Effectiveness of Jute Geotextile Filter for River Bank Protection

by

Roman Kabir

MASTER OF SCIENCE IN CIVIL ENGINEERING

Department of Civil Engineering

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

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

Roman Kabir

DEDICATION

This thesis is dedicated to my parents

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ABSTRACT

This study was undertaken to investigate the effectiveness of Jute Geotextile (JGT) as filter material for river bank protection. Two types of JGTs were selected for the study. Some physical, mechanical and hydraulic property tests were performed on the selected JGTs. It is appreciated that neither any standard test method nor any design approach related to JGT is currently available. The ASTM and DIN standard test methods for determining the properties commonly employed for synthetic geotextiles were adopted. To investigate the effectiveness of JGT in river bank protection, both field trial and laboratory simulation were performed. For field trial, a site was selected where river bank protection work was going on. Soil samples were collected from the river bank. Grain Size Analysis was performed on those samples in order to investigate formation of filter cake underneath the JGT. For laboratory simulation, a model was arranged in geotechnical laboratory of BUET. Soil collected from the river bank was used in the model and untreated JGT was used as a filter material. Reversing water flow was conducted through the model setup for a certain time. After that time, water flow was stopped and soil sample was collected from the setup. Grain Size Analysis of the soil sample was performed to examine the redistribution of particle size of the soil. From field trial it was found that, when JGT is used as filter material in river bank protection, natural soil filter cake is formed partially. Since the river bank remained in good shape for more than two years, it can be said that the partially formed filter cake is stable. From laboratory simulation, it was found that filter cake forms partially after a certain period of time. Both the field trial results and laboratory simulation results indicate that the JGT may be considered as an alternative to synthetic geotextiles as filter material for protection of bank slopes of mild to moderate rivers.

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NOTATIONS

p	factor of granular filter design
q	factor of granular filter design
Q	rate of flow
k_s	coefficient of soil permeability
i	hydraulic gradient through the soil
A	the cross-sectional area through which flow takes place
ΔH	the rate of loss of hydraulic head
ΔL	length of the flow path
T_g	geotextile thickness
ψ	geotextile‘s permittivity
k_g	geotextile‘s permeability
k_{gf}	coefficient of permeability of a granular filter
λ	a reduction factor taking account of the loss of geotextile permeability after installation
d_{50}	the sieve size through which 50% of the soil will pass
d_{85}	the sieve size through which 85% of the soil will pass
O_{95}	95% opening size and corresponds to the size where 95% of the geotextile‘s openings are the same size or smaller
U	the uniformity coefficient of soil.
O_{90}	geotextile opening size corresponding to 90% particle size based on dry glass bead sieving.
d_{90}	the sieve size through which 90% of the soil will pass
d_{40}	the sieve size through which 40% of the soil will pass
d_{10}	the sieve size through which 10% of the soil will pass

O_f	geotextile‘s characteristic pore size as measured by the French AFNOR 38017 test
d_{15}	the sieve size through which 15% of the soil will pass
d_{80}	the sieve size through which 80% of the soil will pass

CHAPTER ONE

INTRODUCTION

1.6 General

Geotextiles are defined as permeable textiles used in conjunction with soils or rocks as an integral part of a man made project. They are used in a wide range of applications, which continues to grow as new forms of geotextiles are developed. The main applications are erosion control, soil filtration, road sub-base separators, reinforcing soils in embankments and retaining walls and the protection of the geomembranes. In 1973, three basic functions of geotextiles were identified, namely separation, filtration and reinforcement. Shortly afterwards drainage was added as the fourth basic function of geotextiles (McGown, 1973).

Synthetic geotextiles are now being widely used for a number of different geotechnical applications. The functions are mainly filtration in cross plane flow, separation of dissimilar materials, reinforcement of weak soils, drainage in in-plane flow etc. (Koerner 1997). Synthetic materials dominated the field because of its special characteristics like high strength, high thermal insulation, low specific gravity, good resilience, chemical inertness etc.

As man seeks to reduce the conflict between the expanding world population and the limited natural resources available to it on the one hand and between the daily deterioration of the environment and the exploitation of natural resources for the industrialization on the other, it is now realized that the promotion of a fiber other than natural cotton and synthetic cellulose has become very important. Recently jute, a natural fiber has come up to supplement and or replace synthetics, has been receiving increasing attention from the industry. Jute fiber is comparable or superior to synthetic fiber in physical and chemical characteristics. Jute is biodegradable and its production can be easily disposed without causing environmental hazards.

Jute geotextile (JGT) is one such diversified product and has proved to be highly effective in addressing a number of soil-related problems in civil engineering. JGTs can be described as natural fiber materials used for civil engineering purpose to meet technical as well as functional requirements for soil related problems. It is an economical and eco-friendly (bio-degradable) answer to geotechnical problems.

Jute is a natural eco-friendly biodegradable fiber and JGTs have emerged as a strong alternative to synthetic geotextiles for many civil engineering applications. The important advantages offered by jute fabrics are ease of availability, economy (lower costs), high moisture absorbing capacity (moisture retention), and ease of installation.

The idea to use natural fibers as filter is not new and they have been used for filtration purpose for a couple of years. These fabrics are totally biodegradable within 1 to 2 years and they are highly absorbent up to five times of their own weights in water. The great ability in water retention is a very well known property. For example, while a natural fiber geotextile absorbs 1.5 kg/m^2 water, a synthetic mat can absorb only 0.3 kg/m^2 (Yilmaz, 2009).

Bitumen ‑ treated woven JGT has performed satisfactorily in controlling erosion of river and canal banks. Woven JGT can serve as a better and cost ‑ effective substitute of the conventional granular filter. Availability of granular aggregates often poses difficulty, apart from the difficulties encountered in exercising quality control. A layer of woven JGT treated with a suitable water ‑ repellant additive may replace the layers of granular aggregates. An armor layer over the fabric is however necessary to prevent the fabric displacement and its exposure to weather.

1.7 Background of The Research

The abundant availability of jute in Bangladesh renders jute fabrics cost effective for various applications such as river bank protection, drainage applications, erosion control etc. Ramaswamy and Aziz (1989), Mandal and Murti (1990), and Karunaratne et al. (1992) have studied to evaluate physical, mechanical and hydraulic properties of natural geotextiles.

Kabir et al. (1988a, 1988b) presented laboratory studies on repeated loading and filter behavior on some grades of jute fabrics, commonly known as jute geotextiles (JGT).

Five grades of jute fabrics were assessed by Kabir et al. to establish their filterability (Kabir et al., 1988a). Pore size and hydraulic conductibility data were produced for each of the grades. Filterability of each of those has been established by using Giroud‘s mechanical filter effectiveness criterion and hydraulic filter effectiveness criterion (Giroud, 1982).

Kabir et al. (1994) tested a number of grades of jute fabrics and fiber drains to establish some of their hydraulic and mechanical behavior. Test results of four grades of jute fabrics were presented enabling establishment of their hydraulic conductivity and filter behavior.

Mohy (2005) carried out a research work to study the feasibility of using JGT in civil engineering application. The Apparent Opening Size (AOS) of tested JGTs were adequate to retain fine to medium sand particles as defined by Unified Soil Classification System.

Debnath et al. (2006) studied the suitability of JGT in geotechnical application. Mechanical and hydraulic properties of woven and non-woven JGTs of various fabric area densities were investigated. Mechanical properties like tensile, extension, flexural and bending behavior were studied. To examine the hydraulic behavior, air permeability, sectional air permeability and water imbibation properties were investigated. It was evident from the investigations that the non-woven fabrics have good water holding capacity coupled with lower bending and flexural characteristics. On the other hand, woven fabric shows high tensile, bending and flexural property compared to non-woven fabrics. Finally they concluded that Woven JGT perform better in geo-technical applications like riverbank protection, cut-slope protection, road construction etc, where tenacity is predominant.

Sanyal and Choudhury (2002) performed a research on application of JGTs as filter and separator for protection of river-banks. The pioneering field trial was given on a portion of the western face of Nayachar island in the estuarine reach of the Hugli river opposite Haldia in 1990-91 under the aegis of Kolkata Port Trust with material support from IJIRA (Sanyal 1992, Sanyal & Chakravorty, 1993). The bank was threatened with severe erosion due to concentration of flow-filaments close to the bank. A stretch was tried with JGTs and the performance after a couple of years was also reported (Sanyal & Chakravarty, 1993). According to the report, the bank did not suffer erosion or subsidence after about one and half years though there was substantial degradation of the JGT (by about 70%).

Ramaswamy et al. (1992), Sivaramakrishnan (1993), Sivaramkrishnan (1994), Krishnan (1994), Datta et al. (1996), Chattopadhyay and Pal (1999), Datta (2007) and Islam et al. (2014) have also studied the effectiveness of JGT as filter on river bank slopes.

1.8 Objectives of The Research

The present study is designed to fulfill the following objectives:

a) To investigate whether or not filter cake forms effectively behind JGT through laboratory testing and field testing.
b) To observe the time required for the formation of filter cake.
c) To investigate the durability of the filter cake, i.e., whether or not it remains sustainable after the degradation of JGT.
d) To investigate whether or not JGT can be used as an alternative to synthetic geotextile as filter material.

1.9 Methodology

A brief description of the methodology to be followed in conducting the research is given below:

a) Laboratory investigations were conducted on the physical properties, i.e. mass per unit area, nominal thickness, the mechanical properties, i.e. wide-width strip tension test, CBR puncture test, the hydraulic properties, i.e. apparent opening size, permittivity of JGT samples.
b) Besides, laboratory studies were conducted to investigate the formation of filter cake. To do this, a system was arranged where gravel were kept under a JGT specimen and the soil structure of known gradation was kept over the JGT specimen. Water was flown through this system to continue the filtration process. Soil samples were collected from the system and

sieve analysis was performed. After that, it was observed that whether the filter cake were formed or not and if formed then how much time it took to form.

c) Furthermore, to investigate about the formation of filter cake, a site has been selected at Panchagar for field trials. Soil samples were collected through tube for necessary tests. Grain size analysis was performed to investigate about the formation of filter cake.

1.10 Organization of The Thesis

The research work conducted for achieving the stated objectives is presented in several chapters of this thesis so that the steps involved in the study may properly delineate the methodology. A brief discussion of the contents of each chapter is as follows:

Chapter Two contains theory of filtration with two main factors of filtration, i.e., permeability and soil retention. Permeability criterion and soil retention criterion are also discussed in that chapter. Besides this theory of formation of soil filter cake use of JGT filter is also presented there.

The laboratory investigation of properties of geotextiles is narrated in Chapter Three as per ASTM and DIN standard. Grain size analysis of soil is discussed in the chapter. Besides field trial and laboratory trial of filter cake formation is described in that chapter.

Chapter Four deals with results and discussions. The results of the tests performed are presented with graphs and charts. Properties of untreated and treated JGTs are compared. Besides this grain size analysis of soil samples have been performed.

Chapter Five includes the conclusions and recommendations on the basis of the present study and eventually recommendations for the future work are presented.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

The stability of a river bank depends on the type and composition of the filter layer. A filter should prevent excessive migration of soil particles while allowing relatively unimpeded flow of liquid from the soil. The function of the filter is:

a) to prevent migration of subsoil particles out of the bank slope (Retention Criteria) and
b) to allow at the same time movement of water through the filter (Permeability Criteria)

The filter may consist of one of the following types of material:

a) granular filter, made of loose, bounded or packed grains.
b) fibre filter, made of synthetic or natural materials.

JGT may be envisaged as a potential alternative to geotextiles in many civil engineering applications. A properly designed JGT is supposed to perform the following functions usually in conjunction, in different application areas related to civil engineering: Separation, Filtration and Drainage, Initial reinforcement, Control of surface soil-detachment, Vegetation or biotechnical support etc.

In this chapter theory about filtration is presented.

2.2 Conventional Granular Filter for River Bank Protection

Conventional granular filter design requires consideration of both the retention capability and the permeability of the granular filter.

The inverted filter shall be designed using the following criteria (BWDB, 2003),

a) The gradation of filter should conform to the following rule,

$$\frac{d_{15} filtermaterial}{d_{85} basematerial} \leq 5 \qquad (2.1)$$

$$\frac{d_{50} filtermaterial}{d_{50} basematerial} \prec p \qquad (2.2)$$

$$\frac{d_{15} filtermaterial}{d_{15} basematerial} \leq q \qquad (2.3)$$

Where p and q are factors of filter design. Their values are shown in Table 2.1.

Table 2.1 Factors of granular filter design (Bangladesh Water Development Board, 2003)

Filter type	p	q
For homogeneous and round grains	5-10	5-10
For homogeneous sharp grains (Sylhet sand)	10-30	6-20
For graded grains (sized khoa, stone chips)	12-60	12-40

b) The sieve curves of all layers should be almost parallel in the area of the smaller fractions.

c) Minimum layer thickness:

Sand - 0.10 m
Gravel - 0.20 m
Stone - 2 times stone diameter

2.3 Geotextile Filter

Geotextiles are widely used as filters, sometimes in applications where they are an alternative to aggregate filters, and sometimes in applications where an aggregate filter would be impractical. The geotextile function of filtration involves the movement of liquid through the geotextile itself (i.e., across its manufactured plane). At the same time, the geotextile serves the purpose of retaining the soil on its upstream side. These two requirements, i.e., good soil retention and high permeability, appear contradictory as soil retention would be most effective with only very small openings in the geotextiles, whereas the flow of water would be least restrained if the openings were very large. A third factor is also involved- the long-term soil-to-geotextile flow compatibility that will not excessively clog during the lifetime of the system. Thus a definition of filtration is as follows:

The equilibrium geotextile to soil system that allows for adequate liquid flow with limited soil loss across the plane of the geotextile over a service lifetime compatible with the application under consideration.

The function of filtration is a major one for the geotextile industry. Geotextiles, when properly designed and constructed, offer a practical remedy to many problems involving the flow of liquids.

Aggregate filters have traditionally been used to prevent fine particles from being washed out of the natural soil into adjacent zones of imported granular material. To achieve a filtering action, there must be two or more layers of aggregate with different gradings, present in the aggregate filter. The layer of most open filter aggregate is placed in contact with the large sized imported material, and the finest filter aggregate is placed in contact with the natural fine soil. This forces the water and any loosened soil particles to follow a tortuous path through the voids which progressively increase in size. These aggregate filters are considerably thicker than geotextile sheets, often by a factor of 500 to 1.

The environments in which geotextile filters have to perform can be subdivided into three categories, based upon the flow conditions. These are listed below in ascending order of severity:

a) Fairly steady unidirectional flow
b) Reversing flow with a moderate cycle time
c) Reversing flow with a very short cycle time

Examples of applications corresponding to these three flow conditions are respectively:

a) Land drainage filters
b) River and coastal defence filters

c) Anti-pumping filters beneath railway ballast.

The use of a geotextile filter can simplify construction of the erosion control measures, as illustrated in Figure 2.1, 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. The advantages of geotextile filters were quickly recognized and Barratt (1966) reports the use of geotextiles beneath both rip-rap protection and articulated concrete blocks, dating back to the late 1950s. Although the role of the geotextile in this application may appear very similar to that where it replaces a graded aggregate filter in a drainage application, there are significant differences. The presence of reversing flow at the banks of a waterway greatly hinders the development of a graded soil filter within the protected soil immediately behind the geotextile filter. As a consequence, the design rules for these erosion control filters differ from those for unidirectional flow conditions.

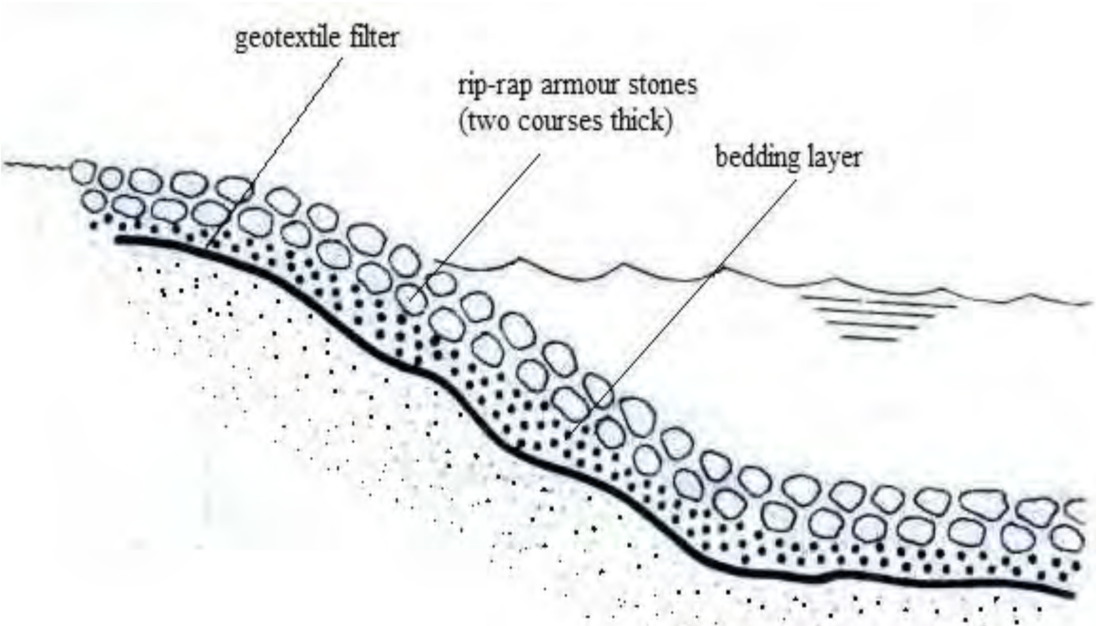


Figure 2.1 Geotextile filter replacing a multi-layer granular filter in a bank protection scheme (after John, 1987)

In addition to ensuring that the geotextile‘s filtration and permeability characteristics are compatible with the soil, the following factors may need to be considered:

a) Point loads from the riprap or armour stones.
b) Abrasion from minor wave-induced movement of the granular material.
c) Tensile forces imposed while handling large geotextile sheets in strong currents.
d) The bridging distance between the points where the geotextile is in contact with the overlying protection.
e) Geotextile extensions induced by settlement or uneven ground contours.

The use of fine granular material as a cushion layer beneath the outer protection helps to deal with some of the problems listed above, since it:

a) Protects the geotextile during placing of the armour.
b) Shields the geotextile against any minor wave-induced movements of the outer layer.
c) Prevents localized loss of contact between the geotextile and the underlying soil, when wave forces pull at the geotextile.

Coarse sand is often used for the cushion layer beneath interlocking concrete blocks. This situation is shown in Figure 2.2 where the sand tends to promote a more even flow pattern in the underlying soil,. If the sand layer is absent, then the flow pattern becomes more concentrated and closely related to the openings between the concrete blocks. In some cases, where the water forces are comparatively small, or where a thick rugged geotextile is used, then the cushion layer can be omitted from beneath gabion or articulated concrete mattresses. This is possible because these forms of erosion protection have a good uniform contact with the underlying geotextile.

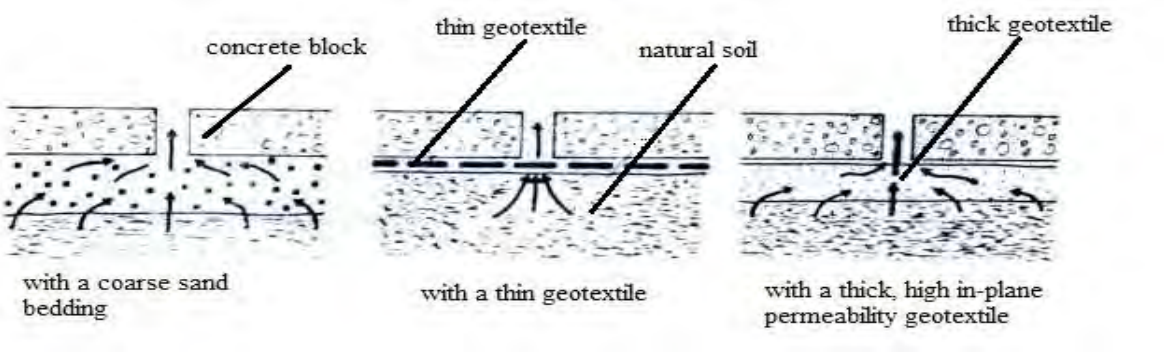


Figure 2.2 Effect of bedding material on flow patterns beneath concrete block revetments (after John, 1987)

2.4 Permeability of Geotextile Filter

One of the main factors in selecting an appropriate geotextile filter is its permeability. The discussion of geotextile permeability refers to cross-plane permeability when liquid flow is perpendicular to the plane of the fabric. The flow of water through soil is often assumed to be steady and laminar, thereby enabling Darcy‘s Law to be applied. This relates the rate of flow to the coefficient of soil permeability, the hydraulic gradient through the soil and the cross-sectional area through which flow takes place:

$$Q = k_s iA \tag{2.4}$$

where,

Q = rate of flow

k_s = coefficient of soil permeability

i = hydraulic gradient through the soil

A = the cross-sectional area through which flow takes place

The hydraulic gradient is the rate of loss of hydraulic head against length of the flow path,

hence,

$$i = \Delta H / \Delta L \tag{2.5}$$

where,
i = hydraulic gradient
ΔH = the rate of loss of hydraulic head
ΔL = length of the flow path

It is possible to define a coefficient of permeability for flow across the geotextile (k_g) in a similar manner and to measure it in specially adapted constant or falling head permeameters. The term ‗coefficient of normal permeability' is sometimes used in order to distinguish this coefficient of permeability from the coefficient of permeability in the plane of the geotextile. Since geotextile permeability means cross-plane permeability, the hydraulic gradient across the geotextile thickness is related to the head loss as follows:

$$i = {}^{\Delta H}\!\big/_{T_g} \qquad (2.6)$$

where,
i = hydraulic gradient
ΔH = the rate of loss of hydraulic head
T_g = geotextile thickness

This can cause two problems when determining a value for the geotextile's permeability coefficient. Firstly, it is difficult to determine an accurate and consistent value for the thickness of a thin geotextile, particularly if it is woven. Secondly, thick geotextiles are often compressible, causing the permeability to change with the level of applied stress. It is therefore more practical to express the permeability in terms of the quantity of water passing per unit area, per unit time, under a specified head loss. Alternatively geotextile's permittivity may be defined as,

$$\psi = \frac{k_g}{T_g} \qquad (2.7)$$

where,
ψ = geotextile's permittivity

k_g = geotextile's permeability

T_g = geotextile thickness

2.5 Permeability Criteria for Geotextile Filter (Unidirectional Flow Condition)

The permeability for geotextile filter should be sufficient to ensure that there is no unacceptable increase in hydrostatic pressure. Giroud (1982) points out that the thicknesses of geotextile filter is typically less than 1/100th that of a granular filter. The head loss across these two types of filter would therefore be of a similar magnitude if the permeability of the geotextile was 1/100th that of the alternative granular filter. Giroud (1982) suggests that, as the normal criterion for the coefficient of permeability of a granular filter is:

$$k_{gf} \geq 10k_s \tag{2.8}$$

where,

k_{gf} = coefficient of permeability of a granular filter

k_s = coefficient of soil permeability

Then, for a geotextile filter:

$$k_g \geq 0.1k_s \tag{2.9}$$

where

k_s = the coefficient of permeability of the soil

k_g = the coefficient of permeability of the geotextile.

Such a low value for the geotextile permeability however, does not allow for any long-term clogging or blocking of the geotextile. Tests conducted by Heerten (1982) on thick mechanically bonded non-woven geotextiles recovered after about 10 years of use, indicated that clogging of the geotextile while in use, reduced its coefficient of permeability to between about 60% and 5% of the original value. Most authorities therefore recommend that the coefficient of permeability of the geotextile should not be less than that of soil.

In the USA the permeability criteria laid down by AASHTO-AGC-ARTBA Task Force 25 for critical and severe applications (John, 1987)

$$k_g \geq 10k_s \tag{2.10}$$

where

k_s = the coefficient of permeability of the soil

k_g = the coefficient of permeability of the geotextile.

The criterion is compatible with that suggested by Steward et al. (1977) many years earlier, for all geotextile applications. Critical or severe applications are defined as those where:

a) Failure of the geotextile could lead to loss of life, or
b) Failure of the geotextile filter could result in significant structural damage, or
c) The cost of repairing the geotextile could exceed its installation cost, or
d) The hydraulic gradient is high, or
e) Reversing flow conditions are present, or
f) The soil is gap-graded.

For applications which are neither critical nor severe, Task Force 25 recommends (John, 1987):

$$k_g \geq k_s \tag{2.11}$$

where

k_s = the coefficient of permeability of the soil

k_g = the coefficient of permeability of the geotextile.

2.6 Permeability Criteria for Geotextile Filter (Reversing Flow Condition)

In West Germany, the Federal Institute for Waterways (BAW, Bundesanstalt fur Wasserbau) has adopted the following geotextile permeability criteria (Abromeit, 1984):

$k_g \geq 10k_s$ on sand (2.12)

$k_g \geq 100k_s$ on cohesive soil. (2.13)

The geotextile permeability criterion suggested by the Franzius-Institut, Hanover (FIH) (Heerten,1982) is

$$\lambda k_g \geq k_s \tag{2.14}$$

Where k_g = the coefficient of permeability of the geotextile.

k_s = the coefficient of permeability of the soil

λ is a reduction factor taking account of the loss of geotextile permeability after installation.

Values of λ determined by Heerten (1982) for woven and non-wovens are reproduced in Figure 2.3 and 2.4 respectively.

The set of geotextile permeability criteria specified by BAW is more stringent than the others quoted above, because the BAW criteria are intended for waterways revetments and take into account the possible restriction imposed on the flow of water by a covering of concrete blocks or rip-rap stones over the geotextile sheet. When alternative criteria are applied to geotextiles used beneath closely-fitting concrete blocks, then the desirable minimum permeability for the geotextile should be increased to take this flow reduction into account.

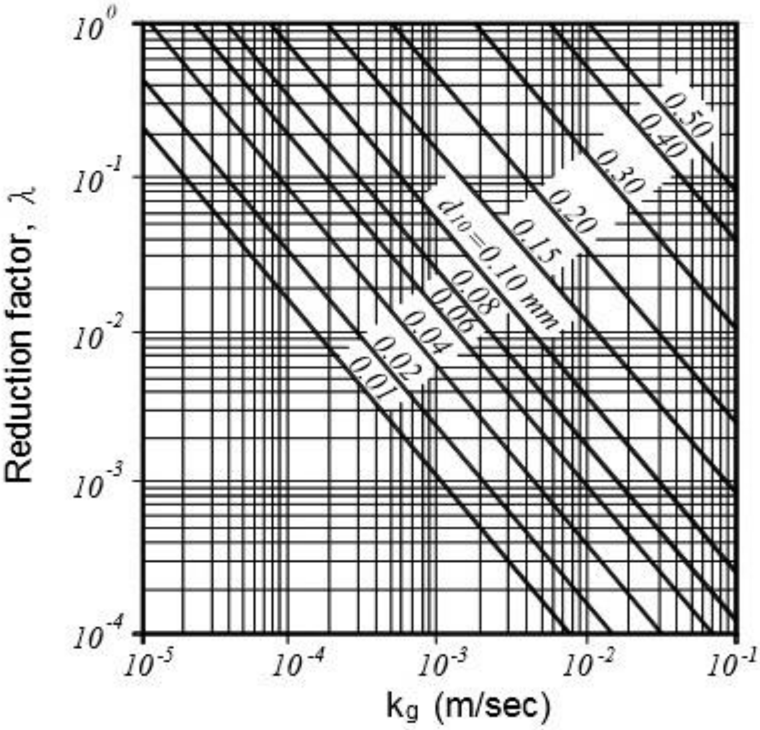


Figure 2.3 Heerten‘s reduction factor (λ) for woven geotextiles (after Heerten, 1981)

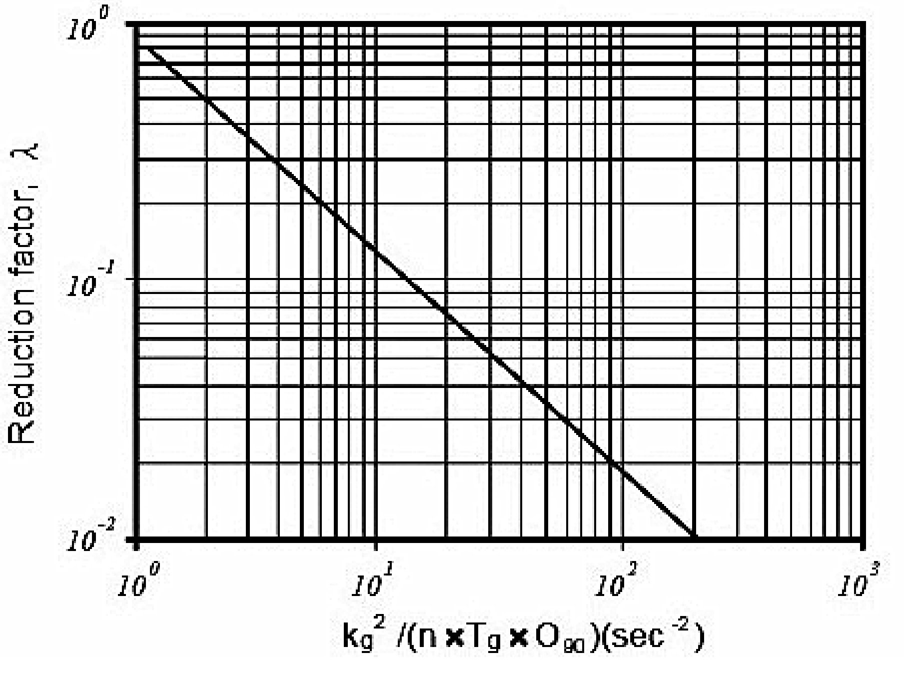


Figure 2.4 Heerten‘s reduction factor (λ) for non-woven geotextiles (after Heerten,1982)

If adequate geotextile permeability is not maintained, then a build-up of water pressure can occur beneath the geotextile. This may cause the geotextile to lose contact with the soil in the gaps between the contact points with the outer protective covering. Such a loss of contact can leave the underlying soil prone to movement beneath the geotextile, resulting in bulges and hollows in the revetment profile. In severe cases, the pressure build-up may be great enough to cause the uplift of both the geotextile and the outer protective covering.

2.7 Soil Retention of Geotextile Filter

Where the flow is unidirectional, the filter effect is not confined to the geotextile but spreads to the adjacent soil. There is inevitably some loss of fine soil particles through both aggregate based filters and geotextile based filters when they are subjected to water flow. In unidirectional flow conditions, the loss of fine material from the natural soil will be greatest immediately adjacent to the geotextile sheet, leaving a zone where the remaining larger soil particles bridge over the geotextile pores. These comparatively large soil particles will restrain slightly smaller soil particles which will in turn restrain even smaller soil particles. This causes the formation of a graded filter structure in the zone of soil in contact with the geotextile shown in Figure 2.5. The graded filter known as ―Filter Cake”. This pattern of soil particle arrangement is considered to be the most efficient system of graded filter. After the formation of this soil filter cake, geotextile filter becomes redundant, (JMDC, 2008). With woven geotextiles, the very uniform pore size is likely to produce arching of the soil particles in a regular pattern as illustrated in Figure 2.6.

