DEVELOPMENT OF CLIMATE RESILIENT SLOPE PROTECTION FOR DYKES IN SALINE ZONES OF BANGLADESH

A Thesis submitted by

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DEDICATED TO

My Parents

And

My Respected Supervisor

Dr. Mohammad Shariful Islam

The thesis titled **"Development of climate resilient slope protection for dykes in saline zones of Bangladesh"**, submitted by B. A. M. Shahriar, Roll No. 1009042222P, Session October 2009 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Science in Civil Engineering on June 27, 2015.

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DECLARATION

It is hereby declared that this thesis and the studies embodied in it are the result of the investigation carried out by the author under the supervision of Dr. Mohammad Shariful Islam, Professor, Department of Civil Engineering, Bangladesh University of Engineering and Technology. Wherever contributions of others were involved, every effort has been made to indicate this clearly with due reference to the literature and acknowledgement of collaborative research and discussions. Neither thesis nor any part of it has been submitted to or is being submitted to for any other purposes (except for publication).

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ABSTRACT

The ability of vegetation to stabilize and strengthen soil is well recognized and this has been widely applied to the reinforcement of soil on unstable slopes. Main objective of the research was to develop a climate resilient slope protection measure for dykes in the saline zones of Bangladesh. To do this, causes of slope failure were determined at first. Suitable vegetation was selected and field trials as well as model study were conducted to investigate the effectiveness of the proposed method.

Main causes of dyke failure in saline zone of Bangladesh are floods caused by cyclone, typhoon, tidal surge etc. Lack of compaction, poor construction and maintenance as well as absence of protection of such steep slopes accelerate their failure.

To select suitable vegetation, growth study had been conducted at BUET premises for vetiver grass (*Vetiveria zizanioides*) and *Kans* (*Saccharum spontaneum)*. Study showed that shoot growth of *Kans* was better than that of vetiver. But, the root morphology of vetiver was better than that of *Kans* as a soil binder. Thus vetiver grass was selected as a suitable vegetation for plantation at dyke slope for their protection.

Field trials were conducted at three different areas of the coastal zone under Satkhira district. Physical and chemical properties of the soils collected from trial locations were determined. These soils are mostly consisted of silt (90%). The Electrical Conductivity (EC) ranged from 1.57 to 12.37 (ds/m). Based on salinity (determined by EC), three trial locations were selected in Kaliganj (low saline zone), Baliapur (moderate saline zone) and Nildumur (high saline zone). From the study, it was found that vetiver grass grew in all the saline zones. However, the growth was best in low saline zone. It was also found that the higher the salinity the lower the rate of growth.

Two cases were selected to evaluate the effectiveness of vetiver grass in slope protection in other regions of Bangladesh–Keraniganj (flood prone region) and Rajshahi (barind tract region). It was found that vetiver was effective in road slope protection in the flood prone area and pond slope protection in the barind tract area.

Model study was conducted to determine the optimum slope of embankment to be protected by vegetation. Three models with 1:0.75, 1:1 and 1:1.5 slopes constructed with silty soil were investigated against artificially generated wave action. From the study, it was found that vetiver grass can protect embankment slopes effectively up to 1:1.

From the stability analysis it is found that vetiver grass plantation increases the factor of safety of the slope. Factor of safety increases up to 36% to 65% depending on the soil properties. Slope protection by vetiver grass costs 35 BDT per square meter which is at least 50 times lower than that of common RC revetment structures.

An installation guideline has been developed in the study for proper vetiver plantation to protect road embankment slopes.

It can be concluded that protection of dyke slopes in coastal regions of Bangladesh using vetiver grass is a low cost, climate resilient and sustainable biotechnical solution.

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NOTATIONS

Symbol	Description
β	Slope angle
γ	Unit weight of soil
γ_{dry}	Dry density
γ_w	Unit weight of water
ϕ	Angle of internal friction
ϕ'	Effective angle of internal friction of the soil
θ	Angle between roots and slip plane
c	Cohesion
c'	Effective soil cohesion
c_u	Undrained shear strength
D_{50}	Mean grain size
FS	Factor of safety
G_s	Specific gravity
h_w	Vertical height of ground water table above slip plane
h_v	Vertical height of groundwater table above the slip plane with the vegetation
n	Slope as 1: n (1 vertical to 'n' horizontal units)
z	Vertical height of soil above slip plane
EC	Electrical conductivity
TN	Total Nitrogen

Chapter One

INTRODUCTION

1.1 General

Bangladesh is a small riverine country located in South East Asia. In total, it has 700 rivers including tributaries which have a total length of 24,140km. It also carries two months of monsoon period in a year. As a result, embankment failure due to erosion and bank breaching is very common phenomena in this country. Embankment failure is a big setback for transportation sector of Bangladesh. High cost of land in this over populated country forces to economic design of road embankment which is often failed by the wave action of heavy tidal force.

