STRENGTH-DEFORMATION CHARACTERISTICS OF ROOTED SOIL

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The thesis titled "**Strength-Deformation Characteristics of Rooted Soil**" submitted by Farnia Nayar Parshi, Student number – 0413042216 P and session April, 2013 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of **Masters of Science in Civil Engineering (Civil and Geotechnical)** on 30th December, 2015.

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DECLARATION

It is hereby declared that, the work presented in this thesis has been done by the author and that, full or part of this thesis has not been submitted elsewhere for the award of any degree or diploma (except for publication).

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ABSTRACT

Embankment protection in Bangladesh is an important issue. Conventional methods for embankment protection are expensive and most of them are not environment-friendly. To this context, bioengineering method has been selected in this study. At first the growth of selected plants has been studied for different soil conditions. To evaluate the effectiveness of different plants in improving the stability of the slopes, strength-deformation characteristics of rooted soil has been illustrated conducting both laboratory and field tests.

For the evaluation of effectiveness of plants as bioengineering solution, four plants namely hardy sugarcane, wild cane, tiger grass and vetiver grass were selected. Growth of these plants in different soils (dredge fill sand, red clay, nursery soil, contaminated soil and saline soil) had been studied in BUET premises in plain land and slope ground. It was found that hardy sugarcane and wild cane grew well in nursery soil and sand whereas vetiver grew better in sandy, clayey, saline and contaminated soil. Among the selected plants, vetiver is widely available in the country and its root morphology is most effective for slope protection.

Strength-deformation characteristics had been evaluated using both laboratory and field tests. Direct shear tests were conducted on twenty different types of specimens with four types of soil and roots. Tests were conducted on samples prepared with 20-25% water contents under normal loads of 10, 15 and 20 kPa. By analyzing the results, it was observed that shear strength increased slightly due to the addition of root while horizontal deformation increased 1.5-2.0 times. Peak shear stress due to the addition of hardy sugarcane, wild cane, tiger grass and vetiver grass root increased up to 12%, 4%, 13% and 7%, respectively. Apparent angle of internal friction, ű=| increased due to the addition of hardy sugarcane and tiger grass root up to 8% and 19%. Again due to the addition of hardy sugarcane, wild cane and vetiver grass root apparent cohesion, c=|increased by up to 50%, 25% and 30%, respectively. From the stress-strain behaviour, it is understood that root is effective in taking load after the failure of the soil.

In addition to these, effectiveness of vetiver grass in remediation of heavy metal from soil had also been studied. Vetiver grass was planted in industrial dump contaminated soil collected from Buriganga river bank. It was found that the concentrations of heavy metals (Pb, Cu, Cr, Ni and Zn) in this soil are above tolerance level. From the analysis, it was found that heavy metal uptake through vetiver was very significant. Uptake of Pb, Cu, Cr, Ni and Zn after a time period of 50 week were 110, 53, 33, 53 and 2389 (gm per sq.m area), respectively.

It is observed that plant root mechanically increase soil shear strength by transferring soil shear stress from soil into tensile forces of the root themselves, via interface friction along the root surface. Orientation and geometry of the root also influenced the effectiveness in reinforcing.

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NOTATIONS

Symbol	Description
ű	Angle of internal friction
ű╡	Apparent angle of internal friction
ɗ	Angle between roots and slip plane
c	Cohesion
c╡	Apparent soil cohesion
ę	Degree
OC	Organic content
W/C	Water content
W_n	Natural water content
W_s	Mass of dry soil
W_w	Mass of water
G_s	Specific gravity
G_T	Specific gravity of water at T degree temperature
LL	Liquid limit
PL	Plastic limit
PI	Plasticity index
Ű	Shear stress
ů	Normal stress
CL	Clay of low plasticity
ML	Silt of low plasticity
SM	Silty sand
OL	Organic soil with low plasticity
EC	Electric conductivity
FS	Factor of safety
T_R	Tensile strength of root
F_{max}	Maximum force
N	Newton (unit of force)
D	Mean root diameter
$Ű_b$	Limiting bond interface friction between root and soil
L_{min}	Minimum root length
V:H	Verticle : Horizontal

Chapter One

INTRODUCTION

1.1 General

Embankment failure and soil erosion has become common problem all over the world including Bangladesh (Hossain et al., 2008; Hossain et al, 2010). Hossain et al. (2008) identified the major causes of embankment failure of Bangladesh are breaching of the embankment, cutting by public, overflow, erosion, seepage, sliding and also for poor planning, design and faulty construction. These cause great economic loss every year (Islam and Arifuzzaman, 2010; Nasrin, 2013). Moreover, riverbank erosion is seen as one of the major causes for national poverty (Rahman, 2010). For road embankments, soil erosion triggers the embankment failure. In Bangladesh, soil erosion mainly caused by heavy rainfall (Islam, 2013; Shahriar, 2015). Soil particles get loosen by rain impact, washed away by surface runoff caused by rains and blown away by winds (Young and Wiersma, 1973; Favis, 2007). Detachment of soil particle by rain impact is related to the grain size of the sediments and the highest detachability was found for fine very well sorted sand with a median grain size of 96 εm (Poesen, 1981).

Common practices for protection are geo-bag dumping, sand bag laying, dredging, revetments, guide bunds, boulders, brick matressing geo textile lying and CC block layer. These are expensive and sometimes do not fulfil the purposes satisfactorily (Bosunia et al., 2001; Islam, 2011). There are also some biological protection such as vegetation (tree plantation), willow post, wooden piling, crisscross porcupine and bandallings (Hensler, 2013; Shahriar, 2015). Again, Bangladesh is a riverine country and most of the lands are in floodplain zone. There are also some marshy lands (*haor* area) in the north-east zone of this country. Because of having low-lands, roads of this country are built on raised embankments. These embankments are mainly constructed with earth. In the past, these earths were mainly clay but now-a-days, due to lack of clay material, embankments are being constructed with dredged fill sand with clay capping. Most of these embankments are kept unprotected and do not maintained well. As a result these earths get erased easily by wind flow and water flow. The arterial road network under the jurisdiction of Roads and Highways department (R&HD) in 2011 was about 21,000 km, which includes over 3478 km national highways and 4221 km of regional highways, 83,304 km earthen and 2,13,331 km paved roads (source: R&HD, LGED). It is not feasible for Bangladesh Govt. to protect all these structures using CC blocks. Sometimes these blocks are proven inefficient for protection and washed away. For all these reasons an alternative and cost-effective measure must be introduced.

Bioengineering is an alternative sustainable technique for slope protection. This technique is becoming more and more popular now-a-days. Vegetation and mechanical structures can be used alone or in conjunction to stabilize slopes (NCHRP SYNTHESIS 430, 2012; Islam et al., 2013). For soil erosion control, use of vegetative cover is an ancient method and being practiced till now all over the world (Pinners, 2000; Truong and Loch, 2004; Bhattacharyya, 2006; Eboli et al., 2011; Suleiman et al., 2013). The use of vegetation in restoring the stability of slopes becomes highly demanded especially to solve the problem of shallow slope failure in both natural and man-made slopes (Petrone and Preti, 2010; Abdullah et al., 2011). This vegetative cover includes both large trees and grasses (Coder, 2010; Jain 2013). Besides, these vegetative cover acts as a shield against rain drop and decreases the rain impact significantly and again, grass roots are very effective in reducing soil detachment rates (De Baets et al., 2006; Gyssels et al., 2006; Shit and Maiti, 2012). It is a very easy to understand that use of vegetative cover increases the soil shear strength i.e., factor of safety of the stability. Different plants have different root structure with different root strength (Nyambane and Mwea, 2011). The variations of root matrix and strength also have an effect in the increase of soil shear strength. It means different species will provide different factor of safety. Root content also has significant effect on soil shear strength (Nasrin, 2013). Same species with different percentage will give different factor of safety.

1.2 Background of the Research Work

Every year Bangladesh faces lots of economic loss due to embankments failure. Low shear strength of embankment soil and erosion of top soil are among the main causes of such failures. Use of bio-engineering i.e., plant system to reduce soil erosion is an ancient and proven technology (Brenner, 1973; Truong and Loch, 2004; Rasel et al., 2010; Abdullah et al., 2011; Suleiman et al., 2013). Even in this country it is very common practice to plant trees on both side slopes of highway road embankments. But these plantations are done randomly and are not well planned. The presence of root matrix increases stability of these slopes by increasing the soil shear strength (Islam, 2000; Jain, 2013; Islam et al., 2013; Islam and Hossain, 2013). Strong roots with dense matrix hold soil particles and acts as fibre reinforcement. Plants such as vetiver (*Vetiveria zizanioides*), wild cane (*Saccharum spontaneum*) and tiger grass (*Thysanolaena maxima*) have potential to increase soil shear strength (Mickovski et al., 2005; Islam et al., 2013; Jain, 2013). Besides, some plants have high tolerances against adverse environment such as vetiver can grow in saline soil (Truong et al., 2002; Islam et al., 2014) and toxic soil (Roongtanakiat, 2009). Moreover, this grass can remove toxic metals (Choudhury et al., 2015), arsenic (Ebrahim et al., 2011) and total dissolved solids (Srisatit et al., 2003) from soil as well as water. In Bangladesh, these native plants are locally available (Rahman et al., 1996). For proper evaluation of factor of safety of slope protection with plant, it is necessary to determine the shear strength and deformation behaviour of rooted soil. Only a few efforts were made in this regard. So, it is felt necessary to determine the strength deformation characteristics of rooted soil. Few applications have already been done in Bangladesh (Islam, 2013; Shahriar, 2015). Besides, this bio-engineering technology can be applied for bridge approach road embankments slope protection.

1.3 Objectives and Scope of the Research

The main objectives of this research are as follows:

(1) To select suitable plants which has strong, deep, dense root matrix that can hold the soil particles together and have tolerance against drought, flood and salinity.

(2) To study the growth of selected plants in different types of soil (sand, clay, saline soil, industrial waste contaminated soil) and geographic regions of Bangladesh.

(3) To study the strength deformation behavior of different rooted soils in both laboratory and field conditions.

1.4 Methodology of the Research

To complete this research work, following steps are followed:

(1) Four plants were selected (hardy sugarcane, wild cane, tiger grass and vetiver grass) based on the root morphology and availability. Bangladesh National Herbarium at Mirpur road, Dhaka-1216 was visited on March, 2014 to study the selected plants and their location. It was found that the selected plants grow in Durgapur in Netrokona district.

(b) Soil samples were collected from in-situ test site in Durgapur, Birishiri (Sada pahar), Garo pahar (Bangladesh-India border) to conduct direct shear test in the laboratory. Also soil sample from Buriganga river bank in Hazaribagh, Dhaka was collected for contaminated soil to conduct heavy metal contamination tests.

(c) General properties such as specific gravity, liquid limit, grain size distribution, shear strength parameters of the soils were determined according to the ASTM standards in the Geotechnical Laboratory of Civil Engineering Department of BUET.

(d) In-situ shear test of grass rooted soil and bare soil were conducted in Durgapur, Sada pahar and Garo pahar site. For this test, a special device was used with slight modification that developed by Islam and Arifuzzaman (2010). This device includes a hydraulic jack (capacity 5 ton), pressure gauge (capacity 100 psi), wooden plate, metal plates, metal box (approximately $40 \times 20 \times 19$ cm^3), normal load (160 kg) and Linear Variable Displacement Transducer (LVDT) with capacity 50 mm. Both pressure gauge and LVDT were calibrated before using in the test.

(i) Preparation of Block Sample

Grass clump was cut at the ground level with a sharp knife. Keeping the root position undisturbed a trench of the size (1m×1m) was made up to the desired depth 19 cm. The rooted area was made in desired block sample shape by a sharp knife.

(ii) Test Procedure

Block samples (approximately 40×20×19 cm^3) were tested under different normal stresses (14.71 kPa, 17.17 kPa and 19.62 kPa) at the field to determine the in-situ strength of the rooted soil and bared soil. After preparing the block sample in the desired shape the metal box was adjusted to it. Then normal load was applied.

(e) In the laboratory, twenty sets of direct shear tests were conducted on reconstituted samples to determine the shear strength parameter (Í) and (űӰof rooted soil and bare soil. Samples were prepared by mixing all four types of grass root at 3% percentage by weight.

(f) Grass samples were collected from the field test site and planted in BUET premises for growth study. Also vetiver grass was planted in four different types of soil (dredge fill sand, red clay, nursery soil, contaminated soil) in 1:1.5 sloped wooden model boxes.

(g) Additionally vetiver grass was planted in five clay pots (size 10 inch dia and 12 inch depth) for proper nurturing. After full growth, grown grasses were planted in three sets of clay pot; each set had four clay pots (size 8 inch dia and 8 inch depth) with salinity level 0, 4.8, 10 and 12.5 ds/m respectively. The soils from each clay pot were tested after 5 weeks of plantation.

(h) Again vetiver grass was planted in a plastic container in contaminated soil collected from Buriganga river bank located at the downstream of industrial waste disposal point. The plants roots, shoots and leaves were tested to determine the heavy metal accumulation using atomic absorption spectrophotometry flame (AAS) at 19^{th}, 22^{nd}, 48^{th} and 50^{th} week, respectively.

1.5 Thesis Layout

This study consists of five chapters. The contents of these chapters are briefly described below:

Chapter One gives an overview of the whole research work including the background, objectives and scopes of the research, brief methodologies applied in research study.

In Chapter Two related literatures are reviewed such as, descriptions of the selected plants as well as their application in soil protection i.e., soil bioengineering and soil reclamation work all over the world. General causes of slope failure in Bangladesh, vetiver grass system, roots tensile strength, soil-root interactions and mechanisms of failure for both rooted and bare soil specimen are described. The plants cope with saline soil and the mechanism of fiber reinforcement as soil binder and review of past researches related to this study are also included in this chapter.

Chapter Three describes the experimental program which include site selection, plant selection, their physical properties and specification, preparation of models for in-situ test, test procedure and test parameters.

Chapter Four deals with the test results obtained from the experiments such as shear strength parameters both in-situ condition and in laboratory with controlled condition and growth study.

Chapter Five is the conclusion chapter where the summary of the research findings has been provided. It also includes recommendations for further study.

Chapter Two

LITERATURE REVIEW

1.1 Introduction

Slope protection by vegetation has become a prominent method due to its sustainability and climate change adaptation (Clark and Hellin, 1996; Truong and Loch, 2004; Rasel et al., 2010; Suleiman et al., 2013). Understanding of growth characteristics of vegetation in different soils and strength-deformation behaviour of rooted soil is important. In this chapter, this study related literature has been discussed briefly. In the first few sections soil bioengineering and their application has been discussed and later past researches related to this topic have been discussed. Soil bioengineering is an excellent tool for stabilizing areas of soil instability. These methods should not, however, be viewed as the sole solution to most erosion problems. Soil bio-engineering has unique requirements and is not appropriate for all sites and situations (Lewis, 2000). But if planted and maintained properly it work effectively and efficiently with lowest cost (Allen and Leech, 1997).

1.2 General Causes of Slope Failure in Bangladesh Perspective

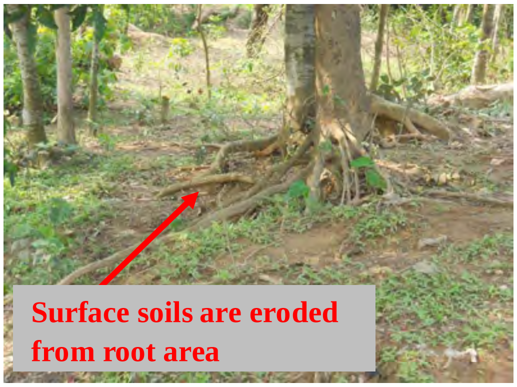
Due to the geographical location, Bangladesh experiences various natural calamities like cyclones, northwester, heavy rainfall, flood etc. The big seasonal winds i.e., monsoon blowing from the Bay of Bengal and Arabian Sea in the southwest brings heavy rainfall to this area. Moreover, Bangladesh is a riverine country and most of the country is dominated by the fertile Ganges-Brahmaputra delta, worldôs largest delta. Most of the lands are mainly made of silt deposit. Earthen slopes including both natural slopes like river bank and manmade slopes like road embankments are mainly made of silt deposit. Now-a-days dredge fill sands from river bed are using for road embankments. These slopes are very vulnerable to erosion against wind and rainfall. Generally road embankments are made of earth fill and compacted with required height. The usual average embankments height is 4.5 m (LGED). Slopes of these embankments easily get erased/damaged mainly due to rainfall impact, surface runoff and wind. Certain amount of surface erosion leads to slope failure of the embankments which finally causes road damage.

Fig. 2.1 Surface erosion in road embankment

(a) (b)

Fig. 2.2 (a) Typical road damage caused by surface erosion and (b) damaged embankment

Fig. 2.1 shows surface erosion started to go deep. If the erosion process goes on, very soon the erosion will become acute. Fig 2.2 shows how the surface erosion triggers slope failure and it leads to road breaking. A certain amount of surface erosion cause uprooting of large trees and causes great calamity. Fig 2.3 shows uprooting process of large trees due to surface erosion.



(a)

(b)

Fig. 2.3 (a) Erosion of surface layer uncovered root area and (b) uprooted tree

1.3 Soil Bio-engineering

Soil bioengineering is now widely practiced throughout the world for the treatment of erosion and unstable slopes (Clark and Hellin, 1996; Allen and Leech, 1997; Battacharyya, 2006; Petrone and Preti, 2010). Soil bioengineering techniques have been used in many centuries. These techniques are used alone or in conjunction with conventional engineering techniques (Barley, 1994; Roadside and Site Development, WSDOT). Though it is an ancient technology but now it has became a part of civil engineering. Soil bioengineering is the use of living plant materials to provide some engineering functions such as erosion control, slope and stream bank stabilization, landscape restoration, and wildlife habitat. It is an effective tool for treatment of a variety of unstable or eroding sites. More recently Schiechtl (1980) has encouraged the use of soil bioengineering with a variety of European examples. This technique can be used to revegetate steep slopes, to treat seepage zones and to control surface erosion (Gray and Leiser, 1982), in construction to provide soil reinforcement and as living retaining walls (wattle fences) and live reinforced earth walls (Polster, 2003). Soil bioengineering method is effective to prevent and control surficial erosion and shallow mass wasting (Islam, 2013). Different methods or combination of methods can be used on: a) natural hill slopes, b) cut and fill slopes along roadways, c) landfill covers, d) spoil banks e) stream banks and f) site reclamation work. Some methods are better and suited than others depending on the particular site conditions and objectives.

In Bangladesh, this technique already has been being practiced by the rural people for soil protection purpose. They are applying it without any technical knowledge. Such applications are presented in Fig. 2.4a and 2.4b.

(a) (b)

Fig. 2.4 Bioengineering practice in Durgapur, Netrokona: (a) fencing for home boundary and (b) corner protection from erosion

2.3.1 Plants Used for Soil Bio-engineering

Both herbaceous and woody vegetation can be used as a soil bio-engineering material (Coder, 2010). The former includes grasses and forbs while the second one includes shrubs and trees. Each type has inherent advantages and limitations. In general, grasses and forbs are superior for preventing and controlling surface erosion, whereas woody vegetation (shrubs and trees) are superior for preventing shallow slope failures or mass erosion (Gray and Sotir, 1996). Plants with special features such as dense, strong and deep root matrix, ability to intake pollutants and can grow in hostile environment such as drought, flooding, salinity, deposition, heavy grazing, waste soil etc are used for these techniques. But plant species that are selected must be suitable for their intended use and be well adapted to the siteôs climate and soil conditions. Important attributes of plants under consideration for soil bioengineering use include availability, habitat value, size/form, root type, and ease of propagation as well as site characteristics (topography, elevation, aspect, soil moisture and nutrient levels), existing vegetation, intended role of vegetation in the project such as rooting characteristics, growth characteristics and ecological relationships of the plants, logistical and economic constraints (WSDOT, 2003).

2.3.2 Root Characteristics

Roots with special bushy structure i.e., having numerous branches and root hairs are effective and mainly used for soil bioengineering technology. Another main requirement is to have enough tensile strength (Jain, 2013). Both requirements are necessary to work out correctly. Otherwise this technology will not work effectively. If the roots are strong enough but do not have branches will fail in tension and pull straight out of the ground with only minimal resistance. The root reaches its maximum pullout resistance then rapidly fails at a weak point. The root easily slips out of the soil due to the gradual tapering (progressive decrease in root diameter along its length) which means that as the root is pulled out it is moving through a space that is larger than its diameter which consequently has no further bonds or interaction with the surrounding soil (Norris, 2005). If the roots do not have enough tensile strength but have multiple branches or forked branches also can undergo tensile failure but predominantly fail in stages as each branch breaks within the soil. These roots break with increasingly applied force in stages in the form of stepped peaks corresponding to the progressive breaking of roots of greater diameters. The root progressively releases its bonds with the soil until final tensile failure.

In some cases when the root has a sinusoidal shape with many small rootlets along its length the root reaches its maximum pull out resistance on straightening and then breaks at the weakest point, however at this point the root is not pulled out of the soil as it adheres and interacts with the soil producing a residual strength. If pulling was stopped at this point, the root would give increased strength to the soil. However, if the root is completely pulled out of the ground then root losses the interaction with soil and as a result soil shear strength cannot increase (Norris, 2005).

2.3.3 Root Tensile Strength

Root tensile strength varies with individual roots as well as their morphological characteristics (Nyambane and Mwea, 2011). Root tensile strength of some plants are presented in Table 2.1. Nyambane and Mwea (2011) determined the root tensile strength using the Hounsfield Tensometer apparatus presented in Fig. 2.5. The sample to be tested will be clamped between two grips. Clamping is the most critical issue when measuring root strength. To improve the clamping and avoid slippage, fine sandpaper can be attached to the grips. The length of each root should be maintained at 0.1m by trimming ends.

Table 2.1 Tensile strength of roots of some plants

Botanical name	Common name	Tensile strength (MPa)
Salix spp	Willow	9-36*
Populus spp	Poplars	5-38*
Alnus spp	Alders	4-74*
Pseudotsuga spp	Douglas fir	19-61*
Acer sacharinum	Silver maple	15-30*
Tsuga heterophylia	Western hemlock	27*
Vaccinum spp	Huckle berry	16*
Hordeum vulgare	Barley	15-31*
	Grass, forbs	2-20*
	Moss	0.002-0.007*
Vetiveria zizanioides	Vetiver grass	40-120 (Average 75**)

* (Wu, 1995)
**(Hengchaovanich and Nilaweera, 1996)

Roots have to clamp into entire wedge grip length in order to achieve a superior grip which could avoid slippage during testing. After clamping the roots into wedge grips, the motor will be driven manually to apply initial tension into the roots, and the mercury scale have to set at zero. Root diameters at either ends have to taken, and the initial length of the exposed root also need to be recorded. The motor drive unit will be then put on subjecting the sample to a movement of the clamps at a constant rate of 10mm/min., and test commence. Loading have to be recorded at every 30 seconds until failure occurred (Nyambane and Mwea, 2011). The elongation of the roots can be recorded by simply taking the length between the grips at failure. The following formula can be then used to calculate T (De Baets et al., 2008).

$$T = \frac{F_{\max}}{\pi(\frac{D^2}{4})} \qquad (1)$$

Where, F_{max} is the maximum force (N) needed to break the root and D is the mean root diameter (mm) before stretching.

Root tensile strength (T) ï root diameter (D) relationship depend on plant species. Tensile strength within a species varies by root diameter. Generally the root tensile strength decreases with increasing root diameter. The T-D relationships can be written as a power law equation of the form (Nyambane and Mwea, 2011).

$$f(x) = ax^{k} \qquad (2)$$

Where, a and k values can be obtained from root tensile strength versus root diameter graphs.

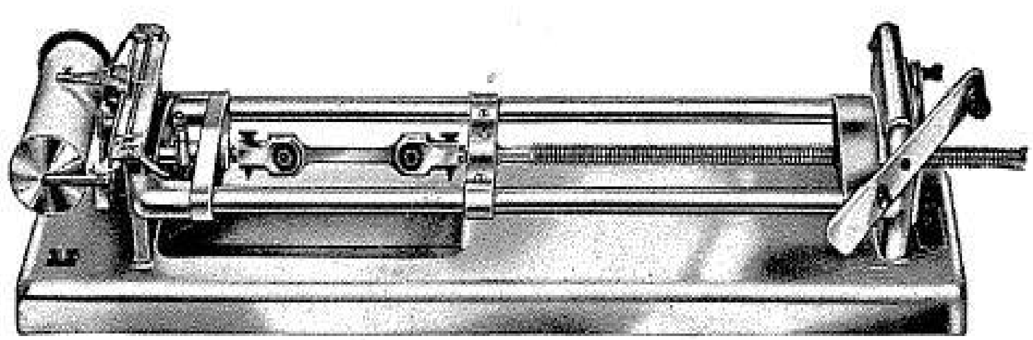


Fig. 2.5 The Hounsfield Tensometer apparatus

2.3.4 Phytoremediation for Soil Reclamation

Phytoremediation is a technique in which plants are used to remove, detoxify or immobilize environmental contaminants from soil, water or sediments, through natural, biological, chemical and physical activities (Hengchaovanich, 2000). This method is based on the fact that green plants can absorb/extract certain elements from their ecosystem and accumulate those substances either as a part of their body or convert them to a non-hazardous form. Heavy metal contamination of soils resulting from agricultural (e.g., chemical fertilizers and sewage sludge) or industrial activities (e.g., metal mining and smelting) is one of the major environmental issues in many parts of the world. Plant roots uptake these metal contaminants from the soil and translocate them to their above soil tissues. For example, some plants have natural ability to grow in the saline or metal contaminated soil; they extract the subsequent metal with the help of their extensive root system and then accumulate that metal within their tissues. So in this way they help to remove toxic metals from soil without being damaged. For this purpose different plant species are used depending upon the type of contaminant and area to be reclaimed.

Approximately 400 plant species from at least 45 plant families have been reported to hyper-accumulate heavy metals and could be good sources for the removal of toxic metals from contaminated sites. The Indian mustard is a common plant which has the capacity to accumulate large quantities (1000 ppm) of lead. Sunflower has proven effective in the remediation of radionuclides and certain other heavy metals. Mulberry has been found to be effective in the reclamation of pesticide contaminated soils (Mustafa and Wazir, 2012).

2.3.5 Types of Phytoremediation

Phytoremediation techniques include different modalities, depending on the chemical nature and properties of the contaminant (if it is inert, volatile or subject to degradation in the plant or in the soil) and the plant characteristics (Fig. 2.6). Thus, phytoremediation essentially comprise six different strategies, though more than one may be used by the plant simultaneously.

(1) **Phytodegradation** (Phytotransformation): Organic contaminants are degraded (metabolized) or mineralized inside plant cells by specific enzymes that include nitroreductases (degradation of nitroaromatic compounds), dehalogenases (degradation of chlorinated solvents and pesticides) and laccases (degradation of anilines).

(2) **Phytostabilization** (Phytoimmobilization): Contaminants, organic or inorganic, are incorporated into the lignin of the cell wall of roots cells or into humus. Metals are precipitated as insoluble forms by direct action of root exudates and subsequently trapped in the soil matrix. The main objective is to avoid mobilization of contaminants and limit their diffusion in the soil (Favas et al., 2014).

(3) **Phytovolatilization:** This technique relies on the ability of some plants to absorb and volatilize certain metals/metalloids. Some element ions of the groups IIB, VA and VIA of the periodic table (specifically Hg, Se and As) are absorbed by the roots, converted into non-toxic forms, and then released into the atmosphere. This technique can also be used for organic compounds (Favas et al., 2014).

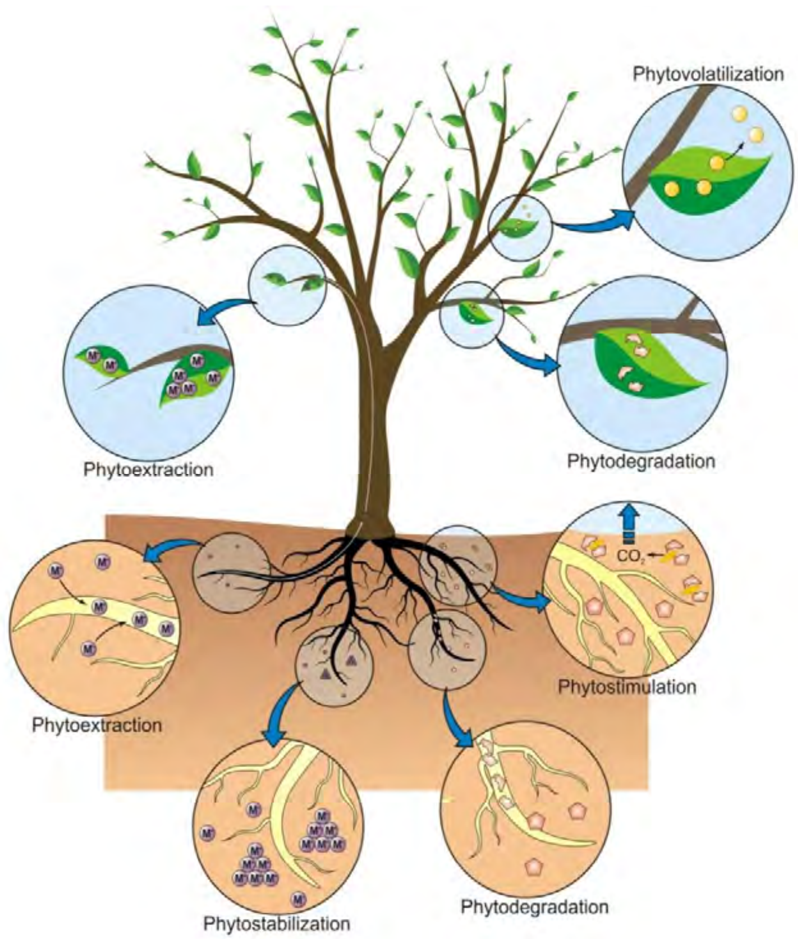


Fig. 2.6 Schematic representation of phytoremediation strategies (after Favas et al., 2014)

(4) **Phytoextraction:** (Phytoaccumulation, Phytoabsorption or Phytosequestration): This involves the absorption of contaminants by roots followed by translocation and accumulation in the aerial parts. It is mainly applied to metals (Cd, Ni, Cu, Zn, Pb) but can also be used for other elements (Se, As) and organic compounds. According to Favas et al. (2014) this technique preferentially uses hyper accumulator plants that have the ability to store high concentrations of specific metals in their aerial parts (0.01% to 1% dry weight, depending on the metal).

