A STUDY ON EROSION CONTROL USING JUTE GEOTEXTILES

A DISSERTATION

submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
WATER RESOURCES DEVELOPMENT

By

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CANDEDATE'S DECLARATION

I hearby certify that the work which is being presented in the dissertation entitled, **"A STUDY ON EROSION CONTROL USING JUTE GEOTEXTILES"** in partial fulfillment of the requirement for the award of the **Degree of Master of Engineering in WRD (Civil)** submitted in the Department of Water Resources Development Training Center, (WRDTC) University of Roorkee; is an authentic record of my own work carried out during the period from December 1, 2000 to the date of submission under the supervision of Dr. Nayan Sharma, Associate Professor WRDTC, and Prof. R. .P. Singh, Visiting Professor, WRDTC, University of Roorkee, Roorkee.

I have not submitted the matter embodied in this dissertation for the award of any other degree.

Dated: May 10, 2001 **(Desta Eshete Gizaw)**

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ABSTRACT

Erosion is the removal of top valuable fertile soil from the rivers, streams, seas, oceans, agricultural lands, canal banks, highway and railway embankments, etc. One of the most striking and intriguing features of erosion is their tendencies widen to from time to time. Erosion control is thus the technique that aims to prevent loss of material from bed and/or bank.

Geotextiles serve as erosion control material in addition to other functions of separation, reinforcement, filtration and drainage. Jute geotextile is all effective erosion control material and has advantages over all other conventional techniques where vegetation is considered to be the long term answer to slope protection and erosion control.

The work reported in this thesis is an experimental investigation concerning the study of erosion using non-uniform graded sand and clay material for preparation of the bed and bank of a one side bank channel flume with and without being covered by different types of jute geotexitiles. The main objective was to determine reliable erosion control mechanism by simple and inexpensive techniques involving the use of geofabrics. Experiments were performed in a one side vertical and other side banked channel; 3.4m long, 0.50m wide flume and having a constant side slopes of IV: 1.5H and IV: 1H. Non-uniform graded sediment of two different types viz. sand and clay, and five different specifications of woven jute geotextiles, viz. Type I, Type II, Type III, Type IV and Type V, and one rot resistance and bitumen treated jute viz. Type VI were used. The data were collected from steady flow conditions on the bed and sides of the channel. The steady state condition was identified only by visual observations on the bed and sides of the channel.

In this study using single and combination of the following parameters i.e., shear stress distribution, velocity profile, Froude number, various longitudinal and bank slopes,

soil texture, etc, the extent and amount of eroded volume of the bed and bank on the experimental flume were observed. From the analysis of experimental data, it was found that the channel covered by thick thread, smaller mesh size, and heavy weight woven jute geotextile with bed and bank covered material non-uniform graded cohesive soil have a better erosion control performance over the others used in the experiment excepting the rot resistance and bitumen treated jute.

LIST OF SYMBOLS

Symbol	Description
D	depth of water
d	particle size
d’	depth of erosion
d’’	depth of deposition
d_p	outer diameter of the Preston tube
Fr	Froude number
G	acceleration of gravity
IJIRA	Indian Jute Industries’ Research Association
Ks	constant
L	length of flume
Ps	static pressure
Pt	total pressure
Q	flume discharge
ρ	density of water
R	hydraulic mean radius
S	slope of the energy grade line
S_b	slope of channel bed
S_L	slope of channel bank
U_b	bottom velocity
V	mean velocity of flow
υ	Kinematics viscosity
W	width of flume
τ_c	critical shear stress
τ_{oc}	computed shear stress
τ_o	average/observed shear stress

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CHAPTER I

INTRODUCTION

1.1 GENERAL

Erosion on bed and bank is a problem of continuing interest and is of great importance to river engineers. Many researchers have done lot of work both experimentally and on the field on various aspects of these problems. Occasionally, shallow slopes like road/railway embankment, river and canal banks, dams, slopes of reservoirs, etc, pose the serious problems of slips owing to use of locally available material, which may not be entirely always suitable for such construction. Lack of timely provision of erosion control measure accelerates the risk.

Hence one must find an appropriate means of controlling mechanism which is likely to be economical, applicable and have consistent property and general use of installation like use of jute geotextile, etc.

1.2 EROSION AND REMEDIAL WORKS

Erosion is the removal of top valuable fertile soil from the rivers, streams, seas, oceans, agricultural lands, canal banks, highway and railway embankment, etc. One of the most striking and intriguing features of erosion is their tendencies to widen from time to time. In addition to being fascinating natural phenomenon posing some of the netting problems in the realm of river mechanics, river erosion, and in particular the bed and bank erosion attendant to the growth and migration of erosion, has become a major challenge to river engineers for bed and bank protection.

The bank material of natural channels is frequently more variable than the bed material. In many cases channel banks possess some degree of cohesion because of finer material, such as silt or clay, so that the analysis of bank erosion is not a simple extension of the non-cohesive situation. A further complication is introduced by vegetation whose root system can reinforce bank material and thereby increase resistance to erosion.

Due to flooded nature of rivers, streams, etc many times is loss of population, towns, villages and coastal landed properties. Hence, in-order to protect the lives and valuable property along riverbanks, which are on a constant threat by the uncontrolled river phenomenon, erosion control measures are becoming a serious issue, and the controlling measures are adversely affected by the threat from increasingly costly labour and scarce materials. It is in this context that geotextiles are used extensively both as filter materials and as armour in combination with other materials in erosion control structures because of their inherent economy, applicability and consistent properties and general use of installation. While vegetation is being established from seeding, natural and manufactured materials are used for erosion control to reduce the velocity of run-off water and sediment loss from the site. These materials work by absorbing the energy released from rainfall, protecting the soil surface to keep seed and fertilizer in place, and by moderating soil temperatures and conserving soil moisture to enhance germination.

Where short term protection is needed by unreinforced vegetation cover alone, biodegradable woven nets from natural fibers are used to aid short term root growth. One of the most effective and economic methods to control erosion though vegetation is jute mesh. Its performance was tested and revealed by India Jute Industries' Research Association (IJIRA) and other organization in India and abroad.

Where vegetation cover alone is insufficient, or is drought prone and, also high velocity overland flow of periodic duration might occur, in such cases synthetic root reinforcing geogrid mesh or other techniques should be employed to provide long term protection.

For slopes in waterfront having velocity of flow in excess of 3 m/sec. or having effect of wave uplift, having inundation or continuous flooding at a stretch for days, boulder pitching or geocell revetment shall be resorted to in protections of flooding in association with reinforced vegetation.

1.3 OBJECTIVES AND SCOPE OF THE STUDY

The bed and bank in the direct neighborhood of hydraulic structure is generally protected against current, waves, eddies and high velocities, to ensure both the safety and durability of the functioning of hydraulic structures. The conventional measures required for protection against erosion is costly, especially when the bed and bank protection is constructed under water.

The degree of slope, slope length and soil texture are the main factors taken into account when using erosion control materials to meet the goals of site stabilization and reduction of sediment loss from construction sites effectively. The efficiency of each materials in controlling the sediment erosion from bed and bank is tested under laboratory and field conditions by the manufacturers, university and transportation personnel, and at research laboratories which standardize testing using rainfall simulators such as the ones at the Hydraulic and Erosion Control Laboratory at the Texas Transportation Institute (TTI) and the Utah Water Research Laboratory in Logan, Utah.

The present study deals with study of erosion on a one-sided-bank flume channel using different types of jute geotextiles on cohesive and non-cohesive sediment bed and bank with nearly flat to steep slopes i.e., 0.05 to 2 percent slope respectively. The discharge and depth of flow kept the same for comparable runs with different material, the same bed and bank slope etc to observe the effect of erosion. With the help of these experimental data, the effective and economic method of reducing sediment loss from the bed and bank were studied. The objective is to investigate experimentally in laboratory geofabric the efficiency of material to reduce erosion with minimum cost.

1.4 METHOD OF STOPPING SOIL EROSION

Erosion on bed and bank and problem arising out of them is a subject under study in all countries. Soon, it became obvious that protection could be either by cohesive material or by large grains that withstand the forces of nature. Flowing water can cause severe erosion and instability of the soil structures. These are susceptible to erosion by water even at very low flow rates. The traditional protection works in riverbank protection structures envisage constructing flexible structures such as rip-rap or heavy armour stones, concrete blocks, articulated concrete mattresses etc to break up the water forces. In highly permeable revetments such as rip-rap are used to dissipate the hydraulic forces, where turbulence occur within the interstices of the erosion control structure resulting in erosion of the base soil through the pores in the facing. To prevent washing away of the underlying soil, layers of granular materials known as graded filters are placed between underlying soil and highly permeable rip-rap.

Erosion of bed and bank are also controlled using natural and synthetic geotextile providing as boundary material beneath a stone layer of rip-rap in protecting slopes adjacent to flowing water, silt fences to block migration of soil fines carried by water, granular filter using gravel and rock to prevent loss of sediment etc. On banks and hill slopes natural geotextiles are provided to protect from erosion facilitating the seeds spread until germination takes place. Where vegetating the slope is difficult or immediate protection is a must, synthetic geotextiles are used.

1.5 GEOTEXTILE FOR SOIL EROSION

The use of geotextiles is very old. In the past, men already used natural fibers to improve the characteristics of soils and earthworks. Since the beginning of the seventies of last century, in the field of geotechnical engineering many different types of synthetic materials were evolved, finding an increasing use in substitution or in combination with natural materials. Erosion control is a remarkable application of geotextiles which, when laid on a bed and bank, prevent the eroding action of rainfall, wind and surface runoff.

The erosion of sand, silt or clay subsoil is prevented by use of geotextile cover with rock or gravel. Geotextiles are also frequently used as a replacement of graded filters because of their comparable performance, improved economy, consistent properties and ease of placement. In bed and bank protection the fabric acts as a mechanism to hold the soil in place while allowing for germination of vegetation and weed growth.

Natural fiber (jute/coir) geotextiles, function in erosion control as a series of small check dams in reducing the velocity of the water flowing down the bed and the bank. It holds seeds nutrients and soil particles in position so that seeds can germinate on the surface and helps growth of vegetation fast. Later on the vegetative cover intercepts rain drops and run off, while root system anchors the soil for permanent reinforcement, when its function ceases. This material, especially jute mesh has a good performance proven for nearly three decades, not only in the U.S. but in Europe, Asia and Canada as well.

1.6 SCOPE OF THE PRESENT STUDY

The present investigation has been carried out within the following scope of study

(i) Cohesive (field clay) and non-cohesive (riverbed sand) sediment were used.

(ii) Five types of woven untreated and one rot resistant chemical and bitumen treated jute's were investigated in the present study.

(iii) Slopes of 1V in 1H and 1V in 1.5H for bank, and 1 in 2000 and 1 in 50 for bed (longitudinal slopes) were used.

(iv) Since the aim of the study is to observe the change of volume in the bed and bank topography with different material, no attempt is made to vary the flow parameters like discharge and depth of flow.

(v) The depth of flow is limited between 8cm and 13.5cm-bank height for 1V in 1.5H and 1V in 1H bank slope respectively.

(vi) Only on the bed shear stress is measured at three locations near to the surface of the wall.

(vii) Velocity is measured at three sections at different depths (0.2d, 0.6d, and 0.8d) for different run and the average of the three considered as the flume velocity.

CHAPTER II

REVEIW OF LITERATURE

2.1 HISTORICAL DEVELOPMENT

Invention of geotextiles as an engineering material brings a new millennium in the history of civil engineering. These products have risen from a relatively minor and specialty product status to worldwide application in so shorts a time span.

Geotextiles are a thin, flexible permeable synthetic material used to stabilize and improve the performance of the soil associated with the civil engineering works. Properly designed and installed, geotextiles have the ability to filter, drain, reinforce and separate the soil. All those basic or primary functions just stated also serve as secondary functions to each other in given applications. In erosion control for coastal and riverbank protection, the primary function of a geotextile is filtration with the separation function playing a secondary role. A tertiary function in some erosion control applications would be reinforcement.

In the late 1950's for the first time a woven synthetic fabric was used for erosion control in Florida. Then, in 1960's geotextiles are extensively used for erosion control both in Europe and U.S.A. Later in 1969, Giroud used non-woven fabric as a filter in the upstream of an earthen dam. In 1970, Wager initiated use of woven fabrics as reinforcement for embankments constructed on very soft foundations. Thereafter, the non-woven fabrics were introduced in North America and a rapid progress was made both in the applications and types of geotextiles.

In the early 1958, filter fabric was used, as an alternative to a granular filter in the reconstruction of waterway concrete block was revetment in storm-lashed coast of Florida. In U.S.A., geotextiles have extensively been used in erosion control structures.

2.2 GEOSYNTHETICS

Geosynthetics originally used to be called by different names such as filter fabrics, plastic filter close, engineering fabric, civil engineering fabric, geofabric and geotechnical fabric. Lately, the names have been more or less well defined. The term, which was proposed in 1983 by Professor R.M Koerner, Director of Geosynthetic Research Institute and now is being increasingly, used, is Geosynthetics. Because these materials are used in soils, so the prefix "geo" seems appropriate and the materials are almost exclusively human made products, therefore the second part of the name " synthetic" is also well justified.

The products which are collectively called Geosynthetics, include:

i) Geotextiles
ii) Geogrids
iii) Geomembranes
iv) Geonets
v) Geocomposites

2.3 TYPES OF GEOTEXTILES

2.3.1 Geotextiles

Geotextiles, as known and used today, were first used in connection with erosion control applications and were intended to be an alternative granular soil filter. Thus, the original, and still sometimes used, term for geotextiles is "filter fabrics". Geotextiles the largest group of Geosynthetics. The term " geotextiles" refers to textiles (fabrics) used in geotechnical engineering. It is also often used in place of conventional mineral filters in erosion control applications along lake or ocean shorelines, canals, stream channels, and other hydraulic structures. Geotextiles are applied to erosion control problems, where they serve to prevent scour or pumping of erosion prone soils used in revetments to the banks of canals and other waterways. They are applied directly to the surface of the bank soil before being covered by a protective layer of granular fill and an outer layer of rip-rap or primary armor stone.

Geotextiles are of two types: synthetic geotextiles and natural geotextiles (fig.2.1). There are at least 20 types of geotextiles. Natural geotextiles include jute grid, paper strips, wood shavings, etc.; thus, biodegradability is an asset in erosion control. These synthetic fibers are made into a flexible, porous fabric from polymers of polypropylene, polyester, and polyamide resins that are melt extruded into fibers, multifilament and monofilaments.

As the term indicates, it is textile material manufactured by the conventional textile materials and also by new generation textile machines. Though its name is related to knitted, woven and non-woven fabrics, currently being applied to many materials, which may at best be treated as geotextile related materials which includes webs, mats, nets, grids, etc.

The use of synthetic geotextiles is increased rapidly and their annual sales per year per meter square exceed 200 million. There are at least 80 specific application areas for geotextiles that have been developed. However, the basic four end-use functions performed by geotextiles when used in the design and construction of earth structures, pavement systems, and other manmade structures supported on or covered by earth/ geotextile systems are:

1) Separation:

Geotextile separation: the introduction of a flexible synthetic barrier placed between dissimilar materials so that the integrity and functioning of both materials can remain intact or is improved.

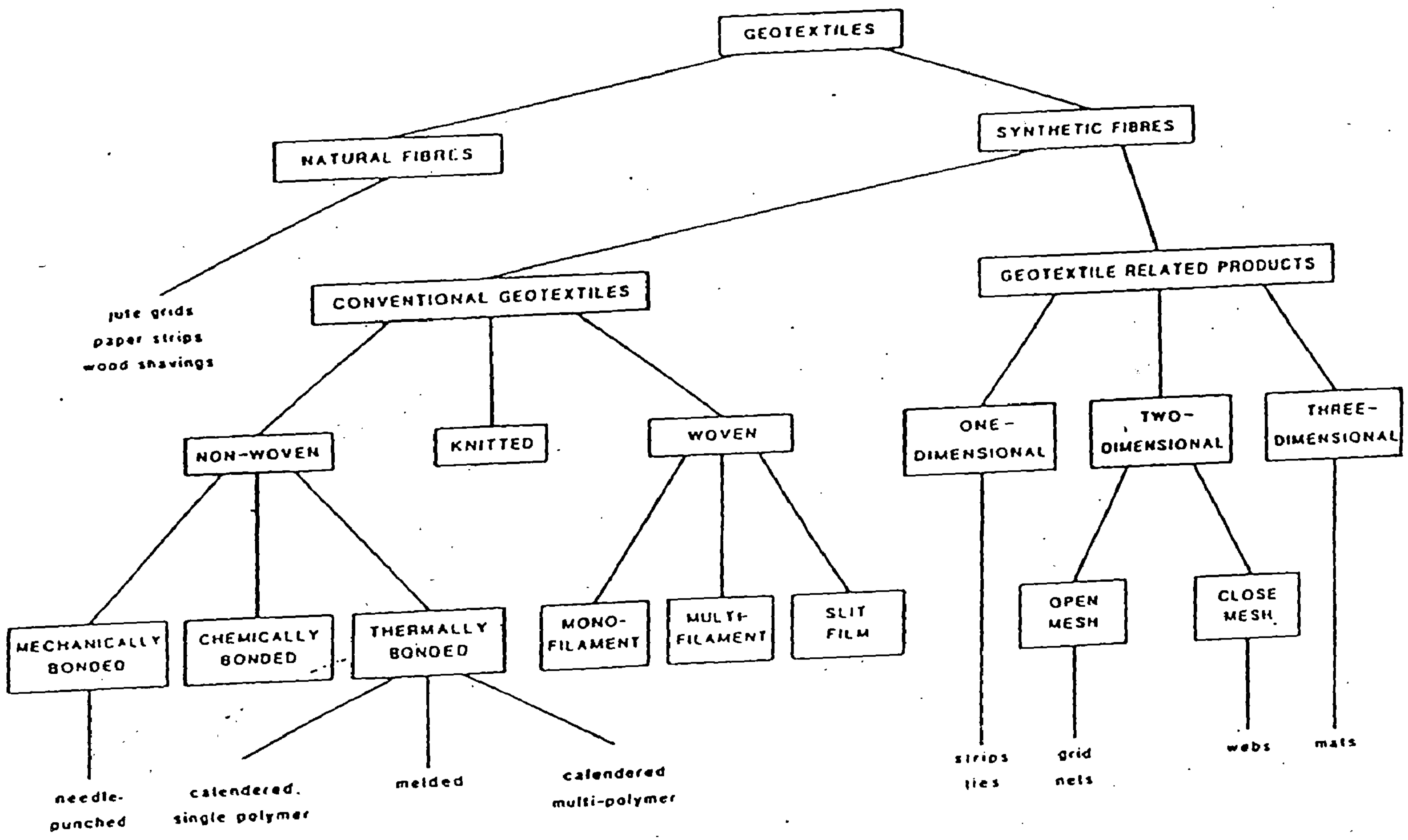


Figure 2.1   Geotextile classification groups

2. Reinforcement:

Geotextile reinforcement: the often-synergistic improvement of system strength created by the introduction of a geotextile (good in tension) into a soil (poor in tension but good in compression) or other disjointed or separated material.

3) Filtration:

The equilibrium fabric-to-soil system that allows for free liquid flow, but no soil loss, across the plane of the fabric over an indefinitely long period of time.

4) Drainage:

According to Koerner, drainage is the equilibrium fabric-to soil system that allows for free liquid flow (but no soil loss) across the plane of the fabric over an indefinitely long period of time. Geotextiles can perform this function.

Depending upon the different fabric structures, geotextiles can be classified as:

i) Woven

ii) Knitted

iii) Non-woven

i)**Woven Geotextiles**: The woven fabric is characterized by two sets of interlacing threads at right angles to each other. One set of thread known as wrap, run along the length of the fabric, and the other known as weft run perpendicular to the warp. The woven fabrics are made from spun yarn, multifilament yarn, and monofilament yarn or tape/slit film (approx.2mm wide) yarn.

Depending upon the pattern of interlacement of wrap and weft threads, different styles of woven fabrics such as plain, twill, satin, etc., can be produced, although plain woven fabrics are the most popular. The plain-weave fabric gives maximum interlacement between warp and weft threads thereby imparting maximum dimensional stability, rigidity and strength to the close.

ii) **Knitted Geotextiles: are** made up on arranged fabric or yarns connected by straight segments. They may be stretched in either direction without significantly stressing the fabrics.

iii) **Non-woven Geotextiles:** are made up of arranged fibers or strands which are held together in one of the following manners:
i.e.,

a) Needle punched non-woven

b) Heat bonded non-woven

c) Resin bonded non-woven

d) Combination bonded non-woven

Non-woven geotextiles are relatively inexpensive, have low to medium strength, and medium to high elongation's before failure.

Typical strength properties of different types of geotextiles are shown in figure 2.2.

2.3.2 Natural Fibre Geotextile

2.3.2.1 Type and Property

Natural geotextiles are made up of natural fibers. Natural fibres can be sources from animals (e.g. Wool and Silk) as well as plants (vegetable fibers). The limited quantity of animal fibers produced world over has very well defined apparel end uses and do not come under question as raw material as geotextiles.

The vegetable fibres can be grouped into three classes namely best fibres, leaf fibres and seed/fruit fibres. Best fibres are extracted from stems of plants and examples are jute, flax, hemp and ramie. Leaf fibres are obtained from leaves of plants and examples are sisal, abace and henequen. Seed fibers like cotton and coir are extracted from seeds/fruits of plants. The best fibers are much softer than the leaf fibres and hence

a) Woven monofilament

b) Woven multifilament

c) Woven slit (split) film

d) Non woven multibounded

e) Non woven needle

f) Non woven needle punched

Photomicrographs of various fabrics used as geotextiles

g) Non woven fabric

h) Fabric woven of yarns spun from staple fibers

i) Knit fabrics

Figure 2.2 Photomicrographs of various fabrics used as geotextiles enjoy a more diversified end-use. Flax, hemp and ramie are used in twins, canvases, fishnets, fire hoses, etc, as where the leaf fibers are employed as mats. Coir has similar end uses as the leaf fibers, where as cotton is used mostly in apparels and jute in sacking and carpeting. Figures of various natural geotextiles are given in Fig. 2.3.

Jute has been cultivated in the Bengal Delta from time immemorial. A leafy, read-like plant, which thrives under hot, humid monsoon, conditions growing typically 2.5 to 3m in height over a period of 4 to 6 months. The steam diameter at the base varies between 20 to 30mm. The method of extraction of fibres from jute stalks is very simple. The jute plants are harvested, tied into bundles and kept submerged under water with a water hyacinth cover for about 5 weeks. The fibres are extracted from the rotten barks, washed in water and dried under sun. Geotextiles made purely of jute fibres –also known as geojute – have been in use since fifteen, when a open meshed woven fabric was used in Europe and USA to cover exposed soil surface with a view to promoting vegetation growth thus arresting soil erosion. Jute geotextiles are marketed under a number of names such as jute fabric, jute burlap, jute net, jute mesh, and jute mat and geo jute. These products are also sold in trade names like "Soilsaver" and "Antiwash". Extensive experimental investigations are carried out on various types of jute fibres and jute fabrics at Department of Civil Engineering, National University of Singapore in order to study their physical and strength properties and performance characteristics. From these investigations, the typical properties of jute fibres were fairly established. Table 2.1 shows the typical properties of jute fibres.

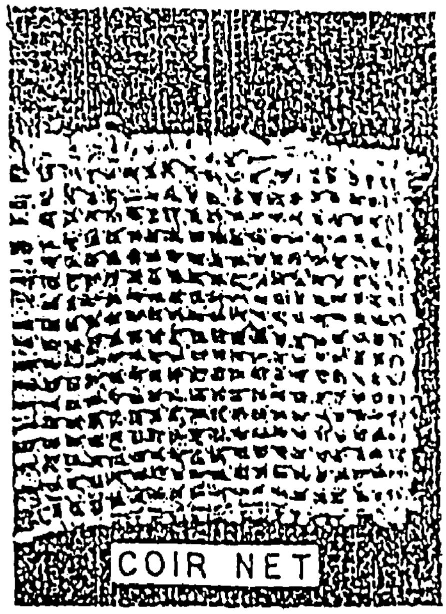
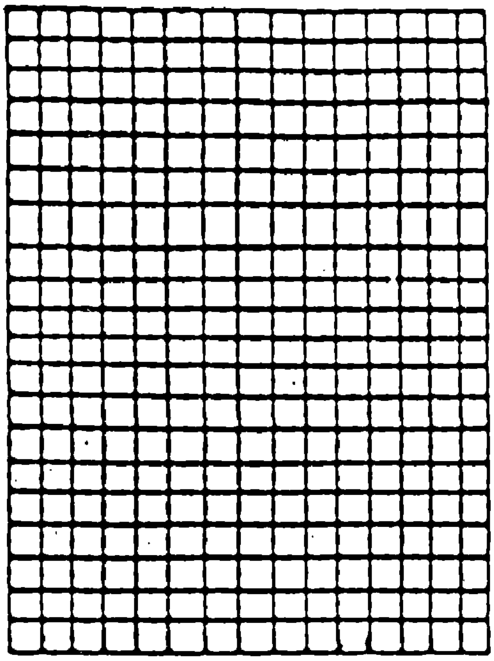


Figure 2.3 Natural Geotextiles

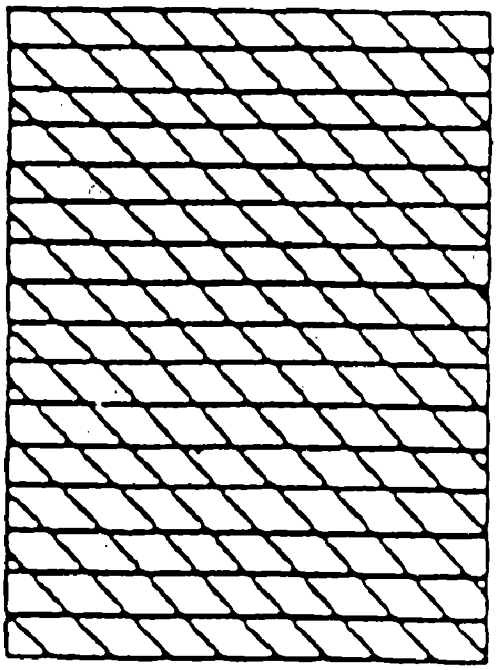
Table 2.1 Typical Property of Jute Fabrics

Property	Range of Value
Fiber length, mm	180 – 800
Fiber diameter, mm	0.01 – 0.20
Specific gravity	1.20 – 1.04
Bulk density, kg/m^3	120 – 140
Ultimate tensile strength, N/mm^2	250 – 350
Modulus of elasticity, k N/mm^2	26 – 32
Elongation of break, percent	2 – 3
Water absorption, percent	25 - 40

Jute net, jute mesh, jute mat and geojute are synonymous. Geojute is jute net or a jute mesh, which consists of heavy, woven jute matting made from 100% jute yarn and has an open mush structural (Fig. 2.4). Regular grades are quoted as being available at 500 g/m^2 and heavy weight grade at $800g/m^2$. Normal thickness is quoted at 5mm but considerable variation is apparent. Normal meshes opening size 11mmx18mm having an open area ratio of about 65 per cent. Standard width is 1.22mm (48 inch) and roll lengths vary but 50m and 70m have been quoted. The weight of such rolls varies from 35kg to 45kg. The material can be specially treated to render it smoulder-free for application in areas of high risk. In addition, a small percentage of mineral oil added to the jute yarn to assist in the spinning process. The usual properties of jute net are given in table 2.2.



a) Jute Mesh



b) Jute net

Figure 2.4 Geojute

Table 2.2 Properties of Geojute

Property	Range of Value
Weight, g/m^2	500-800
Thickness, mm	5
Normal mesh opening, mm x mm	11 x 18
Open area ratio, percentage	65
Standard width, m	1.22
Roll length ,	50-70
Weight of roll, kg	35-45

2.3.2.2 Durability

The strength of natural geotextile is going to fall rapidly with time in a matter of months if allowed to remain embodied in moist soil. This is mainly due to microbiological attacks. The two basic organisms causing decomposition of natural textile materials are bacteria and fungi. Jute materials when exposed to sunlight and rain will become more susceptible to fungal attack. The probability of bacterial damage is greater when soil has soil bacteria.

