AN EXPERIMENTAL STUDY ON THE VOLUMETRIC SUSTAINABILITY OF SAND FILLED GEO-BAGS PLACED IN FLOWING WATER

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By

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A Thesis Submitted in partial fulfillment of the requirement for the degree of
Master of Engineering in Water Resources Engineering

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Certification of Project

The Project titled "**AN EXPERIMENTAL STUDY ON THE VOLUMETRIC SUSTAINABILITY OF SAND FILLED GEO-BAGS PLACED IN FLOWING WATER**", submitted by S. M. Tanvir Hossain, Student No. 1015162051, Session October 2015, to the Department of Water Resources Engineering, Bangladesh University of Engineering and Technology, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Engineering in Water Resources Engineering and approved as to its style and content on 9th May 2022.

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Candidate's Declaration

It is hereby declared that this project or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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LIST OF ABBREVIATION

BWDB	Bangladesh Water Development Board
CEGIS	Center for Environment and Geographic Information Services
JMREMP	Jamuna Meghna River Erosion Mitigation Project
ADB	Asian Development bank
DWRE	Department of Water Resources Engineering
FAP	Flood Action Plan
HEC-RAS	Hydraulic Engineering Center- River Analysis System
IWM	Institute of Water Modelling
PPM	Parts Per Million
PWD	Public Works Datum
SSC	Suspended Sediment Concentration
l/s	Liter per second
mg/l	Milligram per liter
gm	Gram
ml	Milliliter
NHC	Northwest Hydraulic Consultants
EMM	Euroconsult Mott MacDonald Ltd.
FM	Fineness Modulus
B	Beaker

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ABSTRACT

Riverbank erosion in the large rivers of Bangladesh has always been a difficult problem and to address this challenge, geobags are commonly used now-a-days. It is criticized in some cases that sediment loss from the geobags occur due to use of unspecified sand as filler material. Attempts have been taken to carry out an experimental study to investigate if there occurs any sediment loss from the sand filled geobags when placed in flowing water. A total of eight experimental runs were conducted in 70 ft. long tilting flume for two different condition (1 layer 1 bag and 2 layer 3 bag) with geobags weighing 78 kg each, filled with specified and unspecified sand *('Vit Bali')* for two different discharges-100 l/s and 200 l/s. During study, observations on flow condition, sediment concentration, velocity distribution etc. have been carried out. It is revealed that velocity of the flow does not depend on the geobag filler material whether it is specified sand or unspecified sand rather it depends on the layout of the bag, number of layers, number of geobags, flow condition etc. The lower the velocity the lower will be the stress. The more the layer the lesser will be the possibility of bank protection failure. Volumetric measurements and observations reveal that geobags filled with specified sand can contain the filler material satisfactorily and hence, it is sustainable when placed in flowing water.

On the other hand, geobags filled with unspecified sand discharges minor amount of filler material (sand) from the geobags for different flow condition. For one layer one bag condition, the average sediment concentration adjacent to the geobag per square meter bag area becomes 4.5 gm/l for 100 l/s of flow discharge and 5.0 gm/l for 200 l/s of flow discharge. On the other hand, for two layer three bag condition, the average sediment concentration adjacent to the geobag per square meter bag area becomes 2.7 gm/l for 100 l/s flow discharge and 3.0 gm/l for 200 l/s flow discharge. For one layer one bag filled with unspecified sand, the average sediment concentration is less when the flow (discharge) is high. For two layers three bags the average sediment concentration is less when the flow (discharge) is less. It appears that few parameter/phenomena (e.g. water depth adjacent to the geobag, shear force acting on the geobag, vortices generated etc.) might be responsible for the non-linear sediment loss from the geobag for single layer and double layer setup. Therefore, geobags filled with unspecified sand, losses minor amount of fine sediment for different flow condition and hence, it is not sustainable when placed in flowing water.

Hence, it is apparent that if the geobags are filled with sand according to specification then the possibility of failure during heavy flow in the river is negligible in respect to sediment loss from the geobags. On the other hand, if it is difficult to provide specified sand and unwillingly unspecified sand is used, a high possibility is there to fail the bank protection works during heavy flow due to sediment loss from the geobags.

CHAPTER ONE

INTRODUCTION

1.1 Background of The Study

The most common problem faced in river engineering practices in many countries, especially in Bangladesh is river bank erosion and this has been recognized as an unpleasant threat to the society. To save agricultural land, property and infrastructures like bridges, culverts, buildings etc. river bank protection is must be taken alongside the rivers (Islam, 2009). Riverbank protection in the large rivers of Bangladesh has always been a difficult problem. Strong river currents erode the fine sand from the toe of the riverbank. To address this problem artificial covering of the riverbank and bed with erosion resistant material is built. The geometric location rivers during flood is the recurring problem in Bangladesh, which causes serious damage to the property and life alongside the river. Bank erosion responsible for the loss or damage to valuable farmland, wildlife habitat, buildings, roads, bridges, and other public and private structures and property. In economic point of view, mitigation of bank erosion in Bangladesh has become an integral part of poverty reduction (Oberhagemann, 2006).

Bank protection also has an impact on the ecosystem of a reach. Vegetated banks are most environmental friendly protection that offers little or no restriction on habitat, although animals that dig holes may need to be discouraged. It is possible by laying an open geotextile on the bank before adding a layer of topsoil (30–40mm thick) mixed with grass seed over the top. The geotextile helps in binding the grass roots together, at the same time making burrowing more difficult. So, geobags are commonly used as both for temporary and permanent river bank protection elements &have become a popular means of long-term riverbank protection. Geobags are locally fabricated geotextile bags, filled near placement site with river sand. Sand-filled geotextile bags are being used at selected sites on the large rivers of Bangladesh as an economically feasible means of riverbank and scour protection. Geo-bags are available from the manufacturer with different size with specific specifications. However, the scope and limitations of their application are yet to be defined (Stevens and Oberhagemann, 2006).

Most of the river bank and bed protection works in Bangladesh are to be constructed in under water condition. During construction and repair, geobags are delivered directly from vessel with the intention to form a uniform coverage in the settling fashion. This process is simple but their dumping behavior plays a significant role. Recently, dumping and settling behavior of geobags had been conducted in laboratory flumes (BWDB, 2010 and Matin, M, A., 2016). They also studied the incipient condition of geobags and compared with that of CC blocks. However, during construction period, geobags should be filled with sand as per specification with measurement provided by Bangladesh Water Development Board. In under water condition, identification of placement of protective elements in underwater flowing situation is found to be more difficult and it is a matter of research which is yet to be done.

Sometimes geobags are filled & placed in an emergency basis for immediate protection of any river bank erosion. Due to time constraint, intentionally or unintentionally geobags may not be filled properly with specified sand by the contractor. According to BWDB officials, it was complained that some cases considerable amount of volumetric loss occurs due to unspecified sand filled geobags. This study attempts to carry out an experimental investigation on sand filled geobags to assess if there occur any volumetric change or not. Also comparison on volumetric sustainability of both specified and unspecified sand filled geobags will be carried out during this study.

1.2 Objective of The Study

With the background stated above the specific objectives of this study are as follows:

(i) To observe and measure the flow conditions with geobags for various test scenario.

(ii) To analyze the volumetric sustainability of geobags for different flow condition.

1.3 Organization of Thesis Work

Apart from this first chapter which states the background and objective of the study, there are four more chapters. The essence of each chapter is stated below shortly:

Chapter Two deals with literature review and the theoretical background of this study. Here processes & causes of river bank erosion and different types of riverbank protection works are discussed. River bank protection works through Geobags are discussed in briefly.

Chapter Three describes the basic theoretical knowledge of the experiment and data analysis procedure & also details of the laboratory experiment are described. Two experimental investigations are carried out. Experiments were carried out with same size & same weight of geobag with two different types of river or local sand which used as a protective element. The details of the experimental setup, flow condition, experimental conditions, instrumentation and data acquisition system etc. are presented in this chapter. The volumetric sustainability of geobags for different flow condition are also investigated from the photographs and video clips taken during the laboratory experiments.

Chapter Four represents the observation of flow condition, volumetric analysis of sample, sample collection etc. which had been performed in the laboratory experiments.

Chapter Five describes the details of results and discussion of the volumetric analysis, comparison on velocity of different flow condition, velocity distribution diagram of different experiments.

Chapter Six finally, an overview of the main conclusions of this study and recommendations for further study are presented in Chapter 6.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this chapter different types of river bank protection works and corresponding geobags protection works have been discussed. Besides these, it is very important to know the river bank erosion process. So at first the erosion process and different causes of erosion have been described. After that various protection methods which are normally used in Bangladesh have been discussed.

Bangladesh is a riverine country. Thousands of rivers flow over this alluvial land. The flow of river sometimes makes the bank vulnerable. So that the protection of bank is needed where there is the risk of erosion of the bank and where this erosion would cause economic as well as environmental loss. Sometimes if there is sufficient space available, the need for bank protection can be reduced by re-profiling the bank to a flatter slope to reduce velocities of flowing water and also encourage good vegetation growth. Bank protection has an impact on the ecology of a reach. The softer the bank protection the more ecologically friendly it is. Vegetated banks offer little or no restriction on habitat, although animals that dig holes may need to be discouraged. By laying an open geotextile on the bank before adding a layer of topsoil mixed with grass seed over the top a softer bank protection may be achieved. The geotextile assists in binding the grass roots together, at the same time protects the bank with an environment friendly manner.

2.2 Bank Erosion

River bank erosion is one of the critical public concerns in the world at least in some countries. In Bangladesh, it’s an endemic and recurrent natural hazard . When rivers enter the mature stage they become sluggish and meander or braid. These oscillations cause massive riverbank erosion. Every year, millions of people are affected by erosion that destroys standing crops, farmland and homestead land. It is estimated that about 5% of the total floodplain of Bangladesh is directly affected by erosion.

Some rivers cause erosion in large scale and high frequency due to their unstable character. These rivers assume a braided pattern consisting of several channels separated by small islands in their courses.

No systemic pattern has yet been observed of the erosion hazards because of the involvement of a large number of variables in the process. The intensity of bank erosion varies widely from river to river as it depends on such characteristics as bank material, water level variations, near bank flow velocities, platform of the river and the supply of water and sediment into the river.

Impacts of river bank erosion are multifarious: social, economic, health, education etc. The first and foremost impact is social, i.e., homelessness due to land erosion which compels people to migrate (**Figure 2.1**). After forced migration they suffer from economic crisis, namely loss of occupation and loss of property, and they are at the risk of poverty and sometimes involvement in criminal activities (Iqbal, 2010) medical and education facilities exist in their new occupied places. Results are their poor health, sickness and illiteracy of their children.

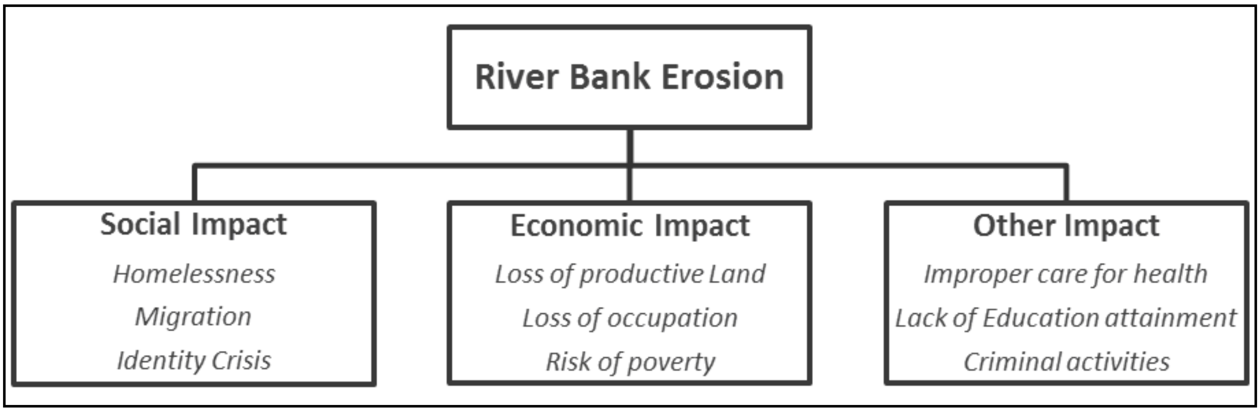


Figure 2.1: Impact of river bank erosion

2.2.1 Process of bank erosion

The erosion of any place may take place in the following two ways:

1. The displacement of the solid particles from adhesive / cohesive contact when taken place causes the erosion.
2. The transportation or washing away of the solid particles from the particular position/ site taken place causing the underlying materials attack or wash and finally there happens an erosion. According to the California Highway Practice, 1970, this type of erosion is nothing but a natural consequence of the flow passing through a solid boundary.

Any river bank erosion processes are mainly two types:

i) Direct fluid entrainment and

ii) Mass failure

The main impacts responsible for surface erosion at river are: (**Figure: 2.2**)

i) Current induced shear stress

ii) Wave load (Wind –generated waves/ ship & Boat generated waves)

iii) Seepage (Excessive pore pressure)

iv) Surface Runoff

v) Mechanical action (desiccation. Ship impact, activities of humans and animals)

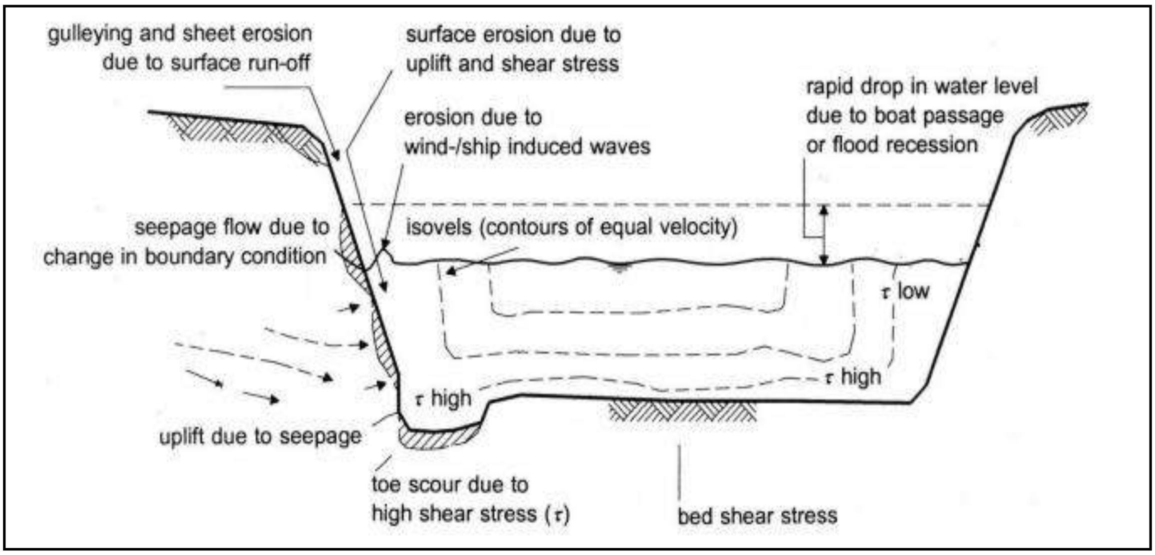


Figure 2.2: Processes of surface erosion (Source: Hamphill and Bramley, 1989)

Mass failure of river banks can be divided into slip failures, block failures and flow slides, initiated by different processes, which are illustrated in **Figure. 2.1**. The actual failing of a river bank may not follow immediately after an impact. In some cases the failure process takes several days. On the other hand, a failure may occur without warning at almost any time if active surface erosion and toe scouring is prevalent or an additional (surcharge) load is .applied to the bank. The risk of mass failure is increased during heavy rain and during quick fall of river stages after flood. Typical bank failure of major river in Bangladesh is shown in **Figure 2.3**.

Figure 2.3: Typical mass failure of river bank (Source: Padma erosion in Shariatpur, Dhaka Tribune, 1st November, 2018)

2.2.2 Causes of bank erosion

Rivers and streams are products of their catchments. They are often referred to as dynamic systems which mean they are in a constant state of change.

The riverbank undergoes to erosion by hydraulic and geo-technical instability. Hydraulic instability is caused by scour at the toe of a marginally stable bank, flood propagation and flood recession, debris and vegetation, removal of bank vegetation, detachment of coarse sediment by wave action, secondary current etc. Besides, constricted bridge crossings or other encroachments that involve acceleration and concentration of flood flows tends to cause 'back eddies' or reverse circulation downstream, which can sometimes erode huge embankments into river bends.

Bank erosion phenomenon in large-scale rivers is a cyclic process of the following four sub-processes (JES 02(1&2), 2011):

i) Steepening of bank slopes caused by erosion of lower part of the slope and riverbed near the slope toe.

ii) Slip failure of the steepened bank slope by losing its stability.

iii) Movement of failed bank material toward riverbed along the slip surface.

iv) Removal of failed bank material on lower part of the slope and riverbed near the slope toe.

A bank may fail to any one or a combination of the following reasons:

(i) Washing away of the soil particle of the bank by current or by the waves which is called erosion.
(ii) Sliding due to the increase of the slope of the bank as a result of erosion and scour.
(iii) Undermining of the toe of lower bank by current, wave, swirls or eddies followed by collapse of overhanging materials deprived of support which is called scour.
(iv) Sloughing or sliding of the slope when saturated with water, this is usually the case during flood of long duration.
(v) Sliding due to seepage of water flowing through bank into the river after receding of the flood, the internal shearing strength is considerably decreased owing to saturation and the stability is further decreased by the pressure of the seepage flow.
(vi) Piping in the sub layer due to movement of ground water to the river which carries away sufficient material with it.
(vii) Scouring of bed and bank by eddies with horizontal axis when flow occurs over a reef or submerged structure.

2.3 Bank Protection Works

Protection means to save something from the attack of someone so the river bank protection is an important part of river training works as well as save the river from the action of wave or current of the river water. The riverbank protection in a sustainable manner is necessary to save the expected losses. Sustainability may be ensured by

proper diagnosis and predictions of bank erosion and treatment applied to select technically and economically justified protective measures.

The purpose of bank protection can be-

(i) Training of the river,
(ii) Protection of adjacent agricultural land,
(iii) Protection of urban lands and valuable properties threatened by river erosion,
(iv) Protection of hydraulic structures as weirs, barrages and bridges against the direction and nature of current.
(v) Protection of flood embankment, and
(vi) Affording facilities for water transportation.

To prevent the river bank erosion, proper countermeasures should be required and necessary action will be taken against river erosion. The protection may consist of only structural works or a combination of structural and non-structural measures. River training works includes all measures taken to control and regulate river flow and river configuration.

Generally, there are three relevant concepts to erosion preventive measures which are as follows (Islam, 2008):

i) *River Training and Flood Control measures which are in stream structures - which implies various measures adopted on a river to stabilize the river channel along a certain alignment with a certain cross section. Its includes high water training which is undertaken with the purpose of providing safe disposal of maximum floods and thus provide protection against damage due to floods. It is mainly concerned with the most suitable alignment and height of marginal embankments and may also include other measures of channel improvement for the same purpose. It can be either passive or active.*

ii) *Erosion Protection-when the protection against scour is achieved by constructions not directly attached to the banks themselves (e.g., such as groynes).*

iii) *Stream Bank Protection- which Structures to protect the bank line directly. Stream banks, even in a regulated channel, are constantly attacked by waves and scoured by the erosive action of the shifting water level. Strong local scour is particularly active along the concave bank of bends. Bank protection may be Direct – in which case it is done by a suitable kind of protective revetment and indirect – when the protection against scour is achieved by constructions not directly attached to the banks themselves (e.g., such as groynes).*

2.3.1 Structural protection measures with groynes

A spur or groyne is a structure made to project flow from a river bank into a stream or river with the aim of deflecting the flow away from the side of the river on which the groyne is built. In general, Groynes are perpendicular to the shore line or river bank or sometimes slightly oblique. Sandbag groynes are constructed using sand or earth-filled bags which are stacked in the form of barrier (**Figure 2.4**). They are used for temporary or short-term purposes. A special type of filter cloth is provided under the bags to prevent the sinking of sandbags into the ground.

