“EFFECT OF SOIL PARAMETERS ON RIVER BANK EROSION ACROSS TWO DIFFERENT SEASONS ALONG A STRAIGHT SECTION”

A DESSERTATION SUBMITTED TO
ASSAM SCIENCE AND TECHNOLOGY UNIVERSITY
IN PARTIAL FULFILMENT OF THE DEGREE OF

MASTERS OF TECHNOLOGY
IN
CIVIL ENGINEERING
(**Water resource Engineering**)

SUBMITTED BY-
SHREYA KARKI
3RD semester
(Roll no- PG/CE/23/35)

UNDER THE GUIDANCE OF
DR. PANKAJ GOSWAMI
PROFESSOR
DEPARTMENT OF CIVIL ENGINEERING
ASSAM ENGINEERING COLLEGE
JALUKBARI, GUWAHATI-13

DECLARATION

I hereby declare that the work presented in the dissertation "Effect of soil parameters on river bank erosion in Biswanath Chariali Region, Assam across two different seasons along a straight section" in partial fulfillment of the requirement for the award of the degree of "MASTER OF TECHNOLOGY" in Civil Engineering (with specialization in Water Resource Engineering), submitted in the Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati – 13 under Assam Science & Technology University, is a real record of my work carried out in the said college under the supervision of Dr. PANKAJ GOSWAMI, Professor, Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati – 13.

Do hereby declare that this project report is solemnly done by me and is my effort and that no part of it has been plagiarized without citation.

Date: SHREYA KARKI

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Date:

Dr. PANKAJ GOSWAMI

(Professor)

Civil Engineering Department

Assam Engineering College

CERTIFICATE

This is the certified that the work presented in the project report entitled “Effect of soil parameters on river bank erosion in Biswanath Chariali Region, Assam across two different seasons along a straight section” is submitted by Shreya Karki, Roll No: PG/C/23/35, a student of M.Tech 3th semester, Department of Civil Engineering, Assam Engineering College, to the Assam Science and Technology University in partial fulfillment of the requirement for award of the degree of Master of Technology in Civil Engineering with Specialization in Water Resources Engineering under my guidance and supervision.

Date:

DR. PANKAJ GOSWAMI
(Professor)
Department of Civil Engineering
Assam Engineering College-781013

CERTIFICATE FROM HEAD OF THE DEPARTMENT

This is to certify that the project report entitled "Effect of soil parameters on river bank erosion in Biswanath Chariali Region, Assam across two different seasons along a straight section" has been submitted by SHREYA KARKI , bearing Roll No: PG/C/23/35, a student of M.Tech. 3th Semester, Water Resource Engineering (Civil Engineering Department), Assam Engineering College, in partial fulfillment of the requirements for the award of the degree of Master of Technology in Water Resource Engineering of Assam Science & Technology University.

Date
Place

DR. JAYANTA PATHAK

Professor & Head
Department of Civil
Engineering Assam
Engineering College
Jalukbari,Guwahati-13

ACKNOWLEDGEMENT

I would like express my heartfelt gratitude and sincere thanks to Dr. Kalyan kalita, Principal(i/c), Assam Engineering College, Jalukbari and to my guide Dr. Pankaj Goswami, Professor for giving their invaluable suggestions and moral support towards completion of project work.

I express my deep gratitude to Dr. Jayanta Pathak, Professor and HOD, Dept. of Civil Engineering, Assam Engineering College, Jalukbari for his continuous help and support towards the project.

I extend my grateful thanks to all the faculty members of the Department Of Civil Engineering,Assam Engineering College for their free exchange of ideas and for lending their helping hand whenever I needed them.

SHREYA KARKI
M-Tech 3rd Semester
Department of Civil Engineering
Assam Engineering College , Jalukbari

ABSTRACT

Bank erosion is the one of the most critical disaster in Assam. Bank erosion may occur due to hydraulic properties or geotechnical properties of soil. A river flows through various soil types. Sometimes it is seen that different places with same hydraulic properties have different erosion. So variation of geotechnical properties may affect the soil erosion. Collection of soil sample from various location of upper Assam region and observed its characteristic and properties is the main objective of this study. From the results of gradation test it is observed that the co-efficient of uniformity of highly eroded soil is greater than the less eroded soil. Co-efficient of uniformity of highly eroded soils are greater than 2 and less eroded soil are less than 2. So far only four samples were collected and tested. So it will be hard to conclude the effect of all properties in erosion of river bank now. In future more samples will be collected and carried out laboratory testing.