Research by Elmer (1973), on aggregate filters over slots and screens, indicates that even fairly uniform sands can bridge a regular mesh opening of two to three times the average soil particle size(d_{50}). Subsequent tests on have confirmed this behavior, Walker (1978). A similar, but more random bridging network is established with thin non-wovens. Thick non-wovens contain a more complex, more tortuous pore structure which increases the risk of clogging, shown in Figure 2.7.

Even in reversing flow conditions, a less efficient graded filter may sometimes partially form within the adjacent natural soil provided the cycle time is not short. Different cases of partially formed filter cake are shown in Figures 2.8, 2.9, 2.10, 2.11 and 2.12.

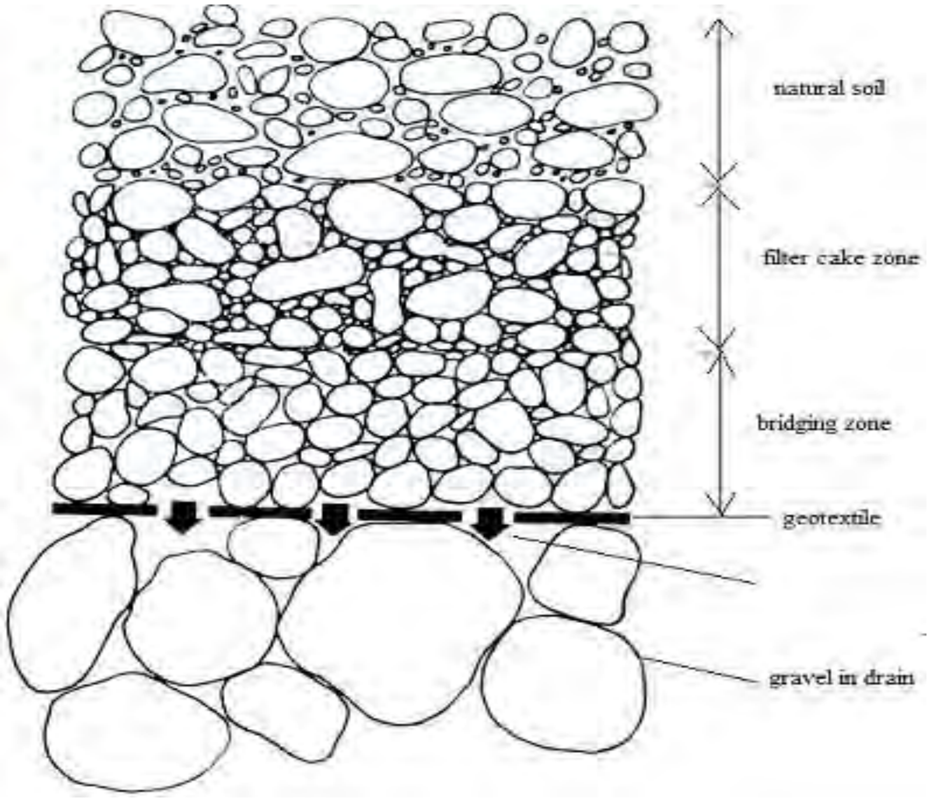


Figure 2.5 Graded filter developed within the soil adjacent to the geotextile (Case 1) (after John, 1987)

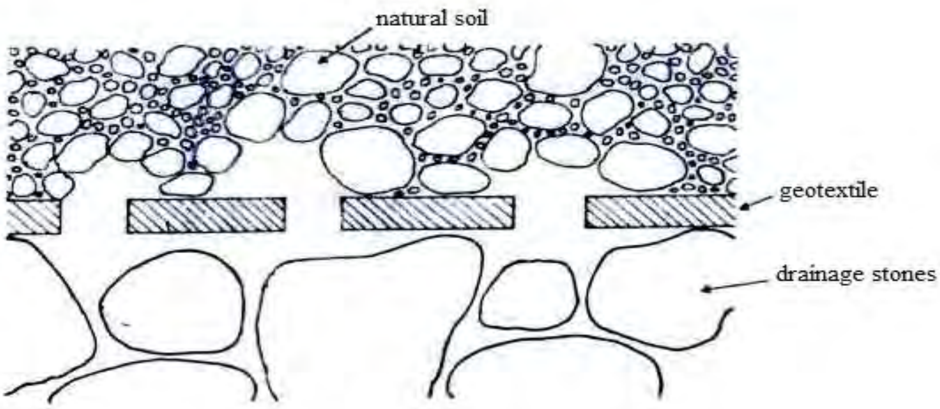


Figure 2.6 Soil arching over geotextile pores (after John, 1987)

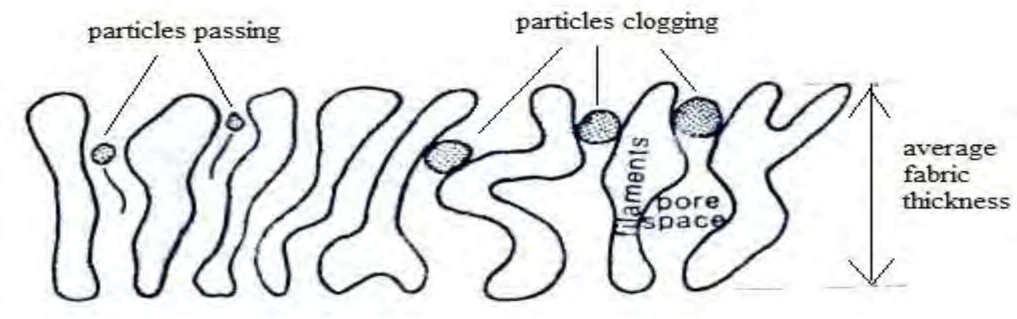


Figure 2.7 Clogging of thick mechanically-bonded geotextile (after John, 1987)

In case of Figure 2.8 large soil particles bridge over the geotextile pores, then fine particles are accumulated over large particles and the medium size particles are accumulated over fine particles.

In case of Figure 2.9 it is shown that medium size particles bridge over geotextile pores. Then fine soil particles are restrained by medium size particles and large particles are restrained by fine particles.

In Figure 2.10, it is shown that medium size particles bridge over geotextile. Then large particles are accumulated over medium size particles and fine particles are restrained by large particles.

From Figure 2.11 it can be shown that fine particles bridge over geotextile. Then medium size particles are restrained by fine particles and large particles are restrained by medium size particles.

In Figure 2.12 it can be seen that fine particles bridge over geotextile. Then large particles are restrained by fine particles and medium size particles are restrained by large particles.

Besides this, when biodegradable geotextile is used as filter, its parts are accumulated between the gaps of concrete blocks and brick chips after biodegradation, which forms a pervious structure and acts as a filter. This type of partial filter cake is shown in Figure 2.13.

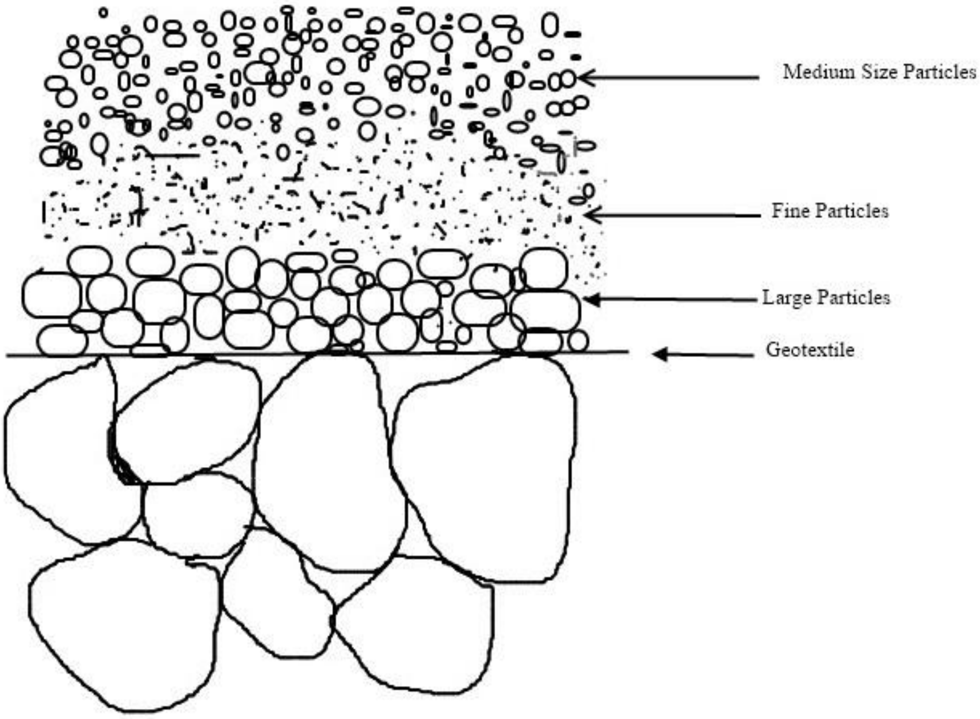


Figure 2.8 Partially formed soil filter (Case 2)

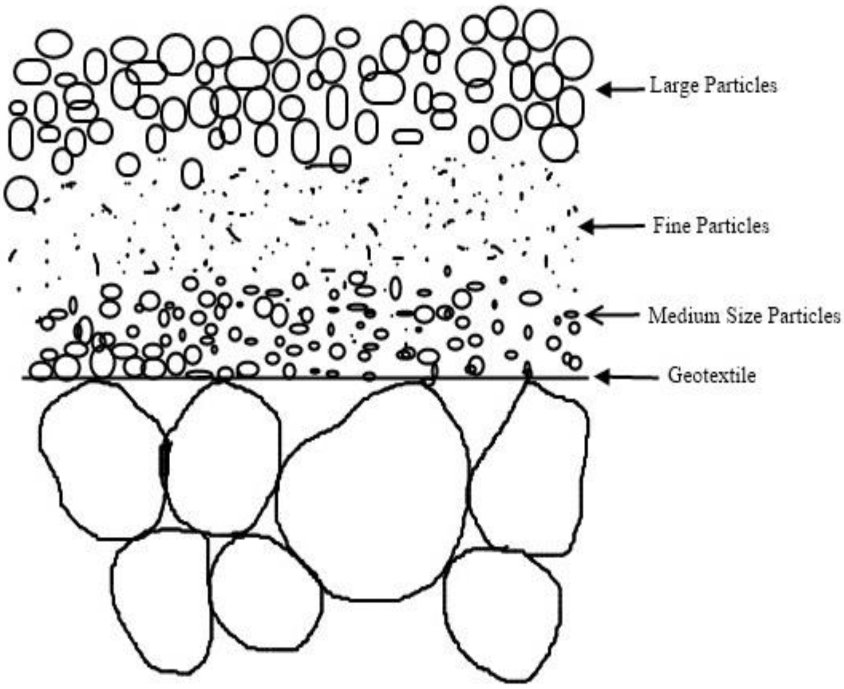


Figure 2.9 Partially formed soil filter (Case 3)

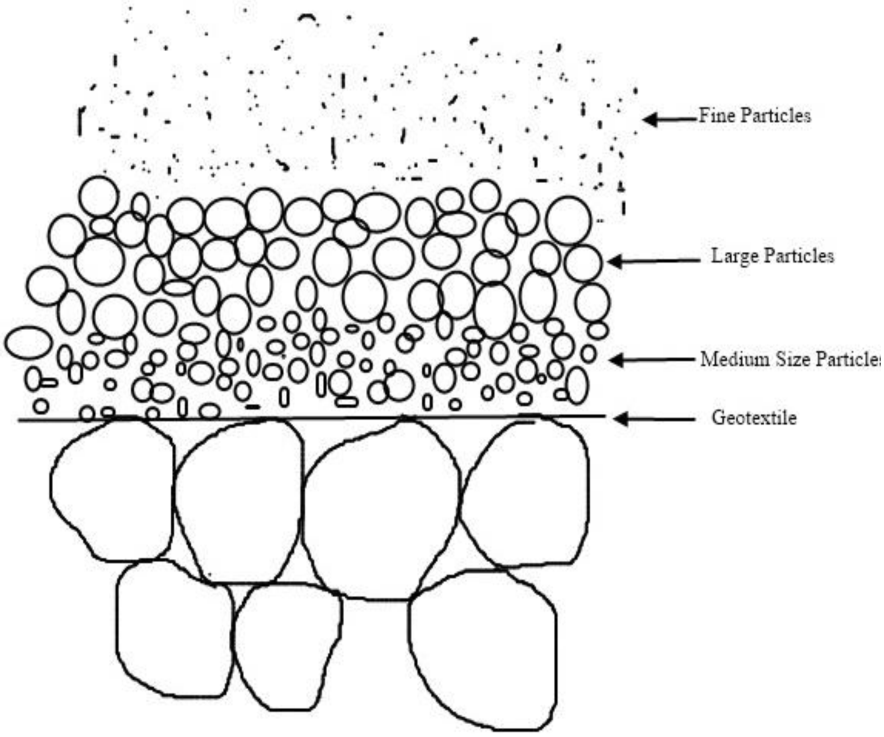


Figure 2.10 Partially formed soil filter (Case 4)

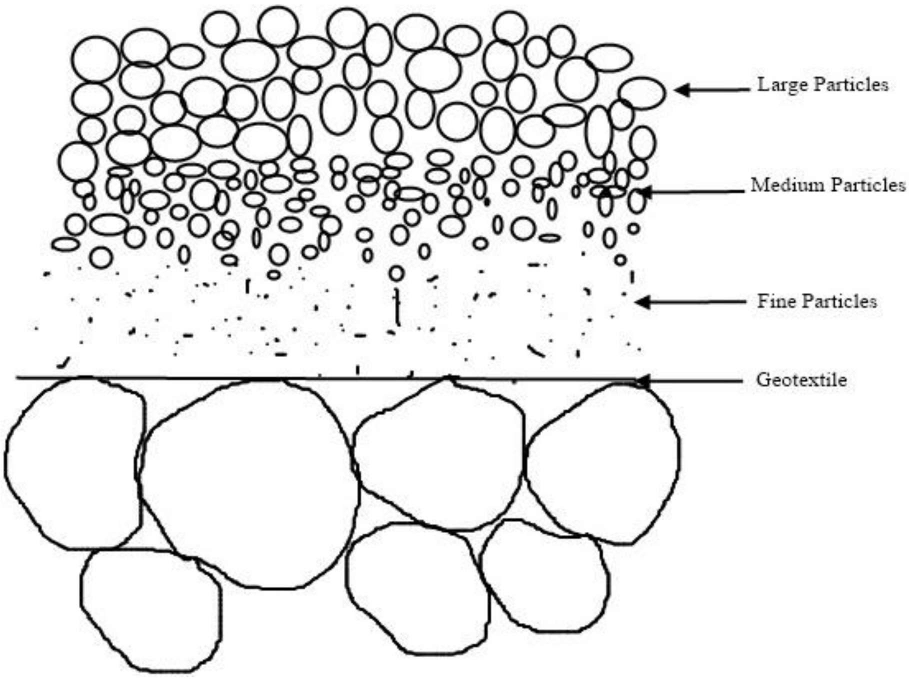


Figure 2.11 Partially formed soil filter (Case 5)

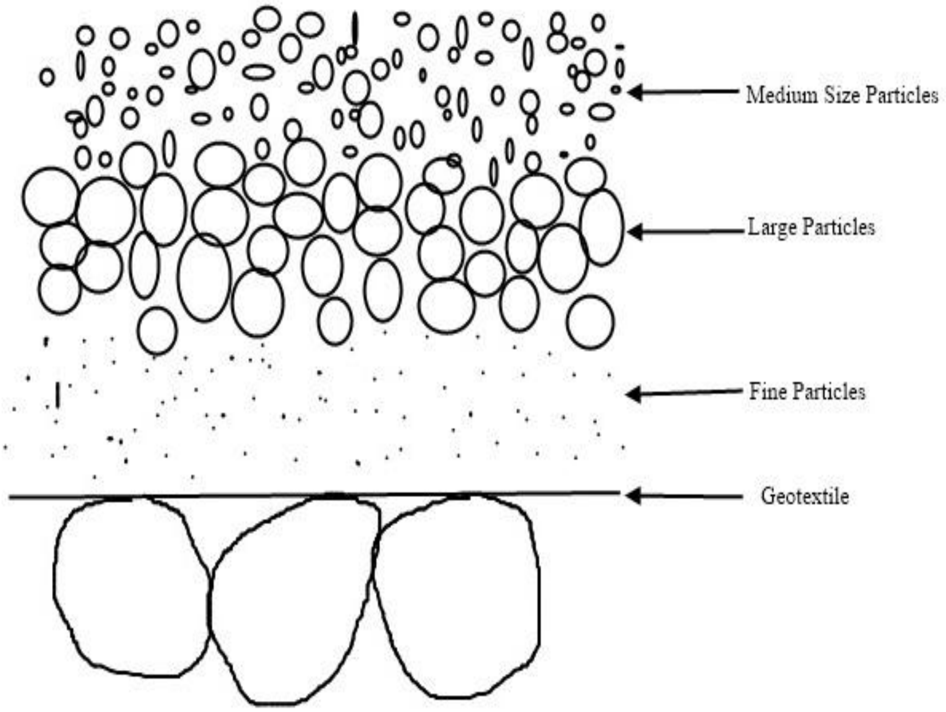


Figure 2.12 Partially formed soil filter (Case 6)

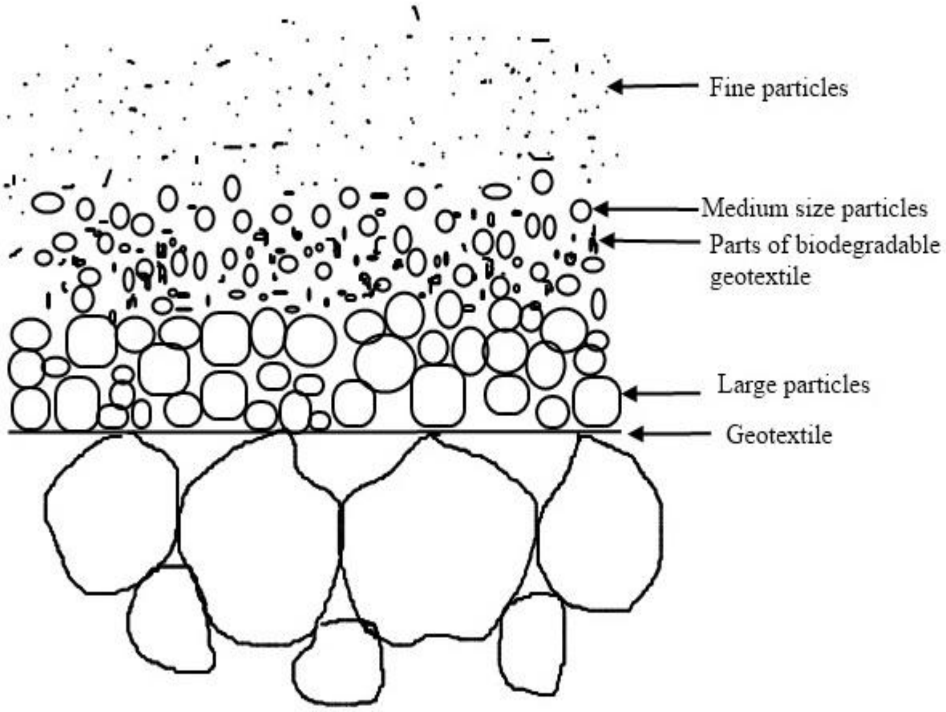


Figure 2.13 Partially formed soil filter when biodegradable geotextile is used (Case 7)

However, rapidly reversing flow conditions give little opportunity for a graded filter to form in the soil. In these conditions, it is often necessary to use imported granular filter material in conjunction with the geotextile filter. Intuition suggests that thin geotextiles should be most suited for unidirectional flow conditions, whereas thick geotextiles should be most suited for rapidly reversing flow conditions, Hoare (1984).

2.8 Soil Retention Criteria for Geotextile Filter (Unidirectional Flow Condition)

2.8.1 American Practice

The initial American geotextile filter criteria were developed by the US Army Corps of Engineers. These were originally intended for woven geotextiles in coastal applications with predominantly unidirectional flow, but were later extended to include non-woven geotextiles and other unidirectional flow cases. These criteria are given in Table 2.2.

Table 2.2 US Army Corps of Engineers geotextile filter criteria (after John, 1987)

Soil description	Geotextile Criteria
$d_{50} > 0.074mm$	$0.149mm \le O_{95} \le 0.211mm$
$d_{50} \le 0.074mm$	$0.149mm \le O_{95} \le d_{85}$
$d_{85} < 0.074mm$	Geotextiles should not be used

where, d_{50}= the sieve size through which 50% of the soil will pass

d_{85}= the sieve size through which 85% of the soil will pass

O_{95}= 95% opening size and corresponds to the size where 95% of the geotextile‘s openings are the same size or smaller.

The initial US Army Corps of Engineers criteria have been updated and amended by the US Forest Service and the Transportation agencies. These criteria are summarized in Table 2.3.

Table 2.3 American geotextile filter criteria (after John, 1987)

Soil description	Geotextile criteria
$d_{50} > 0.074mm$	$0.297mm \le O_{95} \le d_{85}$ (wovens)
	$0.297mm \le O_{95} \le 1.8d_{85}$ (non-wovens)
$d_{50} \le 0.074mm, \quad U \le 2$	$O_{95} \le d_{85}$
$2 \le U \le 4$	$O_{95} \le 0.5Ud_{85}$
$4 \le U \le 8$	$O_{95} \le 8d_{85}U$
$U \le 8$	$O_{95} \le d_{85}$

where U is the uniformity coefficient of soil.

It is generally recommended that for soils with a d_{50} value of less than 0.074 mm, the largest available opening size which conforms with the above criteria should be adopted. Where the soil contains particles over the full range from less than 0.074 mm to greater than 25 mm, then the particle size distribution analysis for the geotextile selection criteria should be based only on the soil finer than 4.75 mm.

2.8.2 Dutch Practice

Initially the Dutch approach to selecting the appropriate geotextile pore size was based on studies conducted at the Delft Hydraulics Laboratory and reported by Ogink (1975). Under static, unidirectional flow conditions, where a natural soil filter will be induced, the following criteria were found to be suitable:

$O_{90} < d_{90}$ for woven geotextiles (2.15)

$O_{90} < d_{90}$ for non-woven geotextiles (2.16)

where,

O_{90} = geotextile opening size corresponding to 90% particle size based on dry glass bead sieving.

d_{90} = the sieve size through which 90% of the soil will pass.

Subsequently tests by K and O (Nederlandse Vereniging Kust-en Oeverwerken, the Dutch Coastal Works Association) indicated that these criteria could safely be relaxed to simply:

$$O_{90} < 2d_{90} \tag{2.17}$$

This soil-tightness criterion has now been adopted by the Rijkswaterstaat, the Dutch Ministry of Transport and Public Works. It is purely empirical and based only on Dutch tests. The value of O_{90} employed with this expression should therefore ideally have been determined using the Delft method. In view of the different results obtained with the different national tests used to measure geotextile pore sizes, caution should be exercised if an alternative method of determining O_{90} has been used.

2.8.3 German Practice

Until recently, the German ―soil-tightness" criteria for geotextile filters were based on work initially carried out at the Franzius-Institut, Hanover University. These recommendations for steady unidirectional flow conditions have been reported by Heerten (1982) to be as shown in Table 2.4.

It should be noted that although Heerten‗s original paper refers to O_{90}, this was merely to conform with the notation adopted at the particular conference. The criteria were in fact based on the wet sieving test method of the Franzius-Institut and should have been denoted in terms of D_w as above.

Table 2.4 German geotextile filter criteria used prior to 1986 (after John, 1987)

Soil description	Geotextile Criteria
$d_{50} < 0.06mm$	$D_w \le 10d_{50}$
	$D_w \le d_{90}$ and $D_w \le 100\mu m$
$d_{50} > 0.06mm, U < 5$	$D_w \le 2.5d_{50}$ and $D_w \le d_{90}$
$d_{50} > 0.06mm$, $U \ge 5$	$D_w \le 10d_{50}$ and $D_w \le d_{90}$

The recommendations detailed above have recently been revised by Working Group 14 of the German Society for Soil Mechanics and Foundation Engineering. These new filter criteria differentiate between problem soils and stable soils. The problem soils are defined as those falling in any of the following three categories:

a) Fine-grained soils with a plasticity index less than 15%
b) Soils whose average particle size (d_{50}) lies between 0.02- 0.1 mm
c) Soils with a uniformity coefficient of less than 15 which also contain clay or silt-sized particles.

For filtration purposes the stable soils are defined as those outside the three categories listed above. The Working Group‘s geotextile –soil-tightness” criteria for unidirectional flow conditions are given in Table 2.5.

These criteria should only be used with the relevant geotextile test data, i.e. the Franzius-Institut wet sieving test. It should be noted that as the Swiss standard test SN 640550 is now identical to the Franzius-Institut test, the Swiss test data is equally appropriate.

Table 2.5 German working Group 14geotextile filter criteria (after John, 1987)

Soil description	Geotextile Criteria
$d_{40} < 0.06mm$, stable soil	$D_w < 10d_{50}$ and $D_w < 2d_{90}$
$d_{40} < 0.06mm$, problem soil	$D_w < 10d_{50}$ and $D_w < d_{90}$
$d_{40} > 0.06mm$, stable soil	$D_w < 5d_{10}U^{\frac{1}{2}}$ and $D_w < 2d_{90}$
$d_{40} > 0.06mm$, problem soil	$D_w < 5d_{10}U^{\frac{1}{2}}$ and $D_w < d_{90}$

where d_{40} = the sieve size through which 40% of the soil will pass

d_{10} = the sieve size through which 10% of the soil will pass

2.8.4 French Practice

The geotextile ‗soil-tightness' criteria most widely used in France are those developed by the Comite Francais des Geotextiles et des Geomembranes (CFGG). These take into account the soil's density, its coefficient of uniformity and the hydraulic loading. These criteria are summarized in Table 2.6.

Table 2.6 CFGG ‗soil-tightness' criteria for hydraulic gradients of less than 5 (after John, 1987)

Soil description	Geotextile Criteria
Well graded (U>4) and dense	$4d_{15} \leq O_f \leq 1.25d_{85}$
Well graded (U>4) and loose	$4d_{15} \leq O_f \leq d_{85}$
Uniformly graded ($U \leq 4$) and dense	$O_f \leq d_{85}$
Uniformly graded ($U \leq 4$) and loose	$O_f \leq 0.8d_{85}$

where O_f = geotextile's characteristic pore size as measured by the French AFNOR 38017 test

d_{15} = the sieve size through which 15% of the soil will pass

When the hydraulic gradient (i) in the vicinity of the geotextile lies between 5 and 20, then the geotextile pore sizes specified above should be reduced by 20%. Similarly, if hydraulic gradient exceeds 20 or reversing flow conditions are present, then the pore size should be reduced by 40%.

Although this test is an accepted measure of the geotextile's O_{95} value and O_f should equal O_{95} in theory, there is considerable difference between the results from the different standard tests. Caution should therefore be exercised if another form of O_{95} value is substituted for O_f in the above criteria.

2.9 Soil Retention Criteria for Geotextile Filter (Reversing Flow Condition)

2.9.1 German Practice

In Germany before 1986, the ‗soil-tightness' criteria applied to reversing flow cases were generally those developed by the Franzius-Institut, Hanover. These criteria are summarized in Table 2.7.

Table 2.7 German geotextile filter criteria for reversing flow conditions before 1986 (after John, 1987)

Soil description	Geotextile Criteria
Cohesionless	$D_w < d_{50}$
Cohesive	$D_w < 10d_{50}$ $D_w \le d_{90}$ $D_w \le 0.1mm$

Working Group 14 of the West German Society for Soil Mechanics and Foundation Engineering has updated these criteria. These criteria are summarized in Table 2.8.

Table 2.8 German Working Group 14 geotextile filter criteria for reversing flow condition (after John, 1987)

Soil description	Geotextile Criteria
$d_{40} > 0.06mm$	$D_w < d_{90}$
$d_{40} \le 0.06mm$	$D_w < 1.5d_{10}\sqrt{U}$ and $D_w < d_{50}$ $D_w \le 0.5mm$

2.9.2 Austrian Practice

In Austria, separate ‗soil-tightness' criteria have been developed for mechanically bonded non-woven geotextiles, as these are considered most appropriate for waterway erosion control applications. These criteria are summarized in Table 2.9.

Table 2.9 Austrian ‗soil-tightness' criteria for mechanically bonded non-wovens in reversing flow conditions (after John, 1987)

Soil description	Geotextile Criteria
Cohesionless	$D_w \le d_{80}$
U>5 and $d_{80} < 0.06mm$	$D_w \le 0.1mm$ $T_g \ge 2mm$

where T_g is the thickness of the geotextile under a pressure of 2 kN/ m^2

and d_{80} = the sieve size through which 80% of the soil will pass

These criteria are generally less stringent than those of the Franzius-Institut, Hanover, and more stringent than those of the German Working Group 14.

2.9.3 American Practice

For reversing flow conditions, ‗soil-tightness' criteria of the US Army Corps of Engineers, the US Forest Service and the Transportation agencies are summarized in Table 2.10.

Table 2.10 American geotextile filter criteria for reversing flow conditions (after John, 1987)

Soil description	Geotextile Criteria
$d_{50} > 0.074mm$	$O_{50} \leq 0.5d_{85}$
$d_{50} \leq 0.074mm$	$O_{95} \leq d_{15}$, or $O_{50} \leq 0.5d_{85}$

2.9.4 French Practice

The geotextile filter criteria advocated by the Comite Francais des Geotextiles et des Geomembranes (CFGG) for reversing flow conditions are given in Table 2.11.

Table 2.11 CFGG ‗soil-tightness' criteria for reversing flow conditions (after John, 1987)

Soil description	Geotextile Criteria
Well graded (U>4) and dense	$O_f \leq 0.75d_{85}$
Well graded (U>4) and loose	$O_f \leq 0.6d_{85}$
Uniformly graded ($U \leq 4$) and dense	$O_f \leq 0.6d_{85}$
Uniformly graded ($U \leq 4$) and loose	$O_f \leq 0.48d_{85}$

2.9.5 Dutch Practice

In Holland, the ‗soil-tightness' criteria for reversing flow conditions advocated by the Dutch Coastal Works Association are given in Table 2.12.