On use of slope protection jute net have a life of 2 to 3 years, whereas coir net have a life of 3 to 5 years. In course of this duration, the jute or jute netting disintegrates under the influence of water, heat and sunlight. The disintegration material being organic in nature forms natural mulch for the vegetative cover. Further, within this period 2 to 3 years, it is expected that vegetation would have got established on the slope and the presence of netting is no longer essential for prevention of erosion.

Most of the factors affecting the durability are:

Fabric density: - a fabric with a higher area density takes longer time for complete loss of strength.

Type of soil embodied: - It is reported that the strength of jute fabric has been reduced by 97% in 14 days in (sand + manure, 1:1) environment where as it is only 19% in sand alone.

i.e., more the organic content in soil, more will be the degradation.

The order of degradation in different environments is as follows:

Clay	Minimum	
Sand	↓	
Garden soil	↓	increasing rate
Burial	↓	of degradation
Sand + clay + manure	↓	
Clay + manure	↓	
Sand + manure	Maximum	

Moisture and Temperature: - it is reported that the minimum moisture requirements for the growth of bacteria and fungi on jute are 20% and 17% respectively. Jute attains these moisture contents when exposed to atmospheres of 90% and 80% relative humidity respectively. For aerobic soil bacterial growth, the ideal temperature is 37°C Where as it is 30°C for fungi growth.

Content of lignin: - more is the lignin content, longer is the life. It is reported that coir fabrics with about 35% lignin content are extremely resistant. Then comes jute with 12% lignin content followed by leaf fibres containing 10% lignin. The other best fibres contain much lower quantity of lignin (0.6 to 3.3).

2.3.2.3 Advantage of Natural Geotextiles

Geotextiles are mostly manufactured from synthetic polymeric materials. These materials are in turn manufactured from by-products of petroleum, a raw material which is becoming scarce with passage of time. Due to this, the synthetic fibres are becoming costlier for which the practicing engineer is reluctant to use these fabrics on a wide scale basis. Moreover, acids, alkalis, microbial activity and UV exposure can attack synthetic geotextiles. In certain bases, by-products of the breakdown of synthetic geotextiles could be ecologically disastrous. For example, polyvinyl and other synthetics may release monomers and dioxins, which could end up in water supplies and are believed to have carcinogenic, tetratogenic and mutagenic effects on human beings leading to miscarriages, new born defects or similar adverse health effects. These are situations, in which long life of geotextile is not required and even becomes disadvantageous. There is a risk that long life geotextile near the ground surface, could be accidentally eaten by grazing livestock or could snare agricultural plant.

Natural geotextiles such as jute is suggestible as it satisfies the above requirements. India has considerable product of jute, there is no question of security and high cost. The cost comparison of natural and synthetic geotextiles is given in table 2.3. From the total world current production of 3 million tones per annum, about 50% come from Bangladesh, about 30% from India and the remainder from China and Thailand. Jute geotextiles are organic in nature and highly biodegradable and decompose in 18 to 24 months. Decomposed jute produces actually provide a non-toxic product that fertilizes plant life. Hence jute is eco-friendly product. In many applications like slope protection, erosion control, temporary structures, drainage, separation layer, soil stabilization and construction of low volume unpaved roads, long term durability and strength loss with age are not significant. In these applications, natural geotextiles are advantageous.

Being vegetable products, Jute as a base material is anti polluted. Being biodegradable, it has the ability to mix with the soil and acts as nutrients for vegetation. These properties attracted many of the geotextiles applicators in preference to synthetic geotextiles. Experience gained in trials and demonstration for high altitude re-vegetation shows very considerable potential for jute geotextiles in the alpine areas.

Table 2.3 Cost comparison of jute and synthetic geotextile

Geotextiles	Cost ($/m^2
Imported synthetic geotextiles	3.20
Indigenous synthetic geotextile (woven	3.20
Indigenous jute treated with rot-resistance chemical	1.12
Indigenous jute	0.173

A comparative cost study of different techniques for erosion of denuded landslides has been shown in table 2.4. From this study, it clearly indicates that jute-geogrid is the most cost effective as compared to other techniques.

Table 2.4 Cost comparison for different erosion control techniques

Technique	Material Cost ($)	Labour Cost ($)	Over head ($)	Total Cost ($)
For 100 sq.m of stretch				
Jute-geogrid	15.56	13.33	11.11	40.00
Coir-geogrid	53.33	13.33	11.11	77.78
Tenax MX-100	66.67	17.78	17.78	102.23
Amoco	111.11	17.78	17.78	148.67
Asphalt mulch	20.00	20.00	17.78	57.78

Note: Costs are approximate and used on the rates prevailing in 1997 prices.

2.3.2.5 Jute and Coir Netting Used for Erosion Control

The natural fibers that have found wide spread applications in surface erosion control are jute and coir. Strands of jute or coir are woven into an open mesh configuration, the size of the mesh ranging from 1.5 to 2.5cm. Normally the fabric is supplied in rolls of 1m to 2m widths and 50m length.

Coir fabric is a completely biodegradable organic fiber consisting of 46% lignin and 54% cellulose, whereas jute is consisting of about 20% hemicellulose, 10% lignin and 70% cellulose. Hemicellulose is the sensitive fraction because of the high water absorption and swell. Due to high content of lignin, coir fabrics, has resistance to rotting under alternate wetting and drying conditions. The retention of tensile strength is also good. Single threads have a tensile strength of the order of 150 to 200N. In the field, coir material its tensile strength for about 3 to 5 years. On the other hand, jute deteriorates within a span of 2-3 years.

2.4 MECHANISMS OF BANK EROSION

2.4.1 Bank Erosion

The banks of natural and artificial channels, which are unprotected, many erode and it is sometimes necessary to prevent the continuing loss of soil by constructing suitable works. There are different methods of protection and materials for construction, but no single method or material offers a sound, technical and economic solution to every erosion problem. Banks erode in different ways for various reasons. It is essential therefore, to establish both the type and cause of the loss of bank material before choosing a method and materials for protection. If the result is to be economic and successful.

Riverbank erosion is becoming acute in many of the alluvial rivers in India as well as other parts of the world. Rivers passing through a populated area have been threatening the towns and villages by eroding the banks, causing loss of agricultural lands and orchards in many parts of the country. Proper remedial measures need to be carried out to prevent such bank erosion. Often recourse could be taken to hydraulic model tests to identify the areas of attack and to evolve suitable remedial measure

2.4.2 Types of Erosion

The riverbank consists of upper and lower sections. The upper bank is the portion between the lower water level and the high water level. The lower bank below the low water acts as the foundation for supporting the upper bank and is generally more susceptible to erosion.

The banks of natural and artificial channels erode in two ways:

a) Abrasion, or removal of materials from the surface of the bank; and
b) Slip, or collapse of the mass of soil in to the channel.

2.4.2.1 Abrasion

Men and animals walking on the face of a bank may cause abrasion. The condition is often aggravated by rainwater flowing down the worn paths and washing soil in to the channel. More usually, however, abrasion is caused by the movement of water in the channel, and is affected by high velocities, currents, local eddies and waves.

It is also recession of bank caused by the erosion of the lower bank at the toe. It is fast when there is a sandy substratum below. The sand is washed away by a strong current along the bank and then triggering bank collapse.

The action on the upper bank is the most severe when the current of water impinges normal to the bank and also when the flood recedes the banks very quickly due to which big cracks develop leading the collapse of the bank.

2.4.2.2 Slip

Slip is caused by a reduction in the internal soil strength or by an increase in the forces tending to cause the movement. The mass of soil, which slips in to the channel, breaks up and is carried away in suspension or as bed load.

Generally, the causes of bank failure need to be analyzed before taking up the protective works. Broadly the causes of bank failure are as under:

i) Washing away of soil particles from the bank by a strong current.

ii) Undermining of the toe of the bank by eddies, currents, etc., followed by collapse of the upper part of the bank due to non-availability of proper support.

Failure of the bank by sliding or sloughing of slope. During long duration of floods, the banks are saturated for a long period. Saturation decreases the shearing strength of soil and thus the pressure of seep.

2.4.3 Principles of Protection

A careful examination of the bank, the morphology of the river and characteristics in the channel should reveal both the modes of failure and its cause. The methods of protection which are technically sound may then be deduced and a solution developed which takes account of funds available, the extent of the river upstream and downstream of any remedial works, availability of labour and materials locally, and difficulties in obtaining manufactured materials.

Method of protecting a riverbank from the loss of materials may be classified under two main headings depending on the type of failure.

a) Protection against abrasion

i) Amour face of bank.

ii) Retard the flow within the channel or near the bank.

iii) Deflect the flow away from the eroding.

b) Prevention of bank slip

i) Reduce seepage through the soil mass to increase intergranular pressure and decrease the forces causing failure.

ii) Drain the soil mass away from the face of the bank.

iii) Protect against surface cracking which allows the entry of moisture and the development of a lubricated potential slip surface.

iv) Increase the strength of the soil mass.

v) Reduce the external forces tending to cause sliding.

seepage flow further reduces the stability of the slope.

The movement of ground water through sub-layer towards the river/stream, which carries soil particles with it, may cause piping in sub-layers and cause the damage to the bank.

2.4.4 Distribution and Limiting Shear Stress

It has been found that the shear stress in channels except for a few cases, is not uniformly distributed along the wetted perimeter. Knowledge of shear stress distribution is necessary for analysis of erosion in channels on the basis of tractive force. The maximum shear stress is about equal to γDS and 0.75 γDS for bottom and sides of the channel, respectively and zero shear stress exists in the corners. Critical trective force is the average tractive force exerted by the flowing water on the sediment particle at the incipient motion condition. The method of describing incipient motion condition in the forms of critical trective force is known as the tractive force approach. Apart from tractive force approach, other approaches such as competent velocity approach and lift force approach are also available for the incipient motion condition of sediment particles. Amongst these methods, the tractive force approach is most commonly adopted.

Shield and Yalin and Kavahan gave the value of critical shear stress τ_c required to move a given particle of size d and unit weight γ_s. Obviously, if the average shear stress τ_o on the bed extended by the flow is more than τ_c particle will move,

$\tau_0 > \tau_c$ motion

$\tau_0 = \tau_c$ incipient motion

$\tau_0 < \tau_c$ no motion

The tractive force per unit surface is $\tau_0 = \gamma DS$. Other names currently in use are shear stress and drag force. However, the more general shear stress equation reads $\tau_0 = \gamma RS$.

2.4.4.1 Measurement of Shear Stress

One of the instruments available for measurement of shear stress is Preston tube. Preston (1954) showed that a circular pitot tube with an outside diameter d_p resting on the wall reads the total pressure p_t relative to the static pressure P_s, $(P_t - P_s)$, depends on the independent variables ρ, υ, τ_0 and d_p. He expressed for actual observations of four pitot tubes by

$$\log \frac{\tau_0 d_p^2}{4\rho\upsilon^2} = -2.604 + \frac{7}{8} \log \frac{(P_t - P_s)}{4\rho\upsilon^2} dp^2 \qquad \text{Equation 2.1}$$

If the left hand side becomes smaller, then Equation 2.1 renders incorrect results; if larger than 6.5, no experimental data are available and so this equation is hold true, two precautions are necessary: the pitot tube must lie in the region of laminar sub layer, which is expected to hold for about one-tenth of the boundary-layer thickness, and the tube diameter must be small compared to the pipe diameter.

2.4.5 Applications in Erosion Control

Protection of banks and beds are the primary function of preserving the profile of the watercourse within certain boundaries. Erosion control applications can be used in the construction of the following:

- Stream bank protection
- Ditch channel and canal slope protection
- Cut and fill slopes
- Scour protection around bridge pier

Different forms of structures are traditionally used to protect inland and coastal erosion is:

- Rip-rap or heavy armour stones
- Concrete blocks
- Articulated concrete mattresses
- Gabion mattresses

The applications of geotextiles in bank protection have generated generally a lot of interest among civil engineers. Geotextiles are used extensively in erosion control structures because of their economy, applicable and consistent properties and general ease of installation. They can be used as an economic alternative for granular filter layers below the rip-rap on the sloping sides of the bank and the bed to be protected from erosion. This offers easy and quick construction compared to conventional one with granular filter. Grouted mattresses prepared with geotextiles can also be used as an alternative to the armour stones wherever there is shortage of these boulders, they have to be procured from long distances at higher costs.

The use of geotextile filter can simplify construction of the erosion control measures, as illustrated in Fig. 2.5-a, where it replaces several layers of granular filter beneath rip-rap armour stones. A geotextile filter can also be used in a similar manner, beneath gabion mattresses or articulated concrete mattresses. In West Germany, the Federal Institute for Waterways Engineering (BAW-Bundesanstalt fur Wasserbau) has established standard designs for protection of the banks of waterway These standards are based on over 15 years of experience in the use of geotextiles in waterway revetments.(Fig 2.5-b) shows the most widely used system of protection, which is bonded rip-rap laid over a layer of thick composite geotextile. This is intended for use on the banks of waterways that have a side slope of between 1 in 4 and 1 in 3.

The minimum properties specified in the BAW standard for the basic geotextiles are:

Thickness ≥ 4.5 mm (over sand and without abrasion)

≥ 6 mm (over cohesive soil or if abrasion is anticipated)

tensile strength ≥ 1.2 KN/ 100 mm

normal permeability coeff. Kg ≥ 10 Ks (on sand)

≥ 100 Ks (on cohesive soil)

Sometimes a thick rough geotextile layer is bonded to a thinner geotextile filter to prevent the loss of soil particles by moving down the slope, to produce a bulge and a depression on the protection works. (Fig. 2.5-c) The weakest part of the standard BAW bank protection design is probably the toe of the revetment. When the erosion protection is installed in dry conditions, the simplest form of enhanced toe protection is to extend the rip-rap revetment into the bed of the waterway to a depth exceeding the anticipated scour, as shown in Fig 2.5-d. An alternative method is fold over and sew the end of the geotextile sheet (Fig. 2.5-e) Gabion, mesh baskets which are filled with relatively small rocks, used in bank protection as a rectangular gabion mattress about 0.17m thick which is suitable for current velocities up to 2.2m/s.

Table 2.5 lists the recommended thickness of gabion mattress related to the current velocity in the waterway.

Table 2.5 Recommended Gabion Mattress Thickness

Current Velocity (m/s)	Mattress thickness (mm)
< 2.2	170
2.2 to 3.2	230
3.4 to 4.2	300
> 4.2	500

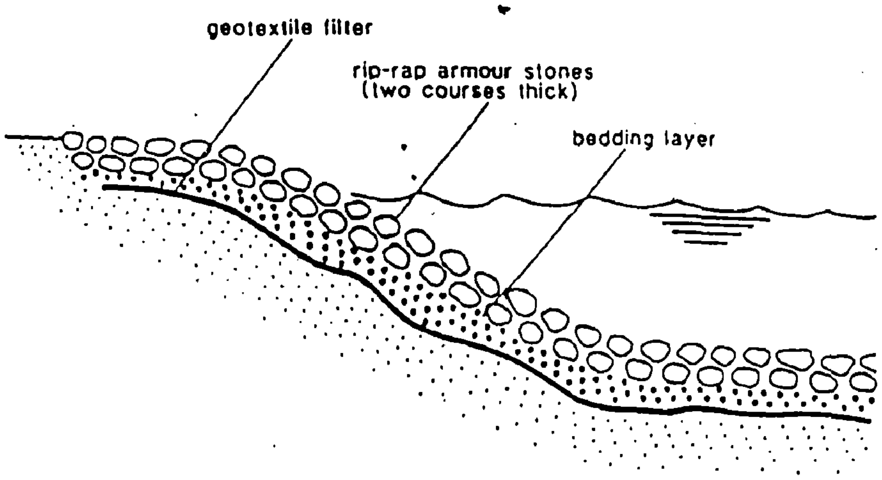


Figure 2.5a Geotextile filter replacing multi-layer Granular filter in bank protection

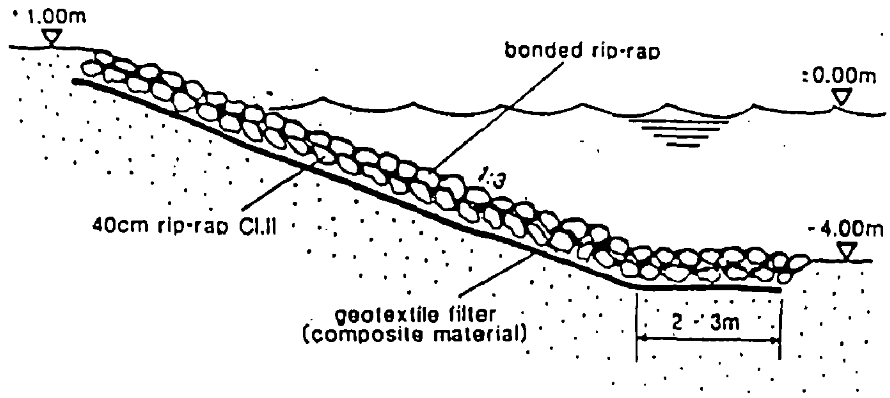


Figure 2.5b Bonded rip-rap protection system for canal sides

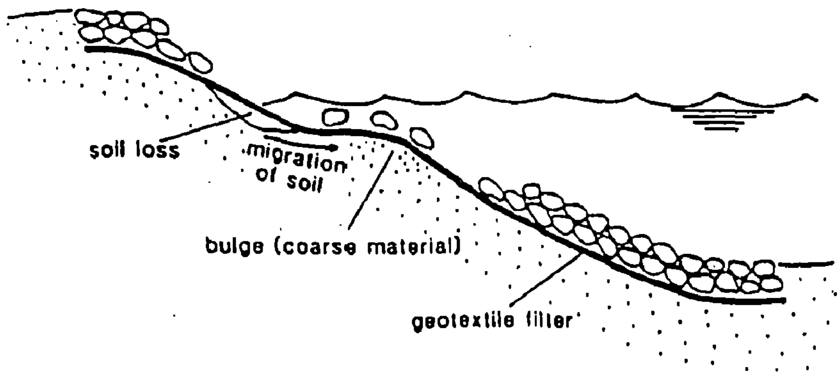


Figure 2.5c Bulging due to soil migration beneath the geotextile

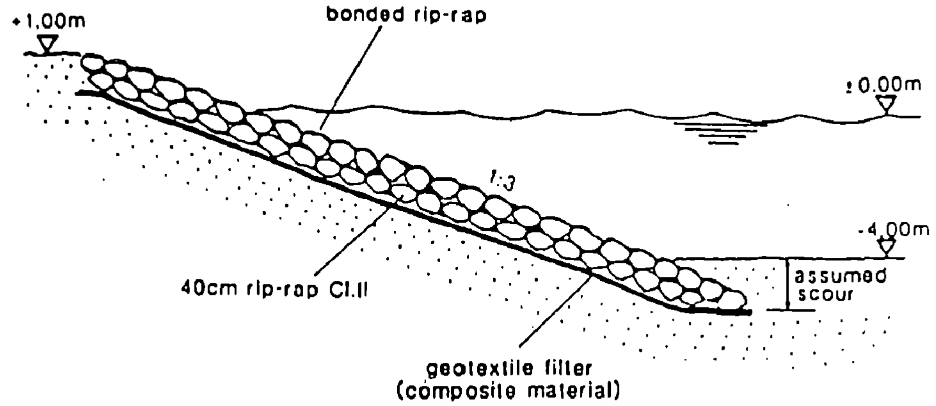


Figure 2.5d Extended toe to deal with scour

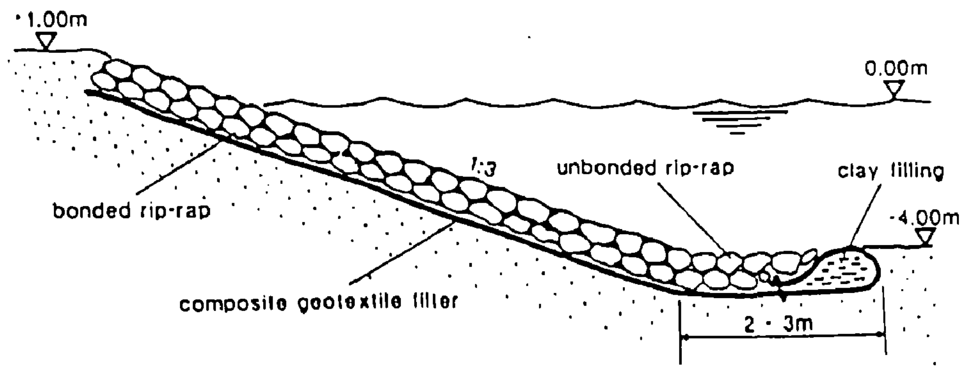


Figure 2.5e Clay filled geotextile toe used to control erosion

2.5 FIELD AND EXPERIMENTAL DATA

2.5.1 Past Case Study With Jute Geotextile for Erosion Control

Using geojute, a field trial has been conducted in West Bengal and in the foothills of Himalayas in Utter Pradesh State to evaluate the efficiency and degradation effects of geojute and the density of growth of vegetation when used for erosion control. Table 2.6 presents a summery of the reported field trials in India for erosion control, using jute geotextiles.

Juyal (1991) et al., reported that the life requirement of geojute in Dehradun , in the foothills of Himalayan, should be of minimum years, to have sufficient density of vegetation cover to grow in these regions.
. Geojute has degraded completely within 2 years of implementation in this area.

Sanyal (1992) reports the extended possible due to bitumenisation of jute fabrics in erosion control. But the bitumenisation process of geojute or other erosion control mats of natural fiber may be related to its ability to absorb more water and thereby modifying the soil environment suitable for plant growth. However, it was reported that in an estuarine condition, bitumenised natural fibers are good enough to protect the banks from erosion.

Table 2.6 Erosion Control Trials Using Jute Geotextiles

Sr. No.	Location	Reported by	Control Measure	Remarks
1.	Sahastradhara Near Dehradun U.P	Juyal et al. * 1991 & 1994	Revegetation of an abandoned and degraded limestone quarry	Geojute. Vegetation in areas treated with Netlon and Geocell is reported to be less compared to Geojute
2.	Nayachara island near Hooghly estuary, West Bengal	Sanyal, 1992 *	Bank protection against erosion	Bitumen coated geojute and mangrove plantation
3.	Nayachara island near Hooghly estuary, West Bengal	Sanyal, 1992	River bank and bed protection	Geojute
4.	Silguri District, West Bengal	Chatterjee et al. 1994	Hill slope protection	Geojute
5.	Digha Sea Shore, West Bengal	Chatterjee et al. 1994	Stabilization of sand	Geojute
6.	Forest and Tea gardens, West Bengal	Ramaswamy, 1994	Stabilization of sand	Geojute

2.5.2 Surface Erosion Control Using Coir Netting

2.5.2.1 Past Case Studies

Full-scale field experiments using coir netting for control of erosion of slopes were carried out at Meerapur-Deval Road. This site was chosen since the slopes were found to be highly susceptible to erosion. Details of the studies at these location is presented below:

Meerapur-Deval Road

About 4kms of approach embankment to the Ganga-Barrage at Muzzafarnagar (U.P) has formed a part of the Ganga canal bank of about 10m height. The embankment is made of silty sand dozed from the canal bed at the time of construction of the canal. The density of the compacted soil was of the order of 1.46 t/m^3. A significant portion of the side slope of the embankment used to be washed away during the rainy season. The loss of soil was of the order of $500m^3$ per kilometer in 1987 and $4444.44 was spent on maintaining the embankment slope in proper condition, per years.

A comparative study of the following techniques of erosion control was conducted at this site.

i. Use of coir netting
ii. Use of stone pitching
iii. Pitching of shoulders with bricks
iv. Control section without any treatment
v. Use of coir netting with pitching of shoulders.

The loss of soil from the sides of the embankment for the above five stretches after a heavy monsoon during the year 1988 was found to be as given in table2.7.

Table 2.7 Efficiency of Different Methods of Erosion Control

Sr.No.	Technique used	Amount of soil lost in cu.m. Per 100 sq.m. of embankment length
1.	Coir netting	300
2.	Stone pitching	125
3.	Brick soling of berms only	600
4.	Control panel	900
5.	Coir netting of slopes Coupled with brick soling of berms	Nil

EXPERIMENTAL SETUP PROCEDURE

3.1 GENERAL

Erosion along a river/stream bed and banks is a common feature of alluvial river, which have the tendency of meandering. Different techniques were used to minimize this effect. A cost effective approach by placing different types of jute geotextile on the soil mass is investigated in this experimental study.

Keeping this in view, experiments were planned and conducted in the River Engineering Laboratory of WRDTC, University of Roorkee (India). This chapter contains the description of equipment used and the experimental procedure adopted for data collection.

3.2 DETAILS OF EXPERIMENTAL SETUP

3.2.1 Flume

A schematic view of the experimental setup is shown in Fig. 3.1. Experiments were conducted in a re-circulating tilting flume; 3.6m long, 0.5m wide and 0.55m deep. A reach of 2.4m in the central portion was provided as mobile bed with non-uniform sediment of thickness 20cm with one side slope was used. The side slope was varied 1V: 1H in one case and 1V: 1.5H in other case.

Two rows of perforated perspex sheets were provided at the upstream end of the flume to destroy the excess energy of inflow and distribute the inflow uniformly over the entire width of the flume. A tailgate at the downstream of the flume was used as a controlling device for regulating the depth. Galvanized iron pipes were provided on the top of side walls over which the frame carrying the pointer gauge, pitot tube and Preston tube could be moved smoothly.

Water was supplied to the flume with the help of mono lift pump from surface tank by a 10cm diameter supply pipe having a valve at he outlet to control the flow. Water after passing through an experimental channel entered into the return channel where a v-notch were fitted on it for measurement of discharge with the help of 20 liter bucket and stopwatch.

Later on, this discharge was cross checked with the observed average discharge measured by the pitot tube, and the value was found nearly equal.

3.2.2 Anchoring Gauge

An ordinary gauge wire staples of 20 by 10, 15 by10, and 10 by10 centimeter were used for fixing the jute's on the bed and banks of the flume. The staples were provided between 30cm to 40cm intervals to have a fixed layer of jute over the surface of bed and bank.

3.2.3 Pitot and Preston Tubes

A pitot and a Preston tube were used with inclined manometer to measure the velocity of flow and flow tractive stress respectively. In both the cases, 6.3mm inner diameter pitot and Preston tubes were used. The static head tube of pitot and Preston tubes were connected to the inclined manometer such that the sine of the inclination is 0.707.

3.2.4 Pointer Gauge

A needle end pointer gauge was used to measure the depth of flow and cross-sectional profile of the flume.