Figure 2.4: Sandbag groyne

2.3.2 Structural protection measures with revetments

Revetment is a one kind of bank protection measure which is covered the bank slope with erosion-resistant materials. Basically a revetment can be an exposed structure as well as a buried structure. Revetments are always made as sloping structures and are very often constructed as permeable structures using natural stones or concrete blocks, thereby enhancing wave energy absorption and minimizing reflection and wave run-up (**Figure 2.5**). However, revetments can also consist of different kinds of concrete slabs, some of them permeable and interlocking. In this way their functionality is increased in terms of absorption and strength. Toe protection is provided at the foot of the bank to prevent undercutting caused by scour. The falling apron and launching apron are two parts of it.

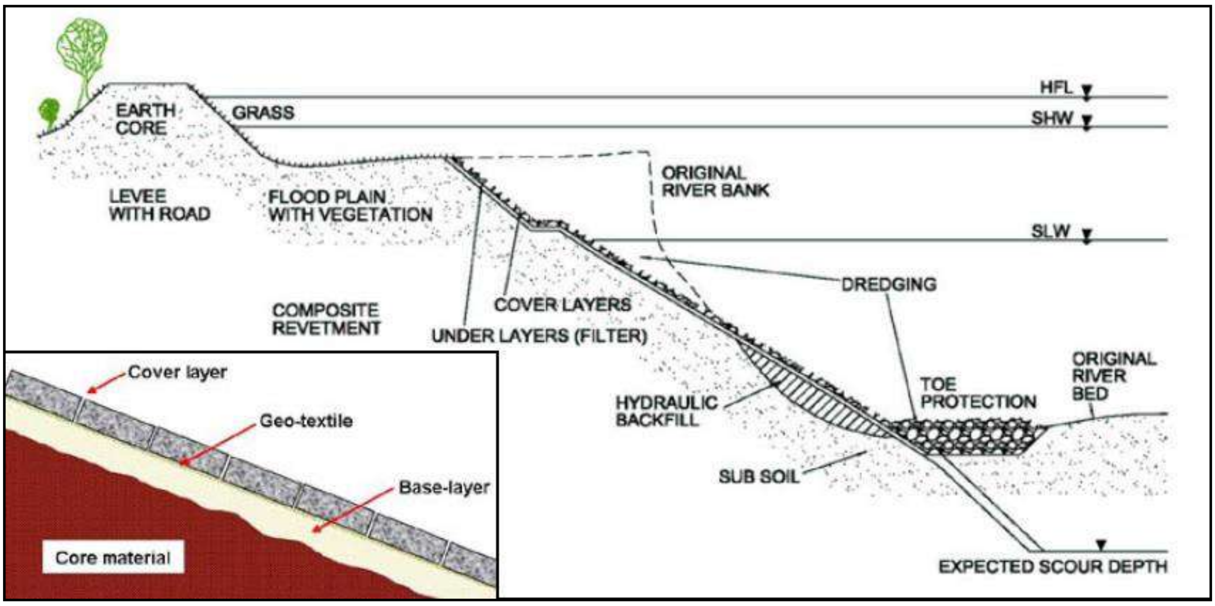


Figure 2.5: Components of revetment works (Source: BWDB, 2010).

Launching apron and falling apron

A launching apron should be constructed to protect the spur from scouring at the base. When river training works are carried out to protect a river bank, the obstruction of high flow discharge and the associated changed water flow pattern can lead to scouring in the form of a deep depression in the river bed close to the river training structure. Scouring can destabilize the structure and thus measures need to be taken to counteract the effect. A launching apron is a flexible stone cover placed on the bed of the river which settles into the scouring area as scouring takes place and covers the base and side of the scour hole. Falling aprons are commonly placed under water, the bank slopes having been covered with stable protection down to the deepest pre-existing level (**Figure 2.6**). A falling apron is a stack of granular material at the toe of a revetment, which will launch onto the slope of the scour hole. The established slope will then be protected by a layer of rock, which will retain the bed material and prevent the formation of a slope that is too steep. Sand filled geobags are commonly and extensively used as launching apron and falling apron unit in the rivers of Bangladesh.

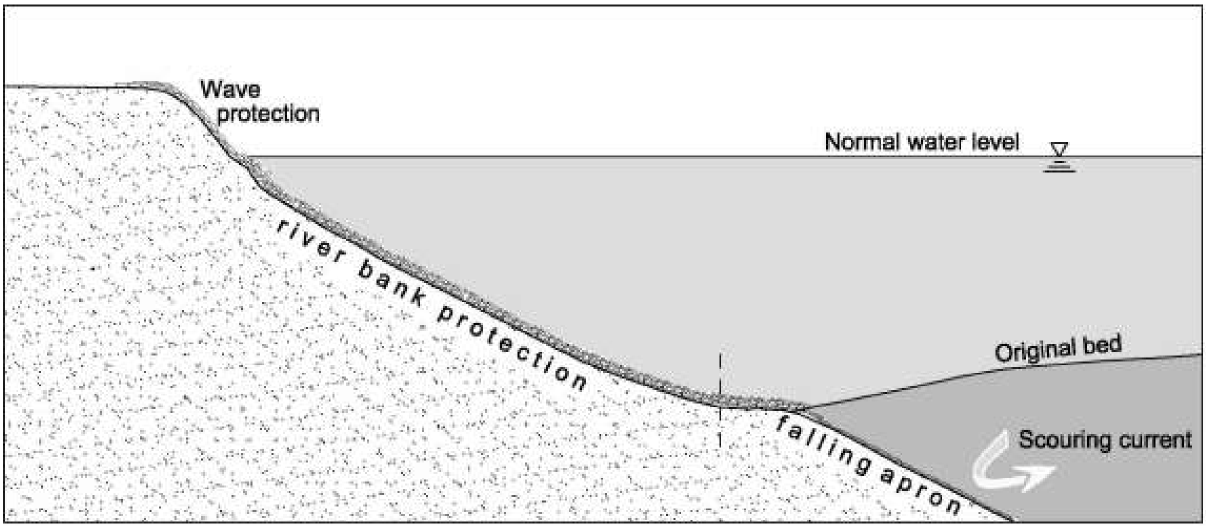


Figure 2.6: The principles of falling apron (Source: BDWB, 2010)

Toe protection structure

Toe protection of revetments may be provided by extension to maximum scour depth. Lower extremity of revetment placed below expected scour depth or founded on non-erodible bed materials. These are preferred method, but can be difficult and expensive when underwater excavation is required. However, different sizes of sand filled geobags are used as underwater toe protection unit as well since these are low cost materials and the filler materials are readily available.

2.4 Geobags Used as Protective Measure

At present, geobags are used in bank protection works as stable protective elements (**Figure 2.7**). Geobags are small soil containers that are made of non-woven geotextile, used for slope protection and river training work. Geobags, also known as 'Geotextiles Bags', 'Geotextile Sand Containers' or 'Non-Woven Geobags', are filled with fine river sand and stitched manually on site to form shape of a bag and serve to reduce costs for protection works.

Figure 2.7: Protection with geobags (Source:www.indiamart.com)

Advantages of geobags used as protection measure

- Erosion control, filtration and drainage in one product for coastal, off-shore, waterfront, waterway structures and foundation applications.
- Long-term durability and performance Erosion control, filtration & drainage, all-in-one the Geotextile bag.
- Environmentally smart: reduces carbon footprint, creates habitat zones, minimizes site disturbance
- Filling: On-site filling with gravel or sand makes it far more convenient.

- Cost-Effective: Highly cost-effective when compared to conventional materials, both in terms of production and installation.
- Weights and Measures: Available in varied sizes and shapes, specific to design requirements.
- Technology and durability: They are engineered for strength and durability with double stitching and stringent quality control.

2.4.1 Types of protective system with geobags

Three types of geobags protective systems are currently used:

(i) multiple layers of launched and dumped geobags,

(ii) composite systems of concrete slabs and cubes on geotextile filter,

(iii)grout-filled mattresses on geotextile filter.

2.4.2 Geobags used as protective work in Bangladesh

Geotextile Bags or geobags do not have a long history in Bangladesh. They were first introduced at the Chandpur Town Protection Site in early 1990. In Bangladesh, geobags have been used under water in protective works since 1999 for its cost effectiveness and sustainability. Bangladesh Water Development Board took up an experimental river erosion mitigation project named Jamuna Meghna River Erosion Mitigation Project (JMREMP) to develop the low cost alternatives for riverbank protection supported by ADB. The project follow up on eight years of implementing effective and low cost river training at several places of the Jamuna and Meghna River.Sand filled geobags were identified as a low cost effective solution during a pre- feasibility study in 2000 and JMREMP has been using sand filled Geobags under water with cement concrete (CC) blocks along the major rivers of the country like Meghna and Jamuna. Subsequently they were used by BWDB Since 2001.

Since the early 2000s, geobag revetments have been systematically built along more than 45 km of riverbanks (Oberhagemann & Hossain 2011). This work has performed well during repeated erosional attacks, mainly due to the self-launching behavior of the geobag aprons, which prevent the toe and the geotechnical collapse of the riverbanks. Based on their successful performance, geobags are currently implemented for the river training works of the Padma Bridge, one of the largest river bridges on earth (Maunsell AECOM

2011). The geobags used for the bridge have a design lifetime of 100- years, in the form of a filter layer under rock riprap, and as riverbank protection on dredged slopes and toe aprons. Since 2015, the Bangladesh Water Development Board (BWDB) is expanding the use of geobag revetments for localized riverbank protection towards river training works of larger river reaches (ADB 2014, NHC and EMM 2016). **Table 2.1** summarizes the key developments of geobag revetments in Bangladesh since 1989.

Table 2.1: Historical use of geobags in the Brahmaputra River basin (Source: ADB 2014, NHC & EMM 2016)

Location and Year	**Type of Work**
Chandpur, 1989	Woven geobags used as filter layer under concrete blocks (Halcrow 1990)
Bahadurabad, 1996	Different sized geobags used as a falling apron (FAP21 2001)
Sirajganj, 1999	Repair of town protection damage in layers with different sized geobags (Halcrow 1998, Halcrow 1999)
Kaitola, Lower Jamuna, Mohanpur, Meghna-Padma confluence, 2002	Various sizes of geobags used for systematically dumped revetment works (ADB 2002, NHC 2006b)
Countrywide, 2004 onwards	BWDB uses geobags as riverbank protection (undocumented)
Padma bridge, 2010	Geobag application for bridge training works with a 100 year life time (Maunsell|AECOM 2011)
Dibrugarh, Palasbari, 2011	125 kg bags for long guiding revetments (ADB 2010)

2.4.3 Sustainability of geobags in the protective work

Geotextile bag or geobag, a geosynthetic product made of polyester; polypropylene or polyethylene has been used worldwide for protecting riverbanks and hydraulic structures from severe scouring and erosion. Sand filled Geobags work as a substitute of C.C. blocks used as dumping material, even though geo-bags are sometimes used as filter material below C.C. blocks. A physical modeling study under JMREMP found that launching performance of sand filled geobags is better than C.C. block. The joint venture study of

BWDB, BUET and IWM suggests that the launching performance of geobag could be found similar to hard materials if area coverage method is applied instead of mass dumping method. The major advantages of geobags are its availability and easy implementation. Geobags are readily available and transportable (when empty) and can be easily filled with local sand and formed with a range of sizes. On the other hand, main demerit of geobag is its high sensitivity to UV radiation and highly alkaline or acidic water and Solar UV radiation stimulates its polymeric ageing process. Depending on its constituent strains' properties, its life expectancy could be reduced 15% to 75% in one-year exposure. Highly acidic and alkaline water could also significantly reduce geobags property through chemical degradation and fortunately major rivers of Bangladesh show neutral pH (6 to 7) Polymeric ageing process. Depending on its constituent strains' properties, its life expectancy could be reduced 15% to 75% in one-year exposure. The properties of geo textile fabrics for manufacturing bags shall be tested according to the relevant standards and meet the technical values of the following tables: (Source: JMREMP 2010)

Table 2.2: The Properties of geo textile fabrics (Source: BWDB, 2010)

Properties	**Test Values**
Opening size O-90	≥0.06 and ≤ 0.08 mm
Mass per unit area	≥400 g/m^2
CBR puncture Resistance	≥4000 N
Tensile Strength	≥ 20.0 KN/m
Elongation at maximum force-MD	≥60% and ≤ 100%
Elongation at maximum force-CMD	≥40% and ≤ 100%
Permeability	≥2*10^{-3}m/s
Minimum thickness	≥ 4.00 mm
Abrasion	≥ 75% of specified
UV Resistance	≥ 70% of original before exposure.

In Bangladesh, the geobags used are made of Polypropylene (PP). Generally, the characteristics of river water and soil in Bangladesh are not suitable for the chemical degradation of Polypropylene geotextile materials. Moreover, most geobags used in Bangladesh are placed under water. So the possibilities of temperature degradation, sunlight degradation are minimal. **Table 2.3** shows the life expectancy of geotextiles according to different authors are given below:

Table 2.3 Life expectancy of geotextiles (*Source: Zellweger, Hannes, 2007*).

Expectancy	**Properties and Exposure**	**Reference**
> 100 years	For believers: summary of geotextile properties for hydraulic and coastal engineering	Pilarczyk, 2000
50 years	For non-believers: .summary of geotextile properties for hydraulic and coastal engineering	Pilarczyk, 2006
>20 years	No specification	S Restall, 2004
30 to 110 years	Long time behaviour of geotextile used in landfills	Muller Rochholz, 2002
50 years	Non-woven geotextile bags in dike revetments	Van de Burg, 2002
> 35 years	Non-woven geotextiles in dike revetments as filters at the "Mittellandkanal" in Germany. The needle punched geotcxtile did not showweakness or problems after 35 years.	Heerten & Saathoff, 2004

2.4.4 Dimensioning geobags

Pilarczyk (2000) discussed resistance of geobags against current attack and the need for more experimental data for final design recommendations. Bezuijen and Vastenburg (2013) provided a guideline for sizing geobags against current loading based on Pilarczyk's formula. The sizes of bags suggested by the guideline are more conservative than those suggested by the USACE formula. Observations of constructed revetments show that smaller bags are stable at higher velocities than the guideline suggests.

If geobags are to be used extensively for large scale river stabilization works, it is justifiable to revisit the hydraulic design of the bags. Systematic diving observations indicate that some of the geobags may be oversized (ADB,2003). During diving investigations, divers have pulled on the geobags with the intentions of displacing them. The bags are extremely resistant to movement, even 78 kg bags with additional hydraulic forces from flow velocities of approximately 2 m/s. Bag sizes have increased over time in line with increased design loads. During first implementation in Bangladesh from 2004 to 2007 mixes of six 78 kg and two 126 kg bags (three 78 kg bags or two 126 kg bags providing coverage of one square meter each) have been used. Model studies conducted in 2005 at the Northwest Hydraulic Consultants (NHC) laboratories in Vancouver (NHC, 2006) indicated that uniform bag sizes also result in good coverage.

At Padma Bridge site, 800 kg bags are used to cope with the design flow velocities of up to 5 m/s. (Source: Geobag Stability for Riverbank Erosion Protection Structures by Angela Thompson, 2019). Large bags can slow down construction intensely. Larger bags means very costing and will require more dredged sand. Larger bags are more difficult to filling and construction, and reducing the amount of protection that can be provided in a dry season, optimizing the sizing process is desirable.

Pilarczyk (2000) discussed resistance of geobags against current attack and the need for more experimental data for final design recommendations and 7 recommended stability coefficient for geobags based on applied engineering judgement. Bezuijen and Vastenburg (2013) provided a guideline for sizing geobags against current loading based on Pilarczyk's formula.

2.5 Selected Previous Studies on Geobags used as Protection Measure

River bank protection is most demanding research platform now-a-days. Many of the researchers are doing a lot of researches on riverbank protection using various protection measures. Some of the researches are discussed below.

Angela, et el. (2019) finds in their study that the filling percentage has a large influence on the stability of the geobags, and consequently they should have a degree of filling of at least 80%. Additionally, they also suggested that the stability formula used for geobags should use the thickness as the characteristic diameter rather than the cube root of the volume.

Md, M H (2016) compares the performance of geo-bags and cement concrete (CC) blocks in the bank protection works. In his study he found that each material is more of a mixed bag with both positive and negative sides being suitable for different cases. His research will help the respective people to understand the potential causes of failure of geo-bags and CC blocks revetments that may lead to taking necessary actions for much better river bank protection works.

Angela, et el. (2020) created numerical models using ANSYS CFX. Initial estimates find the Shields value for geobags lies around 0.09, which is much larger than the value for rocks, around 0.045. The results from their study suggest that the Shields parameter varies with fill percentage of the bags.

Aysha, et el. (2013) developed A CES model which was validated against fixed-bed experimental observations, and the validated model was then used to predict mobile-bed formations. The CES bed predictions were used to produce a failure diagram under geobag-water flow interactions and classification of bed formation under geobag-water flow-riverbank interactions. It is concluded that the CES can be a useful and computationally efficient tool for the prediction of hydraulic parameters and bed formations.

Leila, et el (2021) tested a 1:10 scale distorted physical model in a laboratory flume, comparing a range of different construction methods and revetment side slopes, subjected to different flow loading. The results indicate that whilst failure mechanisms are highly dependent on water depth and revetment slope, the construction method had no noticeable impact. It was thus concluded that the dominating factor is the friction between individual geobags, which itself is dependent on bag longitudinal overlap rather than a specific construction method.

Sara, et el. (2018) presents the results of preliminary flume experiments aiming to study the resistance of river bank protections using bio-engineering techniques.

2.8 Remarks

Erosion is one of many natural river processes. Problem arises where the rate of erosion is considered too rapid to be acceptable. This can be problematic for a number of reasons, for instance loss of valuable agriculture land, risk to local infrastructure and sedimentation downstream. Construction work among river bank protection works is the main task but in an emergency protection work during river bank erosion, the action should be taken as used geobags or concrete block. Before used geobag as a protective element, there should be check and strictly follow the consideration of filler materials like sand, sand F.M and geobags quality as per design.

CHAPTER THREE

METHODOLOGY AND EXPERIMENTAL SETUP

3.1 Introduction

In previous chapter literature review on river bank erosion and river bank protection work has been discussed. In this chapter, experimental setup, geobags preparation for test sample, materials collection and data collection methodology is highlighted.

3.2 Outline of the methodology

The study has been carried out according to following steps of activities:

(i) Theoretical analysis of governing parameters
(ii) Experimental setup
(iii) Preparation of Geobags for test sample
(iv) Materials collection as a protective element.
(v) Test scenarios and experimental run
(vi) Data collection and observations
(vii) Analysis of data
(viii) Performance of geobags

The stepwise methodology is explained in a flow diagram as shown in **Figure 3.1**.

3.3 Experimental Setup

Experimental setup can be divided into two parts.