Table 2.12 Dutch Coastal Works Association‘s ‗soil-tightness‘ criteria for reversing flow conditions (after John, 1987)

Soil description	Geotextile Criteria
With a granular filter layer	$O_{98} \leq 2d_{85}$
Without granular filter: a) Non-critical application b) Critical application	 $O_{98} \leq 1.5d_{15}$ $O_{98} \leq 1.0d_{15}$

2.10 Long-Term Flow Compatibility

Perhaps the most asked question regarding the use of geotextiles in hydraulic related systems is, whether it will clog or not. Obviously, some soil particles will embed themselves on or within the geotextile structure and an understandable reduction in permeability or permittivity will occur. This type of partial clogging can and should be expected. But the questions really if the geotextile will excessively clog, such that the flow of liquid through it will be decreased to the point where the system will not adequately perform its function. There are guidelines available for noncritical, nonsevere cases, but the question can be answered directly by taking a soil sample and the candidate geotextile and testing them in the laboratory. Either the gradient ratio (GR) test to see that the $GR \leq 3.0$; the long-term flow (LTF) test to see that the terminal slope of the flow rate versus time curve is adequate for site specific conditions; or the hydraulic conductivity ratio (HCR) test with resulting HCR values between 0.7 and 0.3 should be performed.

A different approach to the answer of the clogging question is simply to avoid situations that have been known to lead to excessive clogging problems. It has been shown that the following conditions give rise to concerns about geotextile filter applications:

a) Cohesionless soils consisting of gap-graded particle size distributions and functioning under high hydraulic gradients.

b) High alkalinity groundwater where the slowing of the liquid as it flows through the geotextile can cause a calcium, sodium, or magnesium precipitate to be deposited.
c) High suspended solids in the permeating liquid (as in turbid river water) which can build up on or within the geotextile.
d) High suspended solids coupled with high microorganism content, as in landfill leachates, which can combined to build up on or within the geotextile.

For these entire cases one could use a relatively open geotextile and allow for fine particles, sediments or microorganisms to pass through into the downstream drain. In such cases one would generally consider

a) Woven geotextiles with open area ≥ 8%, or
b) Nonwoven geotextiles with porosity ≥ 50%

2.11 Jute Geotextile as Filter

Jute Geotextile (JGT) is a natural Technical Textile. The prefix ―geo” indicates soil and ―textiles” are fabrics laid in or upon soil. According to the latest convention, the term ‗geosynthetics‘ is globally accepted and includes not only man-made geotextiles, but also natural geotextiles such as Jute Geotextiles (JGT). Natural fibres of jute can be processed as fine yarns which, in turn, can either be woven into permeable and drapable fabrics by appropriate weaving machineries (woven fabric) or can be matted together in a random manner (non-woven fabric).

Jute fibres are natural fibres comprising approximately 83% to 87% natural cellulose and 12 to 14% Lignin. The fabric made of jute yarns biodegrades, leaving a fibrous residue which improves the soil-structure. The other important feature of jute is that it does not draw upon the valuable nitrogenous reserves and ultimately decomposes as is usually the case with other natural fibres. Jute Geotextile acts like a straw or peat mulch aided by its degrading fibres which help retain the moisture and improve the soil-permeability. JGT possesses better drapability and also wettability, compared to all other geotextiles.

JGT, like the man-made variety, helps improve, as a change agent, the geotechnical properties of the soil on which it is applied. JGT, being permeable, allows the water retained within soil to permeate across itsplane and also to disperse water along its plane. The extent of cross permeability(termed ―permittivity” when the thickness of the fabric is considered) depends on several factors, especially pore size of JGT (termed ―porometry”). The porometry of JGT is also the determinant in retention of soil-particles on which it is laid. A properly designed JGT (in most cases, in relation to the mean diameter of the soil grains i.e., d_{50}) arrests migration of the major portion of soil-particles and imparts strength to the soil-body by ensuring their retention within it.

It is therefore evident that JGT, as filter, is required to perform basically two contrasting functions – soil-retention on one hand and permeability on the other. Empirical relations recommended in Manuals of different countries for design of man-made Geotextiles for a specific application are not identical. JGT provides a technically superior solution to conventional granular graded filters used for control of erosion of river banks. JGT can be manufactured with pore sizes commensurate with the median grain size of the base-soil to ensure their retention. At the same time, water is allowed to pass across and along JGT in the required measure without causing development of any differential overpressure. The functions of permittivity is therefore important. With a tailor-made JGT, differential water overpressures across it can be effectively dissipated preventing migration of soil-particles concurrently.

JGT, like its man-made counterpart, first retains the coarser particles of the soil. These coarse particles block smaller ones in the soil which in turn prevents migration of even smaller grains. This phenomenon which is known as ‗filter cake formation‘ is in fact an indication of formation of natural filter within the soil and its optimum consolidation. The situation can develop only if it is ensured that JGT has made full contact with the base soil (i.e. if drapability of the JGT is ensured). For ensuring full drapability, JGT requires to be suitably ballasted.

This load on top of JGT not only prevents its uplift under certain conditions, but also protects the fabric from continuous exposure to weather. The situation discussed above is shown in Figure 2.14.

Soil properly overlain by JGT is seen to develop ‗filter cake' usually within a period of 6/7 months from the date of application according to laboratory tests carried out in Research Institutes. Development of ‗filter cake' is a sure indication of the base-soil having attained natural stability. Once the soil attains natural stability, function of any separating fabric – be it manmade or natural, becomes redundant. Though laboratory experiments by some researchers have shown formation of ‗filter cake' within about 6/7 months from the date of application of JGT, it is advisable to ensure durability of JGT for at least one season-cycle. Biodegradation of a JGT therefore does not normally pose any deficiency in its expected performance as such.

Sarma and Som (2006) studied on formation of soil filter cake. They performed a quantitative analysis of the flow behavior of geojute-soil matrix though model studies. The behavior was described in three time-dependent stages, influenced by constituents, compaction, structure of the soil and the geojute.

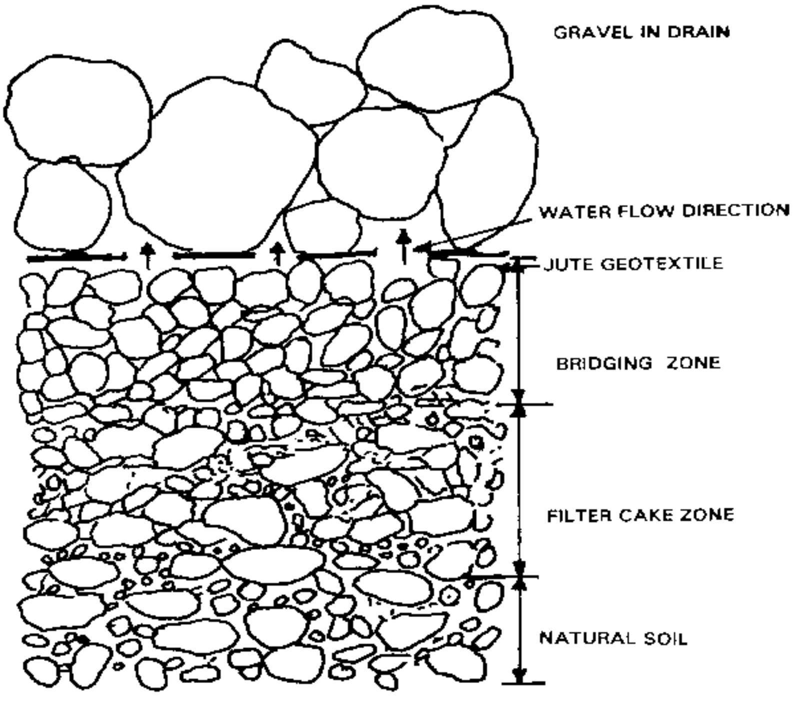


Figure 2.14 Filter cake formation in soil with JGT (after JMDC, 2008)

Effective design of these factors ensures development of 'filter cake' within a reasonable period. They also studied the changes in the process of 'filter cake' formation including biodegradation of geojute with practical implications.

Development of 'filter cake' is an indication of the base-soil attaining natural stability. Once the soil attains natural stability, functions of any separating fabric whether synthetic or natural, become redundant. Laboratory experiments by some researchers have shown formation of 'filter cake' within about 3 to 4 months from the date of application of geojute (Sanyal 2001), although biodegradation of the geojute normally does not pose any deficiency in its expected performance as such. Therefore, a proper understanding of the flow through a geojute-soil matrix, consequent formation of filter cake, clogging, durability, porometry and drapability of geojute are very important to analyze qualitative as well as quantitative behavior. In this experimental study emphasis was given to quantify the flow behavior of geojute-soil matrix varying the consistency of the soil, compaction characteristics and the states of geojute in terms of degradation.

In order to carry out long-term permeability study of geojute-soil system a permeameter as shown in the Figure 2.15, which is being widely used in the research laboratories was adopted. A continuous flow of water through the geojute-soil system was arranged with the help of a water tank-pipe system by maintaining a constant head of 1 m. In this experimental work the variation of the flow through the geojute-soil system was studied with respect to the time by varying percentage constituents of the soil, types of geojutes, compaction density of the soil etc. Detailed investigation by dissecting the compacted soil model after formation of the 'filter cake' was not done as it was already established that 'filter cake' formation is characterized by stable flow rate.

At the interface of the bottom most water-collecting chamber of the mould and the middle soil-retaining chamber a thin iron grating was placed. Above the iron grating a layer of stone chips was placed which simulate the granular load (gravels/boulders) applied onto the geotextile in the field.

Figure 2.15 Permeameter for geojute-soil system (after Sarma 2005)

The average thickness of this stone layer was kept at 10 mm and above this stone layer a circular piece of wet geojute was placed to maintain the drapability of the geojute to remain in proper contact with the River Soil as well as to the granular layer. Above the geojute layer the River Soil, which constitutes 80% fines and 20% coarse particles was compacted at varying Proctor Maximum Dry Densities. After that the topmost long cylindrical mould was placed at the top and the water column was maintained continuously to saturate the geojute-soil system until the water flows through the outlet at the bottom.

Once water started flowing through the outlet the set-up was connected to the tank and pipe system to maintain a constant water head of 1 meter for the rest of the test. Geojute specimens were prepared from the fresh four supplied varieties (Raw and Rot Proof — Canvas and Twill) and some degraded ones extracted from a separate durability test set-up were used in this experiment to study the effect of raw and degraded geojutein the permeability of the geojute-soil system. The River Soil of Proctor Maximum Dry Density (MDD) of 15.23 kg/m^3 at Optimum Moisture Content (OMC) of 15.35%wascompacted at varying densities like 90%, 93%, 95%, and 98% of Proctor MDD for different test set-ups to check for the effect of the compaction density onto the permeability. The fines (<75 micron) content of the River Soil was also varied by adding coarse sand to achieve 40%, 60% and 80% fines content to study the influence of fines content onto the long-term permeability of the geojute-soil system. The discharge of flow through the geojute-soil system was measured in different interval of days. The measurement was commenced from the first day of the discharge through the outlet until a stable flow condition was reached.

The discharges from various test set-ups in ml/hr are plotted in the ordinate with respect to no. of days in the abscissa. The plots are shown in the Figures 2.16 to 2.25.

Figure 2.16 shows the change of discharge with days for a Raw Canvas geojute used in the natural River Soil having 80% fines and 20% coarse compacted at 93% of Proctor MDD designated as NOJI-Raw-93. The initial period up to 16 days shows a sharp decrease in discharge due to the immediate compression of the soil matrix under the influence of flow of water due to the loosely compacted silt at 93% Proctor MDD which tried to achieve a more stable condition by collapsing its loose structure under flow of water. This period may be termed as Initial Orientation Stage where soil particles orient among themselves under this initial compression. The duration of this period depends upon the particle size distribution as well as the degree of compaction. In this stage both coarse and fine particles try to orient if degree of compaction is very low. In Figure 2.16, from 16 days to 65 days the discharge was found to be turbulent due to the facts that in this stage the relative movement of fines took place through the coarse particles as well as compression of the geojute occurred due to such movements and some fines moved across the geojute reducing the concentration of fines in the soil thus increased the permeability of the system. This stage can be termed as Transition Stage. Once this stage was overcome the system tends to achieve a stable condition. A Final Stage was occurred after 65 days and remained stable.

Figure 2.17 shows the change of discharge with days for a degraded Raw Canvas geojute kept 3 months in Natural Clay used with the normal River Soil (80% fines) compacted at 93% Proctor MDD designated as NGJI-3 m-Clay-93. The discharge in this case was found to be in a much higher range than in Figure 2.16 due to the increased porometry of the geojute due to degradation.

Here also the Initial Stage was up to 16 days though the rate of initial compression is lesser than in Figure 2.16. The Transition Stage is 16-60 days and system became stable after 60 days. The rate of turbulence is also lesser in this case than the previous one due to the fact that the robust fibres of geojute also disturb the flow depending upon its structure and quality of fibres. In case of Figure 2.17 the disturbance to the flow by the robust fibres of geojute is less due to some degree of degradation of geojute kept in the Natural Clay for 3 months.

Figure 2.18 depicts the variation of discharge with days for a Raw Canvas geojute placed with the normal River Soil compacted at 95% Proctor MEM designated as NGJI-Raw-95. Here Initial Stage is 24 days after which the Transition Stage continues until 52 days followed by the Final Stage. In this case the range of discharge is less than in Figure 2.17 and Figure 2.16 due to the more degree of compaction of the fines compacted at 95% Proctor MDD, which is higher than 93% Proctor MDD. Here Transition Stage duration is also lesser due to the lesser degree of freedom to the fines and hence the Final Stage is reached earlier than in Figure 2.17 and Figure 2.16.

Figure 2.19 shows a case of use of the Raw Twill geojute placed in the normal River Soil compacted at 93% Proctor MDD designated as NGJII-Raw-93. Here the range of discharges is quite on a higher side. The Initial Stage is normal showing quite significant decrease of discharge due to higher initial compression resulting from lesser degree of compaction (93% Proctor MDD), which is up to 14 days.

The Transition Stage is quite longer due to the lesser degree of compaction as well as the disturbance of the jute fibres to the flow. The Final Stage is achieved after 61 days.

Figure 2.20 depicts the effect on permeability of a Raw Twill geojute placed with normal River Soil compacted at 98% Proctor MDD designated as NGJII-Raw-98. It is obvious from the figure that the discharge is significantly in lower range due to higher compaction density (98% Proctor). The Initial Stage is up to 14 days but rate of compression is very low, much lower than in Figure 2.19. The duration of the Transition Stage is shorter than in Figure 2.19 due to less degree of freedom for movement of the fines through the coarse particles because of higher compaction. The Final Stage is also reached after 40 days much earlier than any other systems.

Figure 2.21 shows a very normal situation of reduction of discharge resulting from significant degree of freedom offered by the loosely compacted matrix (90% Proctor MDD) of normal River Soil and 6 months old Rot Proof Will variety degraded in Natural Clay designated as RPGJII-6 m-Clay-90.

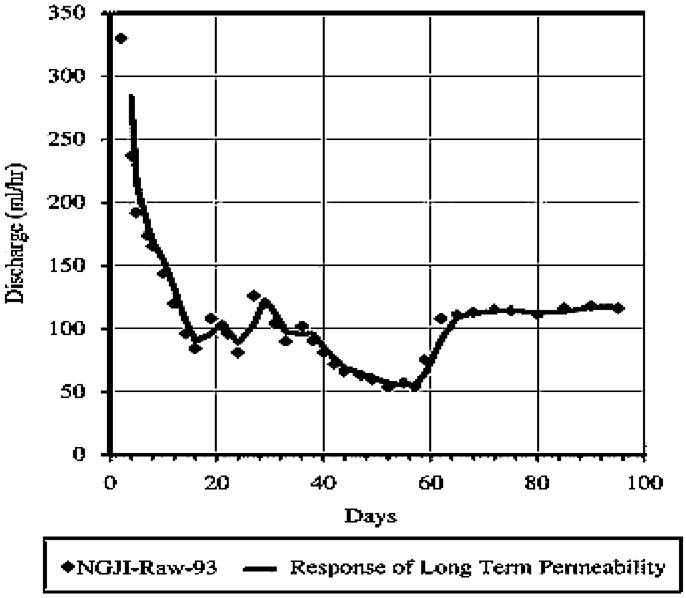


Figure 2.16 Discharge vs Days for Raw canvas geojute with River soil at 93% Proctor MDD (after Sarma 2005)

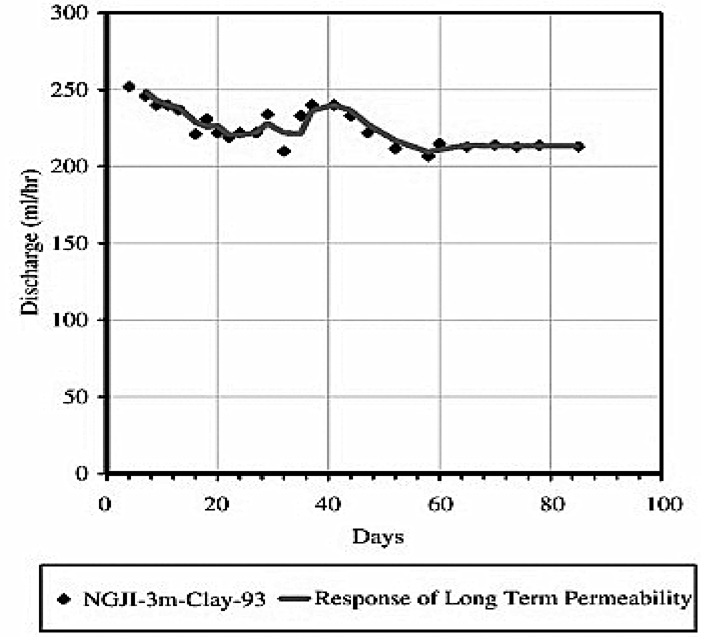


Figure 2.17 Discharge vs Days for 3 months in Natural Clay degraded Raw canvas geojute with River soil at 93% Proctor MDD (after Sarma 2005)

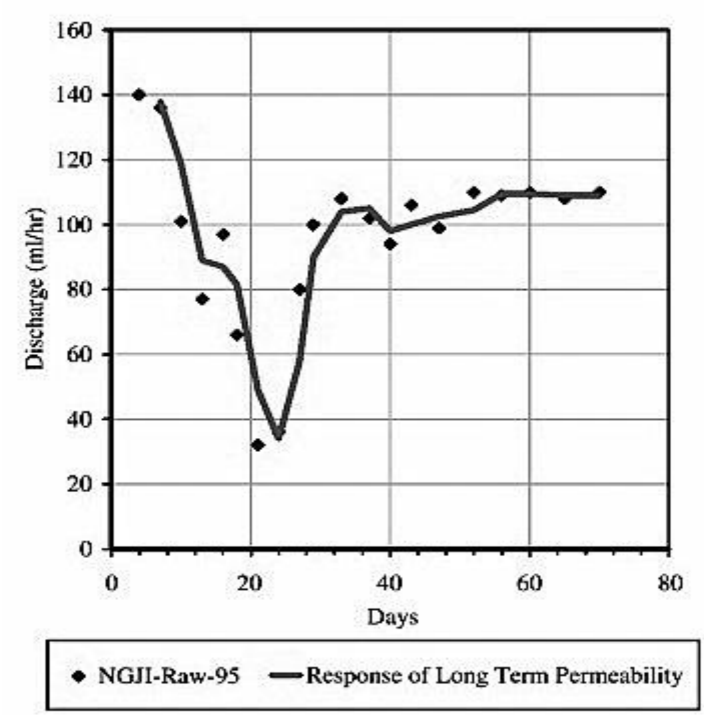


Figure 2.18 Discharge vs Days for Raw canvas geojute with River soil at 95% Proctor MDD (after Sarma 2005)

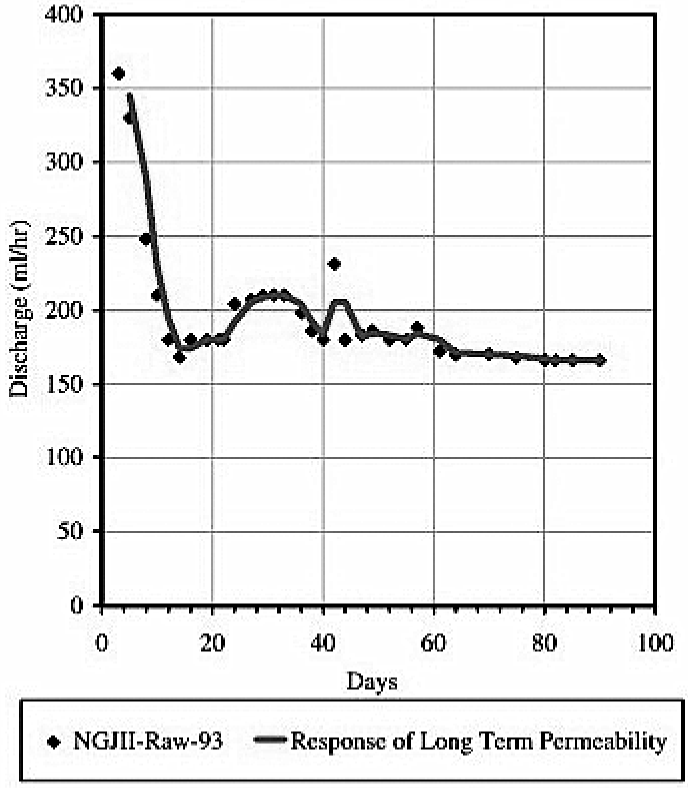


Figure 2.19 Discharge vs Days for Raw Twill geojute with River soil at 93% Proctor MDD (after Sarma 2005)

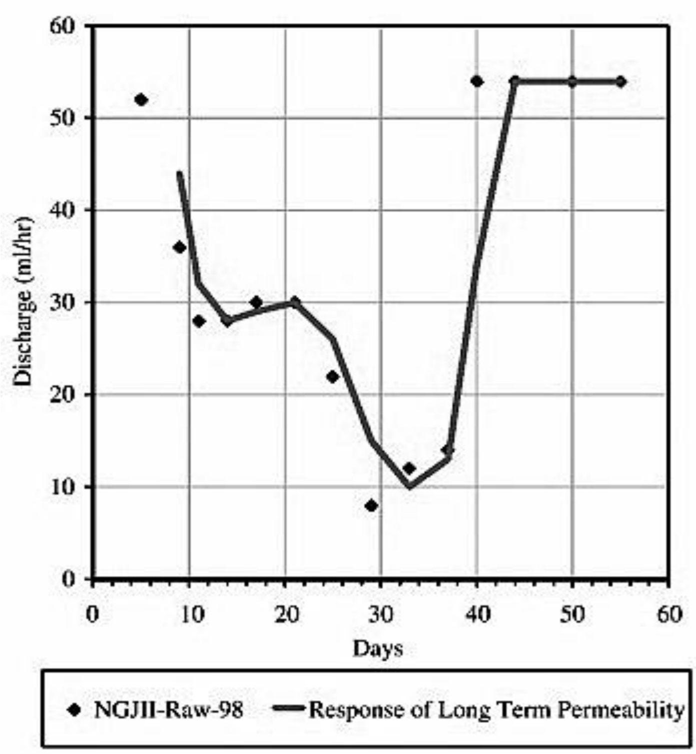


Figure 2.20 Discharge vs Days for Raw Twill geojute with River soil at 98% Proctor MDD (after Sarma 2005)

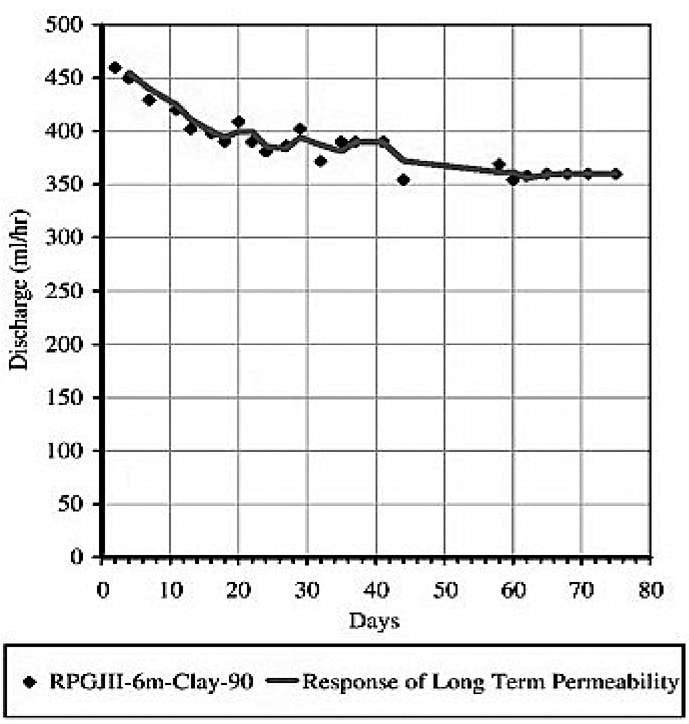


Figure 2.21 Discharge vs Days for 6 months in Natural Clay degraded Rot Proof Twill geojute with River soil at 90% Proctor MDD (after Sarma 2005)

In this case the soil particles moved through the pores of the coarse particles and got compressed under the influence of flow and consequently discharge decreased. The demarcation for the Initial Stage (apparently 18 days), partial Transition Stage (18 to 60 days) and the Final Stage (after 60 days) was not prominently developed like other set-ups. There was less turbulence may be because of the degraded jute fibres. The range of discharges was quite higher.

Figure 2.22 shows a variation of long-term permeability of a system having similar geojute type and compaction density like in Figure 2.15 except reduction of fines to 60% designated as RPCJII-6 in-Clay-90-60%. Here the Initial Stage (8 days) is very short because of the immediate compression of the loosely compacted (90% Proctor MDD) more coarse particles. This compaction density can be achieved in the field without any difficulty. The rate of change of discharge (turbulence) is found to be higher than the previous case (Figure 2.21) due to the more availability of pores and orientation of fines through it. The Transition Stage is 8 to 20 days followed by the Final Stage after 20 days.

Figure 2.23 depicts another case of low discharge with 60% fines due to the higher compaction of 98% of Proctor MDD with 6 months old Rot Proof Canvas geojute degraded in Natural Clay designated as RPGJI6 m-Clay-98-60%. The Initial Stage is reached after 8 days like in Figure 2.22 but duration of Transition Stage is longer (8 to 30 days) followed by Final Stage achieved after 30 days. The longer duration of Transition Stage is due to the lesser disturbance by the two dimensional structure of the Canvas fibres to the fines unlike the previous Twill one in Figure 2.22. But since both of them are degraded in Clay therefore these two figures (Figure 2.22 and Figure 2.23) indicate that the system behave similarly and can be assumed that in degraded state the effect of the geojute upon the whole long-term permeability system becomes redundant.

Figure 2.24 and Figure 2.25 show two cases of variation of long-term permeability of geojute-soil system having 40% fines compacted at 95 % Proctor MDD using 1-year-old Rot Proof canvas (RPGJ1- lyrClay-95-40%) and twill geojute degraded in Natural Clay (RPGJII-lyr-Clay-95-40%) respectively. Here the influence of presence of higher percentages of coarse particles is more pronounced by showing normal compression of the soil matrix under flow until it reaches a stable state. Any effects of use of varieties of geojute or the treatment is not found since both the varieties are degraded. Compaction at 95% Proctor MDD allows considerable particles movement to achieve a stable state much earlier, which is essential in terms of quicker functioning of the geojute-soil system for the required civil engineering purpose. This compaction density is not difficult to achieve in actual field condition.

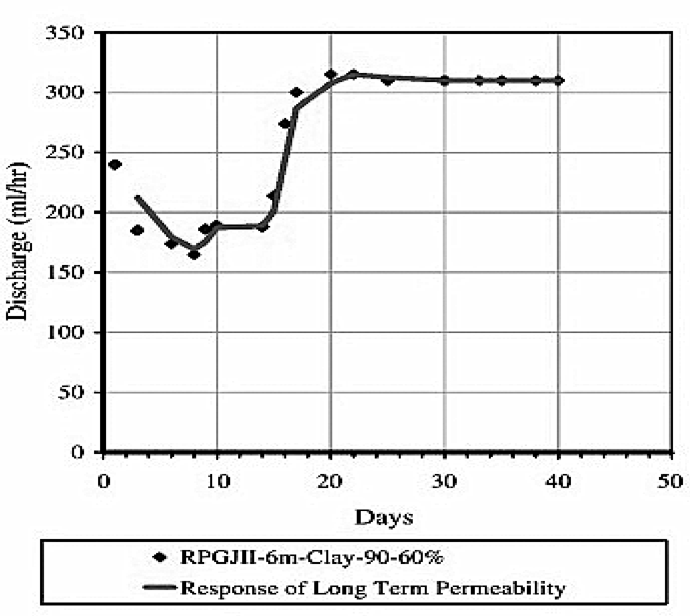


Figure 2.22 Discharge vs Days for 6 months in Natural Clay degraded Rot Proof Twill geojute with River soil (60% fines content) at 90% Proctor MDD (after Sarma 2005)

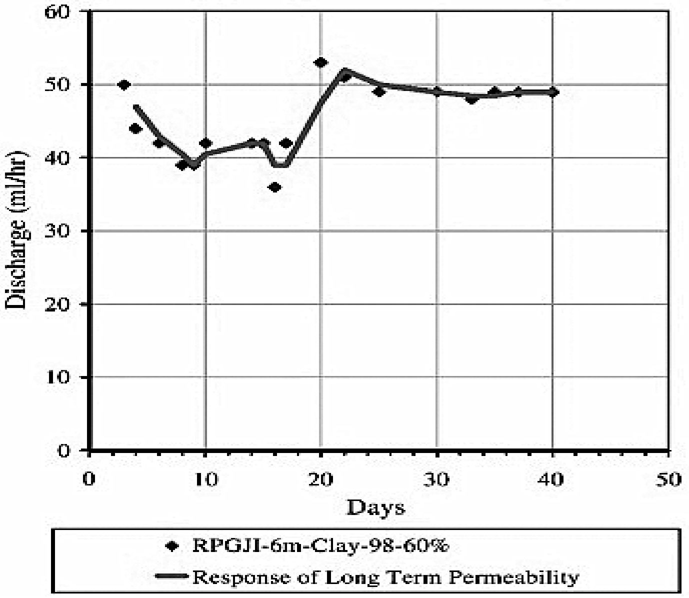


Figure 2.23 Discharge vs Days for 6 months in Natural Clay degraded Rot Proof Twill geojute with River soil (60% fines content) at 98% Proctor MDD (after Sarma 2005)

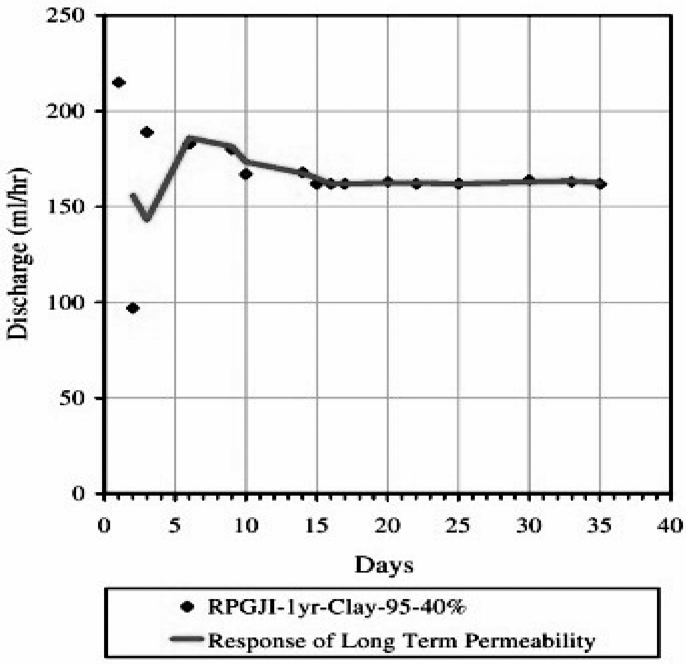


Figure 2.24 Discharge vs Days for 1 year in Natural Clay degraded Rot Proof Canvas geojute with River soil (40% fines content) at 95% Proctor MDD (after Sarma 2005)

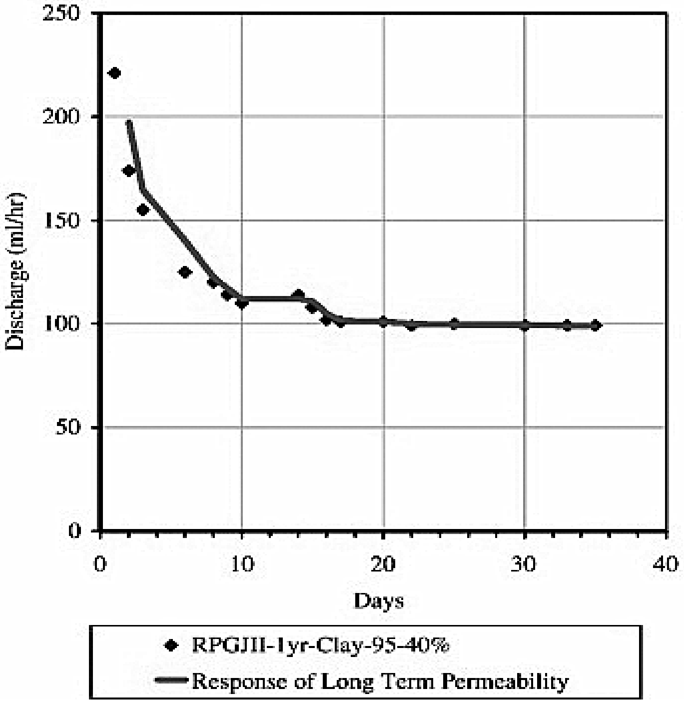


Figure 2.25 Discharge vs Days for 1 year in Natural Clay degraded Rot Proof Twill geojute with River soil (40% fines content) at 95% Proctor MDD (after Sarma 2005)

From the model studies it was observed that biodegradation of geojute does not necessarily affect the performance of the drainage filter after stable 'filter cake' stage is achieved, however in the initial stage of life, the fibres disturb the flow.

