Values of α for set-up 4 in CR1, CR2, CR3 and CR4 are 1.35, 1.34, 1.35 and 1.41 respectively. α in CR4 shows the maximum value (i.e. 1.41) and CR2 shows the minimum value of α (i.e. 1.35).

Setup 5: Groynes at 4L distance:

Values of α for set-up 5 in CR1, CR2, CR3 and CR4 are 1.35, 1.35, 1.35 and 1.47 respectively. α in CR4 shows the maximum value (i.e. 1.47) and CR1, CR2 and CR3 show the minimum value of α (i.e. 1.35).

Set-ups 2 and 4 seem to produce minimum values of α and hence are the preferred options for zone 4.

4.3.2.2 Cross-section-wise comparison of α among 5 set-ups and 4 zones:

Table 4.25: For 20 cm WL (Horizontal Cross Section: Set-ups 1-5)

Sl	Scope	α	Scope	α	Scope	α	Scope	α	Scope	α
1	S1 CR1 Z1 R1	1.35	S2 CR1 Z1 R1	1.74	S3 CR1 Z1 R1	1.32	S4 CR1 Z1 R1	1.34	S5 CR1 Z1 R1	1.86
2	S1 CR1 Z2 R1	1.44	S2 CR1 Z2 R1	1.44	S3 CR1 Z2 R1	1.46	S4 CR1 Z2 R1	1.38	S5 CR1 Z2 R1	1.40
3	S1 CR1 Z3 R1	1.44	S2 CR1 Z3 R1	1.40	S3 CR1 Z3 R1	1.39	S4 CR1 Z3 R1	1.42	S5 CR1 Z3 R1	1.40
4	S1 CR1 Z4 R1	1.35	S2 CR1 Z4 R1	1.45	S3 CR1 Z4 R1	1.37	S4 CR1 Z4 R1	1.36	S5 CR1 Z4 R1	1.34
5	S1 CR2 Z1 R1	1.34	S2 CR2 Z1 R1	1.34	S3 CR2 Z1 R1	1.34	S4 CR2 Z1 R1	1.34	S5 CR2 Z1 R1	1.34
6	S1 CR2 Z2 R1	1.33	S2 CR2 Z2 R1	1.35	S3 CR2 Z2 R1	1.35	S4 CR2 Z2 R1	1.33	S5 CR2 Z2 R1	1.46
7	S1 CR2 Z3 R1	1.39	S2 CR2 Z3 R1	1.38	S3 CR2 Z3 R1	1.34	S4 CR2 Z3 R1	1.38	S5 CR2 Z3 R1	1.40
8	S1 CR2 Z4 R1	1.36	S2 CR2 Z4 R1	1.31	S3 CR2 Z4 R1	1.35	S4 CR2 Z4 R1	1.37	S5 CR2 Z4 R1	1.33
9	S1 CR3 Z1 R1	1.28	S2 CR3 Z1 R1	1.33	S3 CR3 Z1 R1	1.37	S4 CR3 Z1 R1	1.54	S5 CR3 Z1 R1	1.77
10	S1 CR3 Z2 R1	1.40	S2 CR3 Z2 R1	1.38	S3 CR3 Z2 R1	1.39	S4 CR3 Z2 R1	1.37	S5 CR3 Z2 R1	1.35
11	S1 CR3 Z3 R1	1.40	S2 CR3 Z3 R1	1.36	S3 CR3 Z3 R1	1.36	S4 CR3 Z3 R1	1.42	S5 CR3 Z3 R1	1.37
12	S1 CR3 Z4 R1	1.33	S2 CR3 Z4 R1	1.34	S3 CR3 Z4 R1	1.34	S4 CR3 Z4 R1	1.31	S5 CR3 Z4 R1	1.34
13	S1 CR4 Z1 R1	1.34	S2 CR4 Z1 R1	1.37	S3 CR4 Z1 R1	1.34	S4 CR4 Z1 R1	1.34	S5 CR4 Z1 R1	1.34
14	S1 CR4 Z2 R1	1.41	S2 CR4 Z2 R1	1.39	S3 CR4 Z2 R1	1.38	S4 CR4 Z2 R1	1.34	S5 CR4 Z2 R1	1.45
15	S1 CR4 Z3 R1	1.36	S2 CR4 Z3 R1	1.40	S3 CR4 Z3 R1	1.39	S4 CR4 Z3 R1	1.35	S5 CR4 Z3 R1	1.34

Table 4.26: For 15 cm WL (Horizontal Cross Section: Set-ups 1-5)

Sl	Scope	α	Scope	α	Scope	α	Scope	α	Scope	α
1	S1 CR1 Z1 R2	1.41	S2 CR1 Z1 R2	1.34	S3 CR1 Z1 R2	1.36	S4 CR1 Z1 R2	1.34	S5 CR1 Z1 R2	1.37
2	S1 CR1 Z2 R2	1.45	S2 CR1 Z2 R2	1.35	S3 CR1 Z2 R2	1.38	S4 CR1 Z2 R2	1.37	S5 CR1 Z2 R2	1.36
3	S1 CR1 Z3 R2	1.40	S2 CR1 Z3 R2	1.34	S3 CR1 Z3 R2	1.38	S4 CR1 Z3 R2	1.38	S5 CR1 Z3 R2	1.36
4	S1 CR1 Z4 R2	1.36	S2 CR1 Z4 R2	1.34	S3 CR1 Z4 R2	1.35	S4 CR1 Z4 R2	1.35	S5 CR1 Z4 R2	1.35
5	S1 CR2 Z1 R2	1.34	S2 CR2 Z1 R2	1.33	S3 CR2 Z1 R2	1.34	S4 CR2 Z1 R2	1.34	S5 CR2 Z1 R2	1.34
6	S1 CR2 Z2 R2	1.35	S2 CR2 Z2 R2	1.34	S3 CR2 Z2 R2	1.35	S4 CR2 Z2 R2	1.36	S5 CR2 Z2 R2	1.31
7	S1 CR2 Z3 R2	1.36	S2 CR2 Z3 R2	1.37	S3 CR2 Z3 R2	1.36	S4 CR2 Z3 R2	1.37	S5 CR2 Z3 R2	1.35
8	S1 CR2 Z4 R2	1.36	S2 CR2 Z4 R2	1.35	S3 CR2 Z4 R2	1.35	S4 CR2 Z4 R2	1.34	S5 CR2 Z4 R2	1.35
9	S1 CR3 Z1 R2	1.32	S2 CR3 Z1 R2	1.38	S3 CR3 Z1 R2	1.34	S4 CR3 Z1 R2	1.31	S5 CR3 Z1 R2	2.10
10	S1 CR3 Z2 R2	1.35	S2 CR3 Z2 R2	1.37	S3 CR3 Z2 R2	1.35	S4 CR3 Z2 R2	1.35	S5 CR3 Z2 R2	1.35
11	S1 CR3 Z3 R2	1.34	S2 CR3 Z3 R2	1.36	S3 CR3 Z3 R2	1.34	S4 CR3 Z3 R2	1.35	S5 CR3 Z3 R2	1.35
12	S1 CR3 Z4 R2	1.35	S2 CR3 Z4 R2	1.34	S3 CR3 Z4 R2	1.36	S4 CR3 Z4 R2	1.35	S5 CR3 Z4 R2	1.35
13	S1 CR4 Z1 R2	1.35	S2 CR4 Z1 R2	1.33	S3 CR4 Z1 R2	1.35	S4 CR4 Z1 R2	1.34	S5 CR4 Z1 R2	1.35
14	S1 CR4 Z2 R2	1.35	S2 CR4 Z2 R2	1.40	S3 CR4 Z2 R2	1.37	S4 CR4 Z2 R2	1.36	S5 CR4 Z2 R2	1.52
15	S1 CR4 Z3 R2	1.34	S2 CR4 Z3 R2	1.36	S3 CR4 Z3 R2	1.35	S4 CR4 Z3 R2	1.34	S5 CR4 Z3 R2	1.36
16	S1 CR4 Z4 R2	2.43	S2 CR4 Z4 R2	1.38	S3CR4 Z4 R2	1.54	S4 CR4 Z4 R2	1.41	S5 CR4 Z4 R2	1.47

Cross-section-wise comparisons of α are shown in Tables 4.25 and 4.26 for depths of 20 cm and 15 cm respectively.

4.3.3 Comparison of β among 5 set-ups and 4 cross-sections

4.3.3.1 Zone wise comparison of β among 5 set-ups and 4 CRs

Table 4.27: 20 cm: β comparison for Zone 1:

Scope	β
S1 CR1 Z1 R1	1.13
S1 CR2 Z1 R1	1.13
S1 CR3 Z1 R1	1.11
S1 CR4 Z1 R1	1.13
S2 CR1 Z1 R1	1.26
S2 CR2 Z1 R1	1.13
S2 CR3 Z1 R1	1.11
S2 CR4 Z1 R1	1.14
S3 CR1 Z1 R1	1.13
S3 CR2 Z1 R1	1.13
S3 CR3 Z1 R1	1.14
S3 CR4 Z1 R1	1.13
S4 CR1 Z1 R1	1.13
S4 CR2 Z1 R1	1.13
S4 CR3 Z1 R1	1.19
S4 CR4 Z1 R1	1.13
S5 CR1 Z1 R1	1.30
S5 CR2 Z1 R1	1.13
S5 CR3 Z1 R1	1.26
S5 CR4 Z1 R1	1.13

Setup 1: Single groyne:

Values of β for set-up 1 in CR1, CR2, CR3 and CR4 are 1.13, 1.13, 1.11 and 1.13 respectively. β in CR1, CR2 and CR4 show the maximum value (i.e. 1.13) and CR3 shows the minimum value of β (i.e. 1.11).

Setup 2: Groynes at L distance:

Values of β for set-up 2 in CR1, CR2, CR3 and CR4 are 1.26, 1.13, 1.11 and 1.14 respectively. β in CR1 shows the maximum value (i.e. 1.26) and CR3 shows the minimum value of β (i.e. 1.11).

Setup 3: Groynes at 2L distance:

Values of β for set-up 3 in CR1, CR2, CR3 and CR4 are 1.13, 1.13, 1.14 and 1.13 respectively. β in CR3 shows the maximum value (i.e. 1.14) and CR1, CR2 and CR4 show the minimum value of β (i.e. 1.13).

Setup 4: Groynes at 3L distance:

Values of β for set-up 4 in CR1, CR2, CR3 and CR4 are 1.13, 1.13, 1.19 and 1.13 respectively. β in CR3 shows the maximum value (i.e. 1.19) and CR1, CR2 and CR4 show the minimum value of β (i.e. 1.13).

Setup 5: Groynes at 4L distance:

Values of β for set-up 5 in CR1, CR2, CR3 and CR4 are 1.30, 1.13, 1.26 and 1.13 respectively. β in CR1 shows the maximum value (i.e. 1.30) and CR2and CR4 show the minimum value of β (i.e. 1.13).

Set-ups 1, 2, 3 and 4 seem to produce minimum values of β and hence are the preferred options for zone 1.

Table 4.28: 20 cm:β comparison for Zone 2:

Scope	β
S1 CR1 Z2 R1	1.17
S1 CR2 Z2 R1	1.13
S1 CR3 Z2 R1	1.15
S1 CR4 Z2 R1	1.16
S2 CR1 Z2 R1	1.17
S2 CR2 Z2 R1	1.14
S2 CR3 Z2 R1	1.14
S2 CR4 Z2 R1	1.15
S3 CR1 Z2 R1	1.17
S3 CR2 Z2 R1	1.14
S3 CR3 Z2 R1	1.15
S3 CR4 Z2 R1	1.14
S4 CR1 Z2 R1	1.14
S4 CR2 Z2 R1	1.13
S4 CR3 Z2 R1	1.14
S4 CR4 Z2 R1	1.13
S5 CR1 Z2 R1	1.15
S5 CR2 Z2 R1	1.17
S5 CR3 Z2 R1	1.13
S5 CR4 Z2 R1	1.17

Setup 1: Single groyne:

Values of β for set-up 1 in CR1, CR2, CR3 and CR4 are 1.17, 1.13, 1.15 and 1.16 respectively. β in CR1 shows the maximum value (i.e. 1.17) and CR2 shows the minimum value of β (i.e. 1.13).

Setup 2: Groynes at L distance:

Values of β for set-up 2 in CR1, CR2, CR3 and CR4 are 1.17, 1.14, 1.14 and 1.15 respectively. β in CR1 shows the maximum value (i.e. 1.17) and CR2 and CR3 show the minimum value of β (i.e. 1.14).

Setup 3: Groynes at 2L distance:

Values of β for set-up 3 in CR1, CR2, CR3 and CR4 are 1.17, 1.14, 1.15 and 1.14 respectively. β in CR1 shows the maximum value (i.e. 1.17). Again CR2 and CR4 show the minimum value of β (i.e. 1.14).

Setup 4: Groynes at 3L distance:

Values of β for set-up 4 in CR1, CR2, CR3 and CR4 are 1.14, 1.13, 1.14 and 1.13 shown in above table respectively. β shows almost the same value in all of CRs.

Setup 5: Groynes at 4L distance:

Values of β for set-up 5 in CR1, CR2, CR3 and CR4 are 1.15, 1.17, 1.13 and 1.17 shown in above table respectively. β in CR4 shows the maximum value (i.e. 1.17) and CR3 shows the minimum value of β (i.e. 1.13).

All the set-ups seem to produce similar values of β and hence there is no preferred option for zone 2.

Table 4.29: 20 cm:β comparison for Zone 3:

Scope	β
S1 CR1 Z3 R1	1.16
S1 CR2 Z3 R1	1.15
S1 CR3 Z3 R1	1.15
S1 CR4 Z3 R1	1.14
S2 CR1 Z3 R1	1.15
S2 CR2 Z3 R1	1.15
S2 CR3 Z3 R1	1.14
S2 CR4 Z3 R1	1.15
S3 CR1 Z3 R1	1.15
S3 CR2 Z3 R1	1.13
S3 CR3 Z3 R1	1.14
S3 CR4 Z3 R1	1.15
S4 CR1 Z3 R1	1.16
S4 CR2 Z3 R1	1.15
S4 CR3 Z3 R1	1.16
S4 CR4 Z3 R1	1.13
S5 CR1 Z3 R1	1.15
S5 CR2 Z3 R1	1.15
S5 CR3 Z3 R1	1.14
S5 CR4 Z3 R1	1.13

Setup 1: Single groyne:

Values of β for set-up 1 in CR1, CR2, CR3 and CR4 are 1.16, 1.15, 1.15 and 1.14 respectively. β in CR1 shows the maximum value (i.e. 1.16) and CR2 and CR3 show the minimum value of β (i.e. 1.15).

Setup 2: Groynes at L distance:

Values of β for set-up 2 in CR1, CR2, CR3 and CR4 are 1.15, 1.15, 1.14 and 1.15 respectively. β shows almost the same value in all of CRs.

Setup 3: Groynes at 2L distance:

Values of β for set-up 3 in CR1, CR2, CR3 and CR4 are 1.15, 1.13, 1.14 and 1.15 respectively. β shows almost the same value in all of CRs.

Setup 4: Groynes at 3L distance:

Values of β for set-up 4 in CR1, CR2, CR3 and CR4 are 1.16, 1.15, 1.16 and 1.13 respectively. β in CR1 and CR3 show the maximum value (i.e. 1.16) and CR4 shows the minimum value of β (i.e. 1.13).

Setup 5: Groynes at 4L distance:

Values of β for set-up 5 in CR1, CR2, CR3 and CR4 are 1.15, 1.15, 1.14 and 1.13 respectively. β in CR1 and CR2 show the maximum value (i.e. 1.15) and CR4 shows the minimum value of β (i.e. 1.13).

All the set-ups seem to produce similar values of β and hence there is no preferred option for zone 3.

Table 4.30: 20 cm:β comparison for Zone 4:

Scope	β
S1 CR1 Z4 R1	1.14
S1 CR2 Z4 R1	1.14
S1 CR3 Z4 R1	1.13
S1 CR4 Z4 R1	1.12
S2 CR1 Z4 R1	1.17
S2 CR2 Z4 R1	1.12
S2 CR3 Z4 R1	1.13
S2 CR4 Z4 R1	1.14
S3 CR1 Z4 R1	1.14
S3 CR2 Z4 R1	1.14
S3 CR3 Z4 R1	1.13
S3 CR4 Z4 R1	1.13
S4 CR1 Z4 R1	1.14
S4 CR2 Z4 R1	1.14
S4 CR3 Z4 R1	1.12
S4 CR4 Z4 R1	1.13
S5 CR1 Z4 R1	1.13
S5 CR2 Z4 R1	1.13
S5 CR3 Z4 R1	1.13
S5 CR4 Z4 R1	1.23

Setup 1: Single groyne:

Values of β for set-up 1 in CR1, CR2, CR3 and CR4 are 1.14, 1.14, 1.13 and 1.12 respectively. β in CR1 and CR2 show the maximum value (i.e. 1.14) and CR4 shows the minimum value of β (i.e. 1.12).

Setup 2: Groynes at L distance:

Values of β for set-up 2 in CR1, CR2, CR3 and CR4 are 1.17, 1.12, 1.13 and 1.14 respectively. β in CR1 shows the maximum value (i.e. 1.17) and CR4 shows the minimum value of β (i.e. 1.12).

Setup 3: Groynes at 2L distance:

Values of β for set-up 3 in CR1, CR2, CR3 and CR4 are 1.14, 1.14, 1.13 and 1.13 respectively. β shows almost the same value in all of CRs.

Setup 4: Groynes at 3L distance:

Values of β for set-up 4 in CR1, CR2, CR3 and CR4 are 1.14, 1.14, 1.12 and 1.13 respectively. β shows almost the same value in all of CRs.

Setup 5: Groynes at 4L distance:

Values of β for set-up 5 in CR1, CR2, CR3 and CR4 are 1.13, 1.13, 1.13 and 1.23 respectively. β in CR4 show the maximum value (i.e. 1.23) and CR1, CR2 and CR3 show the minimum value of β (i.e. 1.13).

All the set-ups seem to produce similar values of β and hence there is no preferred option for zone 4.

Overall, for 20 cm depth, set-ups 1, 2, 3 and 4 seem to be the preferred options.

<u>Table 4.31: 15 cm:β comparison for Zone 1</u>:

Scope	β
S1 CR1 Z1 R2	1.15
S1 CR2 Z1 R2	1.13
S1 CR3 Z1 R2	1.13
S1 CR4 Z1 R2	1.14
S2 CR1 Z1 R2	1.13
S2 CR2 Z1 R2	1.13
S2 CR3 Z1 R2	1.14
S2 CR4 Z1 R2	1.13
S3 CR1 Z1 R2	1.14
S3 CR2 Z1 R2	1.13
S3 CR3 Z1 R2	1.13
S3 CR4 Z1 R2	1.13
S4 CR1 Z1 R2	1.13
S4 CR2 Z1 R2	1.13
S4 CR3 Z1 R2	1.12
S4 CR4 Z1 R2	1.13
S5 CR1 Z1 R2	1.14
S5 CR2 Z1 R2	1.13
S5 CR3 Z1 R2	1.32
S5 CR4 Z1 R2	1.14

Setup 1: Single groyne:

Values of β for set-up 1 in CR1, CR2, CR3 and CR4 are 1.15, 1.13, 1.13 and 1.14 respectively. β in CR1 shows the maximum value (i.e. 1.15). CR2 and CR3 show the minimum value of β (i.e. 1.13).

Setup 2: Groynes at L distance:

Values of β for set-up 2 in CR1, CR2, CR3 and CR4 are 1.13, 1.13, 1.14 and 1.13 respectively. β in CR1, CR2 and CR4 show the maximum value (i.e. 1.14) and CR3 shows the minimum value of β (i.e. 1.13).

Setup 3: Groynes at 2L distance:

Values of β for set-up 3 in CR1, CR2, CR3 and CR4 are 1.14, 1.13, 1.13 and 1.13 respectively. β shows almost the same value in all of CRs.

Setup 4: Groynes at 3L distance:

Values of β for set-up 4 in CR1, CR2, CR3 and CR4 are 1.13, 1.13, 1.12 and 1.13 respectively. β shows almost the same value in all of CRs.

Setup 5: Groynes at 4L distance:

Values of β for set-up 5 in CR1, CR2, CR3 and CR4 are 1.14, 1.13, 1.32 and 1.14 respectively. β in CR3 shows the maximum value (i.e. 1.32) and CR2 shows the minimum value of β (i.e. 1.13).

Set-ups 1, 2, 3 and 4 seem to produce minimum values of β and hence are the preferred options for zone 1.

Table 4.32: 15 cm:β comparison for Zone 2:

Scope	β
S1 CR1 Z2 R2	1.17
S1 CR2 Z2 R2	1.13
S1 CR3 Z2 R2	1.13
S1 CR4 Z2 R2	1.13
S2 CR1 Z2 R2	1.14
S2 CR2 Z2 R2	1.13
S2 CR3 Z2 R2	1.14
S2 CR4 Z2 R2	1.15
S3 CR1 Z2 R2	1.14
S3 CR2 Z2 R2	1.13
S3 CR3 Z2 R2	1.14
S3 CR4 Z2 R2	1.14
S4 CR1 Z2 R2	1.14
S4 CR2 Z2 R2	1.14
S4 CR3 Z2 R2	1.13
S4 CR4 Z2 R2	1.14
S5 CR1 Z2 R2	1.14
S5 CR2 Z2 R2	1.12
S5 CR3 Z2 R2	1.14
S5 CR4 Z2 R2	1.20

Setup 1: Single groyne:

Values of β for set-up 1 in CR1, CR2, CR3 and CR4 are 1.17, 1.13, 1.13 and 1.13 respectively. β in CR1 shows the maximum value (i.e. 1.17). CR2, CR3 and CR4 show the minimum value of β (i.e. 1.13).

Setup 2: Groynes at L distance:

Values of β for set-up 2 in CR1, CR2, CR3 and CR4 are 1.14, 1.13, 1.14 and 1.15 respectively. β in CR4 shows the maximum value (i.e. 1.15). CR2 shows the minimum value of β (i.e. 1.13).

Setup 3: Groynes at 2L distance:

Values of β for set-up 3 in CR1, CR2, CR3 and CR4 are 1.14, 1.13, 1.14 and 1.14 respectively. β in CR2 shows the maximum value (i.e. 1.13). β shows almost the same value in all of CRs.

Setup 4: Groynes at 3L distance:

Values of β for set-up 4 in CR1, CR2, CR3 and CR4 are 1.14, 1.14, 1.13 and 1.14 respectively. β shows almost the same value in all of CRs.

Setup 5: Groynes at 4L distance:

Values of β for set-up 5 in CR1, CR2, CR3 and CR4 are 1.14, 1.12, 1.14 and 1.20 respectively. β in CR4 shows the maximum value (i.e. 1.20). CR2 shows the minimum value of β (i.e. 1.12).

Set-ups 2, 3 and 4 seem to produce minimum values of β and hence are the preferred options for zone 2.

Table 4.33: 15 cm:β comparison for Zone 3:

Scope	β
S1 CR1 Z3 R2	1.15
S1 CR2 Z3 R2	1.14
S1 CR3 Z3 R2	1.13
S1 CR4 Z3 R2	1.13
S2 CR1 Z3 R2	1.13
S2 CR2 Z3 R2	1.14
S2 CR3 Z3 R2	1.14
S2 CR4 Z3 R2	1.14
S3 CR1 Z3 R2	1.14
S3 CR2 Z3 R2	1.14
S3 CR3 Z3 R2	1.13
S3 CR4 Z3 R2	1.13
S4 CR1 Z3 R2	1.14
S4 CR2 Z3 R2	1.14
S4 CR3 Z3 R2	1.13
S4 CR4 Z3 R2	1.13
S5 CR1 Z3 R2	1.13
S5 CR2 Z3 R2	1.13
S5 CR3 Z3 R2	1.13
S5 CR4 Z3 R2	1.14

Setup 1: Single groyne:

Values of β for set-up 1 in CR1, CR2, CR3 and CR4 are 1.15, 1.14, 1.13 and 1.13 respectively. β in CR1 shows the maximum value (i.e. 1.15). CR3 and CR4 shows the minimum value of β (i.e. 1.13).

Setup 2: Groynes at L distance:

Values of β for set-up 2 in CR1, CR2, CR3 and CR4 are 1.13, 1.14, 1.14 and 1.14 respectively. β in CR1 shows the maximum value (i.e. 1.13). β shows almost the same value in all of CRs.

Setup 3: Groynes at 2L distance:

Values of β for set-up 3 in CR1, CR2, CR3 and CR4 are 1.14, 1.14, 1.13 and 1.13 respectively. β shows almost the same value in all of CRs.

Setup 4: Groynes at 3L distance:

Values of β for set-up 4 in CR1, CR2, CR3 and CR4 are 1.14, 1.14, 1.13 and 1.13 respectively. β shows almost the same value in all of CRs.

Setup 5: Groynes at 4L distance:

Values of β for set-up 5 in CR1, CR2, CR3 and CR4 are 1.13, 1.13, 1.13 and 1.14 respectively. β shows almost the same value in all of CRs.

All the set-ups seem to produce similar values of β and hence there is no preferred option for zone 3.

Table 4.34: 15 cm:β comparison for Zone 4:

Scope	β
S1 CR1 Z4 R2	1.14
S1 CR2 Z4 R2	1.14
S1 CR3 Z4 R2	1.13
S1 CR4 Z4 R2	1.45
S2 CR1 Z4 R2	1.13
S2 CR2 Z4 R2	1.14
S2 CR3 Z4 R2	1.13
S2 CR4 Z4 R2	1.14
S3 CR1 Z4 R2	1.13
S3 CR2 Z4 R2	1.13
S3 CR3 Z4 R2	1.14
S3CR4 Z4 R2	1.19
S4 CR1 Z4 R2	1.14
S4 CR2 Z4 R2	1.13
S4 CR3 Z4 R2	1.14
S4 CR4 Z4 R2	1.15
S5 CR1 Z4 R2	1.14
S5 CR2 Z4 R2	1.13
S5 CR3 Z4 R2	1.13
S5 CR4 Z4 R2	1.17

Setup 1: Single groyne:

Values of β for set-up 1 in CR1, CR2, CR3 and CR4 are 1.14, 1.14, 1.13 and 1.45 respectively. β in CR4 shows the maximum value (i.e. 1.45). CR3 shows the minimum value of β (i.e. 1.13).

Setup 2: Groynes at L distance:

Values of β for set-up 2 in CR1, CR2, CR3 and CR4 are 1.13, 1.14, 1.13 and 1.14 respectively. β shows almost the same value in all of CRs.

Setup 3: Groynes at 2L distance:

Values of β for set-up 3 in CR1, CR2, CR3 and CR4 are 1.13, 1.13, 1.13 and 1.19 respectively. β in CR4 shows the maximum value (i.e. 1.19). CR1, CR2 and CR3 show the minimum value of β (i.e. 1.13).

Setup 4: Groynes at 3L distance:

Values of β for set-up 4 in CR1, CR2, CR3 and CR4 are 1.14, 1.13, 1.14 and 1.15 respectively. β shows almost the same value in all of CRs.

Setup 5: Groynes at 4L distance:

Values of β for set-up 1 in CR1, CR2, CR3 and CR4 are 1.14, 1.13, 1.13 and 1.17 respectively. β in CR4 shows the maximum value (i.e. 1.17). CR2 and CR3 show the minimum value of β (i.e. 1.13).

Set-ups 2 and 4 seem to produce minimum values of β and hence are the preferred options for zone 4.