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 Overview

Bank erosion is a natural process, without it, rivers would not meander and change course. Bank erosion is the wearing away of the banks of a stream or river. Some researchers define bank erosion as 'Bank erosion is a natural geomorphological process affecting several environmental and socio-economic aspects' (by Bravard et al. 1990). 'Bank erosion is the result of a complex interaction between channel hydraulic conditions and physical characteristics of the banks, both which are highly variable in nature' (by Nanson and Hicking 1986, Lewler et al. 1997). 'The fine sand and silty nature of the river bank material and the unstable bank line along the most part of the river create a highly favourable environment for bank erosion. Bank failures are composed of violent actions of the flowingwater and the weak geotechnical propertiesof the bank material'.(By Thorne 1979).

1.2 Bank failure mechanism

River bank erosion is one of the most unpredictable and critical type of disasters that take into account the quantity of rainfall, soil structure, river morphology, topography of river and floods. The direct damage from bank erosion includes loss of lives, loss of productive farmland, undermining of structures such as bridges. All river banks experience erosion, but failure is dependent on location and types of soil.

The various mechanism of stream bank erosion generally falls into two main groups, bank scour and mass failure.

1.2.1 *Bank scour*

Bank scour is the direct removal of bank materials by the physical action of flowing water and the sediment that it carries. As flow speed increases the erosive power of flowing water also increases and scour may occur.

1.2.2 *Mass failure*

Mass failure describes the various mechanism of bank erosion that result in sections of the bank sliding or toppling into stream. Mass failure is sometimes described as collapse or slumping.

1.2.3 *Factors of bank erosion*

- Flooding
- Land use and stream management
- Clearing of river bank vegetation
- River straightening
- Rapid flow drop after flooding
- Saturation of banks from non-river sources
- Redirection and acceleration around infrastructure or debris in the channel
- Intense rainfall events
- Bank soil characteristics

1.3 Types of bank failure

There are two types of river bank failure

- Hydraulically induced failure
- Geotechnical failure
- Gravitational failure

1.3.1 Hydraulic failure

In a stream below water level all bank particles are affected by water which causes erosion. Generally this kind of failure is seen at cohesion less banks. Hydraulic toe erosion occurs when flow is in the direction of a bank at the bend of the river and the highest velocity is at the outer edge and in the Centre depth of the water. In case of cohesion less bank, water currents remove the soil particles and create a cantilever overhang of cohesive material. Shear force exceeds the critical shear at toe of bank and erosion occurs

1.3.2 Geotechnical failure

Some important properties of soil are

- Specific weight or unit weight
- Porosity
- Void ratio
- Permeability
- Compressibility
- Shear strength
- Atterberg limits (liquid limit, plastic limit, shrinkage limit)

Geotechnical failure usually occurs due to variation of stress at the bank. Pore water pressure in the saturated bank reduces the frictional shear strength of soil and increases sliding forces. This type of failure is seen in fine grained soils because they cannot drain as rapidly as coarse grained soils. Subsurface moisture weakens internal shear. Capillary action can also decrease the angle of repose of the bank.

1.3.3 *Gravitational failure*

Gravitational failure includes shallow failure and cantilever failure.

Shallow failure occurs where a layer of material moves along planes parallel to bank surfaces. Failure is typical in soils with low cohesion and occurs when the angle of the bank exceeds the angle of internal friction. Failure is usually associated with steep banks and saturated finer grained cohesive bank materials that allow buildup of positive pore water pressure and strong seepage within structure.

Cantilever failures occur when an overhanging blocks collapses into the channel.

Failure often occurs after the bank has experienced undercutting. Failure is usually in a composite of fine and coarse grained material, and is active during low flow conditions.

There are three principle modes of cantilever failure. These are shear, beam and tensile failure.

Shear failure occurs by downward displacement of an overhanging block along a vertical plan. In this failure the shear stress due to block is greater than the shear stress of the soil.

In beam failure, a block rotates forward about a horizontal axis. About the axis, above is tension and below is compression. The moment of the weight of the block about axis overcomes the resistive moments of the soil's strength in tension and compression.

A tensile failure across a horizontal plan at some height above the base causes the lower part of a block to fall away. This occurs when the tensile stress due to the weight of the lower part of the block overcomes the tensile strength of the soil.