- Laboratory Equipment
- Preparation of experiment

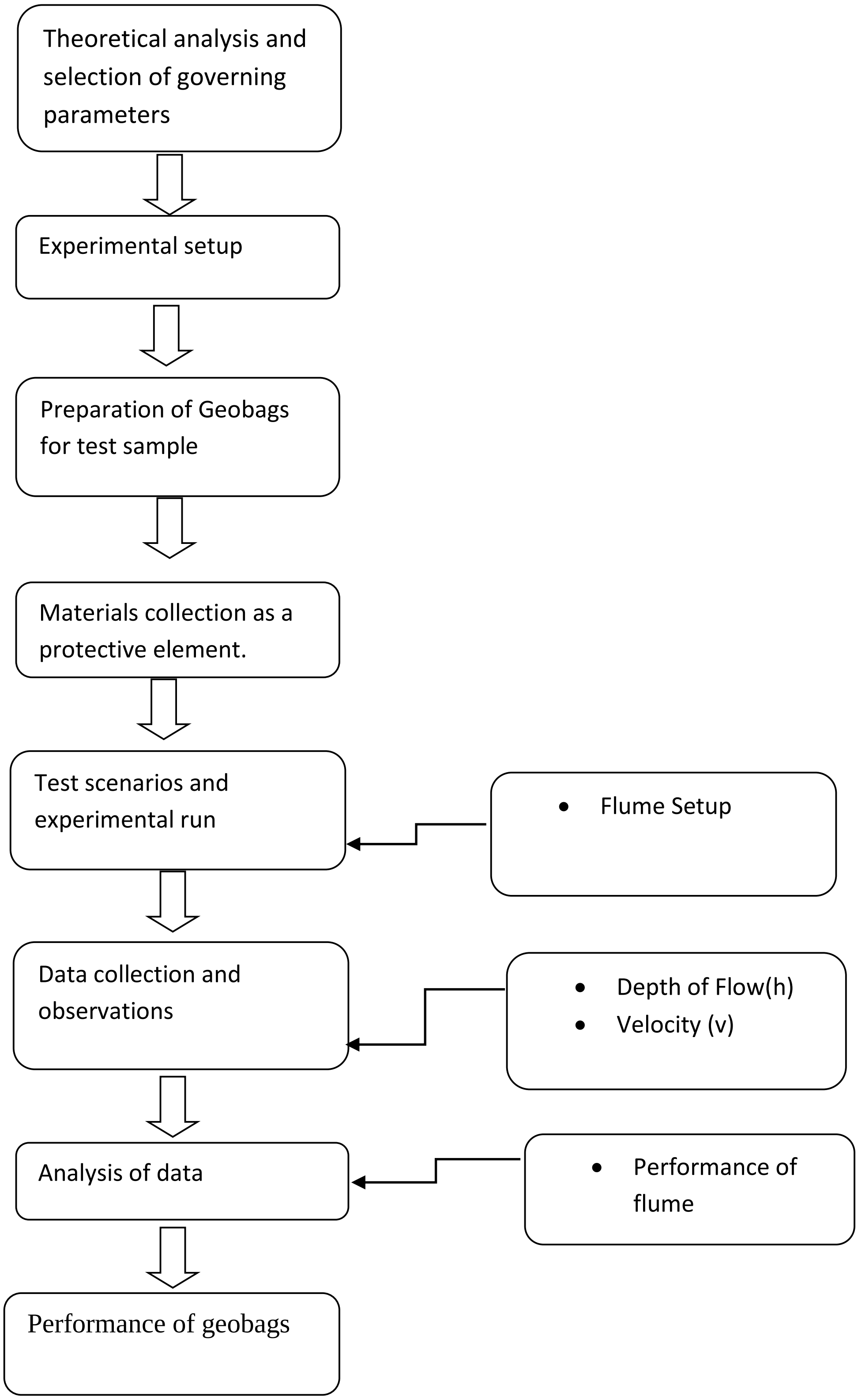


Figure 3.1: Flow diagram of methodology of the study.

3.3.1 Laboratory Equipment

To investigate the performance of proposed geobag and its volumetric sustainability, experimental studies are carried out in a two-dimensional wave flume at the Hydraulics and River Engineering Laboratory of Bangladesh University of Engineering and Technology, Dhaka. The following equipment were used:

i) Laboratory Flume

ii) Electromagnetic flow meter

iii) Current meter

iv) Point gage

v) Electronic weighing scale

Other necessary accessories used to conduct the experiment were stop watch, measuring tape water supply pipes etc.

i) Laboratory Flume

The flume used for the experimental run and data collection had an effective length of 70 ft, width 2.5 ft and depth 2.5 ft. It was rectangular tilting flume placed in the Hydraulics and River Engineering Laboratory, BUET.

The side walls of the flume are vertical and made of vertical clear glass. The bed is painted by water resistant color to avoid excess bed friction. It is supported on an elevated steel truss that spans the main supports. A tail gate is located at the end of the flume to control the depth of flow. Two pumps are there to supply water from the reservoir to the flume through a recirculation channel. Schematic diagram of the flume setup is shown in Figure 3.2.

ii) Electromagnetic Flow Meter

Discharge measurements are taken from the electromagnetic flow meter (Photograph 3.1) in the unit m^3/h. Magnetic flow meter is a volume flow rate meter for conductive fluids in pipelines. It allows measurement of flow rates in both direction. The flow through the pipe is controlled by the valve.

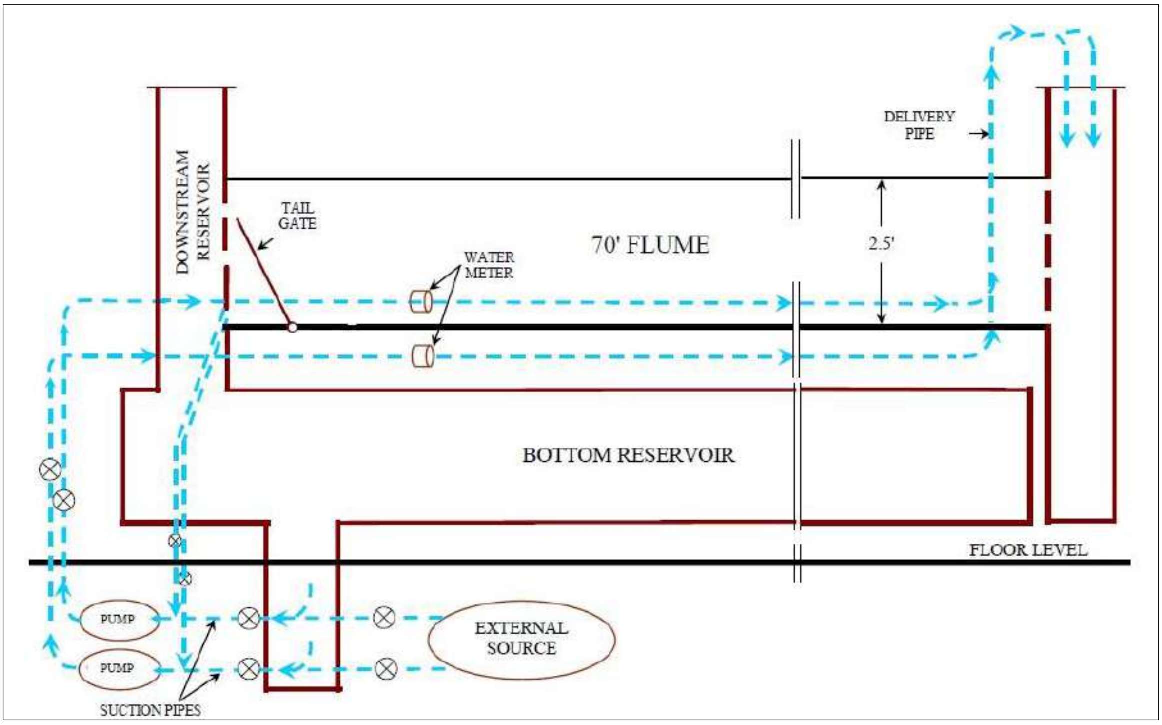


Figure 3.2: Schematic diagram of the experimental flume.

Photograph 3.1: Electromagnetic flow meter.

iii) Current Meter

A small current meter was used for velocity measurement (Figure 3.3). The current meter which was used during the experiment is classic propeller type. It consists of three basic parts: 50 mm diameter propeller, 1 m long 9 mm diameter rod and signal counter set. Minimum depth of water for using the instrument is approximately 4 cm. It is capable of measuring velocity from 3.5 cm/s to 5 m/s. Time and impulse measurement accuracy is ±0.01 seconds and ±0.5 impulses respectively.

The meter is lowered in water of the tank from the trolley by a suspension. The rate of rotation of the wheel depends on the velocity of flow and the meter facing the direction of flow a tail is attached. This tail aligns the meter in the direction of flow. The meter is also fitted with a streamlined weight which keeps the meter in a vertical position. An automatic revolution counter is kept by the operator with the battery which registers the revolutions. The number of rotations of the current meter propeller for various velocities is noted. The velocity of flow can be read from a calibration equation. From the readings a rating curve is prepared. It comes out to be a straight line and the equation is of the form

$V = aN + b$……………. (3.1)

Where V is velocity, N is revolutions of propeller per second and M and C are constants.

For this case values of constants a and b are 0.1334 and 0.029 respectively. Thus Equation 3.1 becomes

$V = 0.1334N + 0.029$……………… (3.2)

Figure 3.3: Current meter used in the study

iv) Point Gauge

The point gauge was used to measure water level in the flume. This point gauge was installed on top of wooden bar in a measuring bridge at different locations of channel.

v) Electronic Weighing Scale

Electronic weighing scale (Photograph 3.2) is a device to measure weight or calculate mass. Individual geobags which were prepared for test runs were weighed in the Electronic Weighing Scale for accuracy. It has a digital display which shows the mass quantity.

Photograph 3.2: Electronic Weighing Scale used in the study

vi) Sieve

For collecting sand sample sieve analysis has been done with some selected number of sieves (Photograph 3.3). They are given by the following table.

Table 3.1: Sieve sizes for sieve analysis

Sieve No	**Sieve Opening(mm)**
10	2.600
16	1.180
30	0.600
60	0.300
100	0.150
200	0.075

Photograph 3.3: Test Sieve used in the study

3.3.2 Preparation of Experiment

Preparation of experiment includes the following steps.

i) Broad-Crested Weir

ii) Preparation of flume

In the following section these has been described briefly.

i) Broad-Crested Weir

Placement of geobag in the flume will act as a broad crested weir in the fume. A broad-crested weir is an overflow structure with a truly level and horizontal crest. It is widely used in irrigation canals for the purpose of flow measurement as it is rugged and can stand up well under field conditions. But practically some problems arise with the weir, as there exists a dead water zone at the upstream of the weir and the head loss is more comparable to other devices. By virtue of being a critical depth meter, the broad crested weir has the advantage that it operates effectively with higher downstream water levels than a sharp crested weir. The broad-crested weir has a definite crest length in the direction of flow. In order to maintain a hydrostatic pressure distribution above the weir crest, i.e. to maintain the streamlines straight and parallel, the length of the weir is designed such that $0.07 \leq H1/L \leq 0.50$ where H1 is the head above the crest and L is the length of the weir (Figure 3.4). Under this condition, critical flow occurs over the weir at section A provides an excellent means of measuring dis of critical flow. The upstream corner of the weir is rounded in such a manner that flow separation does not occur.

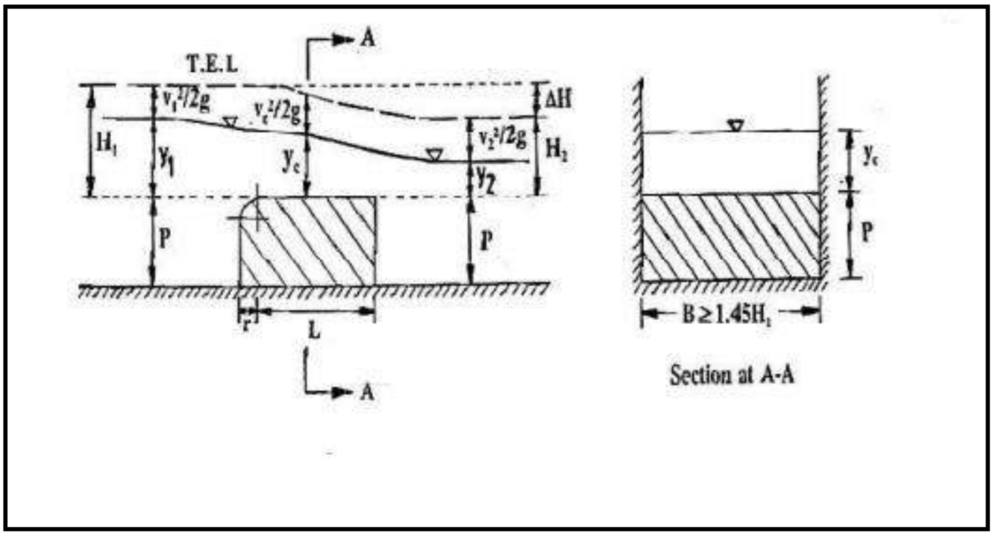


Figure 3.4: Schematic diagram of the flow over a broad-crested weir (Source: Sessional Manual on Open Channel Flow, WRE, BUET, 2018)

ii) Preparation of Flume

Experimental setup was developed in the Hydraulics and River Engineering Laboratory of the Department of Water Resources Engineering, BUET (Photograph 3.4). Geobags were placed in the flume according to the layout for different test run. The maximum possible discharge was taken as 200 l/s. During the test runs different hydraulic parameters like velocity, water depth etc. for discharge 200 l/s and 100 l/s was maintained. Current meter was used for the measurement of velocity at 0.2, 0.6, 0.8 times of total depth of water in both downstream and upstream of the flume. Geobags were placed at the middle section of the flume for the experimental run.

Photograph 3.4: Flume in the Hydraulic and River Engineering Laboratory

3.3.3 Preparation of geobags for test sample

This section consists of the following points. They are discussed below.

i) Prepare Filler Material

ii) Prepare Geobags

i) Prepare Filler materials

Two types of sand samples from river bed deposits was selected as filler material (i) **Specified sand** and (ii) **Unspecified Sand**. As per BWDB specification the size of specified sand was taken as less than 2.6 mm. Firstly this specified sand was free from silt, clay, vegetable roots etc. and was directly collected from the bank of the Turag River at Gabtoli Site. Secondly some of the local sand like *"**Vit bali**"* which contains silt, clay, vegetable roots etc. was randomly collected from Turag river bank at near Birulia bridge, Savar and some was collected from Turag river bank at Rustampur, Savar. Collected sands were transported to the laboratory for sieve analysis. Both types of soil which were collected from different locations were then kept at different place at laboratory carefully so that they were not mixed with each other. Photographs 3.5(a) and 3.5(b) shows the sand collection from site and unspecified and specified sand at photograph 3.6(a) and 3.6(b).

	
Photograph 3.5 (a): Local Sand collection from Site (Birulia bridge, Savar, Date:01.09.20)	**Photograph 3.5 (b): Local Sand collection from Site (Rustampur, Savar, Date:03.09.20)**

	
Photograph 3.6(a): Unspecified sand sample	**Figure 3.6(b): Specified sand sample**

After that sieve analysis had been done, the FM value of Specified and unspecified sand had been calculated. A total of six samples were collected for sieve analysis, three from specified and three from unspecified sand. For specified sand sample, after sieve analysis the average fineness modulus (F.M) was found 1.27 which was greater than 0.90 and average percentage of silt and clay was 0.73%. For unspecified sand sample, after sieve analysis the average fineness modulus (F.M) was found 0.69 which was less than 0.90 and average percentage of silt and clay was 34.18%.

Photograph 3.7(a): Sieve analysis (1)	Photograph 3.7 (b): Sieve analysis (2)

Fineness modulus and grain size distribution tests of the samples were done using ASTM Standard test procedures.

The grain size distribution can be seen from sieve analysis for the both specified and unspecified sand by the value of the particle diameter at 50% in the cumulative distribution. Particle size distribution d_{50} is also known as the median diameter or the medium value of the particle size distribution. From the sieve analysis curve determined average particle diameter (d_{50}) for specified sand is 0.25 mm and for unspecified sand is 0.18mm. The grain size distribution curves of the soil samples are presented in Figure 3.5(a) and 3.5(b) and relevant physical properties are listed in Table 3.2.

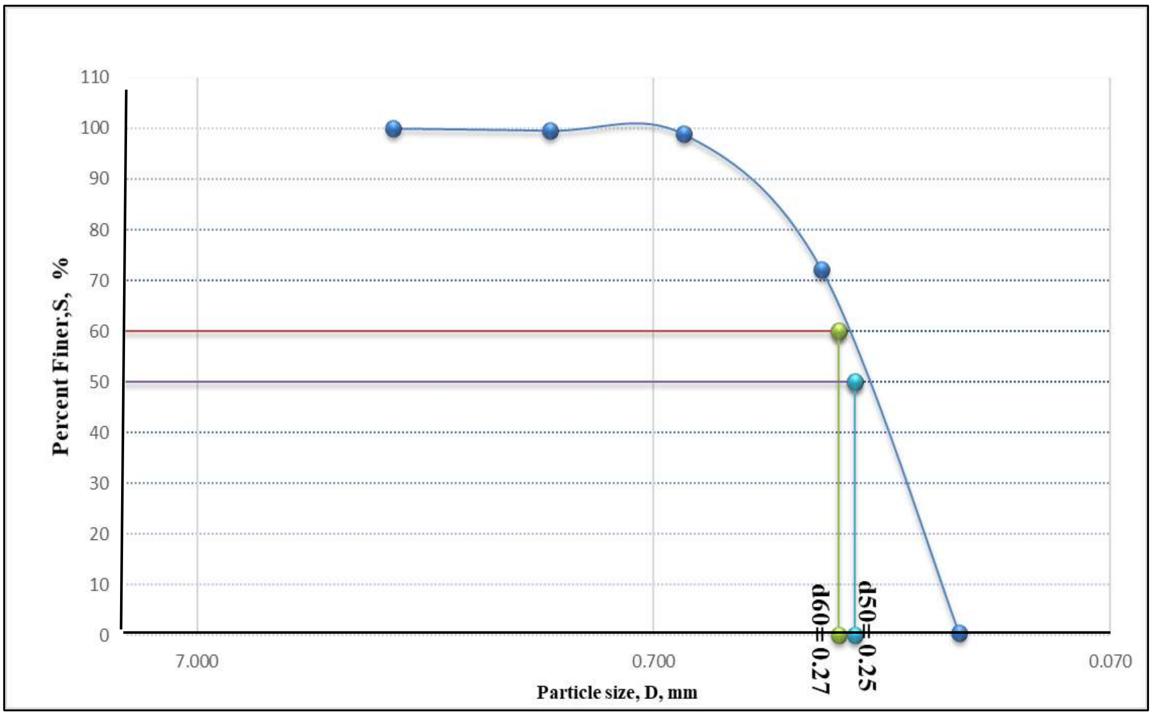


Figure 3.5 (a): Grain size distribution curve for specified Samples

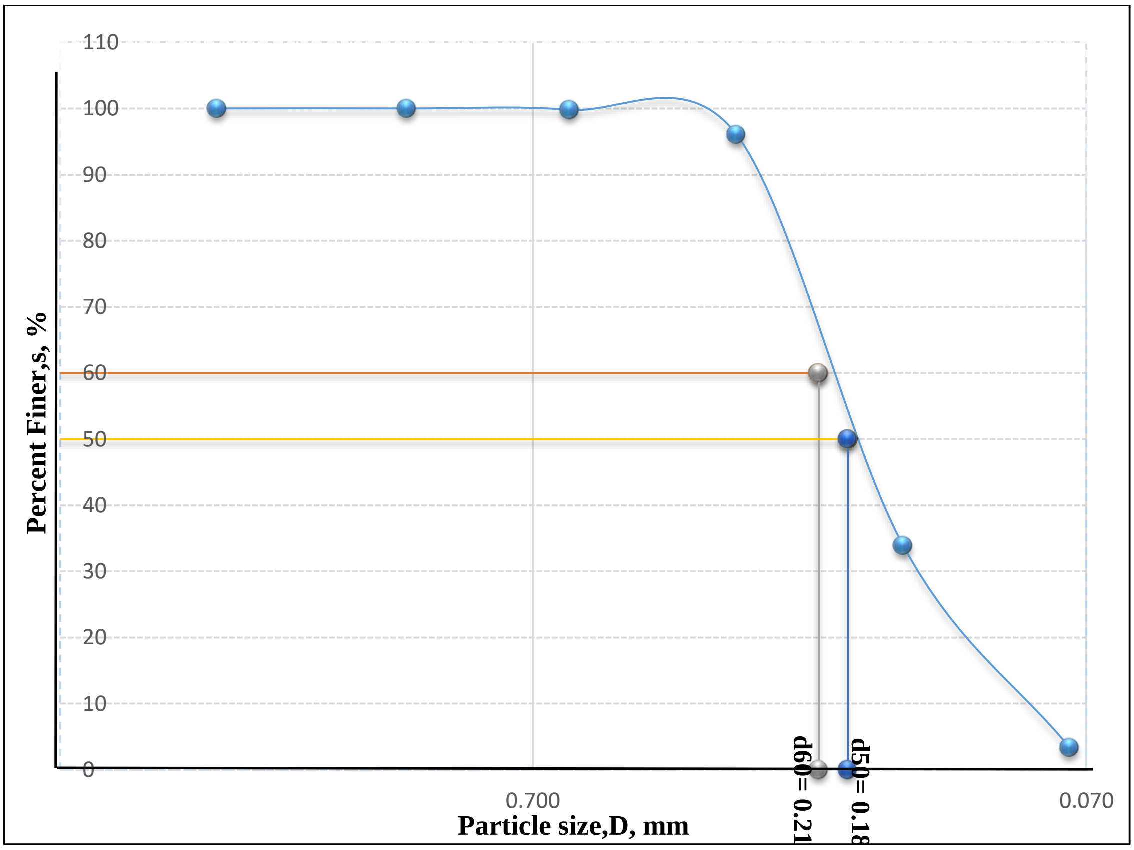


Figure 3.5 (b): Grain size distribution curve for unspecified Samples

Table 3.2: FM, grain size distribution and classification of sands used in the study