4.3.3.2 Cross-section-wise Comparison of β among 5 set-ups and 4 zones:

Table 4.35: For 20 cm WL (Horizontal Cross Section Set-ups 1-5)

Table D1: Horizontally comparision of β : Run 1(20 cm)

Sl	Scope	β	Scope	β	Scope	β	Scope	β	Scope	β
1	S1 CR1 Z1 R1	1.13	S2 CR1 Z1 R1	1.26	S3 CR1 Z1 R1	1.13	S4 CR1 Z1 R1	1.13	S5 CR1 Z1 R1	1.30
2	S1 CR1 Z2 R1	1.17	S2 CR1 Z2 R1	1.17	S3 CR1 Z2 R1	1.17	S4 CR1 Z2 R1	1.14	S5 CR1 Z2 R1	1.15
3	S1 CR1 Z3 R1	1.16	S2 CR1 Z3 R1	1.15	S3 CR1 Z3 R1	1.15	S4 CR1 Z3 R1	1.16	S5 CR1 Z3 R1	1.15
4	S1 CR1 Z4 R1	1.14	S2 CR1 Z4 R1	1.17	S3 CR1 Z4 R1	1.14	S4 CR1 Z4 R1	1.14	S5 CR1 Z4 R1	1.13
5	S1 CR2 Z1 R1	1.13	S2 CR2 Z1 R1	1.13	S3 CR2 Z1 R1	1.13	S4 CR2 Z1 R1	1.13	S5 CR2 Z1 R1	1.13
6	S1 CR2 Z2 R1	1.13	S2 CR2 Z2 R1	1.14	S3 CR2 Z2 R1	1.14	S4 CR2 Z2 R1	1.13	S5 CR2 Z2 R1	1.17
7	S1 CR2 Z3 R1	1.15	S2 CR2 Z3 R1	1.15	S3 CR2 Z3 R1	1.13	S4 CR2 Z3 R1	1.15	S5 CR2 Z3 R1	1.15
8	S1 CR2 Z4 R1	1.14	S2 CR2 Z4 R1	1.12	S3 CR2 Z4 R1	1.14	S4 CR2 Z4 R1	1.14	S5 CR2 Z4 R1	1.13
9	S1 CR3 Z1 R1	1.11	S2 CR3 Z1 R1	1.11	S3 CR3 Z1 R1	1.14	S4 CR3 Z1 R1	1.19	S5 CR3 Z1 R1	1.26
10	S1 CR3 Z2 R1	1.15	S2 CR3 Z2 R1	1.14	S3 CR3 Z2 R1	1.15	S4 CR3 Z2 R1	1.14	S5 CR3 Z2 R1	1.13
11	S1 CR3 Z3 R1	1.15	S2 CR3 Z3 R1	1.14	S3 CR3 Z3 R1	1.14	S4 CR3 Z3 R1	1.16	S5 CR3 Z3 R1	1.14
12	S1 CR3 Z4 R1	1.13	S2 CR3 Z4 R1	1.13	S3 CR3 Z4 R1	1.13	S4 CR3 Z4 R1	1.12	S5 CR3 Z4 R1	1.13
13	S1 CR4 Z1 R1	1.13	S2 CR4 Z1 R1	1.14	S3 CR4 Z1 R1	1.13	S4 CR4 Z1 R1	1.13	S5 CR4 Z1 R1	1.13
14	S1 CR4 Z2 R1	1.16	S2 CR4 Z2 R1	1.15	S3 CR4 Z2 R1	1.14	S4 CR4 Z2 R1	1.13	S5 CR4 Z2 R1	1.17
15	S1 CR4 Z3 R1	1.14	S2 CR4 Z3 R1	1.15	S3 CR4 Z3 R1	1.15	S4 CR4 Z3 R1	1.13	S5 CR4 Z3 R1	1.13
16	S1 CR4 Z4 R1	1.12	S2 CR4 Z4 R1	1.14	S3 CR4 Z4 R1	1.13	S4 CR4 Z4 R1	1.13	S5 CR4 Z4 R1	1.23

Table 4.36: For 15 cm WL (Horizontal Cross Section Set-ups 1-5)

Table D1: Horizontally comparision of β : Run 2(15 cm)												
Sl	Scope	β	Scope	β	Scope	β	Scope	β	Scope	β	Scope	β
1	S1 CR1 Z1 R2	1.15	S2 CR1 Z1 R2	1.13	S3 CR1 Z1 R2	1.14	S4 CR1 Z1 R2	1.13	S2 CR1 Z1 R2	1.13	S5 CR1 Z1 R2	1.14
2	S1 CR1 Z2 R2	1.17	S2 CR1 Z2 R2	1.14	S3 CR1 Z2 R2	1.14	S4 CR1 Z2 R2	1.14	S2 CR1 Z2 R2	1.14	S5 CR1 Z2 R2	1.14
3	S1 CR1 Z3 R2	1.15	S2 CR1 Z3 R2	1.13	S3 CR1 Z3 R2	1.14	S4 CR1 Z3 R2	1.14	S2 CR1 Z3 R2	1.13	S5 CR1 Z3 R2	1.13
4	S1 CR1 Z4 R2	1.14	S2 CR1 Z4 R2	1.13	S3 CR1 Z4 R2	1.13	S4 CR1 Z4 R2	1.14	S2 CR1 Z4 R2	1.13	S5 CR1 Z4 R2	1.14
5	S1 CR2 Z1 R2	1.13	S2 CR2 Z1 R2	1.13	S3 CR2 Z1 R2	1.13	S4 CR2 Z1 R2	1.13	S2 CR2 Z1 R2	1.13	S5 CR2 Z1 R2	1.13
6	S1 CR2 Z2 R2	1.13	S2 CR2 Z2 R2	1.13	S3 CR2 Z2 R2	1.13	S4 CR2 Z2 R2	1.14	S2 CR2 Z2 R2	1.13	S5 CR2 Z2 R2	1.12
7	S1 CR2 Z3 R2	1.14	S2 CR2 Z3 R2	1.14	S3 CR2 Z3 R2	1.14	S4 CR2 Z3 R2	1.14	S2 CR2 Z3 R2	1.14	S5 CR2 Z3 R2	1.13
8	S1 CR2 Z4 R2	1.14	S2 CR2 Z4 R2	1.14	S3 CR2 Z4 R2	1.13	S4 CR2 Z4 R2	1.13	S2 CR2 Z4 R2	1.14	S5 CR2 Z4 R2	1.13
9	S1 CR3 Z1 R2	1.13	S2 CR3 Z1 R2	1.14	S3 CR3 Z1 R2	1.13	S4 CR3 Z1 R2	1.12	S2 CR3 Z1 R2	1.14	S5 CR3 Z1 R2	1.32
10	S1 CR3 Z2 R2	1.13	S2 CR3 Z2 R2	1.14	S3 CR3 Z2 R2	1.14	S4 CR3 Z2 R2	1.13	S2 CR3 Z2 R2	1.14	S5 CR3 Z2 R2	1.14
11	S1 CR3 Z3 R2	1.13	S2 CR3 Z3 R2	1.14	S3 CR3 Z3 R2	1.13	S4 CR3 Z3 R2	1.13	S2 CR3 Z3 R2	1.14	S5 CR3 Z3 R2	1.13
12	S1 CR3 Z4 R2	1.13	S2 CR3 Z4 R2	1.13	S3 CR3 Z4 R2	1.14	S4 CR3 Z4 R2	1.14	S2 CR3 Z4 R2	1.13	S5 CR3 Z4 R2	1.13
13	S1 CR4 Z1 R2	1.14	S2 CR4 Z1 R2	1.13	S3 CR4 Z1 R2	1.13	S4 CR4 Z1 R2	1.13	S2 CR4 Z1 R2	1.13	S5 CR4 Z1 R2	1.14
14	S1 CR4 Z2 R2	1.13	S2 CR4 Z2 R2	1.15	S3 CR4 Z2 R2	1.14	S4 CR4 Z2 R2	1.14	S2 CR4 Z2 R2	1.15	S5 CR4 Z2 R2	1.20
15	S1 CR4 Z3 R2	1.13	S2 CR4 Z3 R2	1.14	S3 CR4 Z3 R2	1.13	S4 CR4 Z3 R2	1.13	S2 CR4 Z3 R2	1.14	S5 CR4 Z3 R2	1.14
16	S1 CR4 Z4 R2	1.45	S2 CR4 Z4 R2	1.14	S3CR4 Z4 R2	1.19	S4 CR4 Z4 R2	1.15	S2 CR4 Z4 R2	1.14	S5 CR4 Z4 R2	1.17

Cross-section-wise comparisons of β are shown in Tables 4.35 and 4.36 for depths of 20 cm and 15 cm respectively.

4.4 Shear Stress Distribution

Shear stress is a better predictor of erosion potential than velocity because it considers the actual force of the water on the boundary of the channel. Shear stress computed in this study is the bed shear stress corresponding to the velocity measured closest to the channel bed (i.e. 0.8h depth from water surface).

4.4.1 Zone-wise comparison among 5 different set-ups and cross sections:

Here unit of water level is cm (centimeter) and water density ρ is kg/cm³.

Table 4.37: Depth 20 cm

Comparison among 5 different set-ups 4 cross-sections at zone 1:

Condition/Setup	Crossection	Distance from edge(cm)	ρ	$\tau_1 = \rho u^*{}_1^2$ Zone 1
WL=20	1	34.5	1000	0.49
	2	69	1000	0.01
1	3	103.5	1000	0.31
	4	138	1000	0.54
WL=20	1	34.5	1000	0.13
	2	69	1000	0.01
2	3	103.5	1000	0.15
	4	138	1000	0.23
WL=20	1	34.5	1000	0.68
	2	69	1000	0.01
3	3	103.5	1000	0.66
	4	138	1000	0.01
WL=20	1	34.5	1000	0.01
	2	69	1000	0.01
4	3	103.5	1000	0.06
	4	138	1000	0.01
WL=20	1	34.5	1000	0.05
	2	69	1000	0.01
5	3	103.5	1000	0.02
	4	138	1000	0.26

Overall, for zone 1, set-up 4 produces the minimum bed shear stress in all the cross-sections.

Table 4.38: Depth 20 cm

Comparison among 5 different set-ups 4 cross-sections at zone 2:

Condition/Setup	Crossection	Distance from edge(cm)	ρ	$\tau_2=\rho u^*{}_2^2$ Zone 2
WL=20	1	34.5	1000	0.38
	2	69	1000	0.62
1	3	103.5	1000	0.46
	4	138	1000	0.50
WL=20	1	34.5	1000	0.11
	2	69	1000	0.20
2	3	103.5	1000	0.14
	4	138	1000	0.24
WL=20	1	34.5	1000	0.47
	2	69	1000	0.64
3	3	103.5	1000	0.82
	4	138	1000	0.66
WL=20	1	34.5	1000	0.56
	2	69	1000	0.56
4	3	103.5	1000	0.63
	4	138	1000	0.66
WL=20	1	34.5	1000	0.62
	2	69	1000	0.16
5	3	103.5	1000	0.43
	4	138	1000	0.64

Overall, for zone 2, set-up 2 produces the minimum bed shear stress in all the cross-sections.

Table 4.39: Depth 20 cm

Comparison among 5 different set-ups 4 cross-sections at zone 3:

Condition/Setup	Crossection	Distance from edge(cm)	ρ	$\tau_3=\rho u*_3^2$ Zone 3
WL=20	1	34.5	1000	0.42
	2	69	1000	0.80
1	3	103.5	1000	0.62
	4	138	1000	0.58
WL=20	1	34.5	1000	0.12
	2	69	1000	0.27
2	3	103.5	1000	0.21
	4	138	1000	0.30
WL=20	1	34.5	1000	0.54
	2	69	1000	1.08
3	3	103.5	1000	0.99
	4	138	1000	0.81
WL=20	1	34.5	1000	0.49
	2	69	1000	0.49
4	3	103.5	1000	0.77
	4	138	1000	0.88
WL=20	1	34.5	1000	0.69
	2	69	1000	0.99
5	3	103.5	1000	0.98
	4	138	1000	1.22

Overall, for zone 3, set-up 2 produces the minimum bed shear stress in all the cross-sections.

Table 4.40: W Depth 20 cm

Comparison among 5 different set-ups 4 cross-sections at zone 4:

Condition/Setup	Crossection	Distance from edge(cm)	ρ	$\tau_4=\rho u*_4^2$ Zone 4
WL=20	1	34.5	1000	0.32
	2	69	1000	1.24
1	3	103.5	1000	0.89
	4	138	1000	0.02
WL=20	1	34.5	1000	0.06
	2	69	1000	0.56
2	3	103.5	1000	0.20
	4	138	1000	0.01
WL=20	1	34.5	1000	0.34
	2	69	1000	1.37
3	3	103.5	1000	0.01
	4	138	1000	1.28
WL=20	1	34.5	1000	0.31
	2	69	1000	0.31
4	3	103.5	1000	1.04
	4	138	1000	0.44
WL=20	1	34.5	1000	0.46
	2	69	1000	1.88
5	3	103.5	1000	1.29
	4	138	1000	0.03

Overall, for zone 4, set-up 2 produces the minimum bed shear stress in all the cross-sections.

Table 4.41: Depth 15 cm

Comparison among 5 different set-ups 4 cross-sections at zone 1:

Condition/Setup	Crossection	Distance from edge(cm)	ρ	$\tau_1 = \rho u_1^{*2}$
				Zone 1
WL=15	1	34.5	1000	0.79
	2	69	1000	0.01
1	3	103.5	1000	0.49
	4	138	1000	0.79
WL=15	1	34.5	1000	0.23
	2	69	1000	0.01
2	3	103.5	1000	0.13
	4	138	1000	0.19
WL=15	1	34.5	1000	0.97
	2	69	1000	0.01
3	3	103.5	1000	0.01
	4	138	1000	1.36
WL=15	1	34.5	1000	0.01
	2	69	1000	0.01
4	3	103.5	1000	0.16
	4	138	1000	0.01
WL=15	1	34.5	1000	0.17
	2	69	1000	0.01
5	3	103.5	1000	0.07
	4	138	1000	0.32

Overall, for zone 1, set-up 4 produces the minimum bed shear stress in all the cross-sections.

Table 4.42: Depth 15 cm

Comparison among 5 different set-ups 4 cross-sections at zone 2:

Condition/Setup	Crossection	Distance from edge(cm)	ρ	$\tau_2=\rho u_2^{*2}$
				Zone 2
WL=15	1	34.5	1000	0.75
	2	69	1000	0.84
1	3	103.5	1000	0.90
	4	138	1000	0.99
WL=15	1	34.5	1000	0.21
	2	69	1000	0.26
2	3	103.5	1000	0.27
	4	138	1000	0.27
WL=15	1	34.5	1000	1.20
	2	69	1000	1.23
3	3	103.5	1000	1.22
	4	138	1000	1.44
WL=15	1	34.5	1000	0.96
	2	69	1000	0.95
4	3	103.5	1000	1.25
	4	138	1000	1.28
WL=15	1	34.5	1000	1.17
	2	69	1000	0.22
5	3	103.5	1000	0.86
	4	138	1000	1.62

Overall, for zone 2, set-up 2 produces the minimum bed shear stress in all the cross-sections.

Table 4.43: Depth 15 cm

Comparison among 5 different set-ups 4 cross-sections at zone 3:

Condition/Setup	Crossection	Distance from edge(cm)	ρ	$\tau_3=\rho u^*{}_3{}^2$ Zone 3
WL=15	1	34.5	1000	0.72
	2	69	1000	1.23
1	3	103.5	1000	1.16
	4	138	1000	1.04
WL=15	1	34.5	1000	0.21
	2	69	1000	0.39
2	3	103.5	1000	0.30
	4	138	1000	0.32
WL=15	1	34.5	1000	1.14
	2	69	1000	1.87
3	3	103.5	1000	1.64
	4	138	1000	1.77
WL=15	1	34.5	1000	0.87
	2	69	1000	1.64
4	3	103.5	1000	1.57
	4	138	1000	1.65
WL=15	1	34.5	1000	1.23
	2	69	1000	1.94
5	3	103.5	1000	1.94
	4	138	1000	2.01

Overall, for zone 3, set-up 2 produces the minimum bed shear stress in all the cross-sections.

Table 4.44: Depth 15 cm

Comparison among 5 different set-ups 4 cross-sections at zone 4:

Condition/Setup	Crossection	Distance from edge(cm)	ρ	$\tau_4=\rho u_{*4}^2$ Zone 4
WL=15	1	34.5	1000	0.47
	2	69	1000	1.66
1	3	103.5	1000	1.29
	4	138	1000	0.12
WL=15	1	34.5	1000	0.10
	2	69	1000	0.62
2	3	103.5	1000	0.28
	4	138	1000	0.01
WL=15	1	34.5	1000	0.82
	2	69	1000	2.95
3	3	103.5	1000	2.22
	4	138	1000	0.06
WL=15	1	34.5	1000	0.59
	2	69	1000	2.43
4	3	103.5	1000	1.02
	4	138	1000	0.02
WL=15	1	34.5	1000	0.77
	2	69	1000	3.28
5	3	103.5	1000	2.32
	4	138	1000	0.03

Overall, for zone 4, set-up 2 produces the minimum bed shear stress in all the cross-sections.

4.4.2 Cross-section-wise comparison among 5 different set-ups and 4 zones:

Cross-section-wise comparisons among various zones for a depth of 20 cm are presented in Tables 4.45 to 4.48. Similarly, cross-section-wise comparisons among various zones for a depth of 15 cm are presented in Tables 4.49 to 4.52.

Table 4.45: Depth 20 cm

Comparison among 5 different set-ups and zones for CR1:

Condition/Setup	Crossection	Distance from edge(cm)	ρ	$\tau_1 = \rho u_1^{*2}$	$\tau_2 = \rho u_2^{*2}$	$\tau_3 = \rho u_3^{*2}$	$\tau_4 = \rho u_4^{*2}$
				Zone 1	Zone 2	Zone 3	Zone 4
Setup 1	1	34.5	1000	0.49	0.38	0.42	0.32
Setup 2	1	34.5	1000	0.13	0.11	0.12	0.06
Setup 3	1	34.5	1000	0.68	0.47	0.54	0.34
Setup 4	1	34.5	1000	0.01	0.56	0.49	0.31
Setup 5	1	34.5	1000	0.05	0.62	0.69	0.46

Overall, for CR 1, set-up 2 produces the minimum bed shear stress in all the zones.

Table 4.46: Depth 20 cm

Comparison among 5 different set-ups and zones for CR2:

Condition/Setup	Crossection	Distance from edge(cm)	ρ	$\tau_1 = \rho u_1^{*2}$	$\tau_2 = \rho u_2^{*2}$	$\tau_3 = \rho u_3^{*2}$	$\tau_4 = \rho u_4^{*2}$
				Zone 1	Zone 2	Zone 3	Zone 4
Setup 1	2	69	1000	0.01	0.62	0.80	1.24
Setup 2	2	69	1000	0.01	0.20	0.27	0.56
Setup 3	2	69	1000	0.01	0.64	1.08	1.37
Setup 4	2	69	1000	0.01	0.56	0.49	0.31
Setup 5	2	69	1000	0.01	0.16	0.99	1.88

Overall, for CR 2, set-up 2 produces the minimum bed shear stress in all the zones.

Table 4.47: Depth 20 cm

Comparison among 5 different set-ups & CR3:

Condition/Setup	Crossection	Distance from edge(cm)	ρ	$\tau_1=\rho u_1^{*2}$	$\tau_2=\rho u_2^{*2}$	$\tau_3=\rho u_3^{*2}$	$\tau_4=\rho u_4^{*2}$
				Zone 1	Zone 2	Zone 3	Zone 4
Setup 1	**3**	103.5	1000	0.31	0.46	0.62	0.89
Setup 2	**3**	103.5	1000	0.49	0.90	1.16	1.29
Setup 3	**3**	103.5	1000	0.15	0.14	0.21	0.20
Setup 4	**3**	103.5	1000	0.13	0.27	0.30	0.28
Setup 5	**3**	103.5	1000	0.66	0.82	0.99	0.01

Overall, for CR 3, set-up 3 produces the minimum bed shear stress in all the zones.

Table 4.48: Depth 20 cm

Comparison among 5 different set-ups & CR4:

Condition/Setup	Crossection	Distance from edge(cm)	ρ	$\tau_1=\rho u_1^{*2}$	$\tau_2=\rho u_2^{*2}$	$\tau_3=\rho u_3^{*2}$	$\tau_4=\rho u_4^{*2}$
				Zone 1	Zone 2	Zone 3	Zone 4
Setup 1	**4**	138	1000	0.54	0.50	0.58	0.02
Setup 2	**4**	138	1000	0.79	0.99	1.04	0.12
Setup 3	**4**	138	1000	0.23	0.24	0.30	0.01
Setup 4	**4**	138	1000	0.19	0.27	0.32	0.01
Setup 5	**4**	138	1000	0.01	0.66	0.81	1.28

Overall, for CR 4, set-up 4 produces the minimum bed shear stress in all the zones.

Table 4.49: Depth: 15 cm

Comparison among 5 different set-ups & CR1:

Condition/Setup	Crossection	Distance from edge(cm)	ρ	$\tau_1=\rho u_1^{*2}$	$\tau_2=\rho u_2^{*2}$	$\tau_3=\rho u_3^{*2}$	$\tau_4=\rho u_4^{*2}$
Setup 1	**1**	34.5	1000	0.79	0.75	0.72	0.47
Setup 2	**1**	34.5	1000	0.23	0.21	0.21	0.10
Setup 3	**1**	34.5	1000	0.97	1.20	1.14	0.82
Setup 4	**1**	34.5	1000	0.01	0.96	0.87	0.59
Setup 5	**1**	34.5	1000	0.17	1.17	1.23	0.77

Overall, for CR 1, set-up 2 produces the minimum bed shear stress in all the zones.

Table 4.50: Depth: 15 cm

Comparison among 5 different set-ups & CR2:

Condition/Setup	Crossection	Distance from edge(cm)	ρ	$\tau_1=\rho u_1^{*2}$	$\tau_2=\rho u_2^{*2}$	$\tau_3=\rho u_3^{*2}$	$\tau_4=\rho u_4^{*2}$
				Zone 1	Zone 2	Zone 3	Zone 4
Setup 1	2	69	1000	0.01	0.84	1.23	1.66
Setup 2	2	69	1000	0.01	0.26	0.39	0.62
Setup 3	2	69	1000	0.01	1.23	1.87	2.95
Setup 4	2	69	1000	0.01	0.95	1.64	2.43
Setup 5	2	69	1000	0.01	0.22	1.94	3.28

Overall, for CR 2, set-up 2 produces the minimum bed shear stress in all the zones.

Table 4.51: Depth:15 cm

Comparison among 5 different set-ups & CR3:

Condition/Setup	Crossection	Distance from edge(cm)	ρ	$\tau_1=\rho u_1^{*2}$	$\tau_2=\rho u_2^{*2}$	$\tau_3=\rho u_3^{*2}$	$\tau_4=\rho u_4^{*2}$
				Zone 1	Zone 2	Zone 3	Zone 4
Setup 1	3	103.5	1000	0.01	1.22	1.64	2.22
Setup 2	3	103.5	1000	0.06	0.63	0.77	1.04
Setup 3	3	103.5	1000	0.16	1.25	1.57	1.02
Setup 4	3	103.5	1000	0.02	0.43	0.98	1.29
Setup 5	3	103.5	1000	0.07	0.86	1.94	2.32

Overall, for CR 3, set-up 4 produces the minimum bed shear stress in all the zones.

Table 4.52: Depth:15 cm

Comparison among 5 different set-ups & CR4:

Condition/Setup	Crossection	Distance from edge(cm)	ρ	$\tau_1=\rho u_1^{*2}$	$\tau_2=\rho u_2^{*2}$	$\tau_3=\rho u_3^{*2}$	$\tau_4=\rho u_4^{*2}$
				Zone 1	Zone 2	Zone 3	Zone 4
Setup 1	4	138	1000	1.36	1.44	1.77	0.06
Setup 2	4	138	1000	0.01	0.66	0.88	0.44
Setup 3	4	138	1000	0.01	1.28	1.65	0.02
Setup 4	4	138	1000	0.26	0.64	1.22	0.03
Setup 5	4	138	1000	0.32	1.62	2.01	0.03

Overall, for CR 4, set-up 2 produces the minimum bed shear stress in all the zones.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

A groyne is a rigid hydraulic structure that is built at an ocean shore (in coastal engineering) or from a bank (in rivers) and it interrupts water flow and limits the movement of sediment. It is usually made out of wood/bamboo, concrete or stone. In the ocean, groynes create beaches or prevent them being washed away by long shore drift. In a river, groynes prevent erosion, which in turn aids navigation. All of a groyne may be under water, in which case it is a submerged groyne. The groynes can also be permeable or impermeable in nature. The permeability of a groyne is defined by the ratio of non-blocked area to the total area. The optimum permeability of a groyne is dependent on various boundary parameters (flow velocities, local turbulence, grain size distribution, etc.) and is strongly interrelated with structural conditions of the groyne field (number and length of groynes, spacing in flow direction). The design of the groynes must allow for an efficient reduction of the flow velocities. The study is consisted of effect of permeable gryone in a meandering channel through a laboratory experiments. The major conclusions of the study results are given below.

5.1.1 Analysis of velocity profiles

Zone-wise distribution of mean velocity (20 cm depth)

- For set-ups 4 and 5, it shows a reduction of velocities at d/s sections of groyne with set-up 4 (i.e. 3 gryones at 3L spacing) producing the most reduction at d/s section and hence the preferred option for zone1.
- There is no significant change in velocities along the reaches for each set-up. Overall, set-up 2 (i.e. this groynes located at L spacing) produces minimum velocities along the reach among all the set-ups for zone2.
- There is significant increase in velocities in zone3 for set-ups 3, 4 and 5. Set-up 2 (i.e. 3 groynes at L spacing seems to be the preferred option) for zone 3.
- Set-up 2 (i.e. 3 groynes at L spacing) seems to be the preferred option for zone 4.

Overall, for 20 cm depth, set-up 2 (i.e. 3 gryones at L spacing) is the safest option among all the set-ups. For zones 2, 3 and 4, set-up 2 produces minimum velocities throughout the cross-sections although zone1 produced minimum velocities for set-up 4 for 20 cm depth case.

Zone-wise distribution of mean velocity (15 cm depth)

- For set-up 4 produces the minimum velocities throughout the cross-sections and hence is the preferred option for zone 1.
- There is no significant change in velocities along the reaches for each set-up. Overall, set-up 2 (i.e. this groyne located at L spacing) produces minimum velocities along the reach among all the set-ups for zone 2.
- There is a significant increase in velocity in CR2 where the groyne is located in the all the set-ups along all reaches. Yet set-up2 (i.e. 3 groynes at L spacing) seems to be the most viable option for zone 3.
- Set-up 2 produces the best results in terms of reduction of velocities, and hence considered to be the most viable option for zone 4.

Overall, for 15 cm depth, set-up 2 (i.e. 3 groynes at L spacing) is the safest option among all the set-ups. For zones 2, 3 and 4, set-up 2 produces minimum velocities throughout the cross-sections although zone1 produced minimum velocities for set-up 4 for 15 cm depth case.

Cross-section-wise distribution of mean velocity (20 cm depth)

- Apart from zone1 (i.e. in which set-up 4 produces the minimum velocities), the other zones (i.e. zone2, zone3 and zone4) produce minimum velocities for set-up 2 in cross-section 1.
- Set-up 2 (i.e. groynes located at L spacing) shows minimum velocities in all the zones and hence it is the preferred option for the bank for cross-section 2.
- Set-up 2 (i.e. groynes located at L spacing) shows minimum velocities in all the zones and hence it is the preferred option for cross-section 3.
- Set-up 2 (i.e. groynes located at L spacing) shows minimum velocities in all the zones and hence it is the preferred option for the bank for a depth of 20 cm.

Overall, for 20 cm depth, set-up 2 (i.e. 3 groynes at L spacing) is the safest option among all the set-ups.