3.2.5 Sediment

Non-uniform sediments of two different types viz. sand and clay were used after carried out sieve analysis. The results of sieve analysis were shown in table 3.1-a and table 3.1-b. The relative density of 2.65 and 2.40 were taken for sand and clay respectively.

3.2.6 Jute

Different types of jute material were used for erosion control depending upon the site condition.

In the present study five different types of woven untreated jute viz. type I, type II, type III, type IV and type V, and one rot resistance chemical and bitumen treated Jute viz. type VI were used in the present study. Details of specifications are shown in table 3.2.

3.3 EXPERIMENTAL PROCEDURES

First of all, the given sediment material viz. non-uniform grading sand and clay to be used for analysis was placed in the flume at a predetermined bed slope.

Since the aim was to determine best method for minimizing erosion in the bed and bank using natural fibers after taking the economy into consideration, different sets of runs were taken independently viz.

1. Bed and bank material sand, with and without treated and untreated jute covered on it.
2. Bed and bank material clay, with and without treated and untreated jute covered on it.

3.3.1 Establishment of Uniform Flow

After the flume was set to the required condition, the desired discharge was allowed to enter the flume by increasing gradually starting from a very low value. The uniform flow was established for each discharge with the help of tail gate. Keeping the depth of flow constant for the same bed and bank, and longitudinal slope.

Again after constant flow has been maintained, discharge was measured on the downstream tank by the volumetric method using v-notch, stopwatch and 20 litter capacity bucket. The time required to fill the bucket was recorded for more than five trials and the average of it was taken for discharge computation.

3.3.2 Depth of Flow

A pointer gauge measured the depth of flow after the flow became uniform. For the experimental purpose it has been taken the same where the slope of bed and bank provided the same, to keep the discharge nearly constant, as the scope of the study was limited to have the same discharge and depth of flow.

3.3.3 Velocity Measurement

It was decided to measure the velocity distribution at three sections over the flume length viz. at 0.6m, 1.2m and 1.8m in each run. In every case the velocity distribution over the depth of flow at the center line of each section viz. 0 to B/3, B/3 to 2B/3, and 2B/3 to B in the flume width was obtained using a pitot tube, and then overage value of velocity over the width at different elevations was obtained arithmetically. In addition to this measurement of velocity was taken at the bank center in each section of 0.6m interval flume length.

3.3.4 Shear Stress Measurement

Once the constant discharge was obtained the boundary shear stress was measured over the entire flume length viz. at 0.6m, 1.2m and 1.8m along the bed. In each case the dynamic pressure was measured at the mid point of the bed width using Preston tube and shear stress is equated on arithmetically using the following formula:

$$\log\frac{\tau_0 dp^2}{4\rho\mu^2} = -2.604 + \frac{7}{8}\log\left(\frac{P_t - P_s}{4\rho\mu^2}\right)dp^2 \qquad \text{Equation 3.1}$$

3.3.6 Volume of Sediment Eroded

In a particular run, after sediment was filled into the flume in the required depth and slope, and at the end of each run before disturbing the bed and the bank, measurement of elevation was taken over the entire flume viz. at 0cm, 7.5cm, 15cm, and at 15cm, 32.5cm and 50cm across the bank and bed width respectively and at 30cm interval along the length.

The change of elevation either positive or negative in a point is considered as a direct relationship to the change of volume eroded or deposited. Theoretically, erosion depth develops asymptotically with time. However, it is practically, not possible to run the experiments for such a long time. It is well known that erosion development is rapid initially and becomes slow after a few hours. The experiments carried out such a fixed time that the eroded particles on the flow negligibly small. The same procedure was repeated for other slopes with and without jute.

The range of experimental data of different parameters are tabulated in table 3.3 and all the data are listed in Appendix A-1

Table 3.3 Range of Experimental Data

Variable	Range
H (cm)	7 – 15
S_L	1 in 50 – 1 in 2000
S_b	1 in 1 – 1 in 1.5
V (m/sec)	0.310 – 0.514
Q (lit/sec)	0.010 – 0.017
Fr	0.350 – 0.535
τ_o (N/m^2)	0.430 – 2.957

3.4 DIFFICULTIES ENCOUNTERED

While conducting the experimental work, the following difficulties and problems were faced.

(i) When electric current was fluctuating, the discharge was fluctuating to such an extent that the reading of inclined manometer was affected.

(ii) Shear stress on the bank was not measured due to the inclination of the bank, the two parallel ends of the Preston tube were not touch at the same elevation on the bank wall.

Table 3.1 Clay and Sand Gradation for Experiment

(a) Sand:

Sieve size (mm)	Gradation obtained (%passing)
1.000	100.000
0.600	99.947
0.425	99.524
0.300	87.475
0.225	49.983
0.150	10.986
0.075	5.546
0.063	2.662
0.050	0.000
0.044	0.000
Pan	0.000

(b) **Clay:**

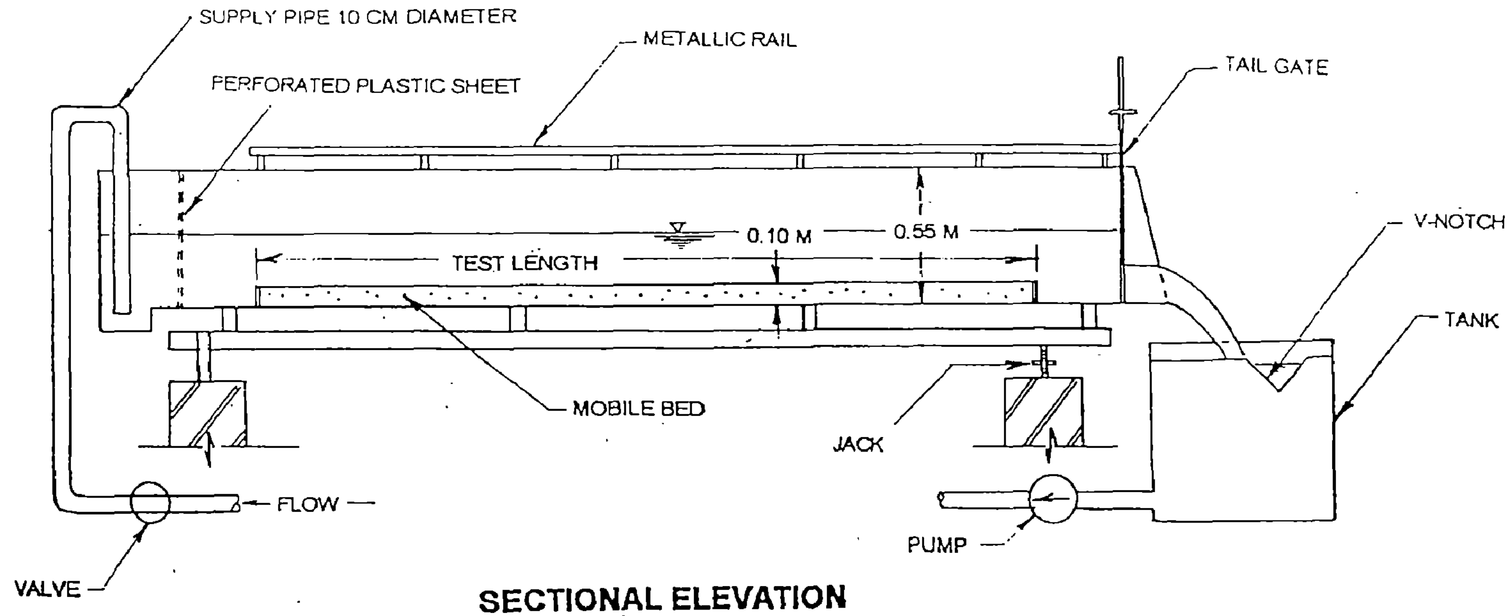
Sieve size (mm)	Gradation obtained (%passing)
1.000	100.000
0.600	99.980
0.425	99.460
0.300	88.651
0.225	86.012
0.150	80.000
0.075	40.000
0.063	8.200
0.050	2.300
0.044	0.000
Pan	0.000

Table 3.2 Jute Material Used for the Study

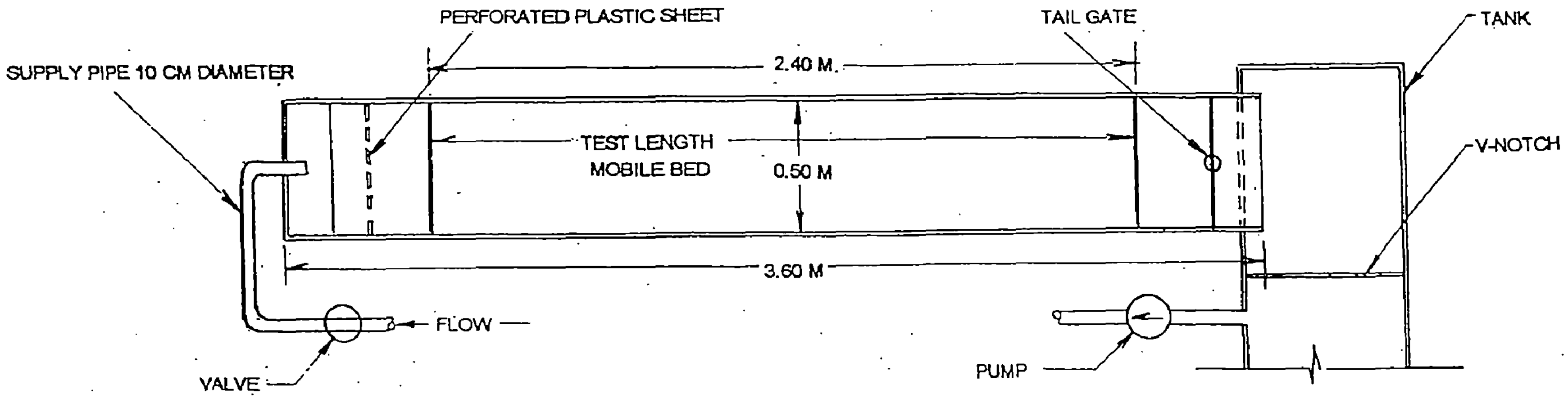
Material	Weight (GM/M^2)		Ends (per D.M)	Picks (per D.M)	Width (cm)	Thick -ness (mm)	Threads (per D.M)	Pore size (090)	Remarks
	Untreated	Treated							
Type I (Quality jute soil saver)	732	-	7.0	7.0	122	5	-	-	Produced in Naffar Chandra Jute Mills Ltd. ,Kankinara: North 24 Parganas, India
Type II (Jute soil saver)	500	-	6.5	4.5	122	5	-	-	Produced in Naffar Chandra Jute Mills Ltd.
Type III (Improved soil saver)	400	-	-	-	122	3	34x15	-	Used for control of surface soil erosion of Tea gardens in Cachar, Assam
Type IV (Quality jute soil saver)	292	-	10.8	12		3	-	-	Produced in Naffar Chandra Jute Mills Ltd. ,Kankinara: North 24 Parganas, India

Type V (Improved soil saver)	250	-	-	-	122	3	11x11	-	Used for control of surface soil erosion and also as agricultural mulch in unsur, Karnataka, India.
Type VI (Rot resistance chemical and bitumen treated)	760	1200	-	-	76	2.5	102x39	150x 200	By Calcutta Port Trust, Haldia, Irrigation and Waterways Directorate, India

* This notation (naming according to weight of the jute) is valid only in this thesis.



SECTIONAL ELEVATION



PLAN VIEW

Figure 3.1 **SCHEMATIC DIAGRAM OF EXPERIMENTAL SETUP**

NOT TO SCALE

CHAPTER IV

ANALYSIS OF DATA AND DISCUSSION OF RESULTS

4.1 PRELIMINARY REMARK

The data collected experimentally for the study of erosion on the bed and bank of a one-side slope trapezoidal channel have been analyzed and presented in this chapter. Erosion on these channels has been studied under different materials and bed conditions with relatively each run for respective comparison. Experimental data collected in the present study are summarized in Appendix A.

4.2 VELOCITY DISTRIBTION

For a particular run, uniform flow was established by maintaining a constant depth of flow throughout the length of flume. Then to ascertain the uniformity of flow over the entire cross-section, velocity measurements were taken over the entire channel cross-section and the velocity profile was plotted. Thus, velocity distributions along the depth showed the customary increase in velocity with height except for small reduction near the surface. With the result of average velocity calculated from each section and the cross-sectional area of flume, the discharge was computed. On lengthwise, the velocity was reduced from upstream to downstream of flume depending on the roughness of the covered material on bed and bank. This indicates that the velocity of flow was maximum in thin bed and bank cover material and minimum in thick cover material. Therefore, erosion was relatively higher in thin than thick layer cover material. Figures 4.1-a, 4.1-b and 4.1-c show the velocity profiles over the whole flume cross-sectional area.

4.3 DISTRIBTION OF SHEAR STRESS

In the present study, shear stress along a flume section was calculated based on the Preston method. The result indicates that in each material a significant variability of shear stress on the bed was observed. In each case, as we go from upstream to downstream along the flume length, the shear stress reduced. From a perusal of Figs. 4.2-a, 4.2-b, 4.2-c, 4.2-d and 4.2-e when we compare material wise maximum shear stress measured in sand and minimum in type IV with a relative increase from type II to I subsequently as shown in Fig. 4.2-a, the above stated variability becomes discernible.

In Fig.4.2-b maximum shear stress was measured in sand and minimum in treated jute (type IV), the value in untreated jute (type I to V) lies between the two ranges with respect to increase in weight, thickness and reduction of mesh size of the jute. Similar situations were seen in Figs. 4.2-c, 4.2-d and 4.2-e.

From Figs. 4.3-a, 4.3-b, 4.3-c, 4.3-d and 4.3-e it is seen that shear stresses have registered increase with increase of longitudinal slope. More or less, keeping the same level of discharge flowing into the flume, sand with longitudinal slope 2% and clay covered with treated jute (Type VI) and with longitudinal slope 0.05%, measurements of maximum and minimum shear stresses respectively as the bank slope is found to be same for both the cases.

The average depth of flow versus average shear stress plot clearly shows that, the shear stress became maximum when the cover of the bed and bank material is smooth or finer layer, keeping the other parameters constant. That is if the bed and bank is made of sand, then the shear stress is higher. In other combination if the bed and the bank is sand with extensively covered by jute Type V, the shear stress is smaller than the previous one but higher than the other jute material used. The same holds true in the case of clay. This indicates that the tractive force required for moving the sediment particle is higher if the bed and bank is without cover material, and lower if the covered material should be thick thread, thinner mesh size and relatively heavy weight. The variation of shear stress with depth of flow is shown in Figs 4.4-a, 4.4-b, 4.4-c, 4.4-d, and 4.4-e.

Generalizing the results with the same discharge, depth, bed and bank condition untreated jute type I have shown to be maximum resistant to shear stress, next to rot resistant chemical and bitumen treated jute (Type VI).

4.3.1 Variation of Bed Shear Stress

Shear stress distribution along a perimeter of known channel section can be calculated by the Preston method, as explained earlier in section 3.3.4 and tractive force approach based on $\tau = \gamma RS$. Each of these are explained, and shear stresses using Preston method and tractive force approach were different.

To check the adequacy of Preston method, the computed value of average shear stress over each section was compared with the average shear stress, τ_o calculated as γRS, for different runs in each section. This comparison is shown in Figs. 4.5-a, 4.5-b, 4.5-c, 4.5-d and 4.5-e. From this figure it is seen that the experimental values of shear stresses are consistently similar than the computed values up to 50 percent. Such a difference can only be ascribed to the inaccuracies in shear stress measurements.

4.4 VARATION OF FROUDE NUMBER WITH MATERIAL

The plots of Froude number versus longitudinal slope were used for observing the effect of gravity force on different bed and bank materials. From Figs. 4.6-a, 4.6-b and 4.6-c, where bed and bank material was sand without being covered by any jute material, have Froude number maximum in both the slopes but larger value for higher slopes. For treated jute, Froude number was minimum in minimum slope, i.e., 0.05% and maximum in maximum slope, i.e., 2%. In untreated jute the Froude number reduced with an increase of the thickness, weight and decrease of mesh size of the jute material sequentially.

Generally, the computed Froude number was maximum in sand without being covered by any jute material and minimum in rot resistant chemical and bitumen treated jute (type VI); untreated jute being with in the two ranges sequentially with increase of weight of jute gram per meter square.

4.5 ANALYSIS OF ERODED VOLUME

The different bed elevations measured in each run were computed by the method of approximation, and from the result a plot of eroded volume versus material cover on the bed and banks were shown in Figs. 4.7-a, 4.7-b, 4.7-c, 4.7-d and 4.7-e. In the computation of the surface area of the flume, bed and bank area were divided in to sub-rectangular regions and each eroded or deposited sediment depth considered as approximate depth of erosion, d' or approximate depth of deposition, d'' respectively. Then using volume formula i.e., volume =L * W * d' or d" the volume of each sub-rectangular region is determined. Summing up all these volumes of the sub region the total volume of sediment eroded or deposited in the flume for one run was estimated. With the same procedure the volume of sediment eroded or deposited for subsequent run were determined.

4.5.1 Eroded Volume of Bed and Bank

In the computation of bed eroded volume, the whole bed area was divided into eight equal area of 0.3m length by 0.5m width. Two and three measurements were taken from respective sides and width, the average of these measured value were taken as average depth of erosion or deposition for the sub region. With volume formula expressed in section 4.5 the volume of sediment eroded from the flume bed was determined.

Similarly in the case of bank, the flume bank into equal sub rectangular regions of 0.3m length by 0.18m width area was considered. In each area, five measured points, two on the length side and three on the width side, same procedure as the bed, the volume of the flume bank were determined. Thus, the sum of the whole bed and bank volume gives total sediment eroded from the flume.

4.6 CONCLUDING REMARKS

The material used in this study viz. sand, clay, treated jute and untreated jute has shown distinguishable response in different parameters under study in this work. From the experimental results it would be seen that sand bed and bank material without being covered by any jute geotextile, experiences maximum shear stress, Froude number and erosive effect on the bed and side of the channel. On the other hand, bed and bank material made of clay being covered with treated jute have minimum shear stress, Froude number and erosive effect on the bed and side of the channel. If untreated jute geotextile is used as protective material in the bed and banks, its erosion resistance becomes maximum when it has thick thread, smaller mesh size and heavy weight, i.e., in the case of type I jute.

Therefore, from the experimental study it would be found that the treated jute type VI as a protective material for bed and banks of a channel have the best erosion resistance capability compared to the other used in this study. From untreated jute geotextiles, type I has shown better erosion resistance response than the other jute material used in the study.

But, looking in to the economic aspect, untreated jute is less costly than the treated jute. So, from this standpoint untreated jute geotextile type I is preferable as a biodegradable erosion control protective cover, wherever suitable vegetative cover is proposed to be cultured after a shorter growing period of say 12 months.

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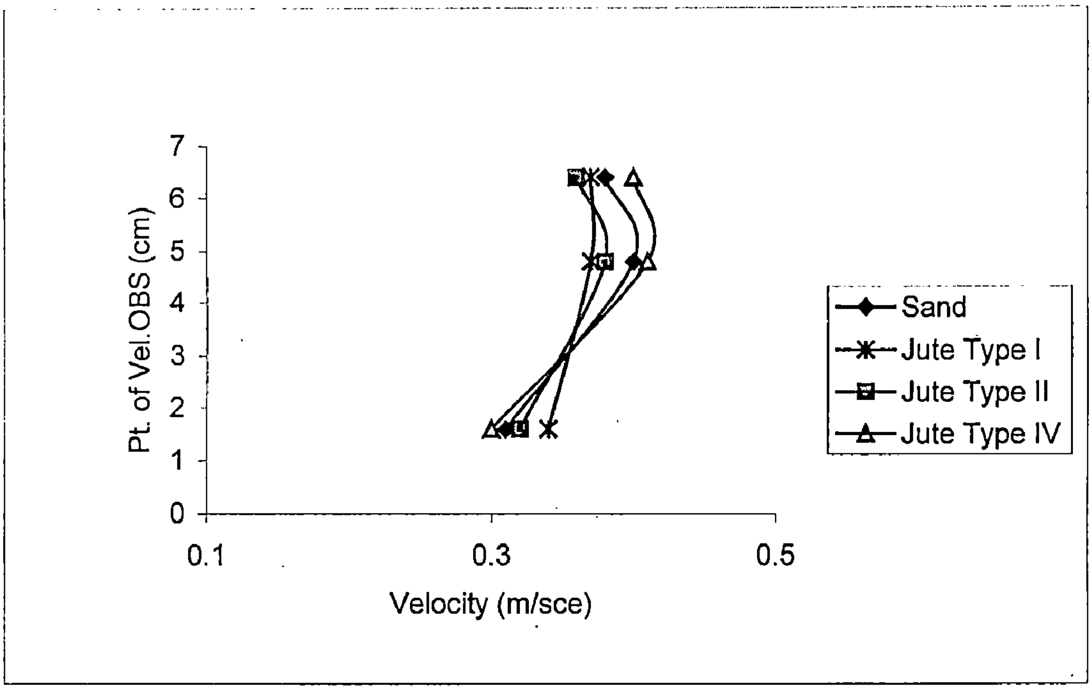

FIG 4.1-a Velocity Profile at 1.2m from inlet with Bed and Bank Sand, Longitudinal Slope 0.05% and Bank Slope 1:1.5

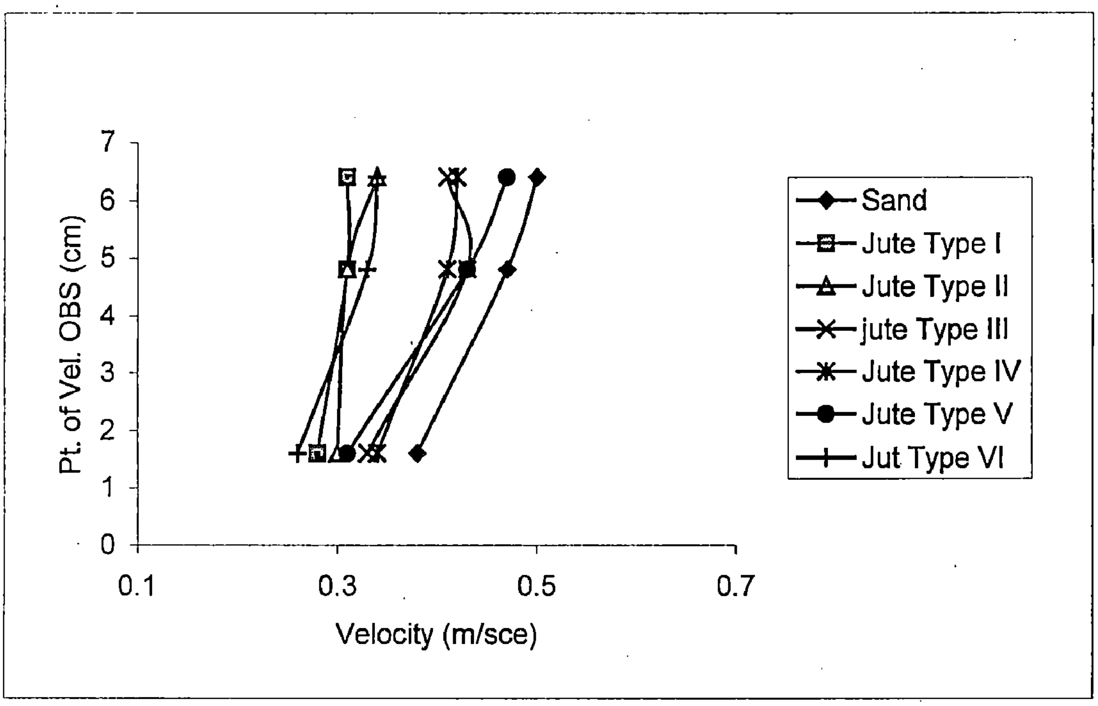

FIG 4.1-b Velocity Profile at 1.2m from inlet with Bed and Bank Sand, Longitudinal Slope 2% and Bank Slope 1:1.5

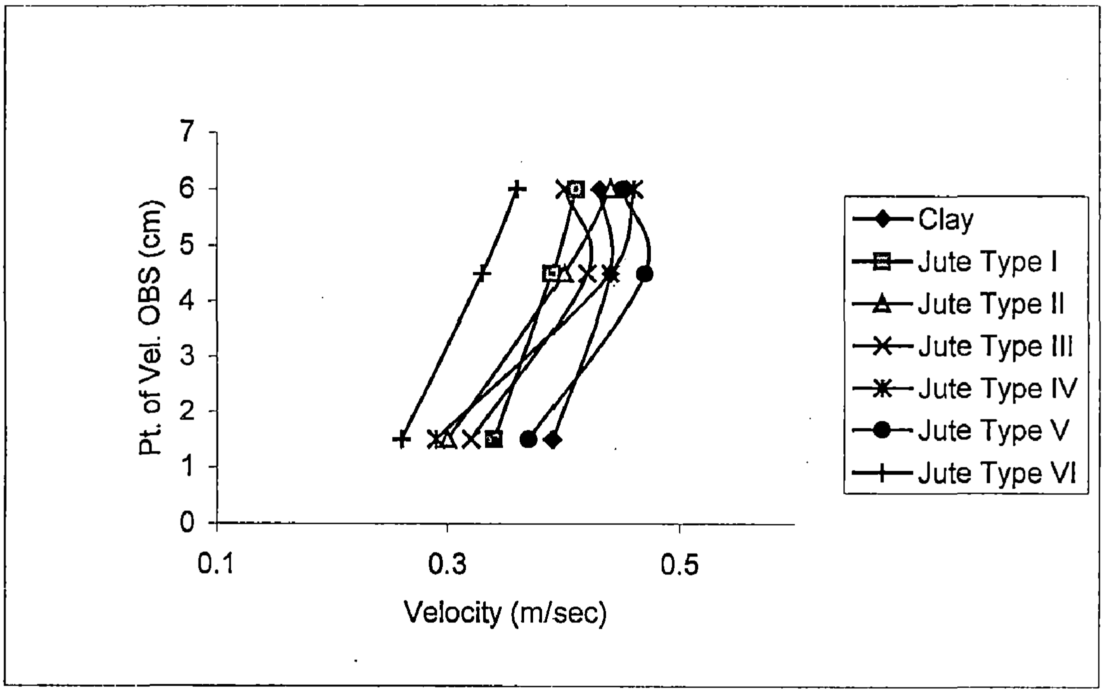

FIG 4.1-c Velocity Profile at 1.2m from inlet with Bed and Bank Clay, Longitudinal Slope 2% and Bank Slope 1:1.5