(5) **Phytofiltration:** This uses plants to absorb, concentrate and/or precipitate contaminants, particularly heavy metals or radioactive elements, from an aqueous medium through their root system or other submerged organs. The plants are kept in a hydroponic system, whereby the effluents pass and are ñfilteredò by the roots (Rhizofiltration), or other organs that absorb and concentrate contaminants. Plants with high root biomass, or high absorption surface, with more accumulation capacity (aquatic hyperaccumulators) and tolerance to contaminants achieve the best results (Favas et al., 2014).

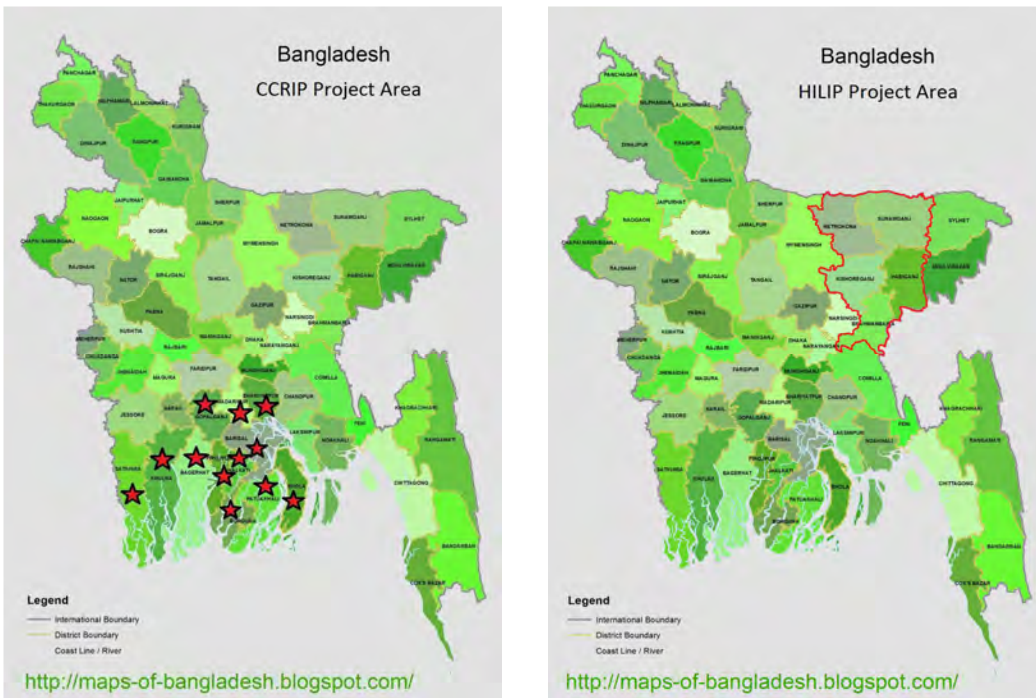
(6) **Rhizodegradation** (Phytostimulation): Growing roots promote the proliferation of degrading rhizosphere microorganisms which utilize exudates and metabolites of plants as a source of carbon and energy. In addition, plants may exude biodegrading enzymes themselves. The application of phytostimulation is limited to organic contaminants (Favas et al., 2014).

1.4 Vetiver Grass System

In 1986, World Bank introduced a special grass named vetiver (*Vetiveria zizanioides*). Initially the World Bank promoted the use of vetiver through its vetiver department and now through the ñThe Vetiver Network International (TVNI)ò. The Vetiver System (VS) is dependent on the use of this unique tropical plant, vetiver grass ï *Vetiveria zizanioides*, recently this grass is reclassified as *Chrysopogon zizanioides*. The plant can be grown over a very wide range of climatic and soil conditions, and if planted correctly can be used virtually anywhere under tropical, semi-tropical, and Mediterranean climates (Truong et al., 2002; Rahman et al., 1996; Dudai et al., 2006). It has characteristics that in total are unique to a single species. When vetiver grass is grown in the form of a narrow self-sustaining hedgerow it exhibits special characteristics that are essential to many of the different applications that comprise the Vetiver System. When used for civil works, its cost is about 1/20 of the traditional engineered systems and designs. Engineers like the vetiver root to a "Living Soil Nail" with an average tensile strength of 1/6 of mild steel (Hengchaovanich, 1998).

2.4.1 VGS in Bangladesh

Soil bio-engineering research has been started recently in Bangladesh and already few researches had been conducted. In Bangladesh vetiver grass is locally known as *óbinna’*, *bennashoba, gondhabena* or *ecorban* (Rahman et al., 1996; Huq, 2006). This grass is being used for land demarcation and sometimes soil protection purposes. Though local people do not have any technical knowledge, they sometimes plant this grass for reservation of their personal pond. But recently this system is being applied in few trial bases for research purposes.



(a) (b)

Fig. 2.7 Map showing the project area of (a) CCRIP project and (b) HILIP project of LGED

This system has been applied in shrimp pond slope protection in Baliapur, Nil dumur and Kaliganj in Satkhira district (Shahriar, 2015), in Keraniganj highway road side slope, in tarash beside the pond (Islam, 2013). Very recently this grass is being planted in twelve districts mainly in coastal regions of Bangladesh under a project named óCoastal Climate Resilient Infrastructure Projectô i.e., (CCRIP). Project areas are presented in Fig. 2.7a. The project areas are Satkhira, Khulna, Bagerhat, Pirojpur, Jhalkathi, Borguna, Patuakhali, Bhola, Barisal, Madaripur, Shariyatpur and

Gopalganj. Under this project a model study has been started at BUET premises to investigate the effectiveness of bioengineering in protecting earthen slopes against rain-cut erosion using veiver grass. In *haor* areas there are two projects CALIP and HILIP had been initiated by LGED to make trials to protect village mound and *upazilla/*union road slope protection and vetiver grass is being used as bio-engineering plant. The selected areas for the projects are Netrokona, Sunamganj, Habiganj, Kishoreganj, Brahmanbaria as shown in Fig. 2.7b. Vetiver is also applied to protect dykes of Shrimp ponds in saline prone area with the help and cooperation of GIZ, Germany. This technology has been adopted by WAB in other shrimp farming for green covering using vetiver grass (Sarder, 2014). Also this system is used for hill slope protection with a layer of jute-geotextile (JGT).

1.5 Root and Soil Friction/Interaction

The soil stabilization effects of plant roots is based on two components, first by the friction between the soil particles that transfer shear stresses from the soil to the root reinforcement system, and second by the soil arches that build up between cylindrical soil units that are reinforced by roots (root stock-soil elements) and stabilize areas that are not rooted (Jain, 2013). Large diameter roots/deep roots of trees act as tendons or anchors connecting planted surface layers to underlying or adjacent stable soil zones where shallow root protects the surface (Hairiah et al., 2006; Jain, 2013).

Root columns act as piles. Dense and strong root of grasses like vetiver, tiger grass, hardy sugarcane etc. acts as micro piles penetrating into the soils. The effect of root reinforcement depends on the morphological characteristics of the root system, the tensile strength of individual roots, the soil-root cohesive strength and the distribution of the root system in the soil (Nyambane and Mwea, 2011).

It is clear that the main roots and secondary roots when bundled up are responsible for the overall strength of the root system, in fact, it is the adhesion between the soil and the root hairs that determine the failure during the pull out during shear event. It can be simply explained by the diagram in Fig. 2.8.

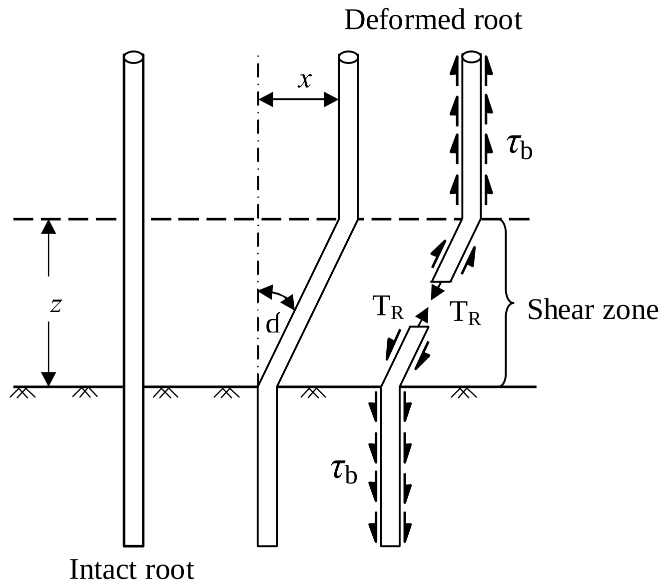


Fig. 2.8 Interface friction between soil and root (Redrawn after Gray and Sotir, 1996)

In order to understand the macroscopic adhesion effect of plant/grass root system, such as cohesion, root-soil interaction needs microscopic observation in order to link the behaviours and responses across different length-scales. According to Gray and Ohashi (1983), simple uniform distribution of interface friction between soil and roots could be directly related to the minimum root length $L_{\min}$ required to prevent root-soil slippage:

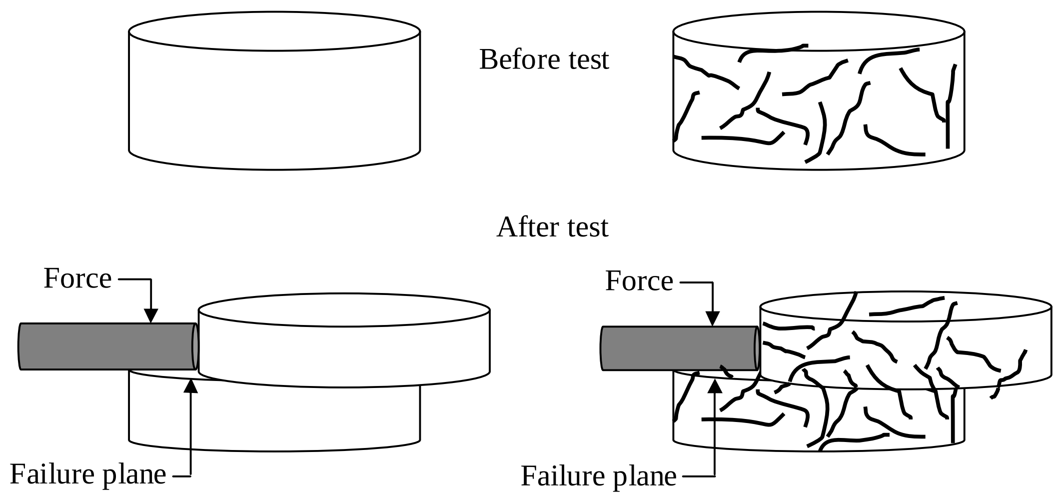
$$L_{\min} = T_R D / 4\tau_b \tag{3}$$

Where, T_R is the tensile strength of the root, D is the root diameter and τ_b is the limiting bond interface friction stress between root and soil (Gray and Ohashi, 1983).

The contribution of interfacial friction plays an important role during the pulling and slipping of the root system from soil. In particular, the root hairs are of the order of micron level and their interfacial area is contributing significantly to the friction due to their increased surface area. One particular function is to facilitate root penetration as these root hairs serve as anchorage points so that the root tip could penetrate deeper into the soil. The very same anchorage mechanism also provides adhesion between the root itself and the soil during shear and catastrophic pull out events which could be directly linked cohesion term in Mohr-Coulomb failure criterion framework.

2.5.1 Failure Mechanism

Fig. 2.9 presents the typical direct shear test samples for both rooted and unrooted soil specimens. Typical curves for axial stress versus axial strain in are presented in Fig. 2.11. From this figure it is seen that, soil without root acts as brittle material but shows some ductile behaviour when it is wet. Because generally for fine grained soil, presence of water creates some amount of cohesion between the soil particles. After adding roots to the soil, ductility increases significantly that the sample behaves like ductile material.



(a) (b)

Fig. 2.9 Typical direct shear test samples for (a) bare and (b) rooted soil specimen

By observing the curves in Fig 2.11 and failure pattern in Fig 2.9, it can be said that firstly soil takes the axial stress and after its failure root takes place and takes stress with large strains. After adding roots in the soil specimen, ductility increases but sometimes peak shear stress and ultimate shear or both reduce. This phenomenon can be explained by the root position inside the specimen presented in Fig. 2.10. Roots are arranged randomly within the soil specimen. So if significant amount of roots are arranged parallel to the failure plane in the failure plane zone, then neither root nor soil can act against shear force. As a result, shear stress reduced. But when roots arranged perpendicularly to the failure plane, more stress required to torn the roots. As a result shear stress of the specimen increases.

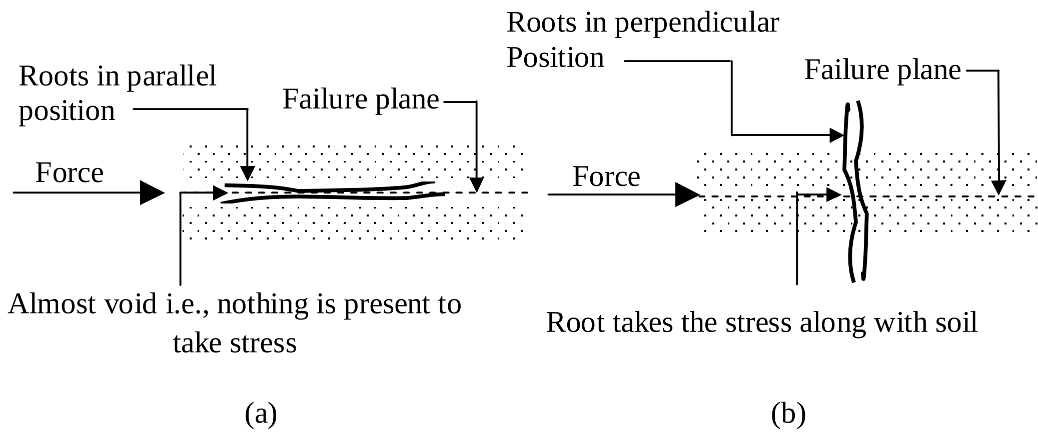


Fig. 2.10 Effect of root orientation in soil specimen (a) roots are parallel to the failure plain and (b) roots are perpendicular to the failure plain

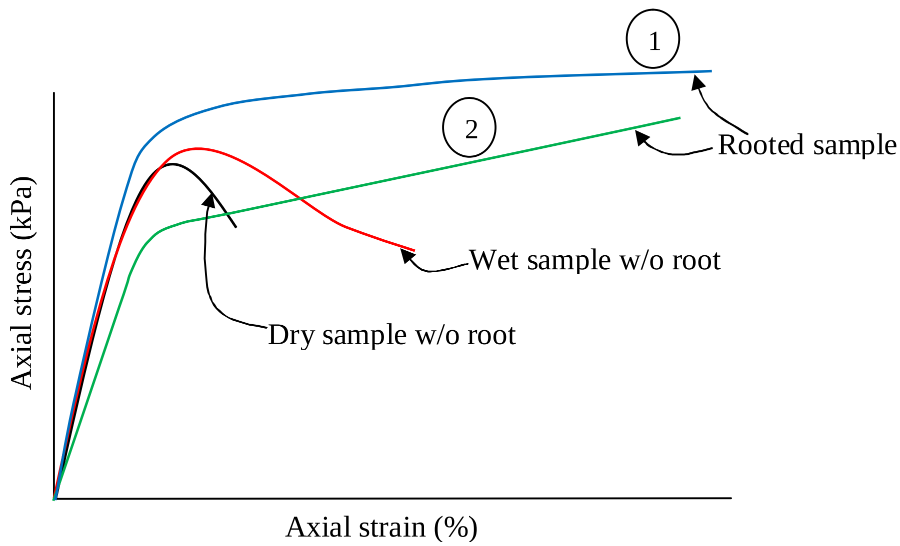


Fig. 2.11 Typical axial stress vs. axial strain curves for rooted and unrooted soil

1.6 Applicability of Bioengineering in Saline Soil

The coastal region covers almost 29,000 km^2 which is about 20% of the country. About 53% of the coastal areas are affected by salinity (Haque, 2006). Common protection systems like CC block layer, RC wall, sand bag layer and geotextile are very expensive and not possible to apply in all dykes and embankments in saline zone. Moreover CC blocks and RC walls are not durable in saline environment due to deterioration of concrete (Bosunia et al., 2001; Islam, 2011). These problems can be solved by applying bioengineering and choosing proper plant. According to the recent researches, vetiver grass (*Vetiveria zizanioides*) can be used as a cheap method to protect shorelines and to reduce overtopping of tidal flow. In several countries field tests were done and also some guidelines for plantation are given (Truong and Pinners, 2007; Verhagen et al., 2008; Shahriar, 2015).

2.6.1 Mechanism of Salt Effects on Plants

Saline soils occur when salts accumulate in the soil. Concentrated sodium (Na), a component of salt, can damage plant tissue whether it contacts above or below ground parts. High salinity can reduce plant growth and may even cause plant death. Fig. 2.12 shows the bad effects of the presence of salt in the root area of the plants.

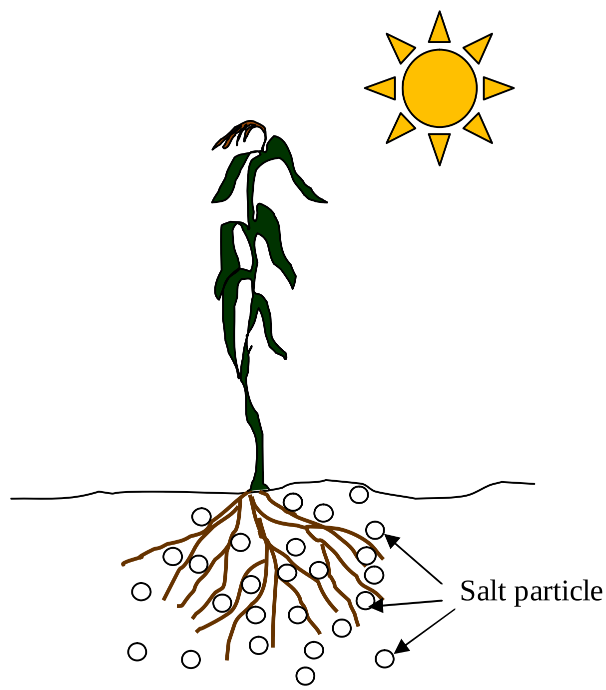


Fig. 2.12 A high salt concentration in the soil is harmful for the plants as the water uptake is reduced (after www.fao.org)

The process by which plants take water in its system is called osmosis. Plant root cells contain a membrane which allows water to pass through, but which prevent salt from entering. As the soilȏs salt content increases, it becomes more difficult for water to pass through the membrane into the root. In addition, if salt levels get high enough then water density in root zone increases and water sucked out of the roots by reverse osmosis process.

High levels of soluble salts also cause changes in soil structure by making it compacted. These compacted soils are problematic for plants. Because salts bind with clay particles presents in the soil and cause them to swell. Compaction occurs more frequently in clayey soils than in sandy soils. Compaction causes reduction of pore spaces between soil particles and thus reduces water and oxygen penetration into the soil and water drainage from the soil. As a result, water and oxygen availability reduces to plant roots and consequently plant growth and pest resistance, is affected.

2.6.2 Sodicity

Salty soils usually contain several types of salt. One of these is sodium salt. Where the concentration of sodium salts is high relative to other types of salt, a sodic soil may develop. Sodic soils are characterized by a poor soil structure: they have a low infiltration rate, they are poorly aerated and difficult to cultivate. Thus, sodic soils adversely affect the plants' growth.

2.6.3 Salt Tolerant Plants

Plants vary in their ability to grow in salty soils. Plants that grow only in saline soils are called ñhalophyticò or salt loving. Halophytic plants are generally found in coastal areas, in salt-water marshes, and in brackish (moderately saline) wetlands. Mangroves are an example of halophyte by botanists. The presence of some of these plants (such as spartina and sea oats) is generally indicative of a saline soil.

The amount of salt in the soil can be measured with a soil test. The Virginia Cooperative Extension Service Soil Test Laboratory reports salt levels using the measure ñparts per millionò or ñppm.ò Salt concentrations of 1-1000 ppm are considered low, and those from 1000- 2000 ppm medium. With the exception of very salt sensitive plants, most landscape plants can tolerate salt concentrations in the medium range. Some plants are more tolerant to a high salt concentration than others. Some examples are given in the Table 2.2.

The highly tolerant crops can withstand a salt concentration of the saturation extract up to 10 g/l. The moderately tolerant crops can withstand salt concentration up to 5 g/l. The limit of the sensitive group is about 2.5 g/l.

Table 2.2 A list of salt tolerant plants

Highly tolerant	Moderately tolerant	Sensitive
Date palm	Wheat	Red clover
Barley	Tomato	Peas
Sugarbeet	Oats	Beans
Cotton	Alfalfa	Sugarcane
Asparagus	Rice	Pear
Spinach	Maize	Apple
	Flax	Orange
	Potatoes	Prune
	Carrot	Plum
	Onion	Almond
	Cucumber	Apricot
	Pomegranate	Peach
	Fig	
	Olive	
	Grape	

Source: www.fao.org

2.6.4 Water Salinity

Water salinity is the amount of salt contained in the water. It is also called the "salt concentration" and may be expressed in grams of salt per litre of water (grams/litre or g/l), or in milligrams per litre (which is the same as parts per million, p.p.m). However, the salinity of both water and soil is easily measured by means of an electrical device. It is then expressed in terms of electrical conductivity: millimhos/cm or micromhos/cm. A salt concentration of 1 gram per litre is about 1.5 millimhos/cm. Thus a concentration of 3 grams per litre will be about the same as 4.5 millimhos/cm.

2.6.5 Soil Salinity

The salt concentration in the water extracted from a saturated soil (called saturation extract) defines the salinity of this soil. According to the soil salinity classification used by FAO presented in Table 2.3, if this water contains less than 3 grams of salt per litre, the soil is said to be non saline. If the salt concentration of the saturation extract contains more than 12 g/l, the soil is said to be highly saline.

Table 2.3 Soil salinity classification

Salt concentration of the soil water (saturation extract)		Salinity
in g/l	in millimhos/cm	
0 - 3	0 - 4.5	non saline
3 - 6	4.5 - 9	slightly saline
6 - 12	9 - 18	medium saline
more than 12	more than 18	highly saline

Source: www.fao.org

2.6.6 Improvement of Saline Soils

Improvement of a saline soil implies the reduction of the salt concentration of the soil to a level that is not harmful to the crops. To that end, more water is applied to the field than is required for crop growth. This additional water infiltrates into the soil and percolates through the root zone. During percolation, it takes up part of the salts in the soil and takes these along to deeper soil layers. In fact, the water washes the salts out of the root zone. This washing process is called leaching. The additional water required for leaching must be removed from the root zone by means of a subsurface drainage system. If not removed, it could cause a rise of the groundwater table which would bring the salts back into the root zone. Thus, improvement of saline soils includes, essentially, leaching and sub-surface drainage.

2.6.7 Improvement of Sodic Soils

Improvement of sodic soils implies the reduction of the amount of sodium present in the soil. This is done in two stages. Firstly, chemicals (such as gypsum), which are rich in calcium, are mixed with the soil; the calcium replaces the sodium. Then, the replaced sodium is leached from the root zone by irrigation water.

2.6.8 Irrigation Water Quality

The suitability of water for irrigation depends on the amount and the type of salt the irrigation water contains.

Higher the salt concentration in the irrigation water, greater the risk of salinization. Table 2.4 gives an idea of the risk of salinization.

Table 2.4 Quality required for watering of plants

Salt concentration of the irrigation water in g/l	Soil salinization risk	Restriction on use
Less than 0.5 g/l	No risk	No restriction on its use
0.5 - 2 g/l	Slight to moderate risk	Should be used with appropriate water management practices
More than 2 g/l	High risk	Not generally advised for use unless consulted with specialists

Source: www.fao.org

The type of salt in the irrigation water will influence the risk of developing sodicity: the higher the concentration of sodium present in the irrigation water (particularly compared to other soils), the higher the risk.

1.7 Past Researches

Soil bio-engineering research has been started in Bangladesh and recently few researches had been conducted. This topic is gaining more and more interest all over the world in the last few decades.

2.7.1 Study on Performance/Growth

In 2000 a trial on vetiver grass on the twenty eight km of coastal embankment began by Dampara Water Management Project (DWMP). The result showed if vetiver grass is planted and managed properly, this will provides outstanding protection against soil erosion. The green leaves and shoot of vetiver is a source of fodder and dried leaves can also be used as thatch and fence.

In Bangladesh, Islam (2003) conducted a study by monitoring the performance of vetiver grass on eighteen coastal polders over eighty seven kilometres of earthen embankments of Bangladesh. As a finding of his study he stated that water borne erosion (either surface run-off or rain cut or wave action or all) is the main problem in maintaining those earthen embankments.

Moula et al. (2008) studied the nursery performance of vetiver grass from June 2000 to June 2001 with different number of tillers. For the better propagation of vetiver grass, optimum numbers of tillers had been investigated and observed that the percentage survivability (mean ± SD) of the clump was found as 73.08 ± 1.57, 96.79 ± 0.91 and 91.67 ± 1.26 for single, double and triple tillers respectively. On the other hand, net tillers per clump (mean ± SD) were found as 10.21 ± 0.81, 16.99 ± 1.06 and 14.02 ± 2.27 for the single, double and triple tillers respectively. The maximum number of tillers per clump was found with double tillers. According to this observation, it is revealed that propagation of vetiver clump was found with double tillers is better than single and triple tillers.

Dudai et al. (2006) studied the growth rate of vetiver grass under Mediterranean condition and found that the plant height and the number of spout per plant in clay soil under long day conditions were significantly higher than under short day and the heights of irrigated vetiver plants in open fields were higher than those of rain-fed plants. They suggested that vetiver platation should be done during winter season (February to March) in order to obtain fast growth of the plants and to increase the possibility of using rain water for their growth.

Shahriar (2015) conducted growth study at BUET premises and coastal zone with different origins of vetiver grass *(Vetiveria zizanioides)* and *kans (Saccharum spontaneum)* and found that shoot growth of *kans* were better in comparison to others but growth of root for locally available vetiver found to be most dense. He conducted field trials (planted vetiver on dykes having soil with 90% silt) at three different areas of coastal zone under Satkhira district with different saline level (electric conductivity, EC ranges from 1.57 to 12.37 ds/m). The trial zones are classified as low, medium and high saline zone and found that, vetiver grows very well in low saline zone (EC 1.57 ds/m) but growth rate was slow for moderate and high saline zone (EC 12.37 ds/m). Shahriar also investigated two case studies and found that vetiver grass is effective in protecting embankment slopes from rain-cut erosion and in protecting pond slope from wind induced erosion. He also conducted model study and used three models with slopes 1:0.75, 1:1 and 1:1.5 to determine the behaviour of vetiver grass protected slopes against wave action and found that vetiver grass is effective in protecting slopes from wave action. Comparing cost of the vetiver system with other common practices, he found that vetiver system costs only 35 Tk per square meter which is 53 times lower than that of common revetment and RC structures.

Islam et al. (2013) investigated performance of vetiver plantation in slope protection against rain-cut and wind induced erosion and found that vetiver grass grows in different soil and climatic conditions of Bangladesh and it is effective for slope protection. They reported that vetiver grows suitably in a sub-tropical climatic condition in sandy soil and protects slope from rain-cut erosion and sliding and in *barind* tract zone and protects pond slope against rain-cut and wind induced erosion. They reported that vetiver plantation is a suitable solution to protect the side slopes of shrimp ponds from flood and wave actions. From comparative cost analysis, they found that vetiver application is about 8 times cheaper than the masonry wall protection and about 5 times cheaper than the revetment stone slope protection system.

2.7.2 Study on Shear Strength/Slope Protection

Hairiah et al. (2006) studied root effects on slope stability in Indonesia. They tested two hypotheses: (1) differences in the distribution of tree roots between species can be used to reduce landslide risks in the context of productive coffee agroforestry systems, (2) shear strength of soil increases with root length density in the topsoil, regardless of plant species. They found that trees with high IRA (Index of Root Anchoring) not always had a low IRB (Index of Root Binding of soil particles) or vice versa. They reported that trees with a high IRA can probably be used to anchor river banks when grown to mature size. Ideally planting a mix of tree species with different pattern of rooting depth will provide a good protection of the soil surface and also increase river bank stability. Based on their preliminary study, they suggested that mix of tree species with deep roots and grasses with intense fine roots will provide the highest river bank stability in the area.

Hossain et al. (2008) studied the causes of embankment failure in Bangladesh. They reported that the major causes of embankment failure of Bangladesh are breaching of the embankment, cutting by public, overflow, erosion, seepage, sliding and also for poor planning, design and faulty construction. The cause of failure of all the flood control embankments in the year 2007 could be attributed to erosion and sliding of embankment materials due to river encroachment and mitigation. Slope stability analyses of the Padma and Jamuna flood control embankments revealed that the country side slopes of both the embankments are not at all stable during the monsoon when the water level is high. The Jamuna flood control embankment is not stable even before and after the monsoon period because the factor of safety calculated for the country side slopes are less than that of the recommended one.

Islam and Arifuzzaman (2010) and Islam et al. (2010) studied the in-situ shear strength of vetiver rooted soil matrix and bare soil. Islam and Arifuzzaman (2010) developed a device to determine the in-situ shear strength of the vetiver rooted soil matrix and used it for silty and sandy soil in coastal zone. They conducted tests on block samples (approximately 29×15×19 cm^3) at different depths under different normal loads for both vetiver rooted soil and soil without roots. They found that for a particular normal stress, the shear strength and failure strain of vetiver rooted soil is 87% and 770% higher than that of a bare soil respectively. Islam et al. (2013) conducted the in-situ shear test and also direct shear test on laboratory reconstitute soil samples at different root content to know the shear strength of vetiver grass and found similar results.

Hengchaovanich (1996) studied the tensile root strength of vetiver and its contribution to soil strength through experiments on tensile root determinations and root-permeated soil shearing and reported that the tensile root strength properties of vetiver grass in association with its inherited morphological root characteristics improve the resistance of soil slopes to shallow mass stability and surface erosion and found that the shear strength increases in soil due to the root penetration of a 2 year old vetiver hedgerow with plant spacing 15 cm veries from 90% at 0.25m depth to 1.25% at 1.5m depth.

Islam and Arifuzzaman (2010) explored the prospect and performance of vetiver grass in protecting coastal embankments against tidal surge. They conducted field tests on block samples to determine in-situ shear strength of vetiver rooted soil and soil without root an found that the shear strength and failure strain of the rooted soil are 87% and 770% higher than those of soil without root.