Cross-section-wise distribution of mean velocity (15 cm depth)

- Minimum velocities are observed in all the zones in set-up 2 apart from zone1 for set-up 4 and hence set-up 2 is the safest option for the bank for cross-section 1.
- Set-up 2 (i.e. groynes located at 'L' spacing) shows minimum velocities in all the zones and hence it is the preferred option for the bank for cross-section 2.
- Set-up 2 (i.e. groynes located at 'L' spacing) shows minimum velocities in all the zones and hence it is the preferred option for the bank for cross-section 3.
- Set-up 2 (i.e. groynes located at 'L' spacing) shows minimum velocities in all the zones and hence it is the preferred option for the bank for cross-section 4.

Overall, for 15 cm depth, set-up 2 (i.e. 3 groynes at L spacing) is the safest option among all the set-ups.

5.1.2 Velocity Distribution Coefficients

The summary of results for zone-wise and cross-section-wise energy and momentum coefficients is shown below.

<u>Energy coefficient (α)</u>

Zone-wise distribution of α (20 cm depth)

- Set-ups 1, 3 and 4 seem to produce minimum values of α and hence are the preferred options for zone 1.
- All the set-ups seem to produce similar values of α and hence there is no preferred option for zone 2.
- All the set-ups seem to produce similar values of α and hence there is no preferred option for zone 3.
- All the set-ups seem to produce similar values of α and hence there is no preferred option for zone 4.

Overall, for 20 cm depth, as zone 1 is critical and hence set-ups 1, 3 and 4 seem to be the preferred options.

Zone-wise distribution of α (15 cm depth)

- Set-ups 2, 3 and 4 seem to produce minimum values of α and hence are the preferred options for zone 1.
- Set-ups 2, 3 and 4 seem to produce minimum values of α and hence are the preferred options for zone 2.
- All the set-ups seem to produce similar values of α and hence there is no preferred option for zone 3.
- Set-ups 2 and 4 seem to produce minimum values of α and hence are the preferred options for zone 4.

Overall, for 15 cm depth, set-ups 2 and 4 seem to be the preferred options.

<u>Momentum coefficient (β)</u>

Zone-wise distribution of β (20 cm depth)

- Set-ups 1, 2, 3 and 4 seem to produce minimum values of β and hence are the preferred options for zone 1.
- All the set-ups seem to produce similar values of β and hence there is no preferred option for zone 2.
- All the set-ups seem to produce similar values of β and hence there is no preferred option for zone 3.
- All the set-ups seem to produce similar values of β and hence there is no preferred option for zone 4.

Overall, for 20 cm depth, set-ups 1, 2, 3 and 4 seem to be the preferred options.

Zone-wise distribution of β (15 cm depth)

- Set-ups 1, 2, 3 and 4 seem to produce minimum values of β and hence are the preferred options for zone 1.
- Set-ups 2, 3 and 4 seem to produce minimum values of β and hence are the preferred options for zone 2
- All the set-ups seem to produce similar values of β and hence there is no preferred option for zone 3.
- Set-ups 2 and 4 seem to produce minimum values of β and hence are the preferred options for zone 4.

Overall, for 15 cm depth, set-ups 2 and 4 seem to be the preferred options.

5.1.3 Shear stress distribution

Shear stress is a better predictor of erosion potential than velocity because it considers the actual force of the water on the boundary of the channel. In all set-ups, cross-sections and zones, shear stress increases with the increase in velocity at the bed level of the meandering channel.

Zone-wise distribution of shear stress (20 cm depth)

- Overall, for zone 1, set-up 4 (i.e. 3 groynes at 3L spacing) produces the minimum bed shear stress in all the cross-sections and hence the better option.
- Overall, for zone 2, set-up 2 (i.e. 3 groynes at L spacing) produces the minimum bed shear stress in all the cross-sections and hence the better option.
- Overall, for zone 3, set-up 2 produces the minimum bed shear stress in all the cross-sections and hence the better option.
- Overall, for zone 4, set-up 2 produces the minimum bed shear stress in all the cross-sections and hence the better option.

Overall, set-up 2 seems to be the best option among all the zones for 20 cm depth.

Zone-wise distribution of shear stress (15 cm depth)

Exactly similar conclusions are obtained for bed shear stress for 15 cm depth as compared to the same for 20 cm depth. As such, set-up 2 seems to be the best option among all the zones for 15 cm depth.

5.1.4 Findings of this study

In Summary of this physical modeling study and experiment, we found that among 5 set-ups and 2 different water levels of 20 cm & 15 cm, set-up 2 (i.e. three permeable groynes located perpendicularly at L spacing, where L is 0.3 of channel width, B) produces minimum velocities as well as minimum bed shear stress along the reach. Hence, set-up 2 seems to be the best and safest option for the bank protection among all the zones, cross sections, set-ups and simulations.

5.2 Recommendations

The major recommendations for the present study is given below.

- In this study, velocity data have been analyzed as a part of placing series of permeable groyne in a meandering channel perpendicular to the bank. In future, inclined groynes can be used in the meandering channel.
- The study has been carried out considering the effect of permeable groyne in fixed bed. Mobile bed channels can be used for the future studies.
- The present study has been carried out for 1D velocity measurements with current meter. Future studies can be carried out with 3D velocity measurements.

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APPENDIX-A

Table A: Data collection_different setup, zone & cross sec

		Distance from Surface Water (cm)	No of Blow at Point (N)				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point Velocity	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
SETUP 1	Condition 1 (WL=20) : Crosssec: 1	16	1.655	1.794	1.842	1.287	At Start point of	0.1334	0.029	0.249777	0.2683196	0.2747228	0.2006858	0.248376	
		12	1.541	1.588	1.689	1.295	meandering	0.1334	0.029	0.23455606	0.24081252	0.25427258	0.201753	0.232849	0.233438
		8	1.594	1.391	1.457	1.258	channel	0.1334	0.029	0.2416396	0.21451938	0.22335046	0.19684388	0.219088	
	MEAN ,V									**0.241990887**	**0.241217167**	**0.250781947**	**0.199760893**	**0.233438**	
	Condition 1 (WL=20) : Crosssec: 2	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
		16	0.00	1.538	2.392	2.676	At Groyne	0.1334	0.029	0.029	0.2341692	0.3480928	0.3859117	0.249293	
		12	0.00	1.860	2.207	2.900	position	0.1334	0.029	0.029	0.27717736	0.32345382	0.41586	0.261373	0.253283
		8	0.00	1.827	2.100	2.675		0.1334	0.029	0.029	0.27274848	0.30914	0.385845	0.249183	
	MEAN ,V									**0.029**	**0.261365013**	**0.32689554**	**0.395872233**	**0.253283**	
	Condition 1 (WL=20) : Crosssec: 3	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
		16	0.94	1.800	2.152	2.1926	At immeiate	0.1334	0.029	0.15391576	0.26912	0.31611682	0.32149284	0.265161	
		12	1.00	1.700	2.033	2.0735	right position of	0.1334	0.029	0.1624	0.25578	0.3002022	0.3056049	0.255997	0.259444
		8	1.237	1.538	1.833	2.233	Gryone	0.1334	0.029	0.19406916	0.23422256	0.2735222	0.3268822	0.257174	
	MEAN ,V									**0.170128307**	**0.253040853**	**0.29661374**	**0.317993313**	**0.259444**	
	Condition 1 (WL=20) : Crosssec: 4	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
		16	1.728	1.954	1.854	0.000	At right position	0.1334	0.029	0.2594485	0.28961024	0.2763236	0.029	0.213596	
		12	1.628	1.815	1.815	0.100	of Gryone	0.1334	0.029	0.24616186	0.271121	0.271121	0.04234	0.207686	0.208383
		8	1.689	1.628	1.761	0.166		0.1334	0.029	0.25427258	0.24616186	0.26387738	0.05115774	0.203867	
	MEAN ,V									**0.253294313**	**0.268964367**	**0.27044066**	**0.04083258**	**0.208383**	
	Condition 1 (WL=15) : Crosssec: 1	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
		12	2.472	2.633	2.607	1.490	At Start point of	0.1334	0.029	0.35873812	0.38028222	0.37680048	0.227766	0.335897	
		9	2.292	2.330	2.244	1.694	meandering	0.1334	0.029	0.3347528	0.339822	0.3283496	0.25501962	0.314486	0.311756
		6	2.093	2.033	1.980	1.567	channel	0.1334	0.029	0.3082062	0.3002022	0.293132	0.23799778	0.284885	
	MEAN ,V									**0.33389904**	**0.34010214**	**0.332760693**	**0.240261133**	**0.311756**	
	Condition 1 (WL=15) : Crosssec:	Distance from Surface Water	No of Blow at Point				Remarks	a	b	Point Velocity	Point	Point	Point	Average	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
		12	0.000	2.110	2.937	3.399	At Groyne	0.1334	0.029	0.029	0.310474	0.4207958	0.4824266	0.310674	
		9	0.000	2.200	2.923	3.495	position	0.1334	0.029	0.029	0.32248	0.4189282	0.495233	0.31641	0.307225
		6	0.000	2.167	2.664	3.133		0.1334	0.029	0.029	0.31803778	0.3843776	0.4469422	0.294589	
	MEAN ,V									**0.029**	**0.31699726**	**0.408033867**	**0.474867267**	**0.307225**	
	Condition 1 (WL=15) : Crosssec: 3	Distance from Surface Water	No of Blow at Point				Remarks	a	b	Point Velocity	Point	Point	Point	Average	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
		12	1.462	2.207	2.733	2.910	At immeiate	0.1334	0.029	0.22399078	0.3234138	0.3935822	0.41714064	0.339532	
		9	1.375	2.274	2.508	2.715	right position of	0.1334	0.029	0.212425	0.3323516	0.3635672	0.391181	0.324881	0.332892
		6	1.605	2.240	2.575	2.733	Gryone	0.1334	0.029	0.24314702	0.327816	0.372505	0.3935822	0.334263	
	MEAN ,V									**0.226520933**	**0.327860467**	**0.376551467**	**0.400634613**	**0.332892**	
	Condition 1 (WL=15) : Crosssec: 4	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
		12	1.980	2.433	2.440	0.000	At right position	0.1334	0.029	0.29310532	0.3535622	0.354496	0.029	0.257541	
		9	2.192	2.475	2.433	0.000	of Gryone	0.1334	0.029	0.3214128	0.35915166	0.3535622	0.029	0.265782	0.268067
		6	2.087	2.366	2.433	0.667		0.1334	0.029	0.30735244	0.3446244	0.3535622	0.1179778	0.280879	
	MEAN ,V									**0.307290187**	**0.352446087**	**0.353873467**	**0.058659267**	**0.268067**	

	Condition 2 (WL=20) : Crosssec: 1	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
		16	1.495	0.795	0.836	0.600	At Start point of meandering channel	0.1334	0.029	0.228433	0.13501298	0.1405224	0.10904	0.153252	
		12	0.900	0.870	0.736	0.535		0.1334	0.029	0.14906	0.1449913	0.12714238	0.100369	0.130391	0.132028
		8	0.736	0.633	0.700	0.433		0.1334	0.029	0.12714238	0.1134422	0.12238	0.08680222	0.112442	
	MEAN ,V									0.168211793	0.131148827	0.130014927	0.098737073	0.132028	
	Condition 2 (WL=20) : Crosssec: 2	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
		16	0.000	0.963	1.300	1.490	At Groyne position	0.1334	0.029	0.029	0.15751756	0.20242	0.227766	0.154176	
		12	0.000	0.933	1.163	1.633		0.1334	0.029	0.029	0.15350222	0.18410418	0.2468422	0.153362	0.154415
		8	0.000	0.933	1.133	1.733		0.1334	0.029	0.029	0.15350222	0.1801422	0.2601822	0.155707	
	MEAN ,V									0.029	0.154840667	0.188888793	0.244930133	0.154415	
	Condition 2 (WL=20) : Crosssec: 3	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
		16	0.301	0.861	1.030	0.970	At immeiate right position of Gryone	0.1334	0.029	0.0691534	0.14384406	0.16638866	0.15837132	0.134439	
		12	0.301	0.797	0.970	0.803		0.1334	0.029	0.0691534	0.13535982	0.15837132	0.13606684	0.124738	0.134632
		8	0.800	0.767	0.970	0.933		0.1334	0.029	0.13572	0.13127778	0.15837132	0.15350222	0.144718	
	MEAN ,V									0.091342267	0.13682722	0.161043767	0.14931346	0.134632	
	Condition 2 (WL=20) : Crosssec: 4	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
		16	1.029	1.180	1.300	0.000	At right position of Gryone	0.1334	0.029	0.1662686	0.186412	0.20242	0.029	0.146025	
		12	1.167	1.204	1.300	0.000		0.1334	0.029	0.18463778	0.1896136	0.20242	0.029	0.151418	0.145588
		8	1.034	1.066	1.208	0.000		0.1334	0.029	0.1669356	0.1712044	0.1901472	0.029	0.139322	
SETUP -2	MEAN ,V									0.172613993	0.18241	0.198329067	0.029	0.145588	
	Condition 2 (WL=15) : Crosssec: 1	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
		12	1.167	1.096	1.114	0.400	At Start point of meandering channel	0.1334	0.029	0.18463778	0.1752064	0.1776076	0.08236	0.154953	
		9	0.933	1.063	1.100	0.700		0.1334	0.029	0.1534622	0.1708042	0.17574	0.12238	0.155597	0.15283
		6	1.033	0.967	0.967	0.600		0.1334	0.029	0.1668022	0.15795778	0.15795778	0.10904	0.147939	
	MEAN ,V									0.168300727	0.16798946	0.170435127	0.104593333	0.15283	
	Condition 2 (WL=15) : Crosssec: 2	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
		12	0.000	1.192	1.457	1.722	At Groyne position	0.1334	0.029	0.029	0.1880128	0.22335046	0.25868812	0.174763	
		9	0.000	1.163	1.362	1.827		0.1334	0.029	0.029	0.18410418	0.2106908	0.27274848	0.174136	0.174135
		6	0.000	1.100	1.400	1.833		0.1334	0.029	0.029	0.17574	0.21576	0.2735222	0.173506	
	MEAN ,V									0.029	0.182618993	0.21660042	0.2683196	0.174135	
	Condition 2 (WL=15) : Crosssec: 3	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
		12	0.600	1.067	1.330	1.100	At immeiate right position of Gryone	0.1334	0.029	0.10904	0.17129778	0.206422	0.17574	0.165625	
		9	0.600	1.133	1.367	1.200		0.1334	0.029	0.10904	0.1801422	0.21131778	0.18908	0.172395	0.169369
		6	0.731	1.133	1.200	1.167		0.1334	0.029	0.12648872	0.1801422	0.18908	0.18463778	0.170087	
	MEAN ,V									0.11485624	0.17719406	0.20227326	0.183152593	0.169369	
	Condition 2 (WL=15) : Crosssec: 4	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
		12	1.000	1.229	1.233	0.000	At right position of Gryone	0.1334	0.029	0.1624	0.19297528	0.1934822	0.029	0.144464	
		9	1.133	1.291	1.400	0.000		0.1334	0.029	0.1801422	0.20125942	0.21576	0.029	0.15654	0.146802
		6	0.924	1.124	1.262	0.000		0.1334	0.029	0.1522616	0.1789416	0.19740416	0.029	0.139402	
	MEAN ,V									0.1649346	0.191058767	0.202215453	0.029	0.146802	

	Condition	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average	Mean, V
	Condition 3 (WL=20) : Crosssec: 1		Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b	Point	
		16	1.836	2.060	1.881	1.233	At Start point of meandering channel	0.1334	0.029	0.2739224	0.30377732	0.2799254	0.1934822	0.262777	
		12	1.788	1.900	1.887	1.528		0.1334	0.029	0.2675192	0.28246	0.28077916	0.2328352	0.265898	0.257824
		8	1.921	1.556	1.694	1.300		0.1334	0.029	0.2851947	0.23659708	0.2549796	0.20242	0.244798	
	MEAN ,V									**0.275545433**	**0.274278133**	**0.27189472**	**0.209579133**	**0.257824**	
	Condition 3 (WL=20) : Crosssec: 2	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b	Point	
		16	0.000	1.863	2.483	2.824	At Groyne position	0.1334	0.029	0.029	0.27748418	0.3602322	0.40570826	0.268106	
		12	0.000	1.967	2.462	2.957		0.1334	0.029	0.029	0.29135778	0.3574308	0.42343712	0.275306	0.270506
		8	0.000	1.863	2.483	2.824		0.1334	0.029	0.029	0.27748418	0.3602322	0.40570826	0.268106	
	MEAN ,V									**0.029**	**0.282108713**	**0.3592984**	**0.41161788**	**0.270506**	
	Condition 3 (WL=20) : Crosssec: 3	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b	Point	
		16	2.000	2.417	2.492	0.000	At immeiate right position of Gryone	0.1334	0.029	0.2958	0.3514278	0.3614328	0.029	0.259415	
		12	2.000	2.330	2.417	0.000		0.1334	0.029	0.2958	0.339822	0.3514278	0.029	0.254012	0.251878
		8	1.887	2.138	2.368	0.000		0.1334	0.029	0.2807258	0.3142092	0.3448912	0.029	0.242207	
	MEAN ,V									**0.290775267**	**0.335153**	**0.352583933**	**0.029**	**0.251878**	
	Condition 3 (WL=20) : Crosssec: 4	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b	Point	
		16	0.000	2.133	2.425	2.558	At right position of Gryone	0.1334	0.029	0.029	0.3135422	0.352495	0.3702372	0.266319	
		12	0.000	1.902	2.211	2.757		0.1334	0.029	0.029	0.28267344	0.3239474	0.39683716	0.258115	0.259417
		8	0.000	1.900	2.126	2.715		0.1334	0.029	0.029	0.28246	0.3126084	0.39120768	0.253819	
SETUP 3	MEAN ,V									**0.029**	**0.29289188**	**0.3296836**	**0.386094013**	**0.259417**	
	Condition 3 (WL=15) : Crosssec: 1	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b	Point	
		12	2.591	3.330	3.143	2.100	At Start point of meandering channel	0.1334	0.029	0.3746394	0.473222	0.4482762	0.30914	0.401319	
		9	2.541	2.733	2.767	2.181		0.1334	0.029	0.36799608	0.3935822	0.39807778	0.31997208	0.369907	0.374268
		6	2.341	2.633	2.558	2.140		0.1334	0.029	0.34130274	0.3802422	0.3702372	0.31452936	0.351578	
	MEAN ,V									**0.36131274**	**0.415682133**	**0.405530393**	**0.314547147**	**0.374268**	
	Condition 3 (WL=15) : Crosssec: 2	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b	Point	
		12	0.000	2.980	2.980	4.309	At Groyne position	0.1334	0.029	0.029	0.426532	0.426532	0.6038206	0.371471	
		9	0.000	2.748	3.576	4.400		0.1334	0.029	0.029	0.3955832	0.5060384	0.61596	0.386645	0.376207
		6	0.000	2.667	3.330	4.243		0.1334	0.029	0.029	0.3847778	0.473222	0.5950162	0.370504	
	MEAN ,V									**0.029**	**0.402297667**	**0.468597467**	**0.604932267**	**0.376207**	
	Condition 3 (WL=15) : Crosssec: 3	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b	Point	
		12	0.000	2.724	3.112	3.112	At immeiate right position of Gryone	0.1334	0.029	0.029	0.3923816	0.4441408	0.4441408	0.327416	
		9	0.000	2.833	3.067	3.654		0.1334	0.029	0.029	0.4069222	0.43809778	0.5164436	0.347616	0.339341
		6	0.000	2.649	3.112	3.654		0.1334	0.029	0.029	0.3823766	0.4441408	0.5164436	0.34299	
	MEAN ,V									**0.029**	**0.393893467**	**0.44212646**	**0.492342667**	**0.339341**	
	Condition 3 (WL=15) : Crosssec: 4	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b	Point	
		12	3.067	3.332	3.433	0.855	At right position of Gryone	0.1334	0.029	0.4381378	0.47351548	0.4869622	0.14308368	0.385425	
		9	2.923	3.311	3.311	0.993		0.1334	0.029	0.4189282	0.4706874	0.4706874	0.16150622	0.380452	0.369204
		6	2.814	2.900	3.233	0.430		0.1334	0.029	0.4043876	0.41586	0.4602822	0.08641536	0.341736	
	MEAN ,V									**0.420484533**	**0.453354293**	**0.472643933**	**0.130335087**	**0.369204**	

Setup	Condition	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
SETUP 4	Condition 4 (WL=20) : Crosssec: 1	16	0.000	1.967	1.967	1.266	At Start point of meandering channel	0.1334	0.029	0.029	0.29135778	0.2913978	0.1978844	0.20241	
		12	0.000	1.688	1.730	1.330		0.1334	0.029	0.029	0.2541792	0.259782	0.206422	0.187346	0.190344
		8	0.000	1.733	1.600	1.233		0.1334	0.029	0.029	0.2601822	0.24244	0.1934822	0.181276	
	MEAN ,V									0.029	0.26857306	0.264539933	0.199262867	0.190344	
		Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
	Condition 4 (WL=20) : Crosssec: 2	16	0.000	1.745	2.591	3.367	At Groyne position	0.1334	0.029	0.029	0.26176966	0.37467942	0.47811778	0.285892	
		12	0.000	1.510	2.400	3.243		0.1334	0.029	0.029	0.230434	0.34916	0.4616162	0.267553	0.273578
		8	0.000	1.728	2.308	3.110		0.1334	0.029	0.029	0.2594485	0.33683384	0.443874	0.267289	
	MEAN ,V									0.029	0.25055072	0.353557753	0.46120266	0.273578	
		Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
	Condition 4 (WL=20) : Crosssec: 3	16	0.660	1.967	2.533	2.100	At immeiate right position of Gryone	0.1334	0.029	0.117044	0.29135778	0.3669022	0.30914	0.271111	
		12	0.363	2.019	2.285	2.247		0.1334	0.029	0.0774242	0.2983346	0.33377898	0.328705778	0.259561	0.261469
		8	0.397	1.842	2.067	2.433		0.1334	0.029	0.0819598	0.2747228	0.30469778	0.3535622	0.253736	
	MEAN ,V									0.092142667	0.288138393	0.33512632	0.330469326	0.261469	
		Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
	Condition 4 (WL=20) : Crosssec: 4	16	0.000	1.794	2.277	1.125	At right position of Gryone	0.1334	0.029	0.029	0.2683196	0.3327518	0.179075	0.202287	
		12	0.000	2.013	2.178	1.667		0.1334	0.029	0.029	0.2975342	0.3195452	0.2513778	0.224364	0.214348
		8	0.000	1.893	2.218	1.508		0.1334	0.029	0.029	0.2815262	0.3248812	0.2301672	0.216394	
	MEAN ,V									0.029	0.28246	0.325726067	0.220206667	0.214348	
		Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
	Condition 4 (WL=15) : Crosssec: 1	12	0.000	2.847	2.823	1.881	At Start point of meandering channel	0.1334	0.029	0.029	0.4087898	0.4055882	0.2799254	0.280826	
		9	0.000	2.442	2.300	1.887		0.1334	0.029	0.029	0.3547628	0.33582	0.28077916	0.25009	0.256807
		6	0.000	2.325	2.211	1.776		0.1334	0.029	0.029	0.339155	0.3239474	0.2659184	0.239505	
	MEAN ,V									0.029	0.3675692	0.355118533	0.275540987	0.256807	
		Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
	Condition 4 (WL=15) : Crosssec: 2	12	0.000	2.467	3.588	3.410	At Groyne position	0.1334	0.029	0.029	0.35805778	0.5076392	0.483894	0.344648	
		9	0.000	2.582	3.355	3.620		0.1334	0.029	0.029	0.3734388	0.476557	0.511908	0.347726	0.343426
		6	0.000	2.317	3.113	3.833		0.1334	0.029	0.029	0.3380878	0.4442075	0.5403222	0.337904	
	MEAN ,V									0.029	0.356528127	0.476134567	0.5120414	0.343426	
		Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
	Condition 4 (WL=15) : Crosssec: 3	12	0.769	2.933	3.267	2.341	At immeiate right position of Gryone	0.1334	0.029	0.13161128	0.4202622	0.46477778	0.3412894	0.339485	
		9	0.499	2.742	3.154	2.558		0.1334	0.029	0.0955666	0.39483616	0.44978362	0.37025054	0.327609	0.331637
		6	0.836	2.691	3.033	2.400		0.1334	0.029	0.1405224	0.3879794	0.4336022	0.34916	0.327816	
	MEAN ,V									0.12256676	0.40102592	0.449387867	0.353566647	0.331637	
		Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Average Point	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b		
	Condition 4 (WL=15) : Crosssec: 4	12	0.000	3.046	3.256	0.234	At right position of Gryone	0.1334	0.029	0.029	0.4353364	0.46332372	0.0602156	0.246969	
		9	0.000	2.909	3.110	0.234		0.1334	0.029	0.029	0.4170606	0.443874	0.0602156	0.237538	0.237454
		6	0.000	2.715	3.115	0.133		0.1334	0.029	0.029	0.391181	0.44450098	0.0467422	0.227856	
	MEAN ,V									0.029	0.414526	0.450566233	0.055724467	0.237454	

	Condition 5 (WL=20) : Crosssec: 1	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b	Average Point
		16	0.997	2.133	2.274	1.505	At Start point of meandering channel	0.1334	0.029	0.16194644	0.3135422	0.3323516	0.229767	0.259402
		12	0.702	2.000	2.033	1.600		0.1334	0.029	0.1226468	0.2958	0.3002022	0.24244	0.240272	0.239353
		8	0.366	1.833	1.940	1.540		0.1334	0.029	0.0778244	0.2735222	0.28775598	0.234436	0.218385
	MEAN ,V									0.12080588	0.294288133	0.306769927	0.235547667	0.239353
	Condition 5 (WL=20) : Crosssec: 2	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b	Average Point
		16	0.000	1.122	2.739	2.934	At Groyne position	0.1334	0.029	0.029	0.1786748	0.3943826	0.4203956	0.255613
		12	0.000	0.861	2.640	3.432		0.1334	0.029	0.029	0.14384406	0.381176	0.4868288	0.260212	0.254278
		8	0.000	0.825	2.368	3.344		0.1334	0.029	0.029	0.139055	0.3448912	0.4750896	0.247009
	MEAN ,V									0.029	0.153857953	0.373483267	0.460771333	0.254278
	Condition 5 (WL=20) : Crosssec: 3	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b	Average Point
		16	0.466	1.533	2.368	2.600	At immeiate right position of Gryone	0.1334	0.029	0.0911644	0.2335022	0.3448912	0.37584	0.261349
		12	0.164	1.456	2.657	2.796		0.1334	0.029	0.05093096	0.2232304	0.3834438	0.4019864	0.264898	0.25986
		8	0.166	1.480	2.351	2.730		0.1334	0.029	0.0510777	0.22645868	0.34261006	0.393182	0.253332
	MEAN ,V									0.06439102	0.227730427	0.356981687	0.390336133	0.25986
	Condition 5 (WL=20) : Crosssec: 4	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b	Average Point
		16	1.000	2.330	2.540	0.535	At right position of Gryone	0.1334	0.029	0.1624	0.339822	0.367836	0.100369	0.242607
		12	1.192	2.400	2.718	0.602		0.1334	0.029	0.1880128	0.34916	0.3915812	0.1093068	0.259515	0.242468
		8	1.100	1.868	2.650	0.268		0.1334	0.029	0.17574	0.2781912	0.38251	0.0646845	0.225281
SETUP 5	MEAN ,V									0.175384267	0.322391067	0.3806424	0.091453433	0.242468
	Condition 5 (WL=15) : Crosssec: 1	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b	Average Point
		12	0.730	2.691	3.067	2.100	At Start point of meandering channel	0.1334	0.029	0.126382	0.3879794	0.43809778	0.30914	0.3154
		9	0.924	2.823	2.682	2.193		0.1334	0.029	0.1522616	0.4055882	0.3867788	0.32149284	0.31653	0.311319
		6	0.863	2.590	2.667	2.067		0.1334	0.029	0.1441242	0.374506	0.3847778	0.30469778	0.302026
	MEAN ,V									0.1409226	0.389357867	0.403218127	0.311776873	0.311319
	Condition 5 (WL=15) : Crosssec: 2	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b	Average Point
		12	0.000	0.960	3.700	4.653	At Groyne position	0.1334	0.029	0.029	0.157064	0.52258	0.6497102	0.339589
		9	0.000	0.726	3.476	4.633		0.1334	0.029	0.029	0.1258484	0.4926984	0.6470422	0.323647	0.329539
		6	0.000	1.000	3.399	4.488		0.1334	0.029	0.029	0.1624	0.4824266	0.6276992	0.325381
	MEAN ,V									0.029	0.148437467	0.499235	0.641483867	0.329539
	Condition 5 (WL=15) : Crosssec: 3	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b	Average Point
		12	1.677	1.716	3.687	4.000	At immeiate right position of Gryone	0.1334	0.029	0.2527118	0.2579144	0.5208458	0.5626	0.398518
		9	0.433	1.980	3.421	3.762		0.1334	0.029	0.0867622	0.293132	0.4853614	0.5308508	0.349027	0.367681
		6	0.465	2.185	3.399	3.741		0.1334	0.029	0.09104434	0.320479	0.4824266	0.5280494	0.3555
	MEAN ,V									0.143506113	0.290508467	0.496211267	0.540500067	0.367681
	Condition 5 (WL=15) : Crosssec: 4	Distance from Surface Water (cm)	No of Blow at Point				Remarks	a	b	Point Veloity	Point Veloity	Point Veloity	Point Veloity	Mean, V
			Zone 1	Zone 2	Zone 3	Zone 4				V(1)=aN+b	V(2)=aN+b	V(3)=aN+b	V(4)=aN+b	Average Point
		12	1.217	1.688	3.767	0.230	At right position of Gryone	0.1334	0.029	0.1913478	0.2541792	0.53147778	0.059682	0.259172
		9	1.328	3.116	3.667	0.426		0.1334	0.029	0.2061552	0.4446744	0.5181778	0.08585508	0.313716	0.289769
		6	1.262	3.092	3.465	0.199		0.1334	0.029	0.1973508	0.4414728	0.49127102	0.05558662	0.29642
	MEAN ,V									0.1982846	0.3801088	0.5136422	0.067041233	0.289769