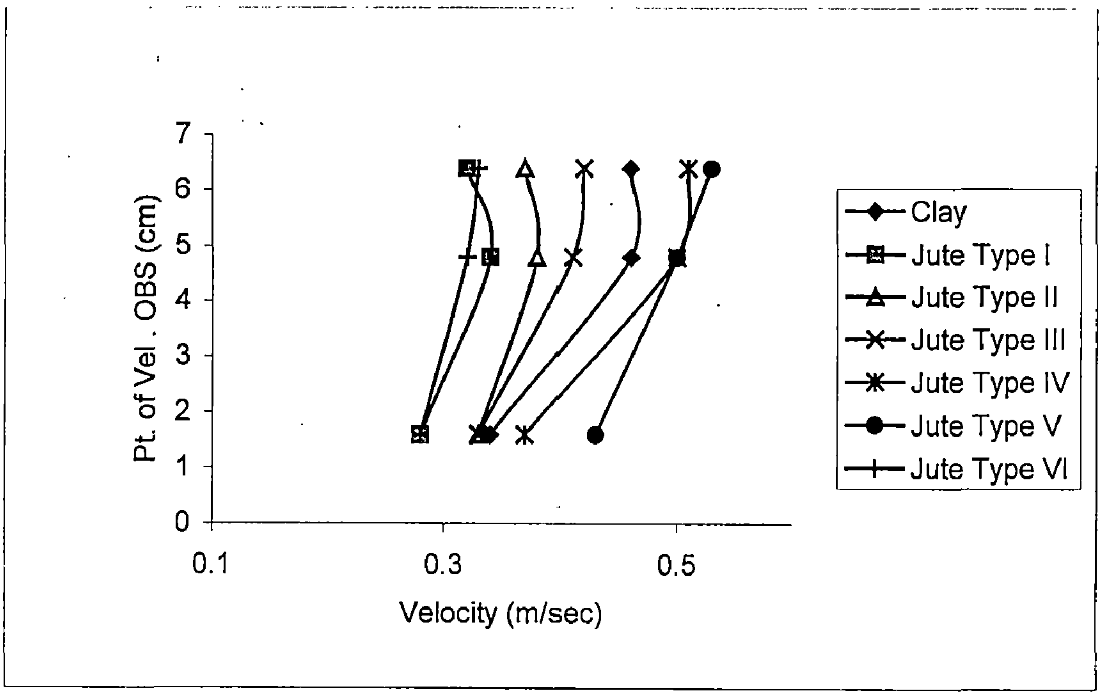

FIG 4.1-d Velocity Profile at 1.2m from inlet with Bed and Bank Clay, Longitudinal Slope 0.05% and Bank Slope 1:1.5

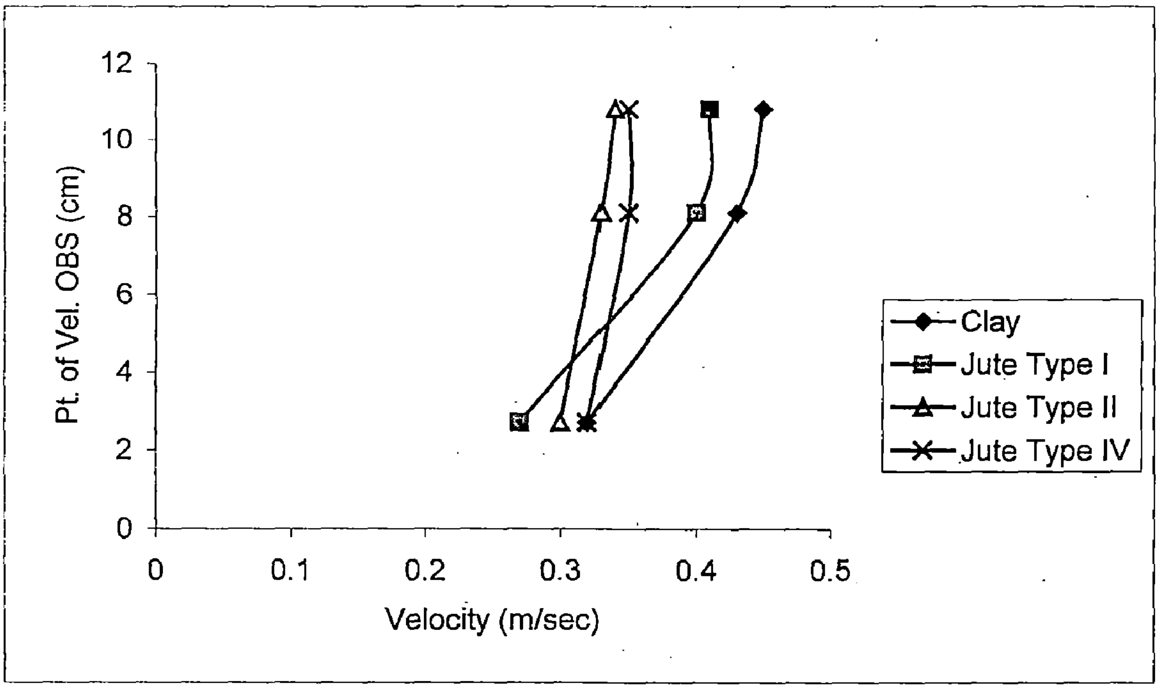

FIG 4.1-e Velocity Profile at 1.2m from inlet with Bed and Bank Clay, Longitudinal Slope 0.05% and Bank Slope 1:1

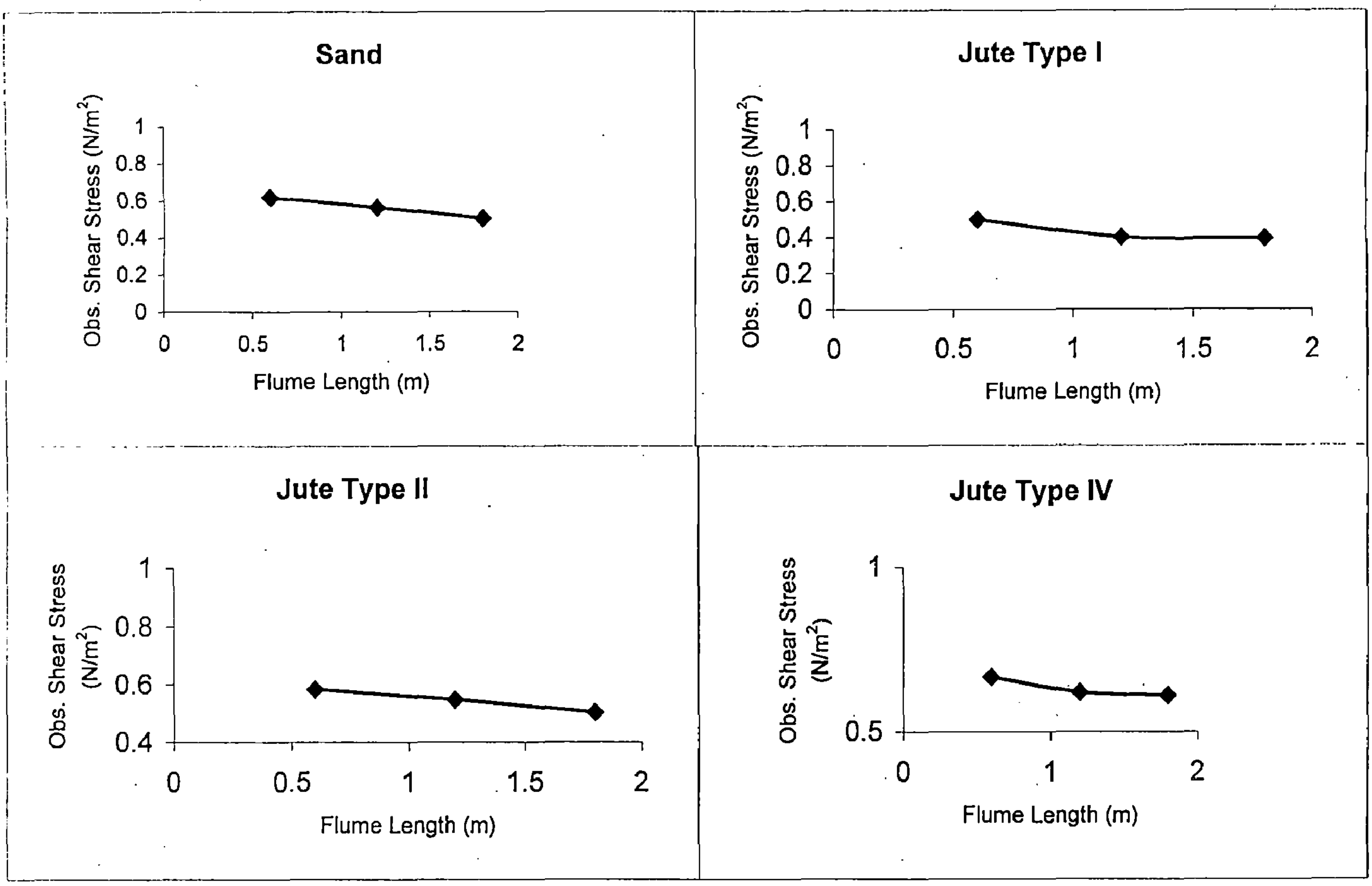

FIG 4.2-a. Observed Shear Stress versus Flume Length with Bed and Bank Sand, Longitudinal Slope 0.05% and Bank Slope 1:1.5

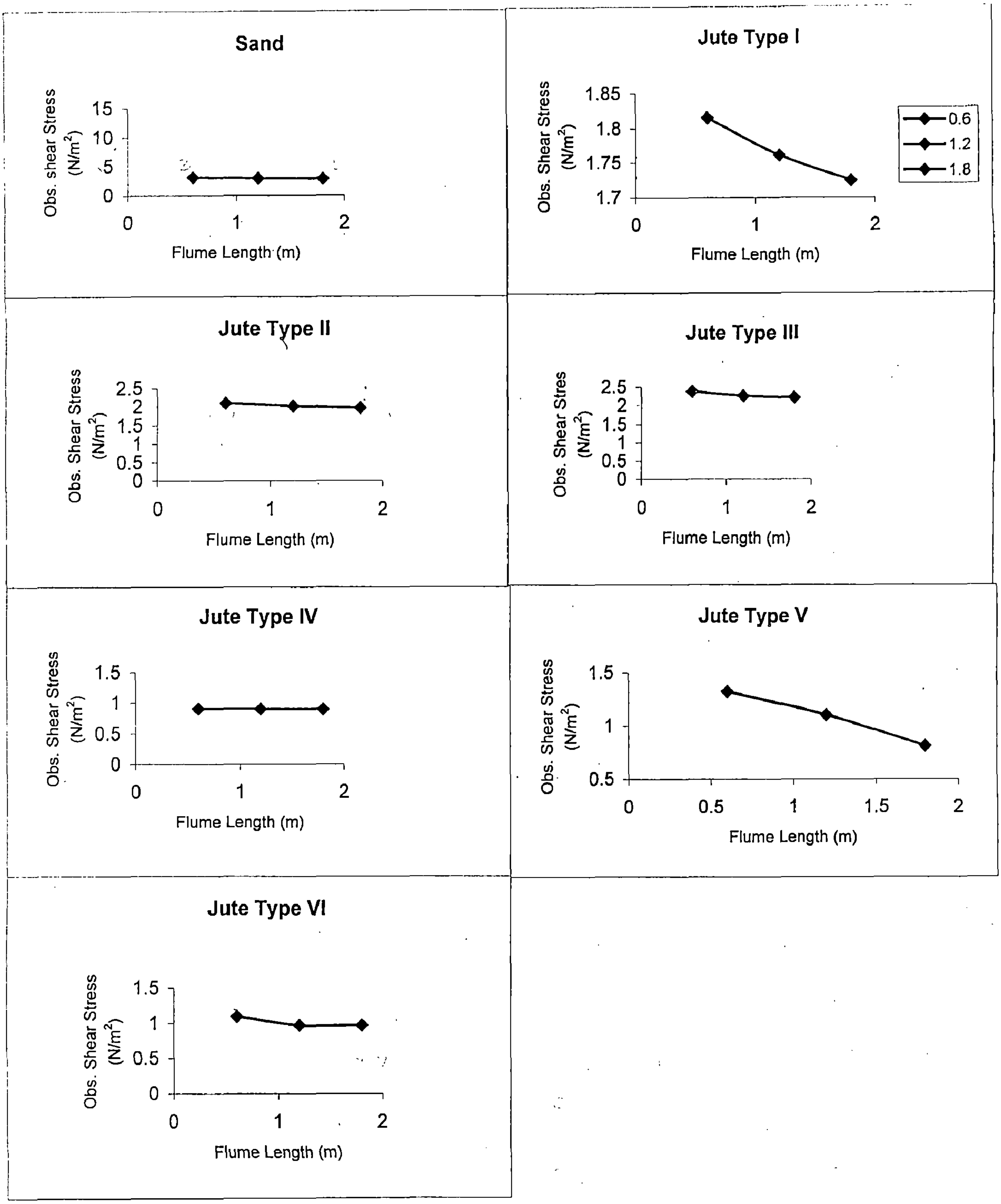

FIG 4.2-b Observed Shear Stress versus Flume Length with Bed and Bank Sand, Longitudinal Slope 2% and Bank Slope 1:1.5

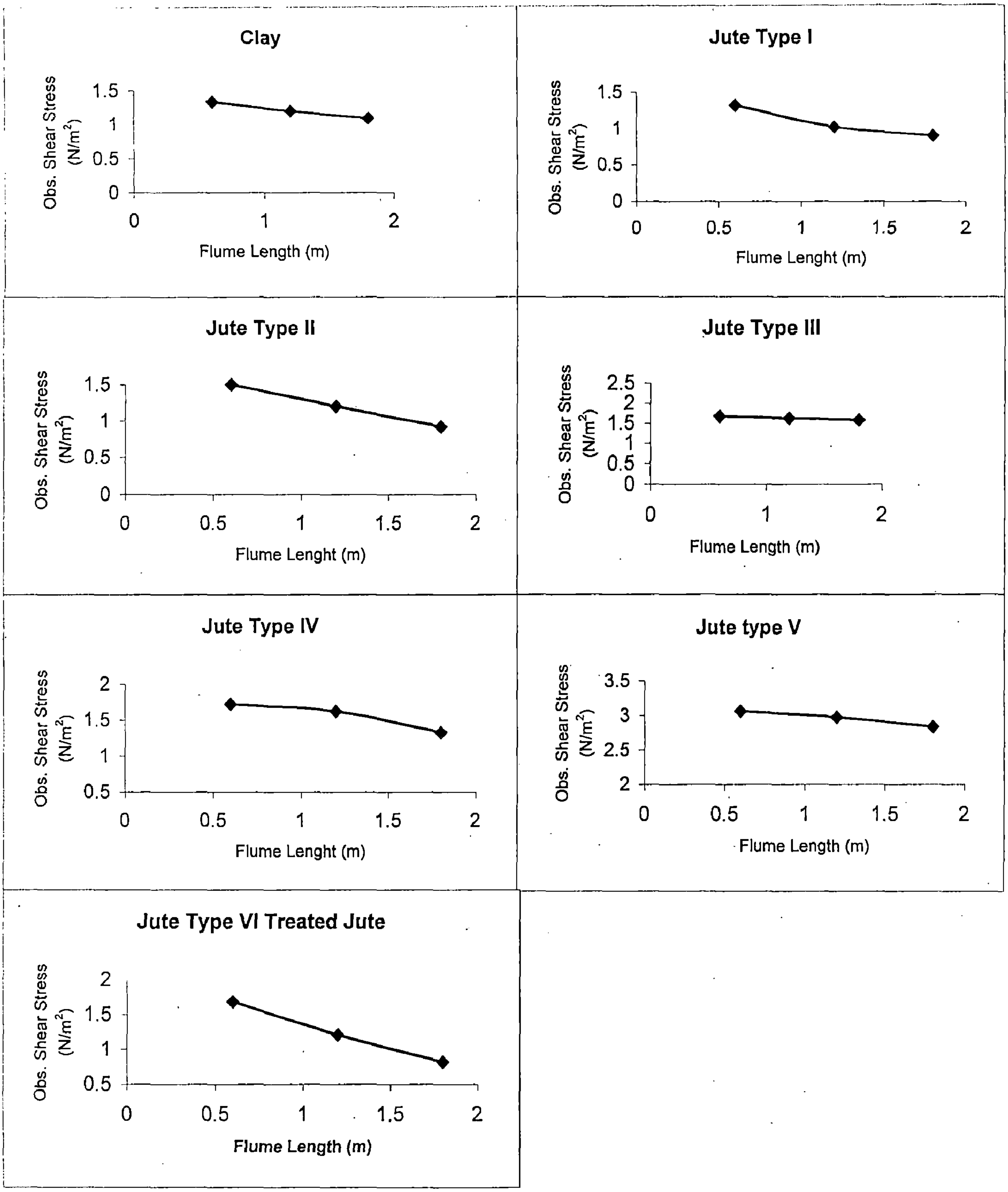

FIG 4.2-c Observed Shear Stress versus Flume Length with Bed and Bank Clay, Longitudinal Slope 2% and Bank Slope 1:1.5

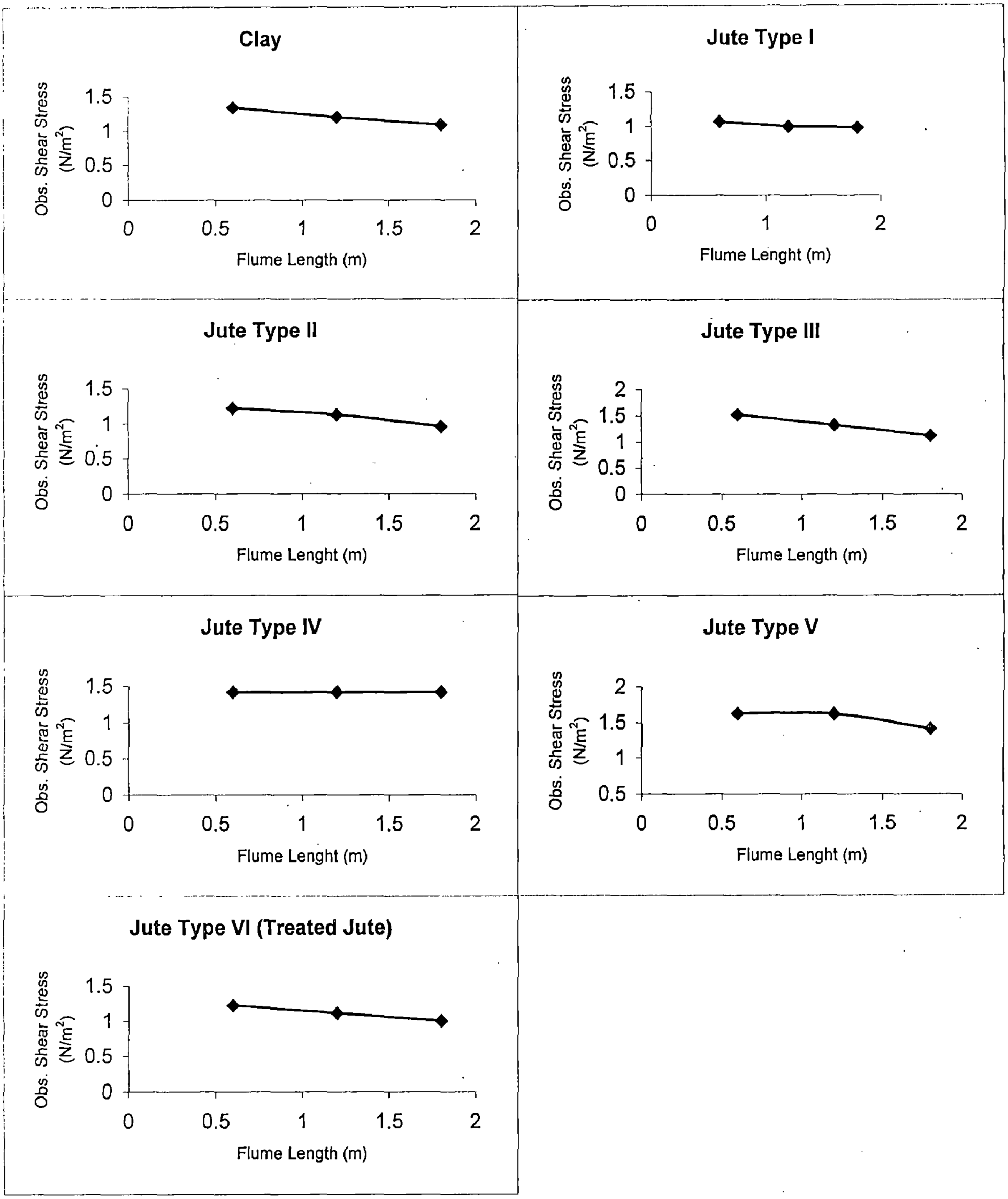

FIG 4.2-d Observed Shear Stress versus Flume Length with Bed and Bank Clay, Longitudinal Slope 0.05% and Bank Slope 1:1.5

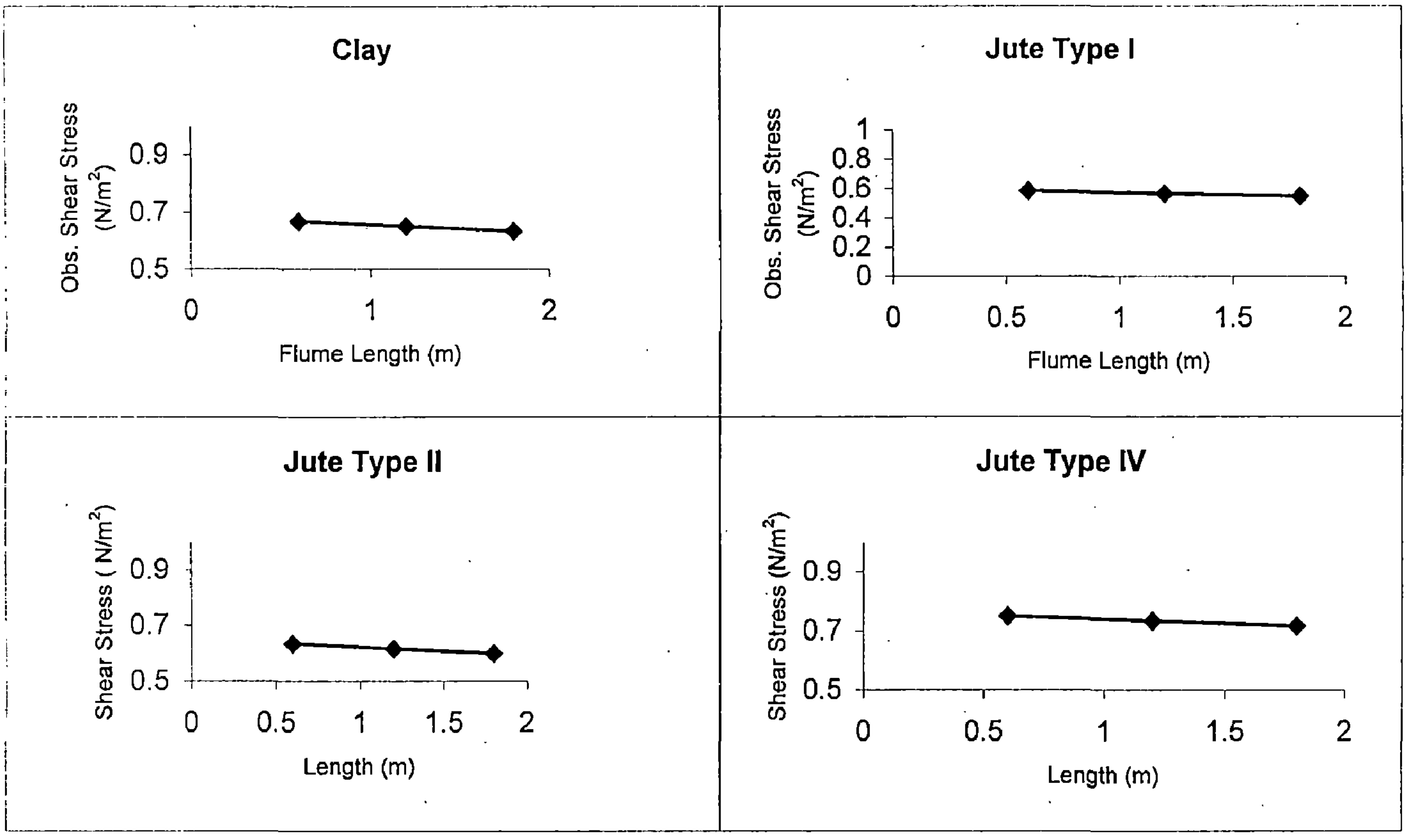

FIG.4.2-e Observed Shear Stress versus Flume Length with Bed and Bank Clay, Longitudinal Slope 0.05% and Bank Slope 1:1

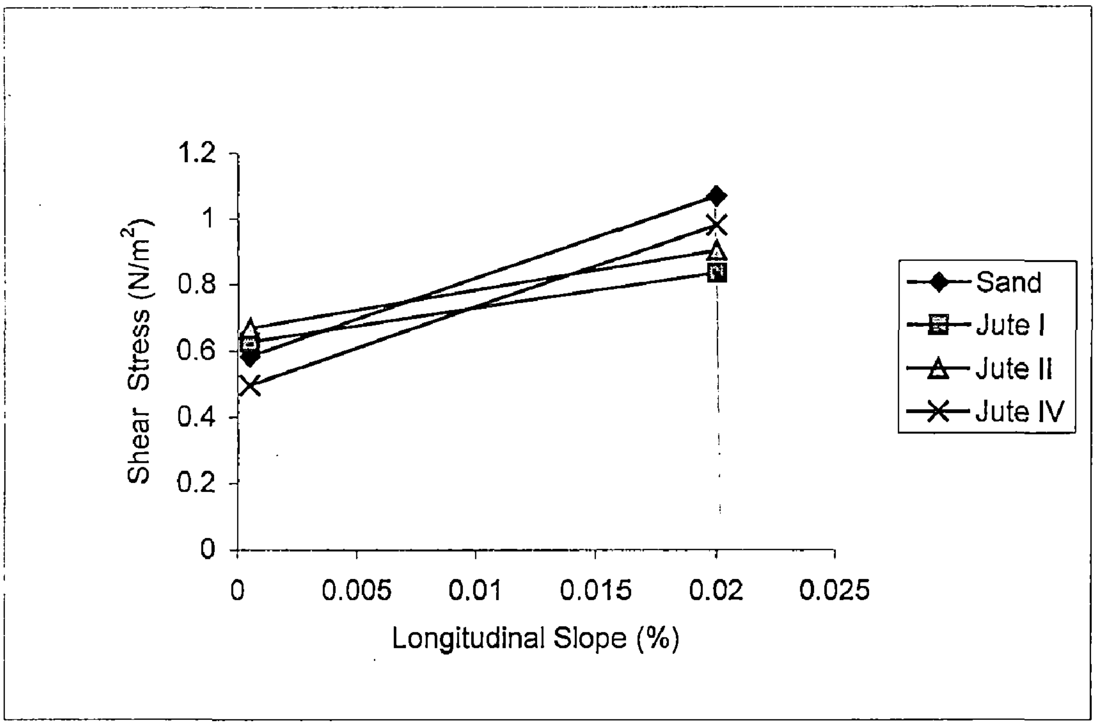

Fig 4.3-a. Shear Stress versus Longitudinal Slope on the Bed with Bed and Bank Sand and Bank Slope 1:1.5 at 0.6m Flume Length