Bangladesh managed to construct about 7,555km of embankment including 4,000km of coastal embankments during the last few decades. It protects about 24% of total land area and 39% of net cultivation area (Banglapedia). These embankments are constructed to protect land from tidal inundation, but cannot prevent overtopping of cyclonic surges and tidal bores. In addition, due to increased agricultural production, these embankments provide good road communication and contribute in the growth of the overall socio-economic condition at the coastal zone. Coastal region of Bangladesh is about 700km long. To protect such long length of embankment against natural calamity and erosion, every year government of Bangladesh has to allocate huge amount of money in its annual budget. So, cheaper maintenance and construction cost of embankment would be a great relief for Bangladesh.

Cultivation and export of shrimp is very successful in the coastal region and it contributes 4% of national GDP every year (Haque et al., 2006). For shrimp cultivation, ponds are dug side by side. These ponds are separated by common dykes around each pond. Slopes of these ponds are also to be maintained for hassle free cultivation (Bashunia et al., 2001). Cropping time is all round the year except November to January. During these three months farmers refurnish their ponds as it becomes a dry season. In Satkhira region, flood occurs during rainy season (July to August) in a regular basis. The whole area becomes flooded and pond boundaries go under water. Flood causes damages to the dykes boundary of the shrimp ponds. Very often farmers engage themselves in boundary deciding argument (Islam, 2011).

During monsoon season, basin type low lands of north eastern part of Bangladesh (called "*Haor*") become flooded every year under water of 2 to 6 meters. Erosion in these areas is the main cause of loss of home for a good number of people every year.

The common causes for embankment slope failure in Bangladesh are heavy rainfall, wave action from river, and inadequate protection of slopes against overtopping of storm surge. Protection against these types of failures can be divided into three types like – i) structural, ii) non-structural and iii) biological protection. Among the structural protections revetment, guide bunds, boulders and brick matressing are common, while dredging, channelization geo-bag dumping etc. are common in non-structural protections. Biological protections refer to bank vegetation, wooden pilling, willow post, bandallings and crisscross porcupines (Hensler, 2013). Most of these are expensive solutions against desired design life for the protection.

Now–a-days, bio-engineering technique is becoming popular in other countries. As Bangladesh could be one of the most affected countries for global warming (Alam et al., 2004), implementation of bio-technology would be the best solution against global warming. Moreover, it is cheaper than typical structural solutions that are provided for slope protection. Vetiver grass (*Vetiveria zizaniodes*) is being used as an efficient bio-technology for slope protection purpose in many countries. The special attributes of vetiver is that it can grow on sites where annual rainfall ranges from 200mm to 5000mm (Truong et al., 2002). It can survive in temperature ranging from 0˚C to 50˚C. It grows on highly acidic soil types (pH ranges from 3.0 to 10.5) and also tolerant to high content of Al, Mn, As, Cd, Cr, Ni, Pb, Hg, Se and Zn in the soil. The saline threshold (EC) of vetiver is 7.8 dS/m. However, in soil with EC values of 10~20 dS/m, the yield of vetiver is reduced by 10%~50% (Islam et al., 2013). Its roots are very strong with a diameter of 0.66 ± 0.32mm having a high tensile strength of around 85.10 ± 31.20 MPa. It is also found that vetiver hedges can survive even for more than 100 years (Islam et al., 2013).

Recently, few efforts have been made to investigate the effectiveness of vetiver in slope protection in Bangladesh (Rahman et al., 1996; Thomas et al., 2002; Islam, 2003; Moula et al., 2008; Huq, 2010; Islam et al., 2010, 2013). In this thesis, application of vetiver grass to protect road embankment, shrimp pond sides in saline zone and pond slope in barind tract zone has been presented. Finally, possibility of vetiver application in haor low-land protection is discussed.

1.2 Background and Present Status of the Problem

Coastal areas of Bangladesh (20% of total area) are often affected by tidal surge, cyclone, typhoon etc. which causes intrusion of saline water. These also cause damage of mud houses, paddy field, cattle etc. (Haque, 2006). As a common protection practice, soil embankment as well as CC block placing, RC wall, sand bag placing, geo-textile laying are done. But due to rapid deterioration of concrete, expensiveness and vandalism use of such CC blocks and RC walls are not durable in saline environment (Bosunia et al., 2001; Islam, 2011).