By varying the consistency of the soil, compaction effort and physico-hydraulic parameters of geojute, the time for complete development of the 'filter cake' can be controlled and controlling of these influencing factors are also simple on site and in the geojute manufacturing industry. Based upon these findings the usual assumption of requirement of 3 to 4 months for filter cake formation is not always true. Higher the compaction of the soil and lesser fines content, the time required for 'filter cake' formation can be reduced significantly within the life span of a particular geojute and for that an optimum design of these factors is necessary. Application of geojute is an environmental friendly practice with a tremendous potential of application of Labour Based Technology that has direct effect on the economy of any jute producing countries because of the more economy of geojute than the geosynthetics. Through these model studies emphasize is drawn on the merits of use of this technically viable, economic and eco-friendly product by eliminating the existing lacunae.

Weggel and Dortch (2012) also studied about formation of filter cake on geotextiles. They developed a numerical model that describes the accumulation of filter cake on a geotextile as flow passes through it are developed and solved numerically. The accumulation of both colloidal and settle-able particles is considered. The equations are first developed for a colloidal suspension and subsequently expanded to include settle-able particles having various settling velocities. Output from the numerical model includes: the flow rate through the geotextile/filter cake layers, the head drop through the layers, the cumulative volume of flow per unit area of geotextile and the rate of accumulation of the various size components of the filter cake. Important model parameters are $\psi y_0 / K$ which relates the permittivity of the geotextile times the water level at the start of the dewatering process to the permeability of the accumulating filter cake, $g\psi^2 / y_0$, a dimensionless permittivity, the α i /ε values that determine how much each sediment size class contributes to the filter cake‘s thickness and the v i /K values that describe the settling velocities of each sediment size class. The size distribution of the particles in various layers within the filter cake can be determined from the model and an example solution is presented that shows how particle size distribution varies within the filter cake.

2.15 Biodegradibility of JGT

Geosynthetics—man-made and natural—act as change agents to the soil on or in which they are laid. Concurrent functioning of separation, filtration and drainage by the fabric ensures maximization of soil consolidation within a period not exceeding two season cycles. Longer life of geotextiles beyond this formative period is thus not a technical necessity.

Jute fibres/yarns usually degrade after one year or so when in contact with soil as a result of microbial attack. Interestingly, laboratory studies and field applications have confirmed that the rate of loss in strength of JGT is compensated by the corresponding gain in strength of soil. The soil ultimately becomes intrinsically self-reliant needing no extraneous support.

Biodegradation of JGT is thus not a technical disadvantage as is usually thought of. JGT can be made to last for more than 2 years and even more by treating it with suitable eco-friendly additives. Research is on to develop a suitable eco-friendly natural additive that can impart a longer life to JGT (up to about 4 to 5 years) without affecting the mechanical properties of the fabric.

2.16 Durability of JGT

It has been established after several laboratory tests on samples of JGT with varying linear density that its biodegradation depends on environmental factors (Rao et al., 1994 and Rao et al., 1998). It has been observed that jute degrades faster inan acidic ambience having pH value less than 5.2. The rate of degradation of JGT is generally fast in the initial stages, but slows down subsequently. On the other hand, when pH is in a higher range (above 7) i.e., in an alkaline environment, the laboratory tests conducted by IIT, Delhi have initially revealed that higher is the linear density of yarns in a JGT, quicker is its degradation, though more elaborate studies are needed for this purpose to come to a definite conclusion.

Bacteria and fungi are two main groups of micro-organisms responsible for the microbial decomposition of any natural Geotextile. Moisture plays a key role in this respect. It has been reported that the minimum moisture requirements for the growth of bacteria and fungi in JGT are 20% and 17% respectively. Jute attains the aforesaid moisture contents when the relative humidity in the atmosphere is 90% and 80% respectively.

Temperature is also instrumental for bacterial and fungal attacks on jute.A temperature of 37^0 C is the most favorable temperature for bacterial growth and 30^0 C for growth of fungi in JGT. Both sunlight and rain causes quick degradation of JGT. The organic content of soil accelerates the decay of jute fibre. The degradation studies on jute so far conducted indicate that the mechanism of its biodegradation is complex, being dependent on interaction of a number of influencing factors.

To prolong the durability of JGT, rot-resistant chemicals are presently used. The chemicals are essentially copper based compounds – usually Copper Napthalate and Cupramonium. The former is a non-leachable compound and costlier. The latter gets leached on continuous exposure to water. A branded product (COMPSOL) is also being used. It is a copper ammonium carbonate solution that meets the US and Canadian WHMIS (Workplace Hazardous Materials Identification system) standards. It is a stable additive completely soluble in water and does not cause hazardous polymerization.

Bitumen (90/15 grade) is also in current use as a coating on JGT for the same purpose in addition usually for its application in bank-protective work in rivers and waterways.

As a result of the application of rot resistant chemicals/bitumen, the life of a JGT can be prolonged to about 4 to 5 years, subject to the specific subsoil ambience. Indian Institute of Technology, Kharagpur has recently been entrusted with a research project to develop an eco-friendly additive that will further enhance the durability of all types of JGT (JMDC, 2008).

Some previous application of river bank protection works have been shown in Table 2.13.

Table 2.13 Previous river bank protection works using treated JGT (JMDC, 2008 & BUET)

Sl. No.	Site & user	Date of Application	Result
1.	Nayachar (on river Hooghly), Midnapore, Calcutta Port Trust, WB	1989	Bank is still in a good shape; cost of jute geotextile 1/3rd of the synthetic geotextile
2.	Hasanpur, Murshidabad Irrigation Department, Govt. of West Bengal	June 1995	Better than granular filter in terms of performance and cost
3.	Ramayanpur, Maldah, Irrigation Department, Govt. of West Bengal	August 1996	Better than granular filter in terms of performance and cost
4.	Barrackpore, 24-pgs (N), Irrigation Department, Govt. of West Bengal	March 1997	Bank is still in a good shape; no sign of erosion observed
5.	Majuli, Assam, SDO, Majuli& AVARD (NE)	April 1997	Bank is still in a good shape and fully stabilized
6.	Ganga Anti Erosion Division, Murshidabad	1998	Bank is in good shape
7.	Mahananda, Embankment Division, Maldah, WB	1998	Satisfactory, no sign of erosion observed
8.	Balurghat, Irrigation Division, WB	1999	No sign of erosion observed
9.	Contai Irriation Division, Govt. of West Benagal	November 2001	Satisfactory
10.	Panchanandapur, Malda Irrigation Division, W.B.	June 2002	Satisfactory
11.	Pathoraj river, Panchagar, Bangladesh Water Development Board	June/July 2011	Bank is in good shape
12.	Garai river, Rajbari, Bangladesh Water Development Board	May/June 2013	Still under observation
13.	MBR channel, Gopalganj, Bangladesh Water Development Board	March/April 2013	Still under observation

2.17 Summary

From the overall discussion of this chapter, it has been learned that, filter material plays a vital role in river bank protection work. The purpose of using filter material is to stop migration of soil particles and also to allow flow of water. So the two main characteristics of filter material are permeability and soil retention.

There can be two conditions in river bank protection work. Unidirectional flow condition and reverse flow condition. When geotextile based filters are used in river bank protection work, they are subjected to water flow. This flow of water causes the formation of a graded filter structure known as ―Filter Cake” in the zone of soil in contact with the geotextile. When the natural filter cake is formed, the filter material used to protect the river bank becomes redundant.

JGT is superior to its man-made counterpart because not only JGT is cheaper than synthetic geotxtile but also jute is biodegradable. Since filter material becomes redundant after formation of natural soil filter cake, JGT performs better than geosynthetics. Longevity of JGT can be increased by treating it with additives. It also enhances the durability of JGT.

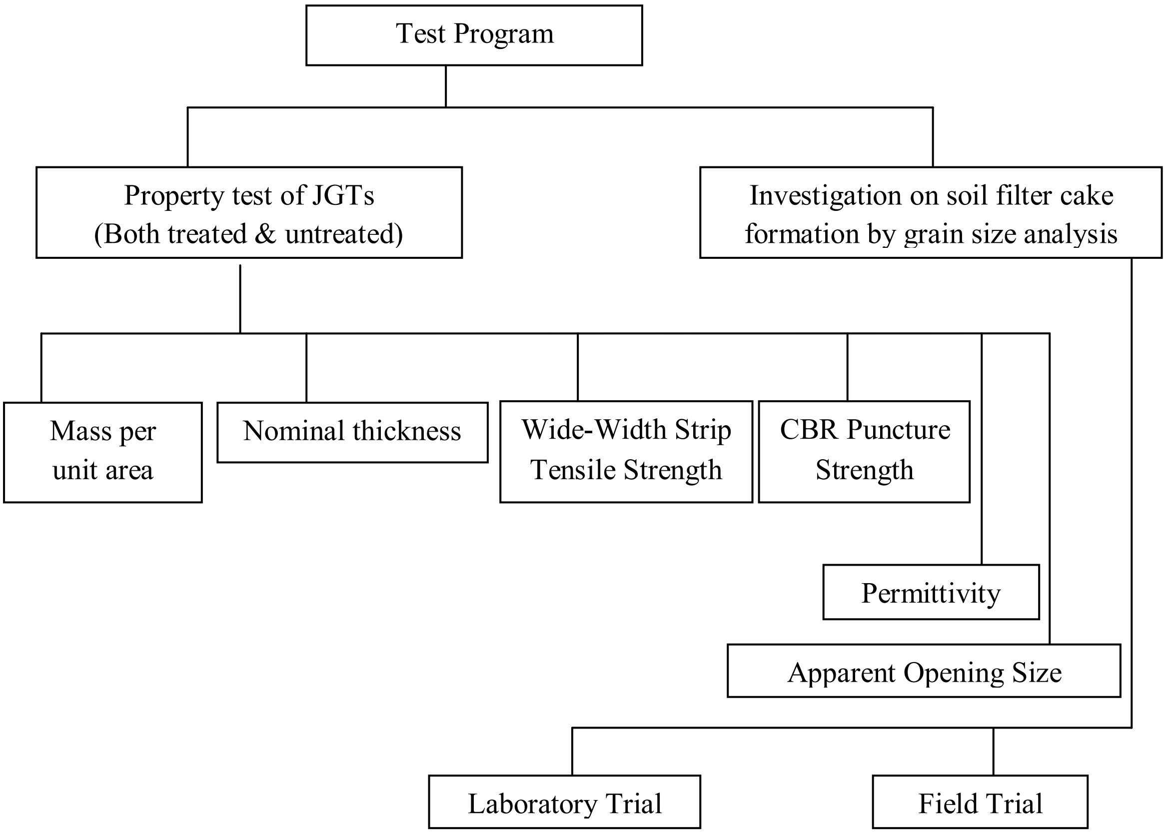
CHAPTER THREE

TEST PROGRAM

3.1 General

Being a growing industry, the geotextile currently does not yet have a completely unified set of worldwide standards and test methods. Yet the activity toward such an ultimate goal is very intense (Koerner, 1997). As observed by Koerner, many of the test methods are not fully standardized as far as test procedures are concerned. In the U.S. the ASTM has a standards committee specially organized for geosynthetics (D35); however, there are also worldwide organizations. Few of them are: International Organization for Standards (ISO), German Standards Committee for Geotextiles (DIN), British Standards Institution (UK) etc.

In this research work six properties of JGT were tested. Besides sieve analysis of soil were performed to investigate the formation of filter cake. The whole test program is shown in the following flow chart:



3.2 Tests of The JGT Properties

3.2.1 Mass per Unit Area

Mass per unit area is the proper term by which the weight of geotextile is meant. Geotextiles mass per unit area is given in grams per square meter (g/m^2) and rounded to the nearest 0.1 g/m^2 . The mass per unit area of a geotextile is determined by weighing test specimens of known dimensions, cut from various locations over the full width of the laboratory sample. The calculated values are then averaged to obtain the mean mass per unit area of the laboratory sample.

As per ASTM D5261-92 a minimum five test specimens are cut such that they are representative of the entire roll width and with a combined minimum total area of 100,000 mm^2 (155 in^2). Each test specimen should be equal to an area not less than 10,000 mm^2 (15.5 in^2). The mass (or weight) is measured to the nearest 0.01% of the total specimen mass. Length and width is measured under zero geotextile tension. Since fabric cost is directly related to mass per unit area, it is an important property.

Calculation of the mass per unit area of each of the specimen to be done as follows:

$$m = M_s \text{ X } 1{,}000{,}000/A \qquad (3.1)$$

where,

m = mass per unit area rounded to the nearest 0.1 g/m^2

M_s = mass of the specimen, g and

A = area of the specimen, mm^2

After calculating individual mass per unit area, the averages of all five specimens are to be found.

In this research work mass per unit area of untreated A. Twill cloth and treated A. Twill cloth JGT samples were tested.

3.2.2 Nominal Thickness

Thickness is one of the basic physical properties of a geotextile used to control the quality of many geotextiles and geomembranes. It is more of a descriptive property than design-oriented property. In certain industrial applications, the thickness may be rigidly controlled within specified limits. Bulk and warmth properties of jute products are often estimated based on their thickness measured before and after abrasion or shrinkage. Thickness values are required in calculation of some geotextile and geomembrane parameters such as permeability coefficients, tensile stress (index), and the like thickness is not indicative of field performance and therefore is not recommended for specifications.

The thickness of a geotextile is the distance between the upper and lower surface when measured under a specific pressure. The thickness of geotextiles and geomembranes may vary considerably depending on the magnitude and the duration of pressure applied. Where observed changes occur, thickness decreases when applied pressure is increased. To minimize variation, specific sample size and applied pressure are indicated in ASTM D 5199-98 to ensure all results are comparable. As per this test method, the thickness testing instrument should have the thickness gage having a base (or anvil) and a free moving presser foot plate whose planar faces are parallel to each other to <0.01 mm.A gage with a 56.4 mm (2.22 in) diameter presser foot, the base should extend at least 10 mm in all direction further than the edge of the 2500 mm^2 circular presser foot, should be used for measurements of geotextiles. This instrument must be capable of measuring a maximum thickness of at least 10 mm to an accuracy of at least ± 0.02 mm. The gages should be constructed to permit gradual application of pressure to a specific force of $2\pm$ 0.02 kPa (0.29 ± 0.003 psi) for geotextiles.

As per this test, a pressure of 2 kPa is recommended as a standard for the determination of the nominal thickness of geotextiles. Test specimens are removed from laboratory sample in a randomly distributed pattern across the width with no specimen taken nearer than 100 mm (4 in) from the roll edge. From each unit in the laboratory sample, test specimens are cut such that the edge of the specimens should extend beyond the edge of the presser foot by 10 mm (0.39 in) in all directions. Normally 10 (ten) specimens are taken for each test.

An important consideration is to check whether the strain gauges have truly come into equilibrium under each load increment. The introduction of a weight would introduce compression of the fabric. Thus, it is important to read the gauges as quickly as possible once the presser plate is deemed to have come to equilibrium at the standardized time duration. The thickness of jute fabric continues to decrease under pressure for considerable time because of compressibility. Muhammad (1993) studied the effect of time on thickness of jute matting under different pressure. For thickness tests, the time interval to record readings from strain gauges may be standardized to 5 minutes while the suggested time interval by ASTM is only 5 sec. Another important finding can be observed that around 98% of compressibility is reached after 5 minutes of applied load. Muhammad (1993) has also tested different numbers of layers under a wide range of pressure. The average thickness, T_{avg} was calculated from the total thickness, T_{total} , and the number of layers tested, N, by

$$T_{avg} = T_{total}/\text{N} \tag{3.2}$$

T_{avg} = average thickness

T_{total} = total thickness

N = number of layers tested

The total thickness of jute under uniform applied load in field condition can be estimated by multiplying the number of sheets used and the average single layer thickness at that particular load.

In this research work thickness of untreated A. Twill cloth and treated A. Twill cloth JGT samples were measured.

3.2.3 Wide-Width Strip Tensile Strength

The most common wide-width test is ASTM D 4595 and ISO 10319. In this test a relatively wide specimen is gripped across its entire width in the clamps of a constant rate of extension (CRE) type tensile testing machine operated at a prescribed rate extension, applying a longitudinal force to the specimen until the specimen ruptures. Tensile strength, elongation, initial and secant modulus and breaking toughness of the test specimen can be calculated from machine scales, dials, recording charts, or an interfaced computer. The equipment to be used in this test must be a constant rate of extension (CRE) type that should conform to the specification D 76. It has automatic load and elongation recorders and special jaws with serrated faces to firmly grip on the specimen to prevent slippage. These special jaws are capable of testing up to 200 mm wide specimens and permit not rotation about the grips.

The strain rate commonly used in this test should be given careful consideration. Haliburton et al, (1980) has suggested using 150mm wide × 300 mm long specimens at a strain rate of 2%/min while Andrawes et al., (1984) recommended 200mm wide × 100 mm long specimen at a strain rate of 10%/min. The difference in specimen size and strain rate adopted by various researchers raises the question as to what effect the specimen size and strain rate will have on the results.

The determination of the wide-width strip force-elongation properties of geotextiles provides design parameters for reinforcement type applications, for example design of reinforced embankments over soft subgrades, reinforcement of slopes. When strength is not necessarily a design consideration, an alternative test method may be used for acceptance testing. Most geotextiles can be tested by this method. This test method is applicable for testing geotextiles either wet or dry. It is used with a constant rate of extension type tension apparatus.

The test specimen for wide-width test is cut 200 mm (8 in) wide by 100 mm (4 in) long with the length being designated and accurately parallel to the direction for which the tensile strength is being measured. The length of the specimen is selected such that it fits the clamps being used. It is kept long enough to extend through the full length of both clamps, as determined for the direction of test. The force range of the testing machine was selected such that break occurs between 10 and 90% of full-scale force. Machine strain is set at a rate 10 ± 3%/min.

In this research work five specimens each of untreated A. Twill cloth and treated A. Twill cloth JGT samples were tested in machine direction (MD) and cross machine direction (XMD).

3.2.4 CBR Puncture Strength

This test is formalized as ISO/DIS 12236 and in Germany as DIN 54307. It uses a conventional soil-testing CBR plunger and mold. As per this test, the penetrating steel rod to be 50 mm in diameter and the geotextile is firmly clamped in an empty mold with a 150 mm inside diameter. The circumference of the plunger should be beveled 0.80 mm on a 45° angle so as not to cut the yarns at the edge of the rod. The laboratory sample should be taken from a swatch extending the full width of the geotextile. The sample so taken should exclude material from the outer wrap and inner wrap around the cores. The test specimen should be cut of a diameter 250 mm to facilitate clamping. No specimen should be taken nearer the edge of the geotextile sample than 1/10th the width of the geotextile sample. Total ten specimens are to be tested for each type of geotextile. The machine speed is to be set 50mm/min until the puncture rod completely ruptures the test specimen.

In this research work, CBR puncture resistances were measured for untreated A. Twill cloth and treated A. Twill cloth JGT samples.

3.2.5 Permittivity (Cross-Plane Permeability)

One of the major functions that geotextiles perform is filtration. In filtration the liquid flows perpendicularly through the geotextile into crushed stone, a perforated pipe, or some other drainage system. It is important that the geotextile allow this flow to occur without being impeded. The geotextile‘s cross-plane permeability is defined with the term Permittivity (Ψ). Permittivity is an indicator of the quantity of water that can pass through a geotextile in an isolated condition. As per ASTM D 4439-98 Permittivity, (Ψ), of geotextiles is defined as the volumetric flow rate of water per unit cross-sectional area per unit head under laminar flow conditions, in the normal direction through a geotextile.

$$\Psi = \frac{k_n}{t} \tag{3.3}$$

where,

Ψ = permittivity (s^{-1})

k_n = permeability (properly called hydraulic conductivity) normal to the geotextile (m/s),

t = thickness of the geotextile (m)

According to ASTM D 4439-98,to measure the permittivity of geotextile test specimens either constant head or falling head can be used, although the standard is written around the constant head test at ahead of 50 mm. The important test consideration for this test are preconditioning of the fabric, temperature and the use of de-aired water. ASTM D 4491 requires a dissolved oxygen content of less than 6.0 mg/l. Tap water is allowed unless dispute arise, in which case de-ionized water should be used.

In constant head test, a head of 50 mm (2 in) of water is maintained on the geotextile throughout the test. The quantity of flow is measured versus time. The constant head test is used when the flow rate of water through the geotextile is so large that it is difficult to obtain readings of head change versus time in the falling head test. In falling head test a column of water is allowed to flow through the geotextile and readings of head changes versus time are taken. The flow rate of water through the geotextile must be slow enough to obtain accurate readings.

In order to obtain a representative value of permittivity, a specimen of 1 m^2 (1 yd^2) is taken. Four circular specimens are selected. The first one is taken from the centre of the sample, second one is taken at one corner (centre located 200 mm (8 in) from the corner), the third one is taken from midway between the first and second specimen. The last one is taken from the same distance from the first and third specimen, located on a line with the other three specimens. The diameters of the cut specimens are considered as 73 mm (2.87 in) so that it fits the testing apparatus. The specimen is conditioned by soaking in a closed container of de-aired water, at room conditions, for a period of 2 hour. The minimum specimen diameter is to be 25 mm (1 in).

The permittivity test described so long, has the geotextile test specimen under zero normal stress, a situation rarely encountered in the field. To make the test more performance-oriented, numerous attempts to construct a permittivity-under-load device have been made. Generally a number of layers of geotextile (from 2 to 5 layers) are placed upon one another with an open-mesh stainless steel grid on top and bottom. This assembly is placed inside a permeameter and loaded normally via ceramic balls of approximately 12 mm diameter. Thus normal stress is imposed on the geotextile, but flow is only nominally restricted. Loading by soil itself (which would definitely affect flow) is completely avoided.

In this research work permittivity of untreated A. Twill cloth and treated A. Twill cloth JGT sample were determined.

3.2.6 Apparent Opening Size (AOS)

Opening pore size of the fabric controls the filtration performance of a geotextile. Pore size of the fabric should therefore determine the retention ability of soil grains and permeability of water. The ideal retention criteria for fabrics should specify an appropriate fabric pore structure in order to provide adequate seepage and to prevent piping in the soil and clogging in the fabric. Fabric pore size distribution is the key parameter that controls a fabric‘s ability to retain the soil grains. Different effective pore sizes have been described by Ogink (1975). A term ―Steepness factor" defined as O_{50}/O_{98} where O_{50} and O_{98} are 50% and 98% opening sizes respectively, is used for determining retention criteria. A high steepness factor of 0.8 to 0.9 is considered as typically favorable while a value of 0.3 to 0.4 is unsuitable for soil retention.

Calhoun (1972) developed a test for equivalent opening size (EOS) to characterize the soil particle retention ability of various fabrics. The test involved in the determination of the size of the rounded sand particles which when sieved through the fabric will pass only 5% or less by weight. The EOS was defined as the ―retention on" size of that fraction expressed as a U.S. standard sieve number. The EOS test only provides a method for determining the relative size of the largest straight through openings in a fabric. Two fabrics may have similar EOS values but dramatically different pore structures and porosities, for example, those found in woven versus nonwoven fabrics.

Apparent opening size (AOS), O_{95} is a property of geotextile, which indicates the approximate largest particle that would effectively pass through the geotextile. A test for measuring the apparent opening size was developed by the U.S. Army Corps of Engineers to evaluate woven geotextiles. The test has since been extended to cover all geotextiles, including the nonwoven types. The AOS or equivalent opening size (EOS) is essentially same. The equivalent ASTM test is designed D 4751. The test uses known diameter glass beads and determines the O_{95} size by standard dry sieving. Sieving is done using beads of successively larger diameters until the weight of beads passing through the test specimen is 5%. This defines the O_{95} size of the geotextile‘s opening in millimeters. It may be noted here that the O_{95} value only defines the one particular void size of the geotextile and not the total pore size distribution. AOS, EOS and O_{95} all refer to the same specific pore size, the difference being that AOS and EOS are sieve numbers, while O_{95} is the corresponding sieve opening size in millimeters.

In ASTM sieving method, a geotextile specimen is placed in a sieve frame, then standard glass beads are placed on the geotextile surface, a mechanical sieve shaker shakes the geotextile and frame laterally. It impairs lateral and vertical motion to sieve, causing the particles thereon to bounce and turn so as to present different orientations to the sieving surface. The procedure is repeated on a new specimen of the same type of geotextile with other various sizes of the glass beads until its equivalent or apparent opening size is determined. AOS is that bead size for which 5% or less of the beads pass through the fabric. The ASTM committee D-35 suggests using ―static masters” to eliminate the buildup of static electricity and to soak the fabric in water to remove the surface coating which may act to clog some of the openings. As a laboratory sample for acceptance testing, a full width swatch 1 m (1yd) long from the end of each roll of fabrics is taken in the lot sample, after first discarding a minimum of 1 m (1yd) of fabric from the very outside of the roll. Five specimens from each swatch in the laboratory sample is cut to fit the appropriate sieve pan.

The AOS test is a poor test. This technique is very time consuming and tedious. Many geotextiles do not have surface films and in general natural geotextiles may not buildup much static electricity during shaking. In order to subject all fabrics to the same simple procedure, for pore-size measurement, a modified method is developed using a dry sieve analysis, which aims at establishing a characterization of a fabric with respect to size and uniformity.According to ASTM for AOS test, the geotextile has to be changed after using a particular uniform size of glass beads to maintain the jute fabric opening at each time of testing. The proposed method uses only one specimen to get the value of AOS.

Using a geotextile as a medium to retain soil particles necessitates compatibility between it and the adjacent soil. This test method is used to indicate the apparent opening size in a geotextile, which reflects the approximate largest opening dimension available for soil to pass through. Test method D 4751 for the determination of opening size of geotextiles is acceptable for testing of commercial shipments of geotextiles.

In this research work different sizes of sand particles were separated through sieve analysis. Then they were passed through geotextiles in the shaking machine. The AOS is assigned as the size designation in mm of the beads of which 5% or less pass. The designated bead size is the retained on size of the sieve pair used to size the beads. Apparent opening sizes of untreated A. Twill cloth and treated A. Twill cloth were determined.

3.3 Grain Size Analysis of Soil

A sieve analysis is consists of shaking the soil through a stake of wire screens with openings of known sizes; the definition of particle diameter for a sieve test is, therefore, the side dimension of a square hole. Sieve analysis of a soil sample is performed when all of its grains are so large that they cannot pass through square openings of 0.074 mm (No. 200 screen). The method of designing inverted filters for dams, levees etc., uses the particle size distribution of the soils involved. This method is based on the relationship of grain size to permeability, along with experimental data on the grain size distribution required to prevent the migration of particles when water flows through the soil. Also the present criterion for establishing susceptibility of soils to frost damage is based on grain size.

For this test 100 gms of oven dried soil is taken and sieved through a nest of sieves using a mechanical shaker. At least 10 minutes of shaking is required. Then each sieve and pan with soil retained on them is weighed. Percentage of soil retained is determined from the following formula,

Percentage retained on any sieve = (wt. of soil retained/ total soil wt) $\times 100\%$

Then cumulative percentage retained on any sieve is determined which is sum of percentages retained on all coarser sieves. After that percentage finer than any sieve size determined from the following formula,

Percentage finer than any sieve size = 100% - cumulative percentage retained.

After determining percentage finer of soil a percentage finer versus soil particle size curve is drawn in a semi log graph paper, from which particle size distribution of soil is observed.

3.4 Field Trial to Investigate Formation of Soil Filter Cake

To investigate about filter cake formation, a site was selected at Panchagar for field trial. A river bank protection project was going on there. Treated JGT shown in Figure 3.1 was used as filter to protect the river bank. Figure 3.2 and 3.3 show the river bank protection work using JGT and synthetic geotextile respectively.

Both treated JGT and synthetic geotextile were used as filter. In this river bank protection work, a layer of local sand was placed over the natural soil. This was done to retain fine soil particles so that they cannot clog the geotextile. Geotextiles were placed over the local sand and ¾" size brick chips shown in Figure 3.4 were placed over the geotextiles.

A layer of 40 cm × 40 cm × 20 cm concrete blocks were placed over the brick chips. Brick chips were used to protect the geotextile from damage due to weight of concrete blocks. Another reason for using brick chips was to help the flow of water.

Figure 3.1 Treated JGTs that were used for river bank protection

Figure 3.2 River bank protection using treated JGT

Figure 3.3 Synthetic geotextile used for river bank protection

Figure 3.4 Brick chips used between concrete blocks and treated jute geotextiles

Figure 3.5 Collection of soil sample through PVC pipe

At the time of implementation, three soil samples were collected from the river bank at different depths:

a) 125 mm depth
b) 300 mm depth
c) 600 mm depth

Sieve analyses of these soil samples were performed.