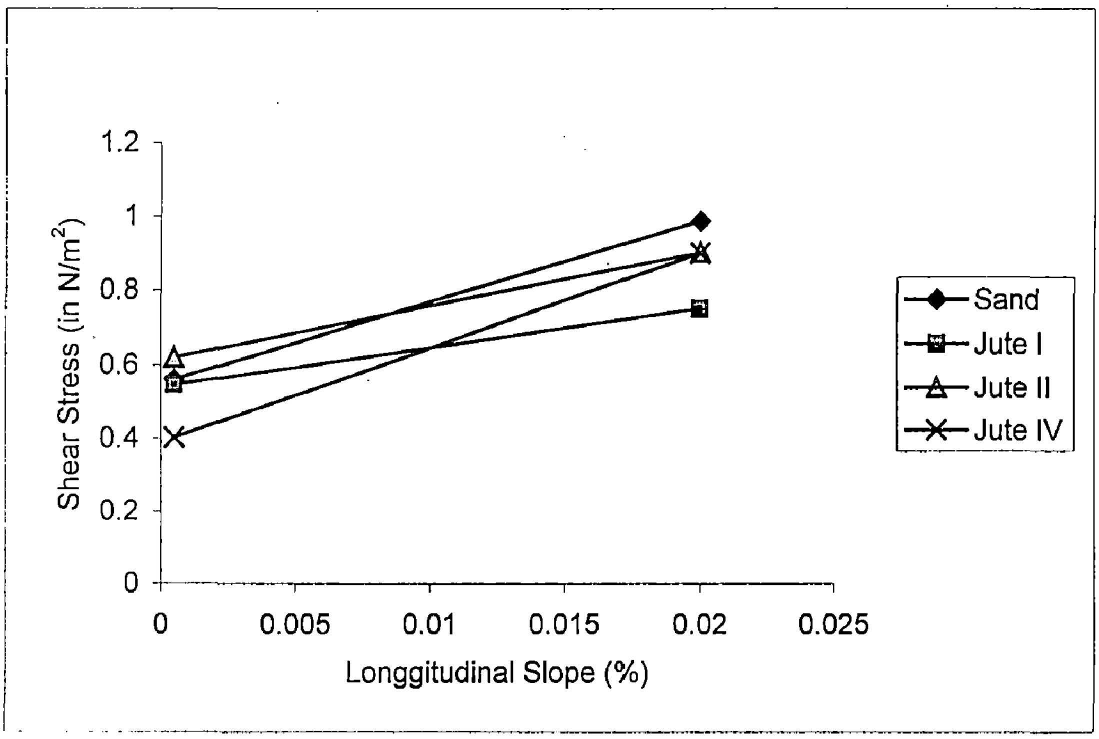

Fig 4.3-b. Shear Stress versus Longitudinal Slope on the Bed with Bed and Bank Sand and Bank Slope 1:1.5 at 1.2m Flume Length

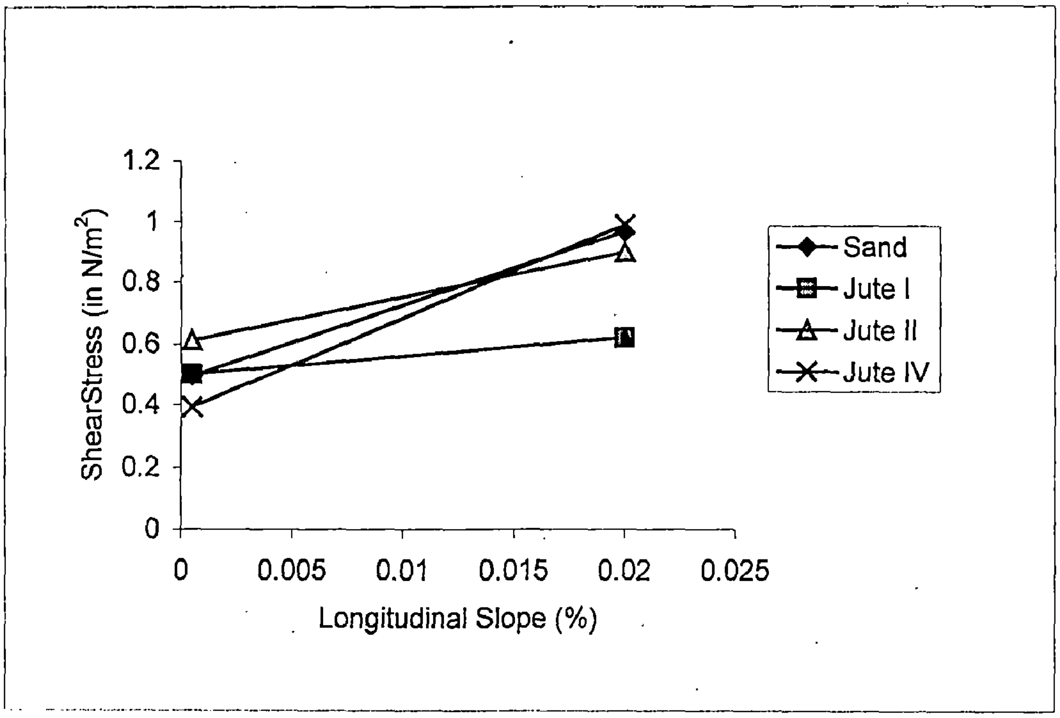

Fig 4.3-c. Shear Stress versus Longitudinal Slope on the Bed with Bed and Bank Sand and Bank Slope 1:1.5 at 1.8m Flume Length

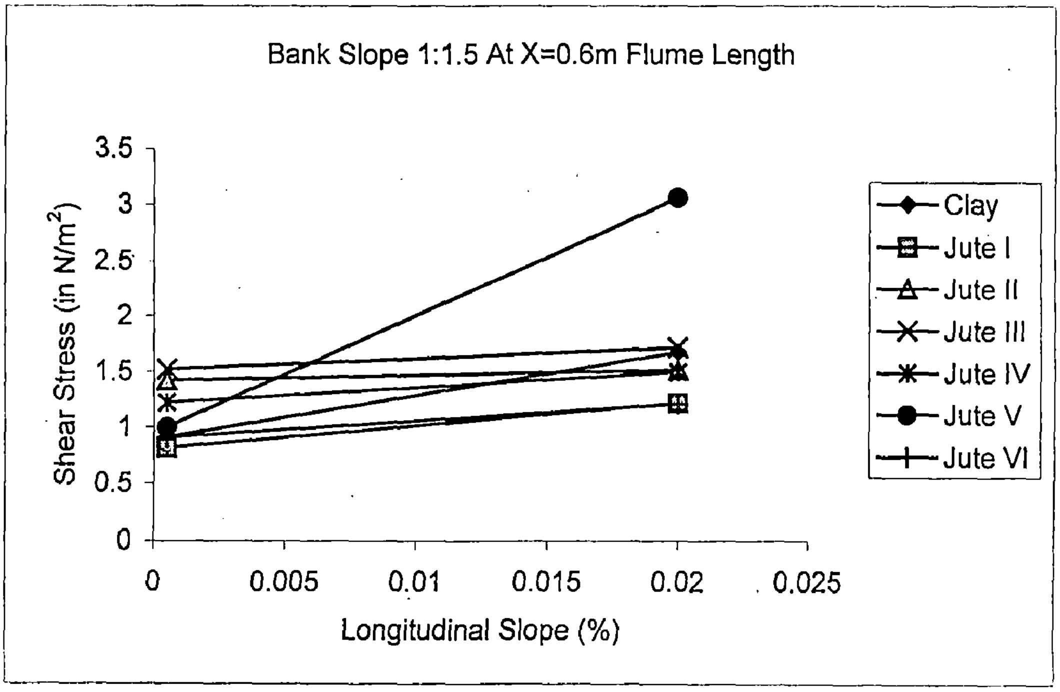

Fig 4.3-d. Shear Stress versus Longitudinal Slope on the Bed with Bed and Bank Clay and Bank Slope 1:1.5 at 0.6m Flume Length

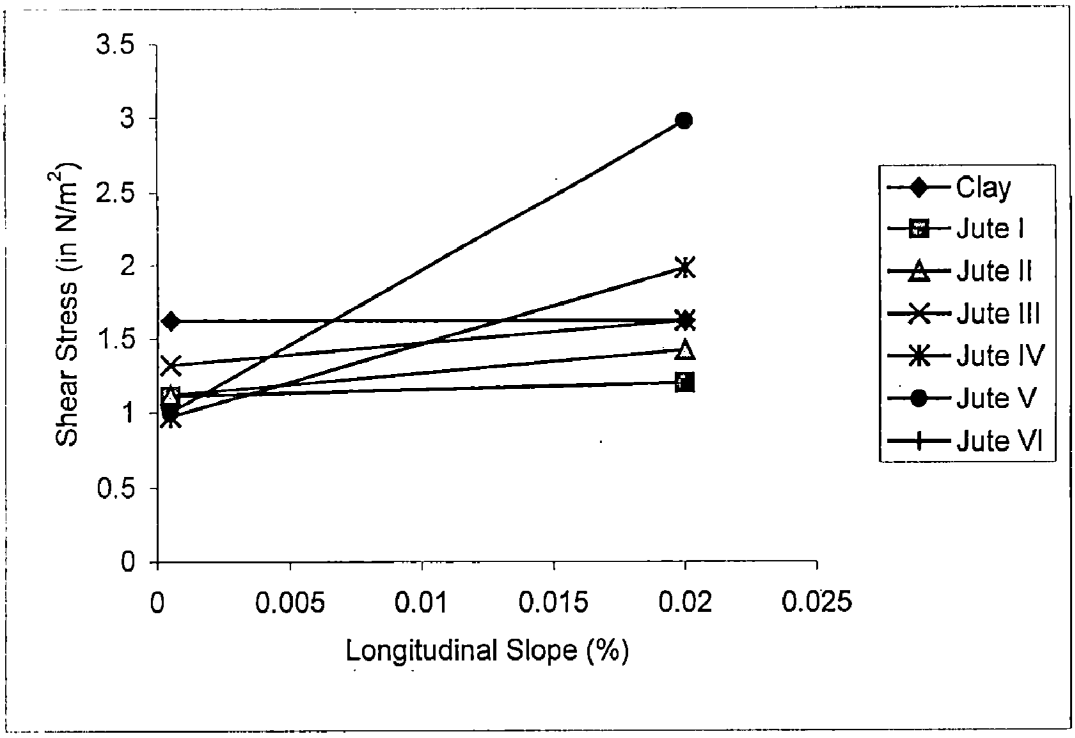

Fig 4.3-e. Shear Stress versus Longitudinal Slope on the Bed with Bed and Bank Clay and Bank Slope 1:1.5 at 1.2m Flume Length

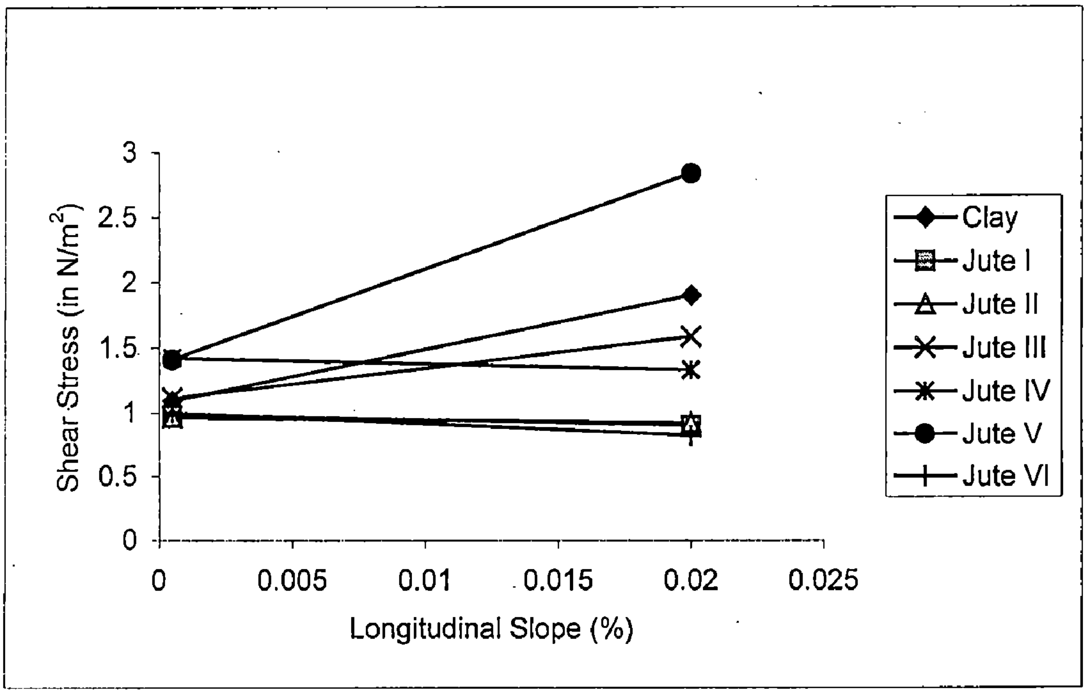

Fig 4.3-f. Shear Stress versus Longitudinal Slope on the Bed with Bed and Bank Clay and Bank Slope 1:1.5 at 1.8m Flume Length

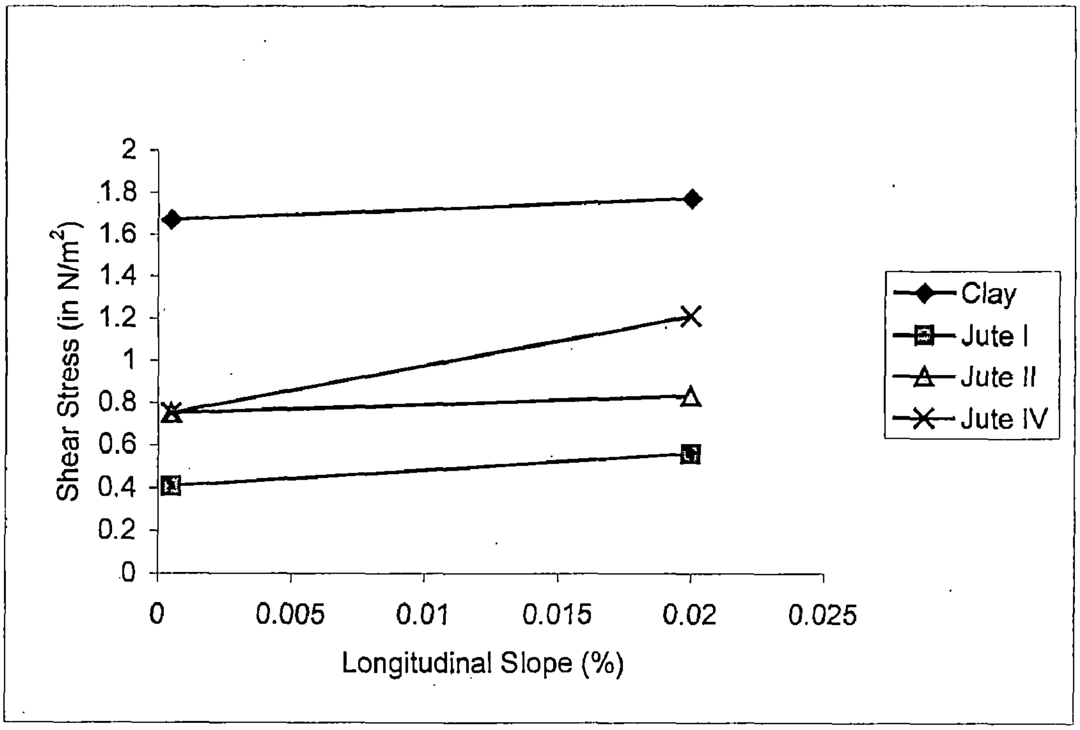

Fig 4.3-g. Shear Stress versus Longitudinal Slope on the Bed with Bed and Bank Clay and Bank Slope 1:1 at 0.6m Flume Length

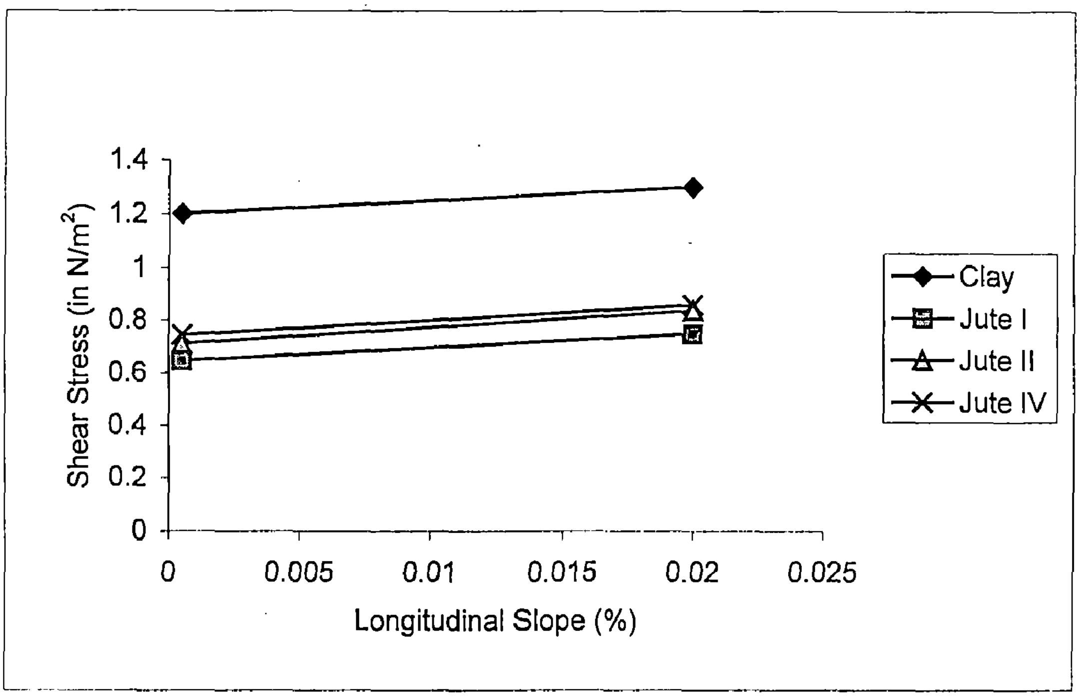

Fig 4.3-h. Shear Stress versus Longitudinal Slope on the Bed with Bed and Bank Clay and Bank Slope 1:1 at 1.2m Flume Length

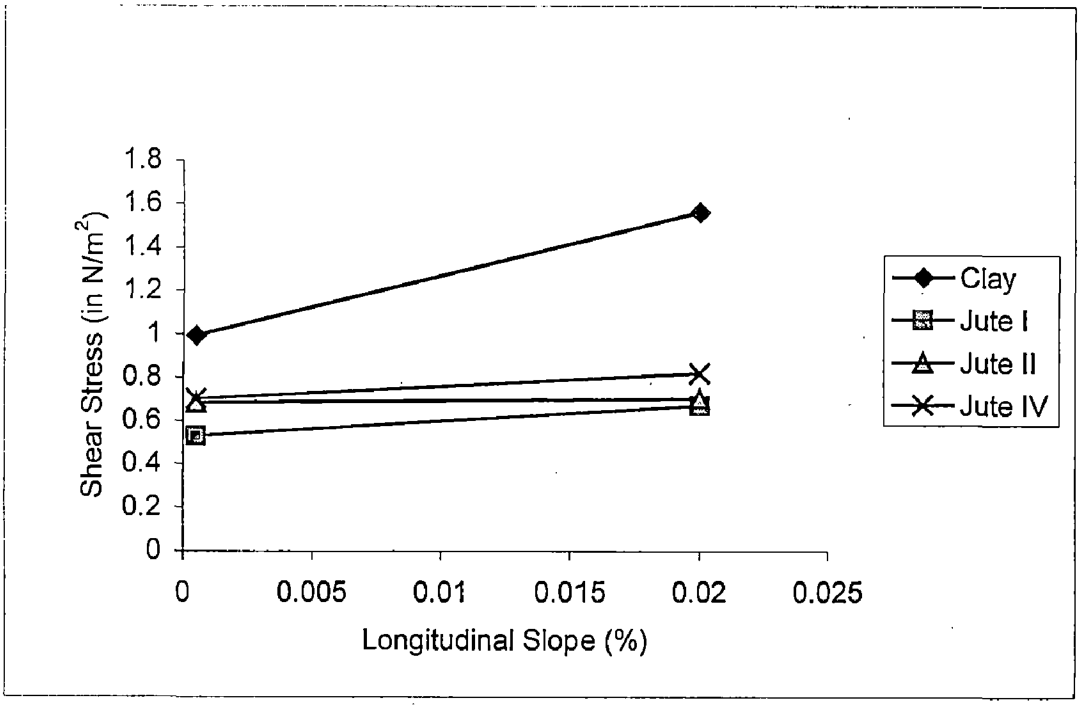

Fig 4.3-i. Shear Stress versus Longitudinal Slope on the Bed with Bed and Bank Clay and Bank Slope 1:1 at 1.8m Flume Length

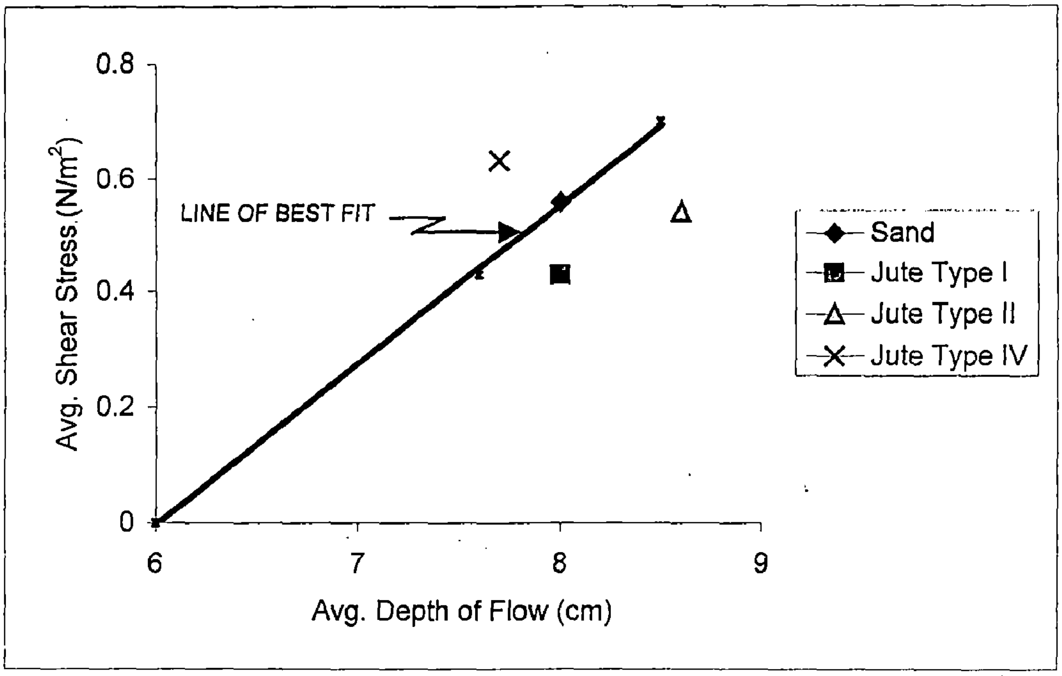

FIG. 4.4-a Average Shear Stress versus Average Depth of Flow with Bed and Bank Sand, Slope 1:1.5 and Bank Slope 0.05%

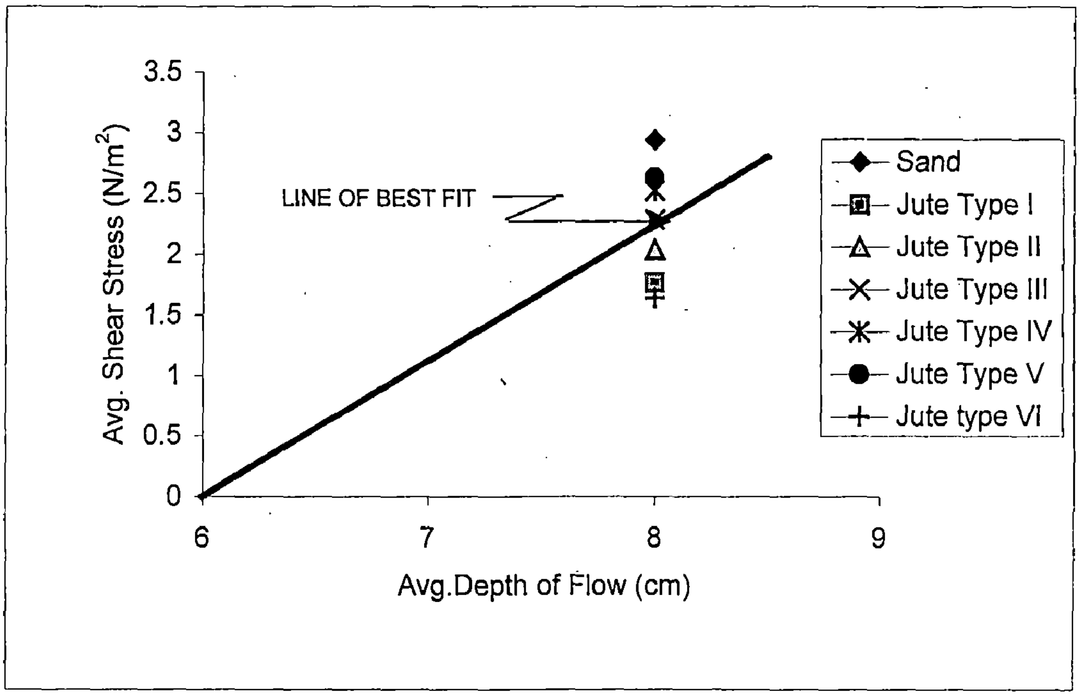

FIG.4.4-b Average Shear Stress versus Average Depth of Flow with Bed and Bank Sand, Slope 1:1.5 and Bank Slope 2%

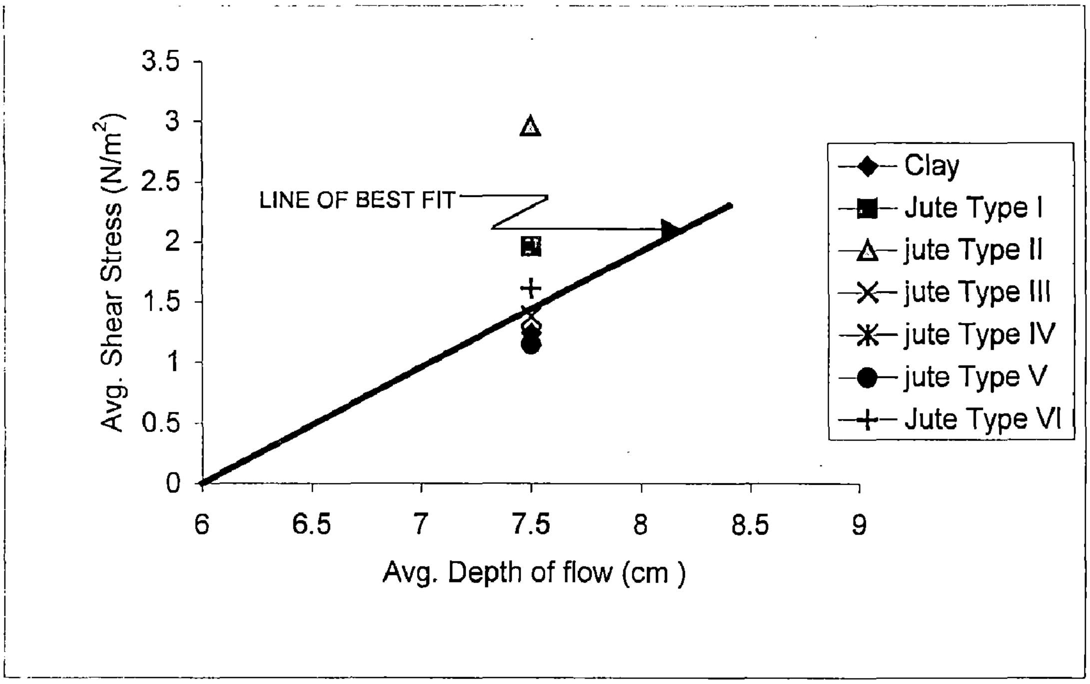

FIG. 4.4-c Average Shear Stress versus Average Depth of Flow with Bed and Bank Clay, Slope 1:1.5 and Bank Slope 2%