Table A1 : Zone wise Velocity comparison between 5 different setup & cross section: 20 cm

Scope	WL	Mean Velocity
		Zone 1
Set up :1_C1	20	0.24
Set up :1_C2	20	0.03
Set up :1_C3	20	0.17
Set up :1_C4	20	0.25
Set up :2_C1	20	0.17
Set up :2_C2	20	0.03
Set up :2_C3	20	0.09
Set up :2_C4	20	0.17
Set up :3_C1	20	0.28
Set up :3_C2	20	0.03
Set up :3_C3	20	0.29
Set up :3_C4	20	0.03
Set up :4_C1	20	0.03
Set up :4_C2	20	0.03
Set up :4_C3	20	0.09
Set up :4_C4	20	0.03
Set up :5_C1	20	0.12
Set up :5_C2	20	0.03
Set up :5_C3	20	0.06
Set up :5_C4	20	0.18

Scope	WL	Mean Velocity
		Zone 2
Set up :1_C1	20	0.24
Set up :1_C2	20	0.26
Set up :1_C3	20	0.25
Set up :1_C4	20	0.27
Set up :2_C1	20	0.13
Set up :2_C2	20	0.15
Set up :2_C3	20	0.14
Set up :2_C4	20	0.18
Set up :3_C1	20	0.27
Set up :3_C2	20	0.28
Set up :3_C3	20	0.34
Set up :3_C4	20	0.29
Set up :4_C1	20	0.27
Set up :4_C2	20	0.25
Set up :4_C3	20	0.29
Set up :4_C4	20	0.28
Set up :5_C1	20	0.29
Set up :5_C2	20	0.15
Set up :5_C3	20	0.23
Set up :5_C4	20	0.32

Scope	WL	Mean Velocity
		Zone 3
Set up :1_C1	20	0.25
Set up :1_C2	20	0.33
Set up :1_C3	20	0.30
Set up :1_C4	20	0.27
Set up :2_C1	20	0.13
Set up :2_C2	20	0.19
Set up :2_C3	20	0.16
Set up :2_C4	20	0.20
Set up :3_C1	20	0.27
Set up :3_C2	20	0.36
Set up :3_C3	20	0.35
Set up :3_C4	20	0.33
Set up :4_C1	20	0.26
Set up :4_C2	20	0.35
Set up :4_C3	20	0.34
Set up :4_C4	20	0.33
Set up :5_C1	20	0.31
Set up :5_C2	20	0.37
Set up :5_C3	20	0.36
Set up :5_C4	20	0.38

Scope	WL	Mean Velocity
		Zone 4
Set up :1_C1	20	0.20
Set up :1_C2	20	0.40
Set up :1_C3	20	0.32
Set up :1_C4	20	0.04
Set up :2_C1	20	0.10
Set up :2_C2	20	0.24
Set up :2_C3	20	0.15
Set up :2_C4	20	0.03
Set up :3_C1	20	0.21
Set up :3_C2	20	0.41
Set up :3_C3	20	0.03
Set up :3_C4	20	0.39
Set up :4_C1	20	0.20
Set up :4_C2	20	0.46
Set up :4_C3	20	0.33
Set up :4_C4	20	0.22
Set up :5_C1	20	0.24
Set up :5_C2	20	0.46
Set up :5_C3	20	0.39
Set up :5_C4	20	0.09

Table A2 : Zone wise Velocity comparison between 5 different setup & cross section: 15 cm

Scope	WL	Mean Velocity
		Zone 1
Set up :1_C1	15	0.33
Set up :1_C2	15	0.03
Set up :1_C3	15	0.23
Set up :1_C4	15	0.31
Set up :2_C1	15	0.17
Set up :2_C2	15	0.03
Set up :2_C3	15	0.11
Set up :2_C4	15	0.16
Set up :3_C1	15	0.36
Set up :3_C2	15	0.03
Set up :3_C3	15	0.03
Set up :3_C4	15	0.42
Set up :4_C1	15	0.03
Set up :4_C2	15	0.03
Set up :4_C3	15	0.12
Set up :4_C4	15	0.03
Set up :5_C1	15	0.14
Set up :5_C2	15	0.03
Set up :5_C3	15	0.14
Set up :5_C4	15	0.20

Scope	WL	Mean Velocity
		Zone 2
Set up :1_C1	15	0.34
Set up :1_C2	15	0.32
Set up :1_C3	15	0.33
Set up :1_C4	15	0.35
Set up :2_C1	15	0.17
Set up :2_C2	15	0.18
Set up :2_C3	15	0.18
Set up :2_C4	15	0.19
Set up :3_C1	15	0.42
Set up :3_C2	15	0.40
Set up :3_C3	15	0.39
Set up :3_C4	15	0.45
Set up :4_C1	15	0.37
Set up :4_C2	15	0.36
Set up :4_C3	15	0.40
Set up :4_C4	15	0.41
Set up :5_C1	15	0.39
Set up :5_C2	15	0.15
Set up :5_C3	15	0.29
Set up :5_C4	15	0.38

Scope	WL	Mean Velocity
		Zone 3
Set up :1_C1	15	0.33
Set up :1_C2	15	0.41
Set up :1_C3	15	0.38
Set up :1_C4	15	0.35
Set up :2_C1	15	0.17
Set up :2_C2	15	0.22
Set up :2_C3	15	0.20
Set up :2_C4	15	0.20
Set up :3_C1	15	0.41
Set up :3_C2	15	0.47
Set up :3_C3	15	0.44
Set up :3_C4	15	0.47
Set up :4_C1	15	0.36
Set up :4_C2	15	0.48
Set up :4_C3	15	0.45
Set up :4_C4	15	0.45
Set up :5_C1	15	0.40
Set up :5_C2	15	0.50
Set up :5_C3	15	0.50
Set up :5_C4	15	0.51

Scope	WL	Mean Velocity
		Zone 4
Set up :1_C1	15	0.24
Set up :1_C2	15	0.47
Set up :1_C3	15	0.40
Set up :1_C4	15	0.06
Set up :2_C1	15	0.10
Set up :2_C2	15	0.27
Set up :2_C3	15	0.18
Set up :2_C4	15	0.03
Set up :3_C1	15	0.31
Set up :3_C2	15	0.60
Set up :3_C3	15	0.49
Set up :3_C4	15	0.13
Set up :4_C1	15	0.28
Set up :4_C2	15	0.51
Set up :4_C3	15	0.35
Set up :4_C4	15	0.06
Set up :5_C1	15	0.31
Set up :5_C2	15	0.64
Set up :5_C3	15	0.54
Set up :5_C4	15	0.07

Table A3 : Velocity comparison between 5 different setup & zone: 20 cm

Scope	WL	Mean Velocity			
		Zone 1	Zone 2	Zone 3	Zone 4
Set up :1_C1	20	0.24	0.24	0.25	0.20
Set up :2_C1	20	0.17	0.13	0.13	0.10
Set up :3_C1	20	0.28	0.27	0.27	0.21
Set up :4_C1	20	0.03	0.27	0.26	0.20
Set up :5_C1	20	0.12	0.29	0.31	0.24

Table A4 : Velocity comparison between 5 different setup & zone: 20 cm

Scope	WL	Mean Velocity			
		Zone 1	Zone 2	Zone 3	Zone 4
Set up :1_C2	20	0.03	0.26	0.33	0.40
Set up :2_C2	20	0.03	0.15	0.19	0.24
Set up :3_C2	20	0.03	0.28	0.36	0.41
Set up :4_C2	20	0.03	0.25	0.35	0.46
Set up :5_C2	20	0.03	0.15	0.37	0.46

Table A5 : Velocity comparison between 5 different setup & zone: 20 cm

Scope	WL	Mean Velocity			
		Zone 1	Zone 2	Zone 3	Zone 4
Set up :1_C3	20	0.17	0.25	0.30	0.32
Set up :2_C3	20	0.09	0.14	0.16	0.15
Set up :3_C3	20	0.29	0.34	0.35	0.03
Set up :4_C3	20	0.09	0.29	0.34	0.33
Set up :5_C3	20	0.06	0.23	0.36	0.39

Table A6 : Velocity comparison between 5 different setup & zone: 20 cm

Scope	WL	Mean Velocity			
		Zone 1	Zone 2	Zone 3	Zone 4
Set up :1_C4	20	0.25	0.27	0.27	0.04
Set up :2_C4	20	0.17	0.18	0.20	0.03
Set up :3_C4	20	0.03	0.29	0.33	0.39
Set up :4_C4	20	0.03	0.28	0.33	0.22
Set up :5_C4	20	0.18	0.32	0.38	0.09

Table A7 : Velocity comparison between 5 different setup & zone: 15 cm

Scope	WL	Mean Velocity			
		Zone 1	Zone 2	Zone 3	Zone 4
Set up :1_C1	15	0.33	0.34	0.33	0.24
Set up :2_C1	15	0.17	0.17	0.17	0.10
Set up :3_C1	15	0.36	0.42	0.41	0.31
Set up :4_C1	15	0.03	0.37	0.36	0.28
Set up :5_C1	15	0.14	0.39	0.40	0.31

Table A8 : Velocity comparison between 5 different setup & zone: 15 cm

Scope	WL	Mean Velocity			
		Zone 1	Zone 2	Zone 3	Zone 4
Set up :1_C2	15	0.03	0.32	0.41	0.47
Set up :2_C2	15	0.03	0.18	0.22	0.27
Set up :3_C2	15	0.03	0.40	0.47	0.60
Set up :4_C2	15	0.03	0.36	0.48	0.51
Set up :5_C2	15	0.03	0.15	0.50	0.64

Table A9 : Velocity comparison between 5 different setup & zone: 15 cm

Scope	WL	Mean Velocity			
		Zone 1	Zone 2	Zone 3	Zone 4
Set up :1_C3	15	0.23	0.33	0.38	0.40
Set up :2_C3	15	0.11	0.18	0.20	0.18
Set up :3_C3	15	0.03	0.39	0.44	0.49
Set up :4_C3	15	0.12	0.40	0.45	0.35
Set up :5_C3	15	0.14	0.29	0.50	0.54

Table A10 : Velocity comparison between 5 different setup & zone: 15 cm

Scope	WL	Mean Velocity			
		Zone 1	Zone 2	Zone 3	Zone 4
Set up :1_C4	15	0.31	0.35	0.35	0.06
Set up :2_C4	15	0.16	0.19	0.20	0.03
Set up :3_C4	15	0.42	0.45	0.47	0.13
Set up :4_C4	15	0.03	0.41	0.45	0.06
Set up :5_C4	15	0.20	0.38	0.51	0.07

Scope	WL	Mean Velocity	Mean Velocity			
		Avg V(zone wise)	Zone 1	Zone 2	Zone 3	Zone 4
Set up :1_C1	20	0.23	0.24	0.24	0.25	0.20
Set up :1_C2	20	0.25	0.03	0.26	0.33	0.40
Set up :1_C3	20	0.26	0.17	0.25	0.30	0.32
Set up :1_C4	20	0.21	0.25	0.27	0.27	0.04
Set up :1	Avg	0.02	0.07	0.01	0.03	0.12
Set up :1_C1	15	0.31	0.33	0.34	0.33	0.24
Set up :1_C2	15	0.31	0.03	0.32	0.41	0.47
Set up :1_C3	15	0.33	0.23	0.33	0.38	0.40
Set up :1_C4	15	0.27	0.31	0.35	0.35	0.06
Set up :1	Avg	0.02	0.10	0.01	0.02	0.14
Set up :2_C1	20	0.13	0.17	0.13	0.13	0.10
Set up :2_C2	20	0.15	0.03	0.15	0.19	0.24
Set up :2_C3	20	0.13	0.09	0.14	0.16	0.15
Set up :2_C4	20	0.15	0.17	0.18	0.20	0.03
Set up :2	Avg	0.01	0.06	0.02	0.02	0.07
Set up :2_C1	15	0.15	0.17	0.17	0.17	0.10
Set up :2_C2	15	0.17	0.03	0.18	0.22	0.27
Set up :2_C3	15	0.17	0.11	0.18	0.20	0.18
Set up :2_C4	15	0.15	0.16	0.19	0.20	0.03
Set up :2	Avg	0.01	0.05	0.01	0.01	0.08
Set up :3_C1	20	0.26	0.28	0.27	0.27	0.21
Set up :3_C2	20	0.27	0.03	0.28	0.36	0.41
Set up :3_C3	20	0.25	0.29	0.34	0.35	0.03
Set up :3_C4	20	0.26	0.03	0.29	0.33	0.39
Set up :3	Avg	0.01	0.13	0.02	0.03	0.14
Set up :3_C1	15	0.37	0.36	0.42	0.41	0.31
Set up :3_C2	15	0.38	0.03	0.40	0.47	0.60
Set up :3_C3	15	0.34	0.03	0.39	0.44	0.49
Set up :3_C4	15	0.37	0.42	0.45	0.47	0.13
Set up :3	Avg	0.01	0.18	0.02	0.02	0.16
Set up :4_C1	20	0.19	0.03	0.27	0.26	0.20
Set up :4_C2	20	0.27	0.03	0.25	0.35	0.46
Set up :4_C3	20	0.26	0.09	0.29	0.34	0.33
Set up :4_C4	20	0.21	0.03	0.28	0.33	0.22
Set up :4	Avg	0.03	0.02	0.01	0.03	0.09
Set up :4_C1	15	0.26	0.03	0.37	0.36	0.28
Set up :4_C2	15	0.34	0.03	0.36	0.48	0.51
Set up :4_C3	15	0.33	0.12	0.40	0.45	0.35
Set up :4_C4	15	0.24	0.03	0.41	0.45	0.06
Set up :4	Avg	0.05	0.04	0.02	0.04	0.13
Set up :5_C1	20	0.24	0.12	0.29	0.31	0.24
Set up :5_C2	20	0.25	0.03	0.15	0.37	0.46
Set up :5_C3	20	0.26	0.06	0.23	0.36	0.39
Set up :5_C4	20	0.24	0.18	0.32	0.38	0.09
Set up :5	Avg	0.01	0.05	0.06	0.02	0.13
Set up :5_C1	15	0.31	0.14	0.39	0.40	0.31
Set up :5_C2	15	0.33	0.03	0.15	0.50	0.64
Set up :5_C3	15	0.37	0.14	0.29	0.50	0.54
Set up :5_C4	15	0.29	0.20	0.38	0.51	0.07
Set up :5	Avg	0.02	0.05	0.08	0.04	0.20

Table B : Summary of Velocity for different Setup, CR & Zone

Horizontally comparision of shear stress(τ) on bed level between different setup & zone

Table: C1 — 20 cm

Condition/Setup	Crossection	Distance from edge(cm)	ρ	z/z_o	1/k	Velocity at bed level u_1	u_2	u_3	u_4	u^*_1	u^*_2	u^*_3	u^*_4	$\tau_1=\rho u^{*2}_1$ Zone 1	$\tau_2=\rho u^{*2}_2$ Zone 2	$\tau_3=\rho u^{*2}_3$ Zone 3	$\tau_4=\rho u^{*2}_4$ Zone 4
										$u^* = u'/((1/k)*\ln(z/z_o)))$							
Setup 1	1	34.5	1000	80	2.5	0.2416396	0.2145194	0.2233505	0.1968439	0.02206	0.01958175	0.020387869	0.017968	0.49	0.38	0.42	0.32
Setup 2	1	34.5	1000	80	2.5	0.1271424	0.1134422	0.12238	0.0868022	0.01161	0.010355227	0.011171087	0.007923	0.13	0.11	0.12	0.06
Setup 3	1	34.5	1000	80	2.5	0.2851947	0.2365971	0.2549796	0.20242	0.02603	0.021597046	0.023275039	0.018477	0.68	0.47	0.54	0.34
Setup 4	1	34.5	1000	80	2.5	0.029	0.2601822	0.24244	0.1934822	0.00265	0.023749942	0.022130399	0.017661	0.01	0.56	0.49	0.31
Setup 5	1	34.5	1000	80	2.5	0.0778244	0.2735222	0.287756	0.234436	0.0071	0.024967644	0.026266931	0.0214	0.05	0.62	0.69	0.46

Table: C2 — 15 cm

Condition/Setup	Crossection	Distance from edge(cm)	ρ	z/z_o	1/k	Velocity at bed level u_1	u_2	u_3	u_4	u^*_1	u^*_2	u^*_3	u^*_4	$\tau_1=\rho u^{*2}_1$ Zone 1	$\tau_2=\rho u^{*2}_2$ Zone 2	$\tau_3=\rho u^{*2}_3$ Zone 3	$\tau_4=\rho u^{*2}_4$ Zone 4
Setup 1	1	34.5	1000	80	2.5	0.3082062	0.3002022	0.293132	0.2379978	0.02813	0.027403047	0.026757665	0.021725	0.79	0.75	0.72	0.47
Setup 2	1	34.5	1000	80	2.5	0.1668022	0.1579578	0.1579578	0.10904	0.01523	0.014418696	0.014418696	0.009953	0.23	0.21	0.21	0.10
Setup 3	1	34.5	1000	80	2.5	0.3413027	0.3802422	0.3702372	0.3145294	0.03115	0.034709255	0.033795979	0.028711	0.97	1.20	1.14	0.82
Setup 4	1	34.5	1000	80	2.5	0.029	0.339155	0.3239474	0.2659184	0.00265	0.030958735	0.029570555	0.024274	0.01	0.96	0.87	0.59
Setup 5	1	34.5	1000	80	2.5	0.1441242	0.374506	0.3847778	0.3046978	0.01316	0.034185643	0.035123274	0.027813	0.17	1.17	1.23	0.77

Table: C3 — 20 cm

Condition/Setup	Crossection	Distance from edge(cm)	ρ	z/z_o	1/k	Velocity at bed level u_1	u_2	u_3	u_4	u^*_1	u^*_2	u^*_3	u^*_4	$\tau_1=\rho u^{*2}_1$ Zone 1	$\tau_2=\rho u^{*2}_2$ Zone 2	$\tau_3=\rho u^{*2}_3$ Zone 3	$\tau_4=\rho u^{*2}_4$ Zone 4
Setup 1	2	69	1000	80	2.5	0.029	0.2727485	0.30914	0.385845	0.00265	0.024897017	0.028218907	0.035221	0.01	0.62	0.80	1.24
Setup 2	2	69	1000	80	2.5	0.029	0.1535022	0.1801422	0.2601822	0.00265	0.014011984	0.016443734	0.02375	0.01	0.20	0.27	0.56
Setup 3	2	69	1000	80	2.5	0.029	0.2774842	0.3602322	0.4057083	0.00265	0.025329301	0.032882703	0.037034	0.01	0.64	1.08	1.37
Setup 4	2	69	1000	80	2.5	0.029	0.2601822	0.24244	0.1934822	0.00265	0.023749942	0.022130399	0.017661	0.01	0.56	0.49	0.31
Setup 5	2	69	1000	80	2.5	0.029	0.139055	0.3448912	0.4750896	0.00265	0.012693214	0.031482346	0.043367	0.01	0.16	0.99	1.88

Table: C4 — 15 cm

Condition/Setup	Crossection	Distance from edge(cm)	ρ	z/z_o	1/k	Velocity at bed level u_1	u_2	u_3	u_4	u^*_1	u^*_2	u^*_3	u^*_4	$\tau_1=\rho u^{*2}_1$ Zone 1	$\tau_2=\rho u^{*2}_2$ Zone 2	$\tau_3=\rho u^{*2}_3$ Zone 3	$\tau_4=\rho u^{*2}_4$ Zone 4
Setup 1	2	69	1000	80	2.5	0.029	0.3180378	0.3843776	0.4469422	0.00265	0.029031113	0.035086742	0.040798	0.01	0.84	1.23	1.66
Setup 2	2	69	1000	80	2.5	0.029	0.17574	0.21576	0.2735222	0.00265	0.016041892	0.019694997	0.024968	0.01	0.26	0.39	0.62
Setup 3	2	69	1000	80	2.5	0.029	0.3847778	0.473222	0.5950162	0.00265	0.035123274	0.043196634	0.054314	0.01	1.23	1.87	2.95
Setup 4	2	69	1000	80	2.5	0.029	0.3380878	0.4442075	0.5403222	0.00265	0.030861319	0.040548133	0.049322	0.01	0.95	1.64	2.43
Setup 5	2	69	1000	80	2.5	0.029	0.1624	0.4824266	0.6276992	0.00265	0.014824191	0.044036848	0.057298	0.01	0.22	1.94	3.28

Table: C5	20 cm

Condition/Setup	Crossection	Distance from edge(cm)	ρ	z/z_o	1/k	Velocity at bed level				u^*_1	u^*_2	u^*_3	u^*_4	$\tau_1=\rho {u^*_1}^2$	$\tau_2=\rho {u^*_2}^2$	$\tau_3=\rho {u^*_3}^2$	$\tau_4=\rho {u^*_4}^2$
						u_1	u_2	u_3	u_4					Zone 1	Zone 2	Zone 3	Zone 4
Setup 1	3	103.5	1000	80	2.5	0.1940692	0.2342226	0.2735222	0.3268822	0.01772	0.021380295	0.024967644	0.029838	0.31	0.46	0.62	0.89
Setup 2	3	103.5	1000	80	2.5	0.243147	0.327816	0.372505	0.3935822	0.02219	0.029923688	0.034002988	0.035927	0.49	0.90	1.16	1.29
Setup 3	3	103.5	1000	80	2.5	0.13572	0.1312778	0.1583713	0.1535022	0.01239	0.011983294	0.014456445	0.014012	0.15	0.14	0.21	0.20
Setup 4	3	103.5	1000	80	2.5	0.1264887	0.1801422	0.18908	0.1846378	0.01155	0.016443734	0.017259594	0.016854	0.13	0.27	0.30	0.28
Setup 5	3	103.5	1000	80	2.5	0.2807258	0.3142092	0.3448912	0.029	0.02563	0.028681633	0.031482346	0.002647	0.66	0.82	0.99	0.01

Table: C6	15 cm

Condition/Setup	Crossection	Distance from edge(cm)	ρ	z/z_o	1/k	Velocity at bed level				u^*_1	u^*_2	u^*_3	u^*_4	$\tau_1=\rho {u^*_1}^2$	$\tau_2=\rho {u^*_2}^2$	$\tau_3=\rho {u^*_3}^2$	$\tau_4=\rho {u^*_4}^2$
						u_1	u_2	u_3	u_4					Zone 1	Zone 2	Zone 3	Zone 4
Setup 1	3	103.5	1000	80	2.5	0.029	0.3823766	0.4441408	0.5164436	0.00265	0.034904087	0.040542045	0.047142	0.01	1.22	1.64	2.22
Setup 2	3	103.5	1000	80	2.5	0.0819598	0.2747228	0.3046978	0.3535622	0.00748	0.025077237	0.027813412	0.032274	0.06	0.63	0.77	1.04
Setup 3	3	103.5	1000	80	2.5	0.1405224	0.3879794	0.4336022	0.34916	0.01283	0.035415522	0.039580061	0.031872	0.16	1.25	1.57	1.02
Setup 4	3	103.5	1000	80	2.5	0.0510777	0.2264587	0.3426101	0.393182	0.00466	0.020671593	0.031274119	0.03589	0.02	0.43	0.98	1.29
Setup 5	3	103.5	1000	80	2.5	0.0910443	0.320479	0.4824266	0.5280494	0.00831	0.029253953	0.044036848	0.048201	0.07	0.86	1.94	2.32

Table: C7	20 cm

Condition/Setup	Crossection	Distance from edge(cm)	ρ	z/z_o	1/k	Velocity at bed level				u^*_1	u^*_2	u^*_3	u^*_4	$\tau_1=\rho {u^*_1}^2$	$\tau_2=\rho {u^*_2}^2$	$\tau_3=\rho {u^*_3}^2$	$\tau_4=\rho {u^*_4}^2$
						u_1	u_2	u_3	u_4					Zone 1	Zone 2	Zone 3	Zone 4
Setup 1	4	138	1000	80	2.5	0.2542726	0.2461619	0.2638774	0.0511577	0.02321	0.022470138	0.024087246	0.00467	0.54	0.50	0.58	0.02
Setup 2	4	138	1000	80	2.5	0.3073524	0.3446244	0.3535622	0.1179778	0.02806	0.031457992	0.032273852	0.010769	0.79	0.99	1.04	0.12
Setup 3	4	138	1000	80	2.5	0.1669356	0.1712044	0.1901472	0.029	0.01524	0.015627874	0.01735701	0.002647	0.23	0.24	0.30	0.01
Setup 4	4	138	1000	80	2.5	0.1522616	0.1789416	0.1974042	0.029	0.0139	0.016334141	0.01801944	0.002647	0.19	0.27	0.32	0.01
Setup 5	4	138	1000	80	2.5	0.029	0.28246	0.3126084	0.3912077	0.00265	0.025783504	0.028535509	0.03571	0.01	0.66	0.81	1.28

Table: C8	15 cm

Condition/Setup	Crossection	Distance from edge(cm)	ρ	z/z_o	1/k	Velocity at bed level				u^*_1	u^*_2	u^*_3	u^*_4	$\tau_1=\rho {u^*_1}^2$	$\tau_2=\rho {u^*_2}^2$	$\tau_3=\rho {u^*_3}^2$	$\tau_4=\rho {u^*_4}^2$
						u_1	u_2	u_3	u_4					Zone 1	Zone 2	Zone 3	Zone 4
Setup 1	4	138	1000	80	2.5	0.4043876	0.41586	0.4602822	0.0864154	0.03691	0.037960518	0.042015463	0.007888	1.36	1.44	1.77	0.06
Setup 2	4	138	1000	80	2.5	0.029	0.2815262	0.3248812	0.2301672	0.00265	0.025698265	0.029655794	0.02101	0.01	0.66	0.88	0.44
Setup 3	4	138	1000	80	2.5	0.029	0.391181	0.444501	0.0467422	0.00265	0.03570777	0.040574923	0.004267	0.01	1.28	1.65	0.02
Setup 4	4	138	1000	80	2.5	0.17574	0.2781912	0.38251	0.0646845	0.01604	0.025393839	0.034916264	0.005905	0.26	0.64	1.22	0.03
Setup 5	4	138	1000	80	2.5	0.1973508	0.4414728	0.491271	0.0555866	0.01801	0.040298504	0.044844184	0.005074	0.32	1.62	2.01	0.03