Item No	Properties	Values of parameters	
		Specified Sand	**Unspecified Sand**
1	Fineness Modulus (FM)	1.27	0.69
2	d_{60} (mm)	0.27	0.25
4	d_{50} (mm)	0.21	0.18
5	Silt and Clay	0.73 %	34.18%

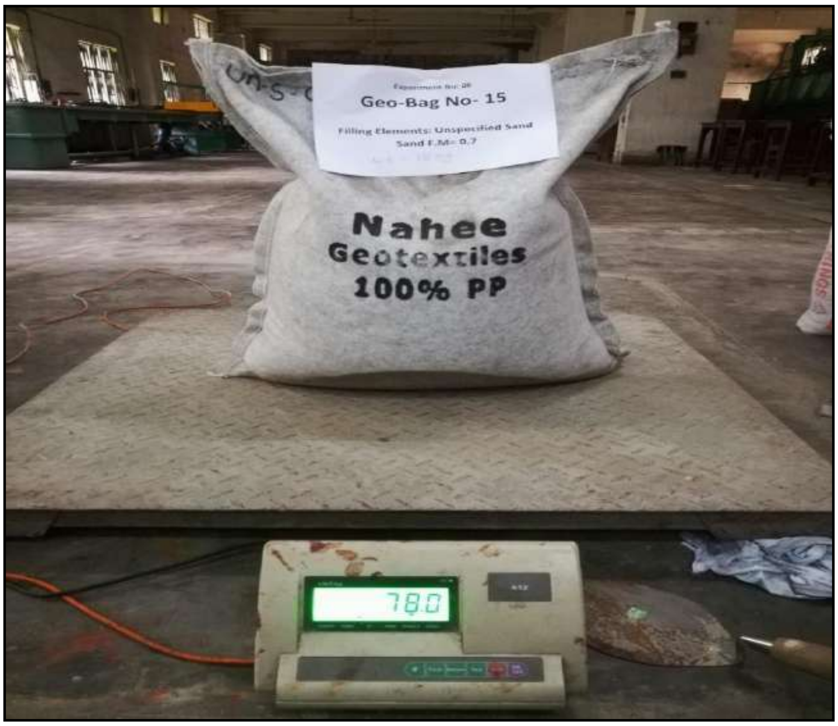
ii) Preparation of geobag

As per BWDB specification, locally fabricated geotextile bags size is 0.8m x 0.65m and the thickness of fabric is 3.0 mm. After filling with dry sand the inner size of the geobags became 0.85.m x 0.70m. Two lines of stitching was provided at each side of the bag. The geobags were manufactured from polypropylene fabric, which is non-woven & needle-punched & not solely thermally bonded. These geotextile bags have a density of about 400 g/sqm. At first the weight of sand was measured and poured into the one side open bag. Then it was sewed to close the bag properly. The final shape was rectangular and looks like a pillow. The following Photographs 3.8(a) and 3.8(b) shows the empty geobag and sand filled geobags respectively.

Photograph 3.8(a): Geo-textile bag (empty)

Photograph 3.8(b): Bags filled with sand

The weight of the sand was selected as 78 kg for each bag. This weight was selected to make the experiment scenario more practical for riverbank protection. Following Photograph 3.9 shows the weighing 78 kg of each bag and Photograph 3.10 shows the sand filled geobags.



Photograph 3.9: Geobag weighing 78 kg

Photograph 3.10: Sand filled geobags before experiment

3.4 Test scenarios:

Total 8 experimental runs were performed with geobags filled with specified and unspecified sand. The layout of the geobags, water depth and discharge were different in each experiment. The overall test scenario is given in the following table for better understand.

Table 3.3: Test Scenario

Sl	Protective Element	Elements Specification	Layer	Discharge (l/s)
1	Geobag	Specified	One Layer one Bag	200
2				100
3	Geobag	Specified	Two Layer three Bags	200
4				100
5	Geobag	Unspecified	One Layer one Bag	200
6				100
7	Geobag	Unspecified	Two Layer three Bags	200
8				100

3.5 Test Procedure:

After preparing the geobags filled with specified and unspecified sand the experiments were performed in the laboratory. According to the test scenario all 8 experimental test runs were completed. Experimental test runs were conducted in one and two layers of geobags. **Figure 3.6** and **Figure 3.7** shows the schematic layout of geobags of the experimental test run.

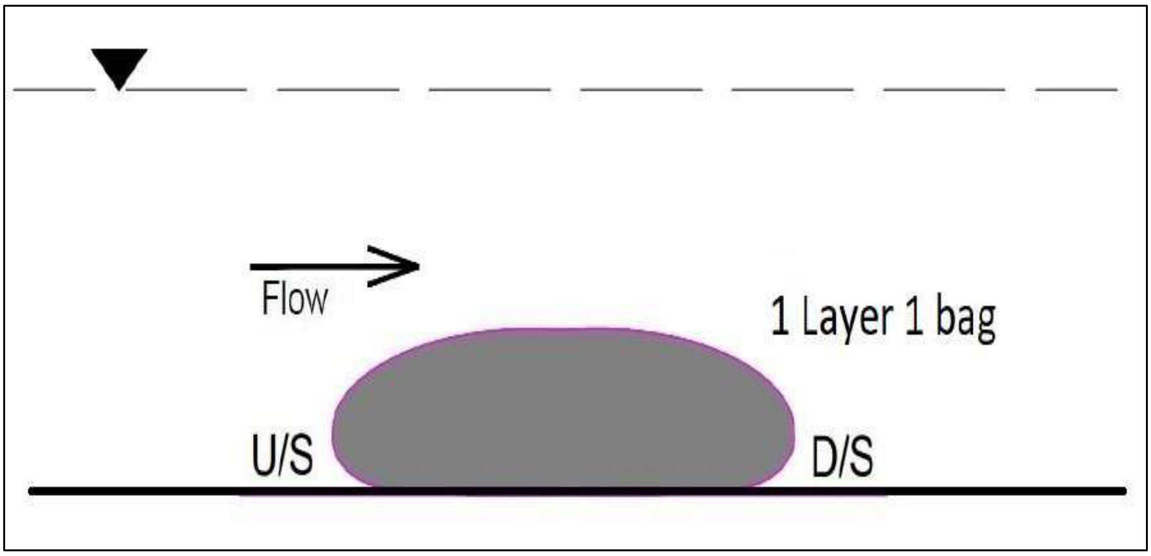


Figure 3.6: Schematic layout of geobag for one layer one bag.

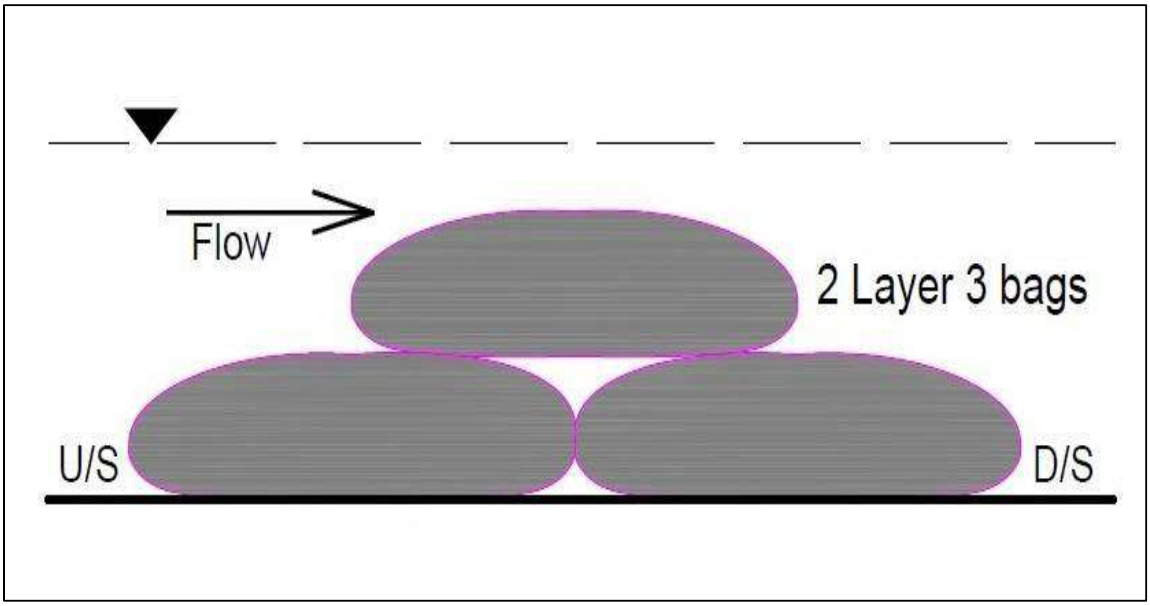
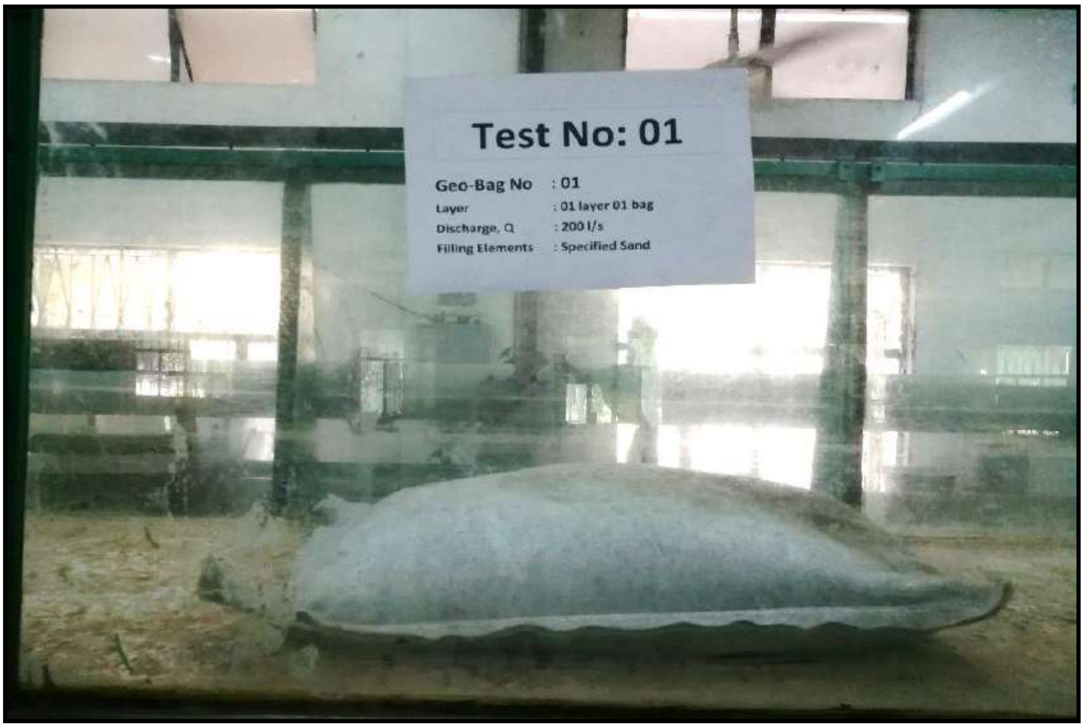


Figure 3.7: Schematic layout of geobag for two layer three bags.

Firstly, in the 1st and 2nd test run for one layer of one bag filled with specified sand was placed which was parallel to the flume and in the middle section of the flume. Maximum discharge of the two pumps together was about 190 l/s to 200 l/s and minimum 100 l/s was given in the flume. Two individual geobags were used for these two runs. Depth of water and velocity was measured by point gauge and current meter, respectively. Flow condition was observed by adding color at the upstream of the test section.

Secondly, in 3rd and 4th experimental test runs, two layers of three bags (at the bottom layer there will be two bags, and on bag at the top) filled with specified sand was placed parallel and at middle section of the flume. A flow of maximum 200 l/s and minimum 100 l/s were given for the third and fourth experimental test run.

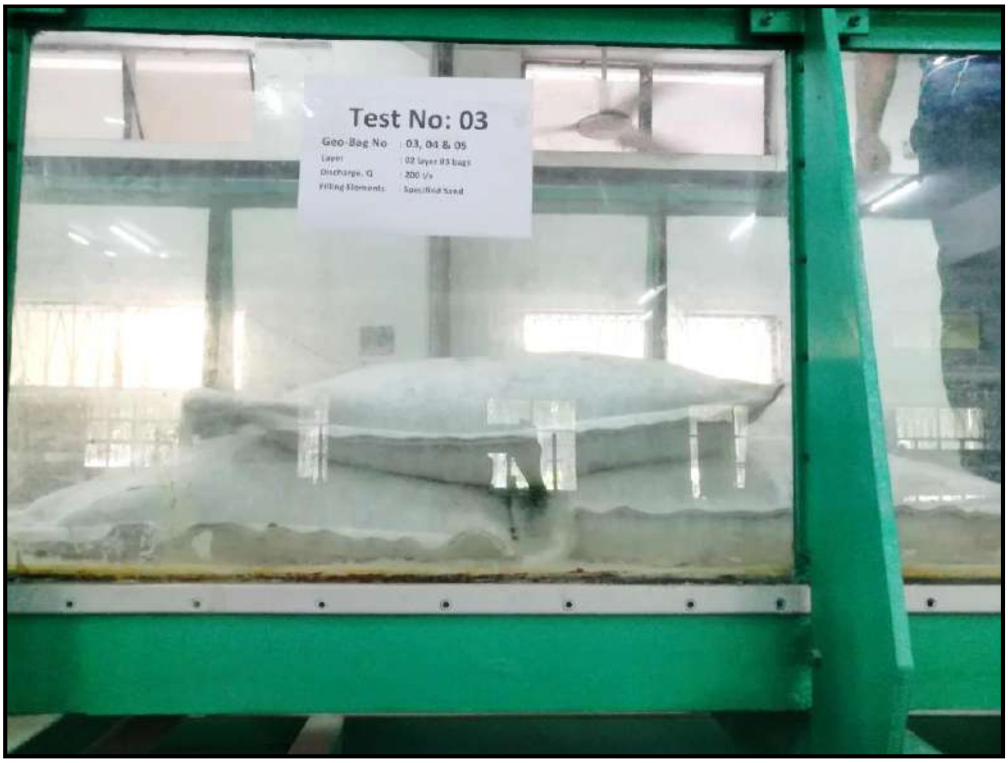
Same procedure was followed for geobags filled with unspecified sand in the 5th, 6th, 7th and 8th experimental test runs. Water level was changed by adjusting the tail gate at the end of flume as required. All eight experimental runs were performed for around 8 hours and water samples were collected for volumetric analysis at 60-minute interval. **Photograph 3.11** to **Photograph 3.16** show the one layer of one geobag and two layers of three geobags placed on the flume bed.



Photograph 3.11: One layer of one geobag placed on flume bed (side view)

Photograph 3.12: One layer of one geobag placed on flume bed (top view)

Photograph 3.13:One layer of one geobag placed on flume bed (front view)



Photograph 3.14: Two layers of three geobags placed on flume (side view)

Photograph 3.15: Two layers of three geobags placed on flume (front view)

Photograph 3.16: Two layers of three geobags placed on flume (top view)

3.6 Summery

In this chapter the methodology and the experimental setup was discussed. Also the procedure of the experiments that has been followed for completion of the thesis work was discussed. The details of the materials used for filling the geobags that is specified or unspecified sand were also given in this chapter. This chapter also contains the details of the preparation of geobags for experimental run.

CHAPTER FOUR

FLOW OBSERVATION AND DATA ANALYSIS

4.1 Introduction

Laboratory experiments have been conducted to investigate the behavior of geobags at different placement was observed in this study which has been discussed earlier in the previous chapter. In this chapter test run, flow observation, sample collection and data analysis will be discussed in details. For each experiment the water level, velocity measurement and volumetric analysis will be performed for determining the output of the experiment.

4.2 Data Observation

Data observation contains the observation of flow condition, measurement of flow depth, velocity and collection of water sample for volumetric analysis of sediment.

4.2.1 Observation of flow condition

Geobags were subjected to hydrodynamics forces and shear caused by the water flowing over them, where gravity force of the bags were the main stabilizing force to hold the geobags in place. Position and the hydraulic condition in the vicinity of the geobags under the action of flowing water was observed for each experimental test run as summarized in **Table 3.1**. Color dyes were used to observe the flow dynamics around the test geobags. Each experiment was carried out through recording of water level, flow rates, flow paths etc. **Photograph 4.1** shows the flow condition after applying color dye during run.

Photograph 4.1: Flow condition after applying color.

4.2.2 Measurement of water depth and velocity

During the flow, depth of water level at upstream and downstream section was determined in the flume. A point gauge was used for measuring the water depth. The measured water depth and velocity in the eight experiments is given in the following **Table 4.1**

Velocity measurements were taken after run had been stable, geobags did not move and became static because gravity force on the bags are the main stabilizing force to hold the geobags in place. Current meter was used for the measurement of velocity at 0.2, 0.6, 0.8 times of total depth of water in both downstream and upstream of the flume. By this method some of the readings were taken. The average velocity at the upstream section and downstream was required for the analysis.

Table 4.1 Water depth and velocity measurement during experimental test run for both u/s and d/s side.

Exp. Test run	Depth of flow, (U/S), cm	Velocity, u/s (m/s)		Water Depth (D/S), cm	Velocity , d/s (m/s)	
		Middle of flume	Right side of flume		Middle of flume	Right side of flume
1	42	0.77	0.73	10	2.22	2.26
2	33	0.49	0.46	6	1.85	1.86
3	53	0.60	0.61	12	2.23	2.83
4	39	0.32	0.29	6	1.88	1.94
5	42	0.77	0.75	11	2.33	2.35
6	33	0.51	0.47	6	1.86	1.87
7	53	0.60	0.60	12	2.22	2.84
8	35	0.32	0.30	6	1.89	1.96

Photograph 4.2: Velocity Measurement by current meter during experimental test run

4.2.3 Collection of Water Sample

Velocity was measured during the test run by using current meter. Water with different discharges flow through the flume for about 8 hours in each test run. During the run, sediment mixed water samples were collected starting from 2 hours and at 60-minutes interval for concentration analyses by dry weight method. This sample was collected at upstream and/or downstream sections near the geobags. **Photograph 4.3** and **Photograph 4.4** shows the sample collection during test run from d/s and u/s, respectively.

Figure 4.3: Sample collection from d/s of test section

Figure 4.4: Sample collection from u/s of test section

4.3 Analyses for Volumetric Assessment

Water sample was collected to perform the assessment of sediment concentration. After collecting the sample water was kept in the beaker for 15 to 20 minutes for settlement **(Photograph 4.5)**. A visual observation was done initially before drying in the oven if there is any sand particle was present or not **(Photograph 4.6)**. Then the beaker with sample was oven dried **(Photograph 4.7)**. After drying in the oven if sand particles were found then weight of the sand particles were measured for further analysis. After the experiments, volumetric sustainability of geobags for different discharges were assessed.