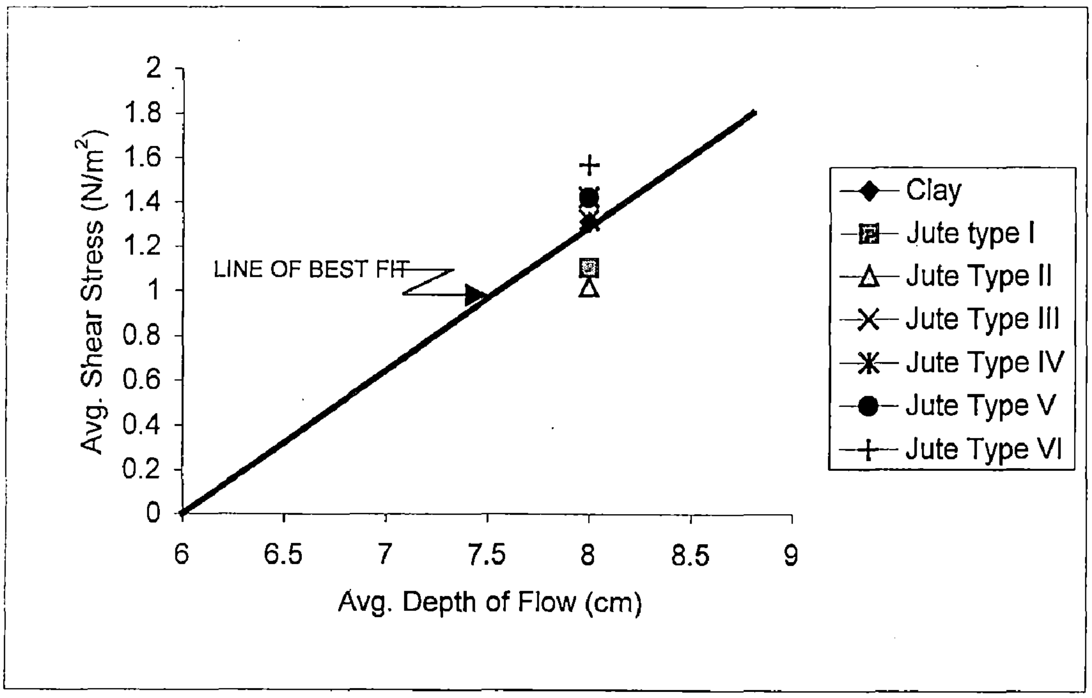

FIG. 4.4-d Average Shear Stress versus Average Depth of Flow with Bed and Bank Clay, Slope 1:1.5 and Bank Slope 0.05%

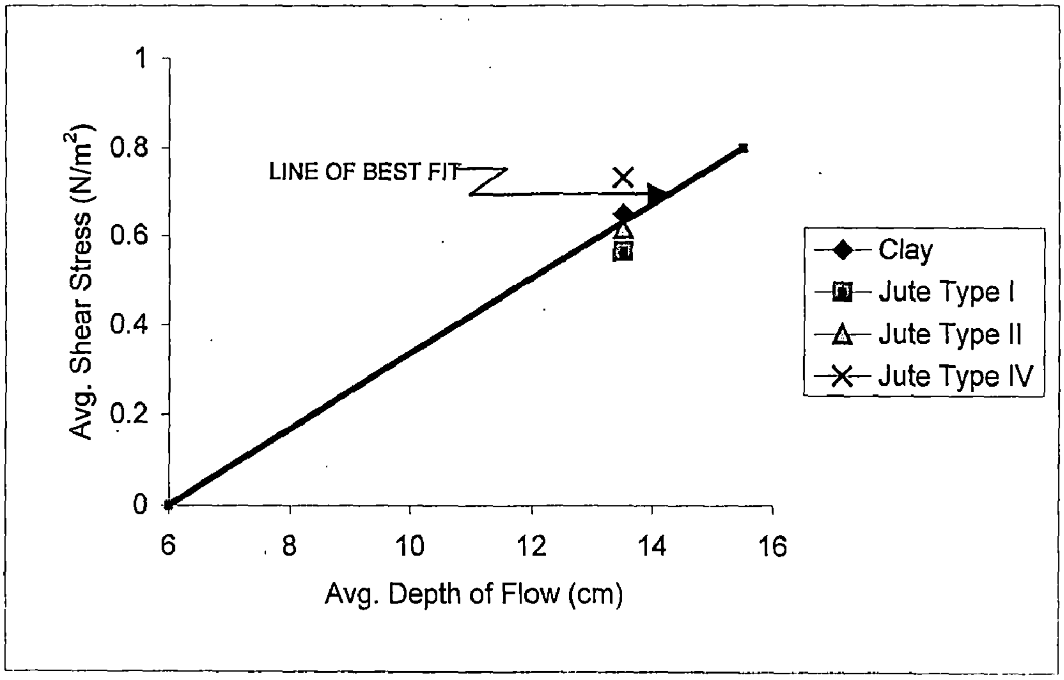

FIG. 4.4-e. Average Shear Stress versus Average Depth of Flow with Bed and Bank Clay, Slope 1:1 and Bank Slope 0.05%

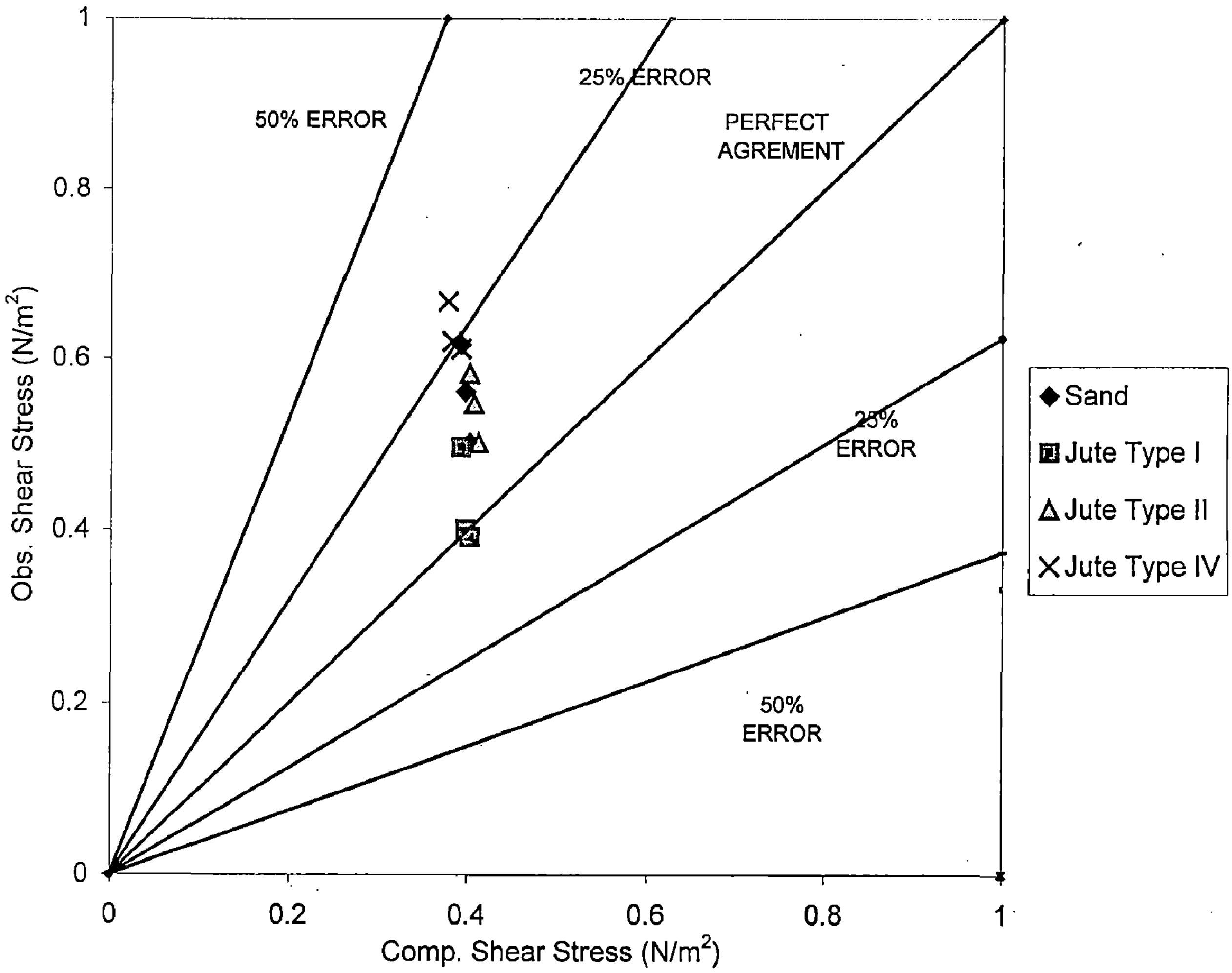

FIG. 4.5-a Comparison Between Observed and Computed Average Shear Stresses in each Material with Bed and Bank Sand, Longitudinal Slope 0.05% and Bank

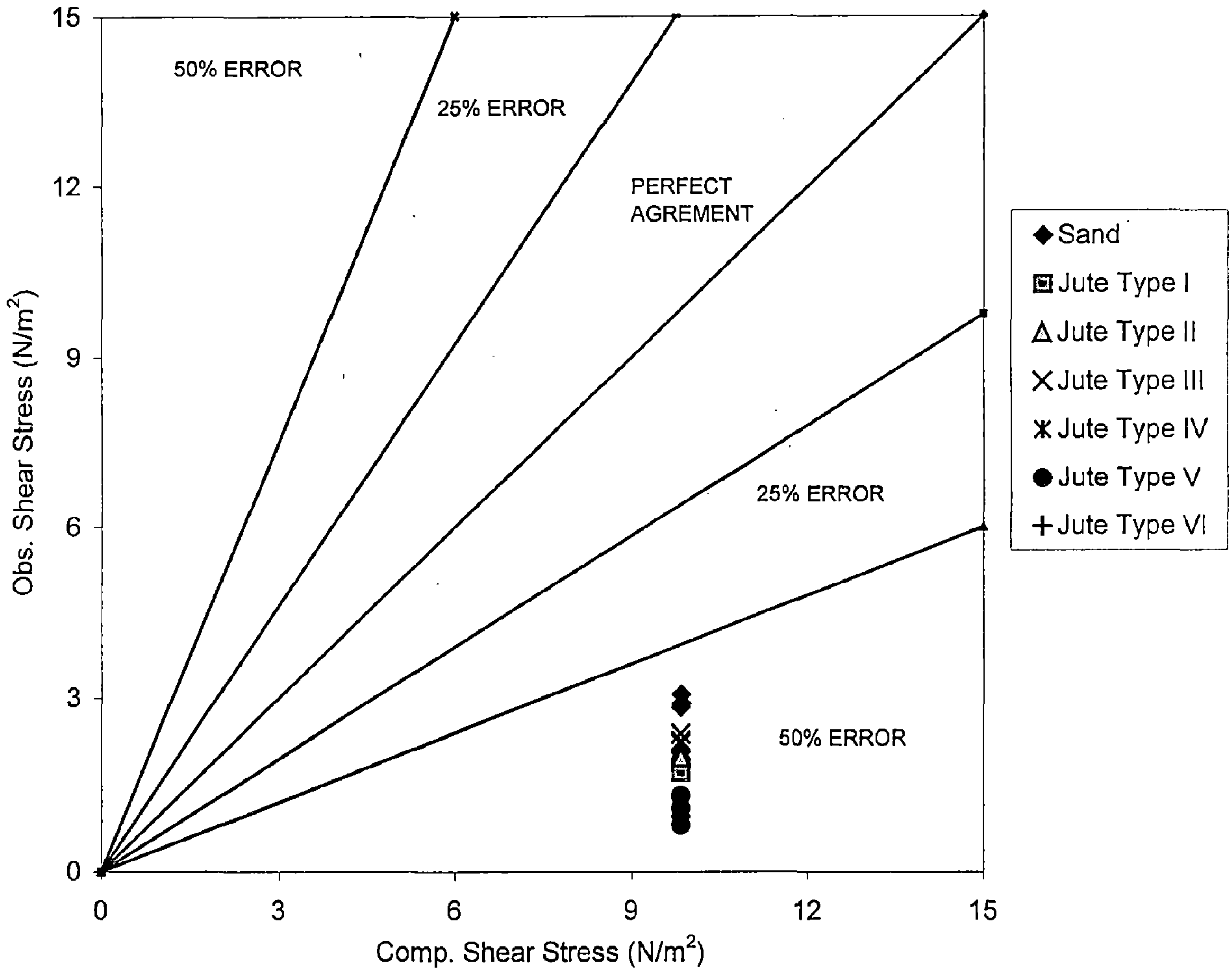

FIG. 4.5-b Comparison Between Observed and Computed Average Shear Stresses in each Material With Bed and Bank Sand, Longitudinal Slope 2% and Bank Slope 1:1.5

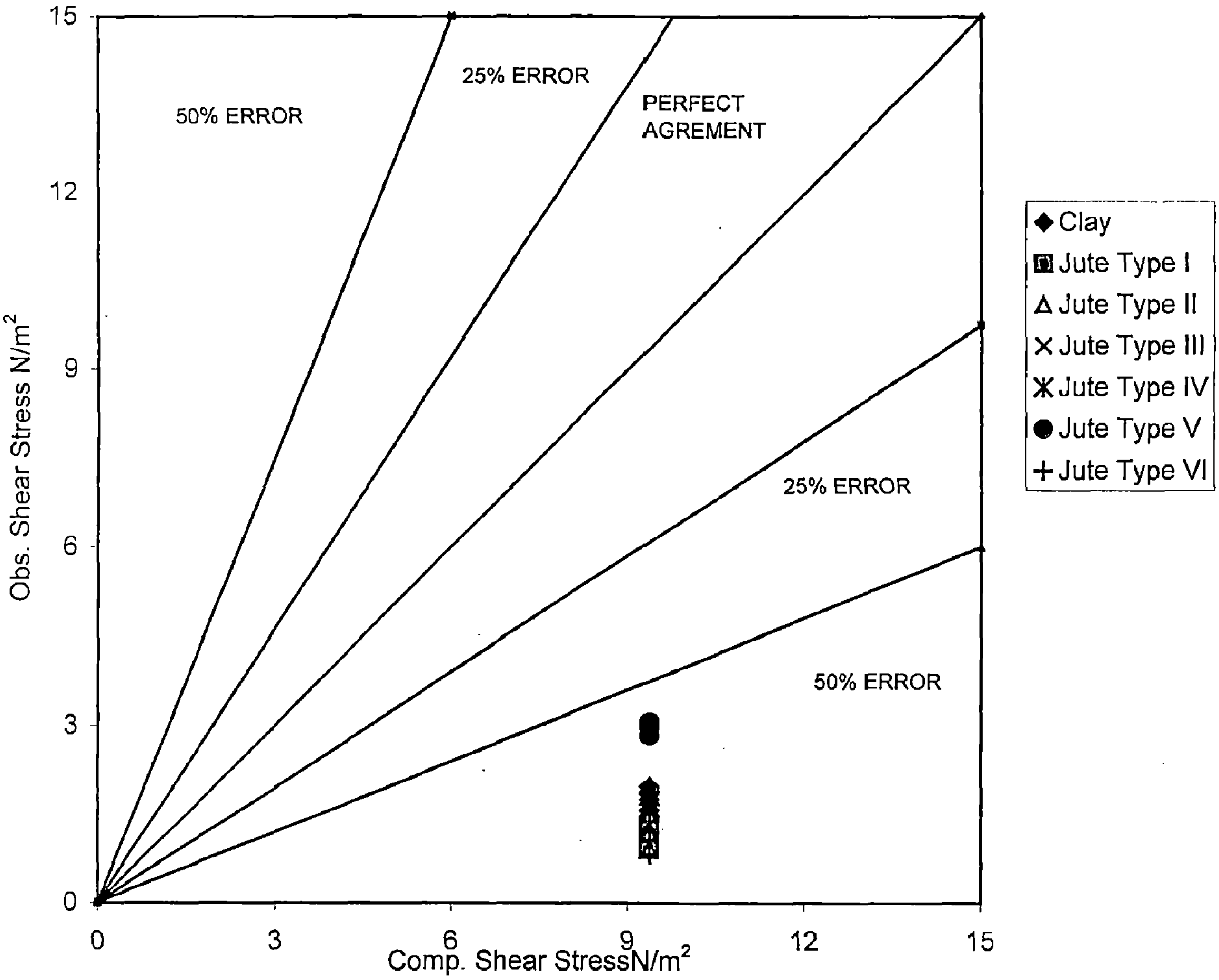

FIG. 4.5-c Comparison Between Observed and Computed Average Shear Stresses in each Material with Bed a Bank Clay, Longitudinal Slope 2% and Bank Slope 1:1.5

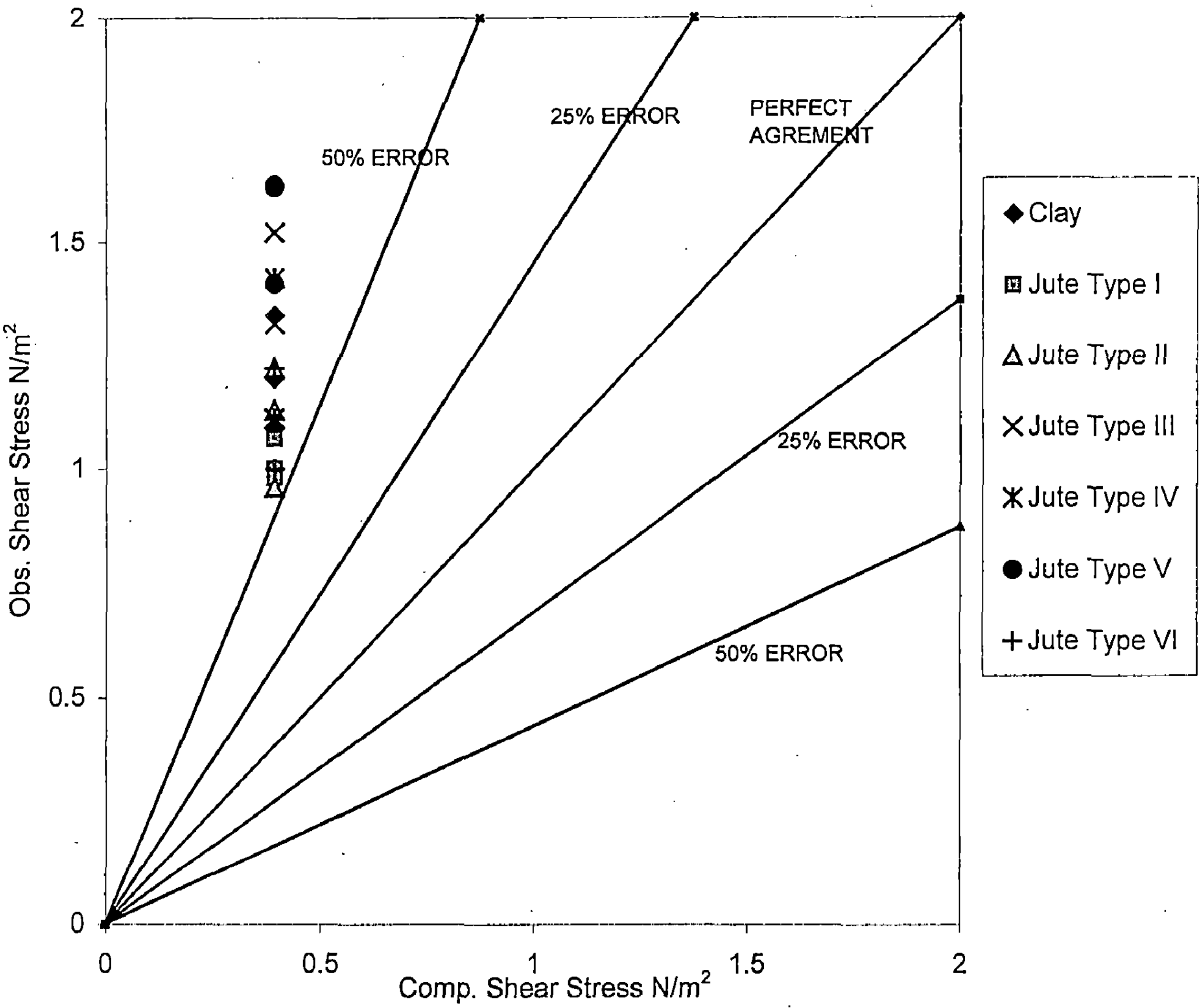

FIG. 4.5-d Comparison between Observed and Computed Average Shear Stresses in each Material with Bed and Bank Clay, Longitudinl Slope 0.05% and Bank Slope 1:1.5

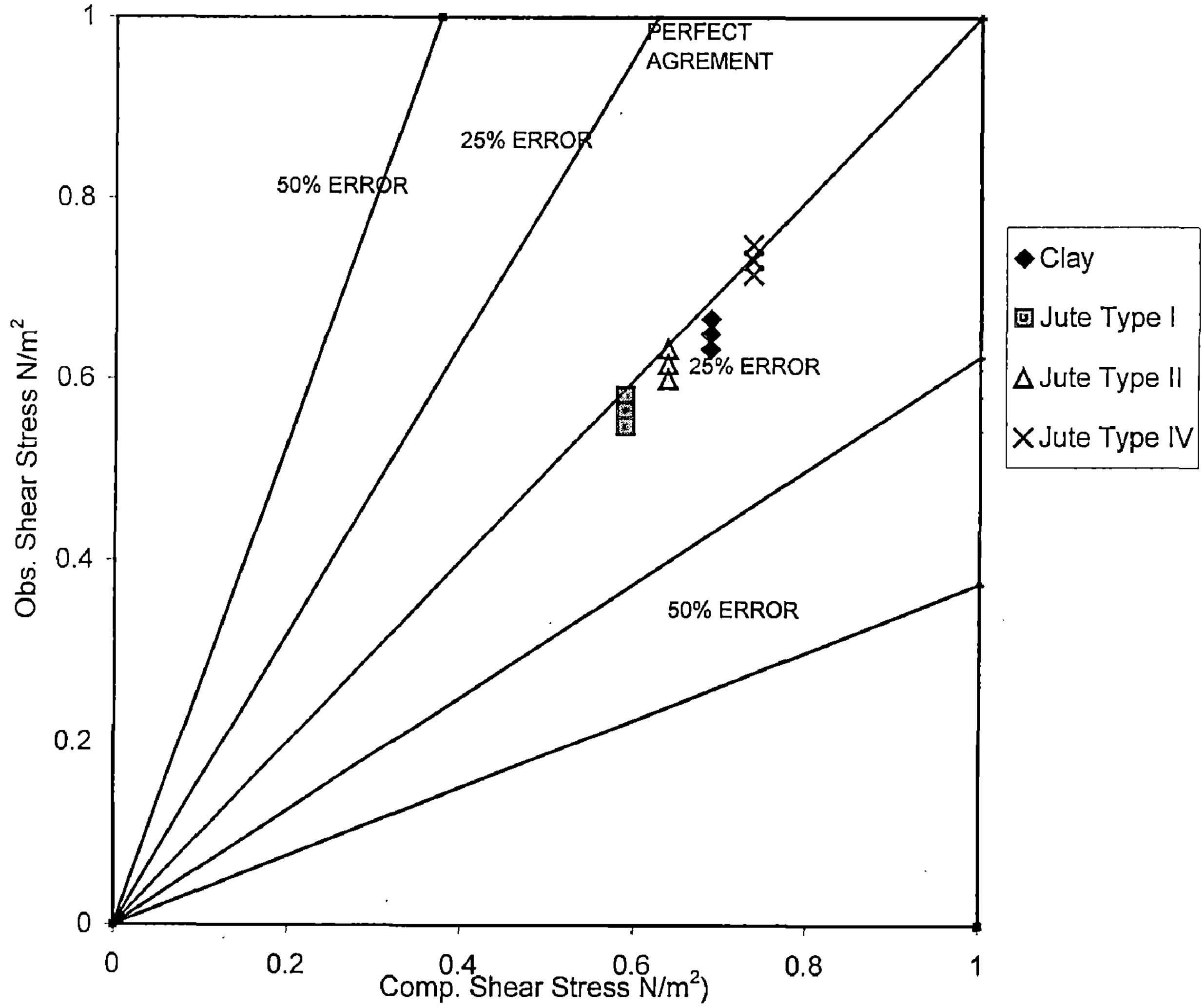

FIG. 4.5-e Comparison between Oberved and Computed Average Shear Stresses in each Material with Bed and Bank Clay, Longitudinal Slope 0.05% and Bank Slope 1:1

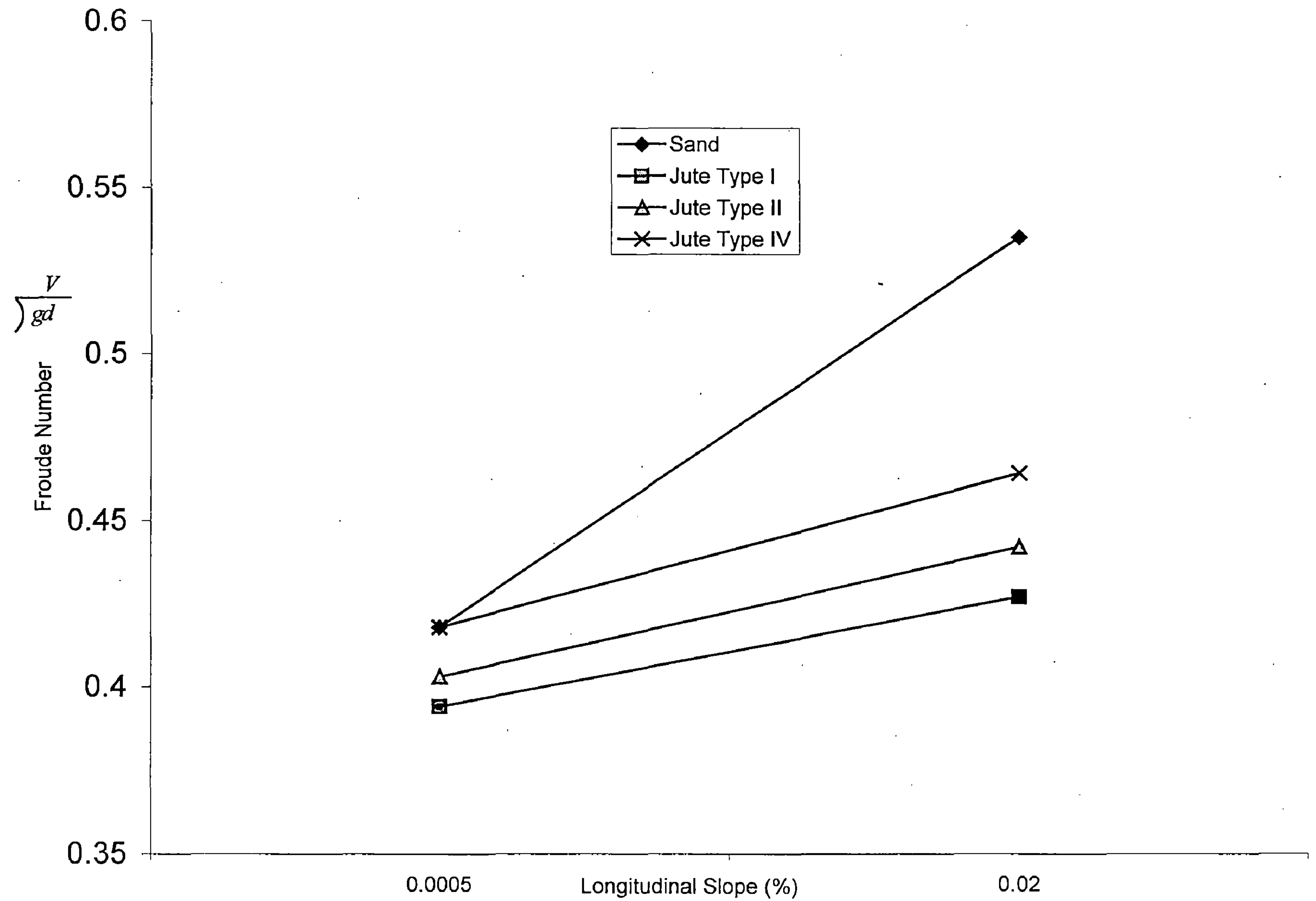

FIG.4.6-a Froude nember versus Longitudinal Sope with Bed and Bank Sand and Bank Slope 1:1.5