Table:C: Calculation of shear stress(τ) on bed level between different setup, cross sec & zone

										$u^* = u'/((1/k)*\ln(z/z_o))$							
	Crossection	Distance from edge(cm)	ρ	z/z_o	1/k	u_1	u_2	u_3	u_4	u^*_1	u^*_2	u^*_3	u^*_4	$\tau_1=\rho u^{*2}_1$	$\tau_2=\rho u^{*2}_2$	$\tau_3=\rho u^{*2}_3$	$\tau_4=\rho u^{*2}_4$
WL=20	1	34.5	1000	80	2.5	0.2416396	0.2145194	0.2233505	0.1968439	0.02206	0.019582	0.020387869	0.017968	0.49	0.38	0.42	0.32
	2	69	1000	80	2.5	0.029	0.2727485	0.30914	0.385845	0.00265	0.024897	0.028218907	0.035221	0.01	0.62	0.80	1.24
1	3	103.5	1000	80	2.5	0.1940692	0.2342226	0.2735222	0.3268822	0.01772	0.02138	0.024967644	0.029838	0.31	0.46	0.62	0.89
	4	138	1000	80	2.5	0.2542726	0.2461619	0.2638774	0.0511577	0.02321	0.02247	0.024087246	0.00467	0.54	0.50	0.58	0.02
WL=15	1	34.5	1000	80	2.5	0.3082062	0.3002022	0.293132	0.2379978	0.02813	0.027403	0.026757665	0.021725	0.79	0.75	0.72	0.47
	2	69	1000	80	2.5	0.029	0.3180378	0.3843776	0.4469422	0.00265	0.029031	0.035086742	0.040798	0.01	0.84	1.23	1.66
	3	103.5	1000	80	2.5	0.243147	0.327816	0.372505	0.3935822	0.02219	0.029924	0.034002988	0.035927	0.49	0.90	1.16	1.29
	4	138	1000	80	2.5	0.3073524	0.3446244	0.3535622	0.1179778	0.02806	0.031458	0.032273852	0.010769	0.79	0.99	1.04	0.12
WL=20	1	34.5	1000	80	2.5	0.1271424	0.1134422	0.12238	0.0868022	0.01161	0.010355	0.011171087	0.007923	0.13	0.11	0.12	0.06
	2	69	1000	80	2.5	0.029	0.1535022	0.1801422	0.2601822	0.00265	0.014012	0.016443734	0.02375	0.01	0.20	0.27	0.56
2	3	103.5	1000	80	2.5	0.13572	0.1312778	0.1583713	0.1535022	0.01239	0.011983	0.014456445	0.014012	0.15	0.14	0.21	0.20
	4	138	1000	80	2.5	0.1669356	0.1712044	0.1901472	0.029	0.01524	0.015628	0.01735701	0.002647	0.23	0.24	0.30	0.01
WL=15	1	34.5	1000	80	2.5	0.1668022	0.1579578	0.1579578	0.10904	0.01523	0.014419	0.014418696	0.009953	0.23	0.21	0.21	0.10
	2	69	1000	80	2.5	0.029	0.17574	0.21576	0.2735222	0.00265	0.016042	0.019694997	0.024968	0.01	0.26	0.39	0.62
	3	103.5	1000	80	2.5	0.1264887	0.1801422	0.18908	0.1846378	0.01155	0.016444	0.017259594	0.016854	0.13	0.27	0.30	0.28
	4	138	1000	80	2.5	0.1522616	0.1789416	0.1974042	0.029	0.0139	0.016334	0.01801944	0.002647	0.19	0.27	0.32	0.01
WL=20	1	34.5	1000	80	2.5	0.2851947	0.2365971	0.2549796	0.20242	0.02603	0.021597	0.023275039	0.018477	0.68	0.47	0.54	0.34
	2	69	1000	80	2.5	0.029	0.2774842	0.3602322	0.4057083	0.00265	0.025329	0.032882703	0.037034	0.01	0.64	1.08	1.37
3	3	103.5	1000	80	2.5	0.2807258	0.3142092	0.3448912	0.029	0.02563	0.028682	0.031482346	0.002647	0.66	0.82	0.99	0.01
	4	138	1000	80	2.5	0.029	0.28246	0.3126084	0.3912077	0.00265	0.025784	0.028535509	0.03571	0.01	0.66	0.81	1.28
WL=15	1	34.5	1000	80	2.5	0.3413027	0.3802422	0.3702372	0.3145294	0.03115	0.034709	0.033795979	0.028711	0.97	1.20	1.14	0.82
	2	69	1000	80	2.5	0.029	0.3847778	0.473222	0.5950162	0.00265	0.035123	0.043196634	0.054314	0.01	1.23	1.87	2.95
	3	103.5	1000	80	2.5	0.029	0.3823766	0.4441408	0.5164436	0.00265	0.034904	0.040542045	0.047142	0.01	1.22	1.64	2.22
	4	138	1000	80	2.5	0.4043876	0.41586	0.4602822	0.0864154	0.03691	0.037961	0.042015463	0.007888	1.36	1.44	1.77	0.06
WL=20	1	34.5	1000	80	2.5	0.029	0.2601822	0.24244	0.1934822	0.00265	0.02375	0.022130399	0.017661	0.01	0.56	0.49	0.31
	2	69	1000	80	2.5	0.029	0.2601822	0.24244	0.1934822	0.00265	0.02375	0.022130399	0.017661	0.01	0.56	0.49	0.31
4	3	103.5	1000	80	2.5	0.0819598	0.2747228	0.3046978	0.3535622	0.00748	0.025077	0.027813412	0.032274	0.06	0.63	0.77	1.04
	4	138	1000	80	2.5	0.029	0.2815262	0.3248812	0.2301672	0.00265	0.025698	0.029655794	0.02101	0.01	0.66	0.88	0.44
WL=15	1	34.5	1000	80	2.5	0.029	0.339155	0.3239474	0.2659184	0.00265	0.030959	0.029570555	0.024274	0.01	0.96	0.87	0.59
	2	69	1000	80	2.5	0.029	0.3380878	0.4442075	0.5403222	0.00265	0.030861	0.040548133	0.049322	0.01	0.95	1.64	2.43
	3	103.5	1000	80	2.5	0.1405224	0.3879794	0.4336022	0.34916	0.01283	0.035416	0.039580061	0.031872	0.16	1.25	1.57	1.02
	4	138	1000	80	2.5	0.029	0.391181	0.444501	0.0467422	0.00265	0.035708	0.040574923	0.004267	0.01	1.28	1.65	0.02
WL=20	1	34.5	1000	80	2.5	0.0778244	0.2735222	0.287756	0.234436	0.0071	0.024968	0.026266931	0.0214	0.05	0.62	0.69	0.46
	2	69	1000	80	2.5	0.029	0.139055	0.3448912	0.4750896	0.00265	0.012693	0.031482346	0.043367	0.01	0.16	0.99	1.88
5	3	103.5	1000	80	2.5	0.0510777	0.2264587	0.3426101	0.393182	0.00466	0.020672	0.031274119	0.03589	0.02	0.43	0.98	1.29
	4	138	1000	80	2.5	0.17574	0.2781912	0.38251	0.0646845	0.01604	0.025394	0.034916264	0.005905	0.26	0.64	1.22	0.03
WL=15	1	34.5	1000	80	2.5	0.1441242	0.374506	0.3847778	0.3046978	0.01316	0.034186	0.035123274	0.027813	0.17	1.17	1.23	0.77
	2	69	1000	80	2.5	0.029	0.1624	0.4824266	0.6276992	0.00265	0.014824	0.044036848	0.057298	0.01	0.22	1.94	3.28
	3	103.5	1000	80	2.5	0.0910443	0.320479	0.4824266	0.5280494	0.00831	0.029254	0.044036848	0.048201	0.07	0.86	1.94	2.32
	4	138	1000	80	2.5	0.1973508	0.4414728	0.491271	0.0555866	0.01801	0.040299	0.044844184	0.005074	0.32	1.62	2.01	0.03

Table D1: Horizontally comparision of α : Run 1(20 cm)

Sl	Scope	α	Scope	α	Scope	α	Scope	α	Scope	α
1	S1 CR1 Z1 R1	1.35	S2 CR1 Z1 R1	1.74	S3 CR1 Z1 R1	1.32	S4 CR1 Z1 R1	1.34	S5 CR1 Z1 R1	1.86
2	S1 CR1 Z2 R1	1.44	S2 CR1 Z2 R1	1.44	S3 CR1 Z2 R1	1.46	S4 CR1 Z2 R1	1.38	S5 CR1 Z2 R1	1.40
3	S1 CR1 Z3 R1	1.44	S2 CR1 Z3 R1	1.40	S3 CR1 Z3 R1	1.39	S4 CR1 Z3 R1	1.42	S5 CR1 Z3 R1	1.40
4	S1 CR1 Z4 R1	1.35	S2 CR1 Z4 R1	1.45	S3 CR1 Z4 R1	1.37	S4 CR1 Z4 R1	1.36	S5 CR1 Z4 R1	1.34
5	S1 CR2 Z1 R1	1.34	S2 CR2 Z1 R1	1.34	S3 CR2 Z1 R1	1.34	S4 CR2 Z1 R1	1.34	S5 CR2 Z1 R1	1.34
6	S1 CR2 Z2 R1	1.33	S2 CR2 Z2 R1	1.35	S3 CR2 Z2 R1	1.35	S4 CR2 Z2 R1	1.33	S5 CR2 Z2 R1	1.46
7	S1 CR2 Z3 R1	1.39	S2 CR2 Z3 R1	1.38	S3 CR2 Z3 R1	1.34	S4 CR2 Z3 R1	1.38	S5 CR2 Z3 R1	1.40
8	S1 CR2 Z4 R1	1.36	S2 CR2 Z4 R1	1.31	S3 CR2 Z4 R1	1.35	S4 CR2 Z4 R1	1.37	S5 CR2 Z4 R1	1.33
9	S1 CR3 Z1 R1	1.28	S2 CR3 Z1 R1	1.33	S3 CR3 Z1 R1	1.37	S4 CR3 Z1 R1	1.54	S5 CR3 Z1 R1	1.77
10	S1 CR3 Z2 R1	1.40	S2 CR3 Z2 R1	1.38	S3 CR3 Z2 R1	1.39	S4 CR3 Z2 R1	1.37	S5 CR3 Z2 R1	1.35
11	S1 CR3 Z3 R1	1.40	S2 CR3 Z3 R1	1.36	S3 CR3 Z3 R1	1.36	S4 CR3 Z3 R1	1.42	S5 CR3 Z3 R1	1.37
12	S1 CR3 Z4 R1	1.33	S2 CR3 Z4 R1	1.34	S3 CR3 Z4 R1	1.34	S4 CR3 Z4 R1	1.31	S5 CR3 Z4 R1	1.34
13	S1 CR4 Z1 R1	1.34	S2 CR4 Z1 R1	1.37	S3 CR4 Z1 R1	1.34	S4 CR4 Z1 R1	1.34	S5 CR4 Z1 R1	1.34
14	S1 CR4 Z2 R1	1.41	S2 CR4 Z2 R1	1.39	S3 CR4 Z2 R1	1.38	S4 CR4 Z2 R1	1.34	S5 CR4 Z2 R1	1.45
15	S1 CR4 Z3 R1	1.36	S2 CR4 Z3 R1	1.40	S3 CR4 Z3 R1	1.39	S4 CR4 Z3 R1	1.35	S5 CR4 Z3 R1	1.34

Table D1: Horizontally comparision of α : Run 2(15 cm)

Sl	Scope	α	Scope	α	Scope	α	Scope	α	Scope	α
1	S1 CR1 Z1 R2	1.41	S2 CR1 Z1 R2	1.34	S3 CR1 Z1 R2	1.36	S4 CR1 Z1 R2	1.34	S5 CR1 Z1 R2	1.37
2	S1 CR1 Z2 R2	1.45	S2 CR1 Z2 R2	1.35	S3 CR1 Z2 R2	1.38	S4 CR1 Z2 R2	1.37	S5 CR1 Z2 R2	1.36
3	S1 CR1 Z3 R2	1.40	S2 CR1 Z3 R2	1.34	S3 CR1 Z3 R2	1.38	S4 CR1 Z3 R2	1.38	S5 CR1 Z3 R2	1.36
4	S1 CR1 Z4 R2	1.36	S2 CR1 Z4 R2	1.34	S3 CR1 Z4 R2	1.35	S4 CR1 Z4 R2	1.35	S5 CR1 Z4 R2	1.35
5	S1 CR2 Z1 R2	1.34	S2 CR2 Z1 R2	1.33	S3 CR2 Z1 R2	1.34	S4 CR2 Z1 R2	1.34	S5 CR2 Z1 R2	1.34
6	S1 CR2 Z2 R2	1.35	S2 CR2 Z2 R2	1.34	S3 CR2 Z2 R2	1.35	S4 CR2 Z2 R2	1.36	S5 CR2 Z2 R2	1.31
7	S1 CR2 Z3 R2	1.36	S2 CR2 Z3 R2	1.37	S3 CR2 Z3 R2	1.36	S4 CR2 Z3 R2	1.37	S5 CR2 Z3 R2	1.35
8	S1 CR2 Z4 R2	1.36	S2 CR2 Z4 R2	1.35	S3 CR2 Z4 R2	1.35	S4 CR2 Z4 R2	1.34	S5 CR2 Z4 R2	1.35
9	S1 CR3 Z1 R2	1.32	S2 CR3 Z1 R2	1.38	S3 CR3 Z1 R2	1.34	S4 CR3 Z1 R2	1.31	S5 CR3 Z1 R2	2.10
10	S1 CR3 Z2 R2	1.35	S2 CR3 Z2 R2	1.37	S3 CR3 Z2 R2	1.35	S4 CR3 Z2 R2	1.35	S5 CR3 Z2 R2	1.35
11	S1 CR3 Z3 R2	1.34	S2 CR3 Z3 R2	1.36	S3 CR3 Z3 R2	1.34	S4 CR3 Z3 R2	1.35	S5 CR3 Z3 R2	1.35
12	S1 CR3 Z4 R2	1.35	S2 CR3 Z4 R2	1.34	S3 CR3 Z4 R2	1.36	S4 CR3 Z4 R2	1.35	S5 CR3 Z4 R2	1.35
13	S1 CR4 Z1 R2	1.35	S2 CR4 Z1 R2	1.33	S3 CR4 Z1 R2	1.35	S4 CR4 Z1 R2	1.34	S5 CR4 Z1 R2	1.35
14	S1 CR4 Z2 R2	1.35	S2 CR4 Z2 R2	1.40	S3 CR4 Z2 R2	1.37	S4 CR4 Z2 R2	1.36	S5 CR4 Z2 R2	1.52
15	S1 CR4 Z3 R2	1.34	S2 CR4 Z3 R2	1.36	S3 CR4 Z3 R2	1.35	S4 CR4 Z3 R2	1.34	S5 CR4 Z3 R2	1.36
16	S1 CR4 Z4 R2	2.43	S2 CR4 Z4 R2	1.38	S3CR4 Z4 R2	1.54	S4 CR4 Z4 R2	1.41	S5 CR4 Z4 R2	1.47

Table D1: Horizontally comparision of β : Run 1(20 cm)

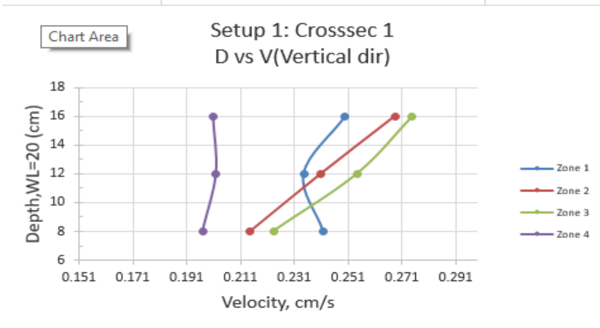
Sl	Scope	β	Scope	β	Scope	β	Scope	β	Scope	β
1	S1 CR1 Z1 R1	1.13	S2 CR1 Z1 R1	1.26	S3 CR1 Z1 R1	1.13	S4 CR1 Z1 R1	1.13	S5 CR1 Z1 R1	1.30
2	S1 CR1 Z2 R1	1.17	S2 CR1 Z2 R1	1.17	S3 CR1 Z2 R1	1.17	S4 CR1 Z2 R1	1.14	S5 CR1 Z2 R1	1.15
3	S1 CR1 Z3 R1	1.16	S2 CR1 Z3 R1	1.15	S3 CR1 Z3 R1	1.15	S4 CR1 Z3 R1	1.16	S5 CR1 Z3 R1	1.15
4	S1 CR1 Z4 R1	1.14	S2 CR1 Z4 R1	1.17	S3 CR1 Z4 R1	1.14	S4 CR1 Z4 R1	1.14	S5 CR1 Z4 R1	1.13
5	S1 CR2 Z1 R1	1.13	S2 CR2 Z1 R1	1.13	S3 CR2 Z1 R1	1.13	S4 CR2 Z1 R1	1.13	S5 CR2 Z1 R1	1.13
6	S1 CR2 Z2 R1	1.13	S2 CR2 Z2 R1	1.14	S3 CR2 Z2 R1	1.14	S4 CR2 Z2 R1	1.13	S5 CR2 Z2 R1	1.17
7	S1 CR2 Z3 R1	1.15	S2 CR2 Z3 R1	1.15	S3 CR2 Z3 R1	1.13	S4 CR2 Z3 R1	1.15	S5 CR2 Z3 R1	1.15
8	S1 CR2 Z4 R1	1.14	S2 CR2 Z4 R1	1.12	S3 CR2 Z4 R1	1.14	S4 CR2 Z4 R1	1.14	S5 CR2 Z4 R1	1.13
9	S1 CR3 Z1 R1	1.11	S2 CR3 Z1 R1	1.11	S3 CR3 Z1 R1	1.14	S4 CR3 Z1 R1	1.19	S5 CR3 Z1 R1	1.26
10	S1 CR3 Z2 R1	1.15	S2 CR3 Z2 R1	1.14	S3 CR3 Z2 R1	1.15	S4 CR3 Z2 R1	1.14	S5 CR3 Z2 R1	1.13
11	S1 CR3 Z3 R1	1.15	S2 CR3 Z3 R1	1.14	S3 CR3 Z3 R1	1.14	S4 CR3 Z3 R1	1.16	S5 CR3 Z3 R1	1.14
12	S1 CR3 Z4 R1	1.13	S2 CR3 Z4 R1	1.13	S3 CR3 Z4 R1	1.13	S4 CR3 Z4 R1	1.12	S5 CR3 Z4 R1	1.13
13	S1 CR4 Z1 R1	1.13	S2 CR4 Z1 R1	1.14	S3 CR4 Z1 R1	1.13	S4 CR4 Z1 R1	1.13	S5 CR4 Z1 R1	1.13
14	S1 CR4 Z2 R1	1.16	S2 CR4 Z2 R1	1.15	S3 CR4 Z2 R1	1.14	S4 CR4 Z2 R1	1.13	S5 CR4 Z2 R1	1.17
15	S1 CR4 Z3 R1	1.14	S2 CR4 Z3 R1	1.15	S3 CR4 Z3 R1	1.15	S4 CR4 Z3 R1	1.13	S5 CR4 Z3 R1	1.13
16	S1 CR4 Z4 R1	1.12	S2 CR4 Z4 R1	1.14	S3 CR4 Z4 R1	1.13	S4 CR4 Z4 R1	1.13	S5 CR4 Z4 R1	1.23

Table D1: Horizontally comparision of β : Run 2(15 cm)

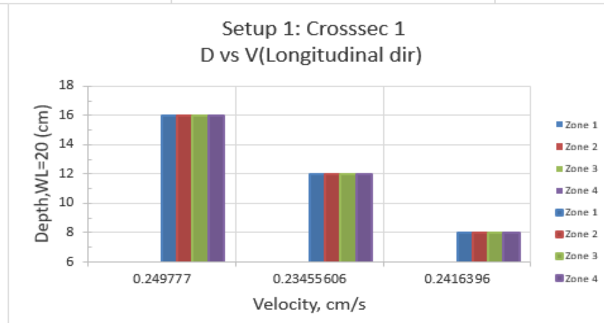
Sl	Scope	β	Scope	β	Scope	β	Scope	β	Scope	β	Scope	β
1	S1 CR1 Z1 R2	1.15	S2 CR1 Z1 R2	1.13	S3 CR1 Z1 R2	1.14	S4 CR1 Z1 R2	1.13	S2 CR1 Z1 R2	1.13	S5 CR1 Z1 R2	1.14
2	S1 CR1 Z2 R2	1.17	S2 CR1 Z2 R2	1.14	S3 CR1 Z2 R2	1.14	S4 CR1 Z2 R2	1.14	S2 CR1 Z2 R2	1.14	S5 CR1 Z2 R2	1.14
3	S1 CR1 Z3 R2	1.15	S2 CR1 Z3 R2	1.13	S3 CR1 Z3 R2	1.14	S4 CR1 Z3 R2	1.14	S2 CR1 Z3 R2	1.13	S5 CR1 Z3 R2	1.13
4	S1 CR1 Z4 R2	1.14	S2 CR1 Z4 R2	1.13	S3 CR1 Z4 R2	1.13	S4 CR1 Z4 R2	1.14	S2 CR1 Z4 R2	1.13	S5 CR1 Z4 R2	1.14
5	S1 CR2 Z1 R2	1.13	S2 CR2 Z1 R2	1.13	S3 CR2 Z1 R2	1.13	S4 CR2 Z1 R2	1.13	S2 CR2 Z1 R2	1.13	S5 CR2 Z1 R2	1.13
6	S1 CR2 Z2 R2	1.13	S2 CR2 Z2 R2	1.13	S3 CR2 Z2 R2	1.13	S4 CR2 Z2 R2	1.14	S2 CR2 Z2 R2	1.13	S5 CR2 Z2 R2	1.12
7	S1 CR2 Z3 R2	1.14	S2 CR2 Z3 R2	1.14	S3 CR2 Z3 R2	1.14	S4 CR2 Z3 R2	1.14	S2 CR2 Z3 R2	1.14	S5 CR2 Z3 R2	1.13
8	S1 CR2 Z4 R2	1.14	S2 CR2 Z4 R2	1.14	S3 CR2 Z4 R2	1.13	S4 CR2 Z4 R2	1.13	S2 CR2 Z4 R2	1.14	S5 CR2 Z4 R2	1.13
9	S1 CR3 Z1 R2	1.13	S2 CR3 Z1 R2	1.14	S3 CR3 Z1 R2	1.13	S4 CR3 Z1 R2	1.12	S2 CR3 Z1 R2	1.14	S5 CR3 Z1 R2	1.32
10	S1 CR3 Z2 R2	1.13	S2 CR3 Z2 R2	1.14	S3 CR3 Z2 R2	1.14	S4 CR3 Z2 R2	1.13	S2 CR3 Z2 R2	1.14	S5 CR3 Z2 R2	1.14
11	S1 CR3 Z3 R2	1.13	S2 CR3 Z3 R2	1.14	S3 CR3 Z3 R2	1.13	S4 CR3 Z3 R2	1.13	S2 CR3 Z3 R2	1.14	S5 CR3 Z3 R2	1.13
12	S1 CR3 Z4 R2	1.13	S2 CR3 Z4 R2	1.13	S3 CR3 Z4 R2	1.14	S4 CR3 Z4 R2	1.14	S2 CR3 Z4 R2	1.13	S5 CR3 Z4 R2	1.13
13	S1 CR4 Z1 R2	1.14	S2 CR4 Z1 R2	1.13	S3 CR4 Z1 R2	1.13	S4 CR4 Z1 R2	1.13	S2 CR4 Z1 R2	1.13	S5 CR4 Z1 R2	1.14
14	S1 CR4 Z2 R2	1.13	S2 CR4 Z2 R2	1.15	S3 CR4 Z2 R2	1.14	S4 CR4 Z2 R2	1.14	S2 CR4 Z2 R2	1.15	S5 CR4 Z2 R2	1.20
15	S1 CR4 Z3 R2	1.13	S2 CR4 Z3 R2	1.14	S3 CR4 Z3 R2	1.13	S4 CR4 Z3 R2	1.13	S2 CR4 Z3 R2	1.14	S5 CR4 Z3 R2	1.14
16	S1 CR4 Z4 R2	1.45	S2 CR4 Z4 R2	1.14	S3CR4 Z4 R2	1.19	S4 CR4 Z4 R2	1.15	S2 CR4 Z4 R2	1.14	S5 CR4 Z4 R2	1.17