Photograph 4.5: Collected sediment mixed water samples during experiments

Photograph 4.6: Visual observation of sediment samples during the experiment

Photograph 4.7: Placement of collected sample on the oven for drying

CHAPTER FIVE
RESULT AND DISCUSSION

5.1 Introduction

In the previous chapter a detailed discussion has been done about the observations during experiments. The methodology of various observations was also discussed. It also contains the measurement of water depth and velocity of each experiment. After observing the flow condition, a volumetric concentration analysis has been done to find out the material concentration in the test beaker. This chapter has highlighted the volumetric concentration analysis and a short discussion on the result.

5.2 Results of Volumetric Analysis

For volumetric analysis, sediment mixed water samples were collected for each experimental test run. After about two hours of test run, water sample was collected in a 400 ml beaker. At about every 60 minutes' interval, these samples have been collected to observe the presence of sediment in water. A total of eight samples were collected for an experimental run, starting from two hours (t=2h) and continued till about eight hours (t=8h). In the test runs for specified sand, there were no loss of sediment from the geobag. But for the test runs with unspecified sand, very small amount of sand had been found in the water sample collected in the Beakers (B1~B8). **Table 5.1** shows the weight of sand in each collected sample during the experimental test runs.

Table 5.1 Amount of sand found in the collected samples

Ex. Test Run	(t=2h) B-1 wt. (gm)	(t=2.5h) B-2 wt. (gm)	(t=3h) B-3 wt. (gm)	(t=4h) B-4 wt. (gm)	(t=5h) B-5 wt. (gm)	(t=6h) B-6 wt. (gm)	(t=7h) B-7 wt. (gm)	(t=8h) B-8 wt. (gm)	Avg. wt. (gm)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	1.00	1.00	1.10	1.10	1.20	0.90	0.90	0.90	1.00
6	0.90	0.90	0.90	1.10	1.10	0.80	0.80	0.80	0.90
7	1.00	1.20	1.20	1.20	1.30	1.30	1.20	1.20	1.20
8	1.00	1.10	1.20	1.20	1.30	1.00	1.00	1.00	1.10

The average value of the sand found from each sample was taken for further analysis. The following **Table 5.2** shows the summery of the volumetric analysis and the sand concentration was found in mg/l.

Table 5.2 Result of Volumetric Analysis

Exp. Test Run	Sand Type	Layer	Water Depth (m)		Flow Discha-rge (l/s)	Sample Water Collection (mL)	Sand in Sample water (gm)	Concentration (mg/l or ppm)
			u/s	d/s				
1	Specified	1 Layer 1 bag	0.42	0.10	200	400	0	0
2	Specified	1 Layer 1 bag	0.33	0.06	100	400	0	0
3	Specified	2 Layer 3 bag	0.53	0.12	200	400	0	0
4	Specified	2 Layer 3 bag	0.33	0.06	100	400	0	0
5	Unspecified	1 Layer 1 bag	0.42	0.11	200	400	1	2500
6	Unspecified	1 Layer 1 bag	0.33	0.06	100	400	0.9	2250
7	Unspecified	2 Layer 3 bag	0.53	0.12	200	400	1.2	3000
8	Unspecified	2 Layer 3 bag	0.35	0.06	100	400	1.1	2750

5.3 Discussion on Volumetric Analysis

From the above **Table 5.2,** it is found that geobags filled with specified sand can withstand in different flow condition and it is sustainable. On the other hand, geobags filled with unspecified sand discharges minor amount of filler material from the bags for different flow condition. Very fine particles adjacent to the top surface (outer part) of the geobag is expected to come out (loss of sediment). However, very fine particles at the inner part (core area) of the geobag is very unlikely to come out of the geobag. This phenomenon is shown schematically in **Figure 5.1** (1 layer 1 bag condition) and **Figure 5.2** (2 layer 3 bag condition).

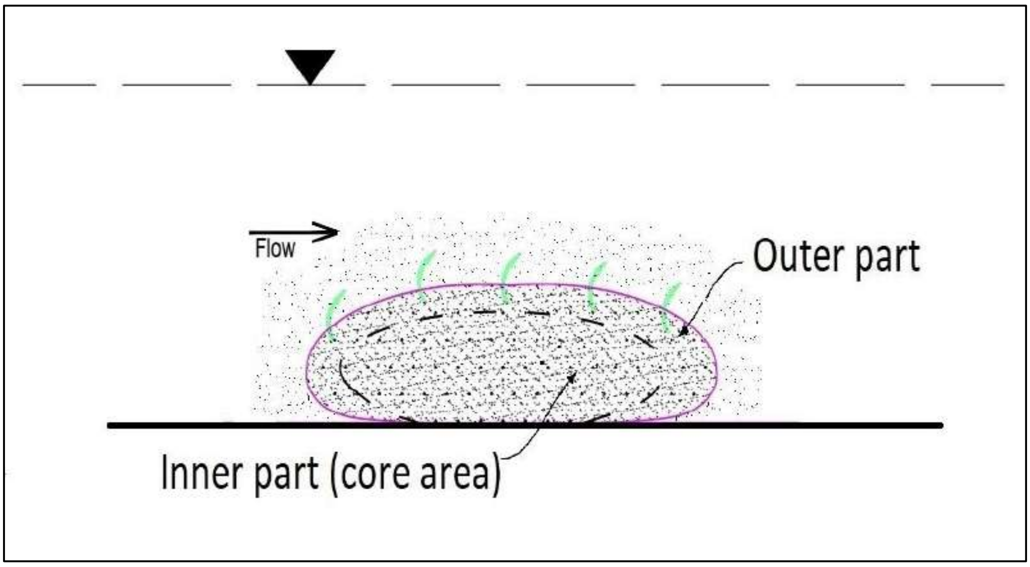


Figure 5.1: Possible mode of sediment loss from geobag filled with unspecified sand during experiment in 1 layer 1 bag condition

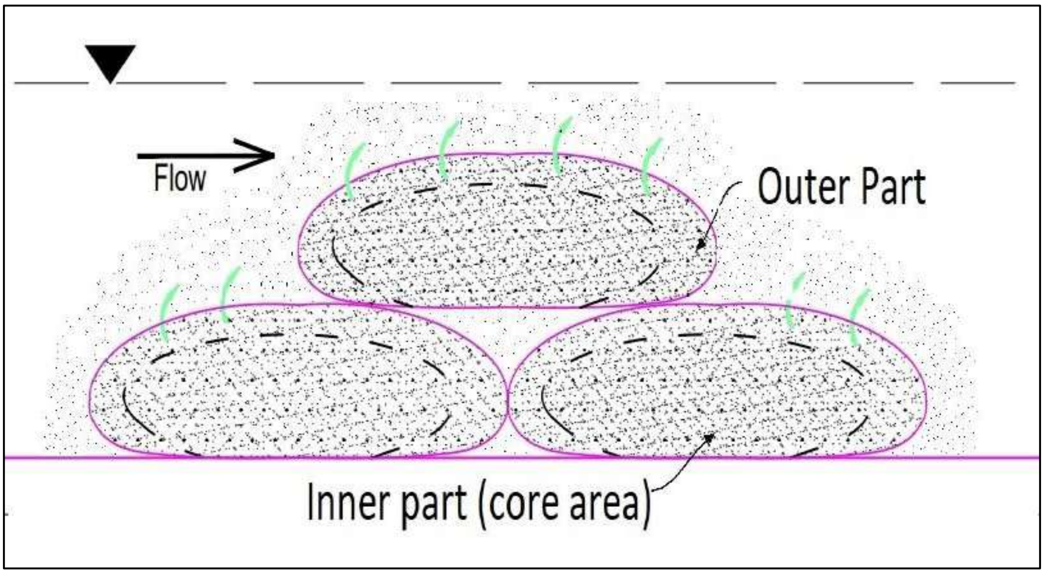


Figure 5.2: Possible mode of sediment loss from geobag filled with unspecified sand during experiment in 2 layer 3 bag condition

Geobags filled with unspecified sand for one layer one bag setup, the average sediment concentration in the flowing water adjacent to the geobag is about 2250 mg/l and 2500 mg/l during 100 l/s and 200 l/s flow discharge, respectively. Whereas two layer three bags filled with unspecified sand, the average sediment concentration in the flowing water adjacent to the geobag is about 2750 mg/l, 3000 mg/l of sand during 100 l/s and 200 l/s flow, respectively.

Surface area of an empty geobag of 78 kg weight is 0.50 m^2. Hence, one layer one geobag has surface area of 0.50 m^2 and two layer three geobags have surface area of 1.0 m^2 which is exposed to the flow (**Figure 5.1 and Figure 5.2**). So, it can be said that the sediment is losing from this surface area. Therefore, for a single bag, the average sediment concentration per square meter bag area becomes 4.5 gm/l for 100 l/s of flow discharge and 5.0 gm/l for 200 l/s of flow discharge. On the other hand, for two layer three bag the average sediment concentration per square meter bag area becomes 2.7 gm/l for 100 l/s flow discharge and 3.0 gm/l for 200 l/s flow discharge. It appears that few parameter/phenomena (e.g. water depth adjacent to the geobag, shear force acting on the geobag, vortices generated etc.) might be responsible for the non-linear sediment loss from the geobag for single layer and double layer setup. For one layer one bag filled with unspecified sand, the average sediment concentration is less when the flow (discharge) is high. For two layers three bags the average sediment concentration is less when the flow (discharge) is less.

Hence, it is apparent that if the geobags are filled with sand according to specification then the possibility of failure during heavy flow in the river is negligible in respect to sediment loss from the geobags. On the other hand, if it is difficult to provide specified sand and unwillingly unspecified sand is used, a high possibility is there to fail the bank protection works during heavy flow due to sediment loss from the geobags.

5.4 Observation on Velocity Measurement

Velocity distribution profile of eight experiments are given from **Figures 5.3** to **Figures 5.18**. Each experiment has upstream and downstream profile. Form these figures it is found that velocity varies with the change of depth. Some important factors dominate the increase and decrease of velocity during the experiments. Number of layers, number of geobags, flow condition etc. are some of the parameters that influence the variation of velocity. Experiment details are previously shown in **Table 5.2.**

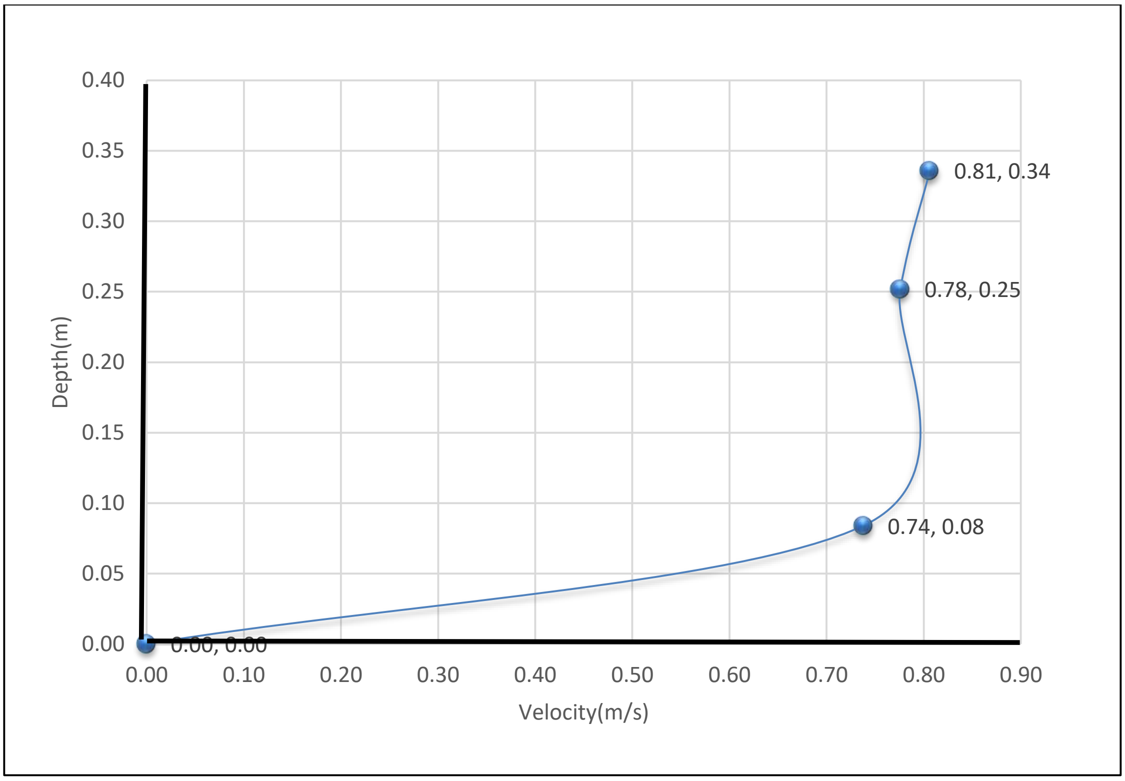


Figure 5.3: Depth Vs Velocity (Exp test run-1, u/s)

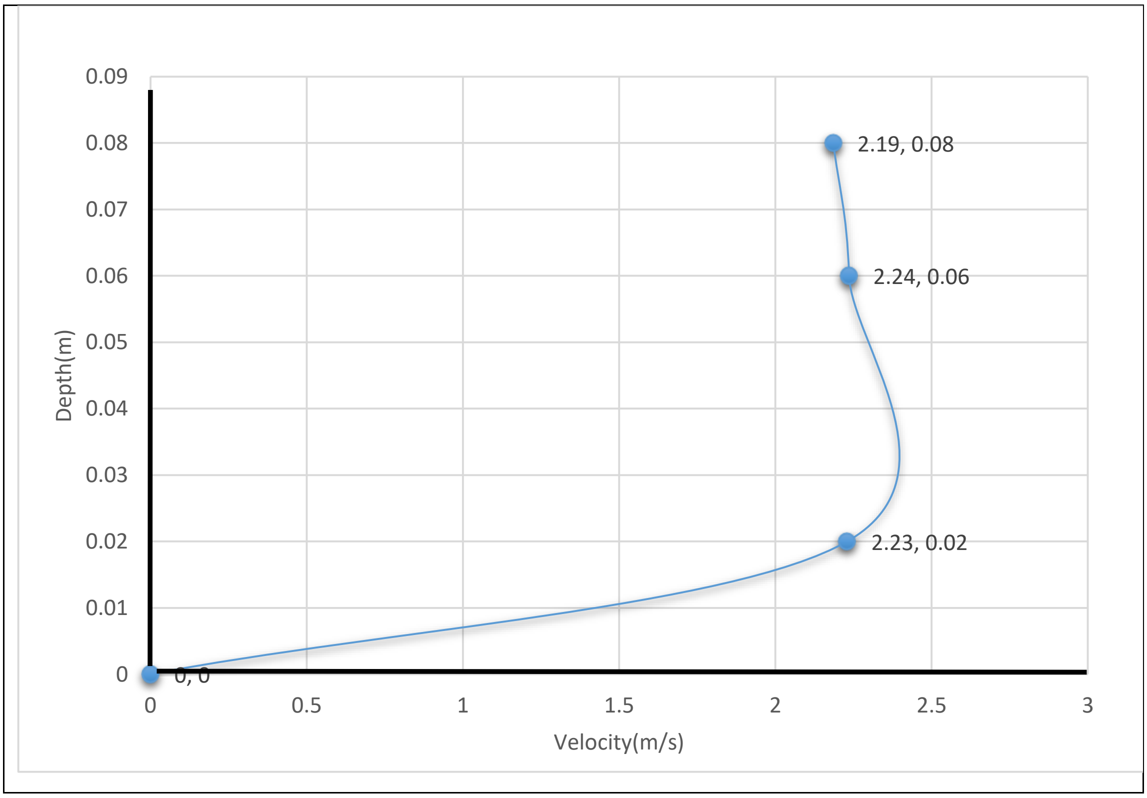


Figure 5.4: Depth Vs Velocity (Exp test run -1, d/s)

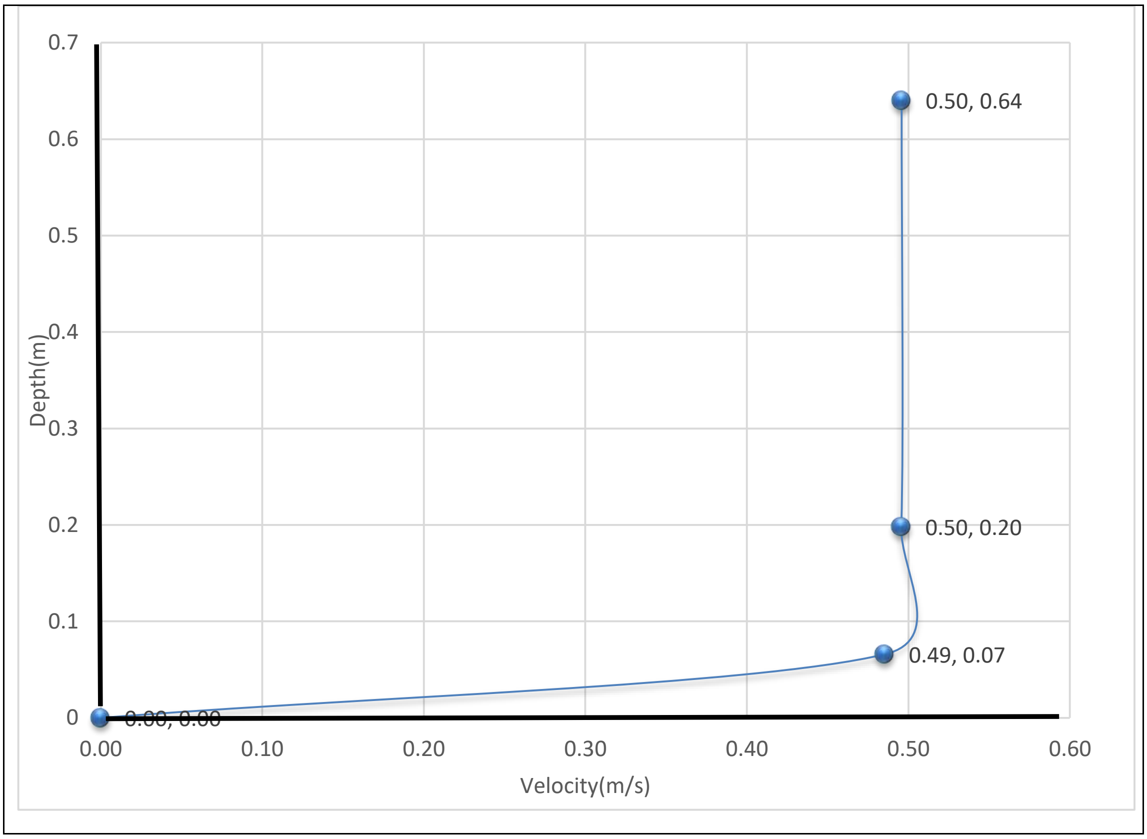


Figure 5.5: Depth Vs Velocity (Exp test run -2, u/s)