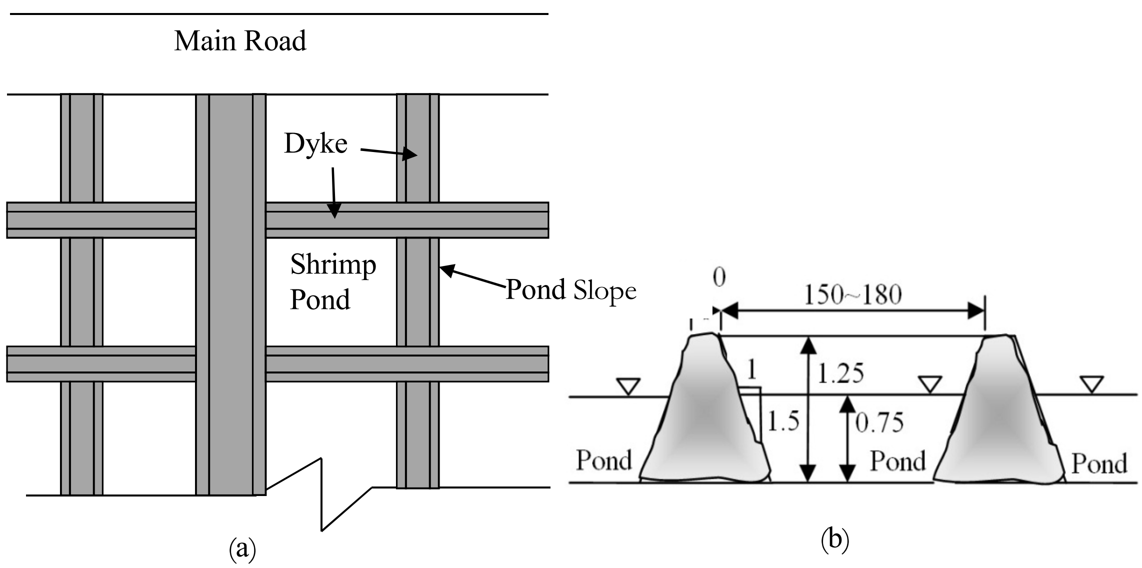


Figure 1.1 Schematic diagram showing dyke of shrimp cultivation pond (a) Plan and (b) Section (dimensions are in meter)

Beside this, shrimp cultivation is done by retention of saline water using dykes around the pond (Hensler, 2013, Alam et al., 2004). Every year nearly Tk. 20,000 per pond has to be spent for dyke repairing purpose. Figure 1.1 shows the plan and section of shrimp cultivation pond and Figure 1.2 shows condition of dykes during flood period. Here we can see that dykes around shrimp pond goes under water due to cyclone attack and farmer is trying to regain the embankment to protect his pond. Considering above

Figure 1.2 Situation of pond dykes during flood. (Source: http://archive.thedailystar.net)

situations, protection of dyke is very important and alternative solutions to be sought. Vegetation like vetiver grass (*Vetiveria zizanioides*) (Truong et al., 2013; Islam et al., 2013), Kankra (*Bruguiera Sexanyur*) can grow in saline zone (Islam et al. 2013). These vegetations can be used as effective protection system for coastal regions (Rahman et al., 1996; Verhagen et al., 2008). Pilot projects are necessary to evaluate the performance as well as to develop a slope protection measure using low-cost and sustainable solutions.

1.3 Objectives of the Research

The main objectives of this research are as follows:

(a) To determine the characteristics/types of the soils used for dyke/embankment construction in the saline zones of Bangladesh. And to determine the reasons of coastal embankment/dyke failure in the saline zones.

(b) To select suitable vegetation for dyke/embankment slope protection in the saline zones.

(c) To develop low-cost sustainable, bio-technical solution for slope protection measure of dykes in saline zone of Bangladesh. To this context, field trail and simulation studies will be conducted to evaluate the efficacy of proposed bio-technology.

(d) To propose design methodology/installation guideline for slope protection of dykes and subsequent construction in saline zones.

1.4 Methodology of the Research

The whole research was conducted according to the following phases:

(a) Three sites were selected at Satkhira district as coastal region. Study area were surveyed to know the reasons of the slope failures. Shrimp farmers were interviewed to know their problems regarding dykes.

(b) Plantation of vetiver grass were done for two sites at a time and third site after 3 months of the first two. It was random time delay to plant vetiver at third site after 3 months of first two.

(c) Undisturbed soil samples were collected from the study area during plantation time. PVC pipe were used to collect these samples. Pipes inserted into the plantation surface perpendicularly with pressure and taken out with the soil inside the pipe slowly by removing the soil around itself. Later polythene were used to close to openings to retain the moisture level as it was.

(d) Specific gravity, grain size analysis, atterberg limit test were conducted according to ASTM standards to classify the soils. Direct shear tests were conducted to determine the shear strength.

(e) Saline content and nutrient content of the collected soil samples were determined by conducting nutrient tests. Through nutrient tests pH, percentage of organic matter (OM), electrical conductivity (Ec), presence of Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg) and Sulphur (S), Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Boron (B) and Chlorine (Cl) were determined.

(f) Vetiver was planted in three areas (Baliapur, Kaliganj and Nildhumur) at the dyke slopes. These areas were chosen as different parts of the saline area which contains dykes with slopes with different salinity content. Areas were cleaned from unwanted grasses and others to ensure proper growth. Vetiver grass collected from same source were planted at the study areas in row pattern. Initial root and shoot lengths were noted. From then growth rate of root and shoot were monitored week by week for measuring it's growth performance. These monitoring were done for 12 months for two sites (Kaliganj and Baliapur) and 9 months for Nildumur area. During the monitoring period initial watering was ensured and no outside watering were done after first two weeks. Beside this, plantation area were kept out from the reach of cattle to ensure proper growth.