As per theory of filter cake formation, sieve analysis of soil samples at different depths should be performed to observe whether the filter cake has formed or not. After 6 (six) months of implementation, four soil samples were collected at different points of the river bank. Collection of soil sample is shown in Figure 3.5. The soil samples were collected through PVC pipes. 1.20 m long and 50 mm diameter pipes were used to collect sample in which the sample length was 900 mm. PVC pipes were used to prevent disturbance of the samples.

Sieve analyses of those samples were performed to investigate about the formation of filter cake. According to depth, the soil samples were designated as:

a) Outside (300 mm away from JGT)
b) Middle (600 mm away from JGT)
c) Inside (900 mm away from JGT)

Another investigation was performed in a different approach after 2 (two) years of implementation. Four samples were collected through 600 mm long and 75 mm diameter PVC pipes. Sample length was 450 mm. Sieve analyses of those samples were performed to investigate about the formation of filter cake. According to depth, the soil samples were designated as:

a) Outside (25 mm away from JGT)
b) Middle (50 mm away from JGT)
c) Inside (75 mm away from JGT)

3.5 Laboratory Simulation to Investigate about Formation of Soil Filter Cake

Laboratory simulation was performed to investigate about the formation of filter cake. For this purpose, a model was arranged in the laboratory. A schematic diagram of the model is shown in Figure 3.6. The whole system was set in a jar. Brick chips of 18.75 mm size were kept at the bottom of the jar. Then geotextile sheet was placed over the brick chips. Untreated A. Twill cloth was used as filter in this case. After that a soil structure of 300 mm diameter and 150 mm height was kept over the geotextile. The setup of laboratory simulation is shown in Figure 3.7. The system was so arranged that water entered into the system from a source through an inlet pipe and flown out of the system through an outlet pipe. Water was kept flowing at a constant rate for seven days. After 7 days, water flow was stopped and three soil samples at different depths were taken. Sieve analyses of those samples were performed. Another investigation was done where the simulation was continued for 14 days.

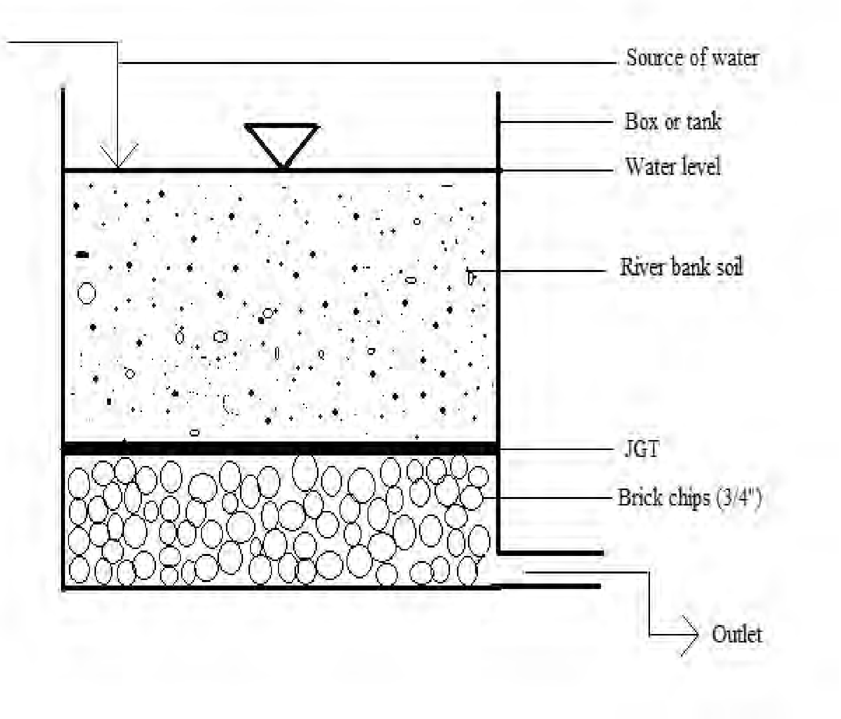


Figure 3.6 Schematic diagram of laboratory simulation model

Figure 3.7 Model arranged for laboratory simulation

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 General

In chapter two, theory of filtration, permeability, permeability criteria for geotextiles, soil retention, soil retention criteria for geotextiles, long term flow compatibility and theory of formation of soil filter cake are described elaborately. The laboratory investigations of properties of geotextiles, sieve analysis of soil, laboratory simulation of formation of soil filter cake are also narrated in chapter three. In this chapter the test results are presented with discussion.

4.2 Properties of JGT used

4.2.1 Mass Per Unit Area

To determine the Mass per Unit Area, as per ASTM D 5261-92, five-test specimen each from both untreated A. Twill cloth and treated A. Twill cloth was cut such that they were representative of the entire roll width. The length and width was measured under zero geojute tension. Then the mass was measured. Thereafter the mass per unit area of each of the sample was calculated as per formula given in Chapter Three. The mass per unit area of untreated A Twill cloth was found to be 767 g/m^2 and that of treated A. Twill cloth was found to be 1177 g/m^2. Comparison of Mass per unit area between untreated and treated JGT has been shown in Figure 4.1.

4.2.2 Nominal Thickness

The thickness of a geotextile is the distance between the upper and lower surface when measured under a specified pressure. As per ASTM D 5199, test specimens were prepared from laboratory samples in a randomly distributed pattern across the width. The apparent thickness of the geotextile decreases with the pressure applied. In the case of geotextile, the specimens were placed in between two weights: the presser plate, upon which the weights are placed, and the anvil. Readings were taken carefully again after inserting the JGT fabric in between the plates and placing the load increment on the presser plate. From the test, the thickness of untreated A. Twill cloth was found to be 1.82 mm and that of treated A. Twill cloth was found to be 3.24 mm. Comparison of Nominal thickness between untreated and treated JGT has been shown in Figure 4.2.

4.2.3 Wide-Width Tensile Stress

The load-extension behavior of the geotextile has been determined by wide-width strip tensile test. The equipment used in this test consisted with a tensile testing machine (WOLPERT). It has load and elongation recorders and jaws with jagged faces to firmly grip on the specimen to prevent slippage.

The test specimen for wide-width test was cut 200 mm (8 in) wide by 100 mm (4 in) long with the length being designated and accurately parallel to the direction for which the tensile strength is being measured. The length of the specimen selected such that it fits the clamps being used. It was kept long enough to extend through the full length of both clamps, as determined for the direction of test. Machine strain rate is set at 10±3%/min.

Five specimens each of both the samples were tested in machine direction (MD) and cross machine direction (XMD). From the test, the tensile strengths in machine direction of untreated A. Twill cloth were found to be 28.45 kN/m and 23.8 kN/m respectively. The tensile strengths in cross machine direction of treated A. Twill cloth were found to be 35.4 kN/m and 23.33kN/m respectively. Comparison of Wide width tensile strength between untreated and treated JGT has been shown in Figure 4.3.

4.2.4 CBR Puncture Resistance

The CBR puncture resistances of both the JGT samples were performed. A conventional soil-testing CBR plunger and mold were used in this test. The penetrating steel rod is 50 mm in diameter and the samples were firmly clamped in an empty mold with a 150 mm inside diameter. The machine speed was set at 50 mm/min.

The outcome test results are shown in Fig. 4.4. The CBR puncture resistance of untreated A. Twill cloth was found to be 3365 N and that of treated A. Twill cloth was found to be 4133 N. Comparison of Mass per unit area between untreated and treated JGT has been shown in Figure 4.4.

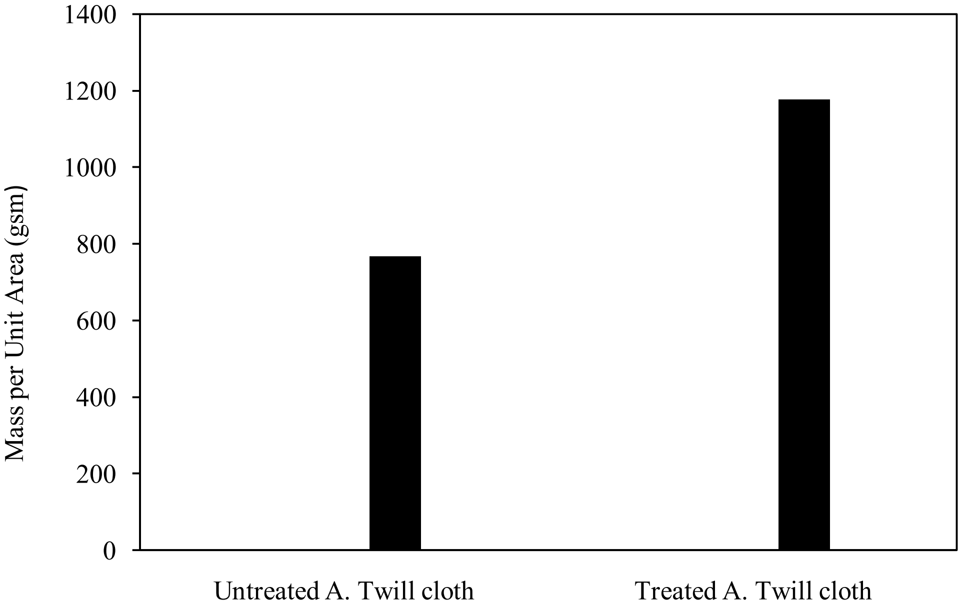


Figure 4.1 Mass per Unit Area of the tested samples

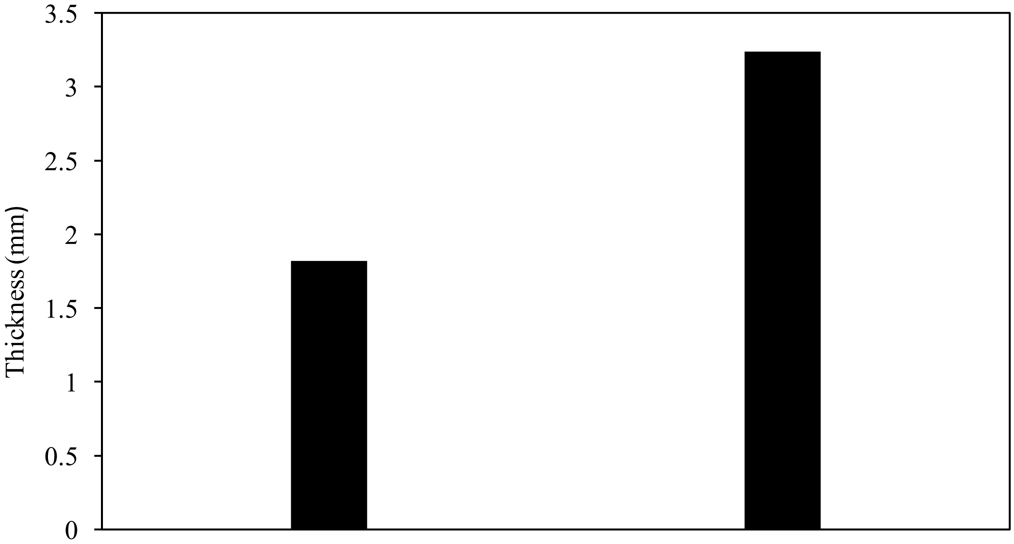


Figure 4.2 Nominal Thickness of tested samples

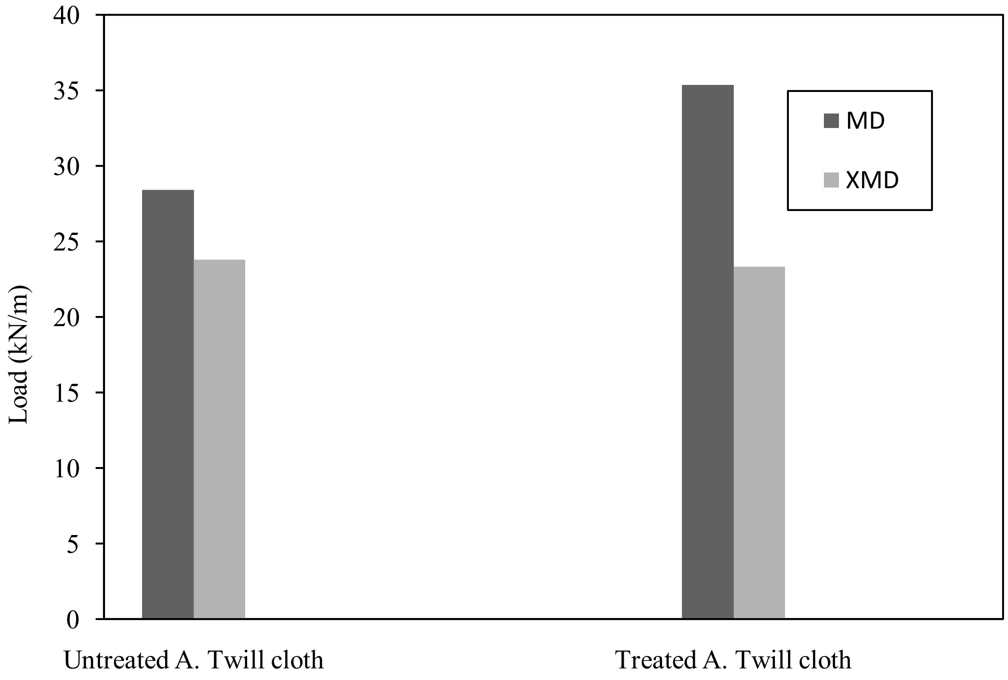


Figure 4.3 Wide-Width tensile strength of tested samples(MD= Machine direction, XMD= Cross machine direction)

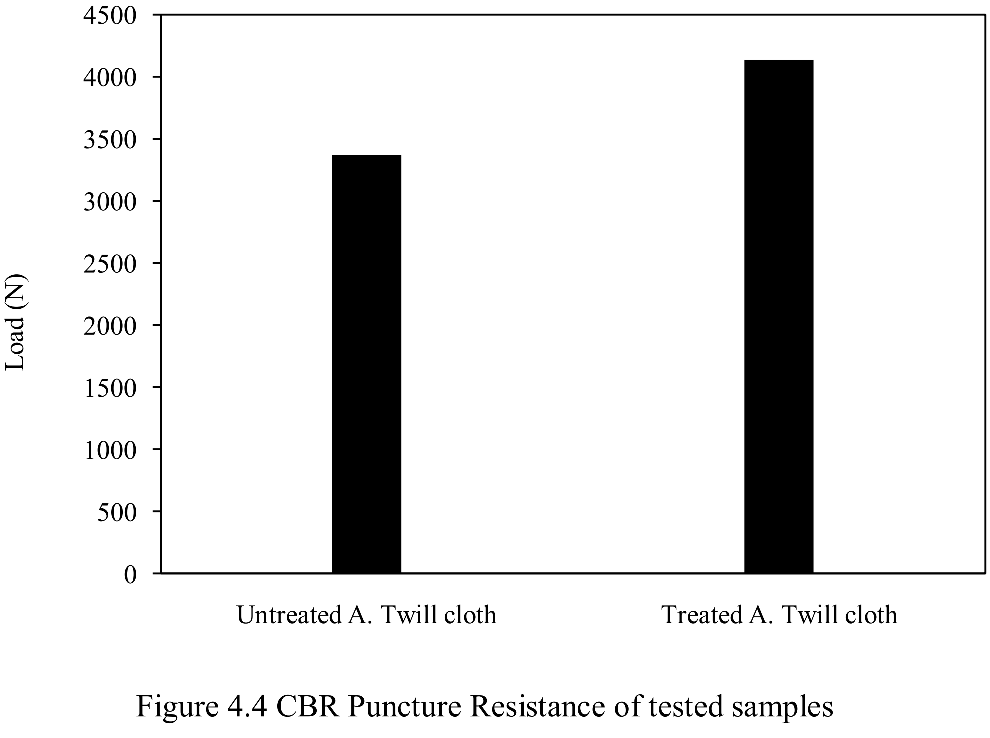


Figure 4.4 CBR Puncture Resistance of tested samples

4.2.5 Permittivity

For the determination of the permittivity as per ASTM D 4431-98, constant head method was followed at head of 50 mm. Due attention was given in the important test consideration for this test i.e., the preconditioning of the fabric, use of de-aired water. The permittivity of untreated A. Twill cloth was found to be 0.26 s^{-1} and that of treated A. Twill cloth was found to be $0.17 s^{-1}$. Comparison of Permittivity between untreated and treated JGT has been shown in Figure 4.5.

4.2.6 Apparent Opening Size (AOS)

Apparent Opening Size (AOS), O_{95} is the property of geotextile, which indicates the approximate largest particle that would effectively pass through the geotextile. As per ASTM sieving method, a JGT specimen was placed in a sieve frame. The sample was secured in such a way that it is taut, without wrinkles or bulges. Care was taken so that the sample was not stretched or deformed such that it changes or distorts the openings in the fabric. Then 50 grams of standard sand fractions were placed on the center of the JGT surface. A mechanical sieve shaker shaked the JGT and the frame laterally for five minutes.

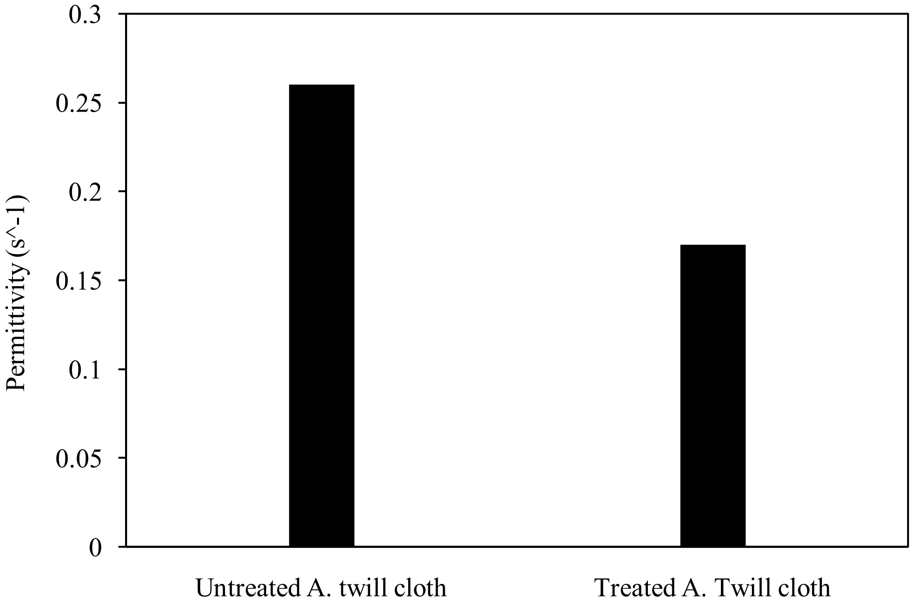


Figure 4.5 Permittivity of tested samples

It imparted lateral and vertical motion to sieve, causing the particles thereon to bounce and turn to present different orientations to the sieve surface. By placing, the sand fractions still on the surface of the specimen in a pan and weighed. The process was repeated by using next smaller sand size fractions until the weight of sand passing through the specimen is 5% or less. The procedure was repeated on a new specimen of the same type of JGT with other various sizes of sand fractions until its equivalent or apparent opening size is determined. In this research work apparent opening sizes of both the untreated A. Twill cloth and treated A. Twill cloth were within the range of 0.3-0.15 mm.

4.3 Grain Size Analysis of Soil Samples

4.3.1 Investigation on Formation of Filter Cake (Field Trial)

To investigate about the formation of soil filter cake, sieve analysis of soil was performed three times: at the time of implementation and after six months of implementation and after two years of implementation. At the time of implementation soil samples were collected at different depths from the river bank and sieve analysis of those samples were performed. The combined graph is shown in Fig. 4.6.

After six months of implementation, soil samples were collected at four different points from the river bank. Three of them were beneath the JGTs and the other was beneath the synthetic geotextile. Each sample was divided into three layers. Sieve analysis tests of all the samples were performed. From the data of those tests combined grain size distribution curves were drawn. Similar investigation was performed after two years of implementation, but in a different approach.

The combined graphs of grain size analysis are shown in Fig. 4.7, Fig. 4.9, Fig. 4.11 and Fig. 4.13. Fineness Modulus of those soil samples were also calculated. Their variations are shown in Fig. 4.8, Fig. 4.10, Fig. 4.12 and Fig. 4.14.

4.3.2 Discussion on Combined Graphs

Considering the first approach (investigation after six months), from the grain size distribution curves it was found that in case of three samples, soil particles of the outside layer or near JGT are coarser than the particles of middle and inside soil layer.

So in these cases it can also be said that, filter cake has been formed partially. In case of the remaining sample the particle sizes of all the layers are almost same.

Considering the second approach (investigation after two years), from the grain size distribution curves it was found that in case of one sample, soil particles of the outside layer or near JGT are coarser than the particles of middle and inside soil layer. So in these cases it can also be said that, filter cake has been formed partially. In case of the remaining three samples the particle sizes of all the layers are almost same.

4.3.3 Discussion on Variations of Fineness Modulus

Considering the first approach (investigation after six months), from the column charts it was found that in case of three samples, fineness modulus of outside soil layer are higher than those of middle and inside soil layers. As it is known that a smaller value of fineness modulus indicates the presence of larger proportions of finer particles, so from fineness modulus charts it can also be said that, filter cake has been formed partially.

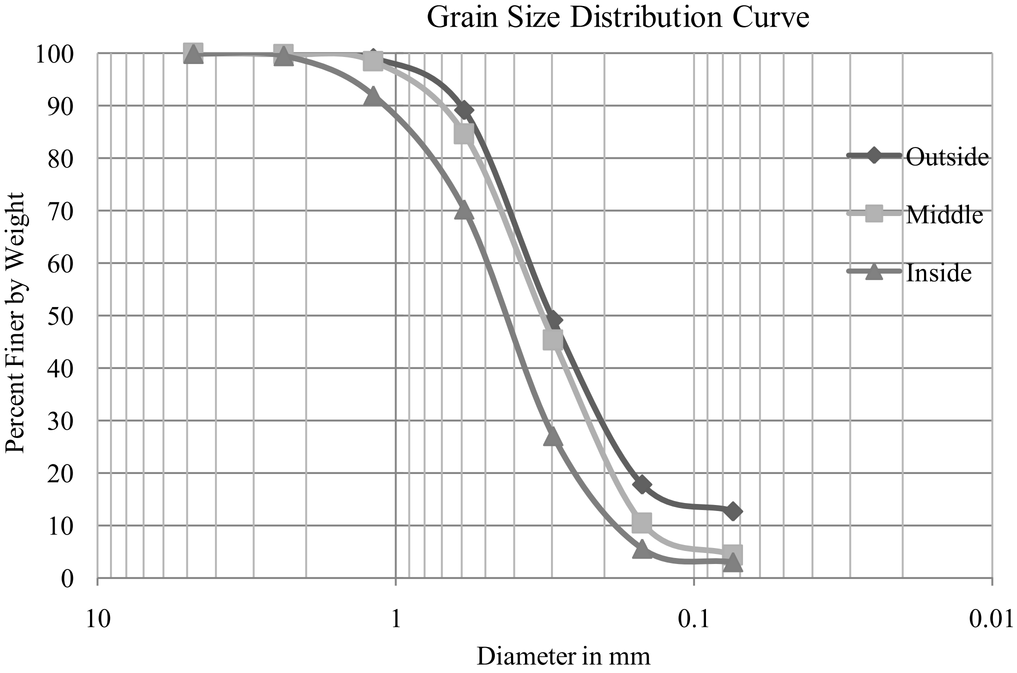


Figure 4.6 Combined Graph of Sieve Analysis (at the time of implementation)

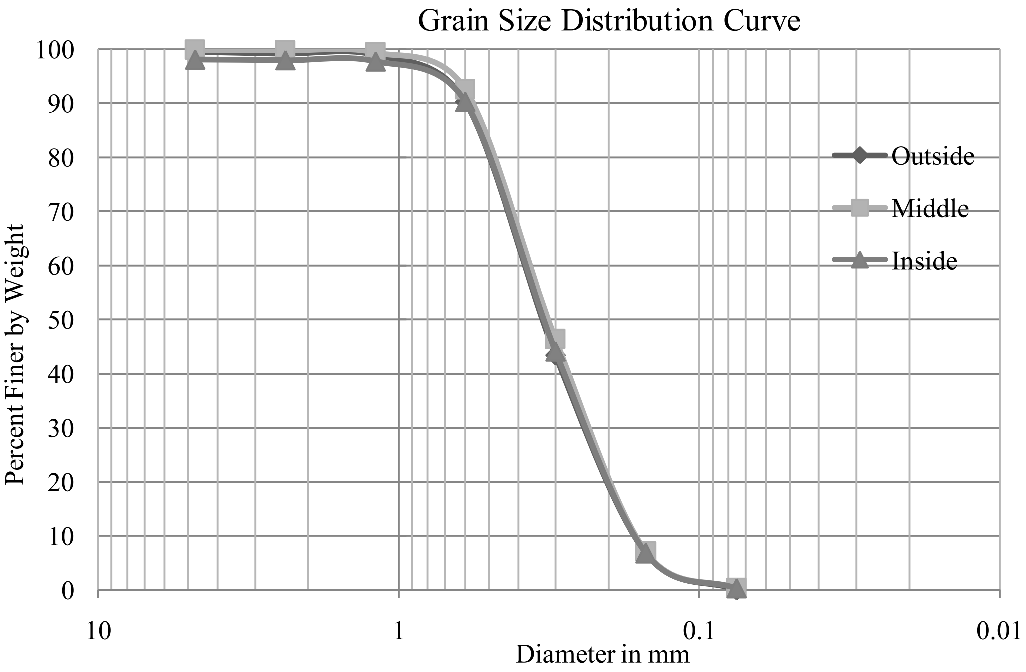


Figure 4.7 Combined Graph after six months (Sample No. 1)

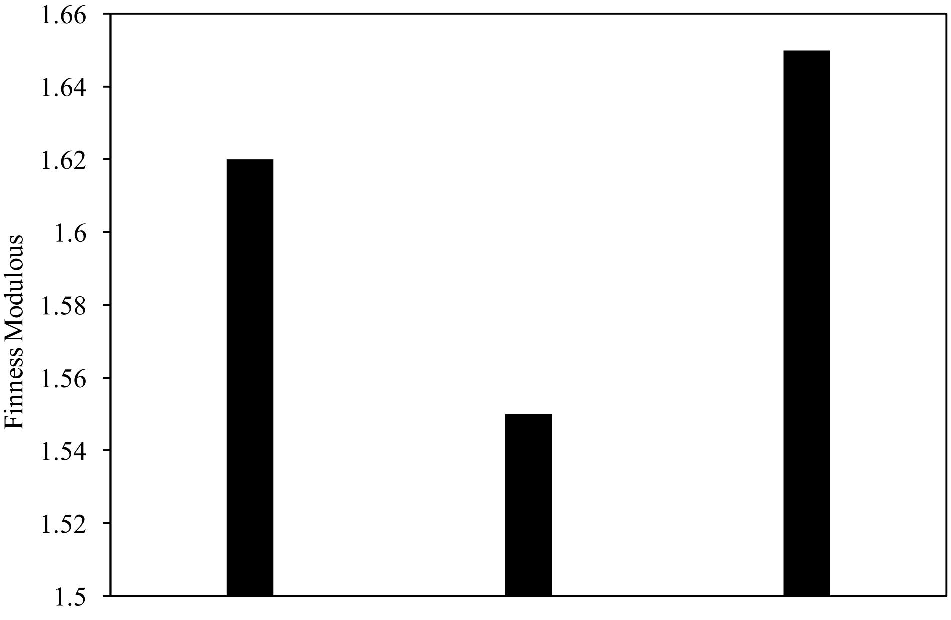


Figure 4.8 Variation of Fineness Modulus (Sample No. 1)

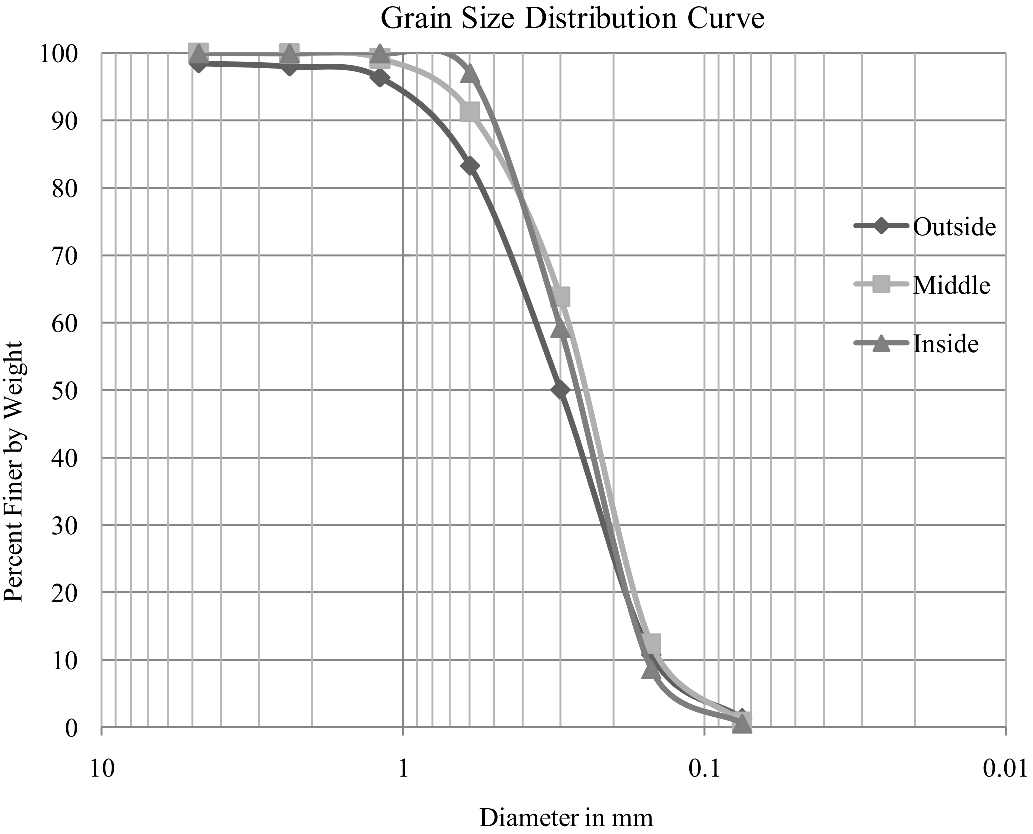


Figure 4.9 Combined Graph after six months (Sample No. 2)