APPENDIX-B

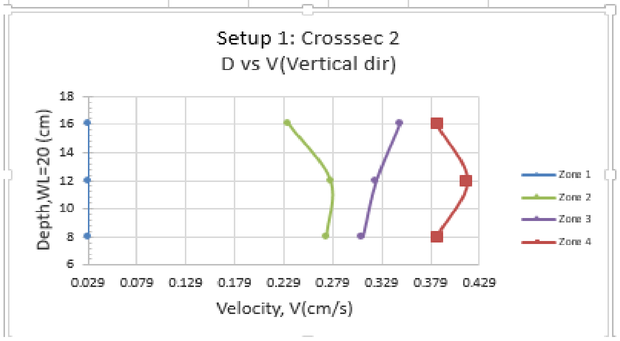
Depth vs Velocity Distribution Curve



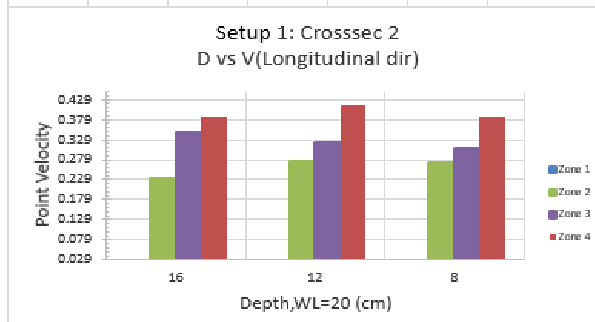
Depth vs Velocity Distribution Curve



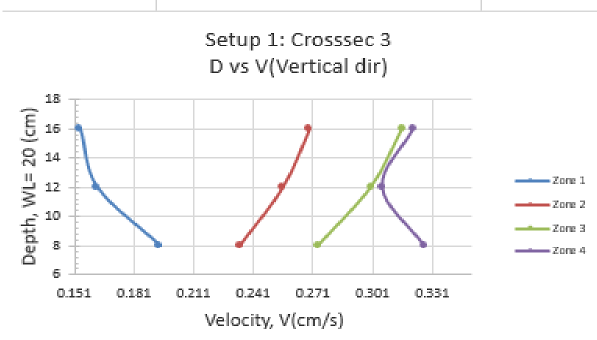
Depth vs Velocity Distribution Curve



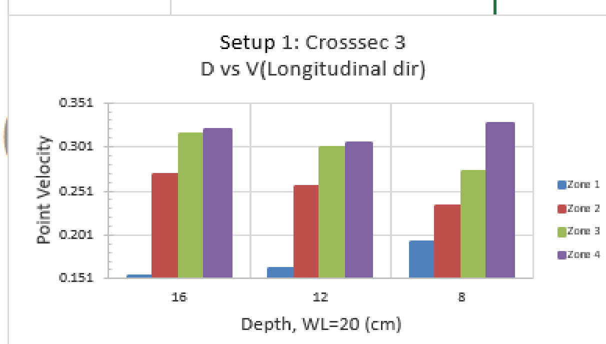
Depth vs Velocity Distribution Curve



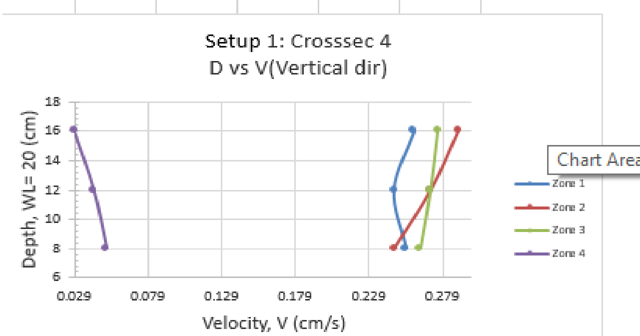
Depth vs Velocity Distribution Curve



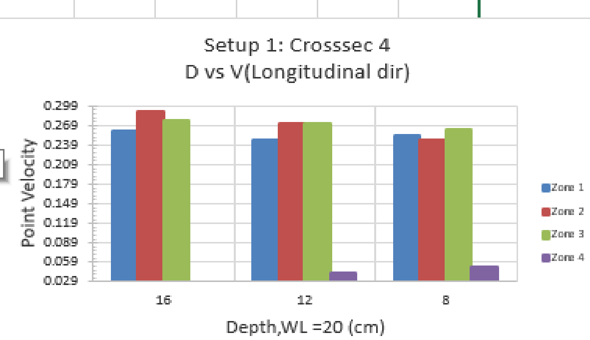
Depth vs Velocity Distribution Curve



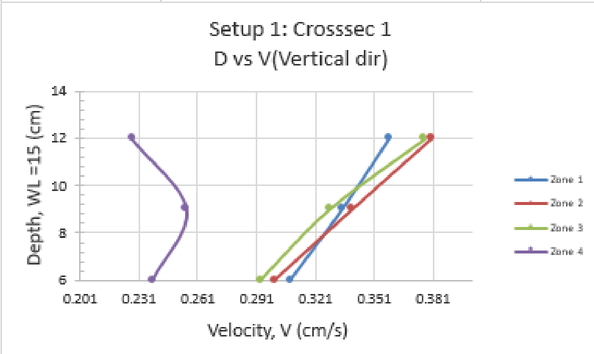
Depth vs Velocity Distribution Curve



Depth vs Velocity Distribution Curve



Depth vs Velocity Distribution Curve



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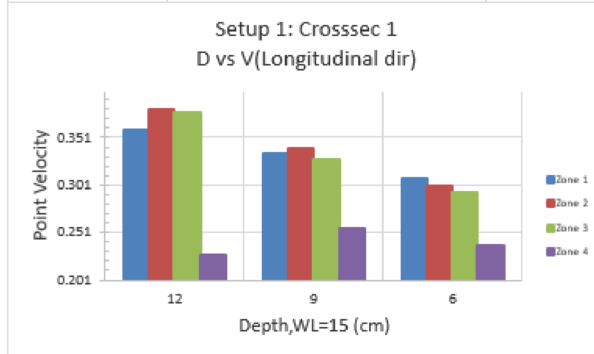

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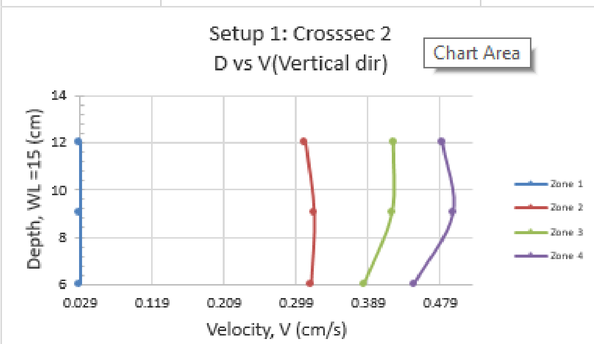

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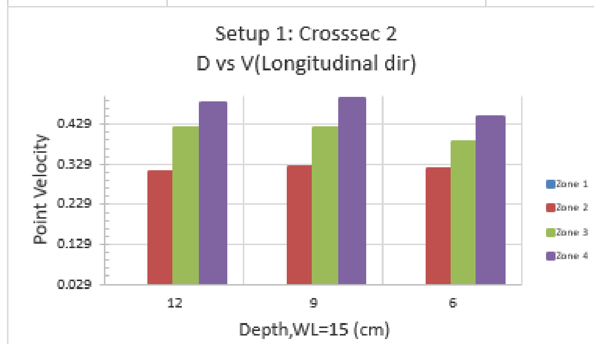

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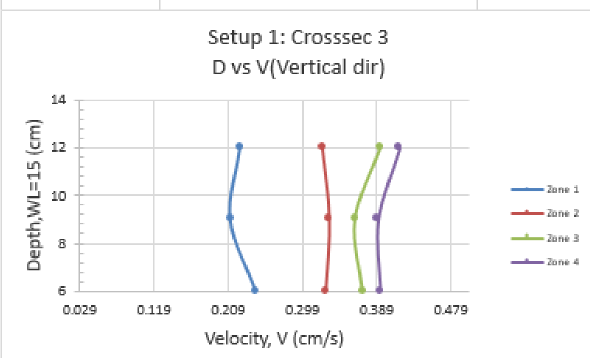

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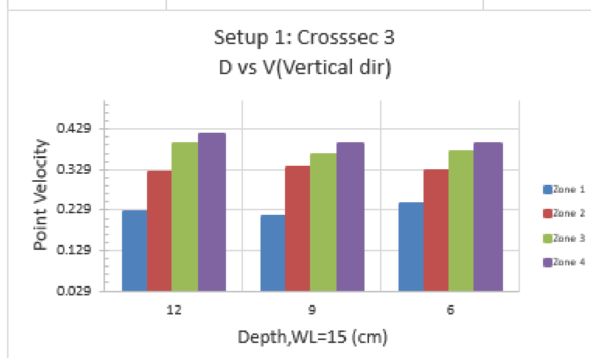

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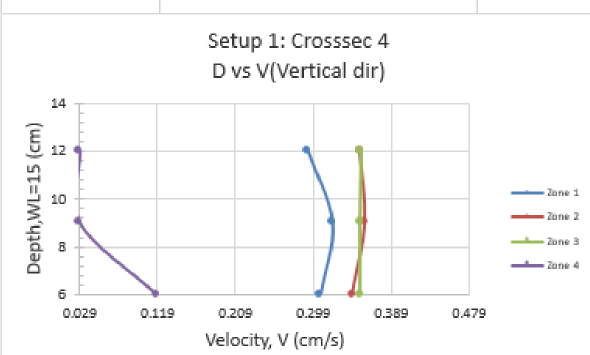

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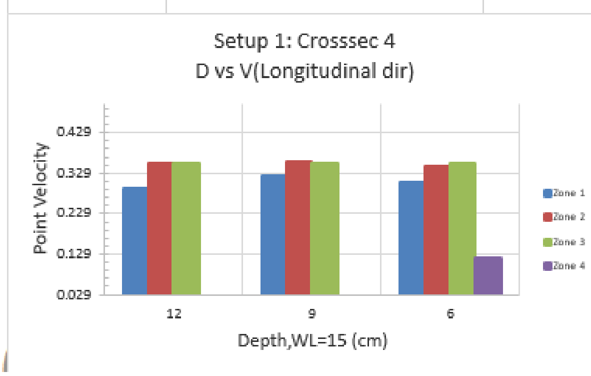

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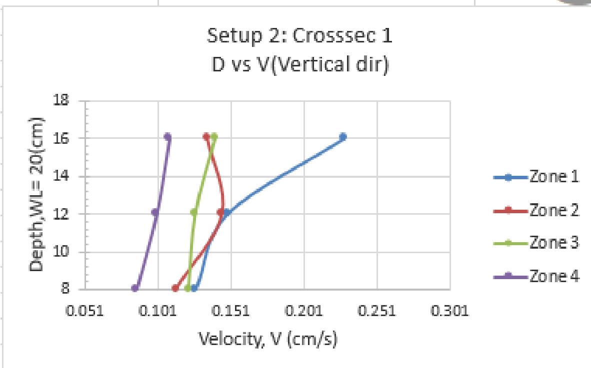

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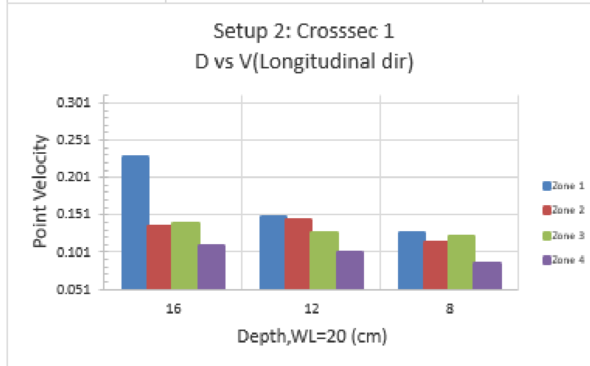

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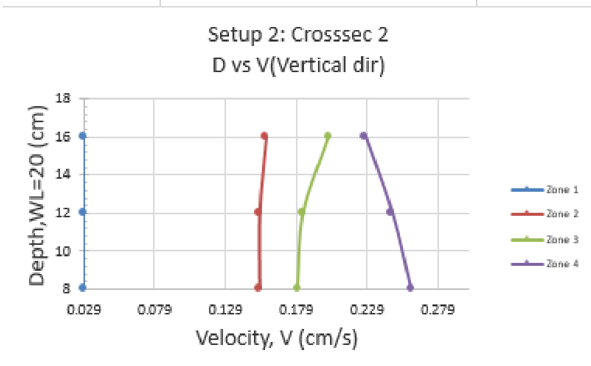

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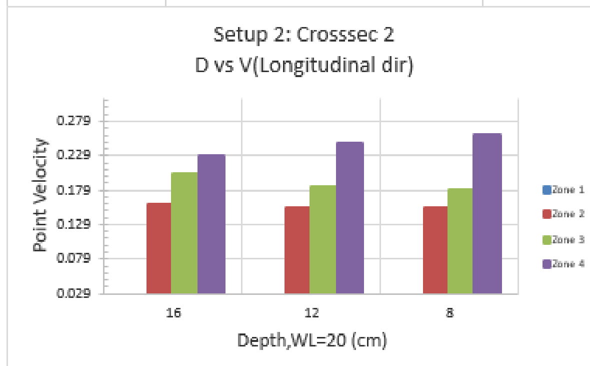

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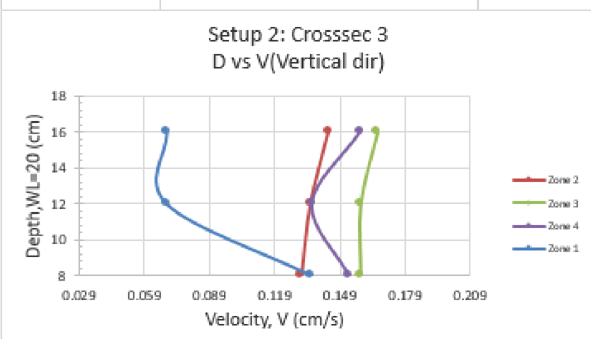

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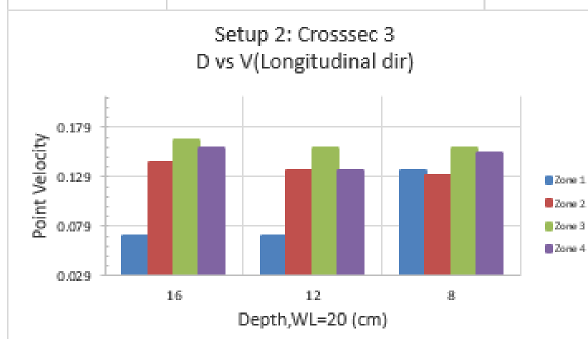

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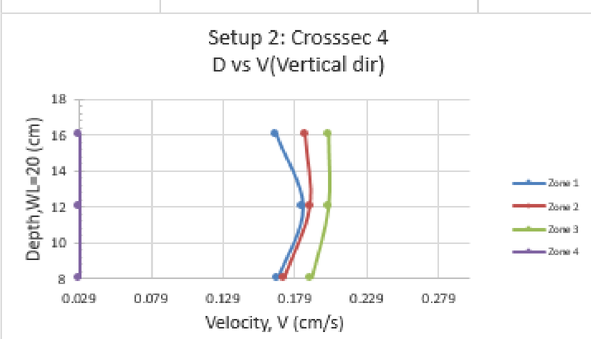

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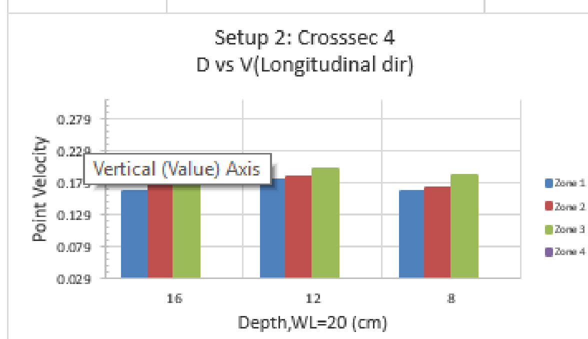

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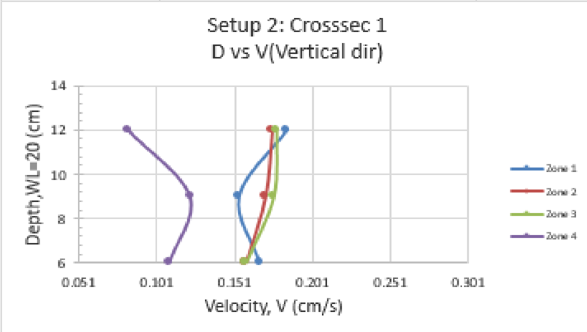

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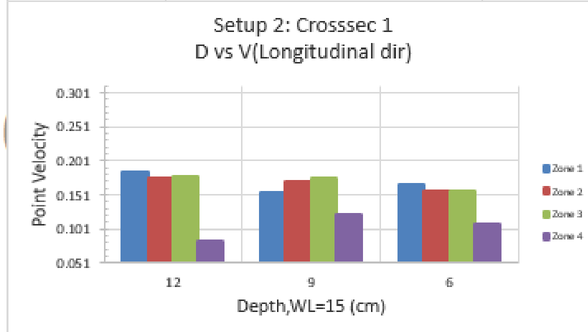

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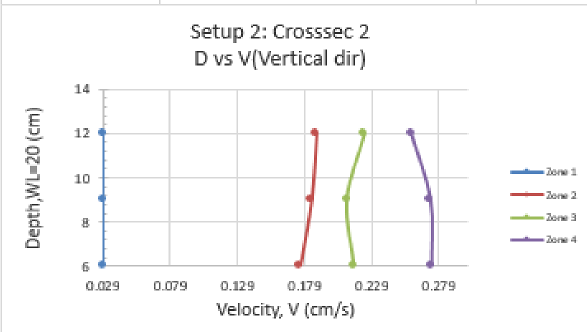

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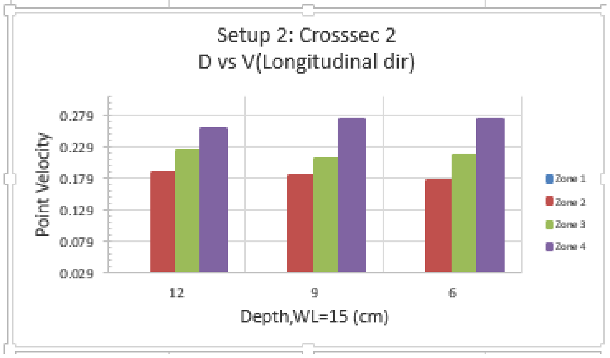

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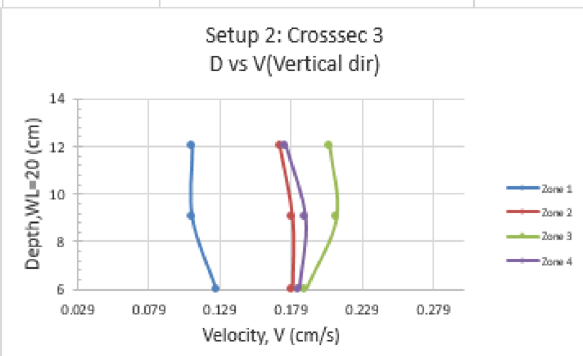

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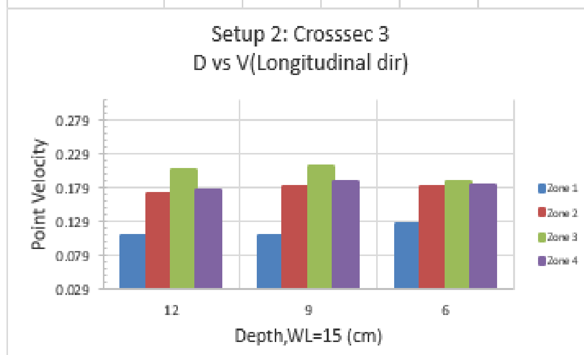

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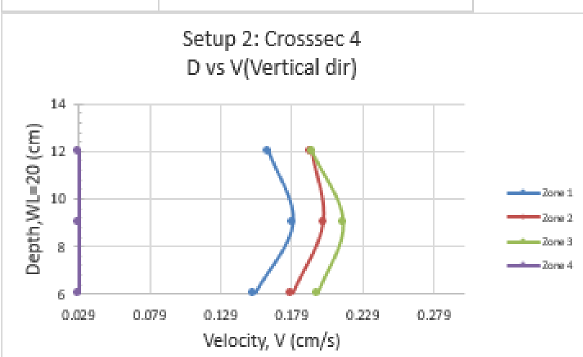

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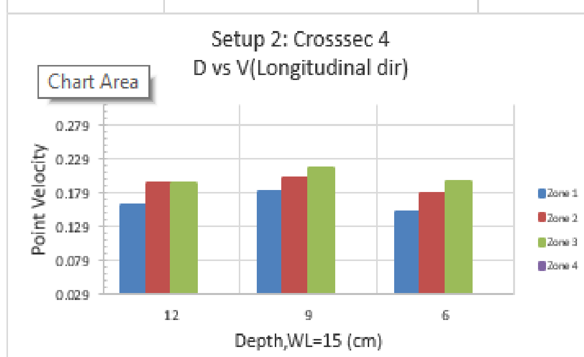

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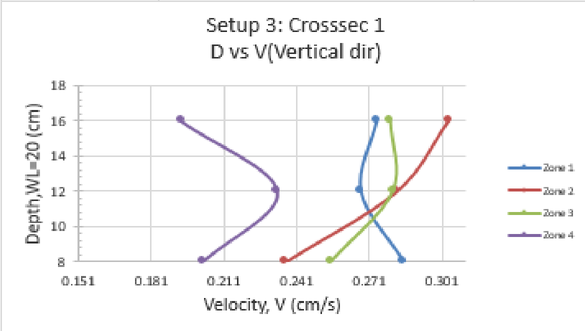

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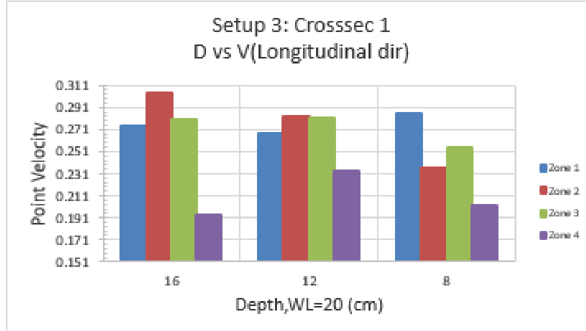

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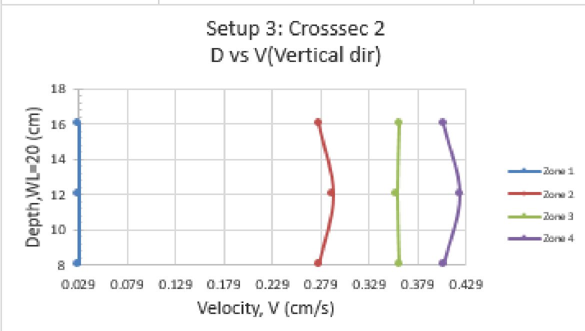

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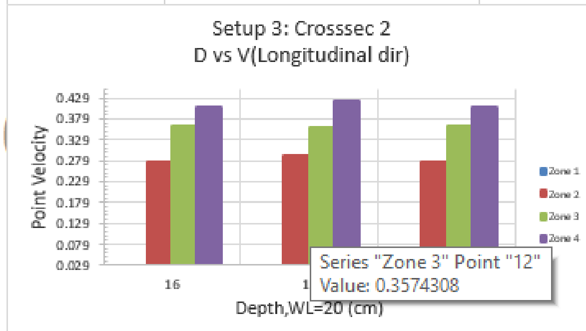

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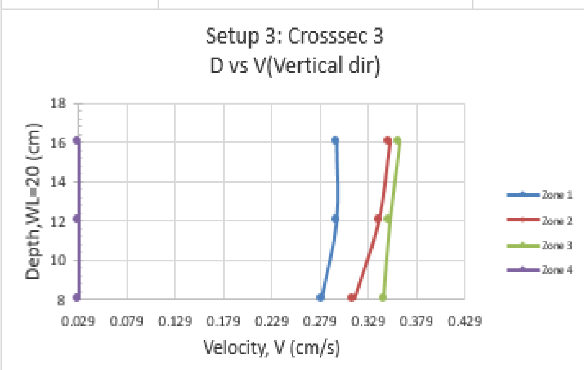

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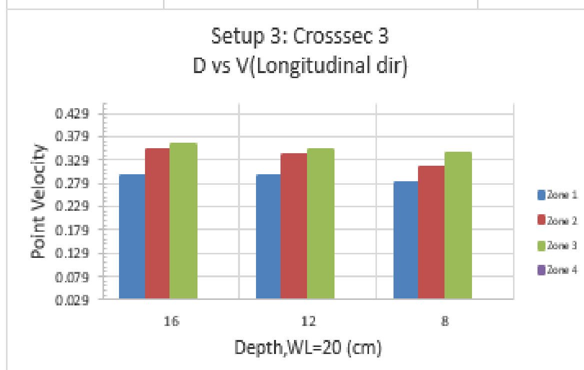

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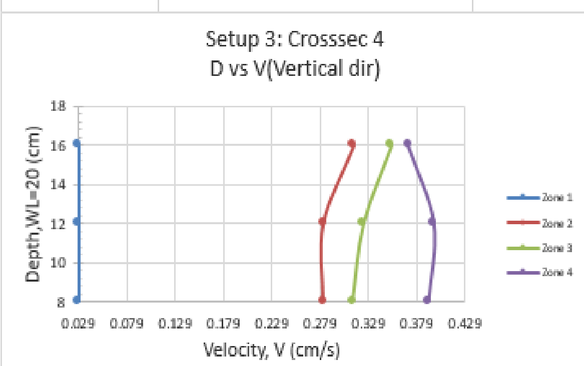

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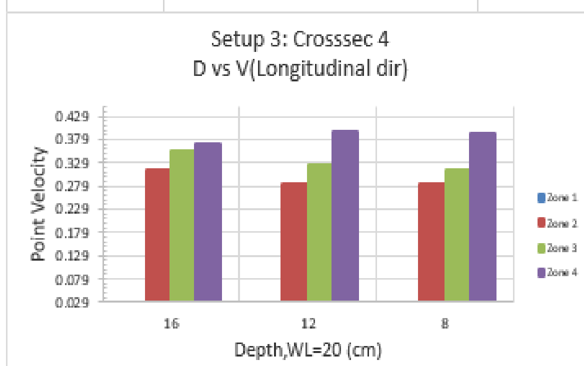

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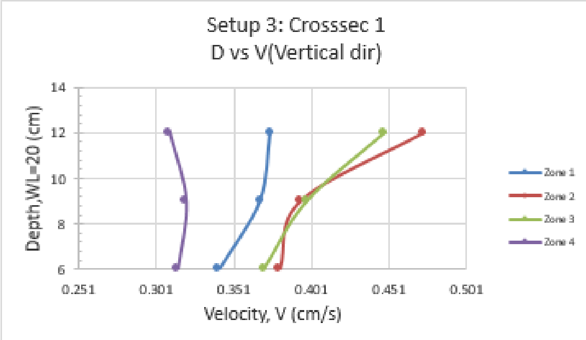

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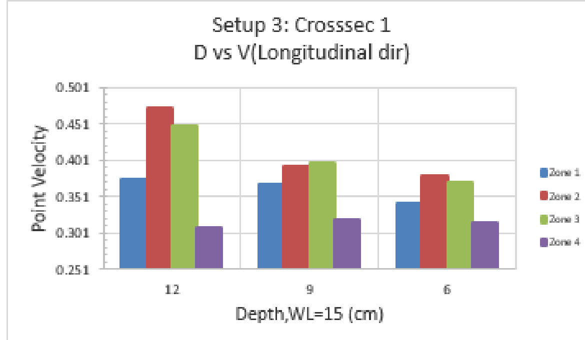

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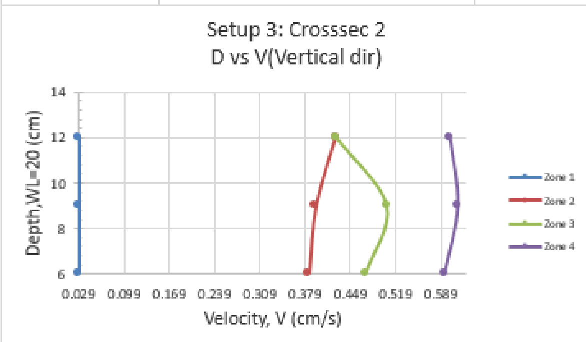

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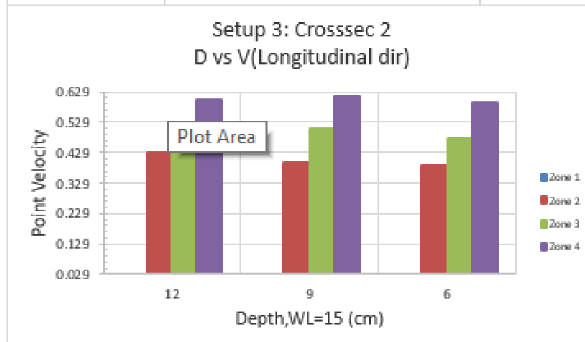

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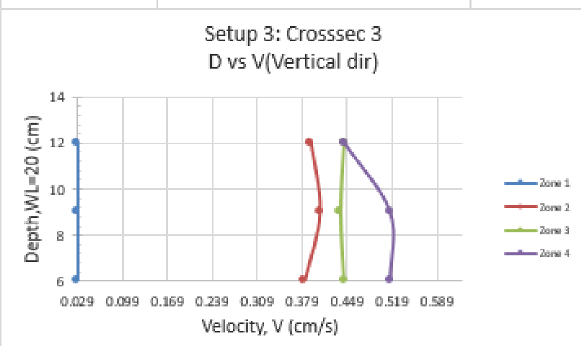

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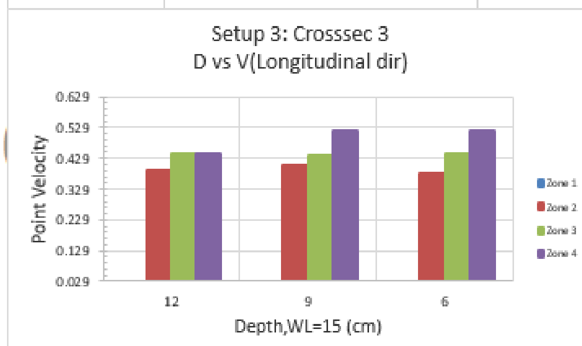