Islam et al. (2013) investigated the application of vetiver system with geo-jute, for slope protection and erosion control of embankments and slopes. They conducted in-situ shear tests on vetiver rooted soil system and found that the shear strength and effective cohesion of vetiver rooted soil matrix are respectively 2.0 times and 2.1 higher than that of the bared soil. Slope stability analyses showed that vegetation increases factor of safety significantly. They also compared the cost of vetiver with other traditional practices used for slope protection and found that plantation of vetiver grass costs least to other common practices.

Islam (2012) investigated slope and road embankment stabilization against rain-cut erosion. He found that vetiver grass plantation along the slope increase the factor of safety by 50% i.e., this system is effective to protect the slope for long time. However, periodic maintenance is required for getting better performance. Moreover geo-jute is effective in growing vetiver in all seasons. This vegetation system reduces erosion, improves ground water recharge and removes pollutants from water.

Nasrin (2013) studied the shear strength of rooted and bare soil by conducting in-situ shear strength test and direct shear test on laboratory reconstitute samples. According to this study vetiver grass plantation is found to be effective to protect the embankment slopes against top soil erosion and runoff. It may work better in wave action. It also works against shallow depth failure.

Gautam (2015) reported that the planting of broom grass/tiger grass has a direct impact on preventing surface soil erosion on steep hillsides. Tiger grass grows in clumps and has many tangled up roots that grow to about one metre below the ground. This makes it highly effective in preventing soil erosion on hillsides as the grass is less likely to fall compared to other plants and trees that would have been planted there. The roots and leaves of the plant slow down water drops and the flow of water after heavy rain by absorbing the water in the soil. Growing tiger grass on degraded land has been proven to help rehabilitate it as it helps retain ground moisture and promote fertility.

Jain (2013) studied shear strength of unvegetated soil control samples, *Thysanolaena maxima,* and *Saccharum spontaneum* after 4, 8 and 12 weeks of growth. For determination of tensile root strength, he tested about 80 vetiver root specimens of different classes varying from 0.2 to 2.2 mm with about 15-20 cm long length. Roots were collected from two year old vetiver plants grown on embankment slope. The unbranched and straight roots (fresh condition maximum two hours after collection) were vertically connected to hanging spring balance via a wooden clamp at one end while the other end was fixed to a holder that was pulled down manually until the root failed. He also performed large-scale direct shear testes for vetiver grass on a sloped soil profile of an embankment vegetated with vetiver in order to determine the root reinforcement effect of this grass. The test apparatus comprised a shear box (8 mm thick steel plates capable of holding firmly a soil block of 50cm × 50cm × 50 cm in dimensions), a hydraulic jacking system (capacity 10 tons), a proving ring (capacity 3 tons) and dial gauges. He reported that in the 4-week growth scenario, both plants exhibited lower shear strengths than their unvegetated counterparts but at 12-week growth, both species exhibited higher soil stability. He also reported that root tensile strength of vetiver decreases with the increase of root diameter. He concluded that together all three plants (*Thysanolaena maxima, Saccharum spontaneum* and *Vetiveria zizanioides*) are very effective as reinforcement for the prevention of soil erosion.

Islam and Hossain (2013) conducted in-situ shear tests of the ground with the vetiver roots to investigate the stabilization properties corresponding to the embankment slopes. They also performed numerical analyses with the finite element method using elasto-plastic subloading t_{ij} model, which can stimulate typical soil behaviour. It is revealed from their field tests that the shear strength of vetiver rooted soil matrix is higher than that of the unreinforced soil and vetiver root reinforced soil showed ductile behaviour. They evaluated the effectiveness of vetiver root in geotechnical structures- strip foundation and embankment slope by finite element analyses. They reported that the reinforcement with vetiver root enhances the bearing capacities of the grounds and stabilizes the embankment slopes.

2.7.3 Study on Land Reclamation

Numerous researches have been done on phytoremediation for different plants and remediation of different heavy metals from soil as well as water.

Ying et al. (2012) proved that hardy sugarcane is a Cu hyperaccumulator. Their study also showed that *S.arundinaceum* could be used as one of remediation plants for the abandoned farmlands contaminated by multi-metals Cu, Zn, Pb, and Cd.

Srisatit et al. (2003) used Vetiveria zizanioides (Linn.) Nash and Vetiveria nemoralis (Balansa) A. Camus (Prachuabkirikhan ecotype) for arsenic removal experiments. They grown both plants for one month and then put them in control, 50, 75, 100, 125 and 150 mg As/kg soil and observed their growth and analyzed for arsenic accumulation in roots, stems and leaves after 15 days upto 90 days. They observed that all of the plants grew well in every concentration of arsenic, with 100% survival. Accumulation of arsenic in the root of both species was higher than in the leaf. The total amount of arsenic accumulation in V. zizanioides (Linn.) Nash was more than in V. nemoralis (Balansa) A. Camus. In addition, the arsenic removal efficiency of both species increased with increasing exposure time. They reported that the highest efficiency of V. zizanioides (Linn.) Nash was 0.05% after 90 days at an As concentration 75 mg As/kg soil dry weight and the highest efficiency of V. nemoralis (Balansa) A. Camus was 0.04%, after 90 days at an As concentration of 125 mg As/kg soil dry weight.

Hidayati et al. (2009) reported that wild cane i.e., *Saccharum spontaneum* have high tolerance and high biomass production to Mercury and Cyanide highly contaminated area. They studied Mercury and Cyanide accumulation of some species that grow locally in a gold mine area. They found that accumulation of Cyanide in wild caneʼs root is nil and in shoot is 10.25 ppm.

Nazareno and Buot, (2015) studied the accumulation of cadmium (Cd) and chromium (Cr) in the plant tissues as well as in the plant root-zone soil using atomic absorption spectrophotometry (AAS). They used 32 plants that grows in Cebu City landfill and found that the landfill substrate was generally acidic based on the results of the pH measurement. Of the 32 plant species sampled, *Cyperus odoratus* showed potential for Cd uptake and internal transfer; *Cenchrus echinatus, Vernonia cinerea* and *Terminalia catappa* for Cr uptake, and *Cynodon dactylon* for Cr internal transfer. The plants in the landfill differed in their response towards the heavy metals. They recommended to conduct further studies to confirm the behavior of *C. odoratus* towards Cd, and *C. echinatus, C. dactylon, V. cinerea,* and *T. catappa* towards Cr, in controlled experiments as the plant samples analyzed were collected from the field.

Choudhury et al. (2015) and Ahmed (2015) studied heavy metal uptake by Indian mustard and Marigold plants from heavy metal contaminated Buriganga riverbed sediments. They found that the Buriganga riverbed sediments showed concentrations of chromium, lead, copper and zinc in the sediments higher than the toxicity reference values given for these heavy metals in soil for terrestrial plants, and soil invertebrate. They conducted tests to determine the accumulation of roots, shoots and leaves using atomic absorption spectrophotometry (AAS). They observed that both Indian mustard and Marigold plants accumulated these heavy metals in different parts of the plant from the contaminated sediments and was able to maintain a growth rate of more than 90% compared to that in non-contaminated soil. They reported that Marigold showed higher uptake efficiency for chromium, lead, and copper, while Indian mustard was found to be more efficient for zinc uptake.

Table 2.5 Approximate angle of repose for soil texture

Soil Condition	Angle of Repose
Very wet clay and silt	1V : 3H
Wet clay and silt	1V : 2H
Dry sand and gravel	1V : 1.75H
Dry clay	1V : 1.5H
Moist sand	1V : 1.25H

1.8 Summary

All the knowledge and topics including substantive findings of past researches related to this research paper, as well as theoretical and methodological description has been discussed in this chapter which can be summarized as follows:

(a) The general causes of slope failure are discussed in this chapter. Earthen slopes, made of deposited silty soil with low plasticity are very vulnerable to rainfall and wind. Most of the slopes remain unprotected and get damaged easily by rain impact, rain water runoff, flood water, wind, human and animal activity.

(b) Then the recent topic soil bioengineering has been described here which is become very popular in past few decades. In Bangladesh, the research on bioengineering is being practiced since past seven or eight years, though people are applying this technique privately (for land barrier mark, raised yard boundary, pond slope protection etc.) in some areas. This technique earned Governmentsô attraction recently and few projects (CCRIP, HILIP, CALIP) are being initiated for field applications.

(c) Vetiver grass system is now becoming the highest practiced bioengineering plant. This grass is being called as ómiracle grassô because it has high potential to protect soil surface from erosion, to purify soil from contamination, to clean wasted water, to make medicine, perfume etc.

(d) Root soil interaction is very important for bioengineering work. To make the work effective and efficient, it is very important to understand the interaction behavior of soil and plants root that will be used for soil protection work.

(e) Saline soil i.e., saline water intrusion is becoming a threat worldwide. Hi-technical protection measures are expensive and sometimes do not work properly due to construction faults, proper maintenance, poor supervision etc. Salt tolerant plants can be used as bioengineering plants in soil slope protection work in saline zone.

(f) Findings of the past researches related to this study have been discussed here.

Chapter Three

EXPERIMENTAL AND ANALYTICAL PROGRAM

1.1 Introduction

To evaluate the performance of root reinforced earthen structure like earth embankments, the shear strength properties should be known (Nasrin, 2013). In the common engineering materials like iron, steel, molecular bonds hold the material together and the shear strength is governed by the molecular bond. The stronger the molecular structure, higher the shear strength of that material. But Soil is a particulate material, so shear failure occurs when the stresses between the particles are such that they slide or roll past each other. Due to the particulate nature of soil, unlike that of a continuum, the shear strength depends on the inter-particle interactions rather than the internal strength of the soil particles themselves (Coduto, 2001; Jain, 2013).

As the main element of earthen embankment is soil, so it is very important to determine the properties of the soil to understand their behaviour. The process of sample preparation and test procedures including both in-situ test and laboratory investigations are discussed in the chapter.

1.2 Study Areas

To study the effect of different plant roots on soil shear strength is the main objective of this study. Four plants were selected on the basis of previous researches, root morphology and availability in Bangladesh. Few researches have been done (Rahman et al., 1996; Thomas et al., 2002) to find places where selected grasses grow naturally. For this purposes, Bangladesh National Herbarium at Zoo road, Dhaka-1216 was visited on March, 2014. Bangladesh National Herbarium a scientific organization where plant specimens collected from different parts of the country are documented and preserved as reference material. The herbarium has a scientific collection of approximately 100,000 preserved specimens of plants and also their availability in Bangladesh. According to their information, it was found that in Netrokona district, selected plants (hardy sugarcane, wild cane, tiger grass and vetiver grass) grow naturally. As a result, Netrokona district was selected as study area for field test site.

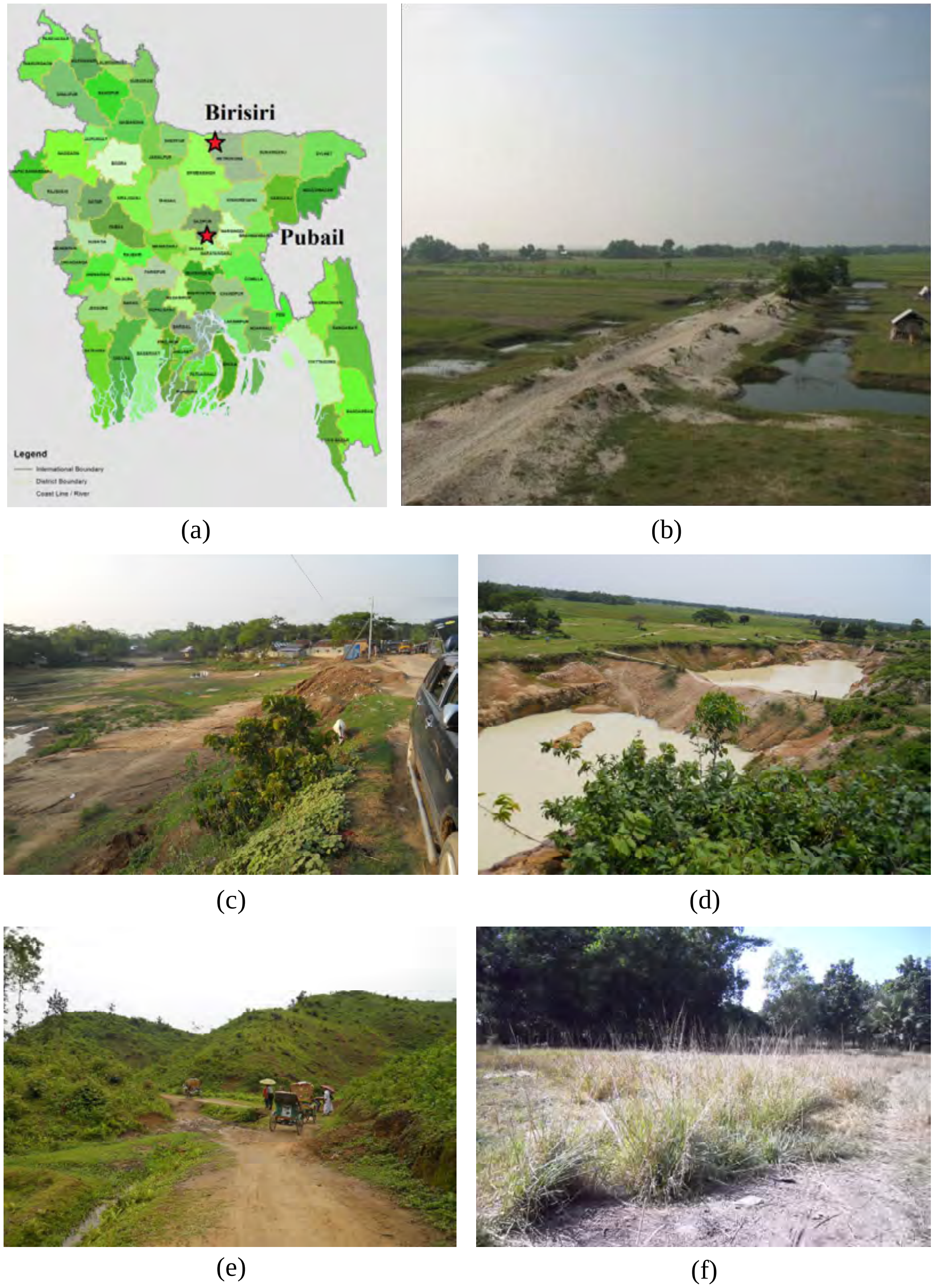


Fig. 3.1 Map showing the study areas (a) location of study areas on Bangladesh, (b) Kuakata, (c) Durgapur road embankment, (d) *Sada pahar*, (e) *Garo pahar* and (f) Pubail, Gazipur

For in-situ test, ôBirishiriô in Netrokona district is selected due to the availability of the selected plants which grow there naturally. In-situ tests are conducted in a road embankment in Durgapur, in *Sada pahar* and in *Garo pahar*. For laboratory investigations, four different types soils were used. These are a) embankment (Durgapur), b) flood plain region, c) hilly region (*Garo pahar*) and d) contaminated organic soil (river bank).

1.3 Experimental Program

In-situ tests were conducted to determine the in-situ shear strength and failure strain of rooted and bare soil in Birishiri. Soil samples and plant samples from in-situ test sites were collected to conduct laboratory investigations and growth study. Laboratory investigations include both index property tests and direct shear tests.

3.3.1 In-situ Test

In-situ shear strength tests were conducted in the field on 9 block samples. Among them 3 samples were bare soil test conducted in Garo pahar located at Bangladesh-India border, 3 samples were in sada pahar in Birishiri and other 3 samples were in side slopes of Durgapur to Daha para road embankment.

a) Equipments Used for In-Situ Test

For determination of in-situ shear strength of soil, a special device was used with slight modification that developed by Islam and Arifuzzaman (2010). The apparatus that were used for these tests are hydraulic jack (capacity 5 ton), pressure gauge (capacity 100 psi), wooden plate, metal plates, metal box (approximately 40×20×19 cm3), normal load (160 kg) and Linear Variable Displacement Transducer (LVDT) with capacity 50 mm. Both pressure gauge and LVDT were calibrated before using in the test. A list of materials and equipments used for experimental set up in field test is given below.

1) Steel model box
2) Weight
3) Steel tape (1 meter)
4) Hydraulic jack and pump (Capacity 5 Ton)
5) LVDT (Range 50 mm)

6) Pressure gauge (Capacity 100 psi)
7) Metal plates
8) Spade
9) Sabol
10) Hydraulic oil Grade No. 32
11) Sickle and Hoe
12) Wrench

(a) (b) (c)

Fig. 3.2 (a) Metal box (40×20×19 cm^3), (b) LVDT (50 mm capacity) and (c) hydraulic pump, hydraulic jack (5 Ton) and pressure gauge (100 psi)

b) Sample Preparation

Grass clump were cut at the ground level with a sickle. Keeping the root position undisturbed a trench of the size around (1m×1m) was made up to the desired depth (19 cm). The rooted area was made in desired block sample i.e., 40×20×19 cm^3 shape by sharp knife. Then the metal box was placed around the earth block sample. Fig. 3.4 illustrates the sample preparation for in-situ test.

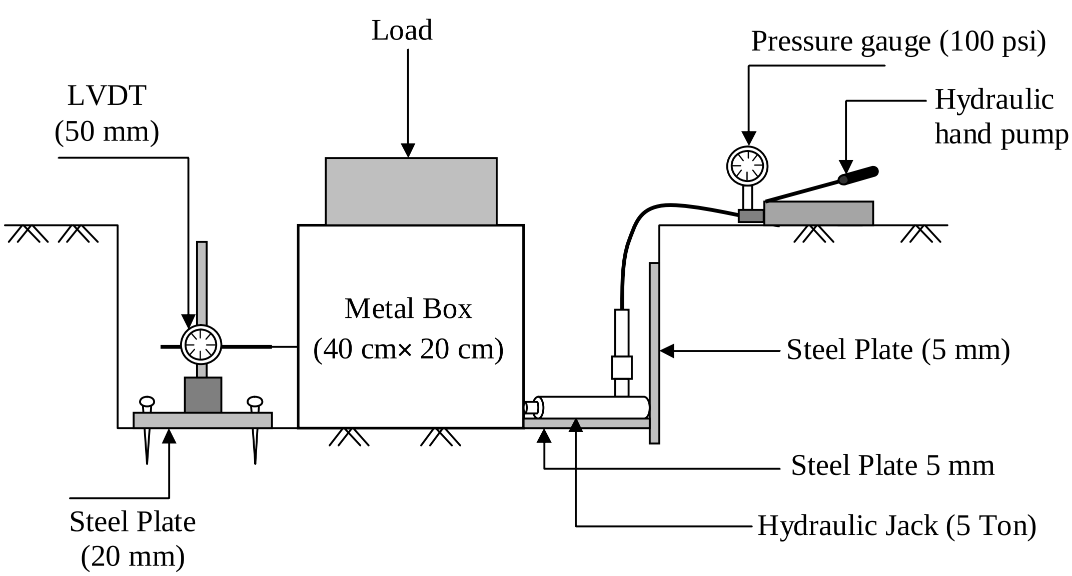


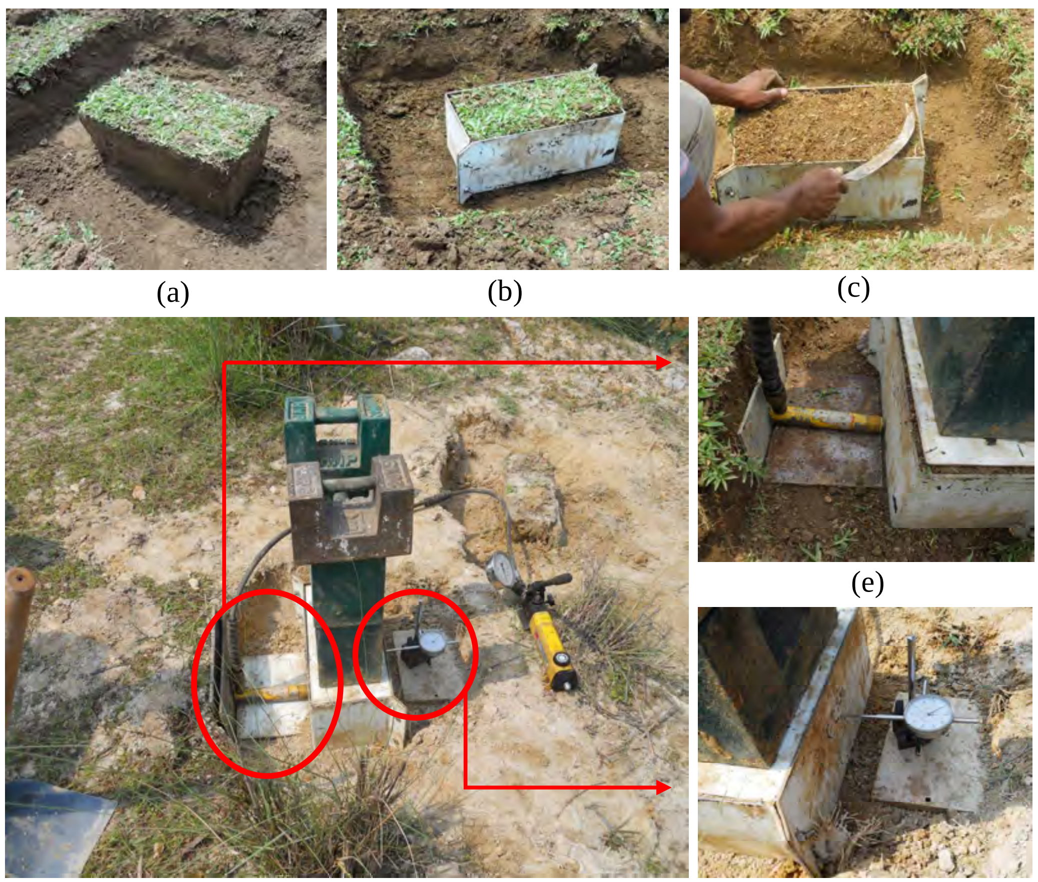
Fig. 3.3 Schematic diagram of field test set-up

c) Experimental Set-Up

A metal cover plate was placed over the earthen block sample for uniform vertical loading. Then weights were placed over the metal cover plate centrally. The hydraulic jack was placed one side of the metal box in a manner that the plunger touch metal surface and force was applied. On the opposite side of the metal box, LVDT was placed to measure the strain. Fig. 3.3 illustrates the experimental set up for in-situ shear strength of soil.

d) Test Procedure

Vertical load 120 kg (14.71 kPa), 140 kg (17.15 kPa) and 160 kg (19.6 kPa) were applied. With hydraulic hand pump, pressure applied through the hydraulic jack, and strain measured with Lateral variable displacement transducer (LVDT).



(a) (b) (c) (d) (e) (f)

Fig. 3.4 (a) Earth block, (b) block in metal box, (c) upper layer clumps are cutting down with a sickle, (d) test arrangement, (e) closer view of hydraulic jack placing and (f) closer view of LVDT attachment

3.3.2 Laboratory Tests

All the laboratory tests except salinity test and heavy metal extraction test were conducted in the Geotechnical Laboratory and salinity test and heavy metal extraction tests were conducted in Environmental Laboratory in Civil Engineering Department of BUET. The list of laboratory tests conducted is given below.

- Specific Gravity
- Atterberg limit test
- Grain size analysis
- Hydrometer test
- Wash sieve
- Direct shear test
- Organic content
- Salinity of soil
- Heavy metal extraction test

1) Specific Gravity

This test is conducted according to the ASTM D 854-14. 50 g of oven-dry soil sample, W_s has been taken into a 250 ml pycnometer and around 100-150 ml water added. Then boiled in a hot basin and vacuum suction was applied to remove air bubbles. After cooled down, water added upto the mark of the pycnometer and weight, W_1 (pycnometer + water + soil) has been taken. Then weight of pycnometer with water, W_2 has been taken. Water temperature also noted down since water density varies with temperature. Then Specific Gravity of the soil was calculated by the following equation.

$$G_s = \frac{1\ \ 1 \times 1\ 1}{1\ \ 1\,1\ 1\ \ 1\,1\ 1\ \ 1}$$

2) Atterberg limit

This includes liquid limit test and plastic limit test. The method followed was ASTM standard ASTM D 4318.

a) Liquid Limit (LL)

Air dried soil samples were crushed by a wooden hammer and then passed through the #40 sieve. Around 200 gm #40 sieve passing samples were collected. Water added to the soil and mixed thoroughly with spatula. If soil seems to be plastic enough, then this mixture needs to keep for at least 16 hours. Because plasticity indicate clay content and clay particles have low permeability. Using casagrande apparatus, for five different blows (ranges are 10 to 15, 15 to 20, 20 to 25, 25 to 30 and 30 to 35), five soil samples were collected and then oven dried. Water contents were measured. Then graph w/c vs. no. of blow was plotted. From this plot, w/c for 25 blows is considered as liquid limit of the soil sample. The equation used for calculation of water content is

$w/c = \frac{1\ \ 1}{1\ \ 1} \times 100\ \%$, where, W_s= mass of dry soil and W_w = mass of water

b) Plastic Limit (PL)

While conducting liquid limit tests, few samples were kept in the air for drying and make a tread of around 1/8 inch diameter. When the thread started to crack, samples are ready. These samples are then oven dried to measure w/c. At least two samples are required. Then the average of two is considered as plastic limit of the soil sample.

3) Grain Size Analysis

Test method is ASTM D 422. Since the soil samples have both fine and coarse particles, this test includes the hydrometer test for fine particles (#200 sieve passing) and sieve analysis for coarse particles (#retained after wash sieve).

(a) Hydrometer

In a hydrometer jar (1000 ml), 100 ml deflocculating agent sodium hypophosphite ($NaPO_2H_2$) has been taken. Then #200 sieve passing 50 gm oven dried soil samples has been taken into this jar and water added upto 1000 ml mark. Then the mixture was thoroughly mixed with the mixing rod. Hydrometer readings were taken at time (in minute) 0.25, 0.5, 1, 2, 4, 8, 15, 30, 1 hr, 2 hr, 4 hr, 8 hr, 24 hr, 48 hr and 72 hrs. For each reading, water temperatures were recorded. Meniscus correction and zero/reagent correction have been taken.

4) Wash Sieve

100 gm oven dried soil have been taken into a #200 sieve and washed thoroughly with water in the sink. The remains were collected in a small bowl and again oven dried.

The oven dried remains were weighted and the value taken as a percent coarse particle and the value of (100 ï remains) indicates percent fine particle.

(b) Sieve Analysis

The remained oven dry soil from wash sieve was used. The sieve nos. are #4, #8, #16, #30, #50, #100 and #200.

5) Direct Shear Test

The tests conducted in direct shear test apparatus were consolidated undrained i.e., CU test. Specimens were kept for consolidation for 1 hrs and the condition was unsaturated. Test method followed ASTM standard ASTM D 3080. Direct shear tests were conducted on twenty different types of soil specimens. For each type of soil, five sets of tests were conducted and these were specimen without roots, with roots of hardy sugarcane, wild cane, tiger grass and vetiver grass. The selected normal loads were 10.83, 15.47 and 20.12 kPa.

Sample preparation: Collected soils were air dried and then crushed by a wooden hammer. Water added to make a paste. Except coarse sand, others were prepared with around 25% water content. Four types of plant roots were collected and cut into 1 inch pieces as shown in Fig. 3.5. Root contents were 3% by weight of dry soil. Roots were preserved in a box mixed with water and kept in a refrigerator. Roots were mixed with soil paste with a knife. Then the mixture was compacted in the ring of 63.5 mm diameter and 25.4 mm height with three layer compaction. Each layer was compacted with 25 blows by a wooden tamping rod. Top layer of the specimen is smoothened by knife. Fig 3.6 illustrates sample preparation.

Test set-up: Specimen was placed in the shear box from the ring. The vertical displacement dial gauge was attached to record the vertical deformation. Then the normal load was applied and kept for at least one hour for consolidation. At the mean time horizontal displacement dial gauge was attached. After one hour shear was applied.

(a) (b) (c) (d)

Fig. 3.5 Root samples of (a) hardy sugarcane, (b) wild cane, (c) tiger grass and (d) vetiver grass

(a) (b)

Fig. 3.6 (a) soil and root mixture and (b) specimen in a ring

6) Organic Content

Organic content was determined under ASTM D 2974 ï standard test methods for moisture, ash, and organic matter of peat and organic soils. For this test oven dried soil specimen (maximum 10 gm and not more than that) were placed in a small porcelain dish. Then the dish was placed in a furnace for 6 hours with a temperature 440ęC. Then removed from the furnace and cooled down into room temperature. The following equation was used to measure organic matter.

$OM = \frac{M_o}{M_d} \times 100\%$, Where, M_o = mass of organic matter and M_d = mass of dry soil

7) Salinity of Soil

Healthy grown vetiver grass was used for plantation in saline soil. Vetiver grass was planted in clay pots of size 250 mm dia and 200 mm depth filled with alluvial soil (G_s= 2.49, Sand= 84%, Silt= 4% and Clay= 12%). Alluvial soil is proper for agricultural work and vetiver grass grows well. The plantation was done in dry season during December. Average relative humidity was around 50% and rainfall occurred hardly two to three times in this time. After five months of regular watering, these grasses grew well having root length of about 1.0m. Fig. 3.7a and 3.7b presents the grass just after plantation and after 5 months.

(a) (b) (c)

Fig. 3.7 (a) Immediately after plantation, (b) after 5 month of plantation and (c) grown grass

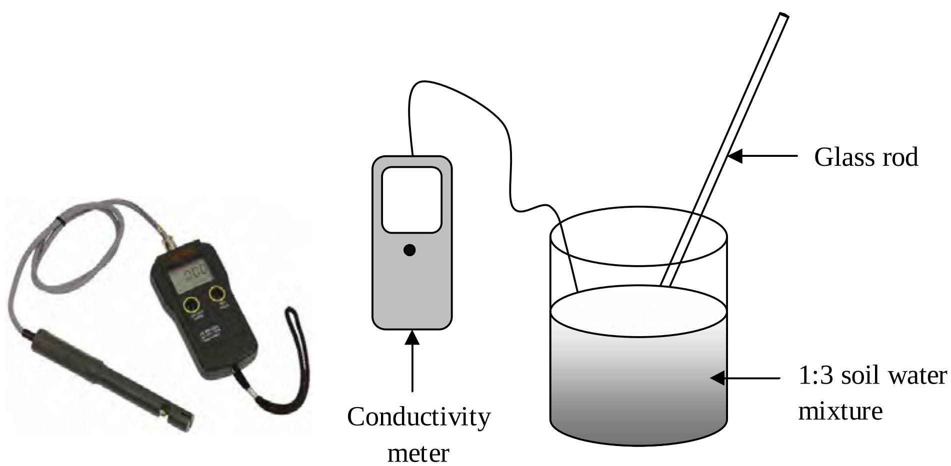
These grown grasses were then planted in clay pots filled with saline soil. The clayey soil (G_s= 2.59, Sand=56%, Silt= 10% and Clay= 34%, LL= 33% and PL= 13%) was used for the study with four different levels of salinity. Saline soil was prepared artificially by mixing with sea salt NaCl. Salt was mixed with dry soils. The amount of salt to be mixed was determined by trials. Commercially available salt was added in such a way so that EC value of the soil becomes 4.8 ds/m, 10.0 ds/m and 12.5 ds/m similar to that of low to moderate and strong saline zone of Bangladesh. Fig. 3.8

shows the vetiver grasses planted for salinity removal investigation. Soil salinity measured before plantation and after 5 weeks of plantation.