1.4 Effect of bank failure

Increase of bank erosion causes bank failure. River bank erosion is one of the most unpredictable and critical type of disasters that take into account the quantity of rainfall, soil structure, river morphology, topography of river and floods. The direct damage from bank erosion includes loss of lives, loss of productive farmland, undermining of structures such as bridges. The river bank erosion has causes major human and economic disasters than the annual flooding. The loss from flood is temporary but the loss of land due to river bank

crosion is permanent. It will affect the economy of the region and its people. Once a section of well developed land (agricultural, industrial or residential) or productive forest land is lost due to river bank erosion, it can hardly be replaced.

1.5 Objective of study

A river flows through various soil types. Therefore the erosions at the bank at all areas are not same. Causes of erosion may be hydraulic properties or geotechnical properties of river bank. It is observed that some areas with same hydraulic properties have different erosion. Geotechnical failure is one of the major causes of river bank failure. There are several geotechnical properties of soil such as bulk density, liquid limit, plastic limit, particle size distribution, shear stress etc. Variation of these parameters may cause different effect on soil erosion.

Main objective of this study are

1. To study the bank failure of various rivers located in upper Assam region.
2. To collect soil samples from various location of river bank in upper Assam.
3. To observe the effect of geotechnical properties of soil on river bank erosion.

CHAPTER 2

LITERATURE REVIEW

2.1 Soil and water management

The main objective of the study was to achieve a better understanding of how and to what extent each of the various properties of a soil affects its erodibility. Wischmeier and Mannering (1969) collected Fifty-five widely differing soils and tested in laboratory. They included 5 sandy loams, 10 loams, 35 silt loams, 2 clay loams, 2 silty clay loams and a silty clay. Various soil properties were taken in count such as soil texture, moisture content, bulk density, percent slope, pH of surface and subsoil. The study showed erodibility is sensitive to small changes in particle-size distribution. A soil type becomes less erodible with decrease in silt fraction corresponding increase clay fraction. For high -silt soil, increased pH increase erodibility if the structure is very fine or fine granular. If the structure is medium or coarse granular, subangular or angular then erodibility decreases with increased of pH. The permeability of surface seals decreased as organic matter content, percent sand, aggregation index, bulk density or moisture equivalent increased. Due to surface sealing, particle detachment decrease.

2.2 Erosion of composite river banks

Composite banks with non-cohesive sand and gravel overlain by cohesive sandy silt/clay are widely observed on rivers flowing through alluvial deposits. Rapid erosion of the lower bank by fluvial entrainment generates cantilevers in the cohesive upper layer of eroding banks. Cantilever failure occurs due to development of a vertical crack upwards from the base of the overhang. The strength of the soil decreases with depth and reaches a

minimum at the base of root matting. Thorne (1981) found three principle mechanisms of cantilever failure. These were shear, beam and tensile failure. They also concluded that the increase in bulk unit weight due to the change from submerged to saturated conditions on drawdown can often be critical to cantilever stability. Increasing moisture content reduces the strength of a soil. The combined effect of increasing the unit weight while decreasing the strength soil can cause failure due to wetting.

2.3 Bank erosion in an incised channel

This paper discus many of the fundamental issues related to the interaction of fluvial and geotechnical process affecting stream banks. The research described the role of pore pressures in the unsaturated zone in increasing bank strength, contrasted with the role of positive pore-water pressure in reducing bank strength. Seepage forces have been shown to increase the resistance of failed cohesive blocks to entrainment by hydraulic forces. Simon et al (1999) concluded that a stable bank is transformed into an unstable bank during period of rainfall through increase in soil unit weight. Prolonged wet periods weaken in situ bank materials resulting in mass failure.

2.4 Stability of stream banks

Stream banks of alluvial channels are usually composed of loose materials, which are unsaturated in ambient conditions. Unsaturated soils are subjected to negative pore water pressures, which causes an apparent cohesion. Matric suction is responsible for an additional term of shear strength, Rmaldi et al. Differences in bank geometry and geotechnical properties along a river introduce a reach and basin scale spatial variability in bank stability.

In this study it is observed that the type of flow responsible for triggering bank failure mechanisms is in-bank moderate flows, with a water stage that exceeds the contact between the sandy gravel and the upper layer of silty sand material. The presence of matric suction in an unsaturated stream bank increases the shear strength of the material.