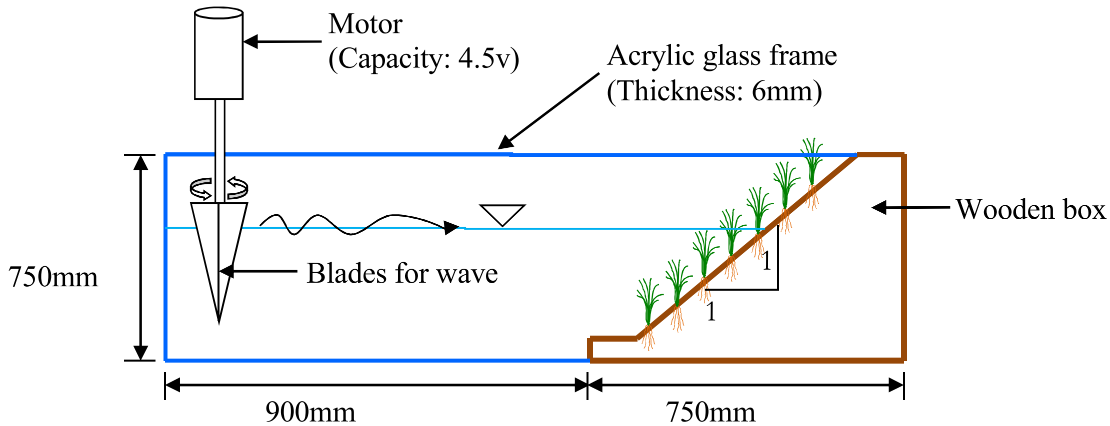


Figure 1.3 Model for studying the effect of wave on slope

(g) Simulation study were conducted to determine the efficacy of the vegetation against wave action using a small scale model. Three wooden box (750 mm x 750 mm x 750 mm) of three different slopes (1:1, 1:0.75, 1:1.5) were made and filled with soil collected from actual study area. Vetiver grass collected from Pubail area were planted there and was left in this situation for 3 months.

(h) Later glass box were used to contain the water and simulate pond condition. Hands were used to propagate wave in the water to hit vetiver grasses. Earlier it was decided to use motor with propeller for this purpose but during execution of the test hand were used. Figure 1.3 shows the test setup. Wave hit the soil and erosion took place. This simulation was done for three selected slope ration of the soil. Amount of wet eroded soil were measured from the bottom of the glass boxes. Comparison made between amount of erosion took place respective to the slope ratio.

(i) Based on the laboratory and field test results a suitable geometry, procedure were proposed for vetiver grass plantation at dykes. It covers vetiver collection system, transportation and storing system, site preparation, plantation spacing, watering, monitoring etc.

(j) Cost benefit analysis were conducted to compare the cost effectiveness of the proposed method with that commonly used. Unit price were taken from PWD rate schedule and local prices. Comparative costs of different types of bank or dyke protection were made to find the cost effective solution.

1.5 Organization of the Thesis

The complete research work for achieving the stated objectives is divided in number of chapters so that it becomes easier to understand the chronological development of the work. Briefly the contents of each chapter are presented below:

Chapter One describe the background of this study, objectives, methodology of the research. Finally the organization of the thesis is summarized in this chapter.

Chapter Two discusses the causes of slope failure, general technology for slope protection, biotechnology for slope protection, general features of coastal zone, past researches both in Bangladesh and abroad, available vegetation in coastal regions, vegetation by vetiver grass and vetiver system.

Selection of plant and study area for the research has been discussed in Chapter Three. Plant collection and storing procedure, test program both in field and laboratory are described here. Procedure for simulation study is also presented in this chapter.

Chapter Four contains detail study result of field trials of vetiver growth in study areas, physical and chemical properties of study area soil, case study of vetiver plantation on other two areas of Bangladesh, slope stability analysis of the slopes, cost comparison among the conventional methods, design methodology of the plantation. It also contains a detail guideline for vetiver plantation procedure to protect slope.

Chapter Five includes the conclusion of the plantation test over the trial areas and procedure for plantation at sloped area for best performance. It also discusses the limitation of this study and future recommendations.

Chapter Two

LITERATURE REVIEW

2.1 Introduction

Slope stability defines the stability of slope covered by soil mass. The inside balance of shear stress and strength determined the stability of soil slope. Stability of soil mass often disturbed naturally by rainfall, wave, turbulent water action, wind etc. to protect stability failure against these actions we use RC wall, CC blocks, geo-textile etc. But these are costly and hazardous and not very long lasting. Thus biotechnology comes to play a role here and plantation over the slope area to prevent the slip action is much more cost effective as well as climate resilient. This chapter deals with the effectiveness of plants over slope stability, technology as well as past researches done on this subject.

2.2 Causes of Erosion

As a country of river Bangladesh is facing several problems for it's road embankments. The design and construction methods used to build the embankments, the nature and extent of erosive forces to destabilize them and above all the attitude of the local people for whom they are built altogether determine the magnitude and degree of instability.

Most earthen embankments face light to moderate erosion problems arising out of rainfall splash, animal actions and the nature of human uses. Some of the critically positioned submerged types of embankment in haor areas of the eastern part and river embankments of the main land are subjected to turbulent water currents and changes in river courses. The problem is acute in offshore islands and coastal belts where the embankments are in addition exposed to erosion by sea waves and tidal fluctuation of water levels.