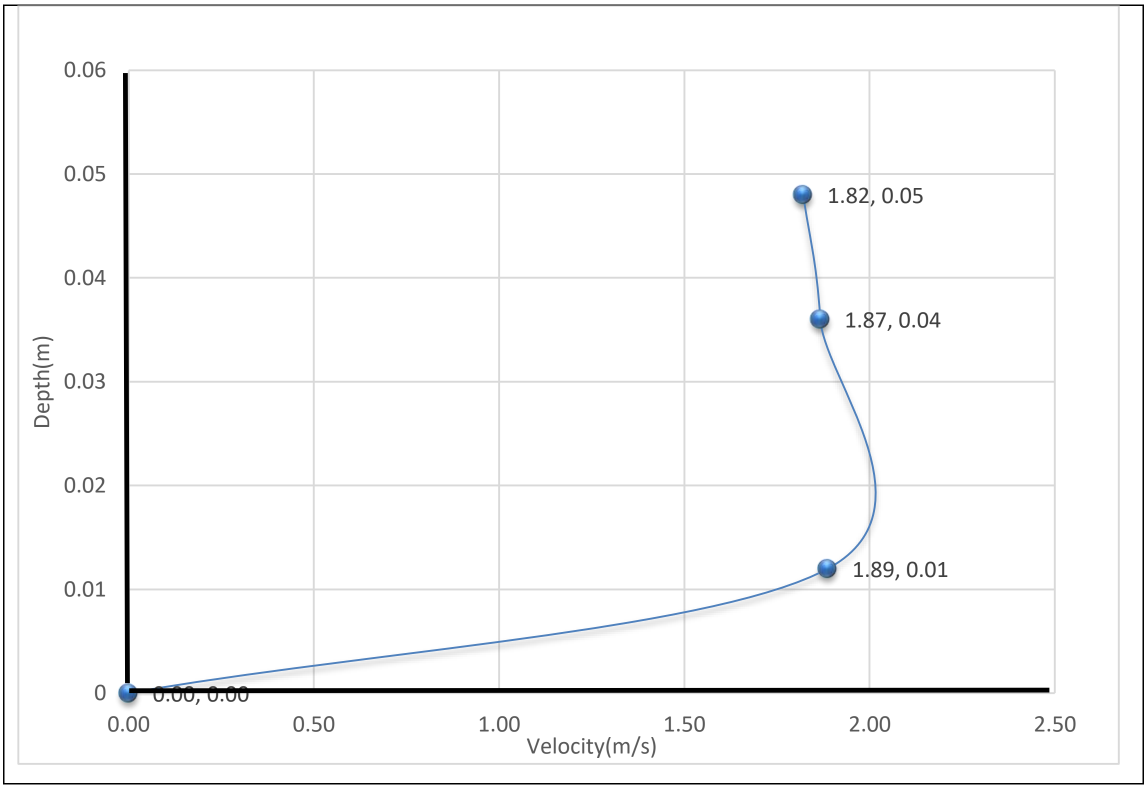


Figure 5.6: Depth Vs Velocity (Exp test run -2, d/s)

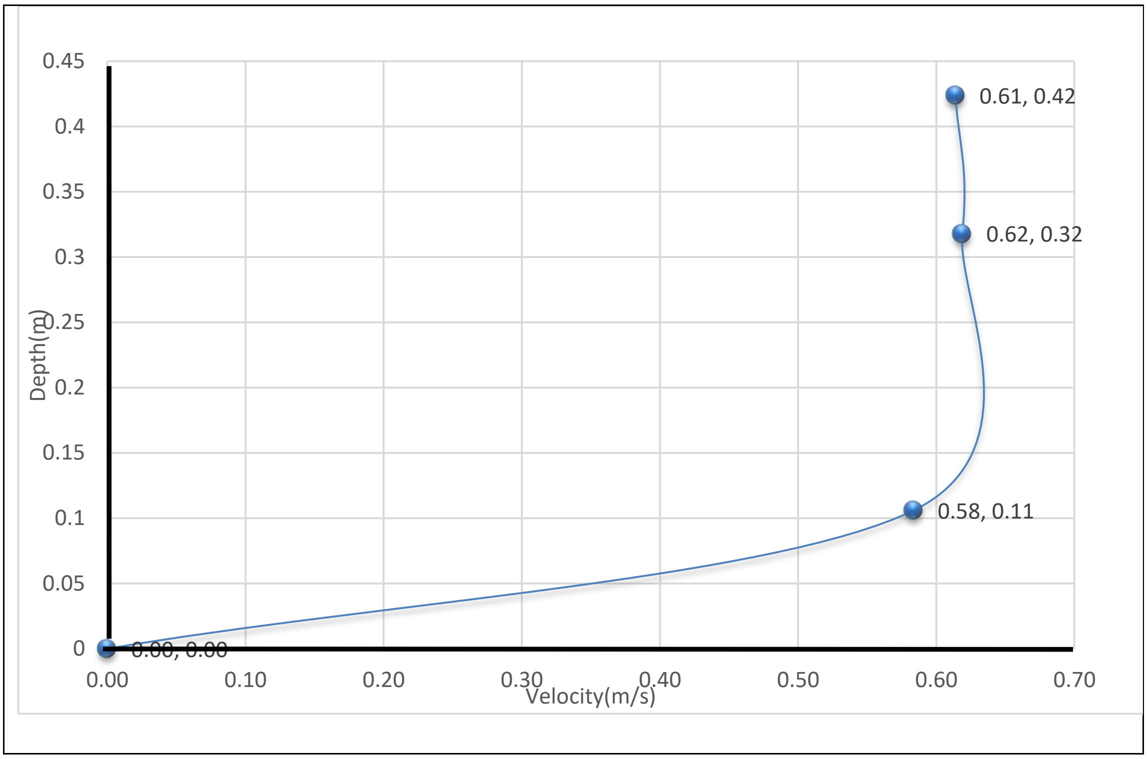


Figure 5.7: Depth Vs Velocity (Exp test run -3, u/s)

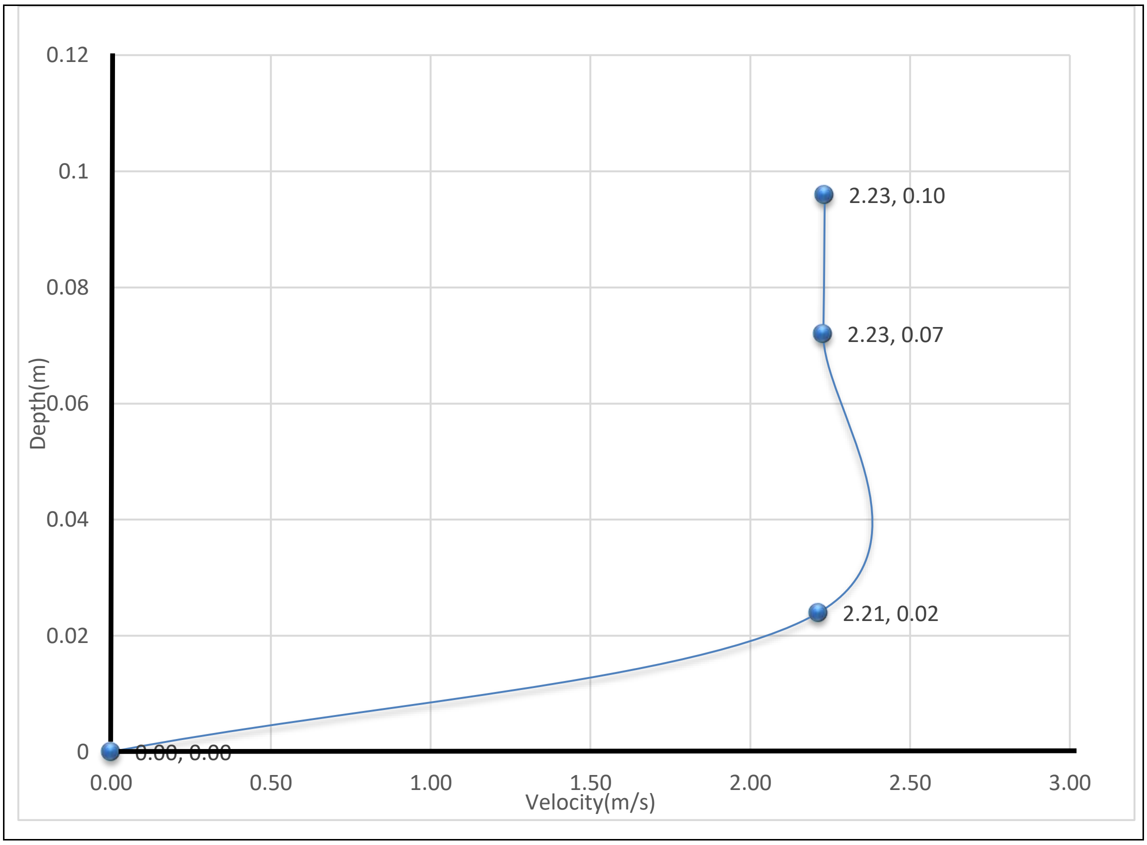


Figure 5.8: Depth Vs Velocity (Exp test run -3, d/s)

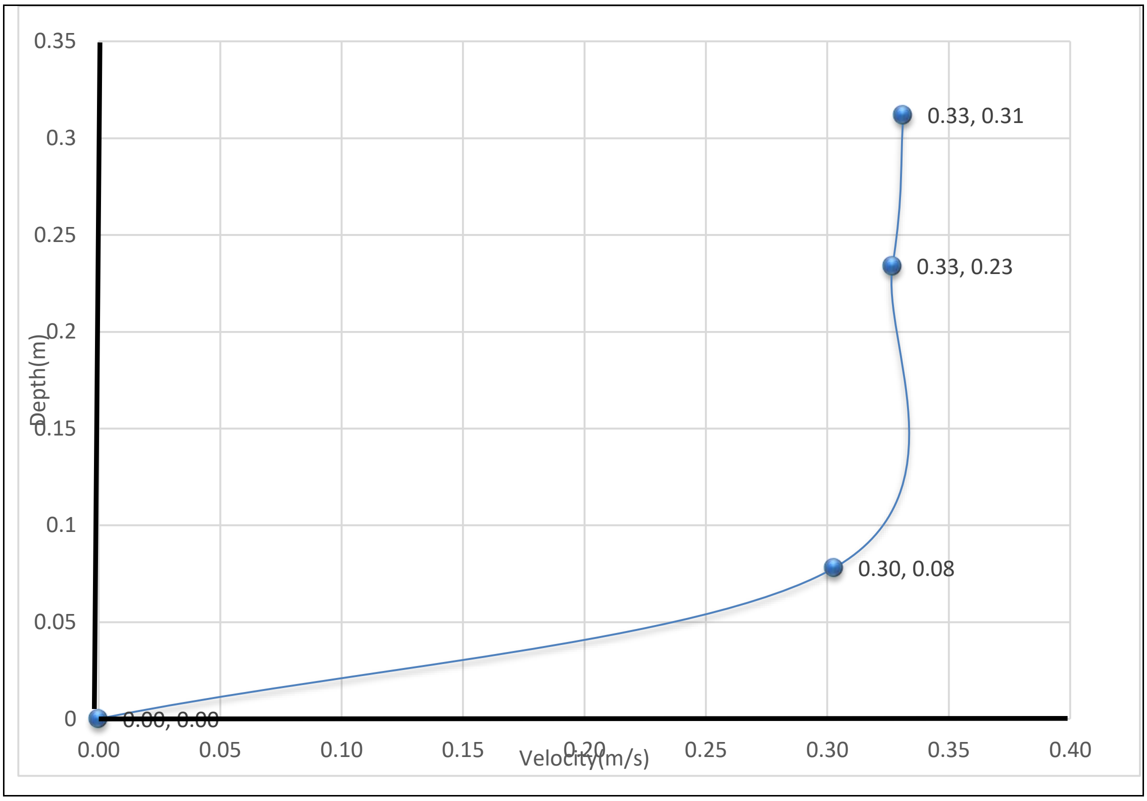


Figure 5.9: Depth Vs Velocity (Exp test run -4, u/s)

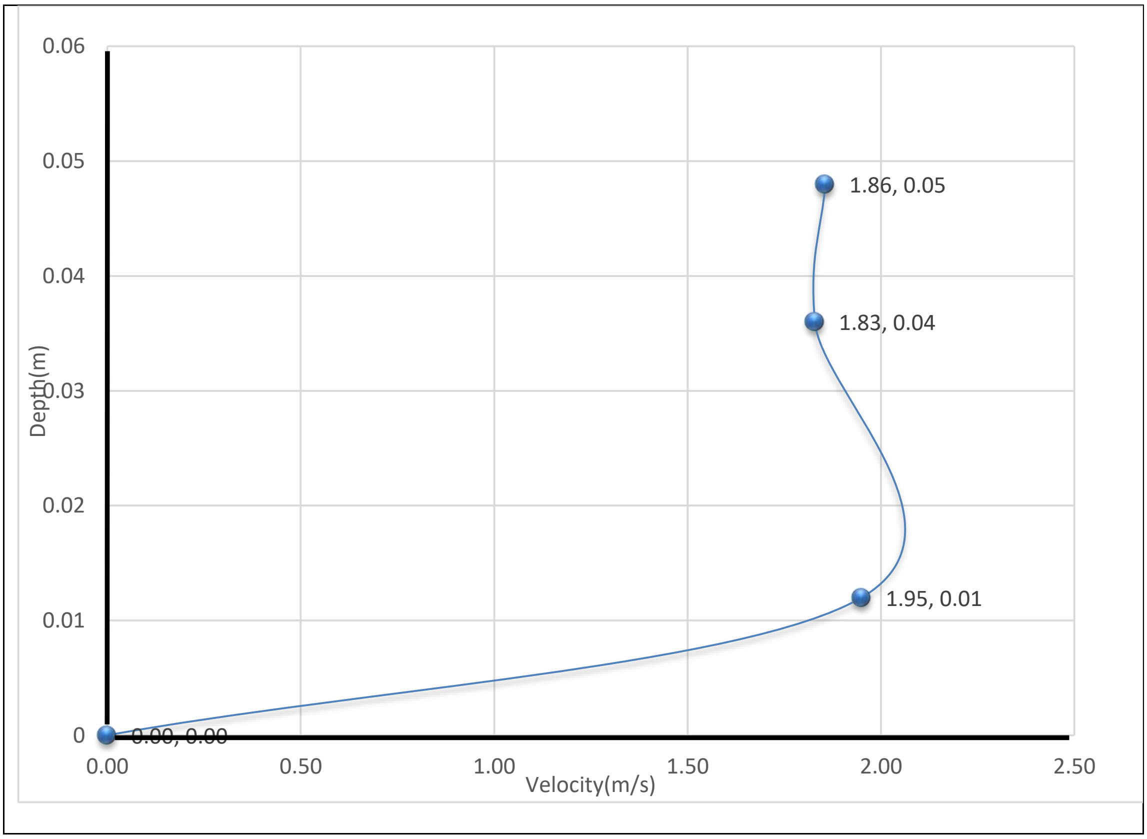


Figure 5.10: Depth Vs Velocity (Exp test run -4, d/s)

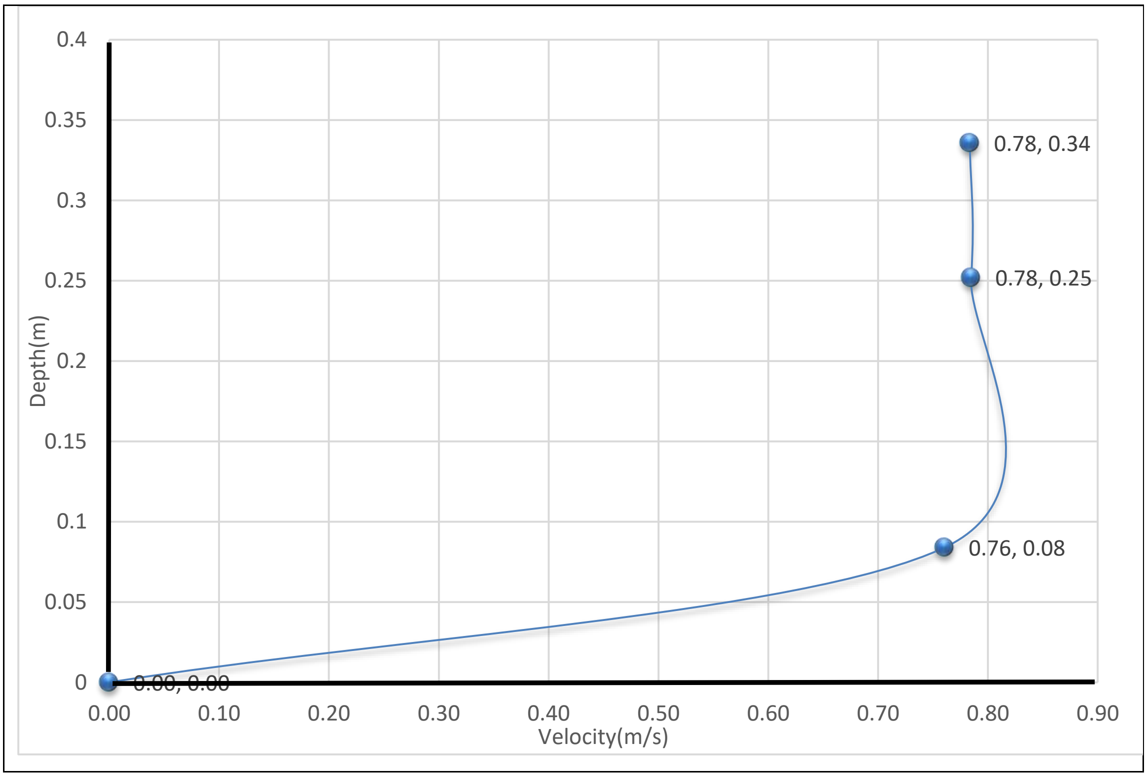


Figure 5.11: Depth Vs Velocity (Exp test run -5, u/s)

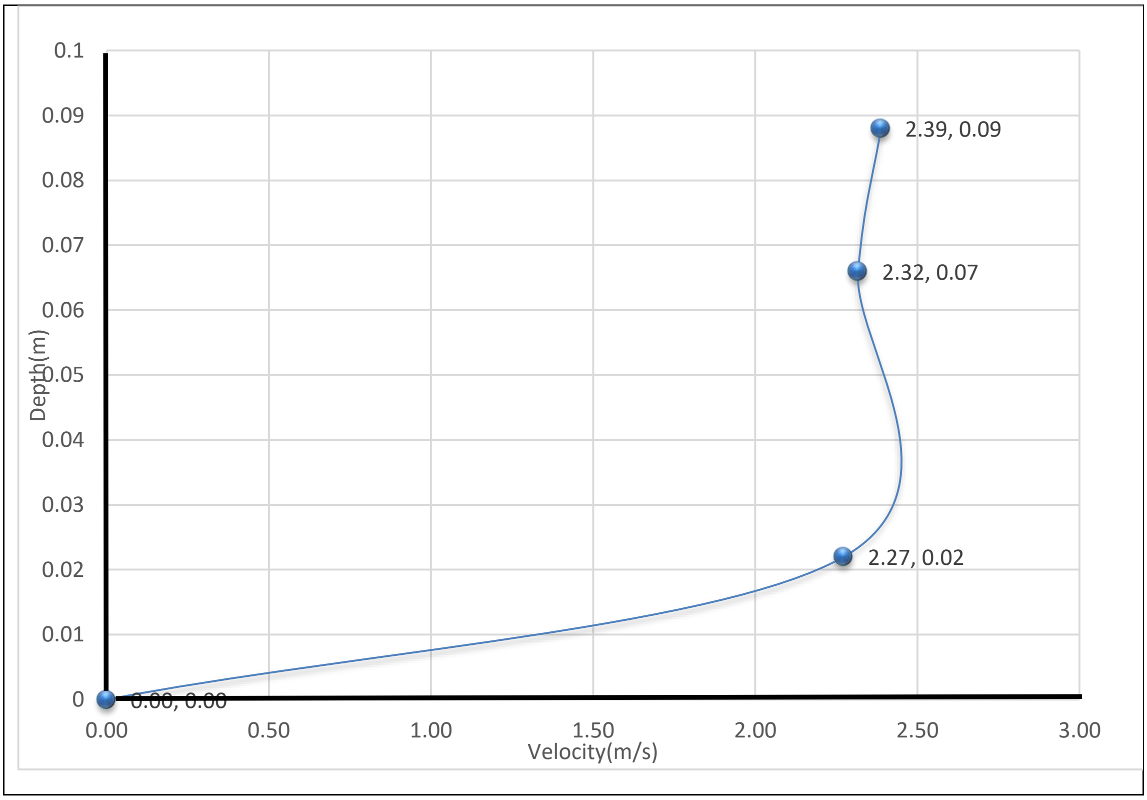


Figure 5.12: Depth Vs Velocity (Exp test run -5, d/s)