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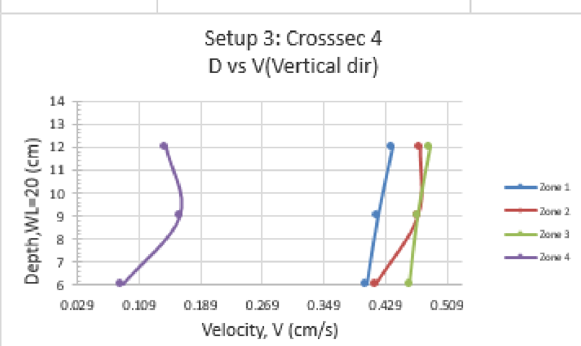

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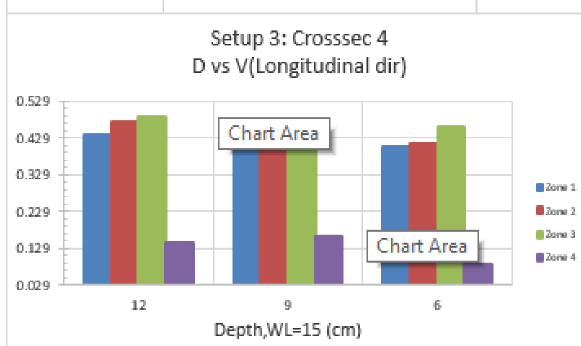

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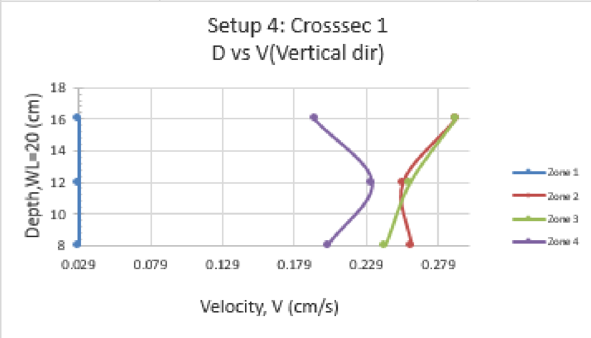

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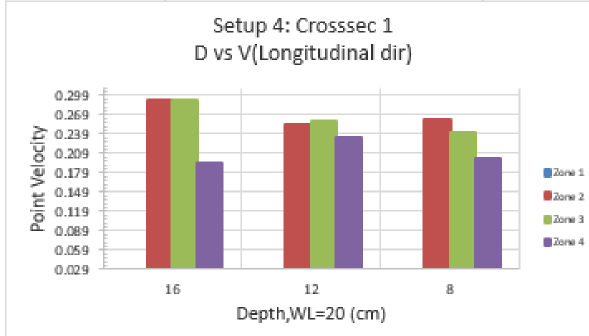

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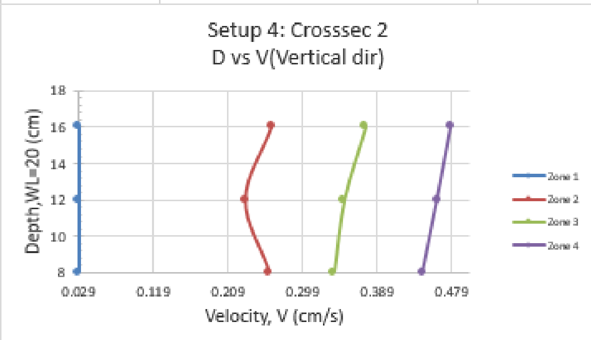

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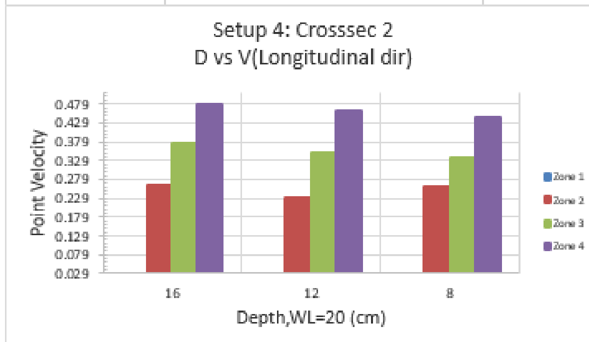

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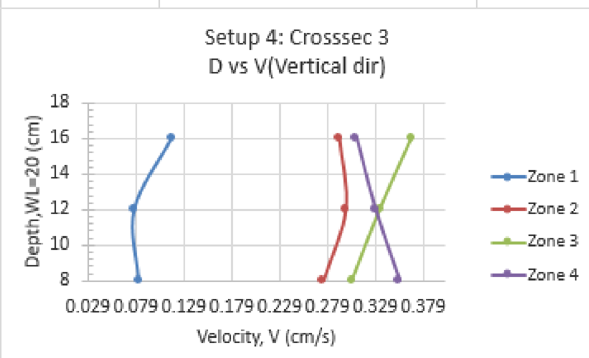

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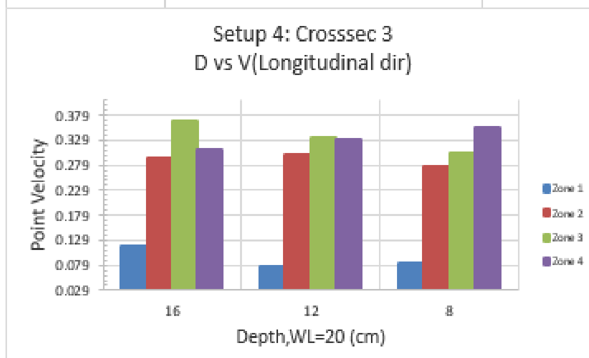

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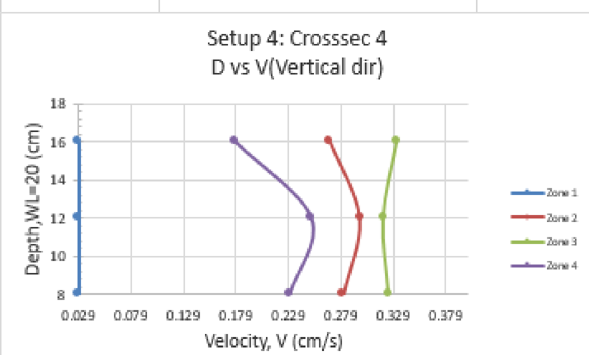

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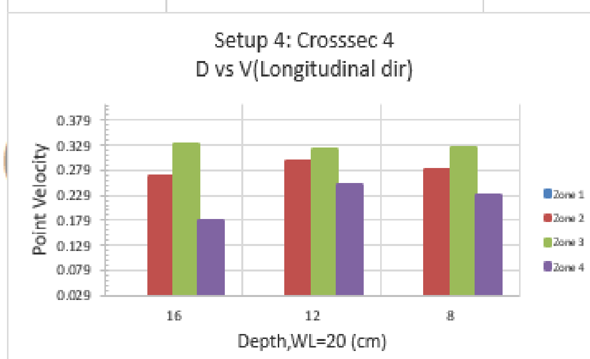

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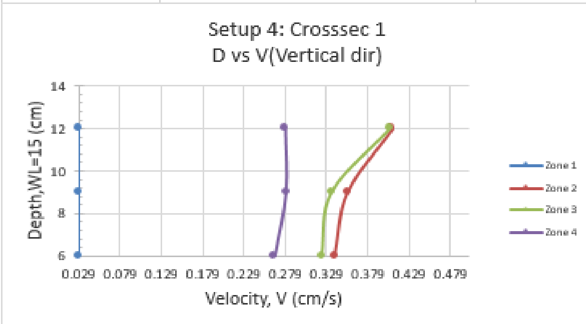

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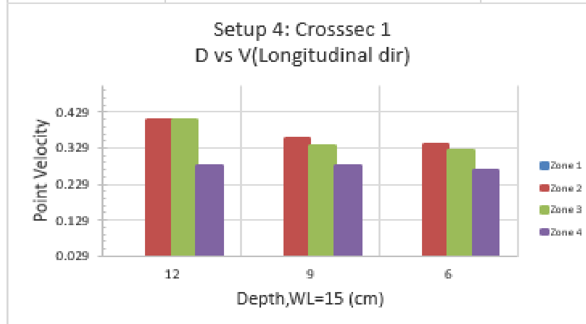

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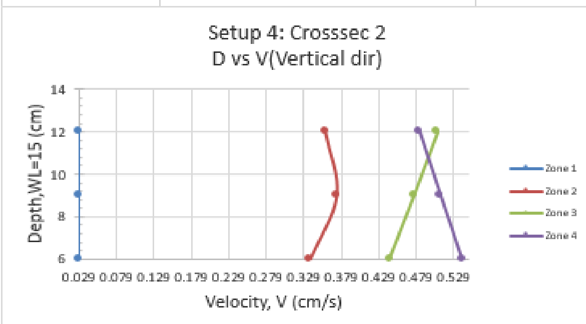

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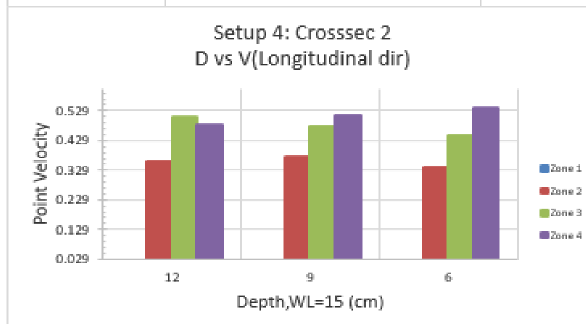

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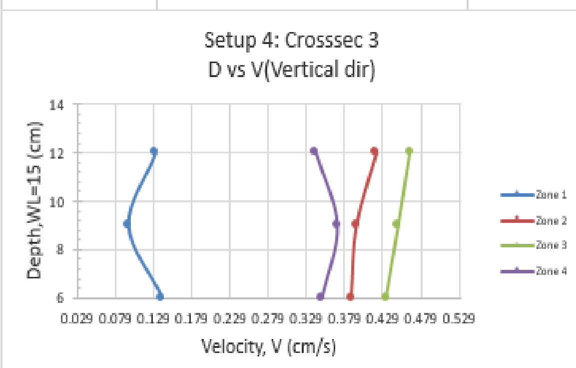

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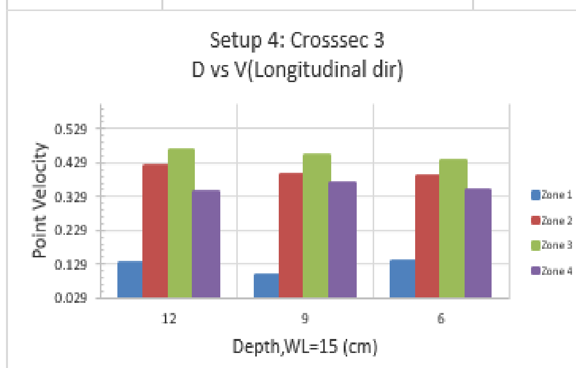

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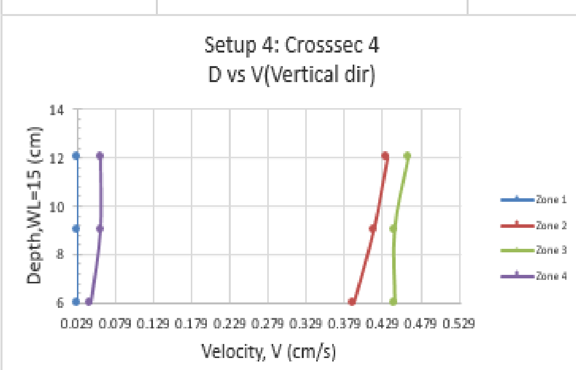

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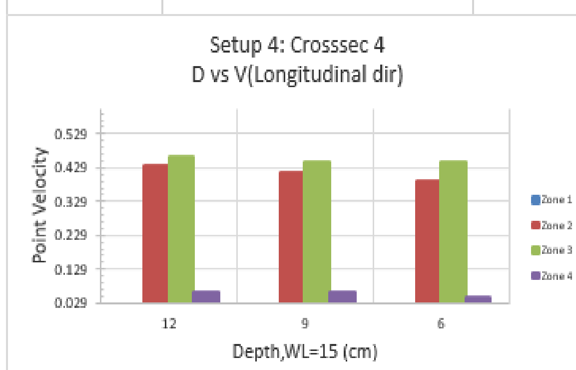

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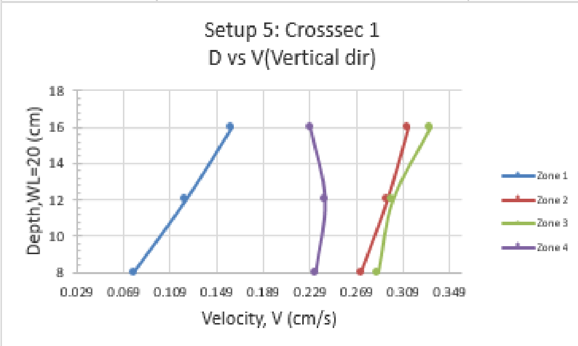

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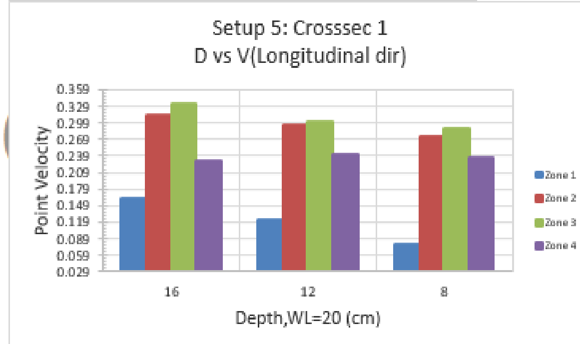

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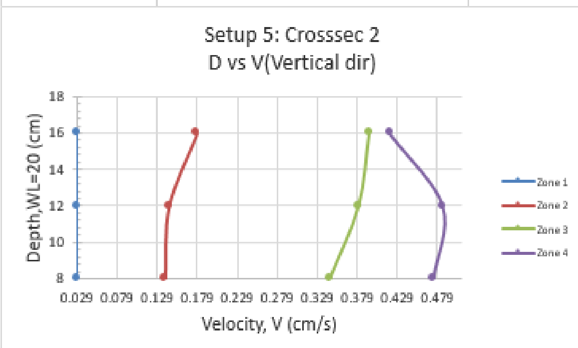

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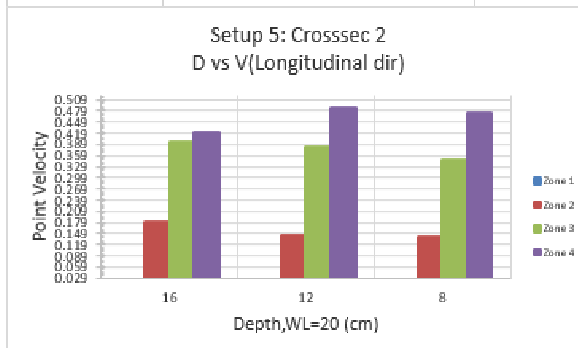

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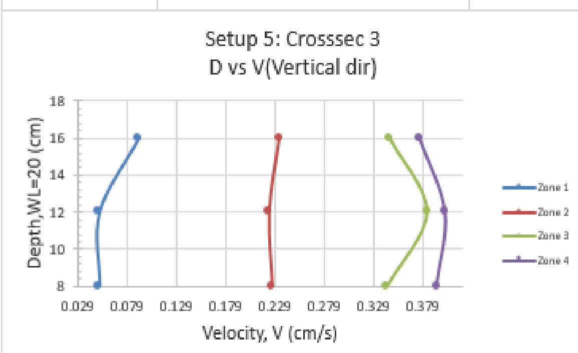

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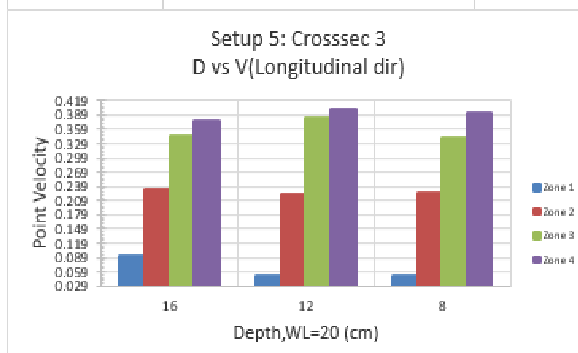

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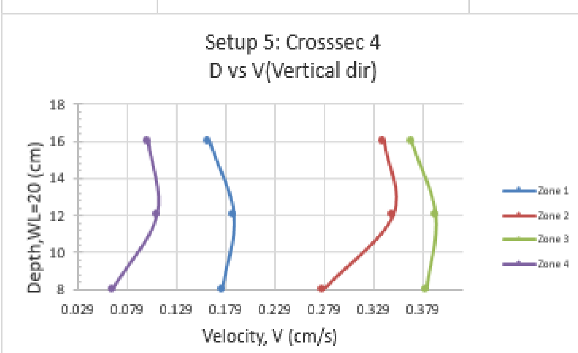

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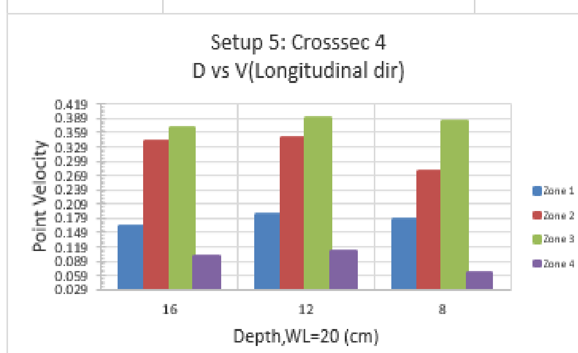

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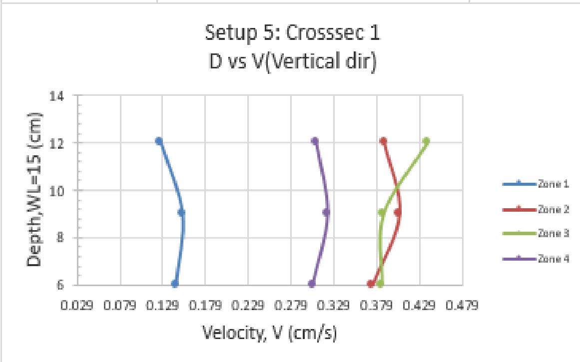

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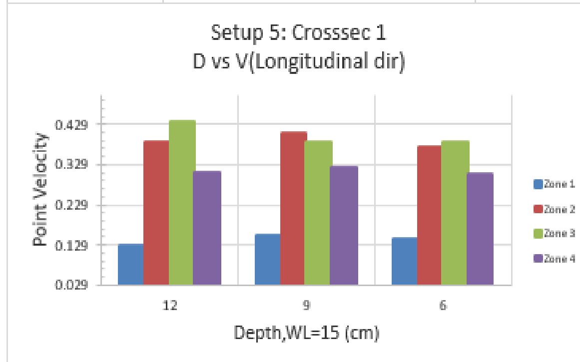

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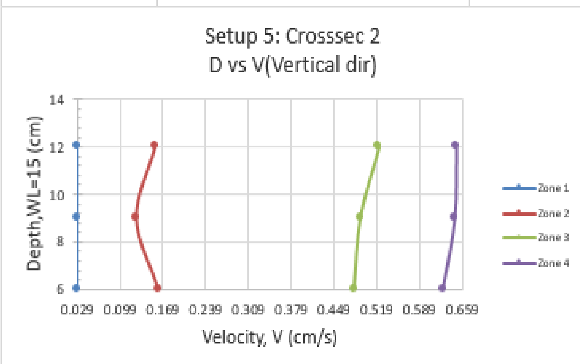

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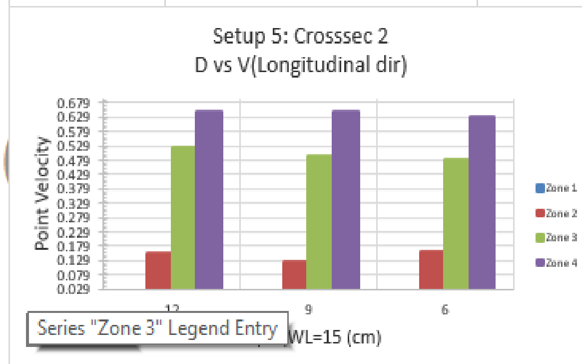

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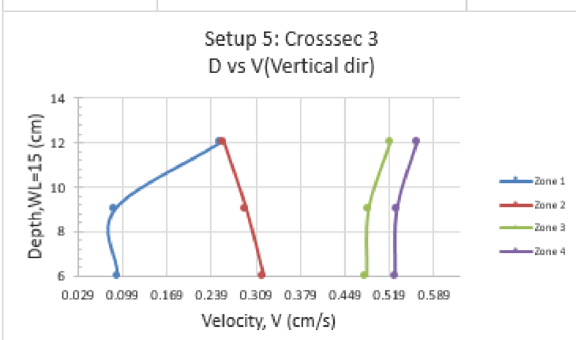

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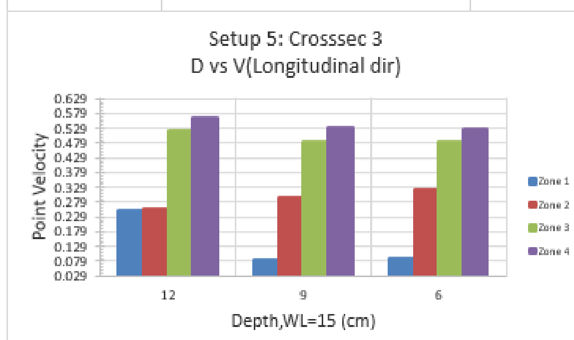

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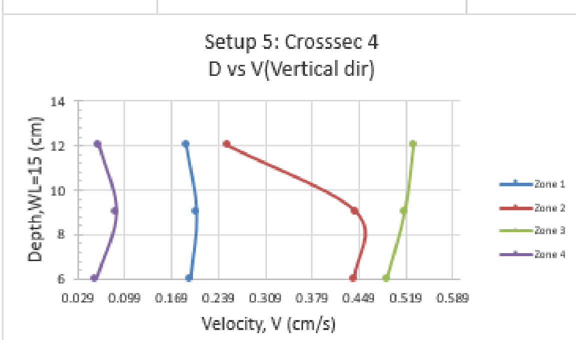
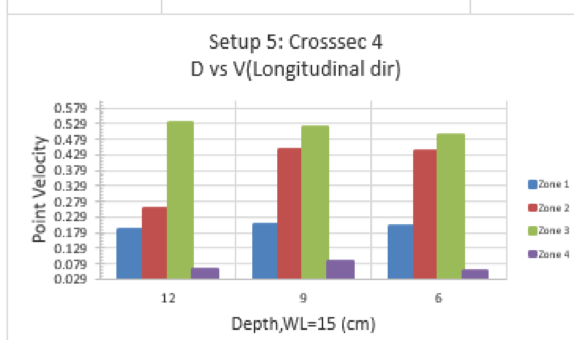
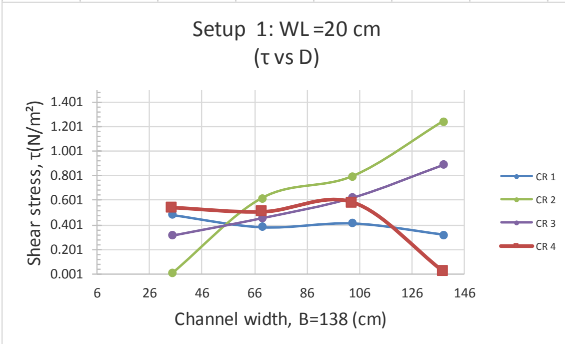


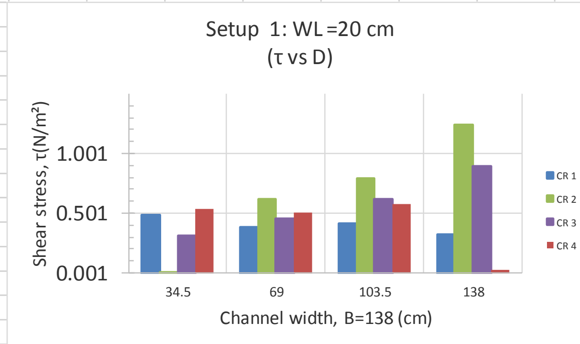
Depth vs Velocity Distribution Curve



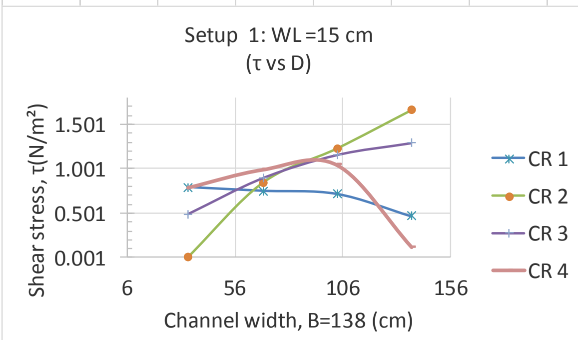
Shear stress vs channel width curve



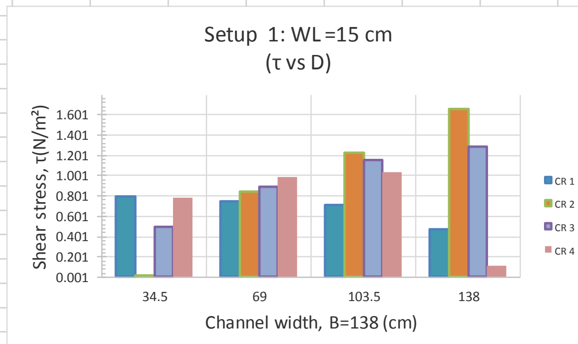
Shear stress vs channel width curve



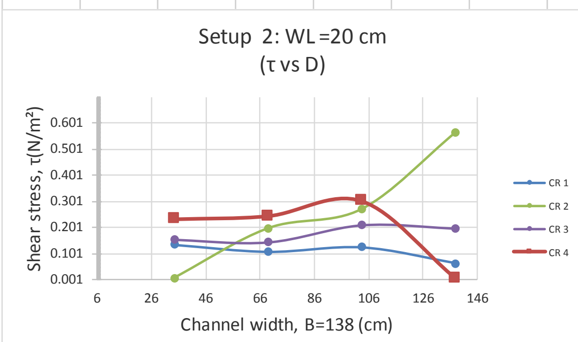
Shear stress vs channel width curve



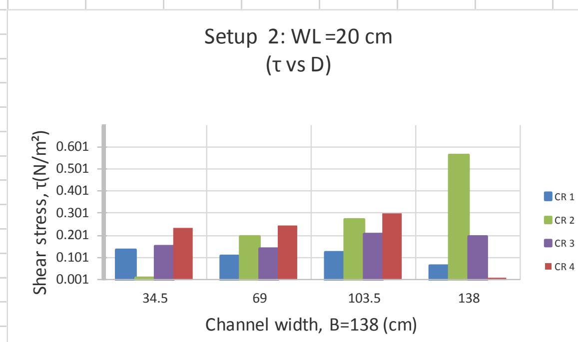
Shear stress vs channel width curve



Shear stress vs channel width curve



Shear stress vs channel width curve



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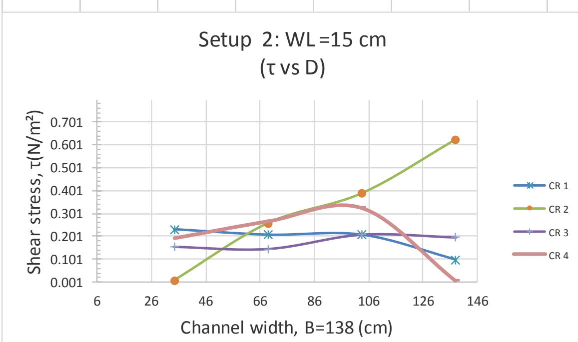