Erosion takes place mainly due to two types of reason: natural forces and human interferences (Arifuzzaman, 2011). These types of reasons are discussed in the following sections:

2.2.1 Natural Forces

Rainfall impact (from both the regular monsoon rains and torrential rains)

Mean annual rainfall varies from about 1736 mm in the northwest (Khulna district) (Source: http://en.climate-data.org/location/3943/) to over 3770 mm in the south (Cox's Bazar) (Source: http://en.climate-data.org/location/56253/). The heaviest rainfall occurs in July and ranges from 357 mm to over 1060 mm accordingly. The slope erosion caused by rain runoff is enormous and its speed/force grows exponentially towards the toe. Toe erosion is the combined effect of runoff and wave action. The main features of rainfall impact are:

(a) The embankment crest is mainly affected with the formation of ghoghs and initiation of piping action leading to collapses in combination with either.

(b) Surface runoff caused by rainfall results in sheet erosion and the formation of gullies and rills on poorly protected embankment shoulders, slopes and toes.

(c) Flooding (monsoon/periodic floods and those created by storms/cyclones).

(d) The high head of water on the river side induces piping across the embankment, which may lead to breaching and collapse of the polder system.

(e) Monsoon flooding often gives rise to serious erosion of embankments by undermining due to current, vortex and wave forces; the entire embankment gets affected, beginning with the damage of shoulders and crest due to undermining, and gradually the overtopping causes a complete wash down.

Wave action (daily/periodic and created by constant wind)

Wave force is also main cause of erosion of embankment, river bank type structures. Main features of wave actions are as follows:

(a) Tidal waves cause damage to the embankments located too near to the sea (the earthen embankments in the coastal zones should have adequate setback not allowing its exposure to wave actions). A severe hydraulic load is steadily exerted on the toes and slopes and causes erosion. Wave forces looses the bonding of the soils and thus it falls along the failure line.

(b) Cyclonic storms in the coastal zone (occurring repeatedly) act upon the water surface, causing it to advance towards the shore with enormous hydraulic loads. The waves thus formed eventually hit the embankment toe and slopes. The high hydraulic loads exerted on the embankment cause erosion and if there is overtopping, the physical structure of the embankment is destroyed.

Turbulent water currents (mainly in rivers and at coastlines)

Main features of turbulent water currents are as follows:

(a) The high velocity flow of water associated with vortex motion in rivers and estuaries often causes erosion of the banks by undermining, and the eventual collapse of the embankment threatens unless protective measures are taken.

(b) At the mouth of a branch river or canal, especially in the surroundings of sluice gates, the turbulent water current erodes the banks and subsequently the embankments.

(c) The presence of continuous borrow-pits on a river or seaside induces undercutting of the embankment toes and slopes due to complete inundation of the riverbank or seashore during the monsoon. The borrow-pits and adjoining lowlands thus inundated induce a parallel water current to flow along very near the embankment toes and slopes, thereby eroding the surfaces rapidly.

2.2.2 Human Interference

There are many diverse reason for erosion causes by human interference. The most commonly observed erosion problems out of the varied human uses are presented below:

Travel Paths for Men and Cattle

The people living around use the embankments as the main travel paths. The crests thus serve as a rural communication road between villages. Besides plying rickshaws, vans, bicycles and bullock carts, in many areas motorized vehicles also move regularly on these earthen embankments in the dry season. Movement of bullock carts in the rainy season inscribes deep path marks along the track which induce further decaying of the embankment crest by trapping of the rainwater inside.

The people and their cattle, while moving along the damaged crest, often tend to take a better alternative route along the shoulders, slopes and even toes. Gradually the shoulders and slopes are also affected.

Villagers frequently have to cross over the embankment to have direct access to the river or the sea to meet their various daily needs. The slopes of both the sides near such passages and boat-landing ghats erode continually. Also the bank and foreshore areas are destroyed due to frequent crossing of the embankment, thus inducing funnel action of the river or sea to advance towards the embankment, eroding toes and slopes. The movement of people on the embankment becomes more intense if the concentration of economic activities around and on the embankments is higher.

Homesteads and Agricultural Practices

Embankments often become the privileged sites for the construction of villages and isolated homesteads. This is mainly due to the fact that the embankments give the people a sentiment of security from flooding. Those who have lost their lands and properties due to river erosion or acquisition of land for development activities and practically have no shelter find no other way than to become squatters to live on the embankments. Also the poor and landless people who are marginal day laborers without any house to live in build their huts on the embankment slopes.

Very often, steep or very steep embankment slopes are cultivated with annual or biennial crops imposing regular soil tillage. By loosening the soil and denuding it, repeated soil tillage results in severe erosion. To obtain a gentler slope and to facilitate agricultural practices, the upper part of the embankment slope is cut and the earth is spread over the lower portion. Farmers usually plant banana and papaya on the shoulders and slopes. After their eviction or if these trees are cut down by them to harvest the crops, the roots are subjected to rapid decay, leaving root holes. The unmanaged cultivation of these species destabilizes the embankments. Thus if cultivation over the embankment can be managed in proper manner, protection and cultivation both can be achieved. Moreover root system would help attaching the soil particles together to act monolithically.