2.5 The effects of vegetation in river bank erosion

The most significant factors determining the soil erosion rate in this study was bulk density. Thmpson (2006) found that increase in bulk density resulted in decreases in soil erodibility and increases in the critical shear stress. Thompson also found that soil texture influenced the critical shear stress. In this report the critical shear stress was negatively correlated to potassium intensity factor. The soil with high potassium intensity factor values was typically friable and easily eroded. Critical shear stress increased with increases in the grain size standard deviation and decreases in sand content. Soil cohesion decreases with increased sand content. Therefore soils with higher sand contents were easy to erode at lower shear stress.

2.6 Embankment and river bank failure

Hossain et al (201 1) collected Soil samples from the broken part of bank embankment of Jamuna river and eroded bank of Padma river. The samples were carried out laboratory test. As a result it is found that the liquid limit of both sample were 25% and 32% respectively. Embankment soil is not plastic and river bank soil is 27% of plastic limit.
According to soil classification embankment soil is fine sand and river bank soil is silty soil with lower liquid limit. From the compaction test, the maximum dry densities of embankment soil and river bank soil were found 1.59g/cm' and 1.72gm/cm at optimum water content of 21.2% and 16.5% respectively.

2.7 Erosion rate at cohesive material

After performing series of jet experiment Aira et al (2008) concluded that the erosion rate decreased as the cohesion increased. Erosion rate also depend on some factor such as particle size distribution. They found that erosion rate tended to increase with increasing particle size.

CHAPTER 3

METHODOLOGY

3.1 Study Area

- **BORGANG RIVER:** The Borgang River is a tributary of the Brahmaputra River in Assam. The Borgang river originates from Daphla Hills of Arunachal Pradesh. Recently the river has started to erode the adjoining places on the bank of the river at Borgang area causing floods.

BORGANG RIVER
Lat: 26°44'40.91"N
Long: 93°19'13.68"E

- **BRAHMAJAN RIVER:** It is river in Biswanath district of Assam. It is a north bank tributary of River Brahma

BRAHMAJAN RIVER
Lat: 26°52'43.18"N
Long: 93°29'51.87"E

3.2 General

Soil samples were collected from different locations of rivers in Assam mainly River Brahmaputra and its tributaries. All samples were disturbed and performed test as per IS code in laboratory of Assam Engineering College.

3.3 Various tests procedure

3.3.1 *Grain size Distribution*

As the soil samples were fine grain in nature, samples were passes through the arrangement of sieve sizes 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm, 0.15mm and 0.075mm. Tests were performed as per IS.2720 (PART 4)-1985. The portion of soil passing 4.75-mm IS Sieve obtained was oven dried. This oven dried material shall then be riffled so that a fraction of convenient mass is obtained. This shall be about 200gm. If substantial proportion of the material only, just passes the 4.75-m IS Sieve or less if the largest size is smaller. The soil specimen should be passed thoroughly over the nested in order of their fineness with the finest sieve (75-micron IS Sieve) at the bottom. Passing shall be continued until the water passing each sieve is substantially clean. Care shall be taken to see that the sieves are not overloaded in process. The fraction retained on each sieve should be emptied carefully without any loss of material in separate trays. Oven dried at 105to 100° C and each fraction weighed separately and the masses recorded. The fraction retained on the sieve should tip without loss.

3.3.2 *Liquid limit determination*

This test was performed as per IS: 2720 (PART 5)-1985. About 150 gm of soil sample obtained shall be worked well into a paste with addition of distilled water. In case of highly clayey soils, to ensure uniform moisture distribution, it is recommended that the soil in the mixed state is left for sufficient time (24hrs) in an air-tight container. The wet soil paste shall then be transferred to the cylindrical cup of cone penetrometer apparatus, ensuring that no air is trapped in this process. Finally the wet soil is leveled to the top of the cup clamped in this position. The initial reading is either adjusted to zero or noted down as is shown on the graduated scale. The vertical clamp is then released allowing the cone to penetrate into the soil paste under its own weight. The penetration of the cone after 5 seconds shall be noted to the nearest millimetre. If the difference in penetration lies between 14 and 28mm the test is repeated with suitable adjustments to moisture either by addition of more water or exposure of the spread paste on a glass plate for reduction in moisture content. The test shall then be repeated at least to have four sets of values of penetration in the range of 14 to 28mm. The exact moisture content of each trial shall be determined in accordance with IS: 2720(PART 2) -1973.