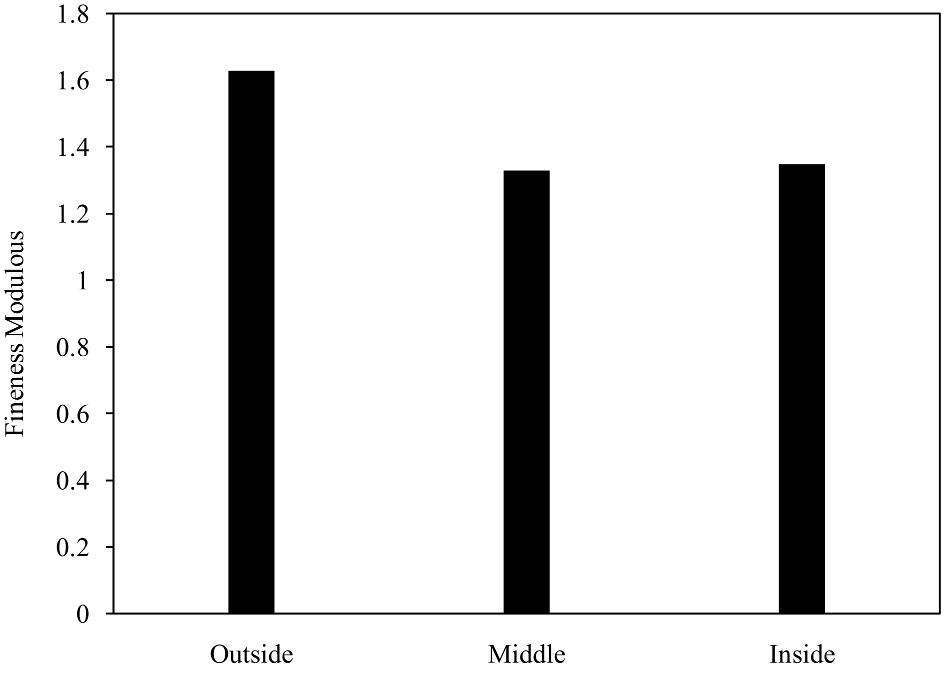


Figure 4.10 Variation of Fineness Modulus (Sample No. 2)

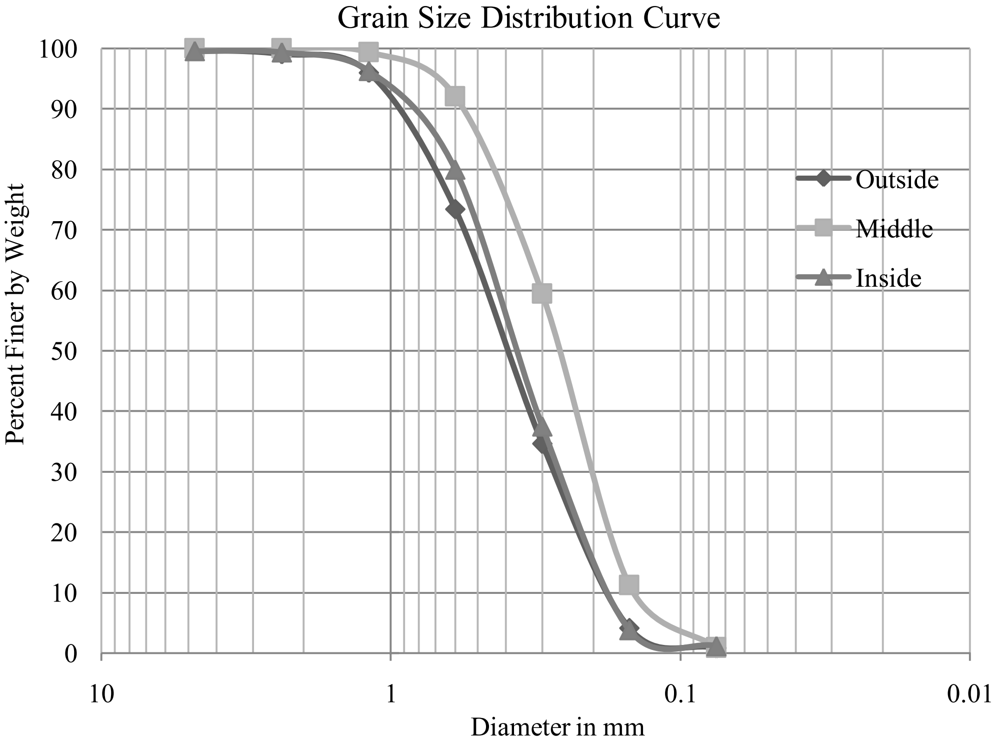


Figure 4.11 Combined Graph after six months (Sample No. 3)

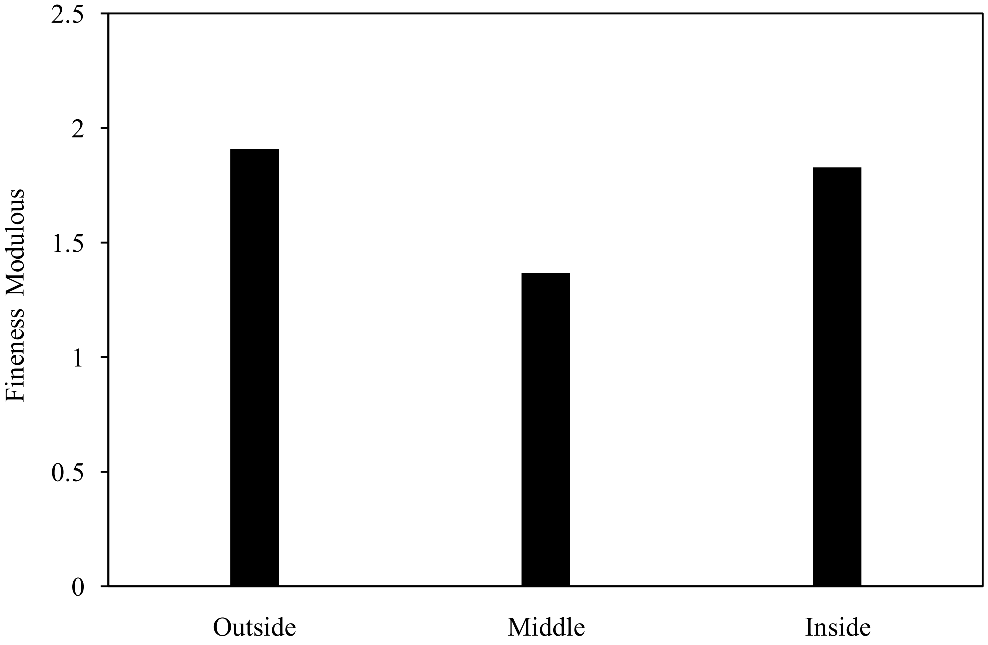


Figure 4.12 Variation of Fineness Modulus (Sample No. 3)

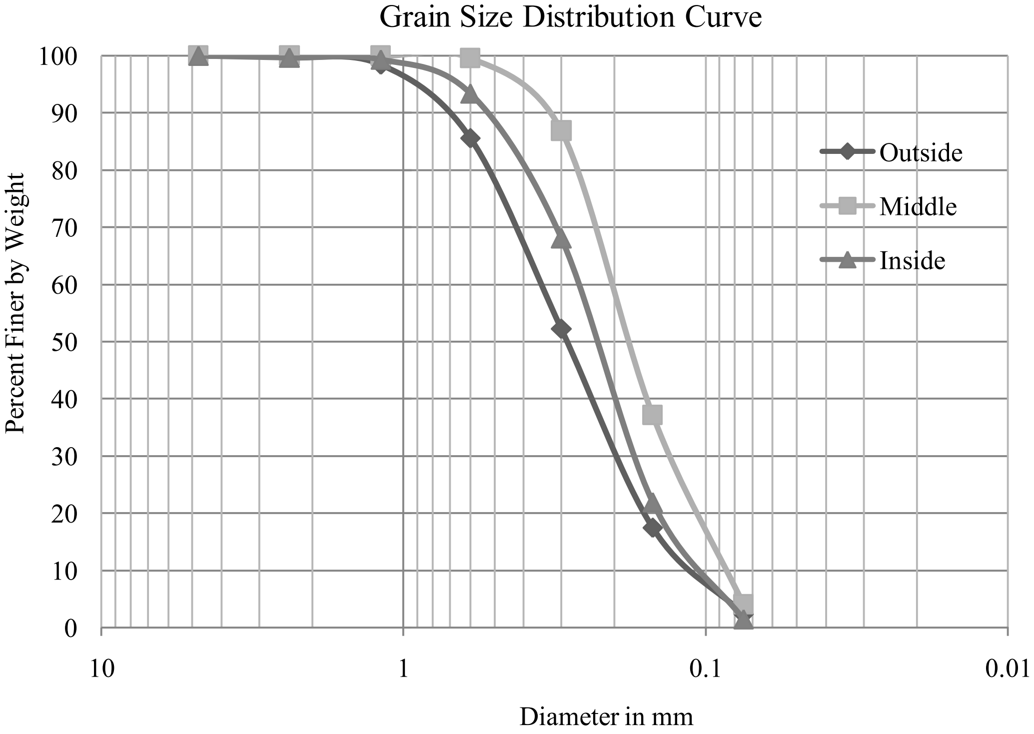


Figure 4.13 Combined Graph after six months (Sample beneath Synthetic Geotextile)

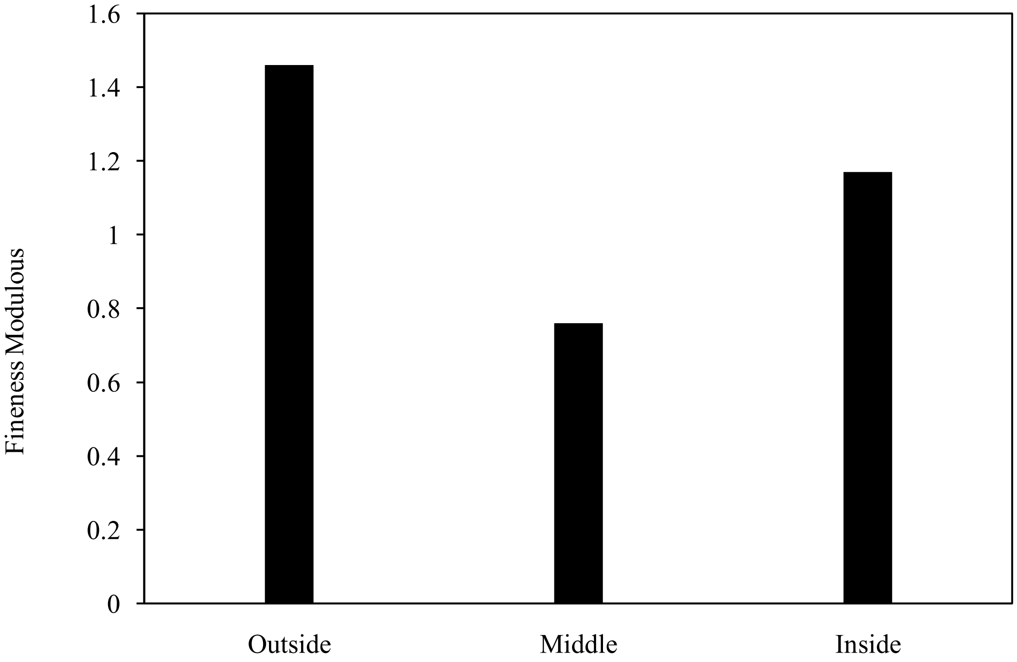


Figure 4.14 Variation of Fineness Modulus (Sample beneath Synthetic Geotextile)

Considering the second approach (investigation after two years), from the column charts it was found that in case of one sample, fineness modulus of outside soil layer are higher than those of middle and inside soil layers. As it is known that a smaller value of fineness modulus indicates the presence of larger proportions of finer particles, so from fineness modulus charts it can also be said that, filter cake has been formed partially.

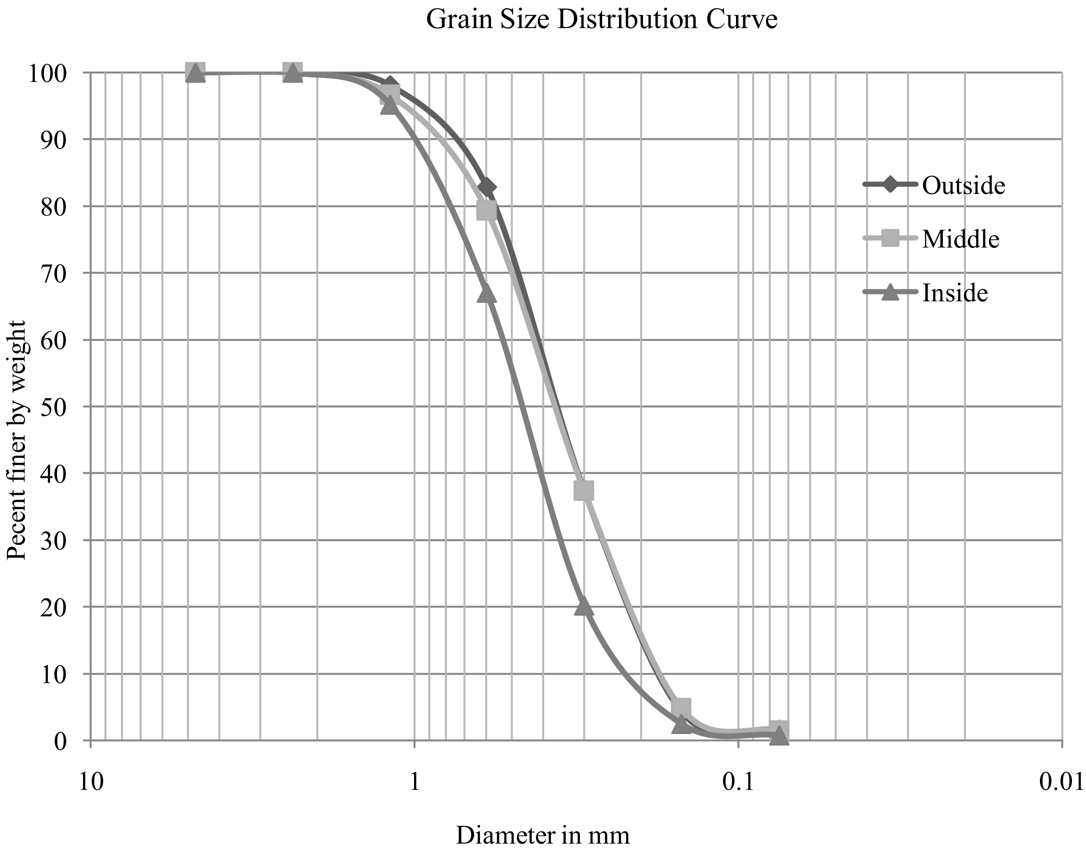


Figure 4.15 Combined Graph after two years (Sample No. 1)

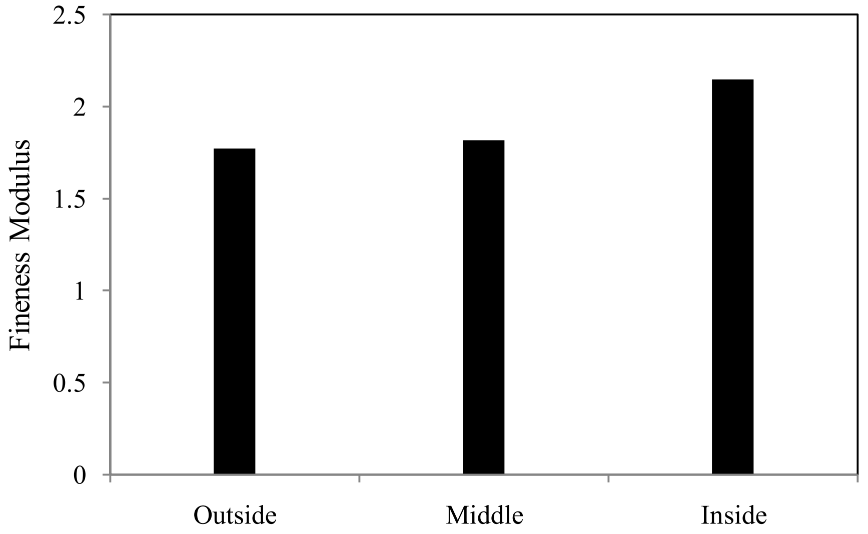


Figure 4.16 Variation of Fineness Modulus after two years (Sample No. 1)

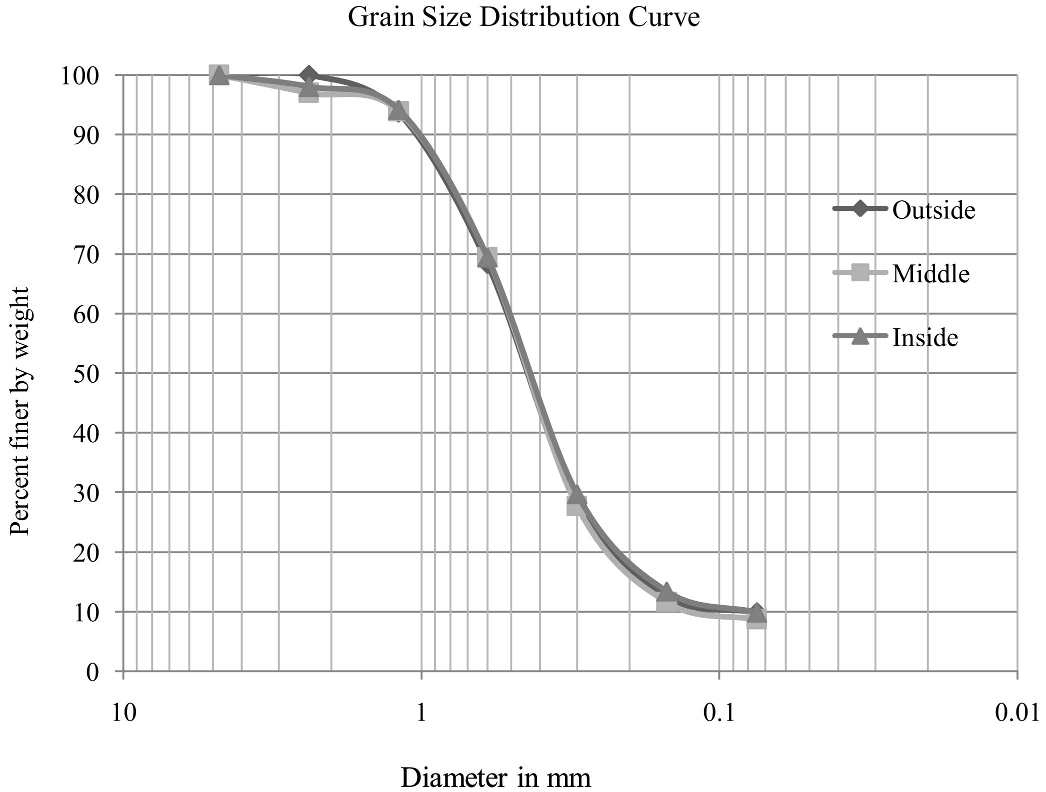


Figure 4.17 Combined Graph after two years (Sample No. 2)

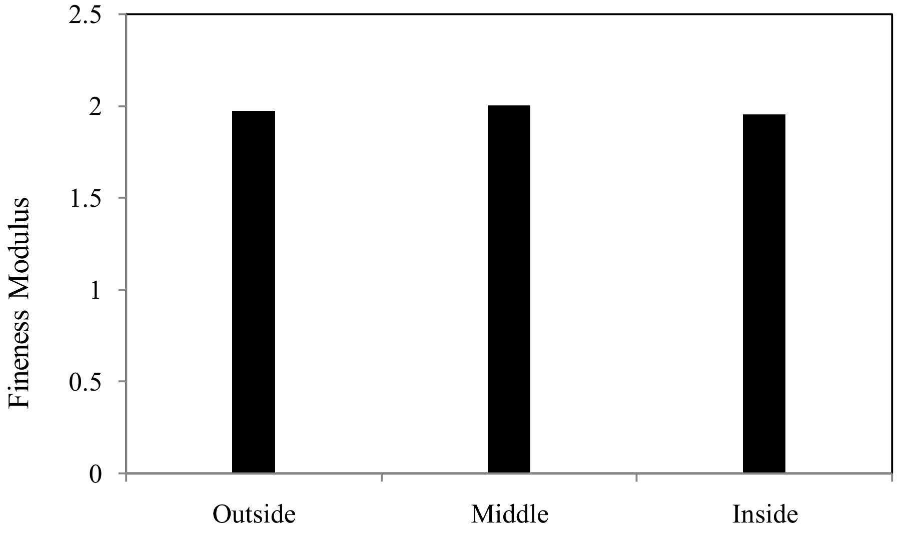


Figure 4.18 Variation of Fineness Modulus after two years (Sample No. 2)

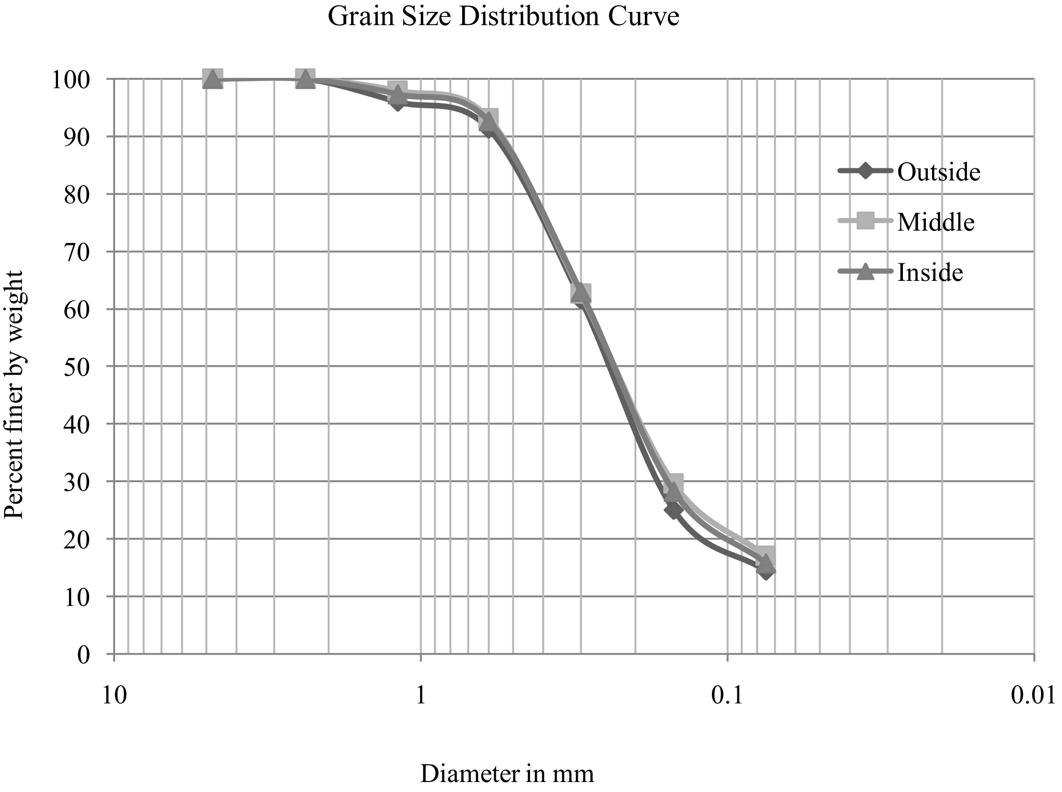


Figure 4.19 Combined Graph after two years (Sample No. 3)

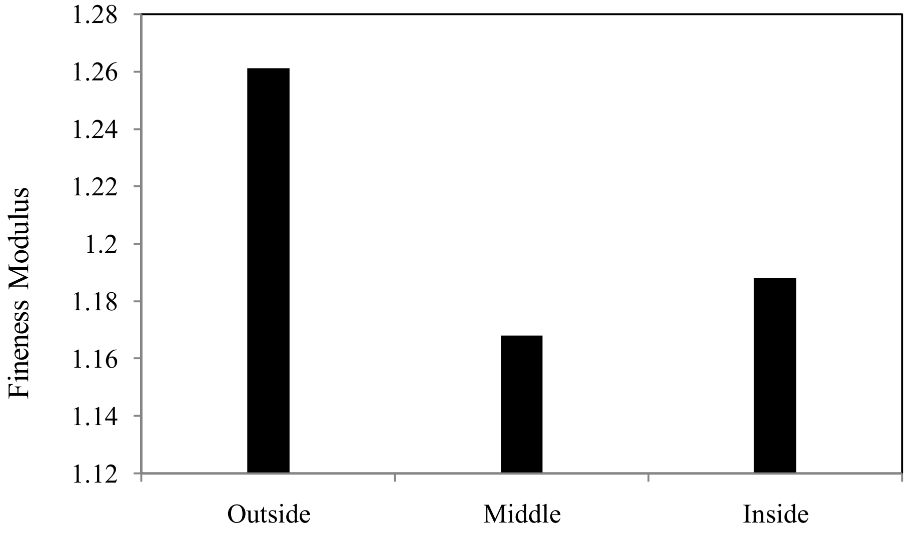


Figure 4.20 Variation of Fineness Modulus after two years(Sample No. 3)

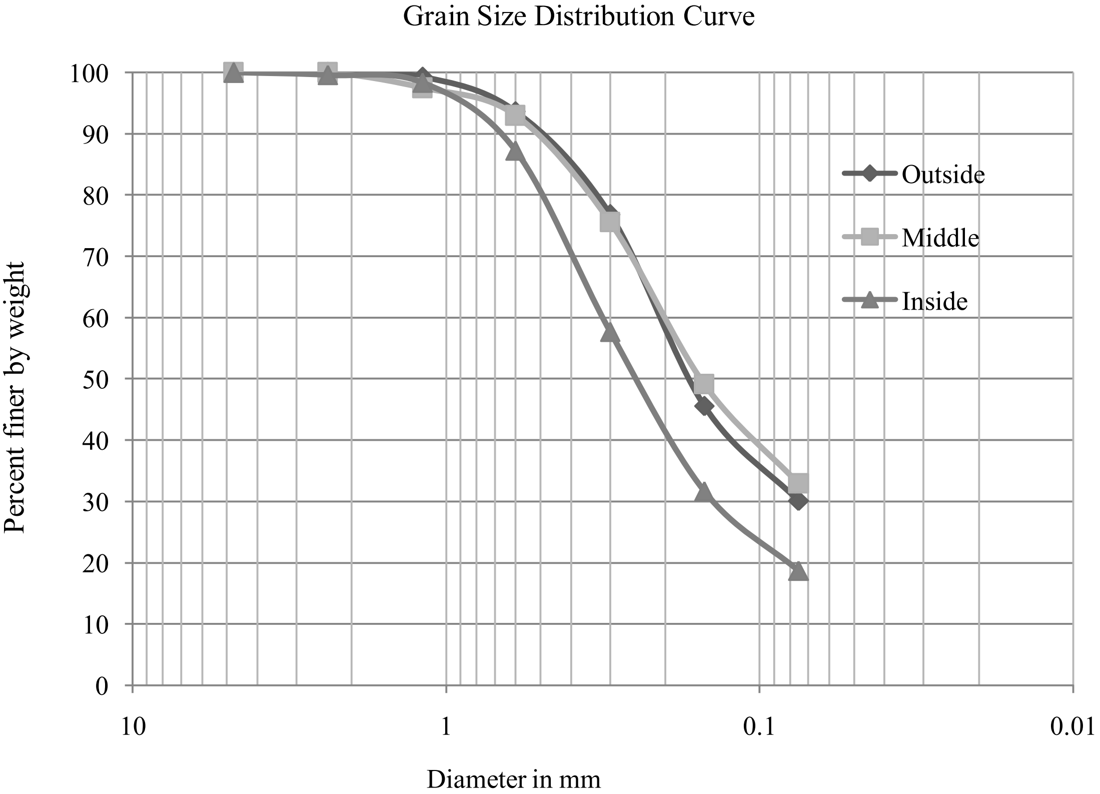


Figure 4.21 Combined Graph after two years (Sample beneath Synthetic Geotextile)

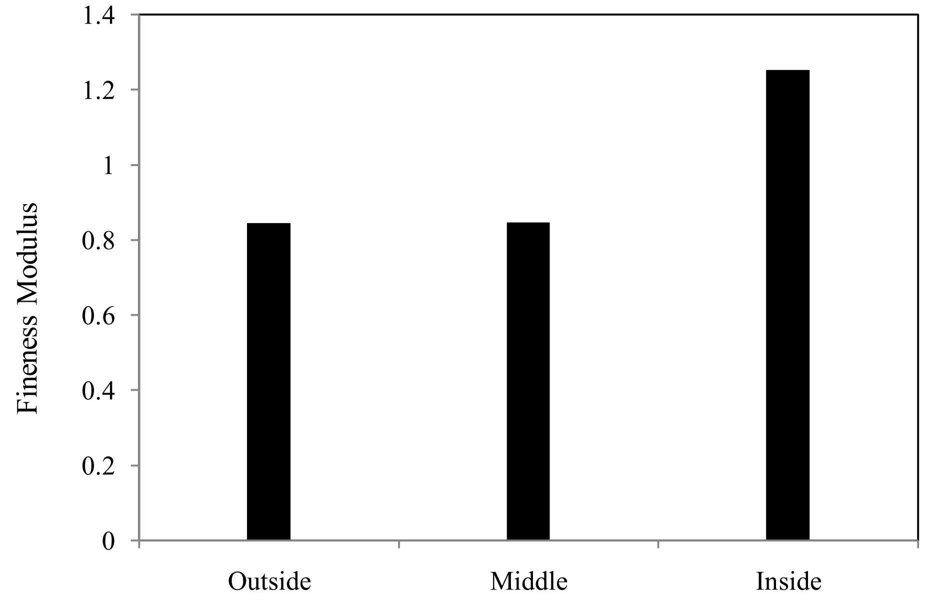


Figure 4.22 Variation of Fineness Modulus after two years(Sample beneath Synthetic Geotextile)

4.3.4 Comparison of Fineness Modulus in different times (Field Trial)

From Figure 4.23 and 4.24 the variation of soil particle size can be shown for sample 1. At outside portion the percentage of large particles increased after initial stage. This was caused due to bridging of large soil particles over JGT. At middle portion the percentage of fine particles increased after first inspection but decreased after second inspection. Same thing happened in case of inside portion. The reason was migration of soil particles due to reversing flow condition.

In case of sample 2 shown in Figure 4.25 and 4.26, at outside portion the percentage of large particles increased after initial stage. This was caused due to bridging of large soil particles over JGT.

At middle portion the percentage of fine particles increased after first inspection but decreased after second inspection. Same thing happened in case of inside portion. The reason was migration of soil particles due to reversing flow condition.

From Figure 4.27 and 4.28 (Sample 3) it can be seen that at outside portion the percentage of large particles increased after initial stage but decreased after two years.

This was caused due to bridging of large particles after initial stage and migration of soil particles. Both at middle and inside portion percentage of fine soil particles increased after initial stage. The reason was migration of soil particles due to reversing flow condition.

From Figure 4.29 and 4.30 (Sample 4) it can be seen that at outside portion particle size was almost same after initial stage but percentage of fine soil particles increased after two years. In case of both middle and inside portion percentage of fine soil particles increased after initial stage but percentage of large particles increased after two years. The reason was migration of soil particles due to reversing flow condition.