Agricultural practices on embankments are encouraged by:

(a) A high demographic pressure on the available land and accordingly a shortage of land for the rural population;

(b) Minimal land acquisition by the government brought about by high appropriation costs; as such, there is often no or insufficient provision to resettle people displaced by the construction of embankments; and

(c) A poor performance of routine maintenance activities for the embankments.

Cattle Grazing

Cattle, mainly belonging to people living on the embankment, cause erosion by uncontrolled browsing of natural grasses. When the embankment is overgrazed, plant species and the vegetative cover, especially the grasses, show retarded growth, weaken and cannot continue to ensure adequate protection of the embankment. The squatters, most of whom are poor and landless, prefer to keep goats as pet animals with their limited scope at the embankment homesteads. The grazing of goats is particularly harmful to the vegetative cover.

Slopes grazed by heavy cattle, mainly cows and buffaloes, often show a typical pattern of browsing tracks running more or less along the contours. These paths form unstable micro-terraces, where the upslope soil material is deposited at the lower side of the track and finally reaches the embankment toe in successive down-slope movements. The uncontrolled grazing of heavy cattle destroys the foreshore gardens and shrubs or bushes growing on the riverbanks, resulting in direct exposure of the embankment surfaces to wave action and water currents. The community people rarely feel it necessary to prevent their grazing animals from destroying the embankment slope vegetation because of their lack of knowledge on the importance of stable embankment as well as unscrupulous attitude of profiteering through grazing.

Public Cuts

Public cuts and tubes linking a river or seaside with the country side of its embankment are frequently observed. These cuts weaken the embankments, exposing them to slow but continual erosive forces. During flood or cyclonic storm, breaching or major erosion occurs at those points. The people mainly cut the embankments to fulfil their purposes:

(a) To get rid of the poor and inadequate drainage conditions of the existing structures, they arrange quick removal of excess floodwater from the polder area to the river or the sea. This is a failure of the planning and design end not to take care of this problem appropriately.

(b) They create temporary irrigation inlets for applying sweet river water to the cropping fields when there are prolonged droughts in the polder area. These problems arise due to a need of adequate people participation during planning and design of the embankment.

(c) For short-term economic purposes yielding individual-level benefits, sometimes people allow river or seawater to penetrate inside the polder for shrimp cultivation or any other fishing requirement or salt panning.

Unplanned Afforestation of Embankment Slopes

Afforestation without appropriate planning and management techniques destroys the undergrowth grass cover and becomes ineffective for erosion protection. In such cases, afforestation results in the weakening of the embankment without any substantial contribution to its stability.

However, a differing opinion on afforestation of embankment slopes stresses the need for plantation, provided grass cover is ensured and there is successive management in a most scientific way involving the local people so that appropriate routine maintenance is performed and healthy embankments are ensured.

Uncontrolled Animal Activity

Other animals than grazing cattle also cause erosion of embankments. Burrowing animals such as rats often seek shelter on the embankment during floods. Rat burrows and holes, cavities, tunnels, etc, dug by other animals like earthworms often cause substantial weakening of the embankment. Some rodents, for instance muskrats, are able to remove 0.5 to 1.0 m^3 soil per year to build cavities and chambers (Nazrul, 2000).

Improper Design and Construction Technique

In many cases the embankments are designed with insufficient setback, resulting in increased exposure to waves and current action. This may be due to the high costs involved in land acquisition. Sometimes the setback area is also eroded.

Furthermore, insufficient supervision during construction results in poor-quality earthworks with the use of inappropriate soil materials, insufficient or no clod breaking, inadequate compaction and no or insufficient laying of topsoil layers. Scouring holes and rills appear in no time after completion of the construction. In Bangladesh land accusation is very difficult as amount of left over land is very rare here. Thus government has to construct within a short area as well as short time which make these constructions vulnerable to erosion and slide.

2.3 Causes of Slope Failure

Slope failure could be happen due to several reasons. Each slope is different when it comes to geology, soil composition, vegetation and a myriad other factors. Consequently, for any slope repair strategy to effectively mitigate the threat of landslides and mudslides, it should be tailor-fit to the slope on which it is to be applied and the causes underlying the instability of such slope.

Here are some of the common causes of slope failure:

1.6 **Steepness of the Slope**

It goes without saying that the steeper a slope is, the more unstable it will be. It's true for making sand castles and it's true for making hillside homes. The natural tendency of steep slopes is to move some of its materials downwards until the natural angle of repose is found. Any form of slope modification, whether it be through natural means such as a stream undercutting the banks of a river or by workers removing a section of the slope's base to build roads, will impact the stability of a slope. In Bangladesh, uncontrolled cutting of earth from hill side impact the stability of slope.

1.7 **Water and Drainage**

Water is several times heavier than air. During heavy rains when the soil becomes saturated and water takes the place of air between the grains of soil, the earth in slopes becomes a lot heavier.