A graph representing water content on the y-axis and the cone penetration on the x-axis shall be prepared. The best fitting straight line is then drawn. The moisture content corresponding to cone penetration of 20 mm shall be taken as the liquid limit of the soil and shall be expressed to the nearest first decimal place.

3,3.3 *Plastic limit determination*

The soil samples were taken after passing through 425 microns IS sieve. Sample was mixed thoroughly with distilled water on the glass plate until it is plastic enoush to be Shaped into a smal ball. Suitable amount of sample should be taken and rolled house co the hand and the glass plate to form the soil sample into thread becomes 3mm diameter without crack. The rolling and remoulding process should be recated until the thread star erumbling at the diameter of 3mm. If the soil sample start crumbling before 3mm diameter then water should be added more and repeat the process. The pieces of crumbed soil thread were collected and dried in oven and calculated its moisture content.

3.3.4 Direct Shear Test

This test was carried out as per the provisions in IS 2720 (Part 13):1986 on the disturbed soil specimens. The test is carried out on either undisturbed samples or remoulded samples. To facilitate the remoulding purpose, a soil sample may be compacted at optimum moisture content in a compaction mould. Then specimen for the direct shear test could be obtained using the correct cutter provided. Alternatively, sand sample can be placed in a dry state at a required density, in the assembled shear box. A normal load is applied to the specimen and the specimen is sheared across the pre-determined horizontal plane between the two halves of the shear box. Measurements of shear load, shear displacement and normal! displacement are recorded from the dial gauge and the proving ring connected to the shear box. A graph of shear stress against displacement is plotted in a normal graph paper. From this graph, the highest values of shear stress for loads 0.5 kg, 1 kg and 1.5 kg are determined.

Then another graph is plotted for these maximum shear stresses against normal stresses. From this graph, the value of cohesion and angle of internal friction of the soil sample is determined. The test is repeated for two or more identical specimens under different normal loads. From the results, the shear strength parameters can be determined.

3.3.5 *Determination of Field Unit Weight*

The field unit weight is determined by the core cutter method (IS : 2720, Part 29,1966). In this method, a core cutter is used to collect the undisturbed soil samples. The core cutter is placed on the ground and inserted to the ground by hammering it with a load.

After getting full penetration, the core cutter is dug out gently without disturbing it. The weight of the core cutter with soil brought from the field is measured and by removing the soil, the empty weight of the core cutter is measured. The difference between the two gives the weight of the soil. Then the inside dimensions of the core cuter (length and inner diameter are measured and its volume (V) is calculated. The ratio of the weight to volume gives the field unit weight (bulk density).

Field unit weight (bulk) or field density, y = (W,-Wo)/V g/c.c.

Where, W1 = Weight of core cutter + Wet soil.

Wo = Weight of the empty core cutter.

V = Volume of the core cutter.

3.3.6 *Determination of Permeability*

The permeability of soil samples are determined by Falling head permeability test.

The falling head test is used for relatively less permeable soils where the discharge is small. A stand pipe of known cross-sectional area "a" is fitted over the permeameter and water is allowed to run down. The water level in the stand pipe constantly falls as water flows. Observations are started after steady state of flow has reached. The head at any time instant "t" is equal to the difference in the water level in the stand pipe and the bottom tank. Let h1 and h2 be heads at time intervals t1 and t2 (t1>t2) respectively. The co-efficient of permeability is determined as $k = 2.303\ (aL/At)\ \log(h1/h2)$

Where, L = Length of the sample.

A= Total cross-sectional area of sample.

CHAPTER-4

RESULTS

4.1 Determination of grain size distribution by sieve analysis.

Total weight of each sample

Table no 1 : Grain size distribution of sample no 1

Size of Seives (mm)	Percentage finer
4.75	97.8808
2.36	81.432
1.18	70.1038
0.6	59.3746
0.425	53.6334
0.3	50.2636
0.15	21.6628
0.075	5.4474
0	0.0042