(a) (b)

Fig. 3.8 (a) Vetiver clumps and (b) plantation in saline soil

Procedure: First the soil samples were dried in the oven for 24 hours at 100°C. Then 50 gm of oven dried soil was mixed with 150 ml distil water (soil: water=1:3). Then the mixture was stirred with a glass rod. Finally the EC (Electrical conductivity) of the mixture was determined using Conductivity meter/PH meter. Conductivity meter and schematic diagram of soil salinity test is presented in Fig 3.9.



(a) (b)

Fig. 3.9 (a) PH/conductivity meter and (b) schematic diagram of salinity test of soil

8) Heavy metal extraction

This experiment was conducted to look into the fact that whether vetiver grass *(Vetiveria Zizanioides)* has the potential to uptake heavy metals (Pd, Cu, Cr, Zn and Ni) from industrial waste contaminated soil. Locally available vetiver grass was collected and planted in a plastic container filled with riverbed sediments collected from Buriganga River. Plants were harvested on 19^{th}, 22^{nd}, 48^{th} and 50^{th} week after plantation. Heavy metal extraction tests were conducted for soil sample (before plantation and after each harvesting time), leaves, shoots and roots separately. Vetiver grass in plastic container and grass sample is presented in Fig. 3.10a and 3.10b respectively.

(a) (b) (c)

Fig. 3.10 (a) Vetiver grass in plastic container, (b) uprooted grass sample and (c) washed sample

Procedure: Leaves, shoots and roots were separated from the plants washed with distil water, oven dried at 105-110°C for 24 hours and then grounded in a porcelain grinder. Fig. 3.11a, b and c show the separated root, after over dried and grinded root respectively. For soil 5 gm grinded sample was kept with aqua-regia (7.5 ml hydrochloric acid and 2.5 ml nitric acid) in a beaker and for plants 2 gm grinded sample was kept with 25 ml nitric acid along with few drops of water and kept overnight. Then the samples were shifted in a volumetric flask and boiled for two hours. Fig 3.12b and c show sample after adding acid and being boiled respectively. Then after cooling the sample 10 ml of perchloric acid was added to the flask (except for the soil) and heated again for one hour to boiling. If the sample colour turns into light yellow, the digestion process is assumed to be completed and if not, then 2 to 3 ml of nitric acid is added to the flask and heated again. The process was repeated until the sample colour turned in to light yellow. After that, distilled water was added up to 500 ml and stirred for 5 minutes. Then cooled and finally filtered using a filter paper (0.45 micron). The filtrates were stored in plastic bottles for analysis using an atomic absorption spectrometer (Shimadzu AA6800). Fig. 3.13 presents the filter process and stored sample in plastic bottles.

(a) (b) (c)

Fig. 3.11 (a) Separated root, (b) oven-dry root and (c) grinding of oven dried sample

(a) (b) (c)

Fig. 3.12 (a) Grinded sample in a beaker, (b) after adding Nitric acid and (c) boiling of samples

(a) (b)

Fig. 3.13 (a) Filtering of yellow liquid samples and (b) stored samples in plastic bottles

3.4 Growth Study

Three types of growth were studied with the grasses whose roots were used for laboratory investigations.

3.4.1 Selected Grasses

Three types of plants were collected from in-situ test sites, Birishiri. Then they were planted in BUET premises. Monitoring pictures of these plants are presented in Fig. 3.14.

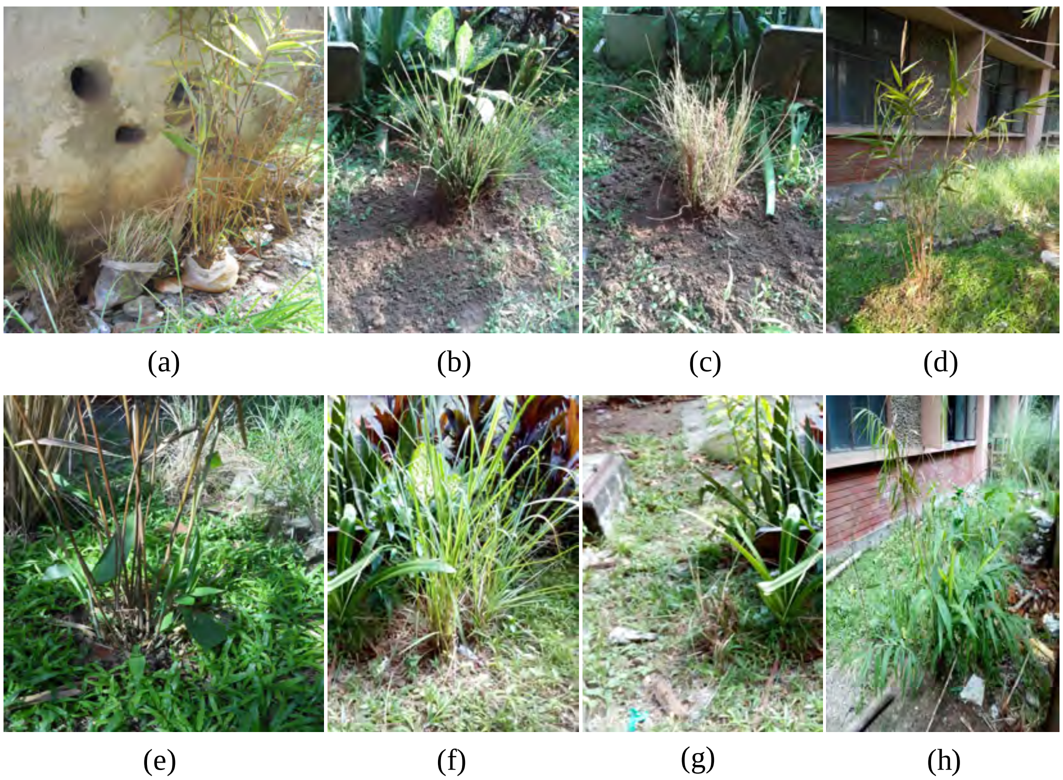


Fig. 3.14 (a) Collected plants, (b) hardy sugarcane, (c) wild cane, (d) tiger grass immediately after plantation, (e) new tilts are coming out from tiger grass (*jharu* plant), after 5 months of plantation: (f) hardy sugarcane, (g) wild cane and (h) tiger grass

3.4.2 Vetiver Grass in Contaminated Soil

Vetiver grass was collected from Pubail, Gazipur and planted in industrial waste contaminated soil collected from Buriganga river bank. Then vetiver grass was planted in a plastic container (size 56 cm×38 cm×32 cm). The clumps were cut into 6 inch shoot height with 2 inch root for plantation. These plants were monitored regularly and watered on daily basis for first one month and then in alternate day. Fig. 3.15 shows the schematic diagram of plantation.

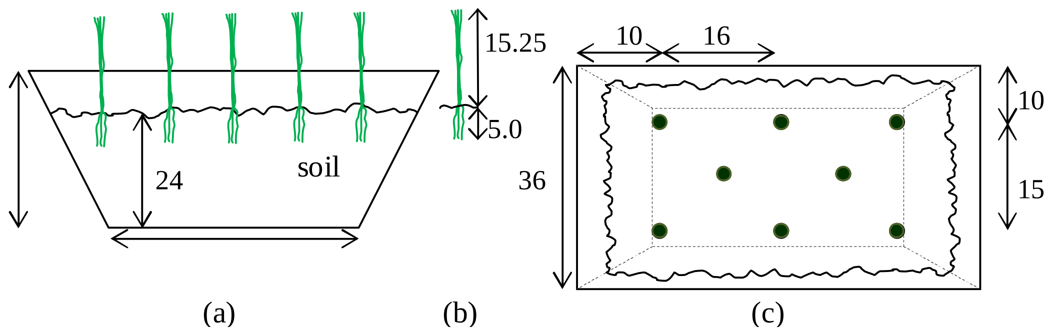


Fig. 3.15 Schematic diagram of a) plastic jar section, b) vetiver clump size and c) plan view of plantation (all dimensions are in cm)

3.4.3 Vetiver Grass in Nursery Soil

Around 1500 vetiver grasses were planted in 15 cm×20 cm sized poly bags in nursery soil. These soils were mixed with some cow dung before plantation. Plantation was done in pre-monsoon hot season. These grasses were collected from Pubail area in Gazipur. The initial root and shoot length of the tillers were around 5-8 cm and 15-20 cm, respectively. The plants were moved in jute sacks and carried to the BUET Premises through a Micro-Bus.

(a) (b)

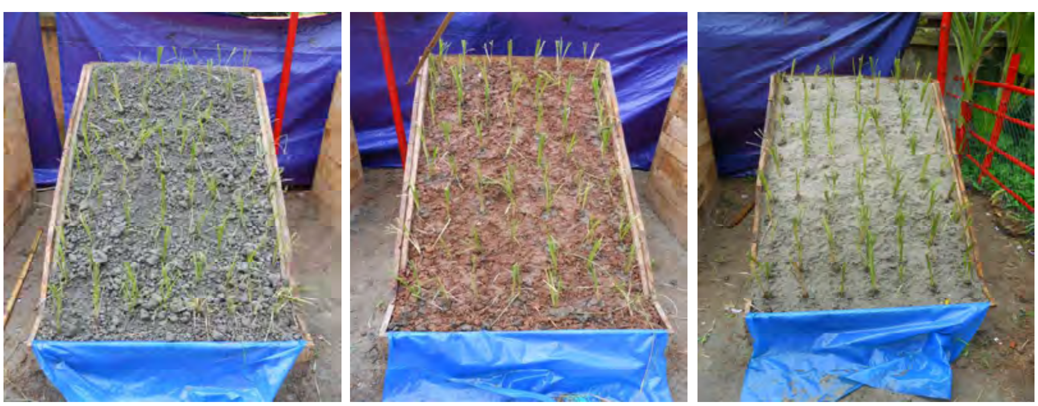
Fig. 3.16 (a) Cow dung mixed nursery soil and (b) immediately after plantation in polybags

Nursery soils and polybags were brought from nearby nursery. The plants were kept in a safe place where they got adequate sun light. Watering was applied in the morning and evening everyday for the first three weeks and are monitored in a regular basis. These grasses got plenty of rainfall which helped their growth significantly. Fig. 3.16 shows the planted grass in polybags.

3.4.4 Vetiver Grass in Different Soils

Six wooden model box slopes were prepared with slope 1:1.5 and placed in the BUET premises. A slight hand compaction (with a brick) was made at the sites before placing the slope models. Then these boxes are filled with collected soils. Four boxes were filled with nursery soil and one was red clay and the other was dredge fill sand.

(a) (b) (c)



(d) (e) (f)

Fig. 3.17 Planted vetiver grass in (a) nursery soil with 20 cm spacing, (b) nursery soil with 15 cm spacing, (c) nursery soil with 10 cm spacing, (d) nursery soil with triangular spacing, (e) red clay and (f) dredgefill sand

The nursery soil was collected from Savar, red clay was collected from nearby excavation site, dredge fill sand from Uttara and contaminated soil was collected from Buriganga river bed. Plants were collected from Pubail in Gazipur district and nurtured in polybags with cow dung mixed nursery soil. For each point, two tillers were planted together. The plantation was done on June. In Bangladesh, monsoon season lasts from June through October. So artificial watering did not need to apply. A temporary shade (for one month) with tarpaulin sheet was provided with bamboo frame to protect the slope soil from direct raindrop impact but they got enough rainwater. Watering was done whenever the soil becomes dry with a plastic pipe. For dredge fill sand, red clay and one nursery soil filled boxes, the grass spacing was 10 cm c/c in row and 15 cm c/c in column. For other nursery soil filled boxes, the grass spacing was 15 cm c/c in column and 15cm c/c, 20 cm c/c and triangular spacing in row, respectively. The planted grass in the model slopes are presented in Fig. 3.17.

3.5 Slope Stability Analysis and Surface Erosion Control

Slope stability analysis is performed to assess the safe design of human-made or natural slopes (e.g. embankments, road cuts, open-pit mining, excavations, landfills etc.) and the equilibrium conditions. Slope stability is the resistance of inclined surface to failure by sliding or collapsing. Stability is determined by the balance of shear stress and shear strength. If the forces available to resist movement are greater than the forces driving movement, the slope is considered stable. A factor of safety is calculated by dividing the forces resisting movement by the forces driving movement.

To show the influence of vegetative cover on slope stability a special equation is developed by Coppin and Richards (1990).

$$FS = \frac{(c' + c_R') + [\{(\gamma z - \gamma_w h_v) + W\}\cos^2\beta + T\sin\theta]\tan\varphi' + T\cos\theta}{\{(\gamma z + W)\sin\beta + D\}\cos\beta}$$

Where,

c_R' = enhanced effective soil cohesion due to soil reinforcement by roots (kN/m^3)

W = surcharge due to weight of vegetation (kN/m^2)

h_v = vertical height of ground water table above the slip plane with the vegetation (m)

T = tensile root force acting at the base of the slip plane (kN/m)

θ = angle between roots and slip plane (degrees) and

D = wind loading force parallel to the slope (kN/m)

3.6 Summary

In this Chapter a brief description about the selected sites for both in-situ tests and laboratory test is given. The methodologies of all the tests conducted in the field and laboratory are described here with detailed pictures. Growth performance of selected plants and growth of vetiver grass in contaminated soil, saline soil and in different types of soils in model boxes are described here. The equation used for slope analysis i.e., Coppin and Richards (1990) has been briefly described with necessary terms.

Chapter Four

RESULTS AND DISCUSSIONS

3.4 Introduction

Slope failures of earth embankments leads to several greater damages. This slope includes road embankments, river bank, dykes, hill slopes etc. In Bangladesh, slope failure is a very common problem (Hossain et al., 2008; Nasrin, 2013; Islam, 2013). The reason behind it can be explained as, Bangladesh forms the largest delta in the world and mainly made of alluvial deposit which is basically silty soil (Rahman, 2010). So embankments made of such soil are very vulnerable to rain-cut erosion and wave action. Common protection measures are placement of geotextiles, construction of retaining walls, use of geo grids, vegetation, passive anchors like soil nails; dowels, rock bolts; pretensioned multi strand anchors, shear keys like counterforts, piles; caissons, compaction, deep mixing with lime and/or cement, permeation or pressure grouting with cementitiuous or chemical binders, jet grouting. Most of these are expensive and not feasible for the country due to the lack of quality, construction supervision, skilled labour and maintenance. Moreover, these are not eco-friendly. The average height of road embankments in Bangladesh is around 4.5 meter (LGED). Usually surface erosion causes maximum damage which leads to local slope failure.

Among all the protection measures, one of the simplest and cost effective means for stabilizing bare soil surfaces is the use of vegetation (Islam, 2013; Shahriar, 2015). Application of vegetation for soil stabilization is called bio-engineering. Soil bio-engineering uses live plants for soil protection. Some plants have strong root system that have the ability to bind soil particles together and can be used for soil protection work. The performance varies from plant to plant and soil types (Nyambane and Mwea, 2011).

To investigate the variation in strength for different rooted soil is the main objective of this research. Four different roots and four different types of soil combinations were used for laboratory investigation. Some field tests were also conducted for determination of in-situ shear strength of rooted soil. Analysis has been done on the results of laboratory and field tests to find the strength deformation characteristics of rooted soil specimens. Growths of vetiver grass were studied at BUET in different types of soil in slope models including saline soil and contaminated soil. Detail laboratory test results, in-situ test results and growth study results are presented in this chapter.

3.5 Selected Sites for Soil Collection and Testing

Different sites were selected based on different perspective. A brief description about the selected sites is given below.

4.2.1 Contaminated Soil

To study the effectiveness of bioengineering system in land reclamation, an area near the industrial waste dumping zone at Buriganga river bank had been selected. Initially soil samples from three different locations of Buriganga river bank were collected. Then metal accumulations in the soils were determined in the laboratory. The collected samples were sand, organic clay and clayey sand. Their chemical properties i.e., the concentration of heavy metals (lead, Pb; chromium, Cr; copper, Cu; nickel, Ni and zinc, Zn) is presented in Table 4.1.

Table 4.1: Heavy metal concentration of soil samples collected from Buriganga river bank

Location No.	Sample description	Pb (ppm)	Cr (ppm)	Cu (ppm)	Ni (ppm)	Zn (ppm)
I	Sand	18.9	25	14.0	12.7	30.3
II	Organic clay	47.0	167	44.3	32.0	120.1
III	Clayey sand	26.8	46	21.3	19.0	92.0

Soil samples from location II (Table 4.1) which was organic clay showed higher contamination than other two locations. This site was at the downstream of an industrial waste disposal point. Based on the results presented in Table 4.1, sample for further experiment was selected. Soil was collected from the selected location of Buriganga river bank. The co-ordinates of the site is 23.723€N, 90.35987E.

4.2.2 Soil from Vetiver Grown Land

A nearby place from Dhaka named Pubail where plenty of vetiver grass grows naturally was selected. Pubail site is located at Gazipur district. This area is in flood plain zone of Bangladesh. All the vetiver grasses used for this research were collected from this site.

4.2.3 Growth and Model Study at BUET Premises

Vetiver grasses were planted at BUET premises in artificial slopes made of wood which is showed in Fig. 3.17 of Chapter 3. Three types of soil were used in model study. These were dredge fill sand collected from Uttara, red clay collected from BUET premises and nursery soil collected from Savar.

4.2.4 Field Test Sites

There are several grasses grow in Bangladesh. Few of them have dense root matrix which is capable of decreasing soil erosion. For in-situ shear test of rooted soil, óBirishiriô in Netrokona district was selected due to the availability of selected plants which grow there naturally. Netrakona is situated in the northern part of Bangladesh, near the Meghalayan (Indian) border. Birishiri is a small place in the Upazila named Durgapur which is located at 25.1250°N, 90.6875°E. Durgapur area is influenced by the river Someshwari. This river is known as Simsang river in the Indian state of Meghalaya. For field test three test locations were selected. These were Durgapur road embankment, Sada pahar and Garo pahar. The location of the study areas has been shown in Fig. 3.1 of Chapter Three.

4.2.5 Buriganga River Bank

Buriganga river bank site had been selected to analyze the deposited soil structure. Undisturbed sample from Buriganga river bank had been collected in 3 inch dia PVC pipe. The undisturbed samples collected by PVC pipe is shown in Fig. 4.1. By observing the undisturbed soil sample from Buriganga river bank, it is seen that soil sample has different layers composed of different types of soil.

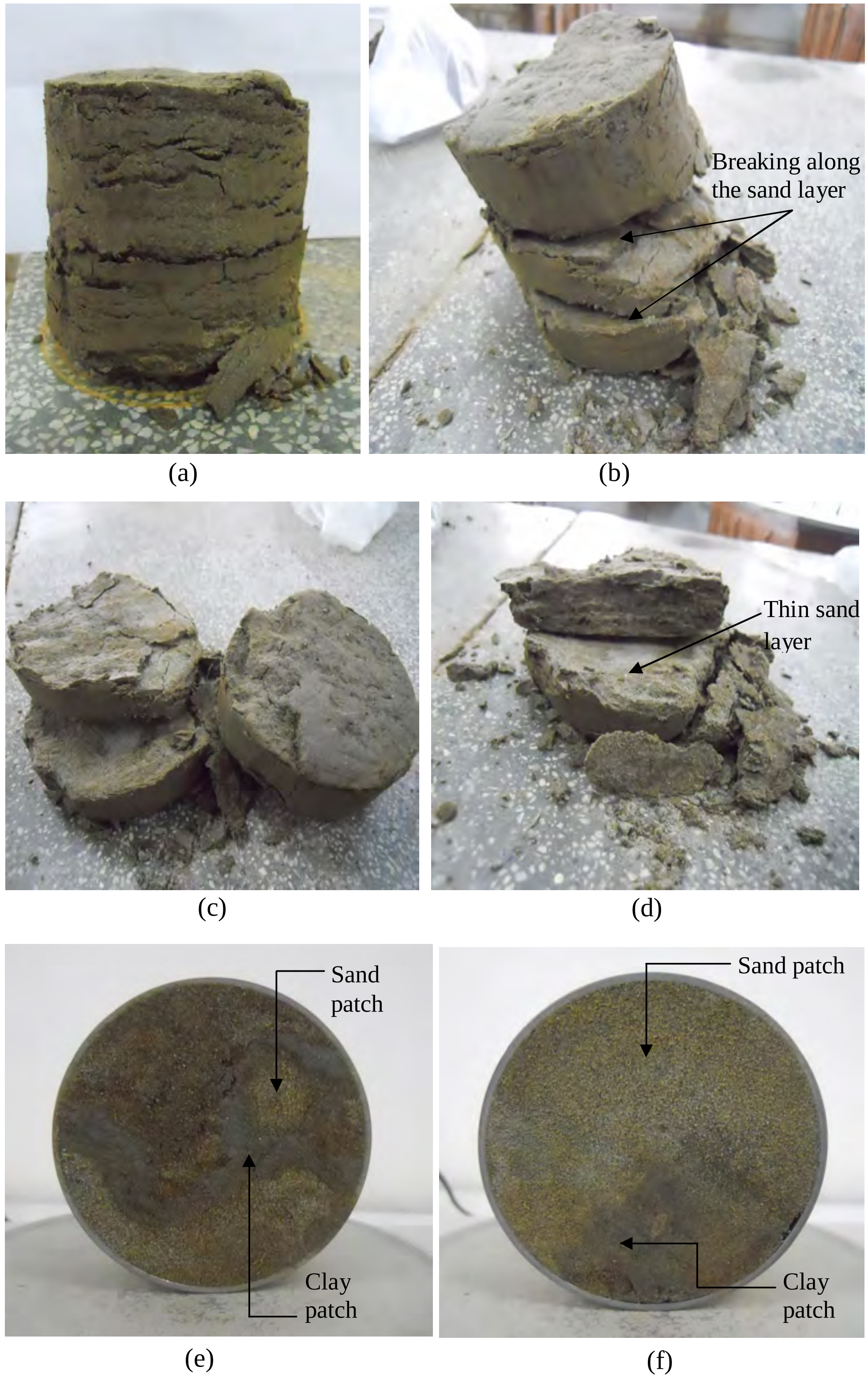


Fig. 4.1 Sandwiched soil texture of Buriganga river bank sample retrieved (a) undisturbed sample, (b) breaking of sample along the sand layer, (c) broken sample, (d) close view with visible multiple thin sand layer, (e) close view of the top of the ring sample and (f) close view of the bottom of the ring sample

From the photographs of Fig. 4.1, it is seen that there are thin layers of clay and sand in the soil column. Presence of these sand layers between the clay layers makes the soil structure vulnerable. These thin layers of sand get washed away easily with water runoff which causes sliding of top and bottom layers. As a result, river bank/embankments get damaged easily.

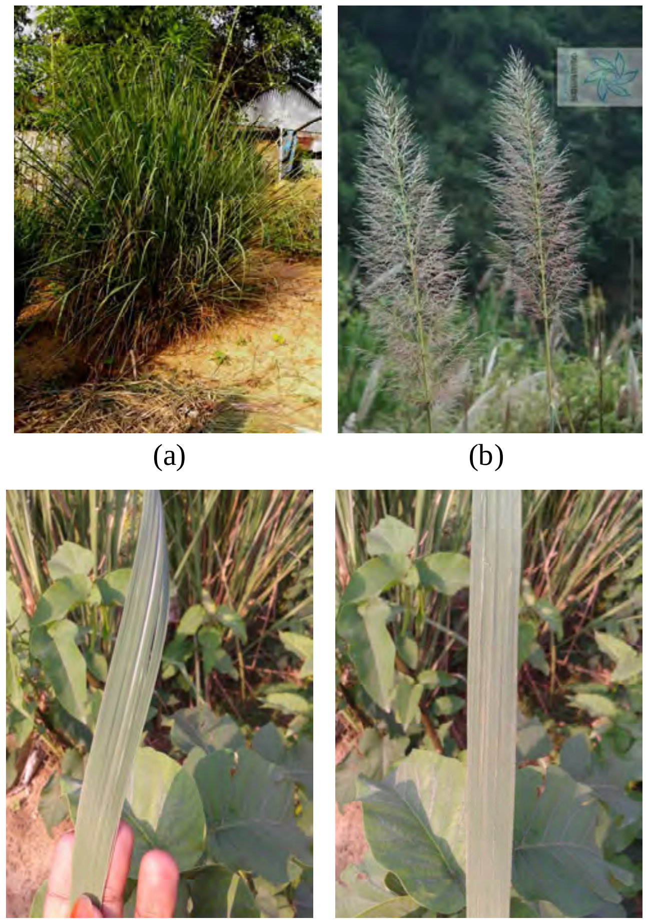
3.6 Selected Plants

In this study, the main objective was to study the effect of different plant root on soil shear strength and deformation. After studying previous researches on increasing soil shear strength as well as soil purification using plants root system, few plants were selected. As a bio-engineering plant, vetiver grass is well accepted all over the world. But there are some other locally available plants which are being used for soil protection purposes by the local people and also have soil binding capacity. Some of such plants are *nol khagra (Phragmites kark),* hardy sugarcane *(Saccharum arundinaceum), ulu ghass (Imperata cylindrical),* wild cane *(Saccharum spontaneum), Ikor (Sclerostachya fusca)* etc. These plants also have ability to work as soil binder (Jain, 2013; Nyambane and Mwea, 2011). But there is a lack of information on the property of these plants as soil binder due to lack of researches. Selected plants for this study are: (1) Hardy sugarcane (*Saccharum arundinaceum),*(2) Wild cane *(Saccharum spontaneum),* (3) Tiger grass *(Thysanolaena maxima)* and (4) Vetiver grass *(Vetiveria zizanioides (L.) Nash).*

The selected plants name and their basic characteristics are presented in Table 4.2. Among all the selected plants, vetiver grasss (locally known as *binna* or *binna shoba*) and wild cane (locally known as *kans*) are mostly available in Bangladesh (Rahman et al., 1996). According to the study made by Thomas et al. (2002), it is very common in 40% area, and common in 45% area and rare for last 15% area of Bangladesh. Tiger grass is mainly available in hilly area and hardy sugarcane in northern part of Bangladesh. However, further study is required for determining their availability in the country. Apparently wild cane root is the strongest among these four selected roots.

4.3.1 Hardy sugarcane *(Saccharum arundinaceum)*

Saccharum arundinaceum, commonly known as Hardy Sugar Cane, is a grass native to South Asia mainly in India. In the Assamese language it is known as *meghela kuhiyaar*. This plant is evergreen in tropical regions and clumps can spread 15 ft or more. The features of hardy sugarcane are presented in Fig. 4.2.



(a) (b) (c) (d)

Fig. 4.2 Features of hardy sugarcane: (a) fully grown, (b) flower, (c) top side of leaf and (d) bottom side of leaf

In Bangladesh hardy sugarcane grass is mainly found in northern zone of the country but thorough study is required for the availability throughout the country. Local people already started to use it for soil protection work showed in Fig. 2.4a and 2.4b of Chapter Two. Ying et al. (2012) proved that hardy sugarcane is a Copper, Cu hyperaccumulator. Hyperaccumulator plants means, these plants can accumulate heavy metals in high amount in their system like leaves, stems or shoots and roots.