This becomes a problem when the earth is being held back by a retaining wall at its base. Specifically, if the weight of the earth behind the retaining wall exceeds the retaining wall's structural capacity, the retaining wall will buckle and collapse releasing the earth behind it in a catastrophic deluge.

Water also reduces grain-to-grain contact which, in turn, reduces cohesiveness and the soil's angle of repose. Along with changes in the groundwater fluid pressure in slope rocks during the rainy season, water saturation by itself already increases the probability of downslope mass movement.

1.8 Soil Composition

The composition of the slope's soil is a very important consideration when it comes to mitigating slope failure. Different types of soils will have very different characteristics when it comes to frictional resistance to erosion and cohesion among the grains. Loose soil or sand, for example, has very low cohesion and will easily erode when saturated with water. Soils that have a large amount of clay, on the other hand, tend to expand when exposed to water; this makes them heavier and more prone to movement. Usually small grain sand is used for embankment construction in Bangladesh. If compaction not done properly, slope failure take place due to loose cohesion among the particles. Sometimes, clay type soil toppings are used to protect the top surface of sandy embankment.

Uncovered Slope

The amount and type of vegetation found in a slope is also proportional to the strength of that slope. Vegetation, specifically its roots, holds the soil in place and makes it more resistant to erosion. The bigger the size of vegetation, the more widespread its roots are and the more it is able to hold the soil in place. The more vegetation there is, moreover, the more stable the slope is likely to be. This is the reason why slopes that have had their vegetation removed or razed by bush fires are prime candidates for slope failures during the rainy season.

Bedding Planes

A bedding plane is basically a surface that separates a layer of stratified rock or bed from another. Think of it as butter spread between two slices of bread. Because of their nature, exposed beds in a slope are also at a high risk of slope failure. This is risk is exacerbated if there is a weak layer of rock sandwiched in the bed.

To illustrate, imagine placing a panel of glass on a slide and a block of wood on top of it. The contact surfaces between the slide, the glass and the wood are bedding planes angled downwards. Even though the frictional force keeping the block of wood on the glass is strong, the glass-slide connection is weak, and this causes the whole structure to erode downwards.

1.9 **Joints and Fractures**

Joints and fractures are natural cracks in the rocks forming a slope. These are caused by the natural expansion of rocks due to cooling or the removal of overlying rocks due to erosion. Because of these cracks, the cohesion between the rocks that make up the slope is greatly reduced, increasing the likelihood of a landslide in the slope. In recent time, Bangladesh is facing land slide problem in hill area of Chittagong. Excessive rain and fractures in bed rock is the main causes of these landslides.

Sudden Shocks

Lastly, sudden shocks like earthquakes, hurricanes, volcanic eruptions, the passage of heavy trucks, blasting, and others may trigger the sudden mass movement of the soil in slopes.

2.4 General Technology for Slope Protection

There are several methods available for slope protection worldwide. In Bangladesh use of RC Wall at the bottom of the slope, driven cantilever wall, reinforced earth wall, CC block, geo-textile over the slope are very common to stabilize the slope. Figure 2.1 shows different slope protection methods used around us which consists driven cantilever wall, reinforced earth wall, RCC wall etc. and these are very useful for protecting large amount of soil at a time. On the other hand Figures 2.2, 2.3 and 2.4 shows some conventional slope protection methods used in Bangladesh by local government engineering department and roads and highways department. Figure 2.5 shows some conventional application view of cc block with vegetation and use of geotextile over embankment slope. Currently these methods are widely used in Bangladesh in rural and urban areas.

These protection measures are costly in nature and time consuming. More over some of these are vulnerable to saline water.

2.5 Biotechnology for Slope Protection

Now a days global warming is a big issue for our world and Bangladesh is in most vulnerable position. Thus, slope protection methodology turns into climate resilient options for better results. Vegetation is one of the methods for slope protection. It is easy