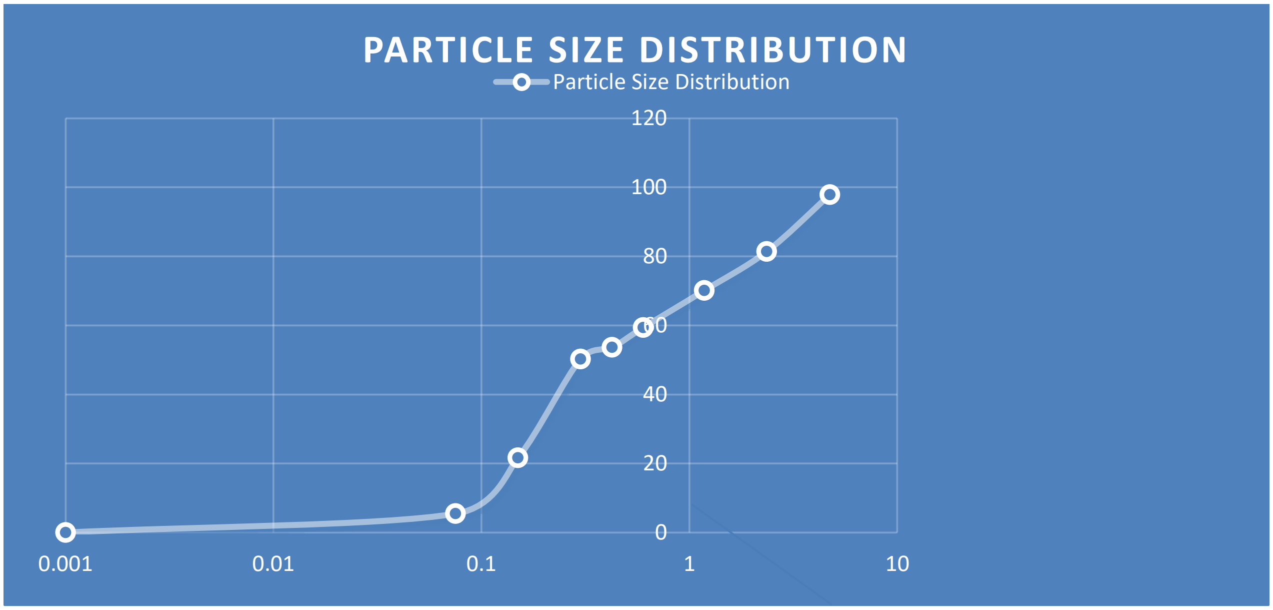

Fig 3: Graph showing particle size distribution of sample

- **Coefficient of uniformity (Cu):** A larger Cu indicates larger range of particle sizes.

  $Cu = D_{60}/D_{10}$
- **Coefficient of curvature (Cc):** It is also known as coefficient of gradation.

  $Cc = D_{30}^2/D_{60} x D_{10}$

  Cu>6 is for sands and 1<Cc<3 in well graded soils.

Below results derived from the graph

Cu	**Cc**
6.15	1.53

From the result it can be seen that the sample is well graded sand.

4.2 Determination of Maximum Dry Density (MDD) and Optimum Moisture Content (OMC)

Table 2- Moisture content and dry density of sample 1&2

ERODED SAMPLE		NON ERODED SAMPLE	
Moisture content	Dry Density	Moisture content	Dry Density
0.066	1.5123	0.124	1.539831
0.08	1.5946	0.148	1.591004
0.095	1.6392	0.179	1.598847
0.106	1.6584	0.215	1.558968
0.124	1.6809	0.236	1.493906
0.154	1.649		
0.1733	1.594		
0.18	1.578		