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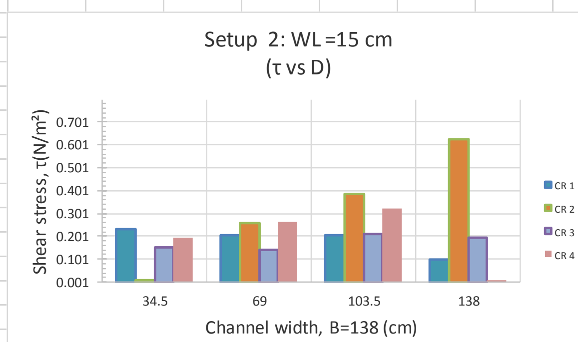

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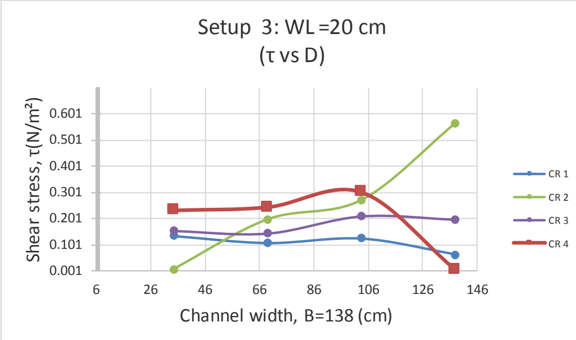

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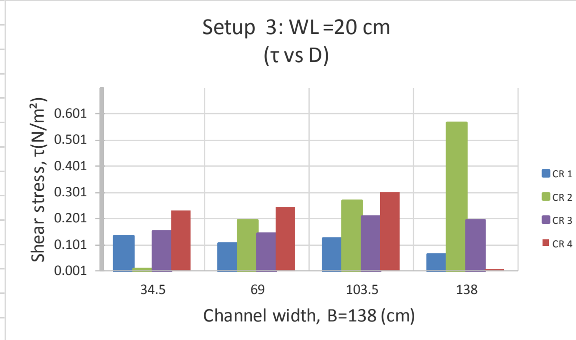

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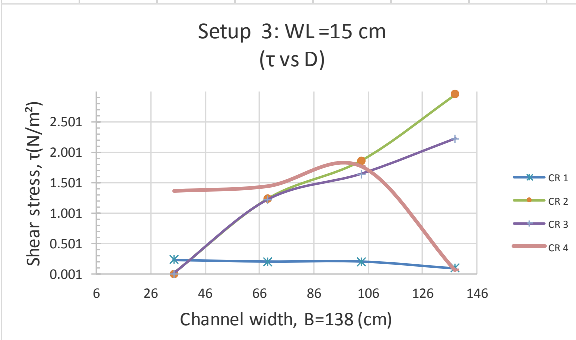

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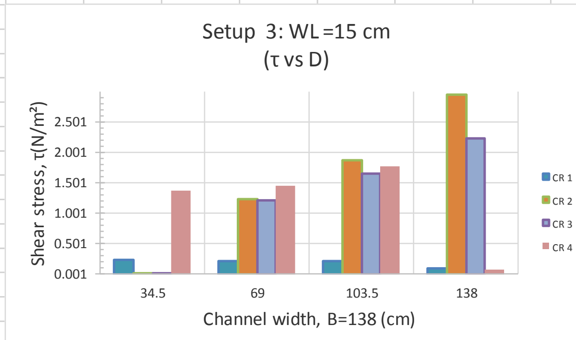

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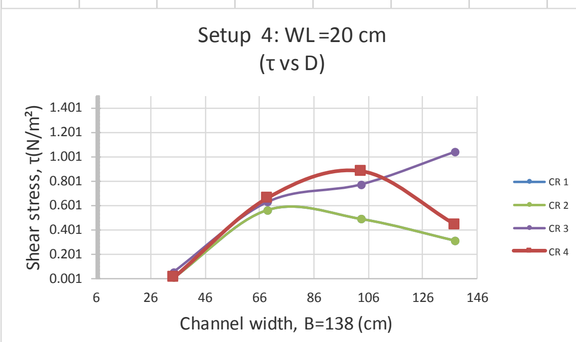

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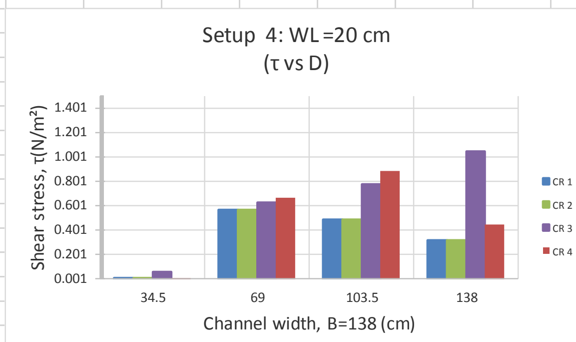

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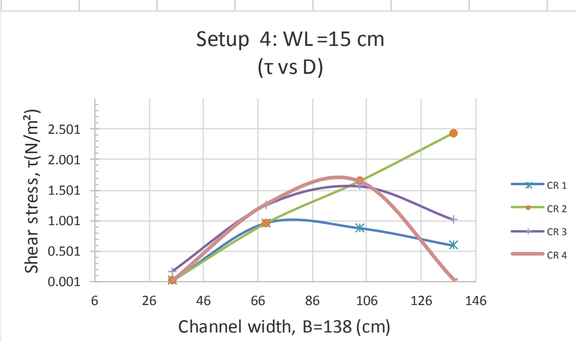

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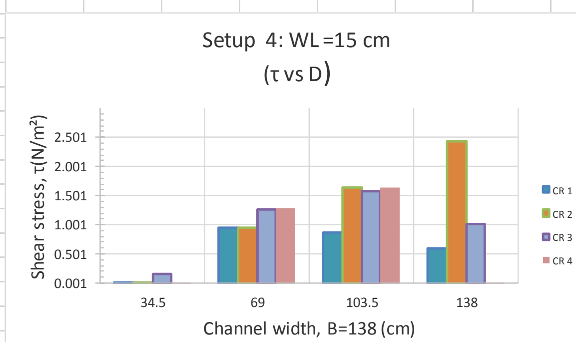

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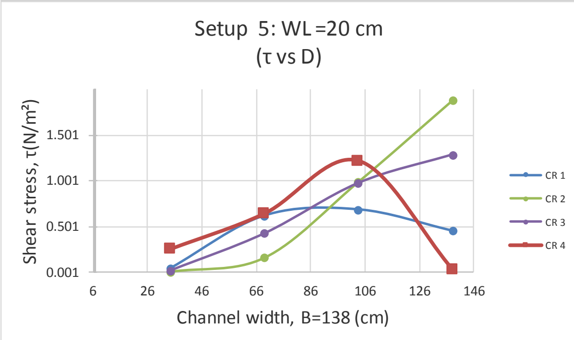
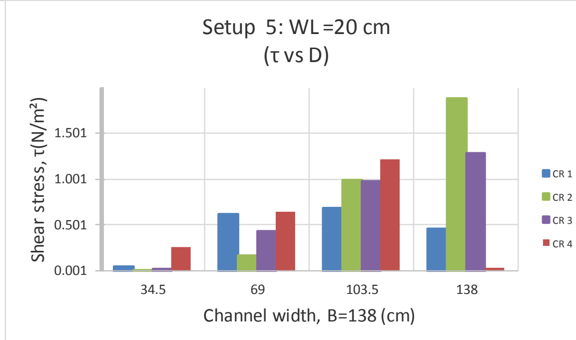
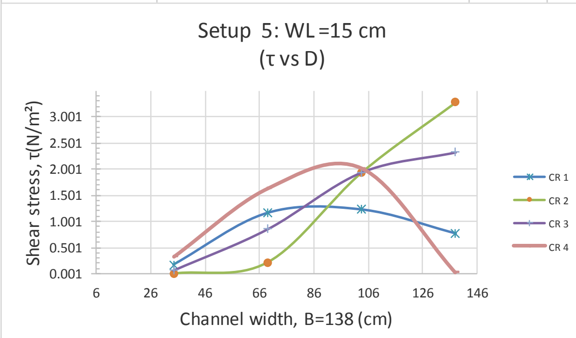


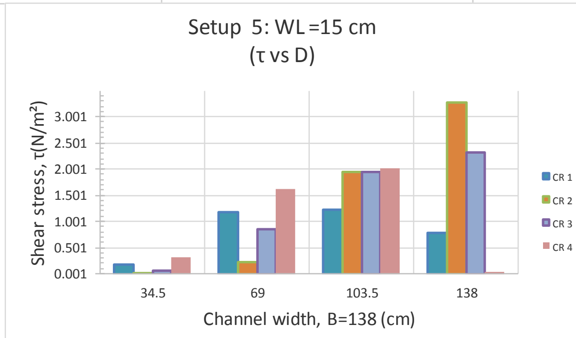
Shear stress vs channel width curve



Shear stress vs channel width curve



Shear stress vs channel width curve



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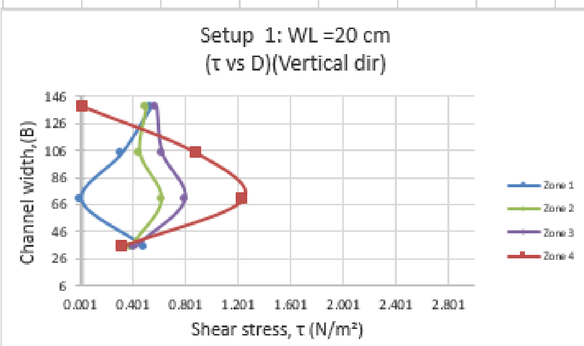

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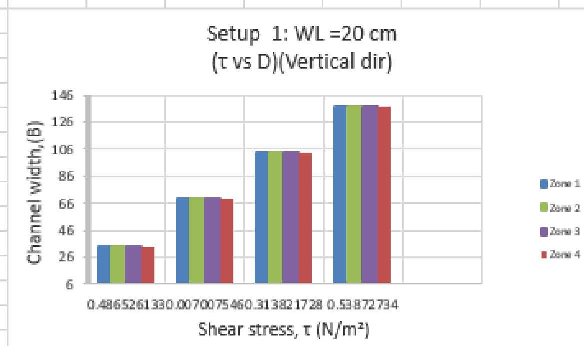

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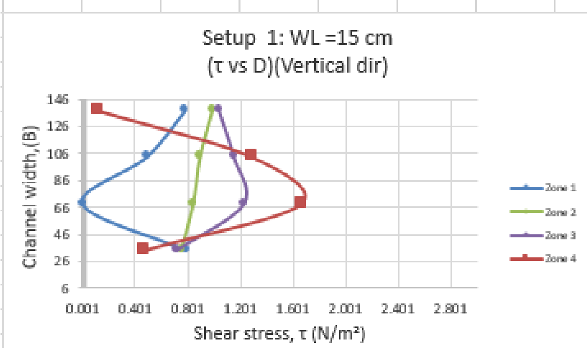

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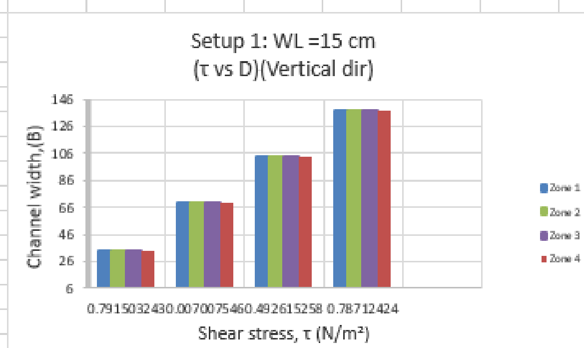

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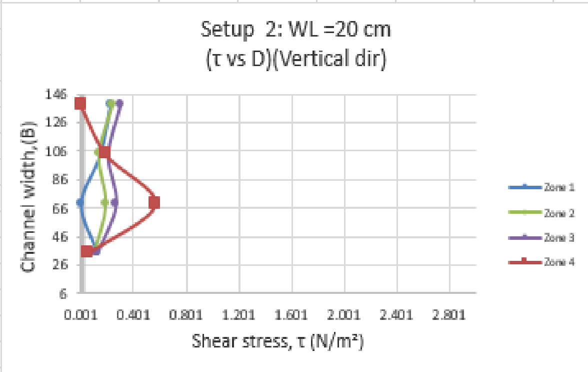

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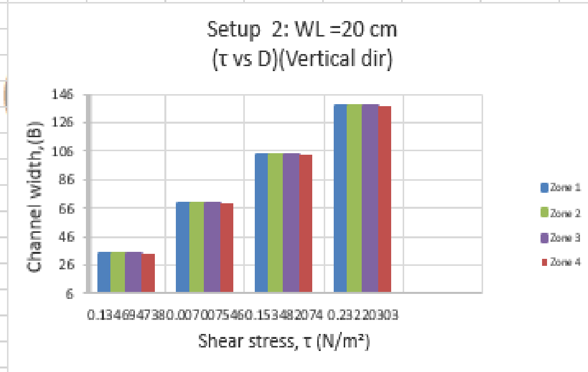

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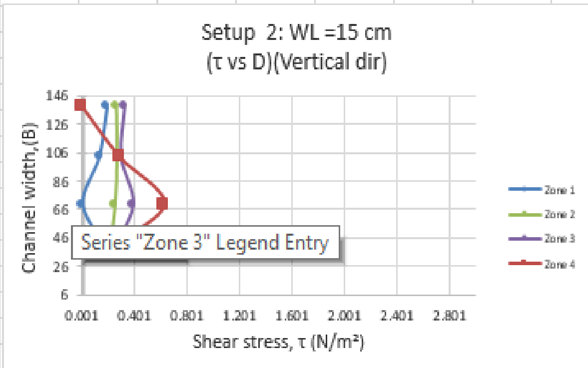

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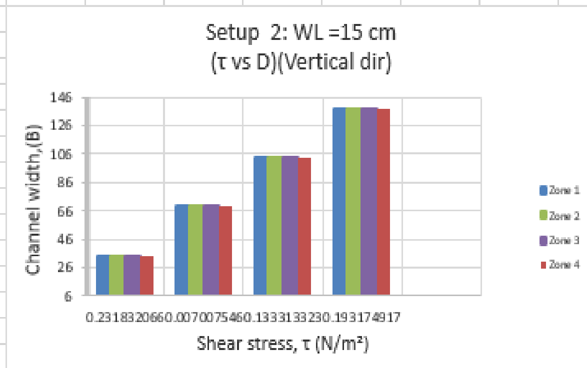

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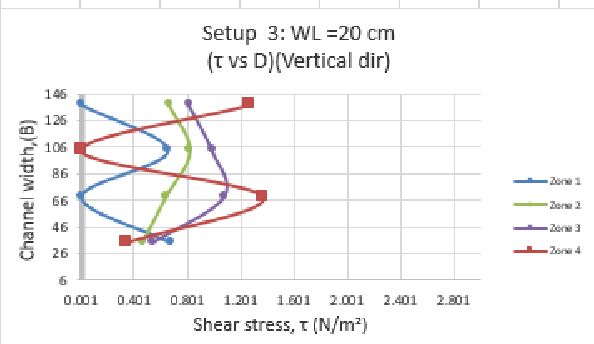

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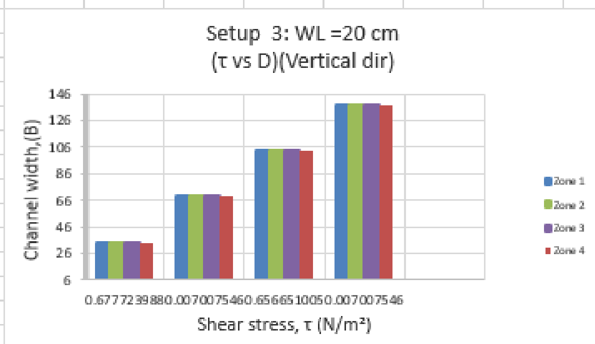

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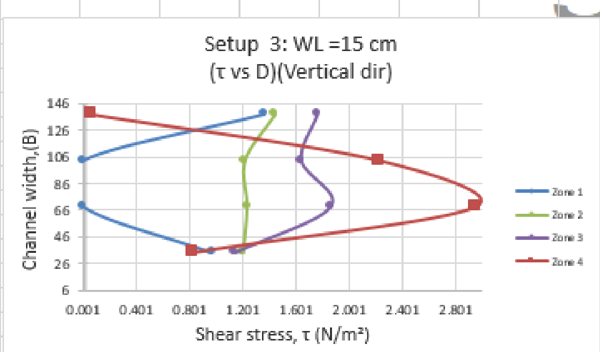

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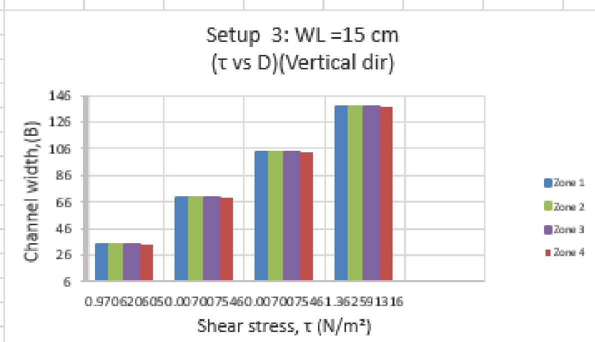

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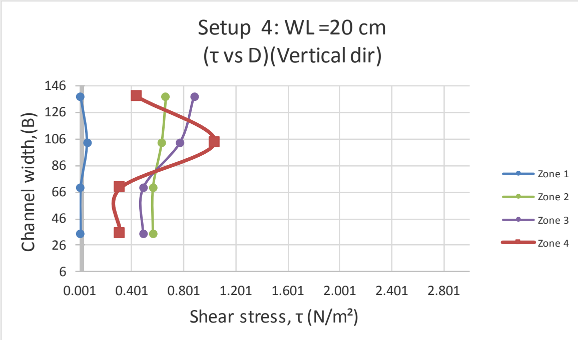

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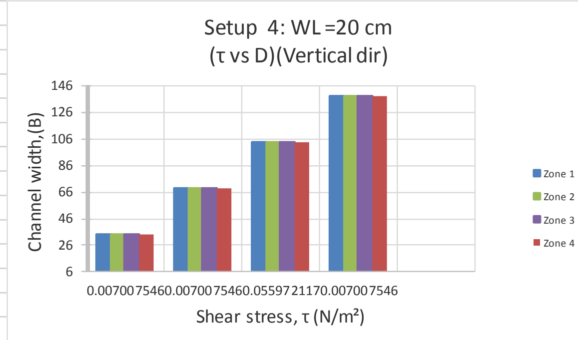

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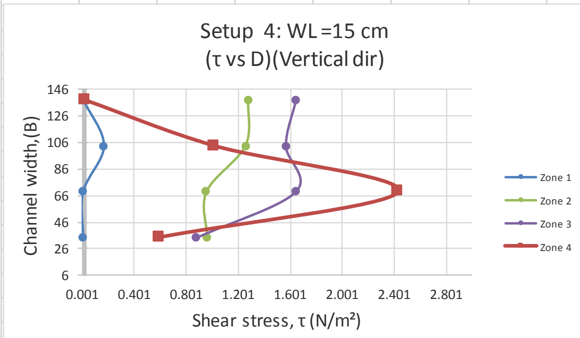

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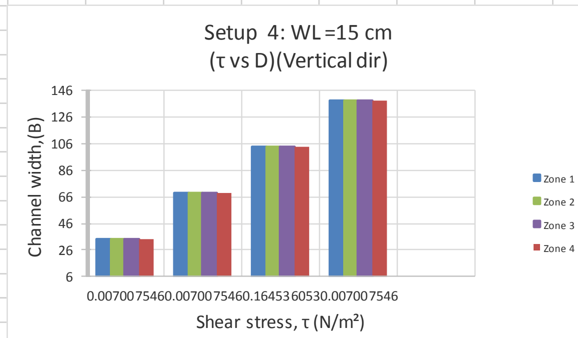

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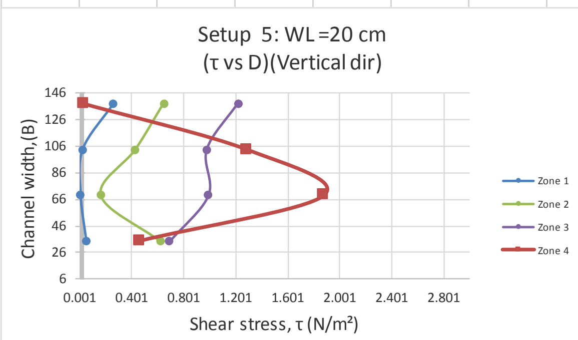

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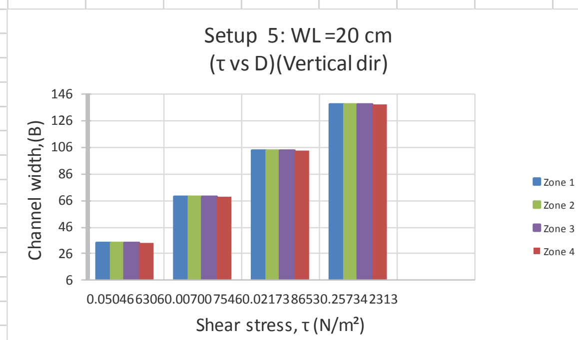

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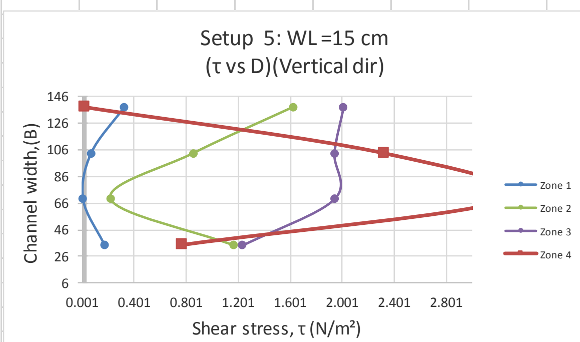

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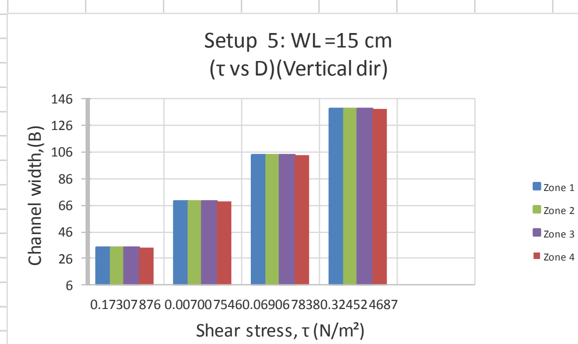
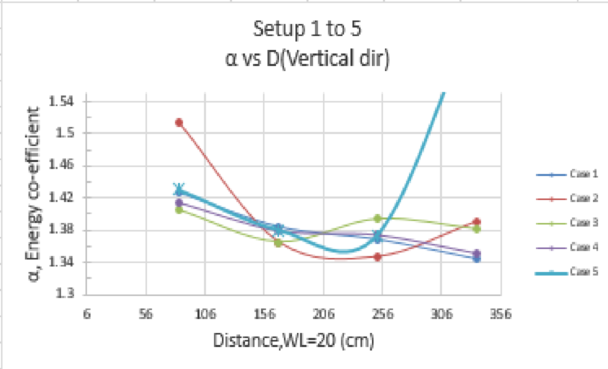
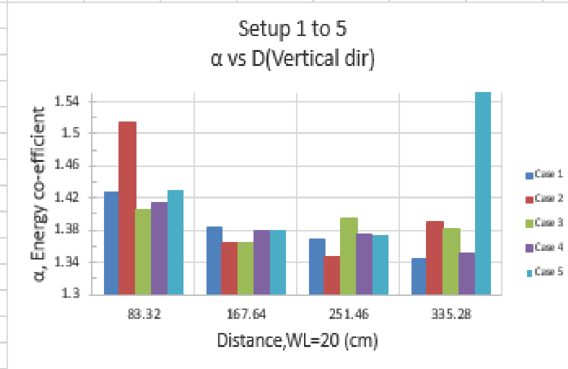


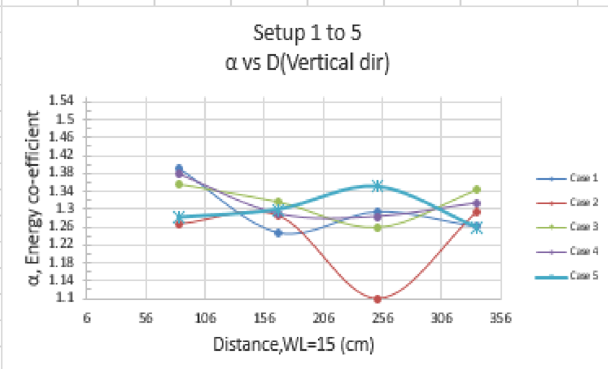
Energy co-efficient vs cross sec distance curve



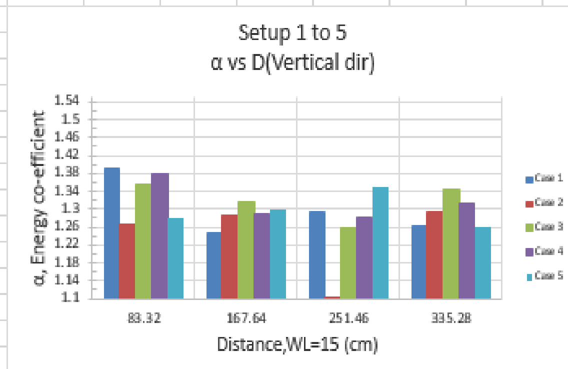
Energy co-efficient vs cross sec distance curve



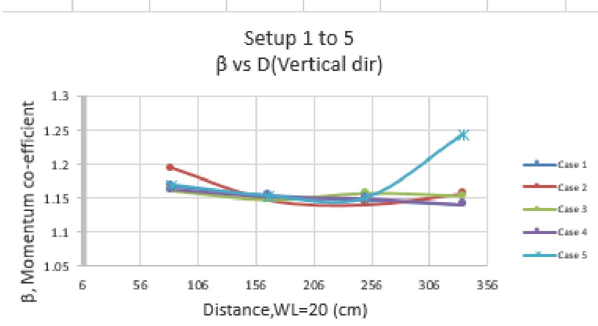
Energy co-efficient vs cross sec distance curve



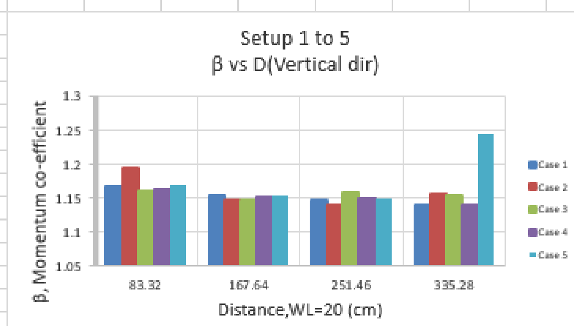
Energy co-efficient vs cross sec distance curve



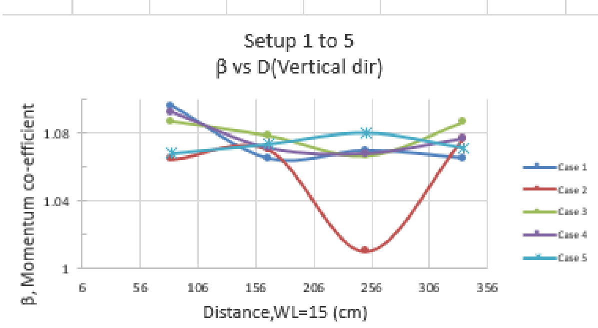
Momentum co-efficient vs cross sec distance curve



Momentum co-efficient vs cross sec distance curve



Momentum co-efficient vs cross sec distance curve



Momentum co-efficient vs cross sec distance curve