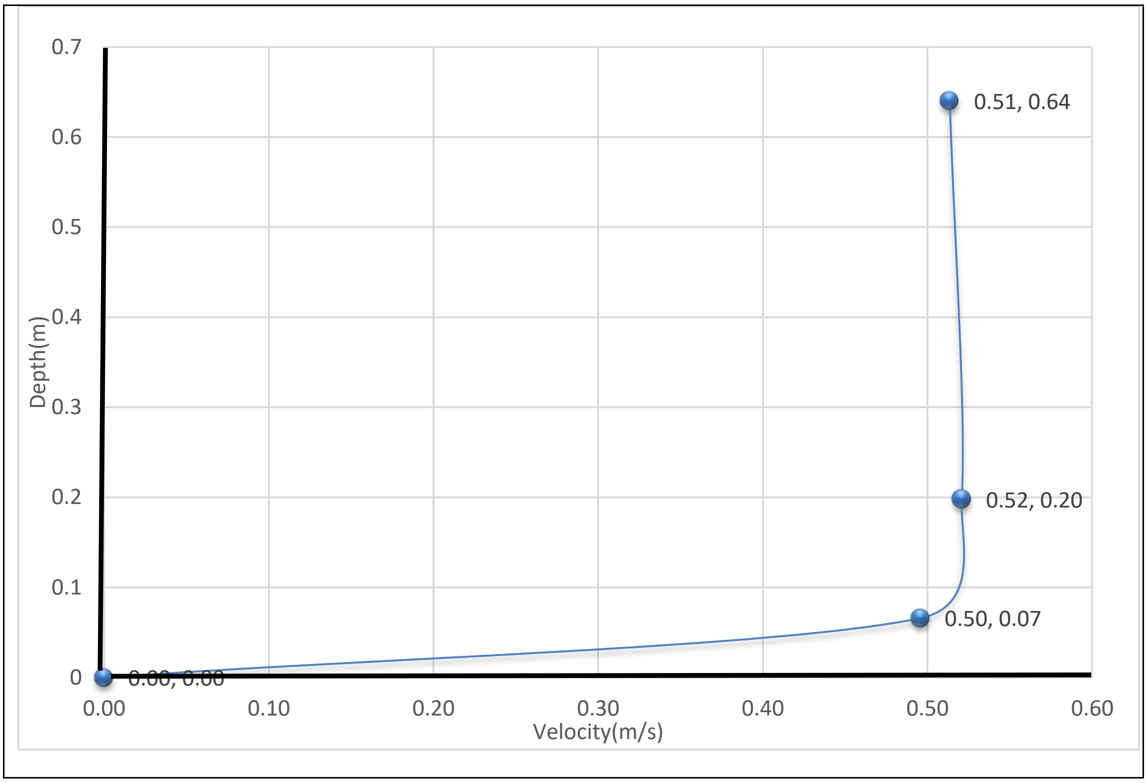


Figure 5.13: Depth Vs Velocity (Exp test run -6, u/s)

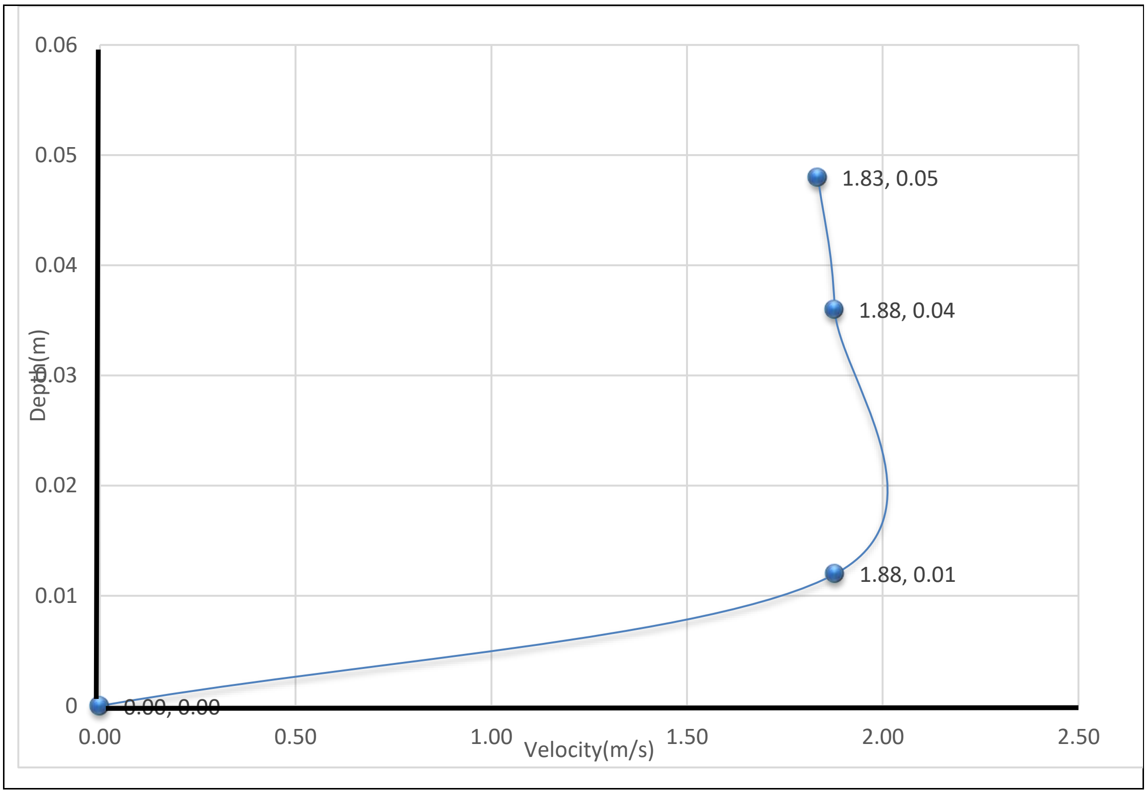


Figure 5.14: Depth Vs Velocity(Exp test run -6, d/s)

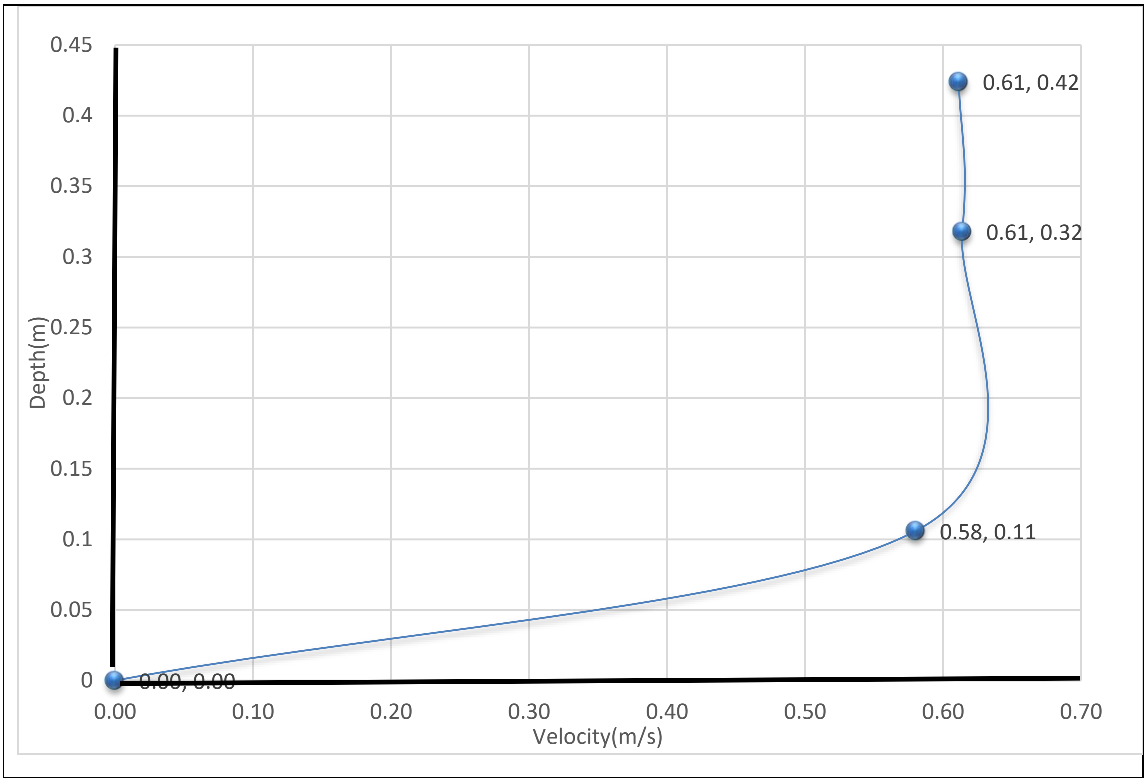


Figure 5.15: Depth Vs Velocity(Exp test run -7, u/s)

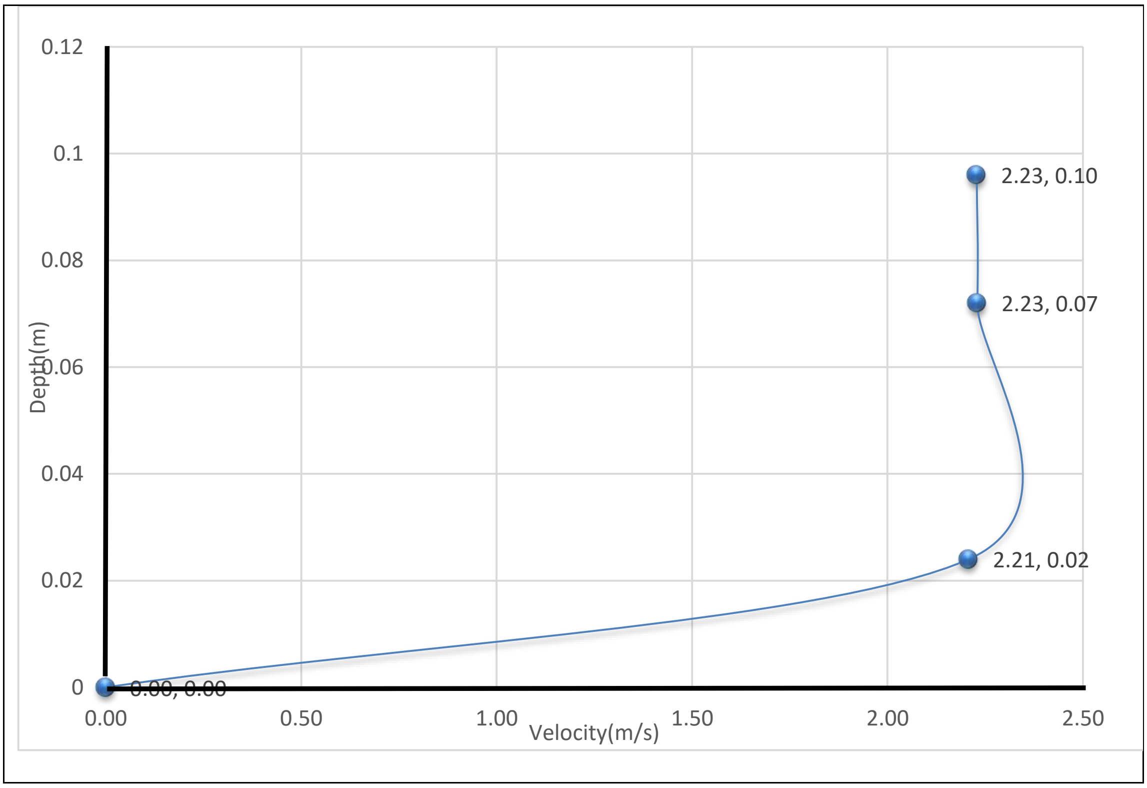


Figure 5.16: Depth Vs Velocity(Exp test run -7, d/s)

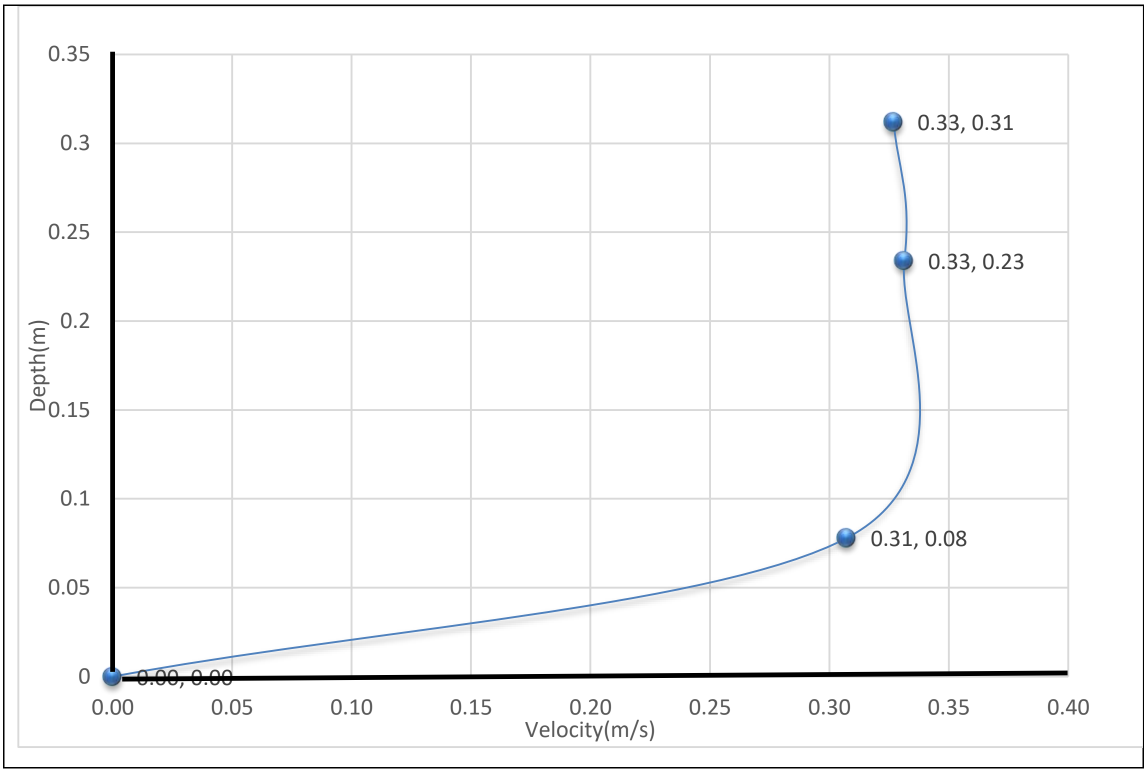


Figure 5.17: Depth Vs Velocity(Exp test run -8, u/s)

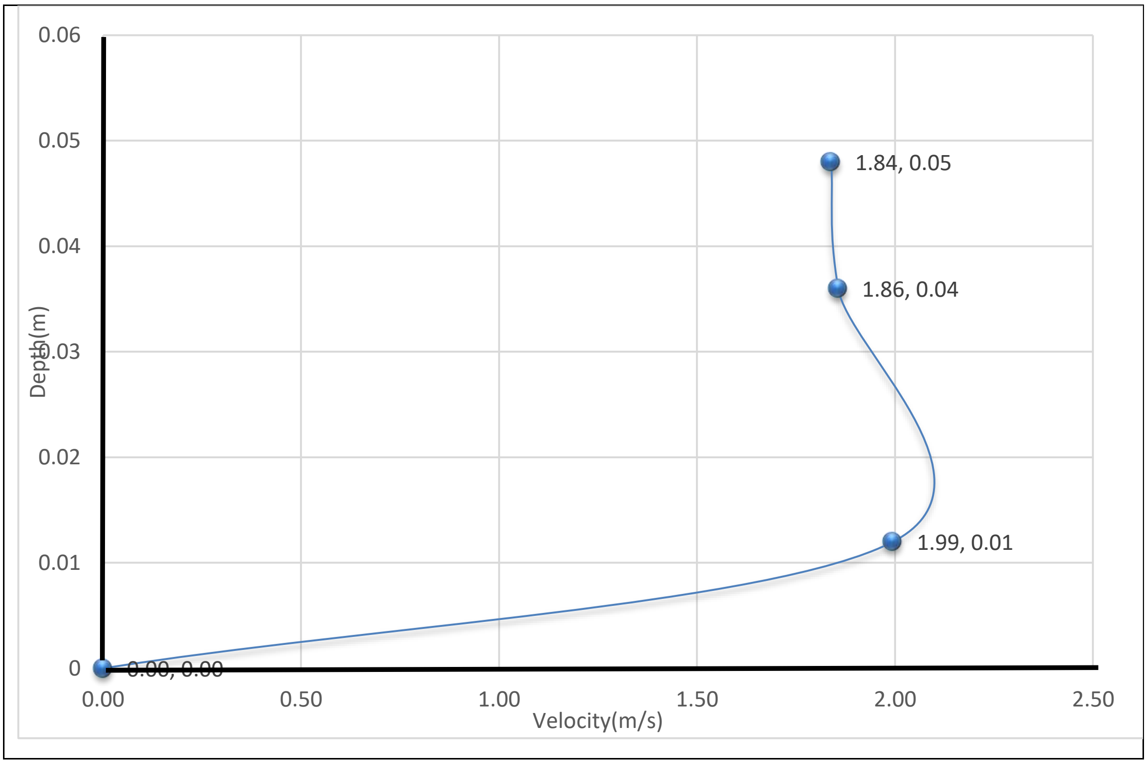


Figure 5.18: Depth Vs Velocity (Exp test run -8, d/s)

5.5 Discussion on Comparison of Velocity for Different Flow

In this research the observed flow conditions were 200 l/s and 100 l/s. Four experimental test run (exp. test run-1, exp. test run -3, exp. test run -5, exp. test run -7) were performed with discharge Q= 200 l/s and rest four experiments (exp. test run -2, exp. test run -4, exp. test run -6, exp. test run -8) were performed with discharge Q=100 l/s. In these experimental test run, geobags were filled with both specified and unspecified sand with different layers. If we compare between the flow the following tables and figures are found for upstream and downstream of the flow for both flow conditions. As the depth of water is different for each experiment, the dimensionless depth has been used to compare.

Table 5.3: Measured velocity for Q=200 l/s at upstream

Exp. test run-1 (1 layer, specified)	Exp. test run -3 (2 layer, specified)	Exp. test run -5 (1 layer, unspecified)	Exp. test run -7 (2 layer, unspecified)	y/z
0.73	0.58	0.76	0.58	0.80
0.77	0.61	0.78	0.61	0.60
0.80	0.61	0.78	0.61	0.20
0.00	0.00	0.00	0.00	0.00

Table 5.3 shows the velocities of four experiments when discharge Q=200 l/s at upstream of the flow. Here y/z represents the dimensionless depth of flow. Experimental test run 1 and 5 had 1 layer of 1 geobag with specified and unspecified sand respectively. Experimental test run 3 and 7 comprises with 2 layers of 3 geobags with specified and unspecified sand respectively. Experimental test run 1 and 5 had less interruption of flow than experimental test run 3 and 7. The graphical representation of the above table is given below (**Figure 5.19**).