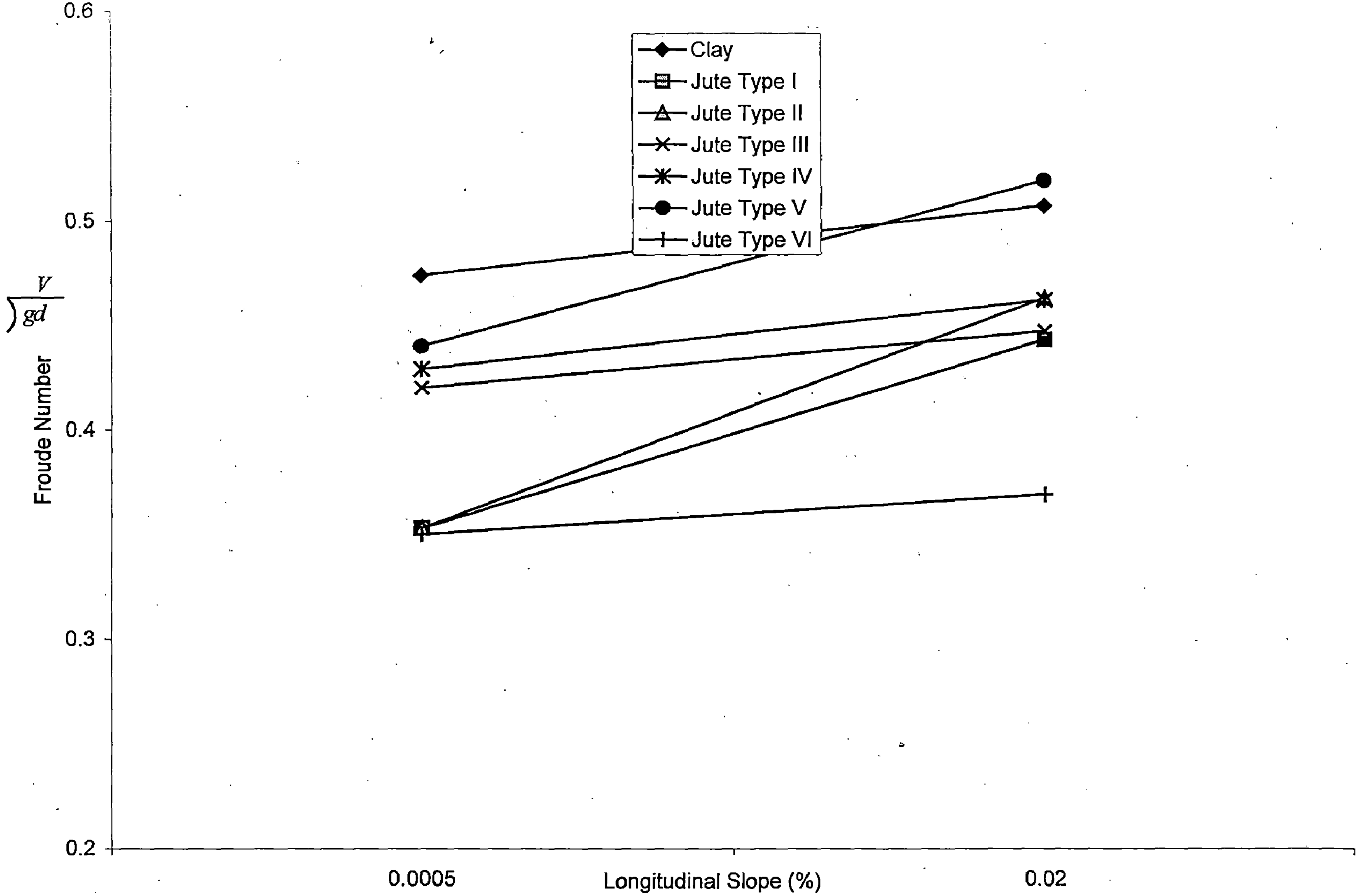

FIG. 4.6-b Froude number versus Longiyudinal Slope with Bed and Bank Clay and Bank Slope 1:1.5

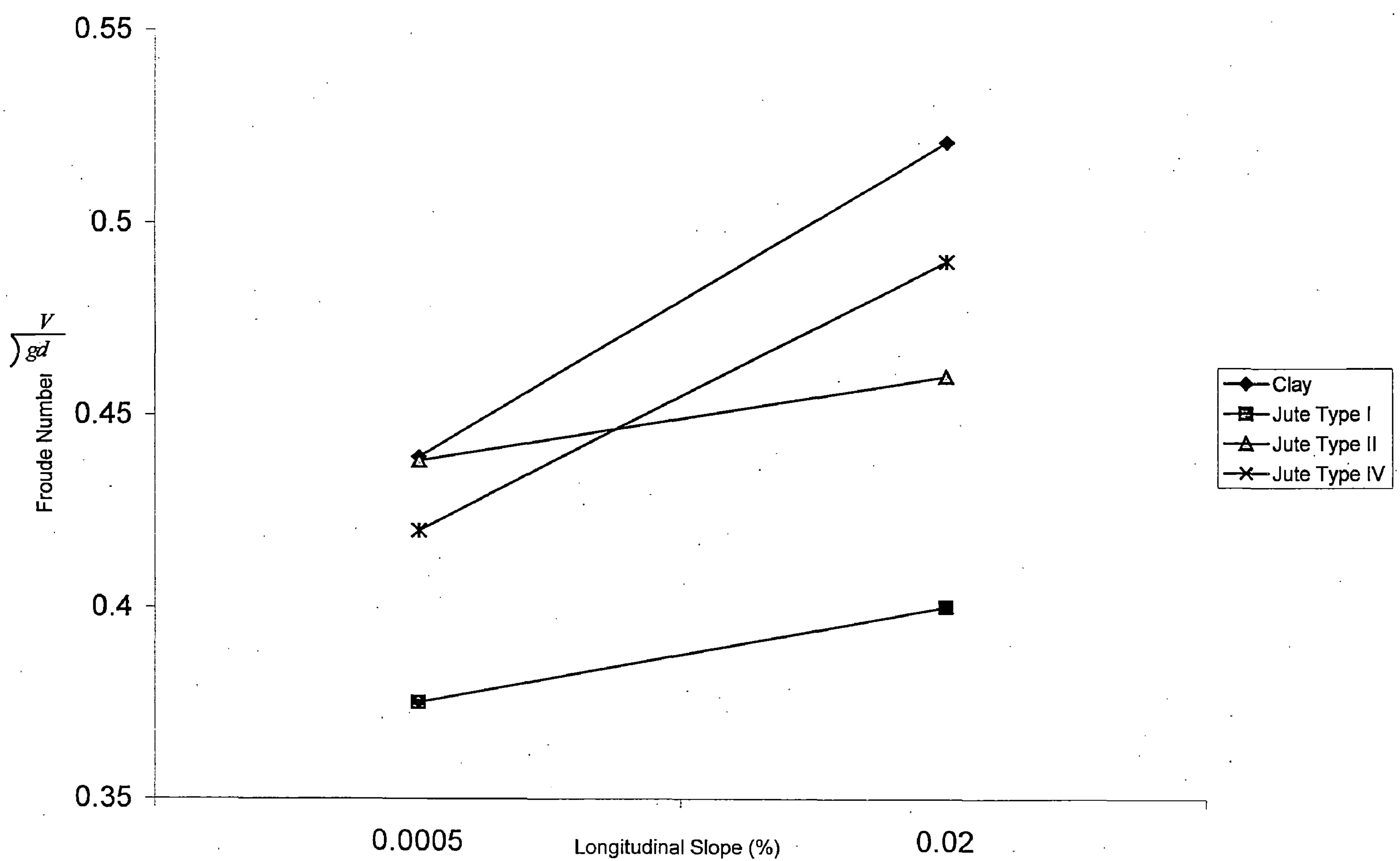

FIG. 4.6-c Froude number versus Longitudinal Slope with Bed and Bank Clay and Bank Slope 1:1

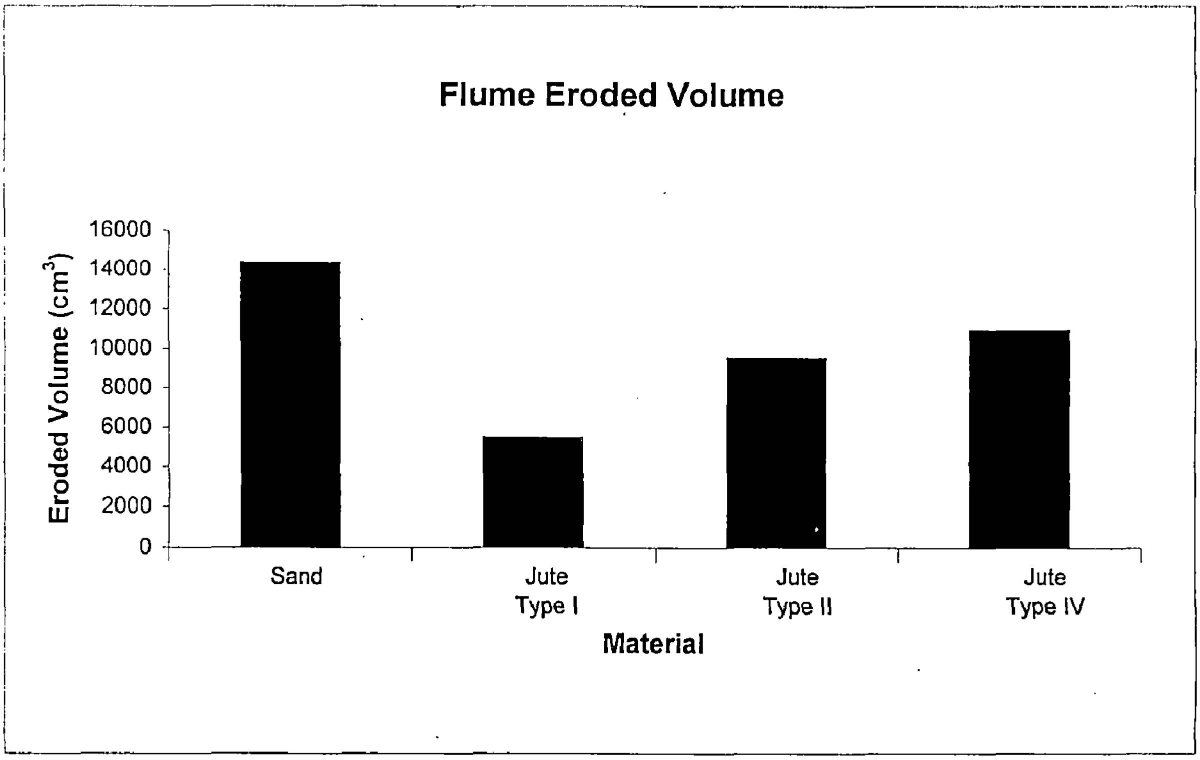

FIG. 4.7-a Flume Volume Eroded after Run with Bed and Bank Sand, Longitudinal Slope 0. and Bank Slope 1:1.5

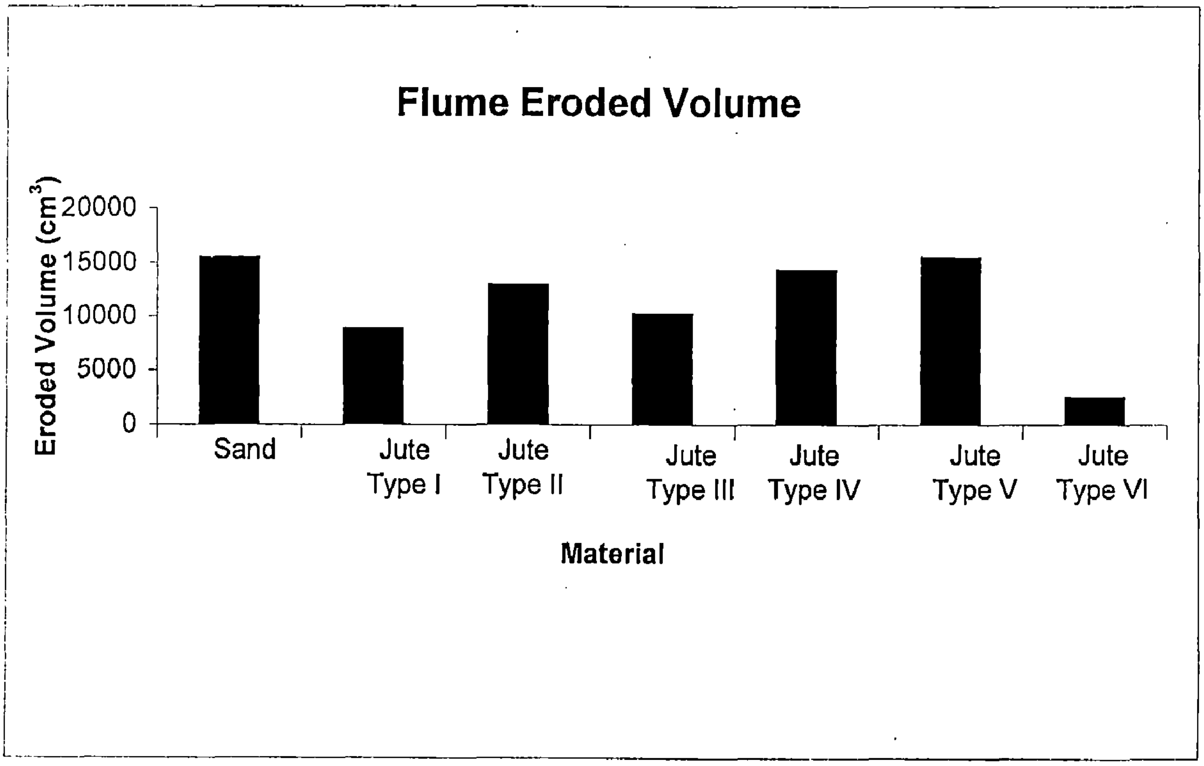

FIG. 4.7-b Flume Volume Eroded after Run with Bed and Bank Sand, Longitudinal Slope 2% and Bank Slope 1:1.5

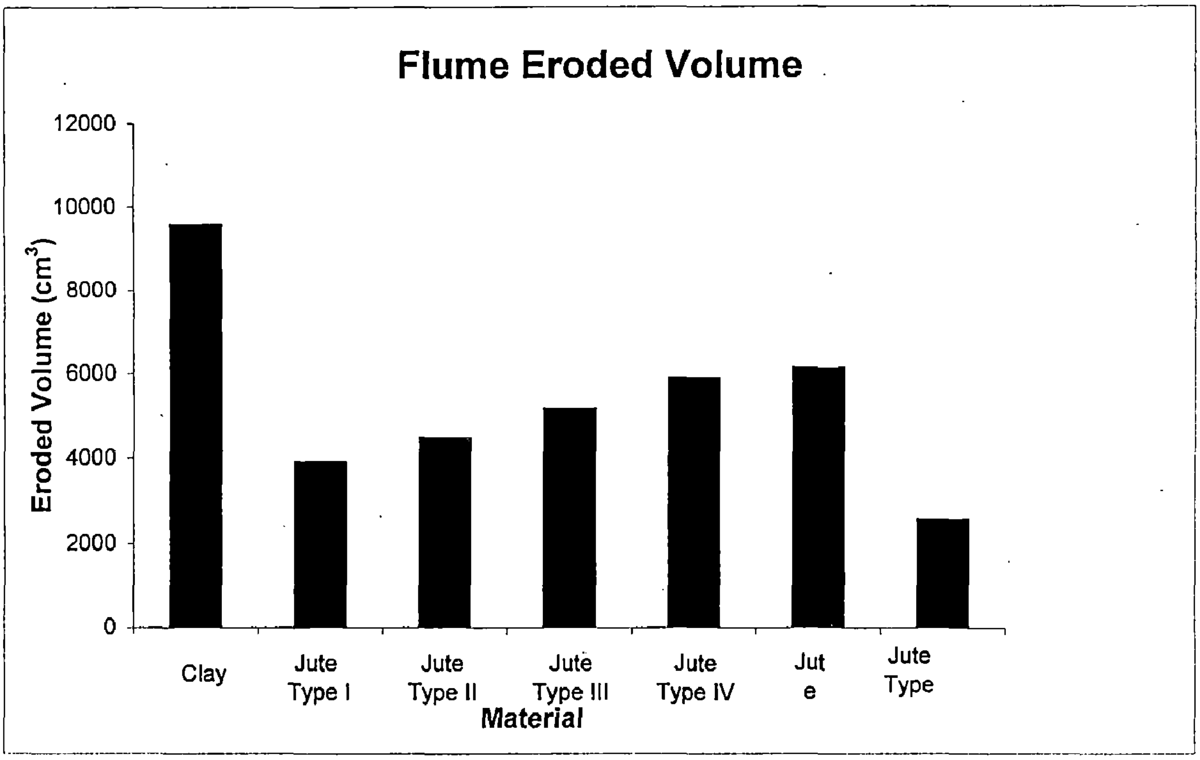

FIG 4.7-c Flume Volume Eroded after Run with Bed and Bank Clay, Longitudinal Slope 2% and Bank Slope 1:1.5

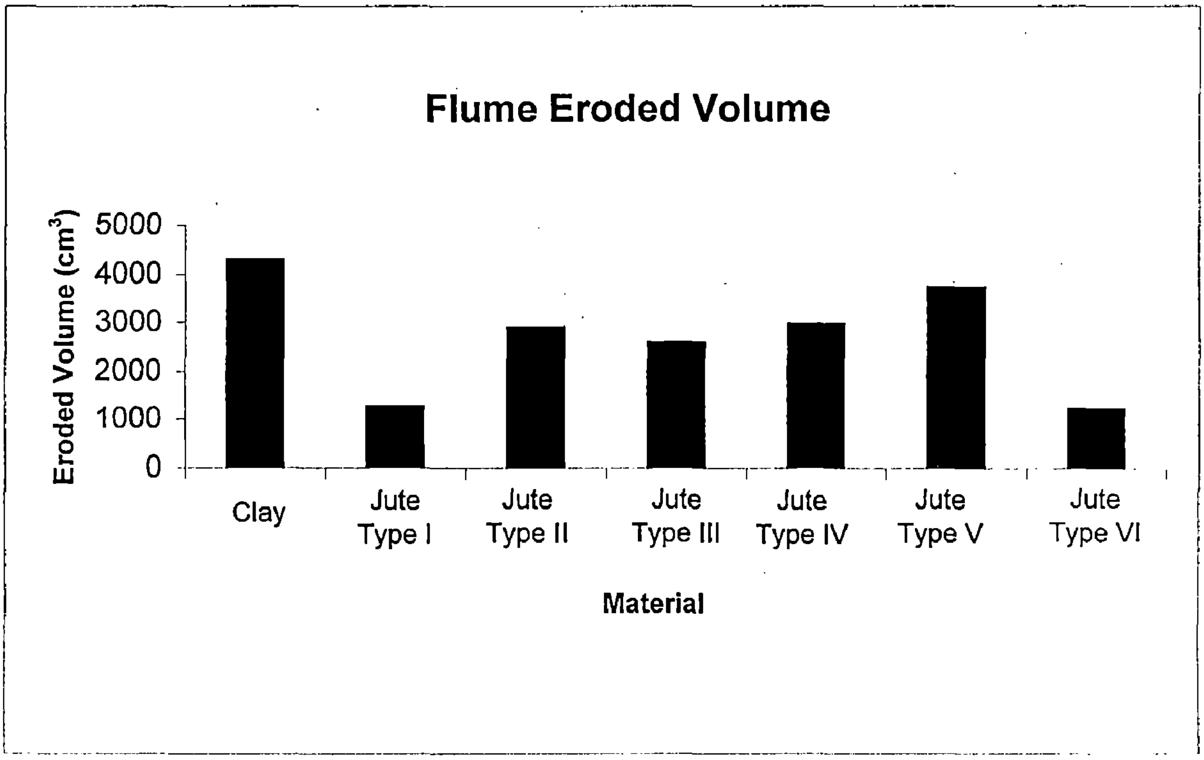

FIG 4.7-d Flume Volume Eroded after Run with Bed and Bank Clay, Longitudinal Slope 0.05 and Bank Slope 1:1.5

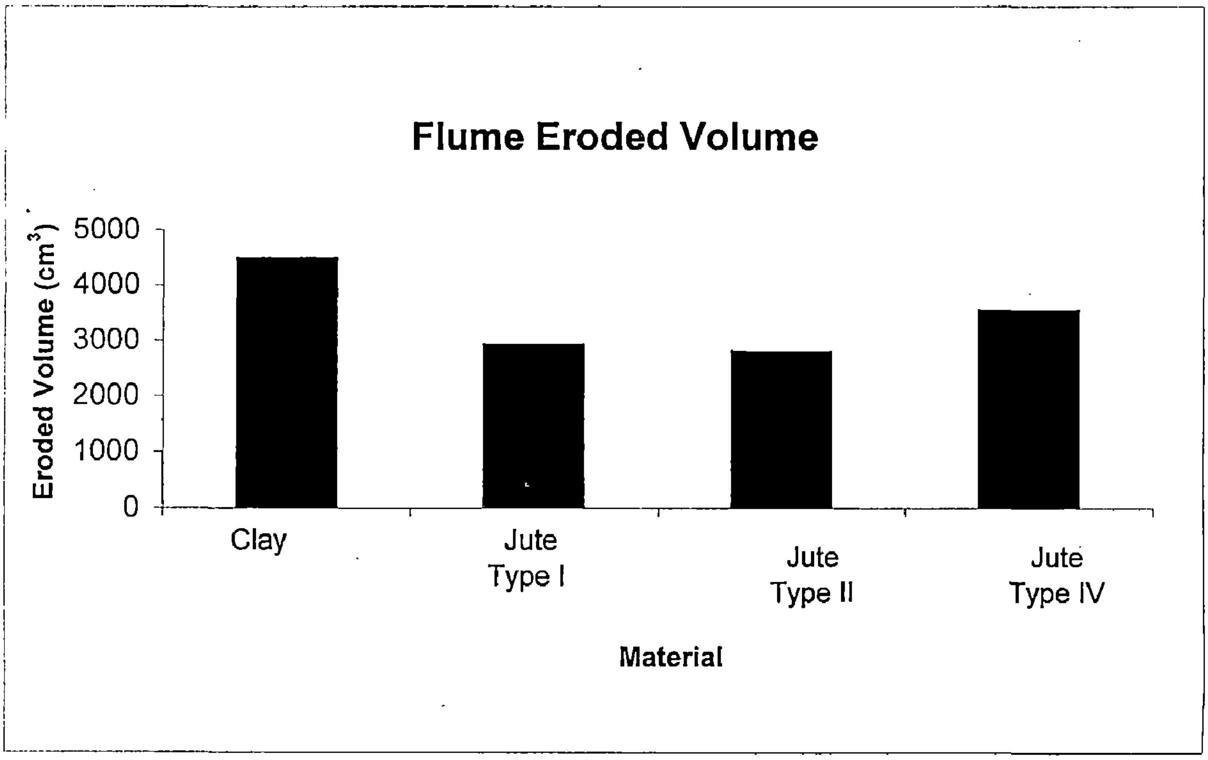

FIG 4.7-e Flume Volume Eroded after Run with Bed and Bank Clay, Longitudinal Slope 2% and Bank Slope 1:1

CONCLUSIONS AND SCOPE FOR FURTHER STUDY

5.1 INTRODUCTION

This thesis embodies experimental work concerning study of erosion phenomenon and its control using different types of jute geotextiles, soil texture, longitudinal and bank slopes maintaining approximately the same discharge and depth of flow. The conclusion and scope for further study arising out on this chapter are presented below.

5.2 CONCLUSIONS

The effect of treated and untreated jute with and without being covered on non-uniform graded sediment of cohesive and non-cohesive material of one side bank channel has been analyzed.

The significant conclusions out of the study may be listed as.

(i) Jute geotextiles offered a good resistance to erosive action of flowing water on bed and bank.

(ii) Jute geotextile are functions in the erosion control process as a series of small check dams in reducing the erosive velocity of water flowing down the slope and resists the loss of sediment from bed and sides of channel.

(iii) Out of different types experimented in the study, type I (weight 732 GM/M^2) jute has relatively offered good performance in keeping the sediments in place next to rot resistance and bitumen treated jute (type VI).

(iv) Ordinarily jute geotextile is cheaper than bitumen treated jute. Its erosion resistance capacity is more or less comparable with bitumen treated jute.

(v) Even though, jute has short lifetime i.e., 18 to 24 months, it spreads seed until germination takes place.

(vi) Jute geotextile untreated is effective erosion control material than all conventional techniques if used only for limited period.

(vii) Thick thread, smaller mesh size, and heavy weight woven jute geotextile covered on a slope of non-uniformly graded cohesive soil (clay) material results a good erosion resistance.

5.3 SCOPE FOR FURTHER STUDY

Very little research has been done to study erosion control effect using jute geotextile mainly on channel bed under water either in prototype or models. Most of the researchers used it on the protection of hill slopes, banks etc. Experimental programme in furtherance to cover the bed and bank of a water structure with layer of jute to minimize the eroding action needs to be taken up for more research. The durability of jute geotextile under water and the functioning as erosion control is left for further study.