Table 4.2 Characteristics of selected plants

Grass name	Vetiver (*binna)*	Tiger grass *(jharu ful)*	Wild cane grass (*kash ful)*	Hardy suger cane (*Teng)*
Scientific name	Vetiveria zizanioides (L.) Nash	Thysanolaena maxima	Saccharum spontaneum	Saccharum arundinaceum
Shoot height (m)	1-3	3- 4	Upto 3	Upto 6 and spread 3 ï 5
Stem dia (cm)	Upto 1.8 m tall, å1 cm	3 m tall, å1 cm	100-200 cm tall, 0.6 ï 1.25 cm	1 ï 2 cm
Leaves width	Leaf blade 25-90 × 0.3-1 cm	Leaf- blade 30-65 × 3-7.5 cm	Leaf blade 60-180× 0.5-1.2 cm	Leaf blade 100 ï 200 × 1 ï 2 cm
Root	Invasive	Non-invasive	invasive	Sometimes invasive
Altitude range	300-1 250 m	upto 1000 m altitude	sea level upto 1300 m	
Rainfall requirements	500-5 000 mm in India	Can survive high rainfall	It prefers a high rainfall, usually in excess of 1 500 mm.	Average
Drought tolerance	It has a high degree of drought tolerance	It has a good degree of drought tolerance	It has a good degree of drought tolerance	It prefers sunny areas and can tolerate drought
Tolerance to flooding	Good; it occurs on poorly-drained lands		It will tolerate some flooding	Plants can withstand periodic inundation
Soil requirements	It will grow on sandy loams to clay soils, on strongly acid to slightly alkaline soils with a pH range from 4-7.5, but prefers neutral to slightly alkaline soils	prefers acid to slightly alkaline soil pH 4.5-7.2, any soil texture, well drained to medium drained soil moisture, partial shade to full sun, medium salt tolerance	Adapted to a wide range of soils, generally of rather sandy types	Prefers acidic or neutral soil with average drainage. Soil type clay, loam or Sandy.
Flowering time	Sept-Dec	Sept-Dec	Throughout the year but mostly at the end of rain	Summer, late summer
Fruiting time	Sept-Dec	Mar-Apr	Sept- Nov (Bonnett et al., 2014)	Fall
Habitat	Seasonally inundated grassy areas around tanks & ponds & ditches in low lands, from sea level upto 100 m elevation	Open hill slopes, along water-courses & margins of forests	Sides of streams, rivers, pools & ponds, filed borders, fringes of forests, low-lying grassy areas.	It naturally grows on hillsides, dry stream beds and sandy riverbanks, from India and southern China to Indonesia.
Availability in Bangladesh	Common throughout the country	Very commonly occurs in the eastern parts of the country	Common throughout the country	Common in northern part of the country
Propagation	Seeds, rhizomes and roots	Seeds and rhizomes	Seeds and rhizomes	Seeds
Use	In India, the *Lodha* ethnic people use	In india, *lodha* ethnic people	In India, *Lodha* ethinic people	The plant is extensively used in

Table 4.2 Characteristics of selected plants (continued)

	root decoction in dyspepsia, root paste in headache (Pal and Jain, 1998).	use flower paste with country liquor & honey as contraceptive. They use root decoction in mouth sore (Pal and Jain, 1998).	use root decoction as diuretic and *Santal* ethnic people use its root paste in the treatment of allergic eruption (Pal and Jain, 1998).	India where it supplies food, fibre, materials for thatching, basket making etc. It is also used as a hedge around betel pepper gardens. The plant is also used medicinally
Economic use	Aromatic roots are the source of vetiver oil, an ingredient in perfumes. The roots are also woven into fragrant mats, rugs, fans and bundles of roots are used in wardrobes to discourage insects or simply to provide a pleasant aroma. The plant has medicinal use and is also often planted to control soil erosion on steep banks (Skerman and Riveros, 1990). The root is useful in burning sensation, bilious fever, sweats, foul breath, strangury, ulcer, spermatorrhoea and headache (Kirtikar, 1935). Vetiver grass is grown for many different purposes. The plant helps to stabilise soil and protects it againsterosion, but it can also protect fields against pests and weeds. Vetiver has favourable qualities for animal feed. From the roots, oil is extracted and used for cosmetics, aromatherapy , herbal skin care and ayurvedic soap . Due to its fibrous properties, the plant can also be used for handicrafts, ropes and more. (Wikipedia)	The inflorescences of this grass are often tied together in bunches to make brooms (Bor, 1960). The young leaves are used as good fodder.	Source of germplasm for breeding sugarcane and sometimes cultivated as an ornamental plant. It is used as fodder grass for cattle, buffaloes and elephants. The root system is extremely extensive and the grass acts as an effective soil binder (Bor, 1960). The foliage is used for thatching and the plant is used in manufacture of paper pulp (Mannetje and Jones, 1992). It also have Ayurvedic medical uses.	The youngest leaves are eaten as vegetable and in salads. The leaf sheathes are a source of fibre, known as 'Munj fibre'. Strong and elastic, it has the wonderful power of enduring moisture without decaying. It is used for making cloth, cordage, ropes, mats etc. The mats are reported to be proof against white ants, but are hard on shoe-leather, harsh to the foot and fatiguing when walked on for any length of time. The leaf blades, and also the flowering stems, are used for thatching. The stems are used for making chairs, stools, baskets, screens etc. The leaf blades are used as a material for making paper. The internodal part of the culm is hardened and then cut into implements for writing. The culms are used like bamboo for construction purposes

Their study also showed that Hardy sugarcane could be used as one of remediation plants for the abandoned farmlands contaminated by multi-metals Copper (Cu), Zinc (Zn), Lead (Pb) and Cadmium (Cd).

4.3.2 Wild Cane *(Saccharum spontaneum)*

It is a perennial grass native to the Indian Subcontinent. This grass grows up to three meters in height with spreading rhizomatous roots. In Bangladesh, it is locally called as *kans.* Pandey et al. (2015) suggests that wild cane has high potential value for revegetation and reforestation on fly ash dump. Hidayati et al. (2009) reported that wild cane can accumulate Cyanide. Plant used in research is quite different from the *kans* grows nearby. Roots are black coloured and have very rough texture. Based on Taxonomy, this plant is classified as wild cane. But some properties are different than locally available wild cane/*kans*. *kans* found throughout the country has weak roots according to strength and whitish colour. But these plants have very strong roots and black colour. Maybe this is because it grows on mineral soil i.e., white clay mine.

(a) (b) (c)

Fig. 4.3 Features of wild cane: (a) fully grown, (b) leaf and (c) root matrix

4.3.3 Tiger Grass *(Thysanolaena maxima)*

This is a perennial grass grows in mountainous regions of Nepal, northern and eastern parts of India, Bhutan, and Philippines. The flowers of this plant are used as cleaning tool or broom. It is a multipurpose species which provides brooms, fuel, feedstock and has high soil conservation value. ôTiger Grassô is a common name for this plant throughout the tropics where it is grown as an ornamental plant. In Bangladesh, this plant is usually known as ñ*jharu ful”* and usually grows in hilly area. Moreover, this grass farming is highly recommended in new shifting cultivation systems on marginal lands to repair the damage from previous slash and burn methods. Kafle and Balla (2008) reported that this grass is very effective in reinforcing the soil by providing a network of strong roots that increases the soilôs resistance to shear. Tiger grass can moderately support the soil mass by its strong and long fibrous roots and can bind average 3.8 cum soil (Kafle and Balla, 2008).

(a) (b) (c) (d)

Fig. 4.4 Features of tiger grass: (a) fully grown, (b) flower, (c) root matrix and (d) top side of leaf

4.3.4 Vetiver Grass *(Vetiveria zizanioides (L.) Nash)*

Vetiver grass is a perennial bunch grass native to India. Recently this grass is renamed as *Chrysopogon zizanioides.* In western and northern India, it is popularly known as *khus khus*. In Bangladesh, locally it is called *binna, binna shoba.* Vetiver grass is accepted as a bio-engineering technique and is being used widely as well as for land reclamation and water purification work. It has a vigorous and massive root system that can penetrate 5 cm thick layer of asphalt concrete (Hengchaovanich, 1998). It can reduce 60ï73% runoff and trap 90ï98% sediments (Xia et al., 1996; Kon and Lim, 1991), the stiff shoots and strong roots can keep the plant stand steadily in water with 0.6ï0.8 m deep and 3.5 m/s velocity of water flow (Ke et al. 2003). High medicinal value gives vetiver grass a different dimension. It also has high economic value.

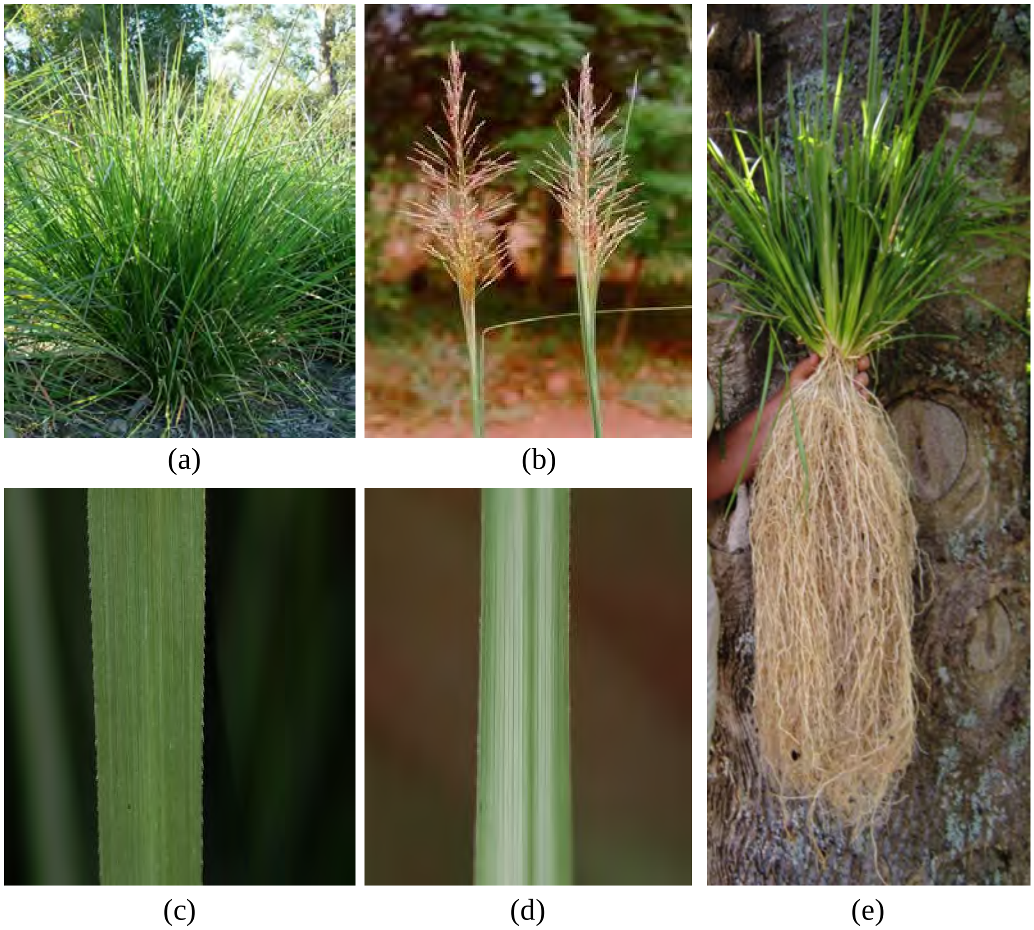


Fig. 4.5 Features of vetiver grass: (a) fully grown clump, (b) flower, (c) leaf front side (d) leaf back side and (e) root matrix

Table 4.3 Root characteristics of different plants

Parameter	Hardy sugar cane	Wild cane ecotype	Tiger grass	Vetiver
Color	Brown	Black	Light brown	Yellowish brown
Diameter (mm)	0.5 ï 5	0.2 ï 2.5	0.2 ï 2	0.2 ï 2.2
Surface condition	Wet	Very dry	Wet	Dry to wet
Surface texture	Rough	Very rough	Less rough	Rough
Root hairs	Fiberous	Fiberous	Fiberous	Very fiberous

All four types of roots that were used for laboratory investigation have difference in many characteristics like in their colours, surface conditions, surface texture, presence of root hair etc. which are presented in Table 4.3. Among them vetiver root has more root hairs and root lengths than the other three. Hardy sugarcane has maximum root diameter while the other three have almost similar root diameter.

3.7 Properties of Collected Soils

The index properties of the collected soil samples obtained from laboratory investigations as well as chemical properties of contaminated soil samples are described below.

4.4.1 Index Properties

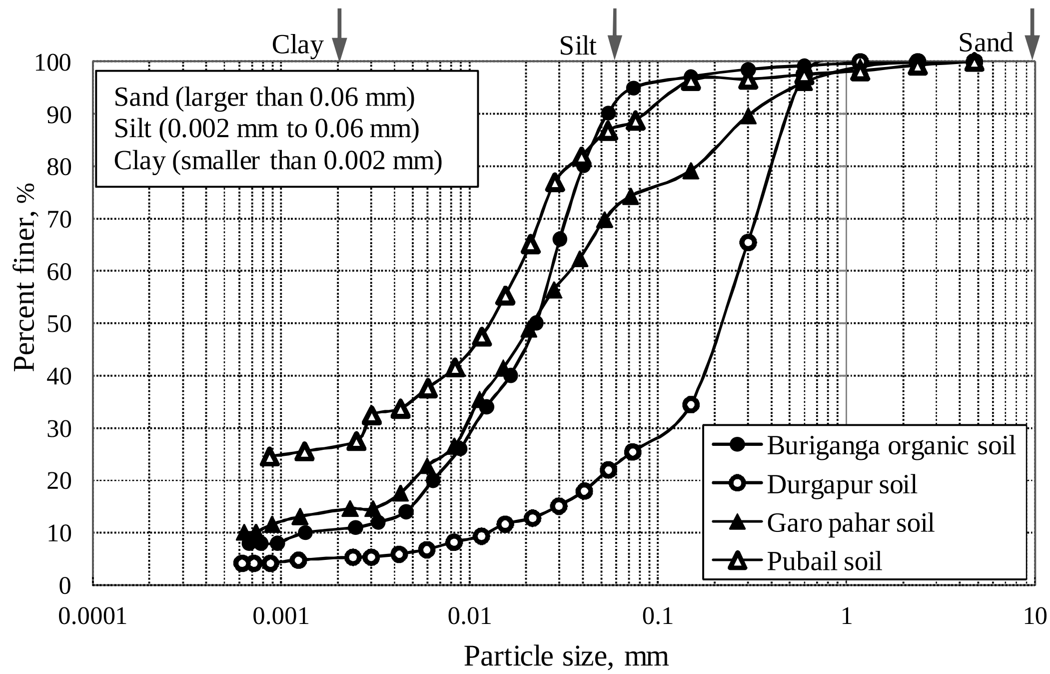
Index properties tests were conducted according to ASTM Standard as mentioned in Chapter Three. Index properties of the selected soil samples are presented in Table 4.4. The soil in Pubail is clayey soil of low plasticity with reddish colour. Durgapur soil is silty sand. Soil in sada pahar is basically clayey silts of low plasticity and called *china clay* and it is a source of natural mineral. Their grain size distribution curves are presented in Fig. 4.5a. For growth study of vetiver grass in wooden model slopes as mentioned in Chapter Three, nursery soil, red clay and dredge fill sands were used. Their grain size distribution curves are presented in Fig. 4.5b. Dredge fill sands were medium fine sand as per MIT classification of soil.

Table 4.4 Index properties of the soil samples

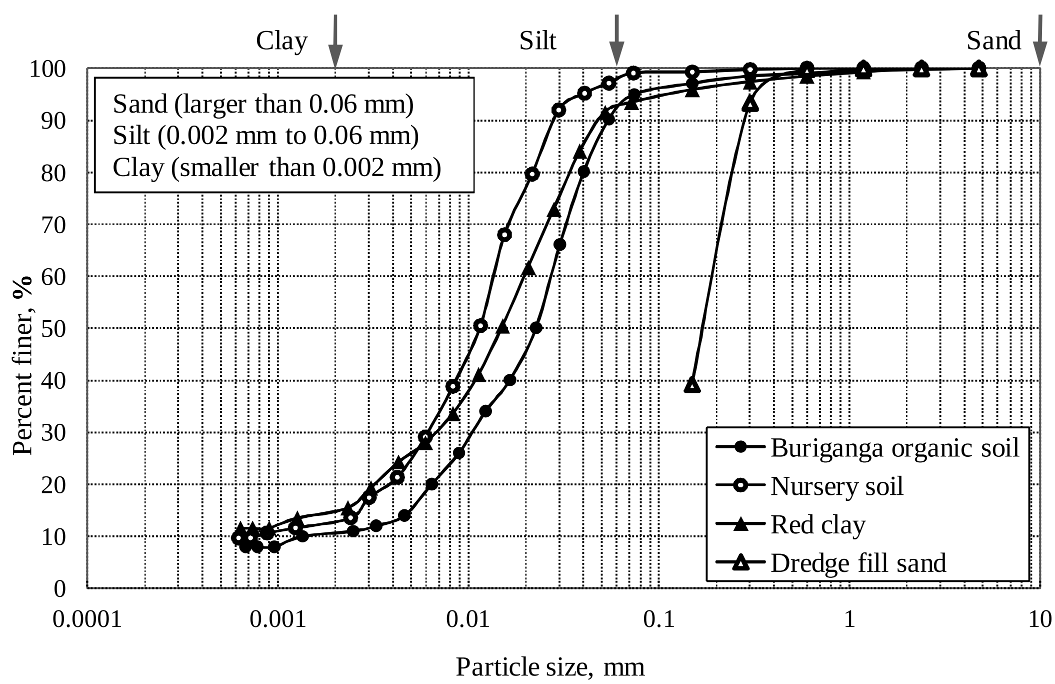
Sample Name	G_s	w_n (%)	Grain size*			Atterberg Limits			Group (ASTM D 2487)
			Sand (%)	Silt (%)	Clay (%)	LL (%)	PL (%)	PI (%)	
Pubail	2.68	25	12	64	24	43	23	20	CL
Durgapur	2.69	13	78	17	5	ï	ï	ï	SM
Sada pahar	2.66	13	46	40	14	28	18	10	ML
Garo pahar	2.62	22	28	58	14	35	23	12	ML
Buriganga soil	2.52	62	08	82	10	42	23	19	OL
Nursery soil	2.75	32	2	85	13	37	27	12	ML
Red clay	2.77	20	7	78	15	44	21	23	CL
Dredge fill sand	2.64	08	61	39	ï	ï	ï	ï	Medium fine sand

*Classification based on MIT Classification

Note: G_s = Specific gravity, W_n = Natural water content, LL = Liquid limit, PL = Plastic limit and PI = Plasticity index



(a)



(b)

Fig. 4.6 Grain size distribution curves for selected soils (a) soil used for laboratory investigation and (b) soil used for growth study in slope model boxes

4.4.2 Chemical Properties

Heavy metal concentration of Buriganga river bank soil has been measured using Atomic Absorption Spectrophotometer Flame (AAS). Test results are presented in Table 4.5. Five prominent heavy metals were chosen based on similar past studies conducted on the presence of heavy metal in Buriganga river bank soil and water. Heavy metal concentrations assessed in this study has similarity with the previous studies (Saha and Hossain, 2011; Ahmed, 2015 and Choudhury et al., 2015)

Table 4.5 Metal concentration of collected soil before plantation

Heavy Metal	Concentration (mg/kg or ppm)
Pb	22.8
Cr	116.0
Cu	33.1
Ni	23.1
Zn	454.0

The US EPA and NYS DEC have set guidelines for determining the safety of various land uses based on total soil metal concentrations using standard EPA methods. Table 4.6 presents these limits.

Table 4.6 Total metal concentrations in soil (mg kg^{-1}) to guide cleanup efforts

Heavy Metal	US EPA	NYS DEC soil cleanup objectives ÿ	
	Soil screening level À	Unrestricted use	Residential use
As	0.4	0.11	0.21
Cd	70	0.43	0.86
Cr (hexavalent)	230	11	22
Cr (trivalent)	120,000	18	36
Cu	-	270	270
Pb	400	200	400
Ni	1600	72	140
Zn	23,600	1100	2200

ÀUS EPA (2002): US Environmental Protection Agency
ÿ NYS DEC (2007): New York State Department of Environmental Conservation (Values based on human health risks)

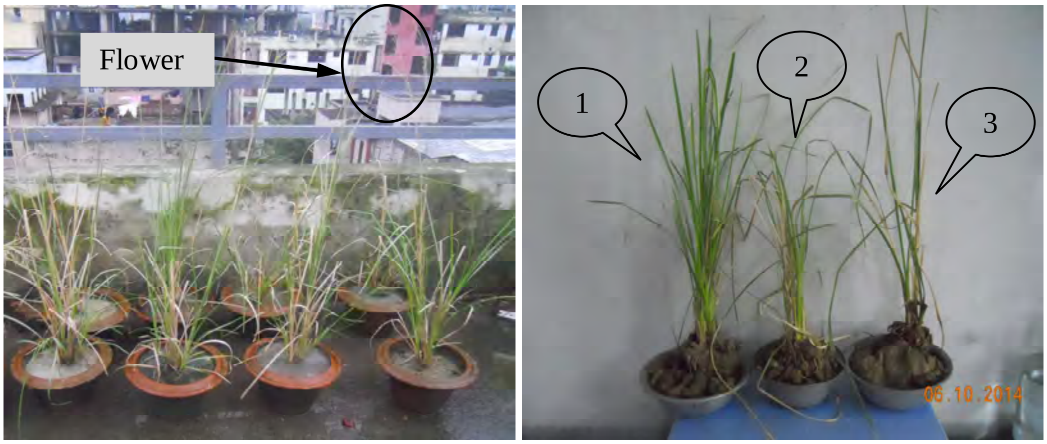
Comparing the results with the tolerances values presented in this table, it is seen that only Chromium concentration is significantly higher than tolerance level. But previous studies showed that all the heavy metals are above tolerance level. Saha and Hossain (2011) found that the concentrations of Pb, Cu, and Zn are above the EPA guideline for heavily polluted sediment and the concentration of Cr fall in the criteria of moderately to highly polluted range.

3.8 Results on Growth Study

After five months of plantation, it is observed that hardy sugarcane, tiger grass and vetiver grass grew very well at BUET premises. For advanced study vetiver grass was selected due to better root matrix and root lengths. Studies on growth performance of vetiver had been conducted internationally and locally. In Bangladesh, Moula et al. (2008), Islam (2013), Nasrin (2013) and Shahriar (2015) studied on growth performance of vetiver grass in different geographic regions with different soil types. In this research, growth study was conducted in different aspects such as growth in contaminated soil, saline soil, dredgefill sand, red clay and silty soil. Wooden model box slopes were prepared to conduct model study on growth performance and efficacy against raincut soil erosion. Results obtained from the studies are discussed below.

4.5.1 Growth in Saline Soil

The presence of salt in soil has great impact on the growth of vetiver grass. This phenomenon has been proved by previousl researches. Truong et al. (2002) in Australia and Islam et al. (2014) and Shahriar (2015) in Bangladesh also studied the effect of soil salinity on vetiver growth. For this study, salt contents or ECs were selected in three ranges i.e., slightly saline, moderately saline and high saline. Saline soil sample preparation and methods are described in the Art. 3.3.2 of Chapter Three. The planted grasses were watered with fresh water two times a day for 1^{st} 2-3 weeks. Since the soil is saline, soil dried up soon. After 4 months of plantation, flowering occurred and all the plants survived as presented in Fig. 4.7(a). The soil with high salinity showed lowest growth of the grass presented in Fig. 4.7(b) and with lower the salt content present in soil, higher the growth of grass. This result is very similar to the previous studies (Truong, 2002 and Shahriar, 2015).



(a) (b)

Fig. 4.7 (a) Vetiver grass in saline soil after 4 months of plantation and (b) effect of soil salinity on growth (after one month of plantation) with (1) low salinity EC = 4.8 ds/m, (2) medium salinity EC = 10.0 ds/m and (3) high salinity EC = 12.5 ds/m

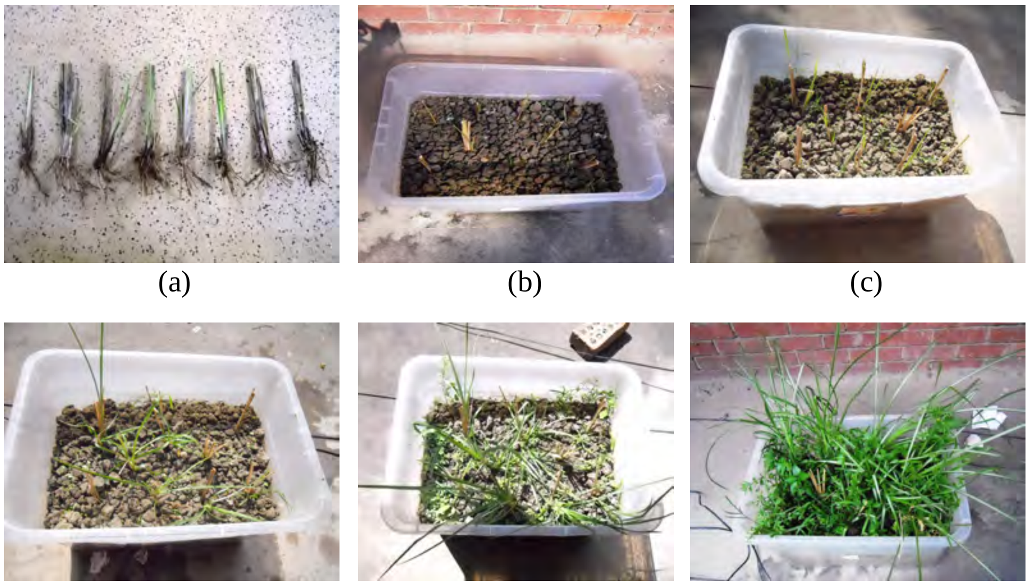
There is no critical point of salinity where plants fail to grow. As the salinity increases growth decreases until plants become chlorotic and die (www.fao.org). Plants differ widely in their ability to tolerate salts in the soil. Salt tolerance ratings of plants are based on yield reduction on salt-affected soils when compared with yields on similar non-saline soils.

When there is too much salt in the soil, which happens if it is regularly flooded with salt-water, then plants take too much in through their roots and too much gets into their tissues (that is, into the cells of their roots, stems and leaves). This excess salt interferes with the chemical reactions in cells which the plant needs to make food and to grow. As a result, the plant's growth is stunted and the plant may even die.

Again salt makes the plants starve for water. When their roots are bathed in salty water, they can actually die of thirst. Plants rely on a process called osmosis to get water from the soil. The tissue around the tiny hairs on plant roots allows water to pass through easily (it is very permeable to water) but it only allows salts and other chemicals through very slowly (it is less permeable to these). When water in the soil is fresh, it tends to flow into the roots and then it is sucked up to the stem and leaves. When the water in the soil is salty, water tends to be sucked out of the roots into the soil and plants starve for water (www.fao.org).

4.5.2 Growth in Contaminated Soil and Accumulation of Heavy Metals

Vetiver grass was planted in contaminated soil in a plastic container as described in the Article 3.3.2 of Chapter Three. Fig. 4.8 shows the growth of vetiver grass in contaminated soil. Samplings were done four times (19^{th}, 21^{st}, 41^{st} and 49^{th} week after plantation). Shoot heights and root lengths were measured during each sampling time.



(a) (b) (c)

(d) (e) (f)

Fig. 4.8 (a) Vetiver grass ready for plantation, (b) immediately after plantation, and after (c) 4 week, (d) 8 week, (e) 12 week and (f) 16 week

The growth rate of vetiver grass in contaminated soil is presented in Fig. 4.9. From the Fig. 4.8 and 4.9 it is seen that the growth rate was almost zero for first four weeks for shoot and root. After that rate increased till 20^{th} week and then growth rate decreased significantly and remained almost same till 50^{th} week.

Table 4.7 Dry mass production per unit

Plan Area 52 cm×32 cm	Plan area is divided into 4 parts for harvesting of Vetiver (Each Plan Area is 13 cm × 8 cm)

	Root (gm)	Shoot (gm)	Leaf (gm)	Root (gm/m^2)	Shoot (gm/m^2)	Leaf (gm/m^2)
week 19	0.97	0	8	93	0.00	770
week 21	0.59	0	6	57	0.00	577
week 41	7.00	20	46	673	1923	4423
week 50	13.50	35	50	1298	3366	4808

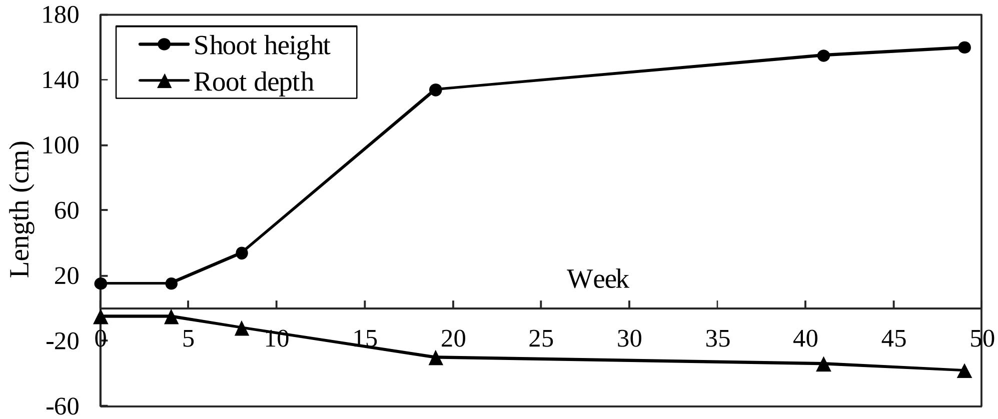


Fig. 4.9 Growth rate of vetiver grass in contaminated soil

Shahriar (2015) found similar pattern of growth in his study. Table 4.7 shows the dry mass production per unit area of soil. Observing this chart, it is clear that at week 41 and 49 the leaf, shoot and root mass increased significantly. In this chart, for week 19 and 21, mass of shoot is zero. Because shoots/stems were not grown in that period.

Fig. 4.10 (aï e) presents the metal concentration in roots, shoots/stems and leaves for individual metals i.e., for lead, chromium, copper, nickel and zinc separately. Fig 4.11 (aï e) presents metal concentrations in root, shoot and leaves in a whole plant. After analysing the data, followings observations are found.

This study was conducted to look into the fact that whether vetiver grass *(Vetiveria Zizanioides)* has the potential to uptake heavy metals (Pd, Cu, Cr, Zn and Ni) from industrial waste contaminated soil.

Lead: Unlike other metals uptake values of lead in root, shoot and leaf are higher and increased along with the time period. The consumption is higher in root than that of shoot.

Copper: Based on the result, the consumption of copper does not follow any pattern. Concentrations in leaf and shoot are higher than in roots. However root has highest concentration of copper after 21 weeks.

Chromium: Concentrations of Chromium in leaf are almost same and do not increase/change with the time period. In root and shoot increased significantly at higher rate. Chromium concentration is highest in root at 49th week.