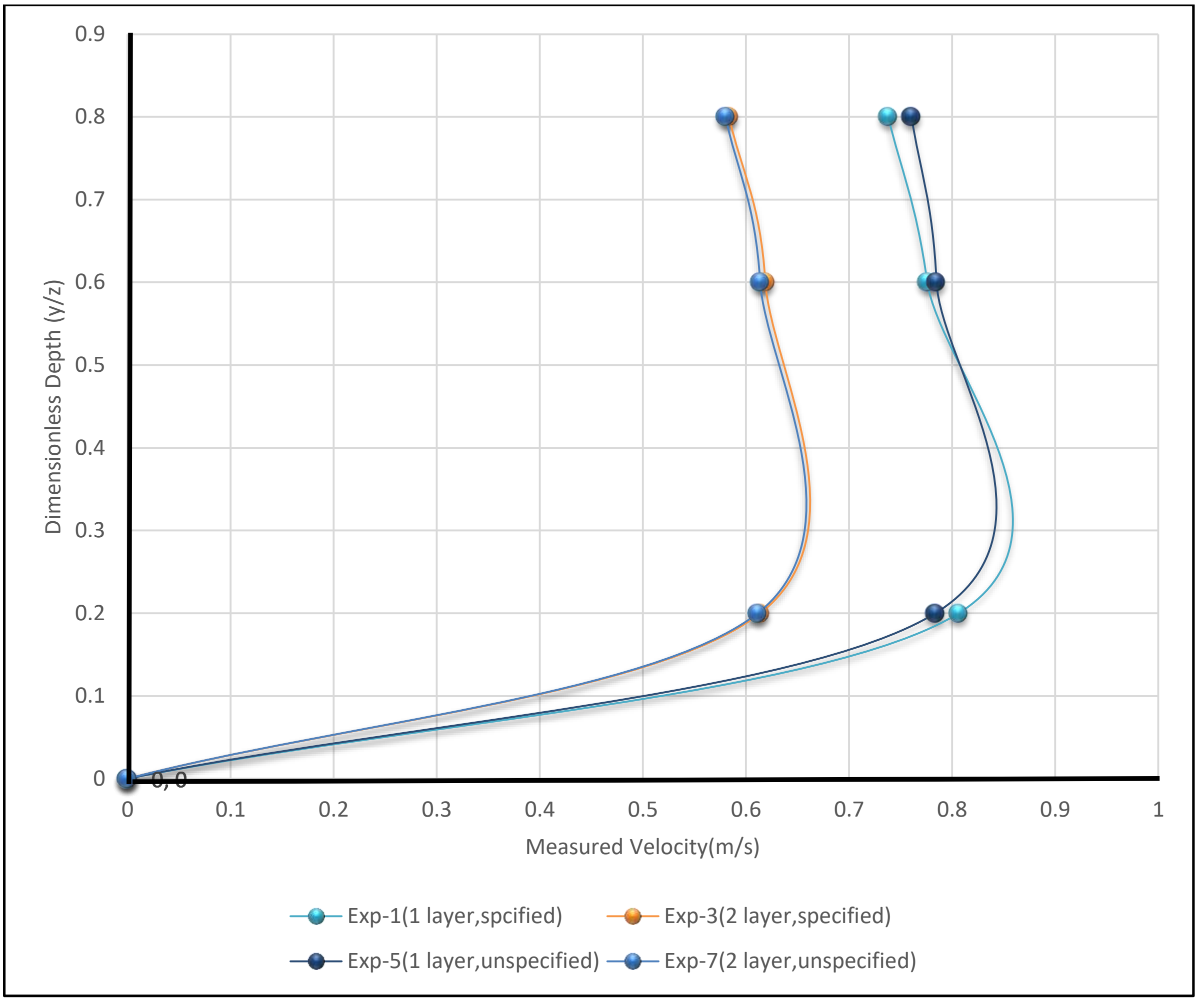


Figure 5.19: Dimensionless depth vs velocity profile at upstream for Q=200 l/s

Table 5.4 Measured velocity for Q=200l/s at downstream

Exp. test run-1 (1 layer, specified)	Exp. test run -3 (2 layer, specified)	Exp. test run -5 (1 layer, unspecified)	Exp. test run -7 (2 layer, unspecified)	y/z
2.23	2.21	2.27	2.20	0.80
2.23	2.22	2.31	2.23	0.60
2.18	2.23	2.38	2.22	0.20
0.00	0.00	0.00	0.00	0.00

Table 5.4 shows the velocities of experiments when discharge Q=200 l/s at downstream of flow. Here the velocities are more or less same. The change in velocities are insignificant. The graphical representation of the above table is given below (**Figure 5.20**).

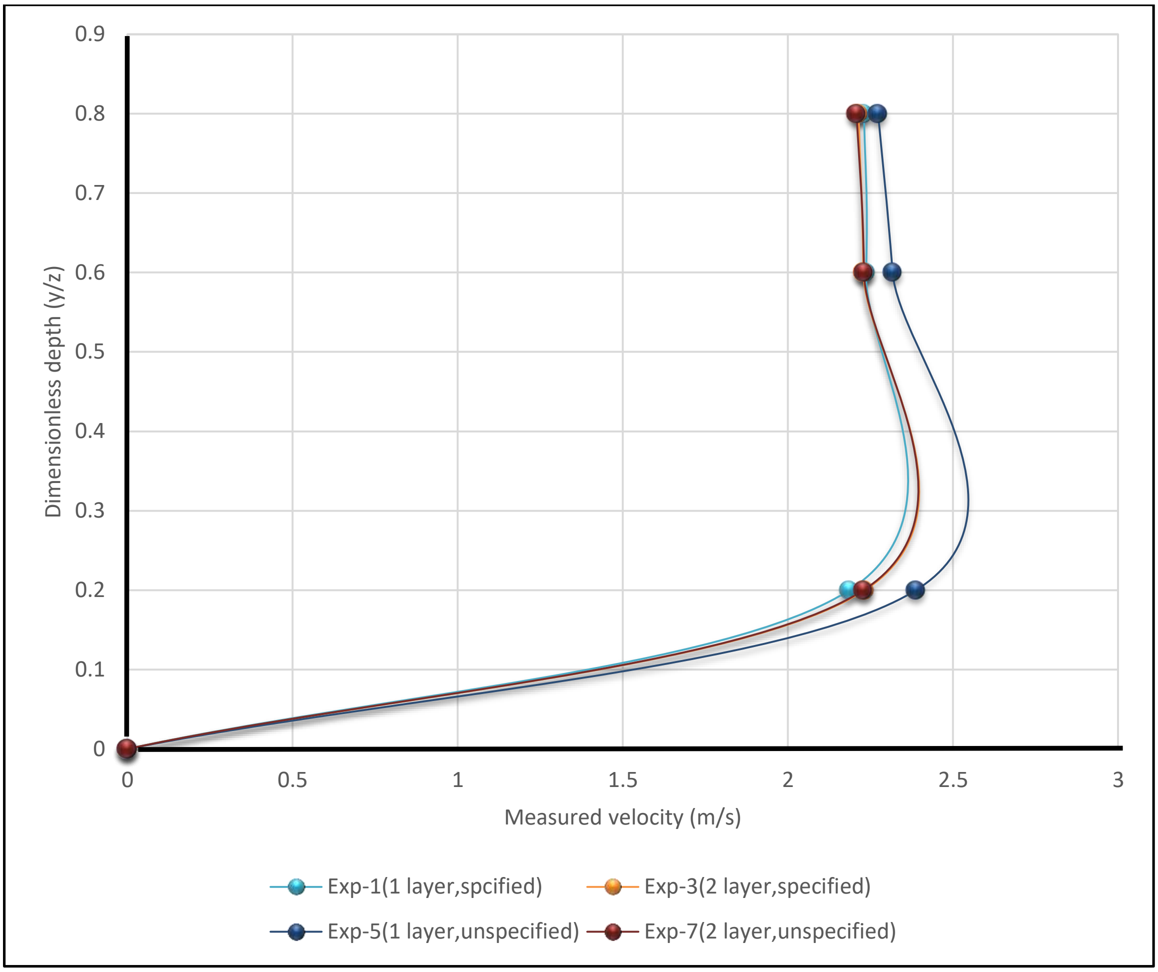


Figure 5.20: Dimensionless depth vs velocity profile at downstream for Q=200l/s

It has been observed that the velocities in Experimental test run 1 and 5 was higher than experimental test run 3 and 7. This is because of the number of bags and layers. Depth of water level at upstream becomes relatively lower due to the backwater effect of geobags which were placed in the flume. At downstream side the velocity becomes higher compared to upstream side. Chute effect of water flowing over the bags. Here the subcritical flow changes in supercritical flow and also specific energy change occurs because of the bags. These bags work as rectangular weir in the flume.

Similar explanation can be given for discharge Q=100 l/s. The variation of the velocities was almost similar at both flow condition. Following table shows the velocities at experimental test run 2, 4, 6 and 8 at upstream of the flow. These experiments were performed for different number of bags and layers.

Table 5.5 Measured velocity for Q=100 l/s at upstream

Exp. test run-2 (1 layer, specified)	Exp. test run -4 (2 layer, specified)	Exp. test run -6 (1 layer, unspecified)	Exp. test run -8 (2 layer, unspecified)	y/z
0.48	0.30	0.49	0.30	0.80
0.49	0.32	0.52	0.33	0.60
0.49	0.33	0.51	0.32	0.20
0.00	0.00	0.00	0.00	0.00

As shown in **Table 5.5**, the velocities in experimental test run 2 and 6 is almost similar because of 1 layer of 1 bag whereas it differs from experimental test run 4 and 8 for 2 layer of 3 bags. Graphical presentation is given below (**Figure 5.21**).

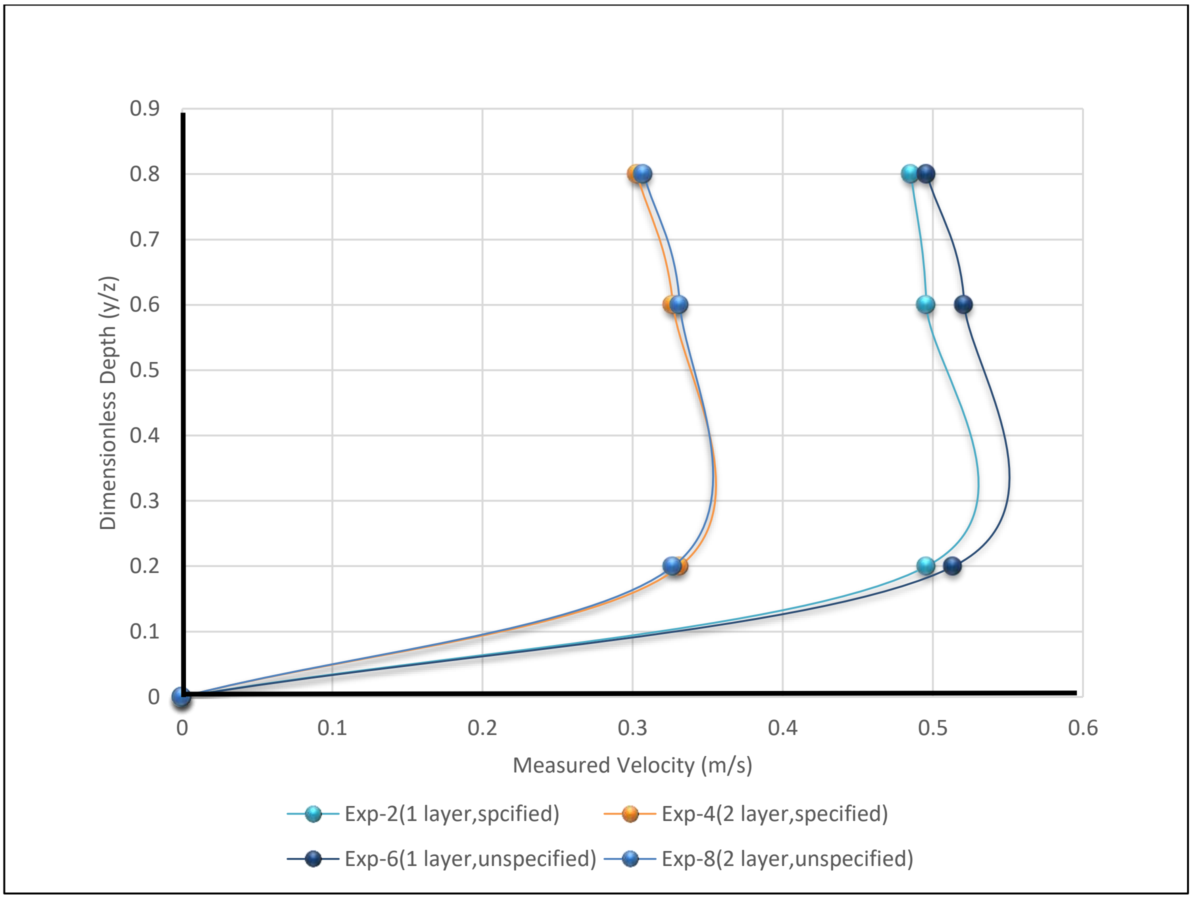


Figure 5.21: Dimensionless depth vs velocity profile at upstream for Q=100 l/s

Table 5.6: Measured velocity for Q=100 l/s at downstream

Exp. test run-2 (1 layer, specified)	Exp. test run -4 (2 layer, specified)	Exp. test run -6 (1 layer, unspecified)	Exp. test run -8 (2 layer, unspecified)	y/z
1.88	1.95	1.87	1.99	0.8
1.86	1.82	1.87	1.85	0.6
1.82	1.85	1.83	1.83	0.2
0.00	0.00	0.00	0.00	0

Table 5.6 shows the measured velocity for experimental test run 2, 4, 6 and 8 for discharge Q=100 l/s at downstream of the flume. These values are taken at the downstream of the flume so that the values are almost similar for these experimental test runs due to the uninterrupted flow condition. The graphical presentation is given below for better understanding (**Figure 5.22**).

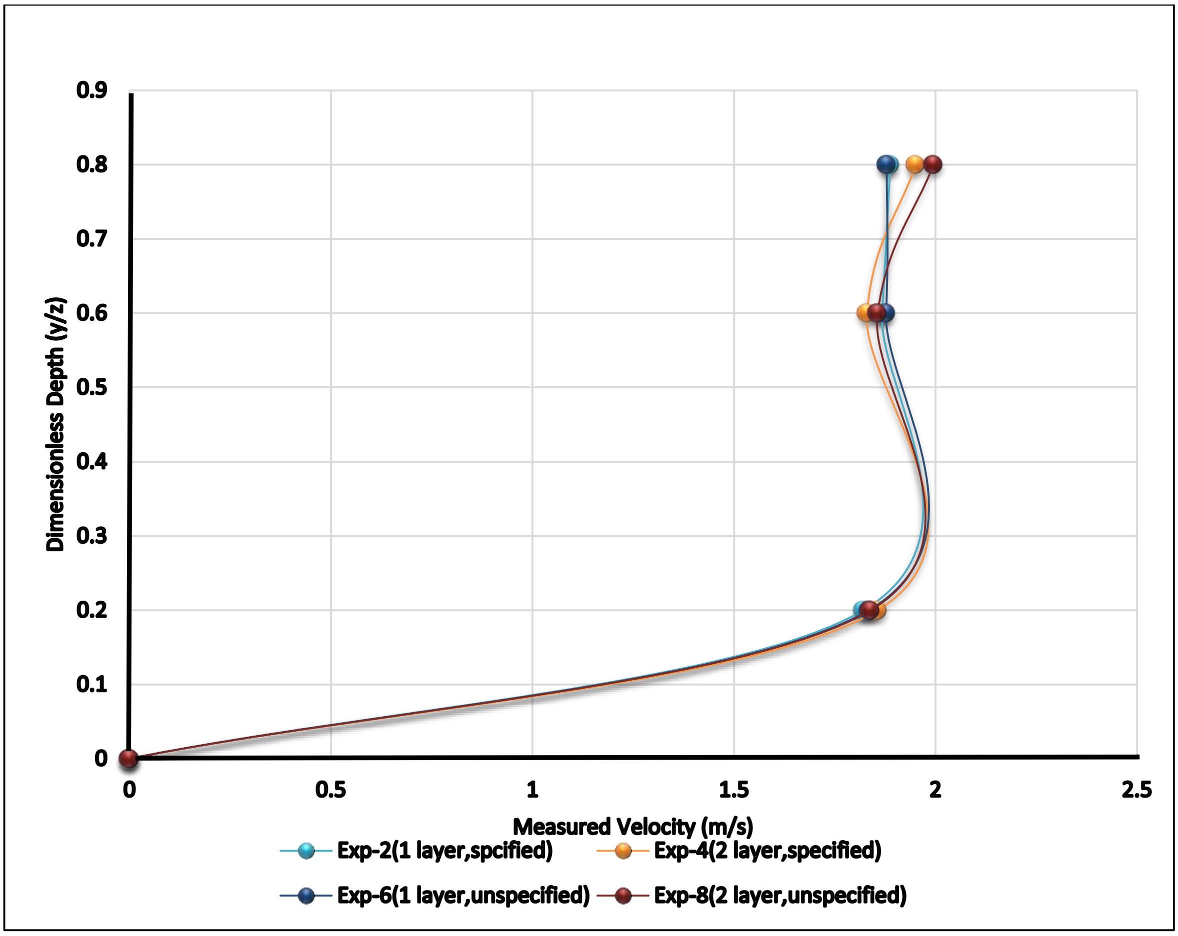


Figure 5.22: Dimensionless depth vs velocity profile at downstream for Q=100l/s

The above discussion reveal that velocity of the flow does not depend on the bag filler material whether it is specified sand or unspecified sand rather it depends on the layout of the bag so far. The experimental test runs with 2 layers of 3 bags gives lower velocity at the downstream than with 1 layer of 1 bag. The lower the velocity the lower will be the stress.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Introduction

Riverbank protection work is mainly a construction of an underwater protection of rivers and sometime it is difficult to maintain the necessary specification of sand used for a bank protection work. If sand filled geobags are used in this purpose, it is very important to follow the specification. This experimental study is expected to give us a better insight what could happen if unspecified sand is used as filler material in geobags used for protection work.

6.2 Conclusion

The conclusion of the study can be set as follows:

i) A total of eight experimental runs were conducted in 70 ft long tilting flume for two different condition (1 layer 1 bag and 2 layer 3 bag) with geobags weighing 78 kg each, filled with specified and unspecified sand *('Vit Bali')* for two different discharges- 100 l/s and 200 l/s.

ii) Volumetric measurement and observation reveals that geobags filled with specified sand can contain the filler material and hence, it is sustainable when placed in flowing water.

iii) Geobags filled with unspecified sand for one layer one bag setup, the average sediment concentration in the flowing water adjacent to the geobag is 2250 mg/l and 2500 mg/l for 100 l/s and 200 l/s flow discharge, respectively.

iv) Geobags filled with unspecified sand for two layers three bags setup, average sediment concentration in the flowing water adjacent to the geobag is 2750 mg/l and 3000 mg/l for 100 l/s and 200 l/s flow discharge, respectively.

v) For one layer one bag condition, the average sediment concentration per square meter bag area becomes 4.5 gm/l for 100 l/s of flow discharge and 5.0 gm/l for 200 l/s of flow discharge. On the other hand, for two layer three bag condition, the average sediment concentration per square meter bag area becomes 2.7 gm/l for 100 l/s flow discharge and 3.0 gm/l for 200 l/s flow discharge.

vi) For one layer one bag filled with unspecified sand, the average sediment concentration is less when the flow (discharge) is high. For two layers three bags the average sediment concentration is less when the flow (discharge) is less. It appears that few parameter/phenomena (e.g. water depth adjacent to the geobag, shear force acting on the geobag, vortices generated etc.) might be responsible for the non-linear sediment loss from the geobag for single layer and double layer setup.

vii) Therefore, geobags filled with unspecified sand, losses minor amount of fine sediment for different flow condition and hence, it is not sustainable when placed in flowing water.

viii) It is revealed that velocity of the flow does not depend on the bag filler material whether it is specified sand or unspecified sand rather it depends on the layout of the bag, number of layers, number of geobags, flow condition etc. The lower the velocity the lower will be the stress. The more the layer the lesser will be the possibility of bank protection failure.

Hence, it is apparent that if the geobags are filled with sand according to specification then the possibility of failure during heavy flow in the river is negligible in respect to sediment loss from the geobags. On the other hand, if it is difficult to provide specified sand and unwillingly unspecified sand is used, a high possibility is there to fail the bank protection works during heavy flow due to sediment loss from the geobags.

6.3 Recommendation for future study

Following recommendations are suggested for future study:

i) Different orientation of geobags with respect to flow direction can be investigated.

ii) Measurement of sediment concentration can be performed chronologically for a better insight of the sediment loss from the geobag.

iii) A wide range of discharge can be considered to investigate the sensitivity of sediment loss.

iv) Similar study may be undertaken in physical modeling facility considering a prototype condition.

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