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APPENDIX A

EXPERIMENTAL DATA

Table 1 Velocity Profile on the Flume Length

For bank slope 1 in 1.5
width of bed = 35 cm
width of bank = 15 cm

For bank slope 1:1
width of bed = 30 cm
width of bank = 20 cm

Run No.	Material	Point of Velocity Observed (cm)	Avg. Velocity at Diff. Ele. (m/sec)	Avg. Velocity of Flume (m/Sec)	Depth of Flow (cm)	Avg. Discharge (lit/sec)	Longit udinal slope (%)	Bank Slope
1.	Sand	1.33 4.00 6.67	0.31 0.40	0.36	8.0 8.0	11.81	0.05 0.05 0.05	1 in 1.5 1 in 1.5 1 in 1.5
2.	Type I	1.33 4.00 6.67	0.34 0.37	0.36	8.0 8.0	11.81	0.05 0.05 0.05	1 in 1.5 1 in 1.5 1 in 1.5
3.	Type II	1.43 4.30 7.167	0.32 0.38	0.35	8.6 8.6	12.83	0.05 0.05 0.05	1 in 1.5 1 in 1.5 1 in 1.5
4.	Type IV	1.28 3.85 6.42	0.30 0.41	0.37	7.7 7.7	10.99	0.05 0.05 0.05	1 in 1.5 1 in 1.5 1 in 1.5
1.	Sand	1.33 4.00 6.67	0.38 0.47	0.45	8.0 8.0	14.76	2.00 2.00 2.00	1 in 1.5 1 in 1.5 1 in 1.5
2.	Type I	1.33 4.00 6.67	0.28 0.31	0.30	8.0 8.0	9.84	2.00 2.00 2.00	1 in 1.5 1 in 1.5 1 in 1.5
3.	Type II	1.33 4.00 6.67	0.30 0.31	0.32	8.0 8.0	10.50	2.00 2.00 2.00	1 in 1.5 1 in 1.5 1 in 1.5
4.	Type III	1.33 4.00 6.67	0.33 043	0.39	8.0 8.0	12.79	2.00 2.00 2.00	~~1 in 1.5~~ 1 in 1.5 1 in 1.5
5.	Type IV	1.33 4.00 6.67	0.34 0.41	0.39	8.0 8.0	12.79	2.00 2.00 2.00	1 in 1.5 1 in 1.5 1 in 1.5
6.	Type V	1.33 4.00 6.67	0.31 0.43	0.40	8.0 8.0	13.12	2.00 2.00 2.00	1 in 1.5 1 in 1.5 1 in 1.5
7.	Type VI	1.33 4.00 6.67	0.26 0.33	0.31	8.0 8.0	10.17	2.00 2.00 2.00	1 in 1.5 1 in 1.5 1 in 1.5
1.	Clay	1.25 3.75 6.25	0.39 0.44	0.42	7.5 7.5	12.80	2.00 2.00 2.00	1 in 1.5 1 in 1.5 1 in 1.5
2.	Type I	1.25	0.34	0.38	7.5	11.58	2.00	1 in 1.5

		3.75 6.25	0.39		7.5		2.00 2.00	1 in 1.5 1 in 1.5
3.	Type II	1.25 3.75 6.25	0.30 0.40	0.38	7.5 7.5	11.58	2.00 2.00 2.00	1 in 1.5 1 in 1.5 1 in 1.5
4.	Type III	1.25 3.75 6.25	0.32 0.42	0.38	7.5 7.5	11.58	2.00 2.00 2.00	1 in 1.5 1 in 1.5 1 in 1.5
5.	Type IV	1.25 3.75 6.25	0.29 0.44	0.4	7.5 7.5	12.19	2.00 2.00 2.00	1 in 1.5 1 in 1.5 1 in 1.5
6.	Type V	1.25 3.75 6.25	0.37 0.47	0.43	7.5 7.5	13.10	2.00 2.00 2.00	1 in 1.5 1 in 1.5 1 in 1.5
7.	Type VI	1.25 3.75 6.25	0.26 0.33	0.32	7.5 7.5	0.72	2.00 2.00 2.00	1 in 1.5 1 in 1.5 1 in 1.5
1.	Clay	1.33 4.00 6.67	0.39 0.44	0.42	8.0 8.0	13.78	0.05 0.05 0.05	1 in 1.5 1 in 1.5 1 in 1.5
2.	Type I	1.33 4.00 6.67.	0.34 0.39	0.38	8.0 8.0	12.46	0.05 0.05 0.05	1 in 1.5 1 in 1.5 1 in 1.5
3.	Type II	1.33 4.00 6.67	0.30 0.40	0.38	8.0 8.0	12.46	0.05 0.05 0.05	1 in 1.5 1 in 1.5 1 in 1.5
4.	Type III	1.33 4.00 6.67	0.32 0.42	0.38	8.0 8.0	12.46	0.05 0.05 0.05	1 in 1.5 1 in 1.5 1 in 1.5
5.	Type IV	1.33 4.00 6.67	0.29 0.44	0.40	8.0 8.0	13.12	0.05 0.05 0.05	1 in 1.5 1 in 1.5 1 in 1.5
6.	Type V	1.33 4.00 6.67	0.37 0.47	0.43	8.0 8.0	14.10	0.05 0.05 0.05	1 in 1.5 1 in 1.5 1 in 1.5
7.	Type VI	1.33 4.00 6.67	0.26 0.33	0.32	8.0 8.0	10.50	0.05 0.05 0.05	1 in 1.5 1 in 1.5 1 in 1.5
1.	Clay	2.25 6.75 11.25	0.32 0.43	0.40	13.5 13.5	19.85	0.05 0.05 0.05	1 in 1 1 in 1 1 in 1
2.	Type I	2.25 6.75 11.25	0.27 0.40	0.36	13.5 13.5	17.86	0.05 0.05 0.05	1 in 1 1 in 1 1 in 1
3.	Type II	2.25 6.75 11.25	0.30 0.33	0.32	13.5 13.5	15.88	0.05 0.05 0.05	1 in 1 1 in 1 1 in 1
4.	Type IV	2.25 6.75 11.25	0.32 0.35	0.34	13.5 13.5	16.87	0.05 0.05 0.05	1 in 1 1 in 1 1 in 1

Table 2 Shear Stress versus Longitudinal Slope on the Flume bed

Run No.	Material	Flume Length (m)	Shear Stress, τ_o (N/m)	Longitudinal Slope (%)	Depth of flow (cm)	Bank Slope
1.	Sand	0.6	0.6162	0.0005	8.0	1 in 1.5
			3.0628	0.0200	8.0	1 in 1.5
		1.2	0.5611	0.0005	8.0	1 in1.5
			2.9097	0.0200	8.0	1 in 1.5
		1.8	0.5012	0.0005	8.0	1 in 1.5
			2.8480	0.0200	8.0	1 in 1.5
2.	Type I	0.6	0.4965	0.0005	8.0	1 in 1.5
			1.8153	0.0200	8.0	1 in 1.5
		1.2	0.4012	0.0005	8.0	1 in1.5
			1.7608	0.0200	8.0	1 in 1.5
		1.8	0.3921	0.0005	8.0	1 in 1.5
			1.7245	0.0200	8.0	1 in 1.5
3.	Type II	0.6	0.5824	0.0005	8.6	1 in 1.5
			2.1009	0.0200	8.0	1 in 1.5
		1.2	0.5467	0.0005	8.6	1 in1.5
			2.0168	0.0200	8.0	1 in 1.5
		1.8	0.5012	0.0005	8.6	1 in 1.5
			1.9748	0.0200	8.0	1 in 1.5
4.	Type IV	0.6	0.6665	0.0005	7.7	1 in 1.5
			2.6568	0.0200	8.0	1 in 1.5
		1.2	0.6200	0.0005	7.7	1 in1.5
			2.5239	0.0200	8.0	1 in 1.5
		1.8	0.6111	0.0005	7.7	1 in 1.5
			2.3911	0.0200	8.0	1 in 1.5
1.	Clay	0.6	1.3400	0.0005	7.5	1 in 1.5
			1.9880	0.0200	8.0	1 in 1.5
		1.2	1.2000	0.0005	7.5	1 in1.5
			1.9800	0.0200	8.0	1 in 1.5
		1.8	1.0900	0.0005	7.5	1 in 1.5
			1.9000	0.0200	8.0	1 in 1.5
2.	Type I	0.6	1.0681	0.0005	7.5	1 in 1.5
			1.3221	0.0200	8.0	1 in 1.5
		1.2	1.0200	0.0005	7.5	1 in1.5
			0.9820	0.0200	8.0	1 in 1.5
		1.8	0.9000	0.0005	7.5	1 in 1.5
			1.2000	0.0200	8.0	1 in 1.5
3.	Type II	0.6	1.2230	0.0005	7.5	1 in 1.5
			1.5000	0.0200	8.0	1 in 1.5
		1.2	1.1300	0.0005	7.5	1 in1.5
			1.2000	0.0200	8.0	1 in 1.5
		1.8	0.9600	0.0005	7.5	1 in 1.5
			0.9200	0.0200	8.0	1 in 1.5
4	Type III	0.6	1.5210	0.0005	7.5	1 in 1.5
			1.6710	0.0200	8.0	1 in 1.5
		1.2	1.3210	0.0005	7.5	1 in1.5
			1.6210	0.0200	8.0	1 in 1.5
		1.8	1.1120	0.0005	7.5	1 in 1.5
			1.5820	0.0200	8.0	1 in 1.5

5.	Type IV	0.6	1.4205	0.0005	7.5	1 in 1.5
			1.7210	0.0200	8.0	1 in 1.5
		1.2	1.4205	0.0005	7.5	1 in1.5
			1.6220	0.0200	8.0	1 in 1.5
		1.8	1.1120	0.0005	7.5	1 in 1.5
			1.5820	0.0200	8.0	1 in 1.5
6.	Type V	0.6	1.6270	0.0005	7.5	1 in 1.5
			3.0628	0.0200	8.0	1 in 1.5
		1.2	1.6220	0.0005	7.5	1 in1.5
			2.9770	0.0200	8.0	1 in 1.5
		1.8	1.4100	0.0005	7.5	1 in 1.5
			2.8360	0.0200	8.0	1 in 1.5
7.	Type VI	0.6	1.2223	0.0005	7.5	1 in 1.5
			1.6810	0.0200	8.0	1 in 1.5
		1.2	1.1123	0.0005	7.5	1 in1.5
			1.2110	0.0200	8.0	1 in 1.5
		1.8	0.9999	0.0005	7.5	1 in 1.5
			0.8210	0.0200	8.0	1 in 1.5
1.	Clay	0.6	1.6700	0.0005	13.5	1 in 1
			1.7700	0.0200	13.5	1 in 1
		1.2	1.2000	0.0005	13.5	1 in 1
			1.3010	0.0200	13.5	1 in 1
		1.8	0.9920	0.0005	13.5	1 in 1
			1.5600	0.0200	13.5	1 in 1
2.	Type I	0.6	0.4082	0.0005	13.5	1 in 1
			0.5600	0.0200	13.5	1 in 1
		1.2	0.6451	0.0005	13.5	1 in 1
			0.7500	0.0200	13.5	1 in 1
		1.8	0.5271	0.0005	13.5	1 in 1
			0.6700	0.0200	13.5	1 in 1
3.	Type II	0.6	0.7491	0.0005	13.5	1 in 1
			0.8310	0.0200	13.5	1 in 1
		1.2	0.7100	0.0005	13.5	1 in 1
			0.8400	0.0200	13.5	1 in 1
		1.8	0.6821	0.0005	13.5	1 in 1
			0.7010	0.0200	13.5	1 in 1
4.	Type IV	0.6	0.7491	0.0005	13.5	1 in 1
			1.2100	0.0200	13.5	1 in 1
		1.2	0.7431	0.0005	13.5	1 in 1
			0.8610	0.0200	13.5	1 in 1
		1.8	0.7000	0.0005	13.5	1 in 1
			0.8200	0.0200	13.5	1 in 1

Table 3 Average Shear Stress versus Average Depth of Flow

Run No.	Material	Avg. Depth of Flow (cm)	Avg. Shear Stress, τ_o (N/m)	Longitudinal Slope (%)	Bank Slop
1.	Sand	8.0	0.5595	0.05	1 in 1.5
2.	Type I	8.0	0.4299	0.05	1 in 1.5
3.	Type II	8.6	0.5434	0.05	1 in 1.5
4.	Type IV	7.7	0.6325	0.05	1 in 1.5
1.	Sand	8.0	2.9402	2.00	1 in 1.5
2.	Type I	8.0	1.7668	2.00	1 in 1.5
3.	Type II	8.0	2.0380	2.00	1 in 1.5
4.	Type III	8.0	2.2859	2.00	1 in 1.5
5.	Type IV	8.0	2.5239	2.00	1 in 1.5
6.	Type V	8.0	2.6348	2.00	1 in 1.5
7.	Type VI	8.0	1.6410	2.00	1 in 1.5
1.	Clay	7.5	1.2370	2.00	1 in 1.5
2.	Type I	7.5	1.9560	2.00	1 in 1.5
3.	Type II	7.5	2.9568	2.00	1 in 1.5
4.	Type III	7.5	1.3740	2.00	1 in 1.5
5.	Type IV	7.5	1.2070	2.00	1 in 1.5
6.	Type V	7.5	1.1473	2.00	1 in 1.5
7.	Type VI	7.5	1.6100	2.00	1 in 1.5
1.	Clay	8.0	1.3100	0.05	1 in 1.5
2.	Type I	8.0	1.1041	0.05	1 in 1.5
3.	Type II	8.0	1.0167	0.05	1 in 1.5
4.	Type III	8.0	1.3180	0.05	1 in 1.5
5.	Type IV	8.0	1.1115	0.05	1 in 1.5
6.	Type V	8.0	1.4205	0.05	1 in 1.5
7.	Type VI	8.0	1.5676	0.05	1 in 1.5
1.	Clay	13.5	0.6497	0.05	1 in 1
2.	Type I	13.5	0.5653	0.05	1 in 1
3.	Type II	13.5	0.6162	0.05	1 in 1
4.	Type IV	13.5	0.7325	0.05	1 in 1

Table 4 Comparison between Observed and Computed Average Shear Stresses

Run No.	Material	Flume Length (m)	Observed Shear Stress τ_o (N/m^2)	Computed Shear Stress τ_c (N/m^2)	Longitudinal Slope (%)	Depth of Flow (cm)	Bank Slope
1.	Sand	0.6 1.2 1.8	0.6162 0.5611 0.5012	0.3924 0.3973 0.4022	0.05	8.0	1 in 1.5
2.	Type I	0.6 1.2 1.8	0.4965 0.4012 0.3921	0.3924 0.3973 0.4022	0.05	8.0	1 in 1.5
3.	Type II	0.6 1.2 1.8	0.5824 0.5467 0.5012	0.4022 0.4071 0.4120	0.05	8.6	1 in 1.5
4.	Type IV	0.6 1.2 1.8	0.6665 0,6200 0.6111	0.3768 0.3826 0.3924	0.05	7.7	1 in 1.5
1.	Sand	0.6 1.2 1.8	3.0628 2.9097 2.8480	9.8400 9.8400 9.8400	2.00	8.0	1 in 1.5
2.	Type I	0.6 1.2 1.8	1.8153 1.7608 1.7245	9.8400 9.8400 9.8400	2.00	8.0	1 in 1.5
3.	Type II	0.6 1.2 1.8	2.1009 2.0168 1.9748	9.8400 9.8400 9.8400	2.00	8.0	1 in 1.5
4.	Type III	0.6 1.2 1.8	2.3812 2.2621 2.2145	9.8400 9.8400 9.8400	2.00	8.0	1 in 1.5
5.	Type IV	0.6 1.2 1.8	0.9025 0.9020 0.8970	9.8400 9.8400 9.8400	2.00	8.0	1 in 1.5
6.	Type V	0.6 1.2 1.8	1.3210 1.1000 0.8120	9.8400 9.8400 9.8400	2.00	8.0	1 in 1.5
7.	Type VI	0.6 1.2 1.8	1.0992 0.9721 0.9526	9.8400 9.8400 9.8400	2.00	8.0	1 in 1.5
1.	Clay	0.6 1.2 1.8	1.9880 1.9800 1.8000	9.3580 9.3580 9.3580	2.00	7.5	1 in 1.5
2.	Type I	0.6 1.2 1.8	1.3221 1.0200 0.9000	9.3580 9.3580 9.3580	2.00	7.5	1 in 1.5
3.	Type II	0.6 1.2 1.8	1.5000 1.2000 0.9200	9.3580 9.3580 9.3580	2.00	7.5	1 in 1.5
4.	Type III	0.6 1.2 1.8	1.6710 1.621 1.582	9.35800 9.3580 9.3580	2.00	7.5	1 in 1.5
5.	Type IV	0.6 1.2 1.8	1.7210 1.6220 1.3290	9.3580 9.3580 9.3580	2.00	7.5	1 in 1.5

6.	Type V	0.6 1.2 1.8	3.0628 2.9770 2.8360	9.3580 9.3580 9.3580	2.00	7.5	1 in 1.5
7.	Type VI	0.6 1.2 1.8	1.6820 1.2110 0.8210	9.3580 9.3580 9.3580	2.00	7.5	1 in 1.5
1.	Clay	0.6 1.2 1.8	1.3400 1.200 1.0100	0.3924 0.3924 0.3924	0.05	8.0	1 in 1.5
2.	Type I	0.6 1.2 1.8	1.0681 1.0000 0.9810	0.3924 0.3924 0.3924	0.05	8.0	1 in 1.5
3.	Type II	0.6 1.2 1.8	1.2230 1.1300 0.9600	0.3924 0.3924 0.3924	0.05	8.0	1 in 1.5
4.	Type III	0.6 1.2 1.8	1.5210 1.3210 1.1120	0.3924 0.3924 0.3924	0.05	8.0	1 in 1.5
5.	Type IV	0.6 1.2 1.8	1.4205 1.4205 1.4205	0.3924 0.3924 0.3924	0.05	8.0	1 in 1.5
6.	Type V	0.6 1.2 1.8	1.6270 1.6220 1.4100	0.3924 0.3924 0.3924	0.05	8.0	1 in 1.5
7.	Type VI	0.6 1.2 1.8	1.2223 1.1123 0.9999	0.3924 0.3924 0.3924	0.05	8.0	1 in 1.5
1.	Clay	0.6 1.2 1.8	0.6665 0.6497 0.6330	0.6867 0.6867 0.6867	0.05	13.5	1 in 1
2.	Type I	0.6 1.2 1.8	0.5823 0.5653 0.5483	0.5886 0.5886 0.5886	0.05	13.5	1 in 1
3.	Type II	0.6 1.2 1.8	0.6330 0.6162 0.5995	0.6377 0.6377 0.6377	0.05	13.5	1 in 1
4.	Type IV	0.6 1.2 1.8	0.7491 0.7358 0.7358	0.7358 0.7358 0.7358	0.05	13.5	1 in 1

Table 5 Froude Number versus Longitudinal Slope by Average Velocity

S. No.	Material	Avg. Velocity (m/Sec)	Depth of Flow (cm)	Froude No.	Longitudinal Slope	Bank Slope
1.	Sand	0.36 0.45	8.0 8.0	0.418 0.535	0.0005 0.0200	1 in 1.5 1 in 1.5
2.	Type I	0.35 0.39	8.0 8.0	0.394 0.427	0.0005 0.0200	1 in 1.5 1 in 1.5
3.	Type II	0.37 0.40	8.6 8.0	0.403 0442	0.0005 0.0200	1 in 1.5 1 in 1.5
4.	Type IV	0.36 0.39	7.7 8.0	0.418 0.464	0.0005 0.0200	1 in 1.5 1 in 1.5
1.	Clay	0.42 0.42	8.0 7.5	0.474 0.507	0.0005 0.0200	1 in 1.5 1 in 1.5
2.	Type I	0.40 0.38	8.0 7.5	0.353 0.443	0.0005 0.0200	1 in 1.5 1 in 1.5
3.	Type II	0.40 0.39	8.0 7.5	0.353 0.463	0.0005 0.0200	1 in 1.5 1 in 1.5
4.	Type III	0.38 0.38	7.7 8.0	0.42 0.447	0.0005 0.0200	1 in 1.5 1 in 1.5
5.	Type IV	0.38 0.40	8.0 7.5	0.429 0.462	0.0005 0.0200	1 in 1.5 1 in 1.5
6.	Type V	0.39 0.43	8.0 7.5	0.44 0.519	0.0005 0.0200	1 in 1.5 1 in 1.5
7.	Type VI	0.31 0.32	8.0 7.5	0.35 0.369	0.0005 0.0200	1 in 1.5 1 in 1.5
1.	Clay	0.51	13.5 8.0	0.439 0.521	0.0005 0.0200	1 in 1 1 in 1
2.	Type I	0.46	13.5 8.0	0.375 0.4	0.0005 0.0200	1 in 1 1 in 1
3.	Type II	0.49	13.5 8.0	0.438 0.46	0.0005 0.0200	1 in 1 1 in 1
4.	Type IV	0.47	13.5 8.0	0.42 0.49	0.0005 0.0200	1 in 1 1 in 1

Table 6 Estimated Volume Eroded from Flume

For bank slope 1:1.5
bank hypotenuse length = 18.023cm
width of bed = 35cm
width of bank = 15
mobile bed length = 240cm

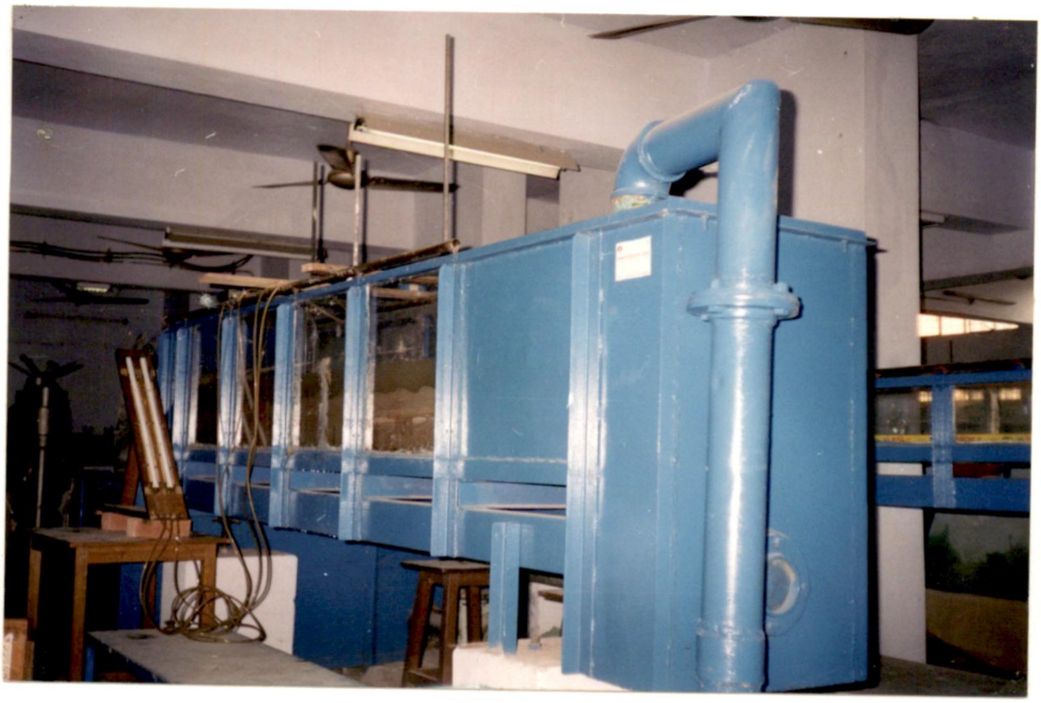
For bank slope 1:1
bank hypotenuse length = 28.28cm
width of bed = 30cm
width of bank = 20

Run No	Material	Avg. Depth of Erosion (scour) on Bed (cm)	Avg. Depth of Erosion (scour) on Bank (cm)	Volume of Erosion from Bed (cm^3)	Volume of Erosion from Bank (cm^3)	Total Volume of Erosion from Flume (cm^3)	Longitudinal Slope (%)	Avg. Depth of Flow (cm)	Bank slope
1.	Sand	0.93	1.44	8062.20	6227.49	14289.69	0.05	8.0	1 in 1.5
2.	Type I	0.40	0.46	3438.72	1974.33	5413.05	0.05	8.0	1 in 1.5
3.	Type II	0.83	1.37	5914.70	3497.06	9511.76	0.05	8.6	1 in 1.5
4.	Type IV	0.81	0.95	6802.10	4109.24	10911.34	0.05	7.7	1 in 1.5
1.	Sand	1.02	1.57	8621.17	6801.14	15422.31	2.0	8.0	1 in 1.5
2.	Type I	0.62	0.83	5195.09	3396.22	8792.10	2.0	8.0	1 in 1.5
3.	Type II	0.77	1.48	6497.74	6415.20	12912.94	2.0	8.0	1 in 1.5
4.	Type III	0.72	0.94	6086.43	4086.69	10173.12	2.0	8.0	1 in 1.5
5.	Type IV	1.07	1.20	9003.89	5230.24	14234.14	2.0	8.0	1 in 1.5
6.	Type V	1.18	1.27	9920.43	5511.35	15431.78	2.0	8.0	1 in 1.5
7.	Type VI	0.19	0.19	1643.70	821.85	2465.55	2.0	8.0	1 in 1.5
1.	Clay	0.71	0.28	5971.00	3582.60	9553.61	2.0	7.5	1 in 1.5
2.	Type I	0.28	0.35	2331.64	1554.44	3886.08	2.0	7.5	1 in 1.5
3.	Type II	0.32	0.40	2733.35	1739.41	4472.77	2.0	7.5	1 in 1.5
4.	Type III	0.37	0.47	3106.00	2046.52	5154.52	2.0	7.5	1 in 1.5
5.	Type IV	0.43	0.50	3696.00	2191.84	5887.84	2.0	7.5	1 in 1.5
6.	Type V	0.45	0.53	3810.67	2310.68	6121.35	2.0	7.5	1 in 1.5
7.	Type VI	0.21	0.18	1775.12	775.12	2550.24	2.0	7.5	1 in 1.5
1.	Clay	0.34	0.33	2859.80	1429.90	2489.70	0.05	8.0	1 in 1.5
2.	Type I	0.09	0.11	790.06	474.05	1264.11	0.05	8.0	1 in 1.5
3.	Type II	0.22	0.23	1886.32	998.65	2884.97	0.05	8.0	1 in 1.5
4.	Type III	0.19	0.22	1606.25	963075	2570.00	0.05	8.0	1 in 1.5
5.	Type IV	0.22	0.25	1874.59	1085.30	2959.89	0.05	8.0	1 in 1.5
6.	Type V	0.27	0.32	2322.27	1393.37	3715.64	0.05	8.0	1 in 1.5
7.	Type VI	0.09	0.11	753.99	466.76	1220.75	0.05	8.0	1 in 1.5
1.	Clay	0.40	0.24	2881.06	2881.06	4481.66	0.05	13.5	1 in 1
2.	Type I	0.26	0.15	1879.22	1879.22	2923.25	0.05	13.5	1 in 1
3.	Type II	0.22	0.22	1833.42	1833.42	2804.06	0.05	13.5	1 in 1
4.	Type IV	0.27	0.28	2316.12	1226.12	3542.30	0.05	13.5	1 in 1

APPENDIX B

PHOTOGRAHPES SHOWING EXPERIMENTAL INSTALLATIONS

Side view of the experimental set-up. Water is flowing in to the tank. The measuring equipment's are also seen.



Side view of experimental set-up. Spindle of the fixed screw fixed on the masonry pillar.

Untreated jute type I (weight 732GM/M^2) laid on the flume bed and bank as the covered layer.

Untreated jute of different type used for bed and bank preparation as a covered layer.