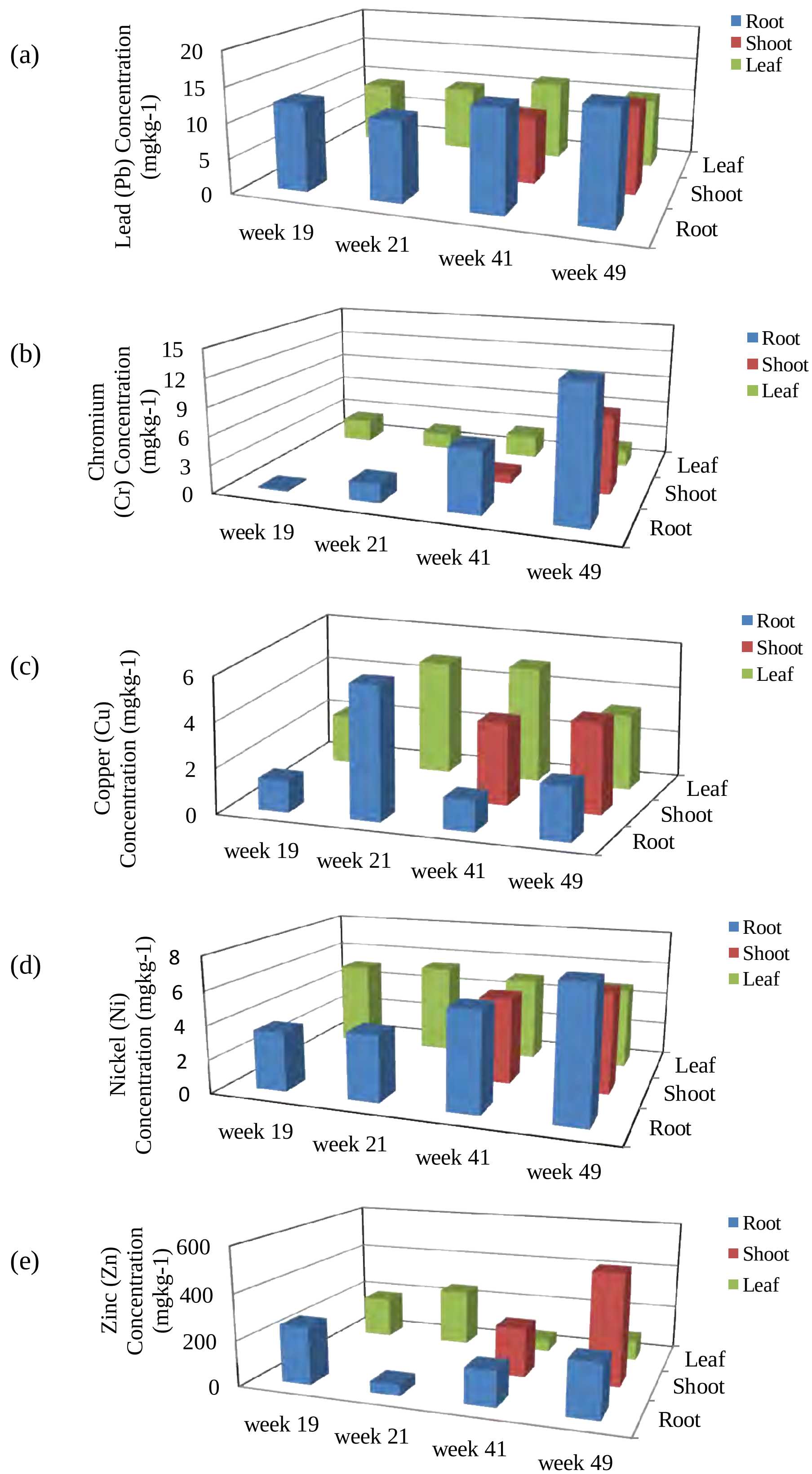


Fig. 4.10 Metal concentrations in root, shoot and leaf of vetiver grass for: (a) lead, (b) chromium, (c) copper, (d) nickel and (e) zinc

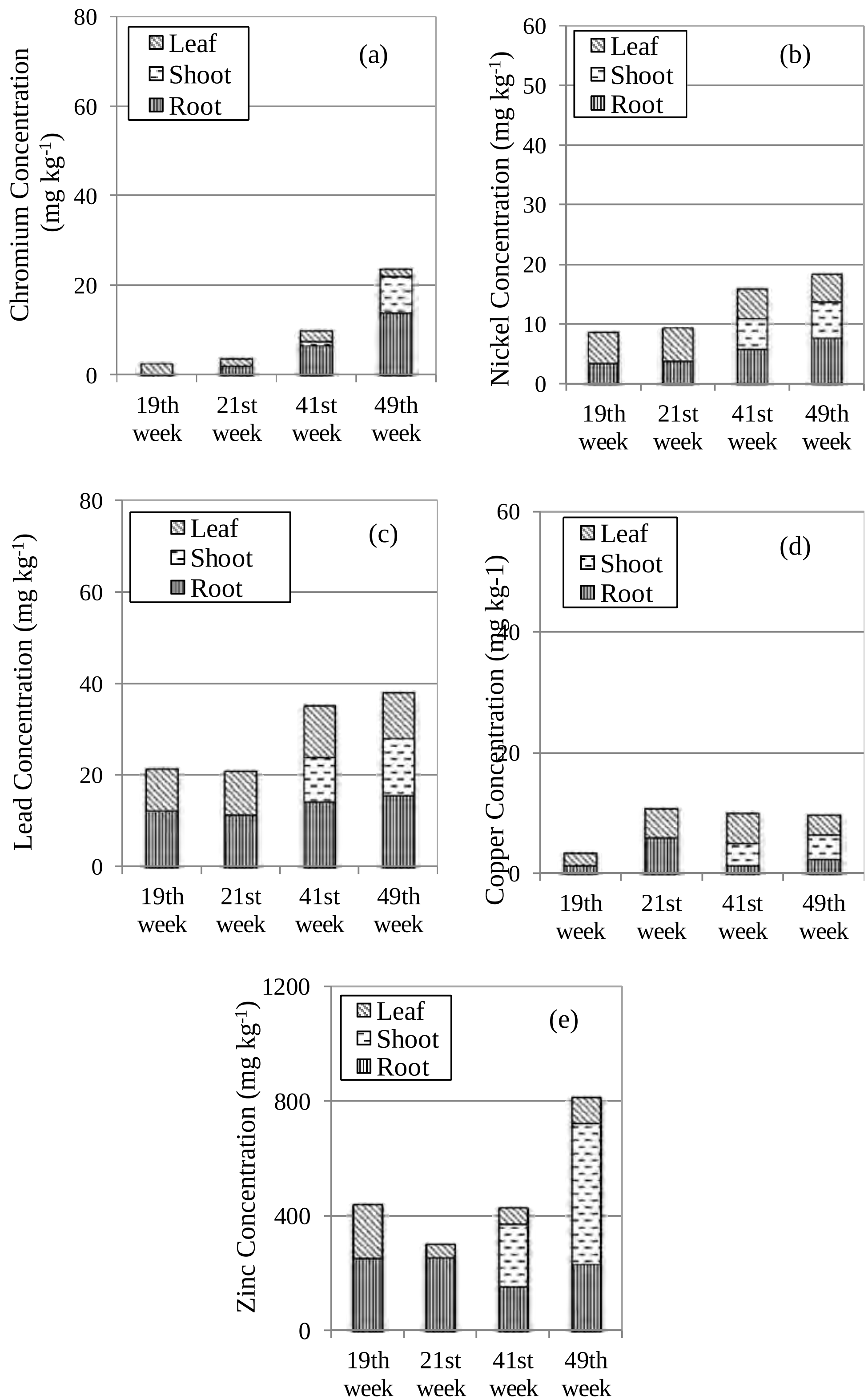


Fig. 4.11 Metal accumulation by vetiver grass from contaminated soil for: (a) chromium, (b) nickel, (c) lead, (d) copper and (e) zinc

Nickel: Concentrations of Nickel in leaf and shoot are almost same and do not increase/change with the time period. But concentration in root increased significantly with time. It is seen that highest concentration of nickel occurred after 49 weeks.

Zinc: Zinc concentration is highest in shoot among all the samples for any time i.e., 19^{th}, 21^{st}, 41^{st} and 49^{th} week.

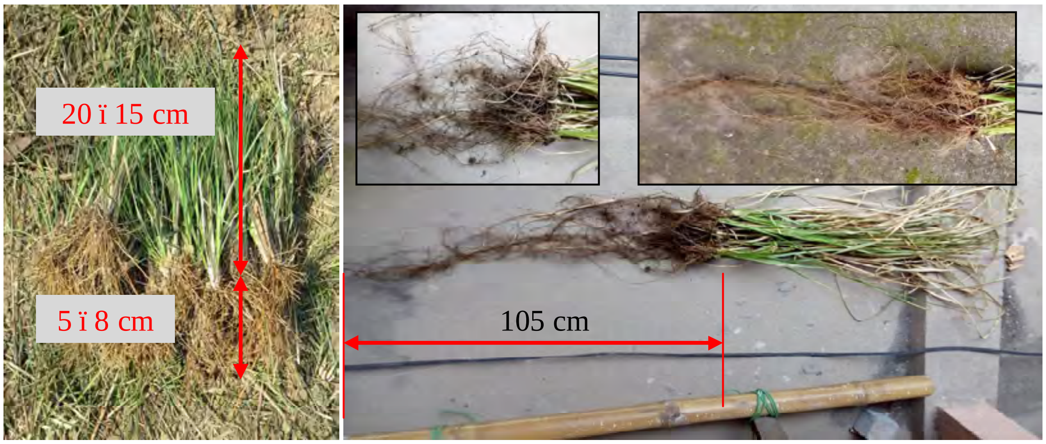
4.5.3 Growth in Nursery Soil

Around 1500 vetiver grasses were planted in 15×20 cm sized poly bags in nursery soil mixed with some cow dung in pre-monsoon hot season in mid of March. The average temperature in Dhaka was 26°C (20° to 32°C). The weather was marginally dry with occasional rain. Only 61mm of rainwater was dumped across on average 5 days. These grasses were almost dried out during plantation as shown in Fig 4.12a. Then they were kept in a safe place where they got adequate sun light and rainfall. Watering was applied in the morning and evening everyday for first one month and then in alternate day and are monitored in a regular basis. Grasses remained almost same for the first two weeks and then green leaves were coming out during third week and further became greener. Fig 4.12b shows green grasses after 12 weeks.

(a) (b)

Fig. 4.12 Growth performance of vetiver grass: (a) immediately after plantation and (b) after 12 weeks

Root and shoot length of vetiver before and after five months of plantation are shown in Fig. 4.13 (a and b). Initial clumps had 20 cm to 15 cm shoot length and 5 cm to 8 cm root length. After five months of plantation during rainy season root length was found to be around 105 cm to 115 cm and shoot length was 95 cm to 100 cm.



(a) (b)

Fig. 4.13 Root and shoot length of vetiver grass: (a) before plantation and (b) after 5 months of plantation

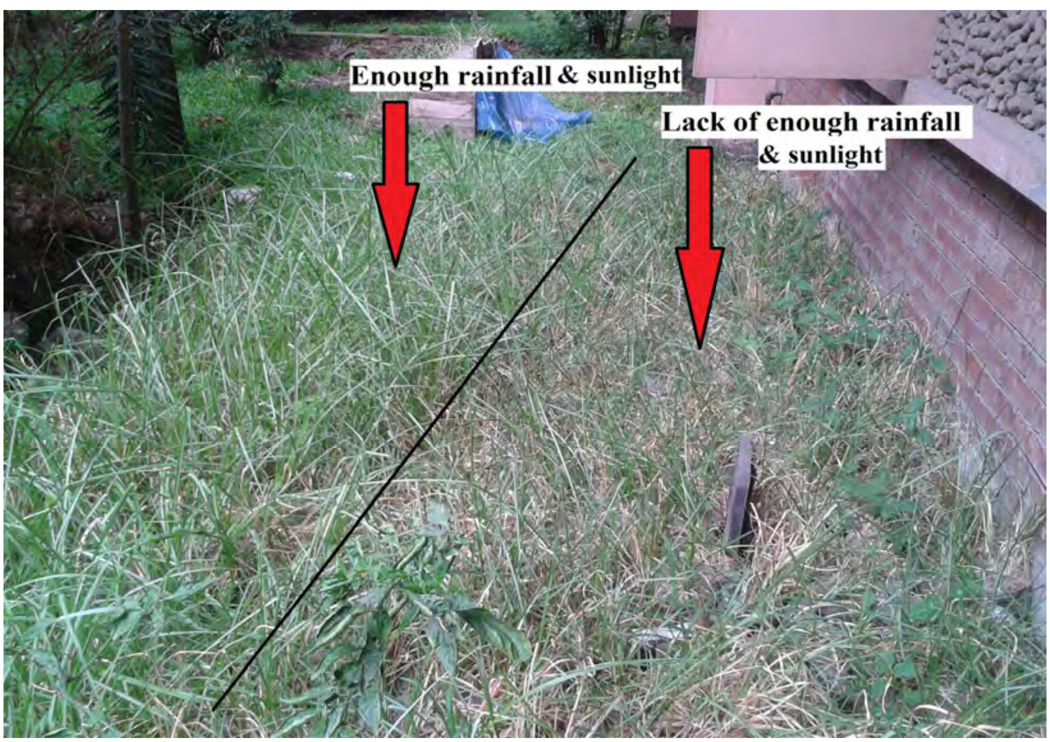


Fig. 4.14 Effects of presence of sunlight and rainfall on growth of vetiver grass

Vetiver grass needs enough sun light for proper growth. Rainfall has also great impact on growth of any plants. In Fig. 4.14, the effects of sunlight and rainfall on growth of vetiver grass are visible clearly. The right portion did not get enough sunlight and rainfall due to the presence of sunshade over it while the left portion got sunlight and direct rainfall.

4.5.4 Growth in Artificial Slope Models in Different Soil

Grown vetiver grass was planted in wooden model slopes which are described in Art. 3.4.4 of Chapter Three. Few observations were made by monitoring the growth performance of these grasses in dredge fill sand, red clay and nursery soil. The index properties, sand, silt, clay percentages of these soils are given in Table 4.4 and the grain size distribution curves are presented in Fig. 4.6b. The growth in sand was poor and flowering did not occur. For red clay, growth was poor to medium and few plants had flower. Vetiver grew excellently in nursery soil. Most of the plants flowered. Triangular spacing is not feasible for field application due to lack of efficient labour. Vetiver grass in model boxes after three month of plantation are shown in Fig 4.15 (a ï f). Relative comparison among the model box slopes are presented in Table 4.8. Fig. 4.16 shows the vetiver grass grew very well in contaminated soil filled plain land.

a) Model-M1: Vetiver Grass in Dredge Fill Sand

From the grain size analysis, the dredge fill sands were found to be medium fine sand. It is highly erodible against rain and wind. Sometimes get disturbed by animal (dog, cat). Growth of vetiver is poor and almost 20% plants died within one month then replanted again. After three months, grass was growing quite well but flowering did not occur. Sands get disturbed easily by rain and wind. Almost 15ï 20 % sand washed out by heavy rainfall.

b) Model-M2: Vetiver Grass in Red clay

This soil becomes very hard at dry state. Around 4% plants died within one month of plantation. After three months, grasses were growing quite well and only few grasses in the down slope have flowered. The growth of grasses in the down side slope were better than that of in the top slope. Soil erosion occurred due to rain and got eroded least about 5-8%.

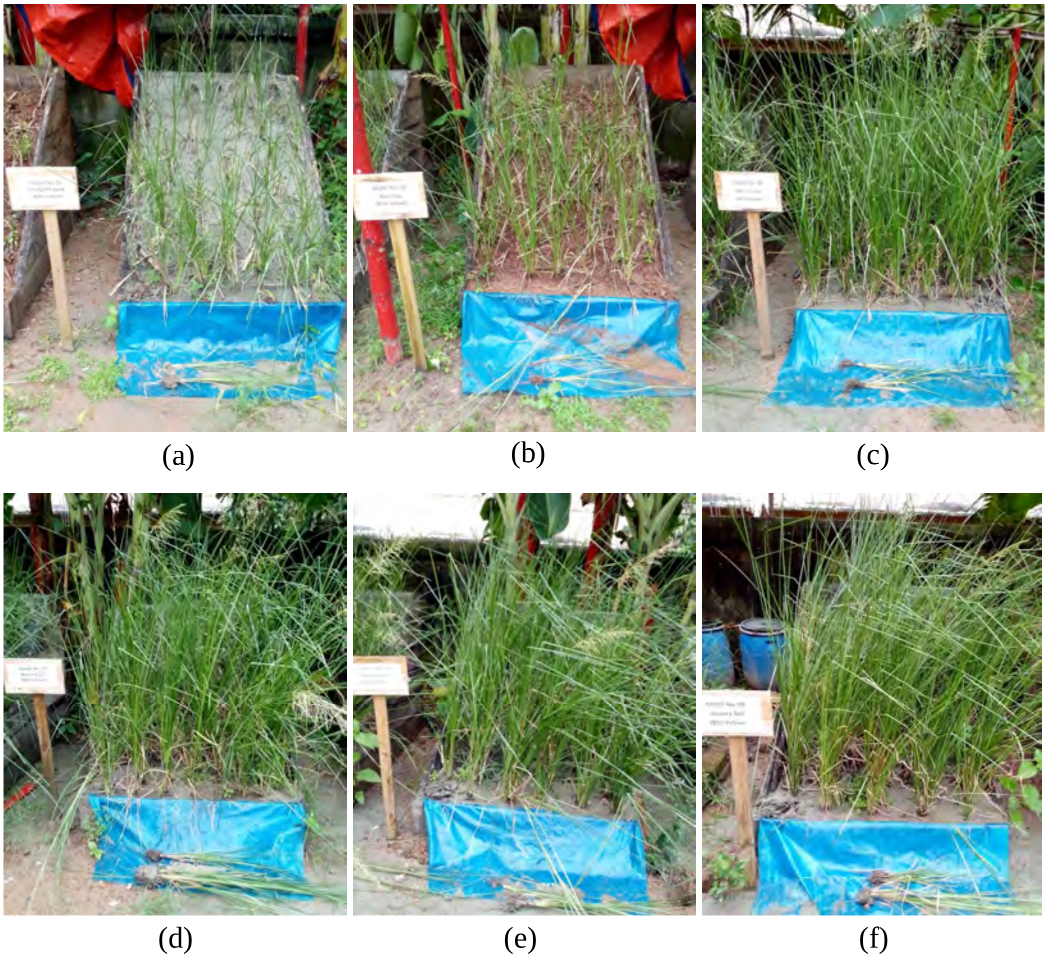


Fig. 4.15 Three months after vetiver grass plantation in different models: (a) Model M1-dredge fill sand, (b) Model M2- red clay, (c) Model M3-nursery soil with triangular spacing, (d) Model M4-nursery soil with 10 cm spacing, (e) Model M5-nursery soil with 15 cm spacing and (f) Model M6-nursery soil with 20 cm spacing

c) Model-M3 to Model-M6: Vetiver Grass in Nursery Soil

According to the MIT classification of soil, nursery soil is classified as silty soil. Around 0.2% plants died within one month of plantation. After three months, grasses were growing very well and have flowered within 8th week. About 5ï 8% soil got eroded due to rainfall.

Table 4.8 Comparison of Model Performances

Name of the model	Age (month)	Soil description	Root length (cm)		Shoot length (cm)		Remarks
			Top	Bottom	Top	Bottom	
M-1	3	Dredgefill sand (Medium fine sand)	13.5	15	52	81	Poor to medium growth No flowering
M-2	3	Red clay (Clay with low plasticity)	3	13	43	63	Medium growth with flowering
M-3	3	Nursery soil (Silt with low plasticity)	30	13.5	84	72	Excellent growth with flowering
M-4	3		20	24	87	126	Excellent growth with flowering
M-5	3		29	26	79	86	Excellent growth with flowering
M-6	3		8	11	50	156	Excellent growth with flowering
M-7	3	Contaminated soil (Organic sandy silt)	10		131		Excellent growth with flowering

Fig. 4.16 Three months after vetiver grass plantation in contaminated soil

3.9 Shear Strength Properties/Parameters

Direct shear tests were conducted on twenty different types of soil specimens. For four different type of soil sample with four different type roots including bare specimen were tested. The selected normal loads were 10.83, 15.47 and 20.12 kPa. Water contents were 20-25% and for coarse sand in Durgapur soil, water content was around 15%. Because further increasing in water content, this soil loses its consistency.

4.6.1 Effect of Different Roots on Strength-deformation Behavior

Four different types of plant roots were used to find the effect on soil apparent shear strength and deformation. The used plants are hardy sugarcane, wild cane, tiger grass and vetiver grass. The root content was 3% by weight of dry soil mass and the root length was 2.54 cm. From stress-deformation relationship showed in the Figs. 4.17ï4.20, it is clear that addition of root increases the ductility of soil.

a) Buriganga waste and organic soil

Fig 4.17 shows the shear stress versus horizontal deformation curves of Buriganga organic soil for four different types of root mixed and bare soil specimens. From this figure, it is seen that vetiver root mixed specimen gave highest peak shear stress. Comparing the rooted specimens with bare soil, the increase in peak shear stress is around 20-24%. The horizontal deformation increases considerably after adding root content. Table 4.9 shows the increase in peak shear stress, $Ű_{max}$ and failure strain for different rooted specimens.

Table 4.9 Comparison of increase (+) or decrease (-) in peak shear stress and horizontal deformation for Buriganga organic soil

Parameter	Hardy sugarcane	Wild cane	Tiger grass	Vetiver grass
Increase/decrease in Peak shear stress, φ$Ű_{max}$ (kPa)	1.28 (5%)	5.74 (22%)	5.31 (20%)	6.38 (24%)
Increase/decrease in horizontal deformation (mm)	5.18 (112%)	4.62 (109%)	1.08 (24%)	2.78 (60%)

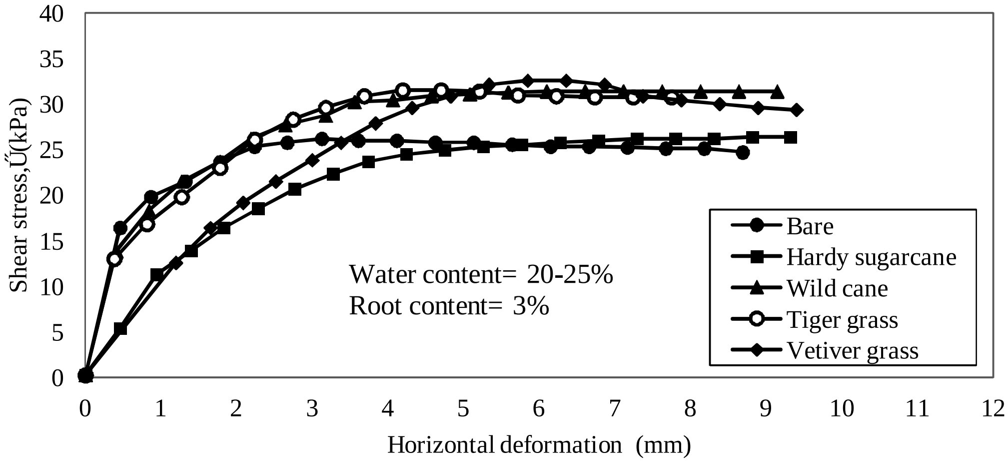


Fig. 4.17 Shear stress vs. horizontal deformation curves for the samples prepared with Buriganga soil

From the Table 4.9, hardy sugarcane and wild cane root mixed specimens gave almost same increase in horizontal deformation (109-112%), where for tiger grass and vetiver root mixed specimens, they gave nearly similar horizontal deformation (24-60%).

b) Durgapur moist sand

From the shear stress versus horizontal deformation curves showed in Fig. 4.18, it is seen that all five types of specimens gave almost same peak shear stress but the horizontal deformation increases considerably. Table 4.10 shows that hardy sugarcane, wild cane and tiger grass root mixed specimens gave almost same horizontal deformation i.e., two times higher than that of bare soil specimen. Hardy sugarcane and tiger grass roots gave similar effect. The soil of Durgapur is moist course sand. So it can be concluded as, for coarse sand addition of root matrix has very little effect increasing shear stress but it can increases the horizontal deformation significantly.

Table 4.10 Comparison of increase (+) or decrease (-) in peak shear stress and horizontal deformation for Durgapur moist sand

Parameter	Hardy sugarcane	Wild cane	Tiger grass	Vetiver grass
Increase/decrease in Peak shear stress, $\Delta\tau_{max}$ (kPa)	-1.28 (4%)	1.27 (5%)	-2.55 (9%)	-0.64 (2%)
Increase/decrease in horizontal deformation (mm)	5.16 (113%)	4.57 (111%)	5.23 (115%)	1.04 (23%)

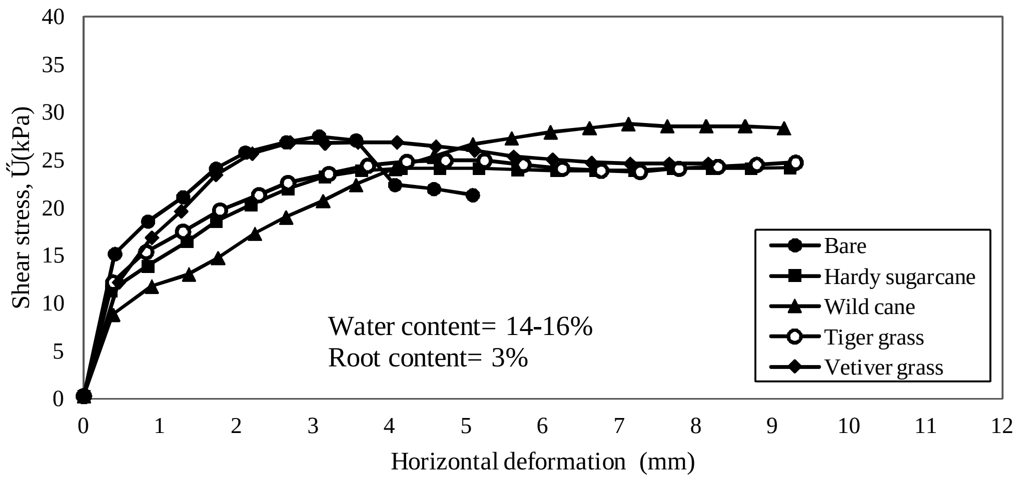


Fig. 4.18 Shear stress vs. horizontal deformation curves for the samples prepared with Durgapur soil

c) Garo Pahar soil

From the shear stress versus horizontal deformation curves presented in Fig. 4.19, it is seen that behaviour of all specimens were almost same i.e., they behaved like ductile material. After mixing root matrixes with soil specimens, shear stress increases significantly. From Table 4.11, increase in peak shear stress for hardy sugarcane and tiger grasses is around 7 kPa. There were very little effects on horizontal deformation.

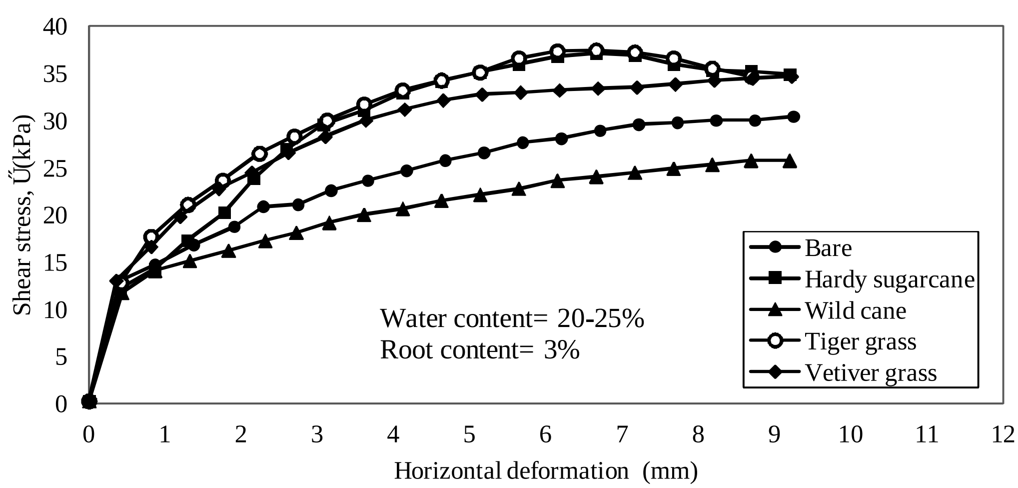


Fig. 4.19 Shear stress vs. horizontal deformation curves for the samples prepared with Garo pahar soil

Table 4.11 Comparison of increase (+) or decrease (-) in peak shear stress and horizontal deformation for Garo pahar soil

Parameter	Hardy sugarcane	Wild cane	Tiger grass	Vetiver grass
Increase/decrease in Peak shear stress, $\varphi\tau_{max}$ (kPa)	6.69 (22%)	-0.42 (1.4%)	7.0 (23%)	5.1 (17%)
Increase/decrease in horizontal deformation (mm)	-1.57 (16%)	-0.05 (0.5%)	-1.57 (16%)	-0.02 (0.2%)

d) Pubail soil

In Fig. 4.20, shear stress versus horizontal deformation curves for Pubail soil with and without roots is presented. From this figure, it is seen that soil itself acts as a ductile material. According to the value presented in Table 4.12, addition of roots had a very little effect on increasing shear stress and sometimes decreases. Again in case of horizontal deformation, the effect is almost nil.

Table 4.12 Comparison of increase (+) or decrease (-) in peak shear stress and horizontal deformation for Pubail soil

Parameter	Hardy sugarcane	Wild cane	Tiger grass	Vetiver grass
Increase/decrease in Peak shear stress, $\Delta\tau_{max}$ (kPa)	2.55 (8%)	1.28 (4%)	- 4.25 (13%)	- 4.88 (15%)
Increase/decrease in horizontal deformation (mm)	-0.7 (8%)	0.96 (11%)	-0.05 (0.5%)	-2.19 (25%)

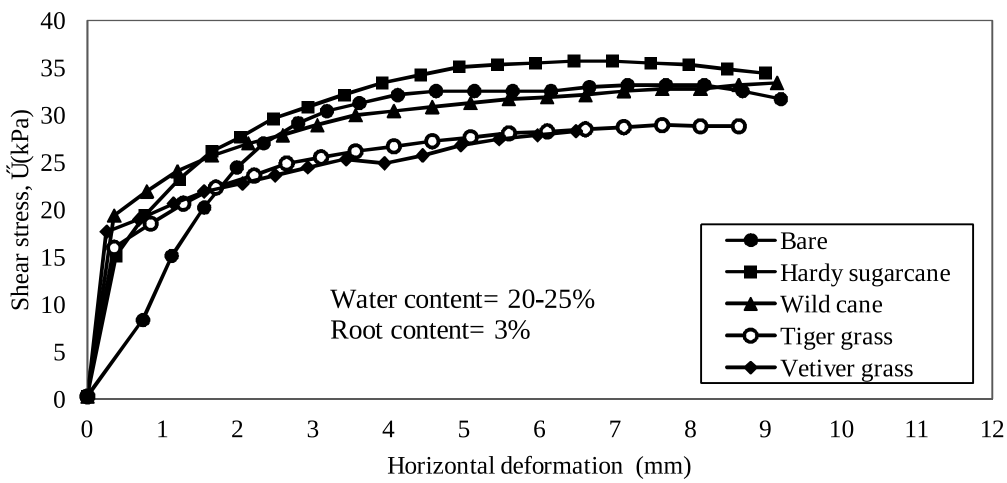


Fig. 4.20 Shear stress vs. horizontal deformation curves for the samples prepared with Pubail soil

According to the classification presented in Table 4.4, the soil of Pubail is clay with low plasticity with clay percentage 24%. High clay content may give this soil ductile property. Table 4.13 presents the peak shear stress and horizontal deformation of bare and different rooted specimens. It is seen from the table that addition of root may not increase shear strength but it increases horizontal deformation significantly i.e., it makes the soil ductile.