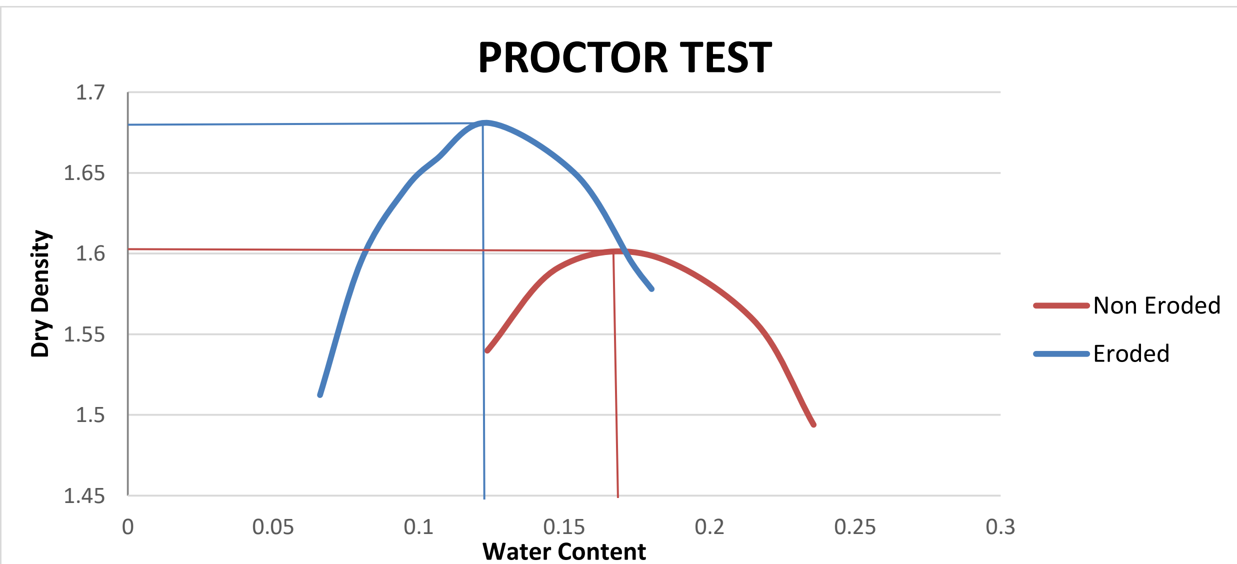

Fig -4 Graph showing MDD and OMC of the two sample

Results derived from graph of both the sample

ERODED SAMPLE		NON ERODED SAMPLE	
OMC	MDD	OMC	MDD
12.4%	1.68	18%	1.6

4.3 Determination of Permeability.

- SAMPLE 1(Eroded): OMC= 13% ; MDD= 1.68G/cc
- Y_d= W/V

⇒ W_{dry}= 1.68x1000=1680g

OMC= Ww/Ws

⇒ W_w= 1680x13/100= 220gm

Total head= 180cm

Time	**Head**
0 min	180
30 min	173
60 min	167.5
90 min	162.7

K	Value
K_1	$1.1x10^{-5}$
K_2	$0.912x10^{-5}$
K_3	$0.82X10^{-5}$
$\mathbf{K_{avg}}$	$\mathbf{0.944x10^{-5}}$

SAMPLE 2 (Non Eroded): OMC= 18% ; MDD= 1.6G/cc

Y_d= W/V

⇒ W_{dry}= 1.60x1000=1600g

OMC= Ww/Ws

⇒ W_w= 1600x18/100= 288gm

Total head= 180cm

Time	**Head**
0 min	180

30 min	173
60 min	167.5
90 min	162.7

K	Value
K_1	$1.1x10^{-5}$
K_2	$0.912x10^{-5}$
K_3	$0.82X10^{-5}$
K_{avg}	**$0.944x10^{-5}$**

Kav of eroded sample > Kav of non-eroded sample

FINDINGS (till now)

- From the Cu and Cc value we find that, the sample is well graded and sandy, i.e well graded sand. We find that maximum dry density of eroded sample is greater than that of non eroded sample. We find from the permeability test that coefficient of permeability of eroded sample is more than that of coefficient of permeability of non- eroded sample.

FUTURE WORK TO BE DONE

- Direct shear test are to be conducted on all samples.
- Collections of soil sample in coming season.
- Conducting Proctor test, Permeability, unit weight determination, grain size distributions, direct shear test for the next set of samples.
- Comparison between the soil parameters of eroded and non eroded sample across two seasons.

REFERENCES

- Ranjan, Gopal and Rao, A.S.R.: A textbok of basic and applied soil mechanics (revised second edition)
- Thomption wynn T.M " The effect of vegetation and soil type on streambank Erosion, southwest virginia (USA)"
- https://assamtribune.com/assam/biswanath-chariali-massive-land-erosion-by-brahmaputra-posing-threat-to-panpur-embankment-1483456
- https://biswanath.gov.in/departments/detail/water-resources-department-flood-and-erosion-scenario
- **Relation of Soil Properties to its Erodibility** W. H. Wischmeier, J. V. Mannering, Soil Science Society of America Journal
- Thorne R Colin, N. K. Tovey 1981, "Stability of Composite River Banks"
- Simon Andrew, Andrea Curini, Stephen E. Daerby, Eddy J Langenden (1999), "Bank and near-bank processes in an incised channel".
- IS-1498 (1970) "Classification and Identification of soils for general

Engineering purposes". Bureau of Indian Standard (BIS), New Delhi.