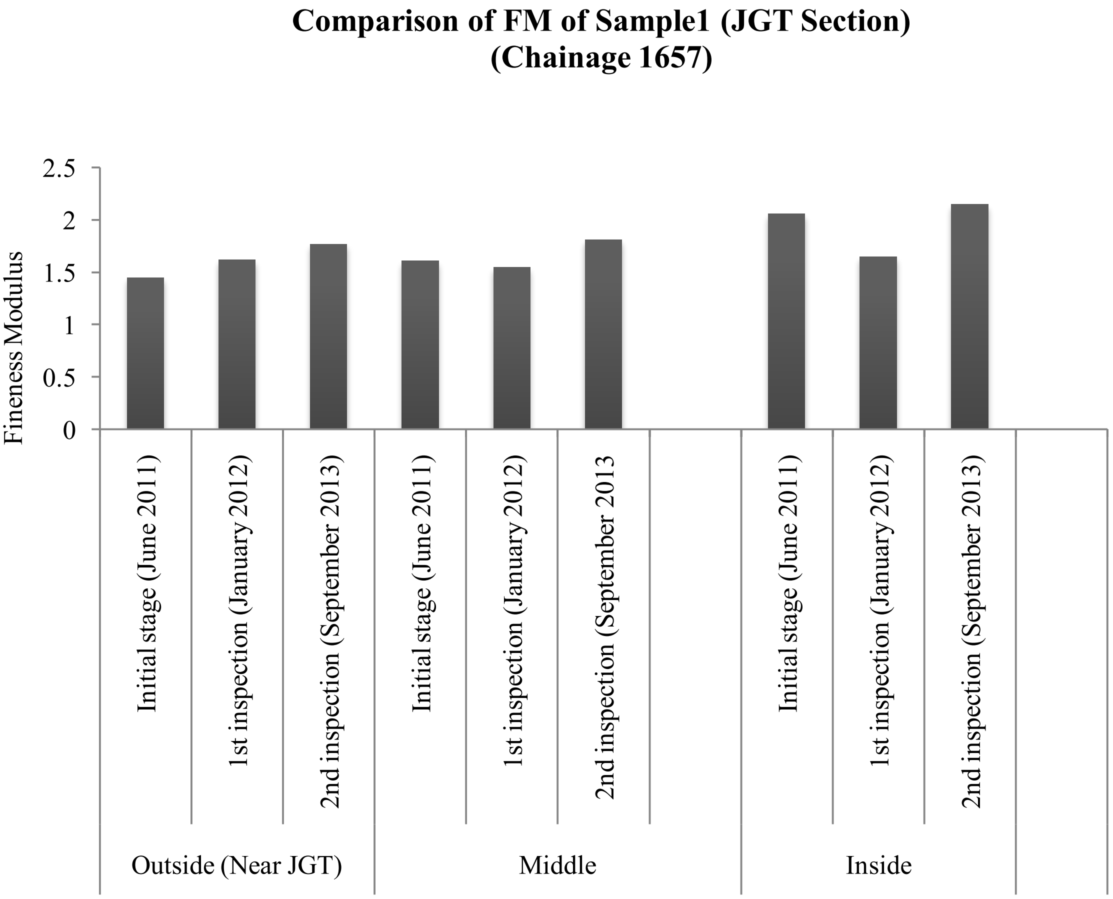


Figure 4.23 Comparison of Fineness Modulus of Sample 1

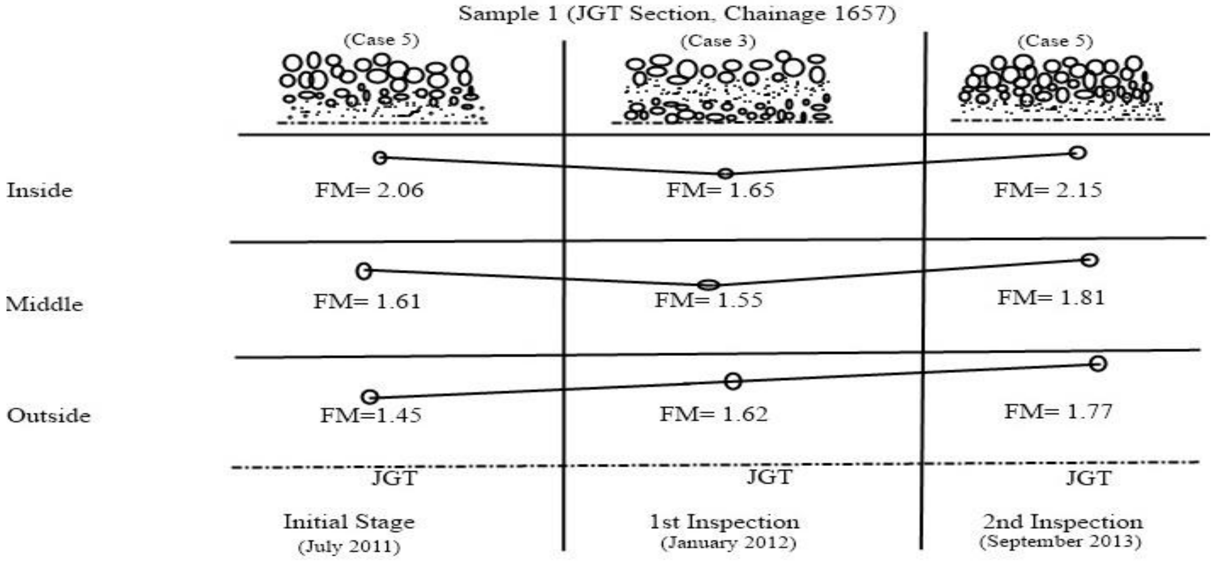


Figure 4.24 Profiling of Change of Grain Size Distribution (Sample 1)

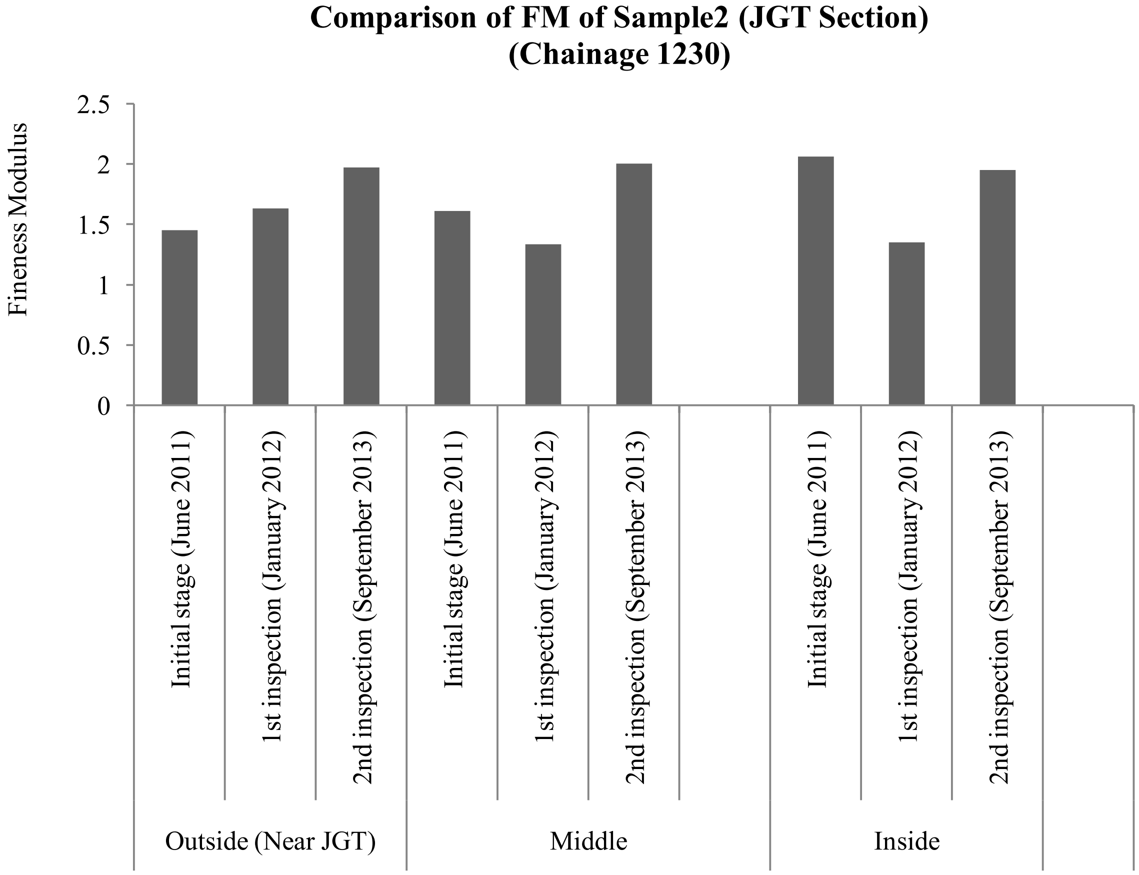


Figure 4.25 Comparison of Fineness Modulus of Sample 2

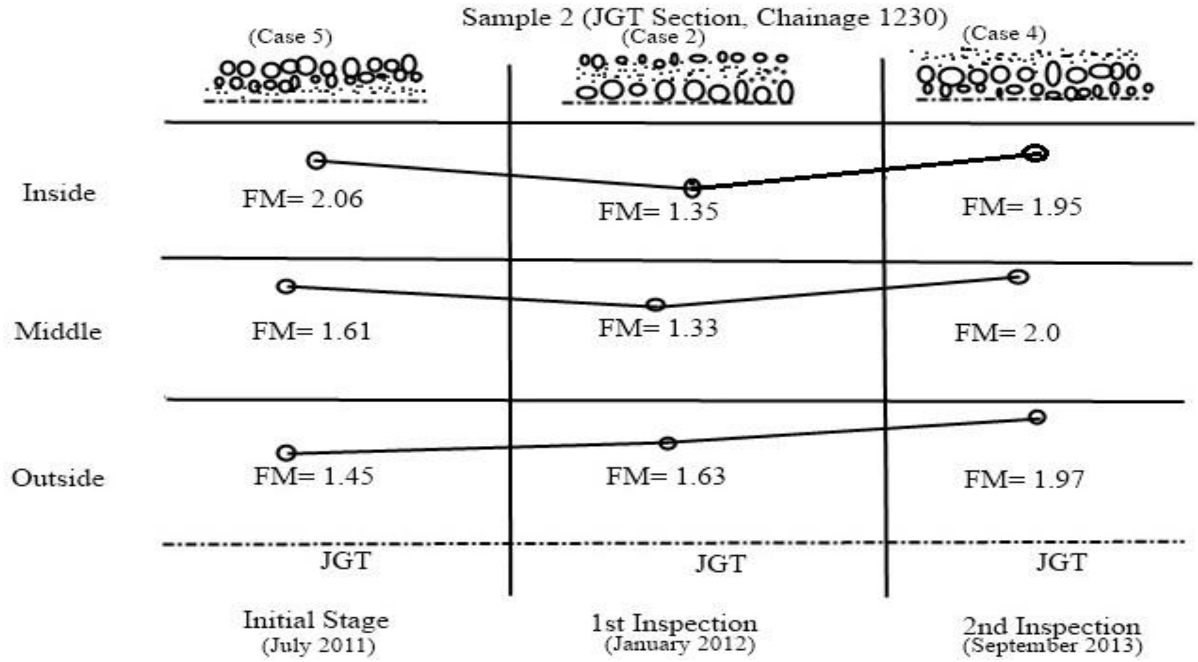


Figure 4.26 Profiling of Change of Grain Size Distribution (Sample 2)

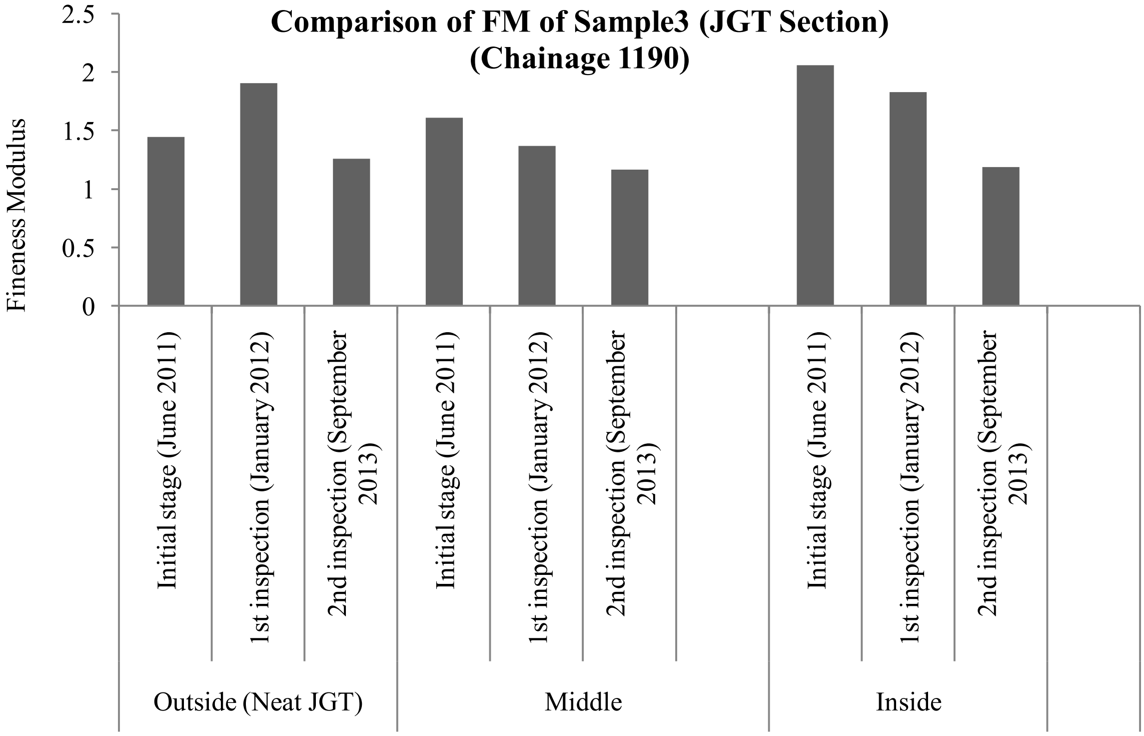


Figure 4.27 Comparison of Fineness Modulus of Sample 3

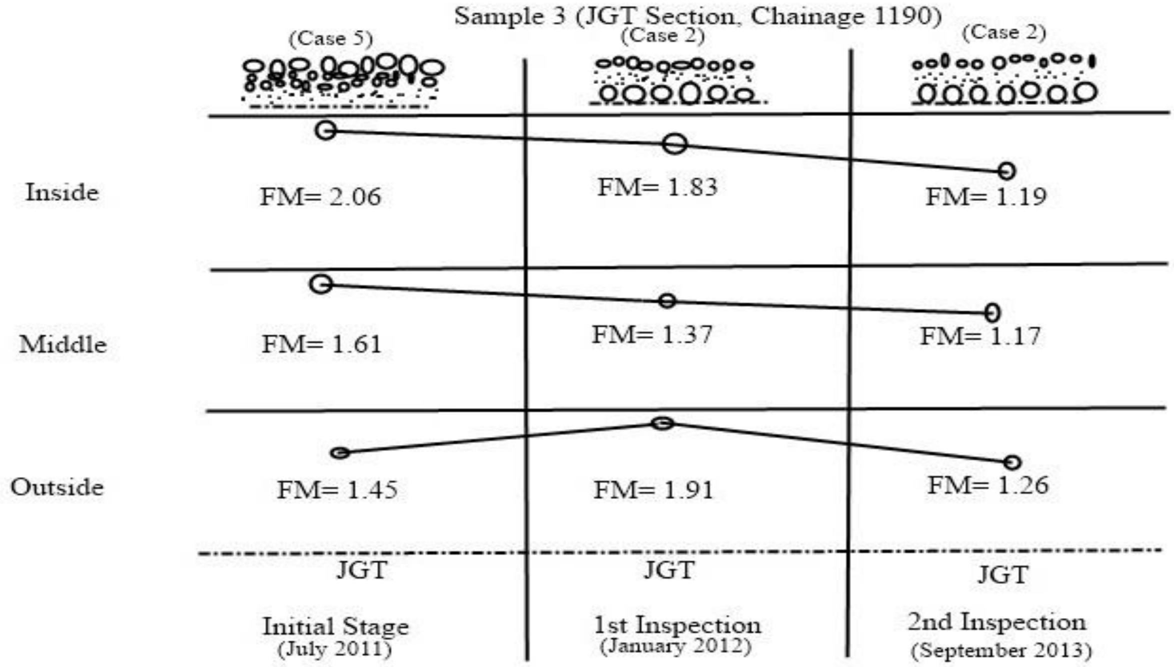


Figure 4.28 Profiling of Change of Grain Size Distribution (Sample 3)

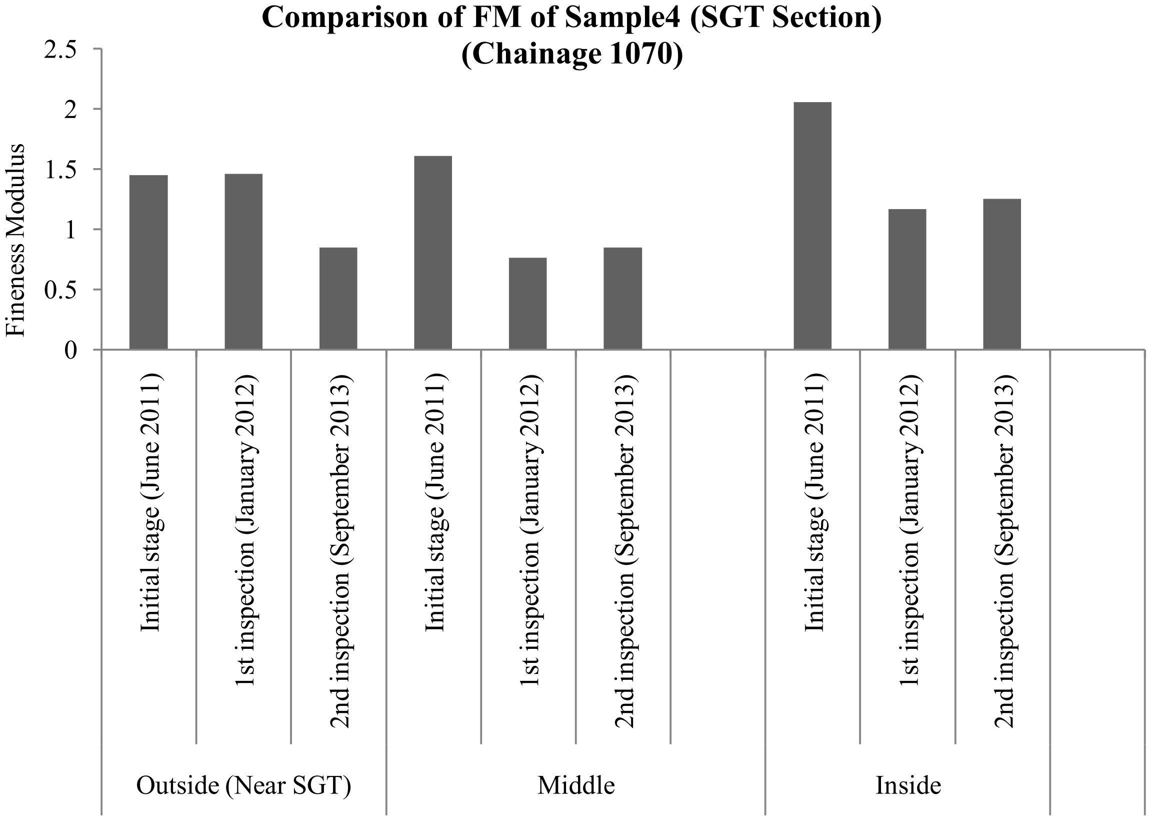


Figure 4.29 Comparison of Fineness Modulus of Sample 4

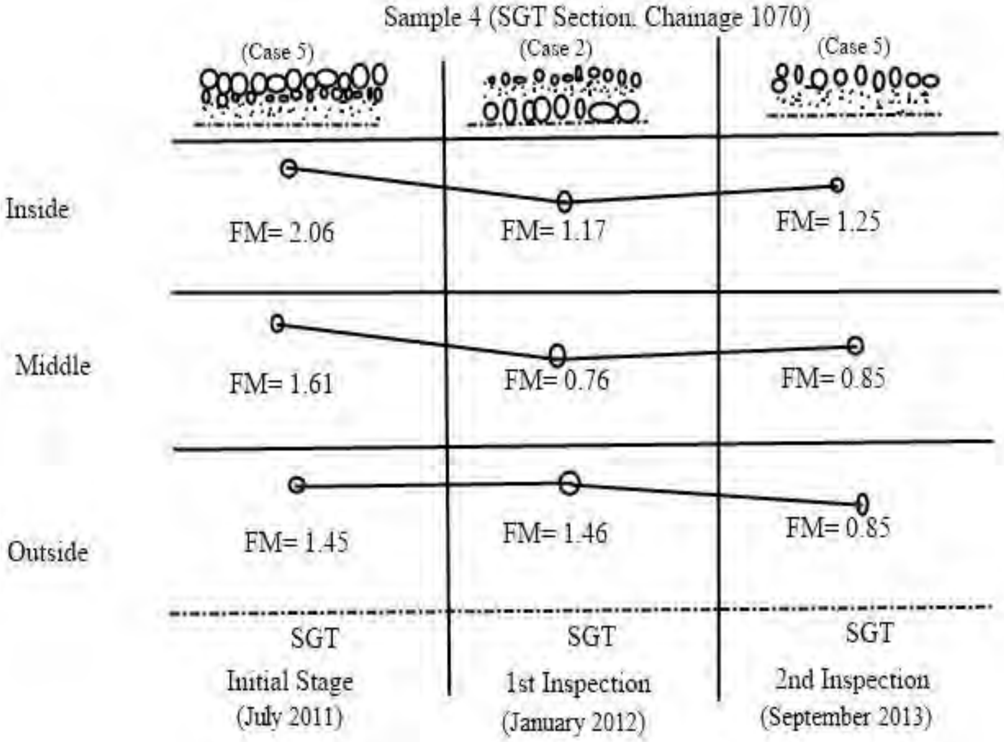


Figure 4.30 Profiling of Change of Grain Size Distribution (Sample 4)

4.3.5 Investigation on Formation of Filter Cake (Laboratory Simulation)

To investigate about the formation of soil filter cake in laboratory condition, a model was arranged using brick chips, JGT and soil. Water was flown through the system for seven days. Then sieve analysis of the soil sample collected from the model was performed. The combined graph of the soil sample at initial stage is shown in Fig. 4.31.The combined graph of the soil sample 7 day simulation is shown in Fig. 4.32.Variation of F.M. is also shown in Fig. 4.33. Another simulation was performed for 2 weeks. The combined graph of the soil sample is shown in Fig. 4.34. Variation of F.M. is also shown in Fig. 4.35.

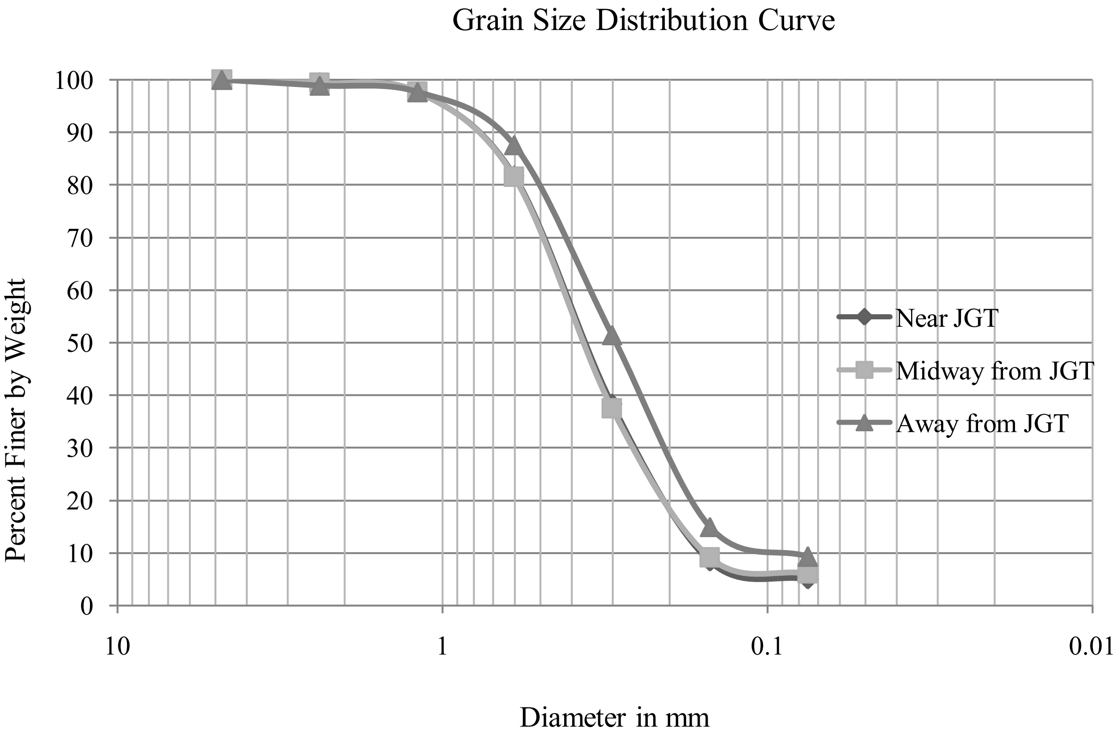


Figure 4.31 Combined Graph at initial stage (Laboratory Simulation)

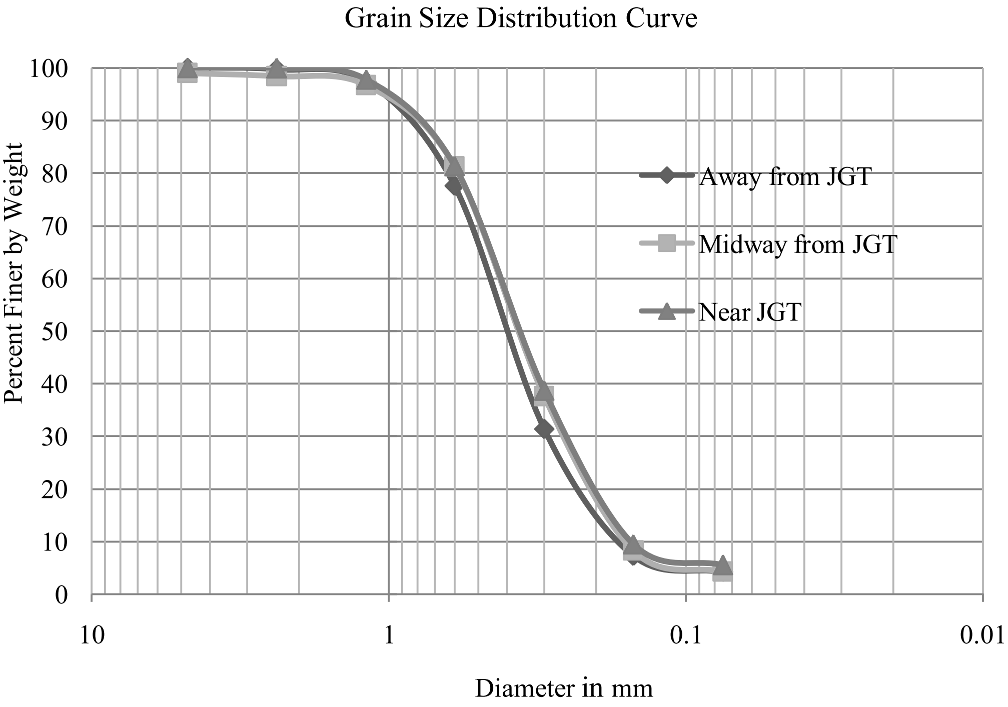


Figure 4.32 Combined Graph after 7 days (Laboratory Simulation)

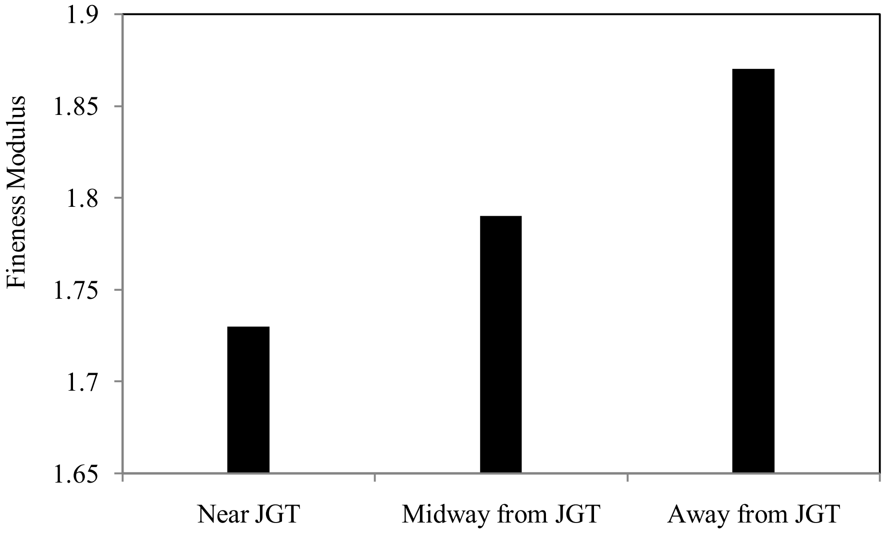


Figure 4.33 Variation of Fineness Modulus (7 day Laboratory Simulation)

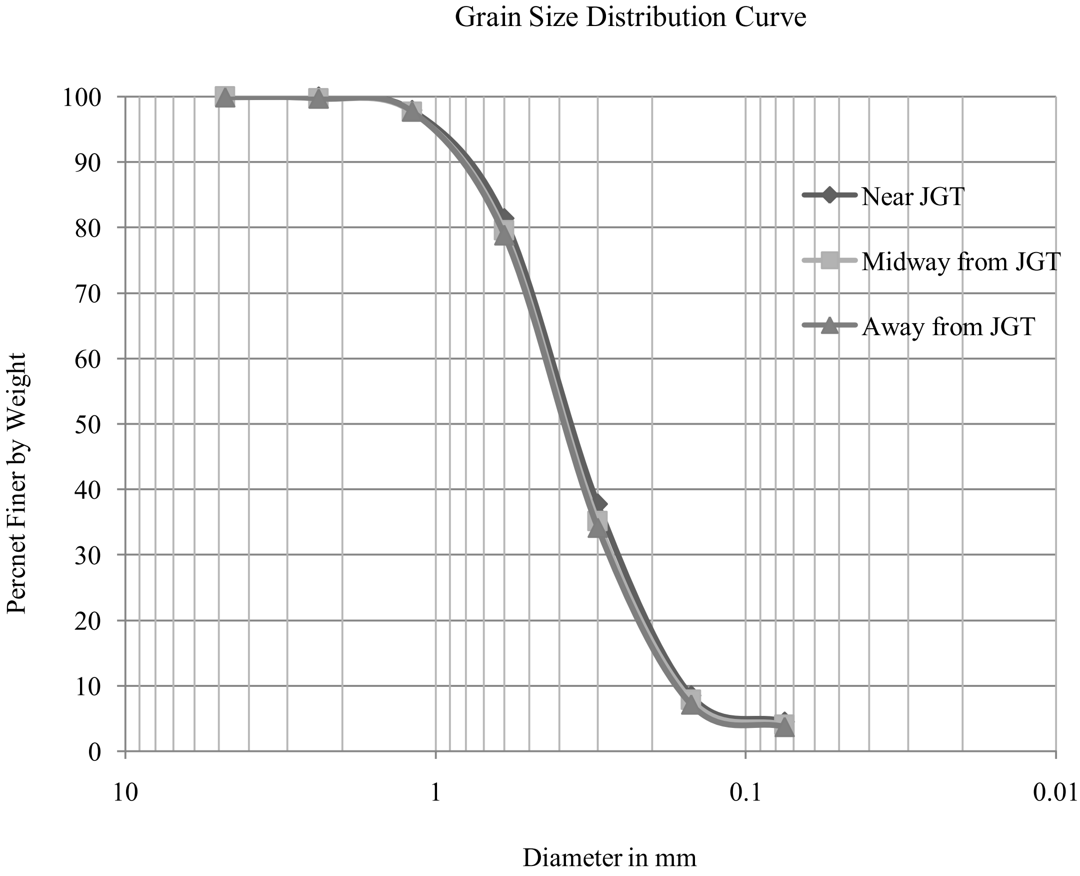


Figure 4.34 Combined Graph after 14 days (Laboratory Simulation)

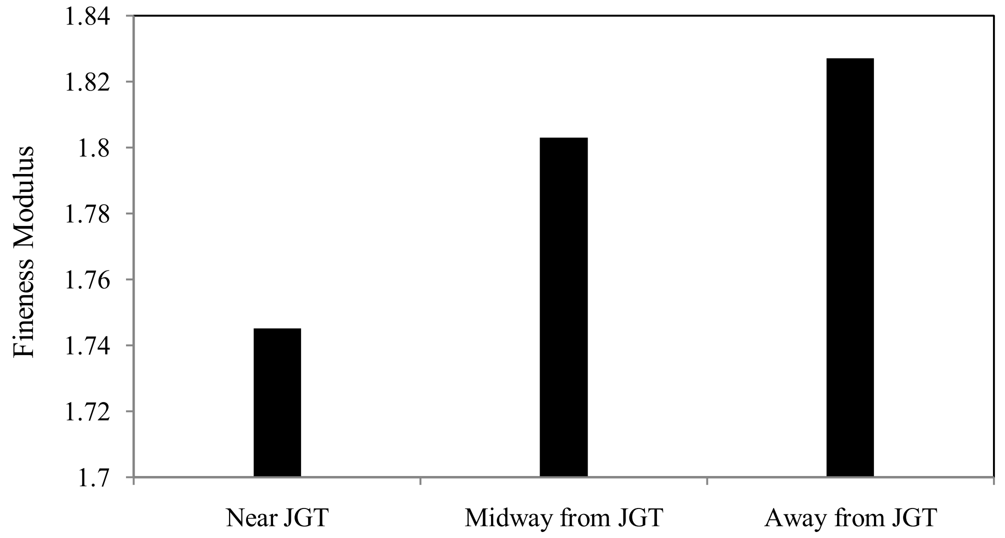


Figure 4.35 Variation of Fineness Modulus (14 day Laboratory Simulation)

4.3.6 Discussion about Laboratory Simulation

From the combined graph and variation of fineness modulus, we can see that, after 7 days, soil particle size near JGT is the finest and the soil particles of midway from JGT are coarser than that of near JGT and the particles of away from JGT are greater than that of the midway from JGT, which is a criterion of partial filter cake. Same case happens in case of 14 day simulation. So it can be said that partial filter cake has been formed.