Table 4.13 Peak shear stress (τ_{max}) and horizontal deformation (Δ_f) of rooted soil specimens

Sample type	Buriganga Organic soil		Durgapur moist sand		Garo pahar soil		Pubail soil	
	τ_{max} (kPa)	Δ_f (mm)	τ_{max} (kPa)	Δ_f (mm)	τ_{max} (kPa)	Δ_f (mm)	τ_{max} (kPa)	Δ_f (mm)
Bare soil specimen	26.20	4.62	27.48	4.57	30.45	9.75	33.21	8.69
Hardy sugarcane	27.48	9.80	26.20	9.73	37.14	8.18	35.76	7.98
Wild cane	31.94	9.65	28.75	9.65	30.03	9.70	34.49	9.65
Tiger grass	31.51	5.70	24.93	9.80	37.46	8.18	28.96	8.64
Vetiver grass	32.58	7.40	26.84	5.61	35.55	9.73	28.33	6.50

Note: τ_{max} = Peak shear stress of soil and Δ_f = horizontal deformation

4.6.2 Effect of Soil Type on Strength-deformation Behavior

Four different types of soil were selected to find the effect of roots. The selected soils were organic soil, coarse sand, hilly soil and clayey soil which represents polluted river bank soil, embankment fills, hill slopes and flood plain soil respectively. The natural water contents of these soils were 62%, 13%, 22% and 25%. For each type of soil, five different types of specimens were made. These were bare soil, hardy sugarcane, wild cane, tiger grass and vetiver grass roots mixture.

a) Hardy sugarcane

Fig. 4.21 presents the shear stress versus horizontal deformation curves for specimens prepared with hardy sugarcane roots with different soil specimens. From this figure, it is clear that the presence of this root has more impact on Garo pahar soil and Pubail soil in case of shear stress. The effect i.e., the curve path is similar. On the other hand, effect on Buriganga organic soil and Durgapur sand are less in shear stress. The results presented in table 4.13 shows that the effect on improving peak shear stress is highest for Garo pahar soil i.e., it increased from 30.45 kPa to 37.14 kPa. In case of horizontal deformation, it is higher for Buriganga organic soil and Durgapur sand which is 9.8 mm and 9.73 mm respectively than that of Garo pahar and Pubail soil that is 8.18 mm and 7.98 mm, respectively.

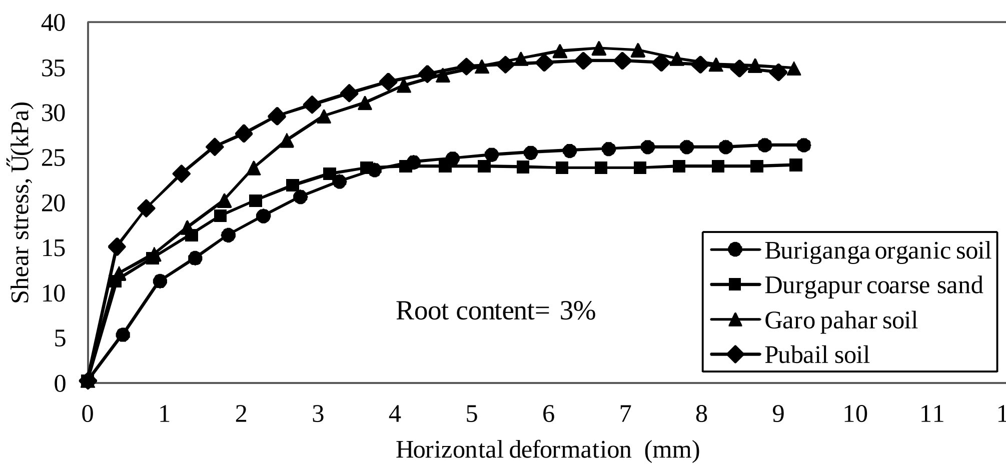


Fig. 4.21 Shear stress vs. horizontal deformation curves for specimens prepared with hardy sugarcane roots with different soil

b) Wild Cane

Fig. 4.22 shows that the effect of wild cane roots on shear stress is higher for Pubail and Buriganga organic soil. But from Table 4.13, for Buriganga organic soil, peak shear stress for bare soil was 26.2 kPa while that for wild cane rooted specimen had 31.94 kPa. So in case of increasing peak shear stress, Buriganga organic soil showed highest improvement. From this table, it is also seen that wild cane rooted specimens gave same horizontal deformation value for all four kind of soil specimens which is 9.65 ï 9.7 mm.

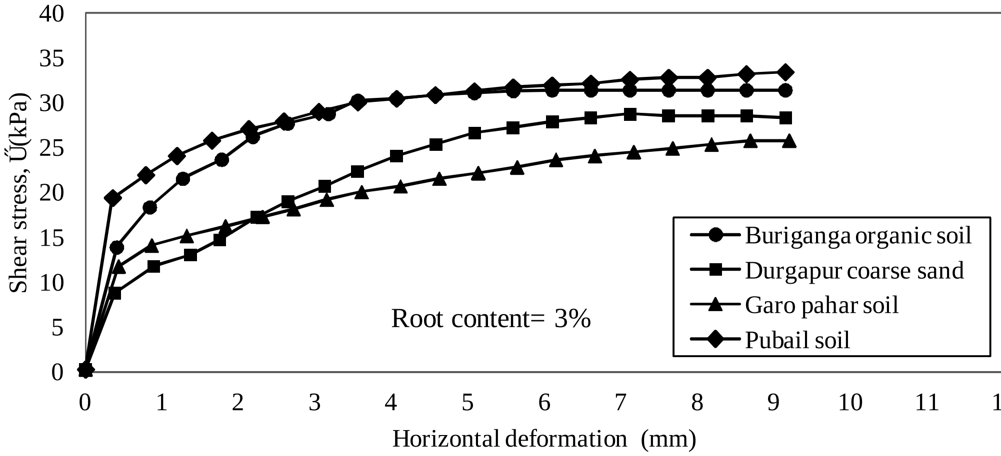


Fig. 4.22 Shear stress vs. horizontal deformation curves for specimens prepared with wild cane roots with different soil

c) Tiger Grass

From the shear stress versus horizontal deformation curves presented in Fig. 4.23, the effect of tiger grass root had highest influence on Garo pahar soil. From Table 4.13, it had increased peak shear stress from 30.45 kPa to 37.46 kPa for Garo pahar soil and from 26.2 kPa to 31.51 kPa for Buriganga organic soil. For Durgapur and Pubail soil peak shear stress decreased slightly. But in case of horizontal deformation, Durgapur soil improved most (value increased from 4.57 mm to 9.8 mm), slightly for Buriganga organic soil (value increased from 4.62 mm to 5.7 mm) and remained almost unchanged for Pubail and Garo pahar soil.

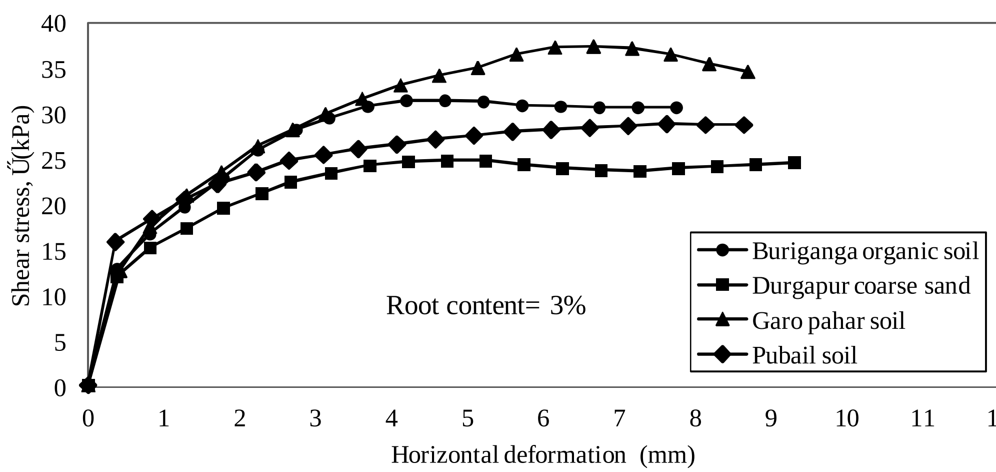


Fig. 4.23 Shear stress vs. horizontal deformation curves for specimens prepared with tiger grass roots with different soil

d) Vetiver Grass

From Fig. 4.24, it is seen that the impact of adding vetiver grass root is higher for Garo pahar soil and Buriganga organic soil than the other two. The value of peak shear stress and horizontal deformation presented in Table 4.13 shows that peak shear stress increased from 26.2 kPa to 32.58 kPa for Buriganga organic soil and from 30.45 kPa to 35.55 kPa for Garo pahar soil and remained almost same for Durgapur soil. In case of horizontal deformation, it increased from 4.62 mm to 7.4 mm for Buriganga organic soil and from 4.57 mm to 5.61 mm for Durgapur soil.

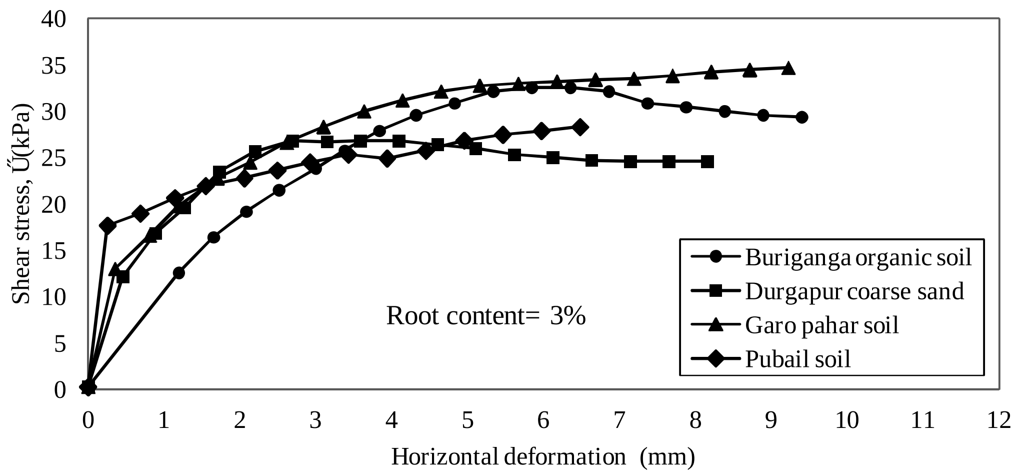


Fig. 4.24 Shear stress vs. horizontal deformation curves for specimens prepared with vetiver grass roots with different soil

Shear stress versus normal stress curves for Buriganga, Durgapur and Garo pahar, Pubail are shown in Fig. 4.25 (a and b) and Fig.4.26 (a and b) respectively. The shear strength properties i.e., c and ű of bare soil specimen values are presented in Table 4.14. and the apparent cohesion, c= and apparent angle of internal friction, ű= of rooted soil specimen are presented in Table 4.15.

Table 4.14 Shear strength properties of the reconstitute bare soil

Sample type	Buriganga Organic soil		Durgapur moist sand		Garo pahar soil		Pubail soil	
	c (kPa)	ű (deg)	c (kPa)	ű (deg)	c (kPa)	ű (deg)	c (kPa)	ű (deg)
Bare soil	15.10	32.0	10.35	37.5	14.73	42.5	12.62	48

Note: c = cohesion of soil and ű = angle of internal friction

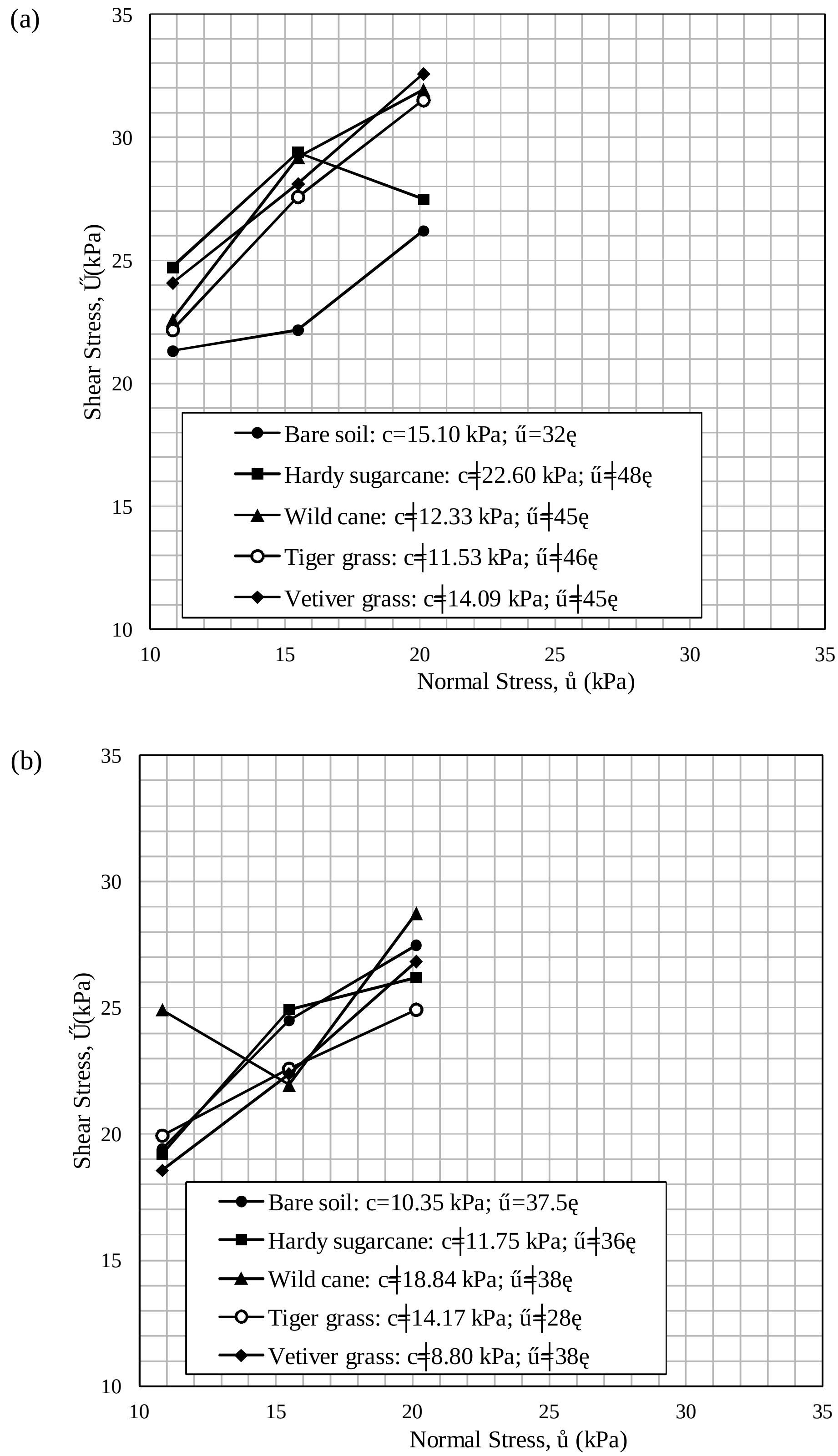


Fig. 4.25 Shear stress vs. normal stress curves for specimens prepared with (a) Buriganga soil and (b) Durgapur soil

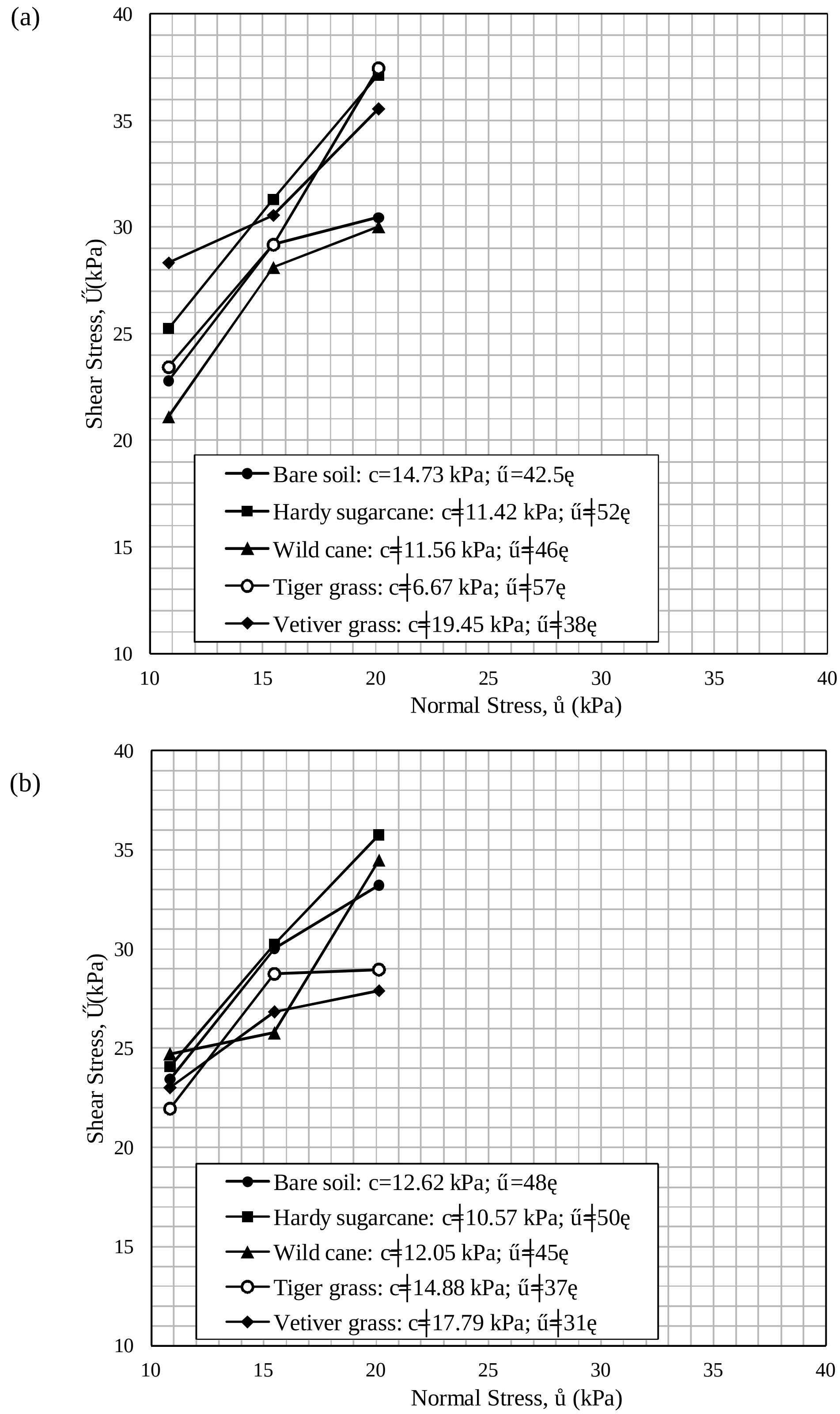


Fig. 4.26 Shear stress vs. normal stress curves for specimens prepared with (a) Garo pahar soil and (b) Pubail soil

Table 4.15 Comparison of shear strength properties of the reconstitute different rooted soil

Sample type	Buriganga Organic soil		Durgapur moist sand		Garo pahar soil		Pubail soil	
	c' (kPa)	ϕ' (deg)	c' (kPa)	ϕ' (deg)	c' (kPa)	ϕ' (deg)	c' (kPa)	ϕ' (deg)
Hardy sugarcane	22.60	48	11.75	36	11.42	52	10.57	50
Wild cane	12.33	45	18.84	38	11.56	46	12.05	45
Tiger grass	11.53	46	14.17	28	6.67	57	14.88	37
Vetiver grass	14.09	45	8.80	38	19.45	38	17.79	31

Note: c'= apparent cohesion of soil and ϕ'= apparent angle of internal friction

4.6.3 Comparison of Shear Strength of Different Rooted Soils

Maximum shear stress, τ_{max} versus root type relationship for normal stress σ = 10.83 kPa is shown in Fig. 4.27. From this figure it is seen that except for Durgapur soil, hardy sugarcane root improved shear stress for other soils. Wild cane roots improved shear stress for all soils except for Garo pahar soil. The roots of tiger grass improved shear stress for each soil slightly. Vetiver roots improved shear stress of Garo pahar soil and Buriganga soil significantly and for other two soils the effect is very low.

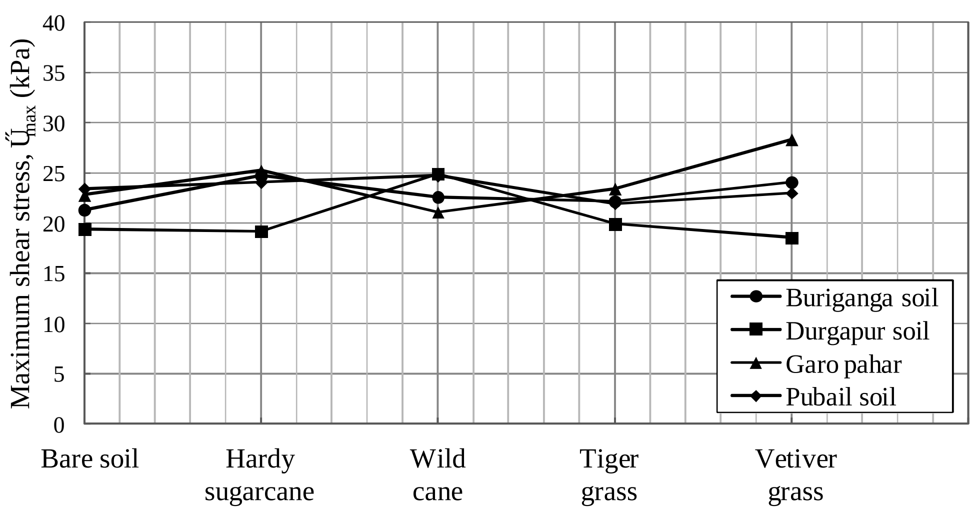


Fig. 4.27 Maximum shear stress of different rooted soils for normal stress σ= 10.83 kPa

3.10 In-situ Test Results

Tests were conducted at 230 to 250 mm depths from EGL for both rooted and unrooted soil. Tests were conducted under arbitrary selected three different normal stresses (14.71 kPa, 17.15 kPa and 19.60 kPa). Fig. 4.28 shows the detail test set-up for the in-situ test. Total 9 block samples were tested in the field under these three normal stresses at same depth. Out of nine samples, three samples were hardy sugarcane rooted, three were wild cane rooted and other three were bare soil. Fig. 4.29 (a and b) shows the failed block sample in Durgapur and Sada pahar. Torn roots are clearly visible in these photographs. The shear stress versus shear strain graphs of block samples are presented in Fig. 4.30 (a ï c). The shear strength parameters of these block samples is presented in Table 4.16. Fig 4.31 (a ï c) shows the shear stress versus normal stress curves for in-situ block samples.

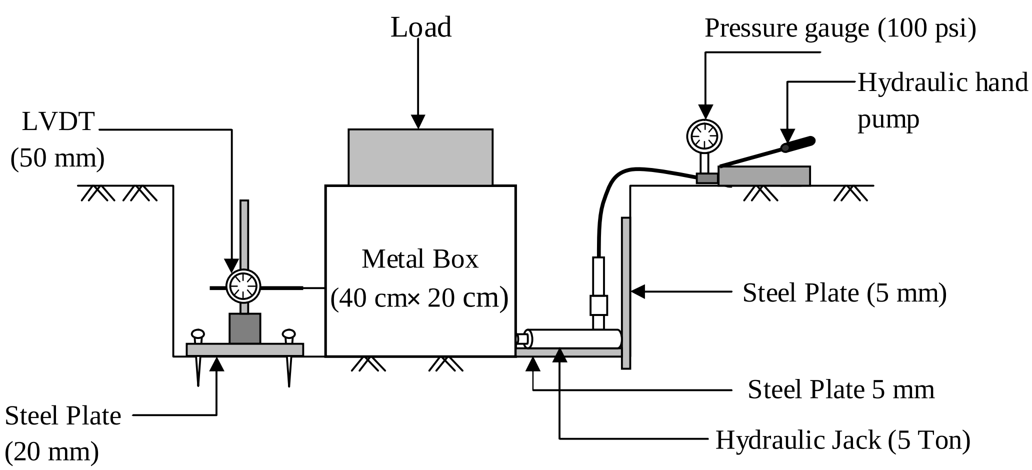
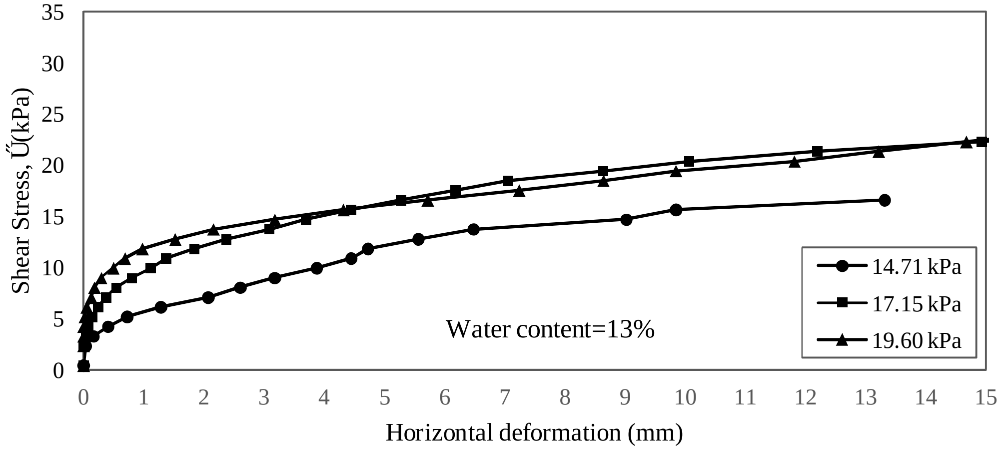


Fig. 4.28 Test set-up for in-situ shear test of block samples (40 cm×20 cm×19 cm)

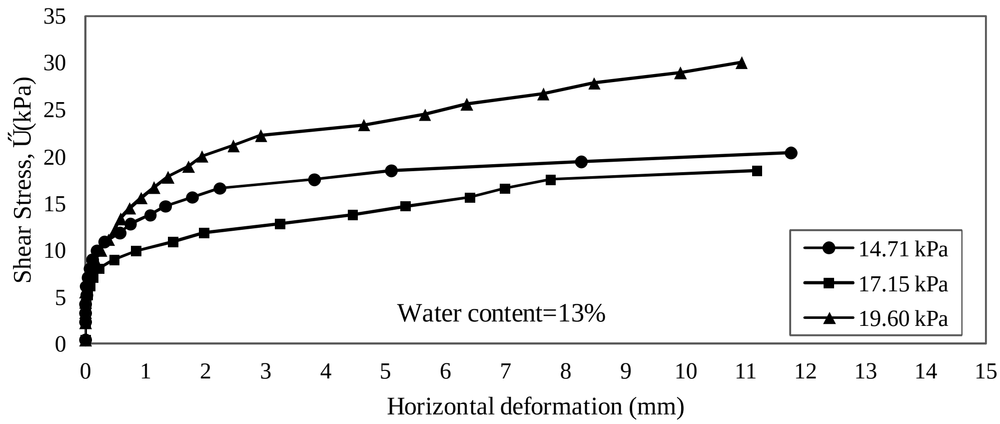
Table 4.16 Shear strength parameters of in-situ test samples

Durgapur site		Sada pahar site		Garo pahar site	
c╡ (kPa)	ű╡ (deg)	c╡ (kPa)	ű╡ (deg)	c (kPa)	ű (deg)
3.5	75	2.5	59	4.0	58

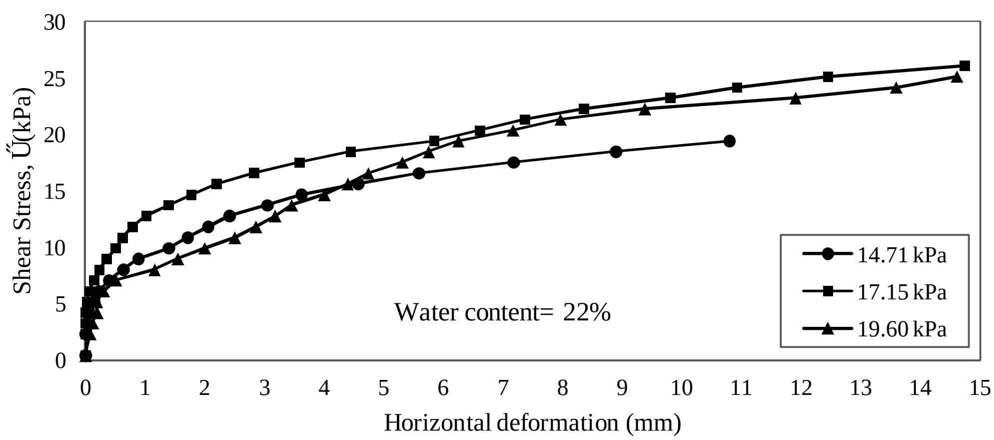
Note: c╪ apparent cohesion of soil, ű╪ apparent angle of internal friction



(a)



(b)



(c)

Fig. 4.29 Shear stress vs. horizontal deformation graphs for block specimens of (a) Durgapur soil, (b) Sada pahar soil and (c) Garo pahar soil

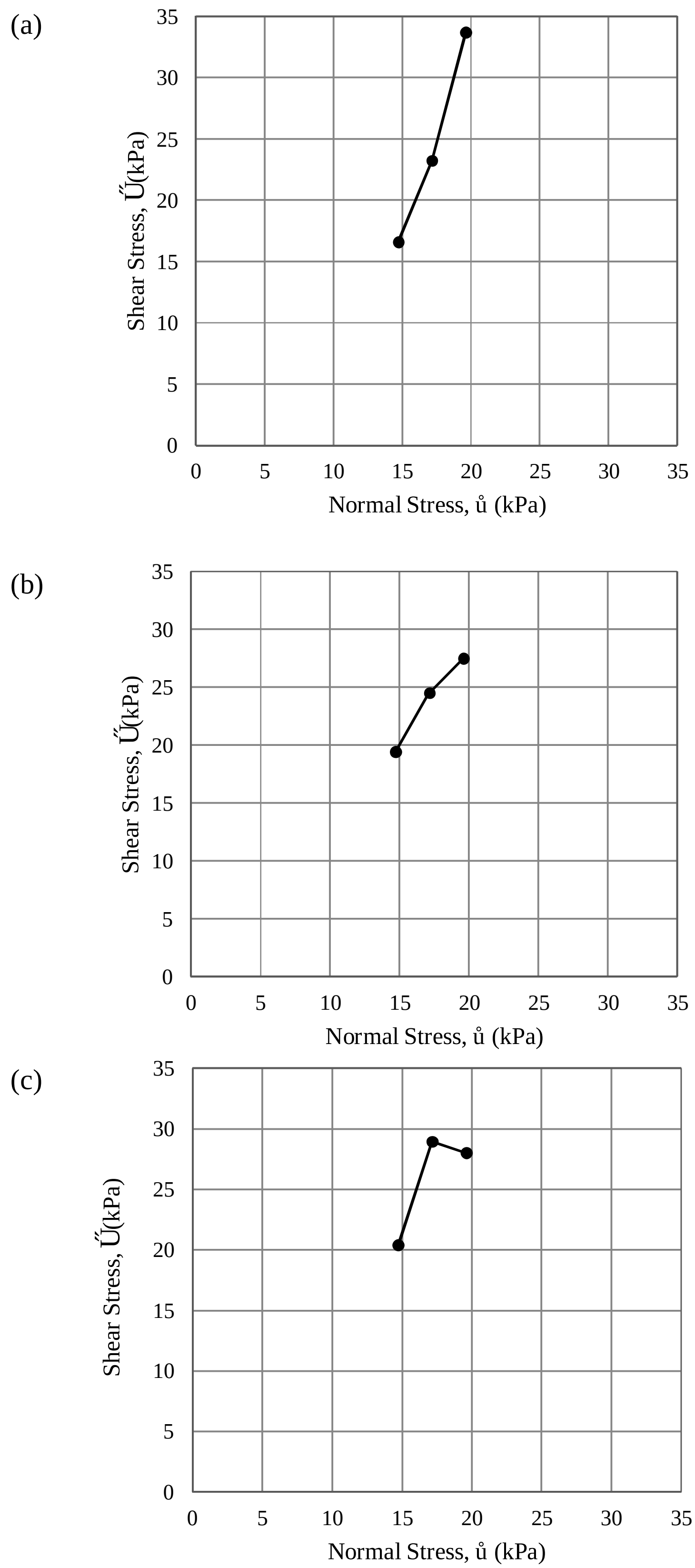


Fig. 4.30 Shear stress vs. normal stress graphs for block specimens of (a) Durgapur, (b) Sada pahar and (c) Garo pahar soil

(a) (b)

Fig. 4.31 Failed block sample (a) Durgapur site with hardy sugarcane root and (b) Sada pahar site with wild cane root

3.11 Application of this Study

Soil Bioengineering methods can be applied wherever the plants i.e., living building materials are able to grow well and develop. This is the case in tropical, subtropical and temperate zones whereas there are obvious limits in dry and cold regions. Since Bangladesh has tropical and subtropical climate, this method can be very effective as plants can grow easily in such climates. Temperature of Bangladesh ranges from as low as 7 degree centigrade at night in the cold season and a day time top of above 40 degree centigrade in the hot season. Annual rainfall varies from 1000mm in the west to 250 mm in the southeast and up to 5000mm in the north near the hills of Assam. Three quarters of the annual rainfall occurs between June and September. These climatic conditions are very favorable for plants to grow. So this technology can be applicable for three different cases such as in road sector, water body preservation and hill side slope protection.

4.10.1 Use in Road Sector of Bangladesh

Most of the land of Bangladesh are made of silty deposit carried by river and flood water. Later this silty soils are using for road embankment structure. Since silt has low plastic behavior which makes these embankments very susceptible to erosion against raindrop impact, surface runoff and wind (De Baets et al., 2006; Gyssels et al., 2006; Shit and Maiti, 2012). If the embankment surface remains bare, due to the heavy monsoon rain, the surface gets eroded greatly shown in Fig 4.32a.

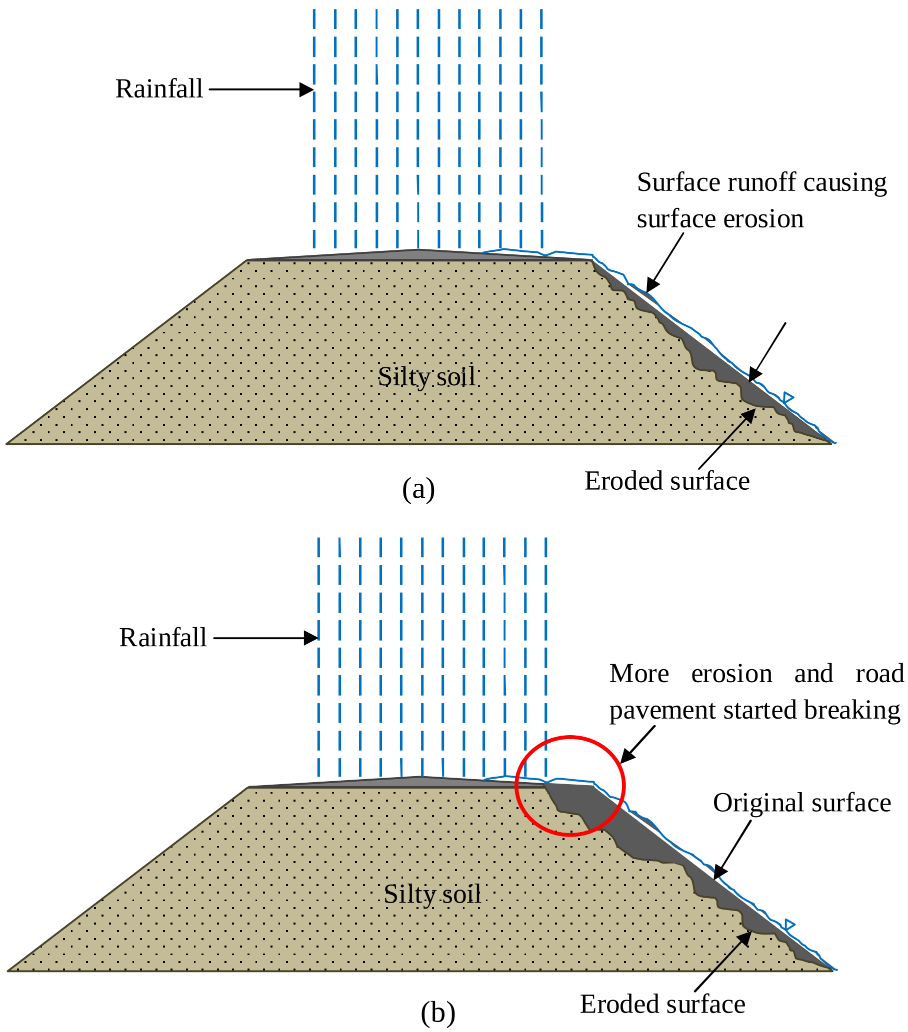


Fig. 4.32 (a) Phase one: Surface getting eroded by surface runoff flow and (b) phase two: further erosion finally caused road breaking

Further erosion causes road breaking which is shown in Fig.4.32b. A proper vegetative cover over the embankment slope surface can reduce this susceptibility significantly (Nasrin, 2013; Islam, 2013, Shahriar, 2015). A dense vegetative cover prevents water intrusion and decrease raindrop impact in a remarkable manner (De Baets et al., 2006; Gyssels et al., 2006; Shit and Maiti, 2012). It also reduces the surface runoff flow velocity and prevents soil particles washed away with flow. Fig. 4.33 illustrates the impact of vegetation in preventing road damage.

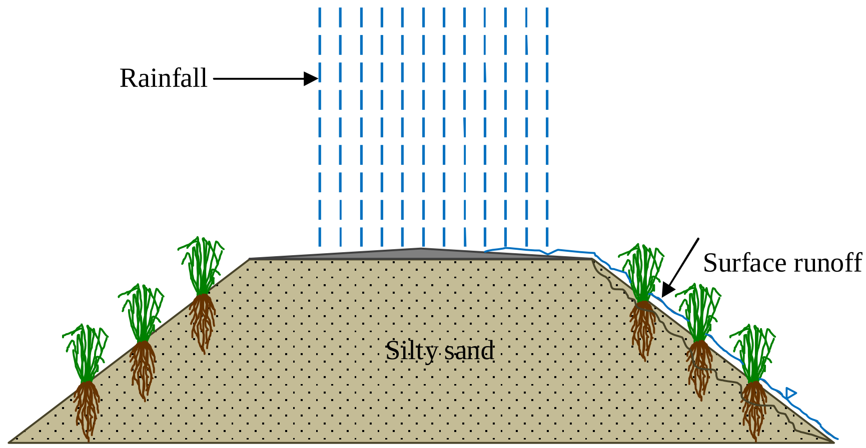


Fig. 4.33 Impact of dense vegetative cover on road protection

The prospect of vetiver plantation in the road sector of Bangladesh has been presented in Table 4.17. It is estimated that, 261 billion tillers will be required only for the road sector. For this, nursery area requires 260635 hectares. It is also estimated that 196 million labour-day will be required for plantation in the road sector only.

Table 4.17 Available road length for bioengineering technique application

Category	Total Length (km)	Paved (km)	Unpaved (km)	Zilla (km)	Regional (km)	Highway (km)	Unknown
Railway	2835	N/A	N/A	N/A	N/A	N/A	N/A
RHD	21302	17336	638	13242	4247	3813	3508
LGED	304379	83303	213331	N/A	N/A	N/A	N/A
Coastal Embankment	4800	N/A	N/A	N/A	N/A	N/A	N/A
Haor	No. villages=2500, height = 5 to 6 m, money requirement per village =7 ï 8 million BDT (using cc block/brick) and road embankment = 4944 km						

4.10.2 Use in Water Body (Pond, Lake) Preservation

Fig. 4.34 illustrates the impact of proper green cover in protecting bank of a water body. Another advantage of dense green cover is, by protecting bank surface from erosion it prevents soil mixing into the water. Thus keep water clean. Again, for turbulent water body preservation, denser cover is required along with large trees to act against wave action (Coder, 2010; Shahriar, 2015). Fig. 4.35 shows protection of turbulent water body with dense vegetation. Sometimes, based on the wave intensity and strength, green cover along with mechanical structure can be applied according to the need (NCHRP SYNTHESIS 430, 2012).

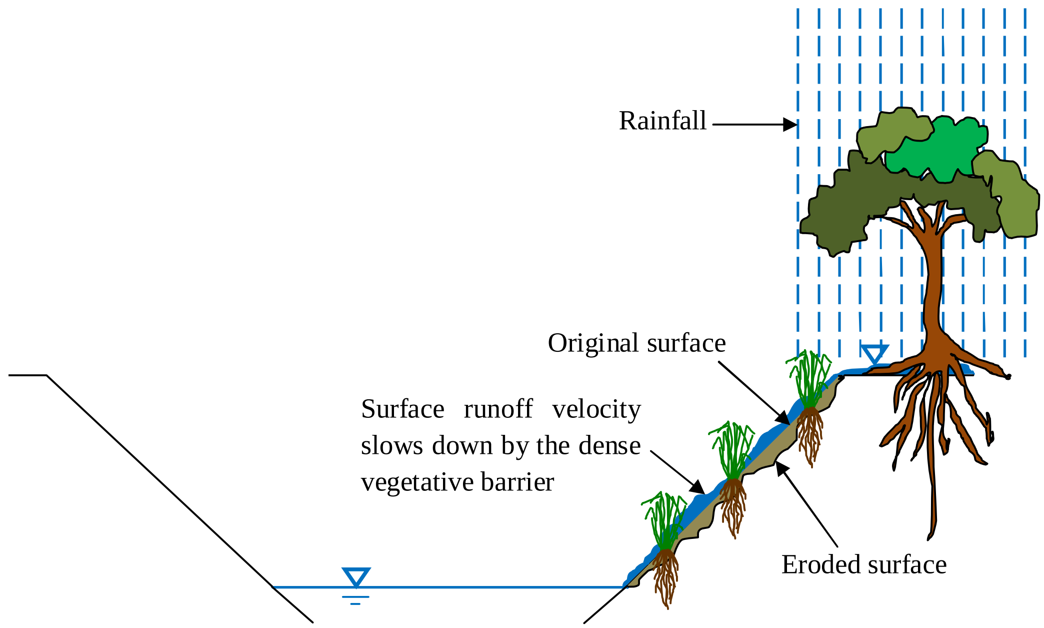


Fig. 4.34 Impact of dense green cover in protection of calm/still water body

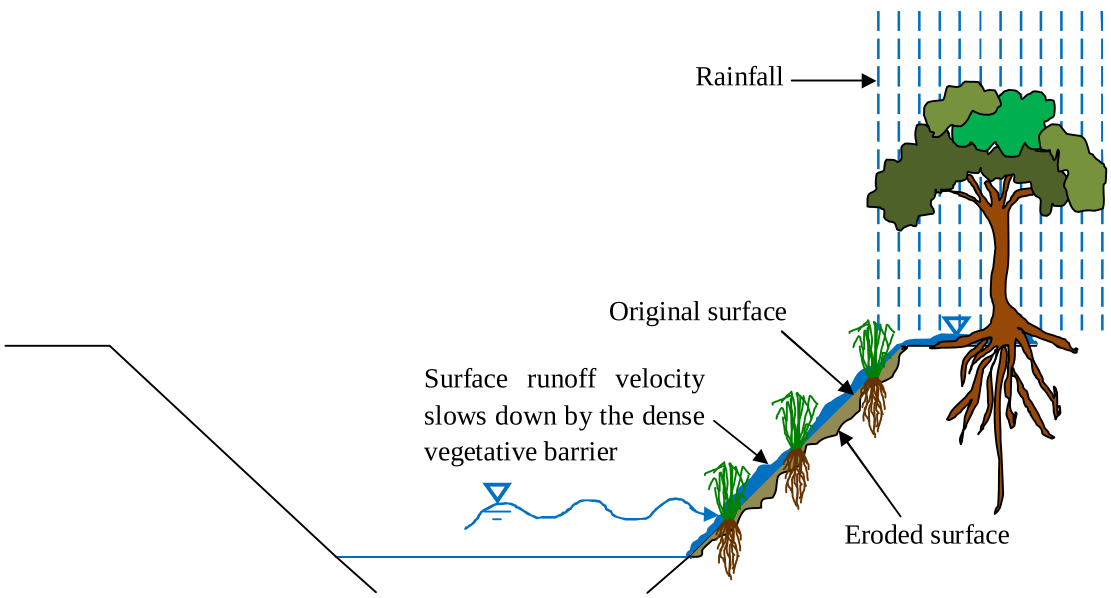


Fig. 4.35 Impact of dense green cover in protection of turbulent water body

4.10.3 Use in Hill Side Slope Protection

According to the history all over the world, most of the landslide in hill side slope occurred after heavy rainfall (Chales, 2015). It is due to the rain water intrusion into the hill soil layer. This water intrusion cause erosion of thin sand layer present in hill layer and also make is slippery. Then the surface layer slipped downward causing landslide. Covering the hill surface with proper vegetation has multifunctional benefits. One is dense vegetative cover prevents water intrusion significantly and decrease raindrop impact (De Baets et al., 2006; Gyssels et al., 2006; Shit and Maiti, 2012). Hill slopes protection by dense vegetation is illustrated in Fig.4.36. It also reduces the surface runoff flow velocity in a remarkable manner. Then later plant uptake water from soil and thus reduces soil water content and prevents further penetration makes soil less permeable (Charles, 2015). Dense grass barrier preserves surface soil while large trees connects surface soil layer to the hard stratum in the deep layer (Coder, 2010; Jain, 2013).

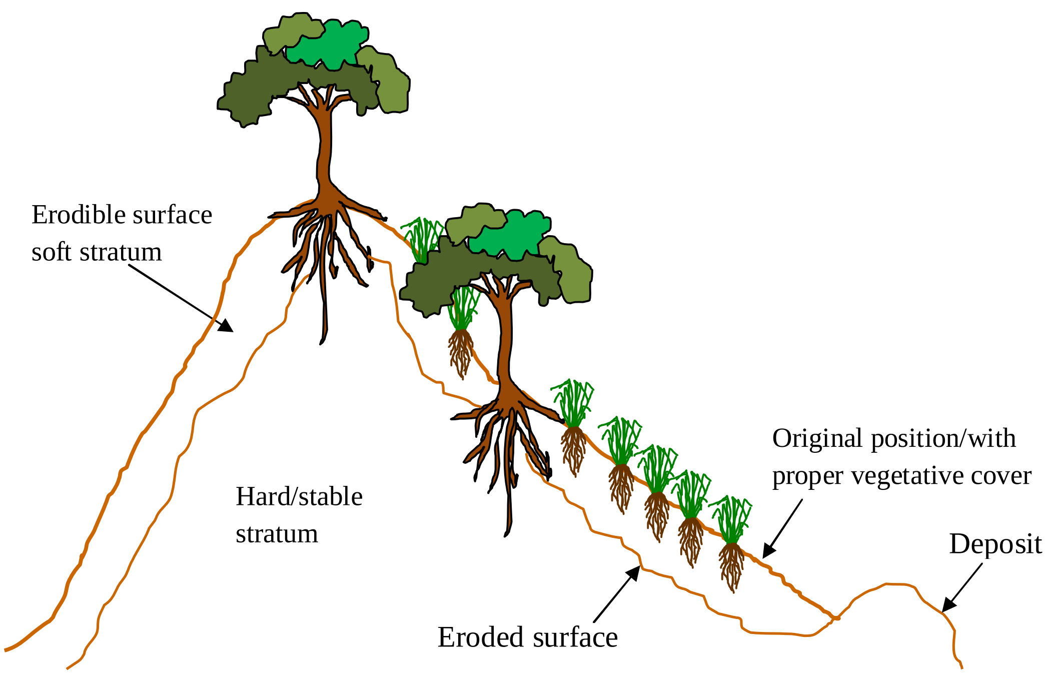


Fig. 36 Hill side slope protection by vegetation

3.12 Summary

The ability of vegetation to stabilize and strengthen soil is now well recognised and this has been applied to the reinforcement of soil on unstable slopes. Effectiveness of plants were investigated in soil erosion control, increasing soil shear strength and removing heavy metals from soil through the process of phytoremediation. Main findings obtained from this research are:

(1) Four plants were selected which are hardy sugarcane, wild cane, tiger grass and vetiver grass in this study. These plants were selected on the basis of their availability and root morphology i.e., ability to act as a soil binder.

(2) All the four types of plants selected in this study grew well. Among the selected plants, it was found that the root morphology of vetiver is most effective for slope protection and soil erosion control. Again, vetiver grass is widely available in the country. As a result, detail studies on growth were conducted for vetiver grass mainly.

Growth of vetiver in nursery soil was better than that of other soils. Survival rate was 99.9%, 88% and 75% for nursery soil, red clay and sand, respectively. Root grew up to 115 cm and shoot grew up to 100 cm in five months in nursery soil. Lack of enough sunlight and rainfall reduced its growth significantly. From the model studies, it was also found that growth rate was maximum during monsoon.

Vetiver grass also grew in saline soil with Electric Conductivity (EC) 4.8 ds/m, 10.0 ds/m and 12.5 ds/m. It was found that growth was higher in low saline soil (EC = 4.8 ds/m) and lower in higher saline soil (EC = 12.5 ds/m). In contaminated soil, the growth rate was very low till second month of the plantation. Rate increased during 2nd to 3rd month. Roots grew up to 45 cm and shoots grew up to 120 cm in ten months time. Survival rate was 100% for both saline and contaminated soil.

(3) Vetiver grass was planted in plastic container with contaminated soil collected from Buriganga river bank. The initial concentration of heavy metals i.e., lead,

chromium, copper, nickel and zinc were 22.8, 116, 33.1, 23.1 and 454 mg/kg, respectively. It was observed that vetiver accumulated these metals in its roots, shoots/stems and leaves in a significant amount. The uptake by vetiver grass (in gm per sq. meter area) of lead, chromium, copper, nickel and zinc in 50 week time are found to be 110.2, 53.34, 32.45, 52.935 and 2388.85, respectively. However, it was found that uptake rate of lead and zinc is higher than other metals (copper, nickel and chromium). Metal accumulation in shoot was found to be higher than that of in leaves and roots.

(4) Laboratory investigations were made by conducting direct shear tests adding 3% root with soils. Four different types of roots i.e., hardy sugarcane, wild cane, tiger grass and vetiver grass roots were used for tests. Four types of soils were selected for laboratory investigation. Buriganga soil represent river bank slopes soil (organic soil), Durgapur soil represents coarse sand which is now-a-days being used for road embankment fill, Garo pahar soil represents hill slope soil and Pubail soil represent flood plain soil. Applied normal stresses were 10.83 kPa, 15.47 kPa and 20.12 kPa.

Effects of each root varied with different types of soils. Such as for hardy sugar cane had more effect on Buriganga soil i.e., apparent cohesion increased for Buriganga soil and remained almost same for other three and apparent angle of internal friction increased for Buringanga and Garo pahar soil and remained same for other two. Wild cane had more effect on Durgapur sandy soil i.e., apparent cohesion increased significantly and decreased or remained almost same for other three except Pubail soil, apparent angle of internal friction increased. For tiger grass, cohesion increased for Durgapur sandy soil and Pubail soil and decreased for other two and angle of internal friction increased significantly for Buringanga and Garo pahar soil and decreased for other two. For vetiver grass apparent cohesion increased for Garo pahar soil and Pubail soil and remained almost same for other two and apparent angle of internal friction increased for Buriganga soil, remained same for Durgapur sandy soil and decreased for Garo pahar and Pubail soil.

Effect on Shear Strength

In case of peak shear stress, Ű$_{max}$ for Buriganga organic soil and Garo pahar soil, it increased for all four types of roots and remained almost same for Durgapur sandy soil. It indicates that additions of roots have almost no effect in increasing shear stress for sandy soil. However, additions of roots in clay soil (Pubail Soil) caused reduction of shear strength slightly.

It was observed that shear strength increased slightly by the addition of root matrix but failure strain increased significantly. Shear strength of bare specimen was found to be in the range between 26 and 33 kPa and that of rooted specimen was between 26 and 37.5 kPa. In-situ peak shear stress, Ű$_{max}$ of Garo pahar was found to be 26 kPa and for sada pahar soil with wild cane root and Durgapur sand with hardy sugarcane root was found to be 30 and 22 kPa, respectively.

Effect on Cohesion

The cohesion of soil specimen was found to vary in the range between 10.35 and 15.1 kPa. Angle of internal friction for the bare soil specimen was in the range of 32 to 48ę. For rooted soil specimen, apparent cohesion, c= for hardy sugarcane, wild cane, tiger grass and vetiver grass was in the range of 10.6-22.6, 11.6-18.8, 6.67-14.88, 8.8-19.5 kPa, respectively. In-situ cohesion, c in Garo pahar was found 4 kPa and apparent cohesion, c= for sada pahar soil with wild cane root and Durgapur sand with hardy sugarcane root was found to be 2 and 3.5 kPa, respectively.

Effect on Angle of Internal Friction

Apparent angle of internal friction, ű= for hardy sugarcane, wild cane, tiger grass and vetiver grass was in the range of 36-52ę, 38-46ę, 28-57ę and 31-45ę, respectively. In-situ angle of internal friction, ű in Garo pahar was found 58ę and apparent angle of internal friction, ű= for sada pahar soil with wild cane root and

Durgapur sand with hardy sugarcane root was found to be 59ę and 75ę, respectively.

<u>Effect on Deformation Behavior</u>

Failure strain, φ_f increased for all four types of roots significantly for the samples prepared with Buriganga organic soil and Durgapur sand. While for Garo pahar soil and Pubail soil, it remained almost same. Failure strain of hardy sugarcane, wild cane, tiger grass and vetiver grass root increased up to 2.12, 2.11, 2.14 and 1.6 times, respectively. In-situ failure strain, φ_f in Garo pahar was found to be 33.5 mm and for sada pahar soil with wild cane root and Durgapur sand with hardy sugarcane root was found to be 22 and 15 mm, respectively.

From the test results, it is clear that similar to the soil nails routinely used in geotechnical engineering, plant roots mechanically increase soil shear strength by transferring soil shear stress from soil into tensile forces of the root themselves, via interface friction along the root surface. However, the orientation and geometry of the root influence the effectiveness increasing the reinforcing effect.

Chapter Five

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The ability of vegetation to stabilize and strengthen soil is now well recognised and this has been applied to the reinforcement of soil on unstable slopes. Effectiveness of bioengineering method for slope protection in Bangladesh perspective had been studied. For this purpose, variation in strength-deformation characteristics of different rooted soil had been investigated. Growth of selected plants in different soil (sand, clay, saline soil and contaminated soil) had also been studied. Laboratory tests, field and model studies were conducted to evaluate the efficacy of the proposed method. Main findings of the study and recommendations for further researches have been included in this chapter.

5.2 Findings of the Study

Main findings of this study obtained by laboratory investigations, field tests and model study are summarized as follows.

In Bangladesh, road embankments are mainly constructed using dredge fill soil which is mainly silty sand. Embankments constructed with such soil fails/damages mainly due to surface erosion caused by heavy rainfall. On the other hand, river bank which are also mostly consisted of silty sand are easily erodible to rain cut erosion and wave action. Hill slopes are damaged due to surface erosion since the slopes has become denuded due to human activities. As a result, hill slopes, river bank and embankments get damaged easily. Plants roots work as micro piles or micro nails in soil. Properly applied vegetation system is effective in protecting such slopes.

Due to the availability and root morphology suitable for soil binder, in this study, four plants were selected which were hardy sugarcane, wild cane, tiger grass and vetiver grass. Vetiver grass has multifunctional activity, highly economic and can grow in silty, clayey, contaminated and saline soil. Again, hardy sugarcane and wild cane grow well and fast in coarse sand. Tiger grass is an economic grass and cultivated in farms in many countries. It is available in the hilly region of Bangladesh. Vetiver grass can be selected for soil protection work in contaminated soil, saline soil, silty and clayey soil. Hardy sugar cane and wild cane can be used for embankments constructed with sandy soil. Tiger grass can be used for slope protection in hilly regions.

All the four types of plants selected in this study grew very well. Detail studies on growth were conducted for vetiver grass mainly due to its better root morphology and availability all over the country. Growth of vetiver in nursery soil was better than that of in other soils. Root grew up to 115 cm and shoot grew up to 100 cm in five months in nursery soil. Lack of enough sunlight and rainfall reduced its growth significantly. From the model studies, it was found that growth rate was very high during monsoon. To determine whether it can grow in coastal region (in saline soil), vetiver grass was planted in saline soil with Electric Conductivity (EC) 4.8 ds/m, 10.0 ds/m and 12.5 ds/m. It was found that growth was lower in higher saline soil (12.5 ds/m). In contaminated soil, the growth rate was very low till second month of the plantation. Rate increased during 2^{nd} to 3^{rd} month. Roots grew up to 45 cm and shoots grew up to 120 cm in ten months time. Survival rate was 100% for both saline and contaminated soil.

Vetiver grass was planted in tubs with contaminated soil collected from Buriganga river bank having initial concentration of lead, chromium, copper, nickel and zinc 22.8, 116, 33.1, 23.1 and 454 mg/kg, respectively. The uptakes (in gm per sq. meter area) of lead, chromium, copper, nickel and zinc by vetiver grass in 50 week time were found to be 110, 53, 32, 53 and 2389, respectively. However, it was found that uptake rate of lead and zinc was higher than other metals (copper, nickel and chromium). Metal accumulation in shoot was found to be higher than that of in leaves and roots.

Strength-deformation characteristics have been evaluated by conducting both laboratory and in-situ tests. Four types of soils and four different types of roots were selected for laboratory investigation. óBuriganga Soilô represents river bank soil, óDurgapur Soilô represents coarse sand which is used for road embankment construction, óGaro Pahar Soilô represents hill slope soil and óPubail Soilô represents flood plain soil. It was observed that shear strength increased slightly due to the addition of root matrix but horizontal deformation increased significantly about 1.5-2 times. Shear strength increased by hardy sugarcane, wild cane, tiger grass and vetiver grass upto 12%, 4%, 13 and 7%, respectively. Apparent angle of internal friction, ű= increased by hardy sugarcane and tiger grass up to 8% and 19%. Apparent cohesion, c= increased by hardy sugarcane, wild cane and vetiver grass up to 50%, 25% and 30%, respectively.

In-situ shear strength, Ű$_{max}$ and horizontal deformation, φ$_{f}$ of bared óGaro Pahar Soilô were found to be 26 kPa and 29 mm, respectively. While Ű$_{max}$ and φ$_{f,}$ of the reconstituted óGaro Pahar Soilô were 31 kPa and 9.75 mm, respectively. Cohesion, c and angle of internal friction, ű obtained from in-situ test conducted on óGaro Pahar Soilô were 4 kPa and 58ę, respectively. On the contrary, cohesion, c and angle of internal friction, ű obtained from laboratory tests were 15 kPa and 42.5ę, respectively. From the comparison of the in-situ and laboratory test results, it is seen that properties obtained from the laboratory test and in-situ tests are significantly different.

From the test results, it is clear that similar to the soil nails routinely used in geotechnical engineering, plant roots mechanically increase soil shear strength by transferring soil shear stress from soil into tensile forces of the root themselves, via interface friction along the root surface. However, the orientation and geometry of the root influence the effectiveness increasing the reinforcing effect.

Application of bioengineering is an eco-friendly, economic and long term sustainable solution. But it must be applied in a proper and technical way. Proper application means it must be maintained and monitored till the plants become matured. From this study, it can be concluded that selected plants especially vetiver can be used as bioengineering system to protect embankment slopes, hill slopes and river bank in Bangladesh. Each of the plants studied has both medicinal and economic value which can contribute greatly in national economic and medicine sector of the country. Moreover by using bioengineering, Bangladesh can earn more benefits by Carbon trading.

5.3 Future Recommendations

During the research, it was felt that future studies can be conducted in the following areas:

(a) Tri-axial tests can be conducted for better understanding of the strength-deformation behavior of the rooted soils.

(b) In this study, direct shear tests were conducted on reconstituted samples. To get undisturbed rooted sample, plants can be grown in PVC pipe. Undisturbed samples of rooted soil can be retrieved from thus planted pipes.

(c) Effectiveness of plants in protecting slopes of layered soil can also be investigated.

(d) Numerical analysis need to be conducted to obtain overall factor of safety against slope failure and soil erosion in a grass-tree combination. This combination include large trees, deep rooted grasses like, vetiver, and very fast growing grasses and plants on the surface.

(e) Extensive field trials are necessary to determine the effectiveness of proposed bioengineering method in slope protection in different geographic regions with different climatic and soil conditions.

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