4.3.7Comparison of Fineness Modulus in different times (Laboratory Simulation)

From Figure 4.36 and 4.37 it can be seen that at initial stage there were medium size soil particles near JGT, at midway from JGT there were large particles and away from JGT there were fine particles. After 7 day simulation Near JGT portion, the percentage of fine particles increased after initial stage and after 14 day simulation same situation remained. At midway from JGT portion the percentage of medium particles increased after initial stage and it remained same after 14 day simulation. In case of away from JGT portion, percentage of medium size particles increased after 7 day simulation and it remained same after 14 day simulation. The reason was migration of soil particles. In both cases partial soil filter cake formed.

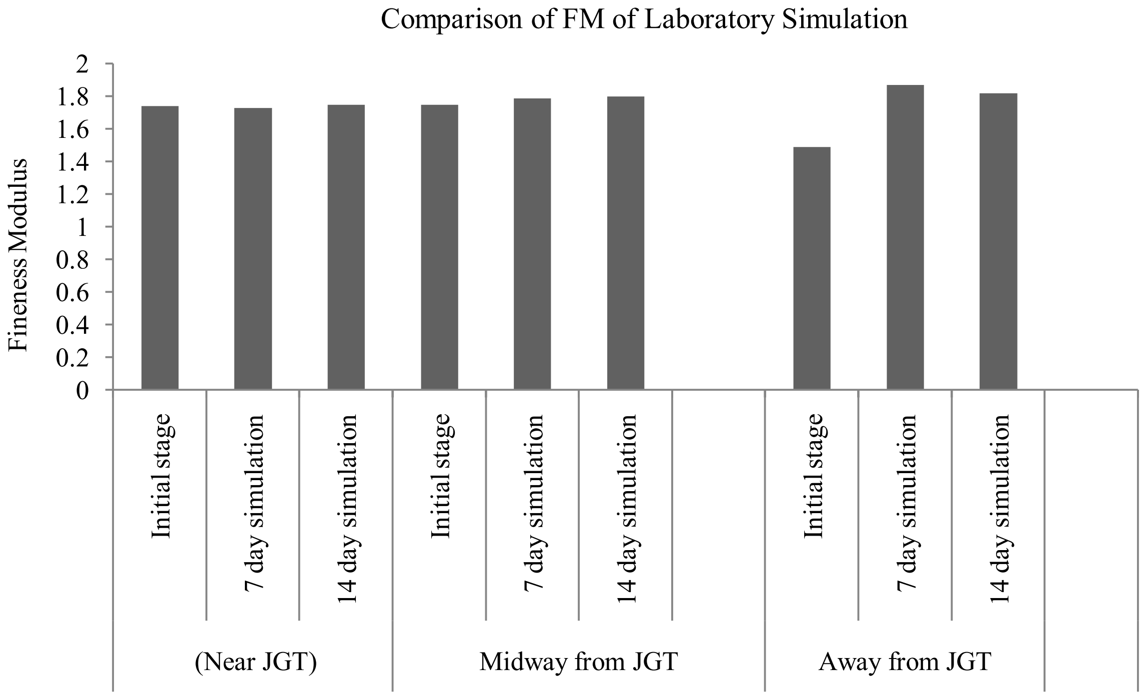


Figure 4.36 Variation of Fineness Modulus (14 day Laboratory Simulation)

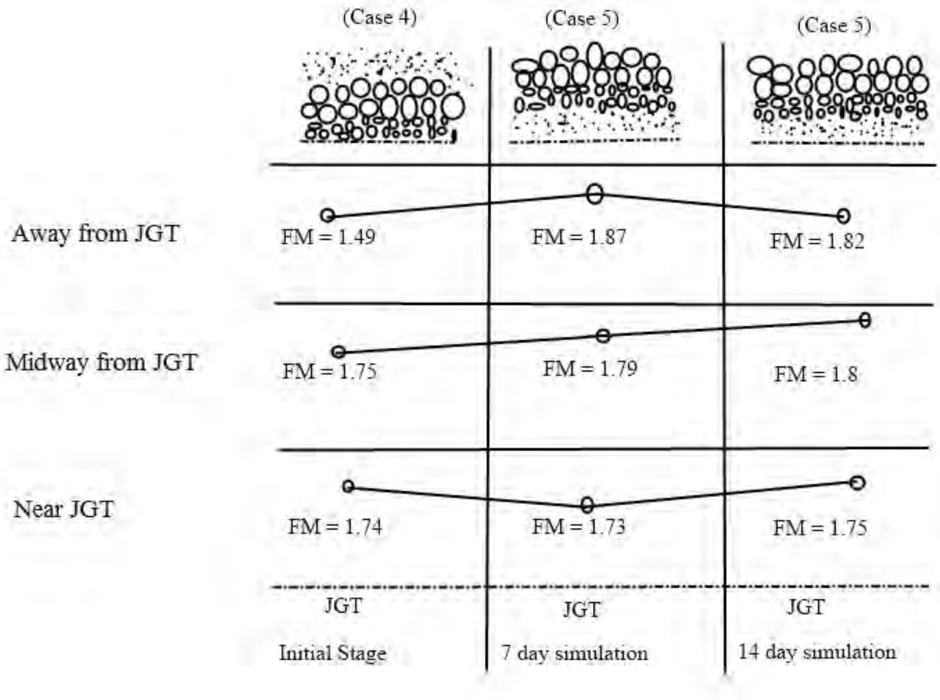


Figure 4.37 Profiling of Change of Grain Size Distribution (Laboratory Simulation)

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The investigation on formation of soil filter cake is the main concern of this study. To this end, two types of JGT samples were selected. One was untreated A. Twill cloth and the other one was treated A. Twill cloth. Total six property tests were performed for each of the samples. Besides, sieve analysis of soil samples were performed to check the formation of filter cake. Both field trial and laboratory simulation were conducted. The findings of the study are as follows:

a) From the field trial, it was found that after first inspection, i.e. after six months of implementation, filter cake formed partially. The second inspection was carried out after two years of implementation and it was found that previously formed filter cake was still in existence without losing its required characteristics.

   From one laboratory simulation, it was found that after seven days of reversible water flow, filter cake formed partially. In another simulation, it was found that filter cake formed partially even after fourteen days of reversible flow.

b) From field trial, it was found that filter cake formed partially within six months of implementation and the river bank was found to be in good shape (no sign of physical distress, ground subsidence etc.) even after two years. This indicates satisfactory durability of the filter cake which formed after six months of implementation.

c) Since from both field trial and laboratory simulations it was found that filter cake formed partially beneath JGT filter, therefore it may be suggested that JGT may be envisaged as an alternative to synthetic geotextiles as filter material for protection of banks of mild to moderate rivers.

   Also, the physical properties (Mass per Unit Area, Nominal Thickness etc.), mechanical properties (Wide Width Strip Tensile Stress, CBR Puncture

Resistance etc.) and hydraulic properties (Apparent Opening Size, Permittivity etc.) of JGT were adequate as filter material. Therefore, JGT may be used as an alternative to synthetic geotextile as filter material for river bank protection.

5.2 Recommendations for Future Research

a) Further field trials may be undertaken in order to investigate about formation of fully efficient filter cake and the time required for its formation.
b) Laboratory simulation can also be performed for a longer period of time to investigate about the formation of filter cake.

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Appendix A
Test Results

Table A1: Mass per Unit Area of JGT

Type of JGT	Specimen No.	Mass of specimen (gm)	Length of specimen, (m)	Width of specimen, (m)	Mass per unit area, m (gram per meter square)	Average mass per unit area (gram per meter square)
Untreated A. Twill cloth	1	55	0.28	0.25	785.71	
	2	60	0.29	0.27	766.28	
	3	40	0.26	0.21	732.6	767
	4	35	0.26	0.17	791.86	
	5	55	0.29	0.25	758.62	
Treated A. Twill cloth	1	50	0.2	0.2	1250	
	2	95	0.29	0.26	1259.95	
	3	90	0.29	0.27	1149.43	1177
	4	85	0.29	0.28	1046.8	
	5	82	0.28	0.25	1176.89	

Table A2: Nominal Thickness of JGT

Type of JGT	Specimen No.	Initial reading of dial gauge	Final reading of dial gauge	Thickness of specimen = (Final reading – Initial reading)*0.01 (mm)	Average thickness (mm)
Untreated A. Twill cloth	1	0	182	1.82	
	2	0	185	1.85	
	3	0	171	1.71	
	4	0	180	1.8	
	5	0	185	1.85	
	6	0	183	1.83	1.82
	7	0	178	1.78	
	8	0	179	1.79	
	9	0	181	1.81	
	10	0	195	1.95	
Treated A. Twill cloth	1	0	295	2.95	
	2	0	327	3.27	
	3	0	326	3.26	
	4	0	346	3.46	
	5	0	333	3.33	3.24
	6	0	315	3.15	
	7	0	330	3.30	
	8	0	318	3.18	
	9	0	325	3.25	
	10	0	323	3.23	

Table A3: Wide-Width Strip Tensile strength of JGT

Type of JGT		Machine direction			Cross machine direction		
	Specimen No.	Load (kg)	Elongation (%)	Elongation (mm)	Load (kg)	Elongation (%)	Elongation (mm)
Untreated A. Twill cloth	1	590	11.3	11.3	470	10.5	10.5
	2	570	11.5	11.5	490	11.5	11.5
	3	580	10.9	10.9	496	10.2	10.2
	4	575	11.4	11.4	480	11.2	11.2
	5	585	11.5	11.5	490	10.3	10.3
	Average load (kg)	580		11.32	485.2		10.74
	Wide-Width strip tensile strength = $\frac{Load*9.8}{200}$ (KN/m)	28.45			23.8		
Treated A. Twill cloth	1	790	11.9	11.9	534	11.9	11.9
	2	762	12	12	440	11.4	11.4
	3	630	11.7	11.7	448	11.2	11.2
	4	704	12.5	12.5	480	10.4	10.4
	5	722	12.1	12.1	476	11.3	11.3
	Average load (kg)	721.6		12.04	475.6		11.24
	Wide-Width strip tensile strength = $\frac{Load*9.8}{200}$ (KN/m)	35.4			23.33		

Table A4: CBR Puncture Resistance of JGT

Type of JGT	Specimen No.	Load (kg)	Average load (kg)	CBR puncture resistance = load*9.81 (N)
Untreated A. Twill cloth	1	340		
	2	330		
	3	280		
	4	390		
	5	370	343	3365
	6	350		
	7	340		
	8	350		
	9	330		
	10	350		
Treated A. Twill cloth	1	460		
	2	410		
	3	394		
	4	430		
	5	445	421.3	4133
	6	404		
	7	410		
	8	400		
	9	425		
	10	435		

Table A5: Permittivity of JGT

Type of JGT	Specimen No.	Diameter of specimen, d (mm)	Area of specimen A= $\frac{\pi d^2}{4}$ (mm^2)	Collection time, (second)					Average time, t (sec)	Permittivity $\psi = \frac{Q}{hAt}$ (s^{-1})	Average permittivity (s^{-1})
				1	2	3	4	5			
Untreated A. Twill cloth	1	105	8659	53	53	54	53	53	53.2	0.26	
	2	105	8659	51	50	52	51	50	50.8	0.27	
	3	105	8659	53	53	53	53	53	53	0.26	0.26
	4	105	8659	56	57	57	58	58	57.2	0.24	

Table A6: Permittivity of JGT

Type of JGT	Specimen No.	Diameter of specimen, d (mm)	Area of specimen A= $\frac{\pi d^2}{4}$ (mm^2)	Collection time, (second)					Average time, t (sec)	Permittivity $\psi = \frac{Q}{hAt}$ (s^{-1})	Average permittivity (s^{-1})
				1	2	3	4	5			
Treated A. Twill cloth	1	105	8659	75	75	75	75	75	75	0.18	
	2	105	8659	79	83	81	83	83	81.8	0.17	
	3	105	8659	76	73	76	75	76	75.2	0.18	0.17
	4	105	8659	86	87	88	85	87	86.6	0.16	

Table A7 Apparent Opening Size of JGT

Sieve No.	Soil Particle size (mm)	Weight of passing sand (gm)			Average weight of passing sand (gm)	% Finer	% Retained
		Specimen No.1	Specimen No.2	Specimen No.3			
#8 - #16	2.38-1.19	-	-	-	-	-	-
#16 - #30	1.19 – 0.6	-	-	-	-	-	-
#30 - #50	0.6 – 0.3	-	-	-	-	-	-
#50 - #100	0.3 – 0.15	2.5	0.5	0	1	2	98
#100- #200	0.15-0.07	5.09	14.22	8.55	9.29	18.58	81.42

So, the Apparent Opening Size of the Untreated A. Twill cloth is in between 0.3-0.15 mm.

For Treated A. Twill cloth:

Table A8

Sieve No.	Soil Particle size (mm)	Weight of passing sand (gm)			Average weight of passing sand (gm)	% Finer	% Retained
		Specimen No.1	Specimen No.2	Specimen No.3			
#16 - #30	1.19 – 0.6	-	-	-	-	-	-
#30 - #50	0.6 – 0.3	-	-	-	-	-	-
#50 - #100	0.3 – 0.15	0.7	0	0	0.23	0.46	99.54

So, the Apparent Opening Size of the Treated A. Twill cloth is in between 0.3-0.15 mm.

Sieve Analysis of Soil Samples for Field Trial (At the time of implementation)

Depth : 5”

Table A9: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	1	0.2	0.2	99.8
#16	1.19	3.2	0.7	0.9	99.1
#30	0.59	42.4	9.9	10.8	89.2
#50	0.297	171.3	40.1	50.9	49.1
#100	0.149	133.5	31.3	82.2	17.8
#200	0.074	21.6	5.1	87.3	12.7

Depth : 1‘

Table A10: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0.8	0.2	0.2	99.8
#16	1.19	5.8	1.3	1.5	98.5
#30	0.59	61	13.9	15.4	84.6
#50	0.297	172.2	39.3	54.7	45.3
#100	0.149	152.8	34.9	89.6	10.4
#200	0.074	26.7	6.1	95.7	4.3

Depth : 2‘

Table A11: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0.4	0.1	0.1	99.9
#8	2.38	2.1	0.4	0.5	99.5
#16	1.19	36.4	7.5	8	92
#30	0.59	105.4	21.7	29.7	70.3
#50	0.297	213	43.2	72.9	27.1
#100	0.149	104.4	21.5	94.4	5.6
#200	0.074	12.6	2.6	97	3

Sieve Analysis of Soil Samples for Field Trial (After 6 months of implementation)

Sample No. 1 Level: Outside

Table A12: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0.4	0.5	0.5	99.5
#8	2.38	0.2	0.3	0.8	99.2
#16	1.19	0.3	0.3	1.1	98.9
#30	0.59	7.2	8.6	9.7	90.3
#50	0.297	39.2	46.9	56.6	43.4
#100	0.149	30.5	36.5	93.1	6.9
#200	0.074	5.9	7.1	100	0

Sample No. 1 Level: Middle

Table A13: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0.1	0.1	0.1	99.9
#8	2.38	0.1	0.1	0.2	99.8
#16	1.19	0.3	0.4	0.6	99.4
#30	0.59	5.8	6.8	7.4	92.6
#50	0.297	39.4	46.2	53.6	46.4
#100	0.149	33.6	39.3	92.9	7.1
#200	0.074	5.8	6.8	99.7	0.3

Sample No. 1 Level: Inside

Table A14: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	1.5	1.9	1.9	98.1
#8	2.38	0.1	0.1	2	98
#16	1.19	0.2	0.2	2.2	97.8
#30	0.59	6	7.5	9.7	90.3
#50	0.297	37.1	46.2	55.9	44.1
#100	0.149	29.9	37.3	93.2	6.8
#200	0.074	5.2	6.5	99.7	0.3

Sample No. 2 Level: Outside

Table A15: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	1.3	1.5	1.5	98.5
#8	2.38	0.4	0.5	2	98
#16	1.19	1.4	1.6	3.6	96.4
#30	0.59	11	13.1	16.7	83.3
#50	0.297	27.9	33.2	49.9	50.1
#100	0.149	32.9	39.3	89.2	10.8
#200	0.074	7.88	9.4	98.6	1.4

Sample No. 2 Level: Middle

Table A16: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0.1	0.1	0.1	99.9
#16	1.19	0.6	0.7	0.8	99.2
#30	0.59	6.7	7.9	8.7	91.3
#50	0.297	23	27.5	36.2	63.8
#100	0.149	43	51.4	87.6	12.4
#200	0.074	9.7	11.6	99.2	0.8

Sample No. 2 Level: Inside

Table A17: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0	0	0	100
#16	1.19	0	0	0	100
#30	0.59	2.3	2.9	2.9	97.1
#50	0.297	30.1	37.8	40.7	59.3
#100	0.149	40.2	50.6	91.3	8.7
#200	0.074	6.4	8.1	99.4	0.6

Sample No. 3 Level: Outside

Table A18: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0.2	0.2	0.2	99.8
#8	2.38	0.9	0.9	1.1	99.1
#16	1.19	2.8	2.9	4	96
#30	0.59	20.2	20.6	24.6	73.4
#50	0.297	40	40.8	65.4	34.6
#100	0.149	29.9	30.5	95.9	4.1
#200	0.074	3.2	3.3	99.2	0.8

Sample No. 3 Level: Middle

Table A19: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0	0	0	100
#16	1.19	0.5	0.6	0.6	99.4
#30	0.59	6.6	7.3	7.9	92.1
#50	0.297	29.6	32.7	40.6	59.4
#100	0.149	43.6	48.2	88.8	11.2
#200	0.074	9.3	10.3	99.1	0.9

Sample No. 3 Level: Inside

Table A20: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0.4	0.4	0.4	99.6
#8	2.38	0.2	0.2	0.6	99.4
#16	1.19	3	3.1	3.7	96.3
#30	0.59	15.8	16.3	20	80
#50	0.297	41.1	42.5	62.5	37.5
#100	0.149	32.9	33.7	96.2	3.8
#200	0.074	2.47	2.6	98.8	1.2

Sample No. 4 Level: Outside

Table A21: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0.1	0.2	0.2	99.8
#16	1.19	0.5	1.3	1.5	98.5
#30	0.59	5.1	12.9	14.4	85.6
#50	0.297	13.2	33.3	47.7	52.3
#100	0.149	13.8	34.8	82.5	17.5
#200	0.074	6	15.1	97.6	2.4

Sample No. 4 Level: Middle

Table A22: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0	0	0	100
#16	1.19	0	0	0	100
#30	0.59	0.1	0.4	0.4	99.6
#50	0.297	3	12.7	13.1	86.9
#100	0.149	11.7	49.7	62.8	37.2
#200	0.074	7.8	33.1	95.9	4.1

Sample No. 4 Level: Inside

Table A23: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0.1	0.3	0.3	99.7
#16	1.19	0.1	0.3	0.6	99.4
#30	0.59	2.4	6	6.6	93.4
#50	0.297	10.1	25.3	31.9	68.1
#100	0.149	18.4	46.1	78	22
#200	0.074	8.17	20.5	98.5	1.5

Sieve Analysis of Soil Samples for Field Trial (After 2 years of implementation)

Sample No. 1 Level: Outside

Table A24: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0	0	0	100
#16	1.19	1.9	1.9	1.9	98.1
#30	0.59	15.2	15.2	17.1	82.9
#50	0.297	45.4	45.4	62.5	37.5
#100	0.149	33.2	33.2	95.7	4.3
#200	0.074	2.8	2.8	98.5	1.5

Sample No. 1 Level: Middle

Table A25: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0	0	0	100
#16	1.19	3.3	3.3	3.3	96.7
#30	0.59	17.4	17.4	20.7	79.3
#50	0.297	41.9	41.9	62.6	37.4
#100	0.149	32.6	32.6	95.2	4.8
#200	0.074	3.4	3.4	98.6	1.4

Sample No. 1 Level: Inside

Table A26: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0	0	0	100
#16	1.19	4.8	4.8	4.8	95.2
#30	0.59	28.1	28.1	32.9	67.1
#50	0.297	46.9	46.9	79.8	20.2
#100	0.149	17.7	17.7	97.5	2.5
#200	0.074	1.7	1.7	99.2	0.8

Sample No. 2 Level: Outside

Table A27: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0	0	0	100
#16	1.19	6.3	6.3	6.3	93.7
#30	0.59	25.4	25.4	31.7	68.3
#50	0.297	40.1	40.1	71.8	28.2
#100	0.149	15.7	15.7	87.5	12.5
#200	0.074	2.6	2.6	90.1	9.9

Sample No. 2 Level: Middle

Table A28: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	3	3	3	97
#16	1.19	3.1	3.1	6.1	93.9
#30	0.59	24.5	24.5	30.6	69.4
#50	0.297	41.7	41.7	72.3	27.7
#100	0.149	16.1	16.1	88.4	11.6
#200	0.074	2.9	2.9	91.3	8.7

Sample No. 2 Level: Inside

Table A29: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	2	2	2	98
#16	1.19	3.8	3.8	5.8	94.2
#30	0.59	24.8	24.8	30.6	69.4
#50	0.297	39.7	39.7	70.3	29.7
#100	0.149	16.3	16.3	86.6	13.4
#200	0.074	3.5	3.5	90.1	9.9

Sample No. 3 Level: Outside

Table A30: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0	0	0	100
#16	1.19	4	4	4	96
#30	0.59	4.7	4.7	8.7	91.3
#50	0.297	29.7	29.7	38.4	61.6
#100	0.149	36.6	36.6	75	25
#200	0.074	10.5	10.5	85.5	14.5

Sample No. 3 Level: Middle

Table A31: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0	0	0	100
#16	1.19	2.1	2.1	2.1	97.9
#30	0.59	4.8	4.8	6.9	93.1
#50	0.297	30.5	30.5	37.4	62.6
#100	0.149	33	33	70.4	29.6
#200	0.074	12.6	12.6	83	17

Sample No. 3 Level: Inside

Table A32: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0	0	0	100
#16	1.19	2.7	2.7	2.7	97.3
#30	0.59	4.6	4.6	7.3	92.7
#50	0.297	29.7	29.7	37	63
#100	0.149	34.8	34.8	71.8	28.2
#200	0.074	12.4	12.4	84.2	15.8

Sample No. 4 Level: Outside

Table A33: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0	0	0	100
#16	1.19	0.7	0.7	0.7	99.3
#30	0.59	5.6	5.6	6.3	93.7
#50	0.297	16.9	16.9	23.2	76.8
#100	0.149	31.2	31.2	54.4	45.6
#200	0.074	15.5	15.5	69.9	30.1

Sample No. 4 Level: Middle

Table A34: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0	0	0	100
#16	1.19	2.5	2.5	2.5	97.5
#30	0.59	4.5	4.5	7	93
#50	0.297	17.4	17.4	24.4	75.6
#100	0.149	26.5	26.5	50.9	49.1
#200	0.074	16.2	16.2	67.1	32.9

Sample No. 4 Level: Inside

Table A35: Grain Size Analysis of Soil Sample

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0.4	0.4	0.4	99.6
#16	1.19	1.2	1.2	1.6	98.4
#30	0.59	11.1	11.1	12.7	87.3
#50	0.297	29.6	29.6	42.3	57.7
#100	0.149	26	26	68.3	31.7
#200	0.074	13	13	81.3	18.7

Sieve Analysis of Soil at initial stage of laboratory simulation:

Table A36: Grain Size Analysis of Soil Sample (Level: Away from JGT)

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	1.42	1.06	0.00	100.00
#8	2.38	1.41	1.05	1.05	98.95
#16	1.19	1.59	1.18	2.24	97.76
#30	0.59	13.67	10.19	12.42	87.58
#50	0.297	48.49	36.13	48.55	51.45
#100	0.149	48.92	36.45	85.01	14.99
#200	0.074	7.65	5.70	90.71	9.29

Table A37: Grain Size Analysis of Soil Sample (Level: Midway from JGT)

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	6.6	3.76	0.00	100.00
#8	2.38	1.01	0.58	0.58	99.42
#16	1.19	3.09	1.76	2.34	97.66
#30	0.59	28.22	16.09	18.43	81.57
#50	0.297	77.36	44.10	62.53	37.47
#100	0.149	49.68	28.32	90.85	9.15
#200	0.074	5.29	3.02	93.87	6.13

Table A38: Grain Size Analysis of Soil Sample (Level: Near JGT)

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0.00	0.00	100.00
#8	2.38	0.79	0.44	0.44	99.56
#16	1.19	3.36	1.85	2.29	97.71
#30	0.59	28.88	15.94	18.23	81.77
#50	0.297	78.85	43.51	61.73	38.27
#100	0.149	54.22	29.92	91.65	8.35
#200	0.074	6.09	3.36	95.01	4.99

Sieve Analysis of Soil after 7 days of laboratory simulation:

Table A39: Grain Size Analysis of Soil Sample (Level: Away from JGT)

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0.51	0.3	0.3	99.7
#16	1.19	3.53	2.3	2.6	97.4
#30	0.59	30.3	19.8	22.4	77.6
#50	0.297	70.6	46.2	68.6	31.4
#100	0.149	36.9	24.1	92.7	7.3
#200	0.074	4.7	3.1	95.8	4.2

Table A40: Grain Size Analysis of Soil Sample (Level: Midway from JGT)

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	3.1	1	1	99
#8	2.38	1.8	0.6	1.6	98.4
#16	1.19	4.9	1.7	3.3	96.7
#30	0.59	45.8	15.5	18.8	81.2
#50	0.297	129.1	43.6	62.4	37.6
#100	0.149	87.1	29.4	91.8	8.2
#200	0.074	11.9	4	95.8	4.2

Table A41: Grain Size Analysis of Soil Sample (Level: Near JGT)

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0.2	0.1	0.1	99.9
#16	1.19	3.7	2.1	2.2	97.8
#30	0.59	29	16.5	18.7	81.3
#50	0.297	75	42.6	61.3	38.7
#100	0.149	51.5	29.2	90.5	9.5
#200	0.074	7	4	94.5	5.5

Sieve Analysis of Soil after 14 days of laboratory simulation:

Table A42: Grain Size Analysis of Soil Sample (Level: Away from JGT)

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0.1	0.1	0.1	99.9
#8	2.38	0.2	0.2	0.3	99.7
#16	1.19	2	2	2.3	97.7
#30	0.59	18.9	18.9	21.2	78.8
#50	0.297	44.7	44.7	65.9	34.1
#100	0.149	27	27	92.9	7.1
#200	0.074	3.4	3.4	96.3	3.7

Table A43: Grain Size Analysis of Soil Sample (Level: Midway from JGT)

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0.3	0.3	0.3	99.7
#16	1.19	2.1	2.1	2.4	97.6
#30	0.59	18.1	18.1	20.5	79.5
#50	0.297	44.4	44.4	64.9	35.1
#100	0.149	27.3	27.3	92.2	7.8
#200	0.074	3.8	3.8	96	4

Table A44: Grain Size Analysis of Soil Sample (Level: Near JGT)

Sieve No.	Sieve opening (mm)	Wt. of soil retained (gm)	% soil retained	Cumulative % retained	% Finer
#4	4.76	0	0	0	100
#8	2.38	0	0	0	100
#16	1.19	2.1	2.1	2.1	97.9
#30	0.59	16.5	16.5	18.6	81.4
#50	0.297	43.7	43.7	62.3	37.7
#100	0.149	29.2	29.2	91.5	8.5
#200	0.074	4	4	95.5	4.5