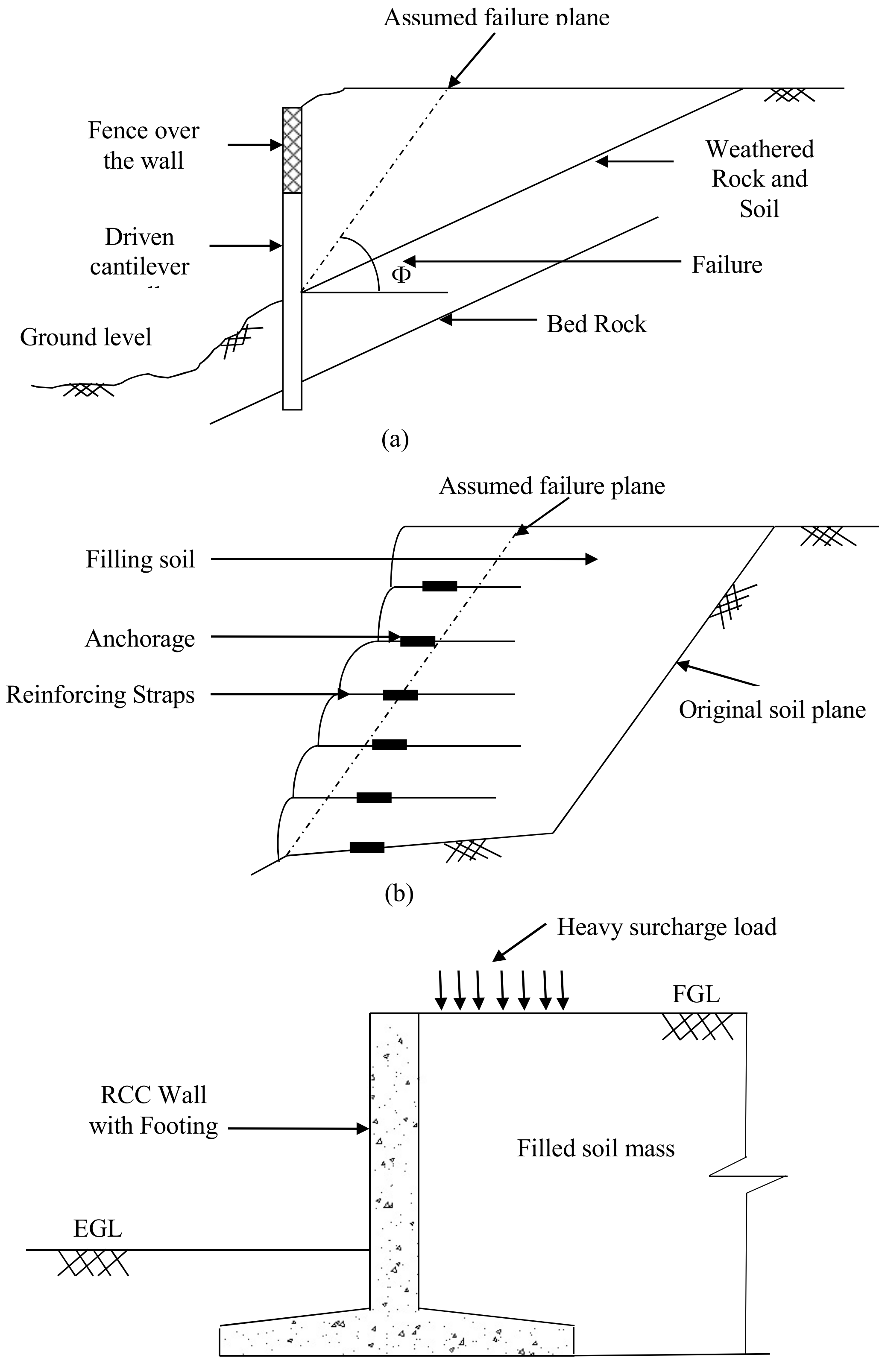


Figure 2.1 Different slope protection method (a) driven cantilever wall; (b) reinforced earth wall; (c) RC Wall with footing.

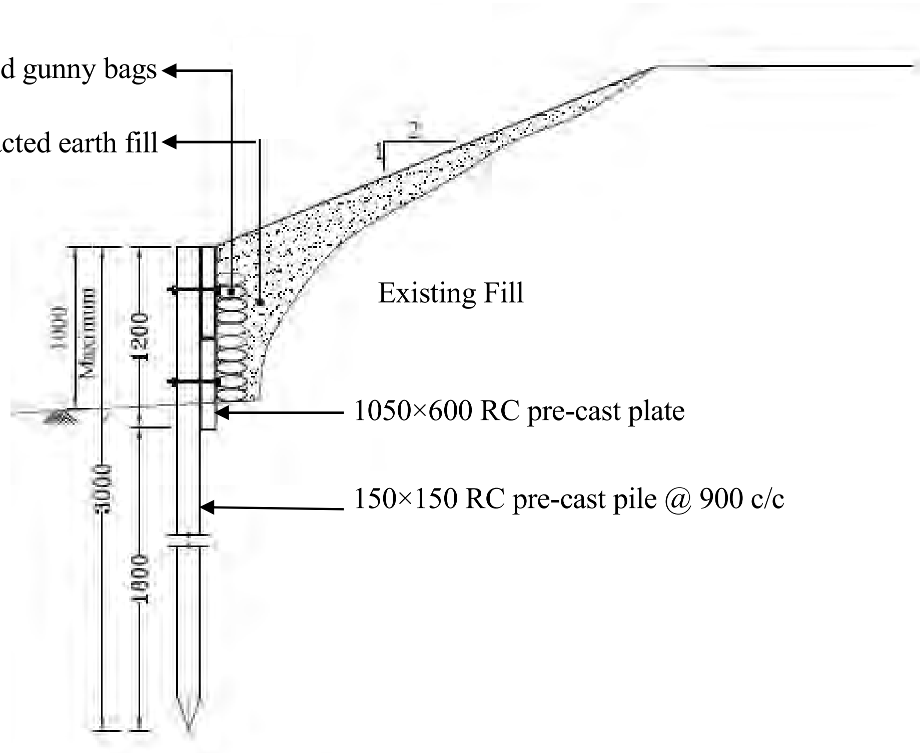


Figure 2.2 Conventional slope protection using CC block and palisading (Road Design Standards, LGED, 2005)

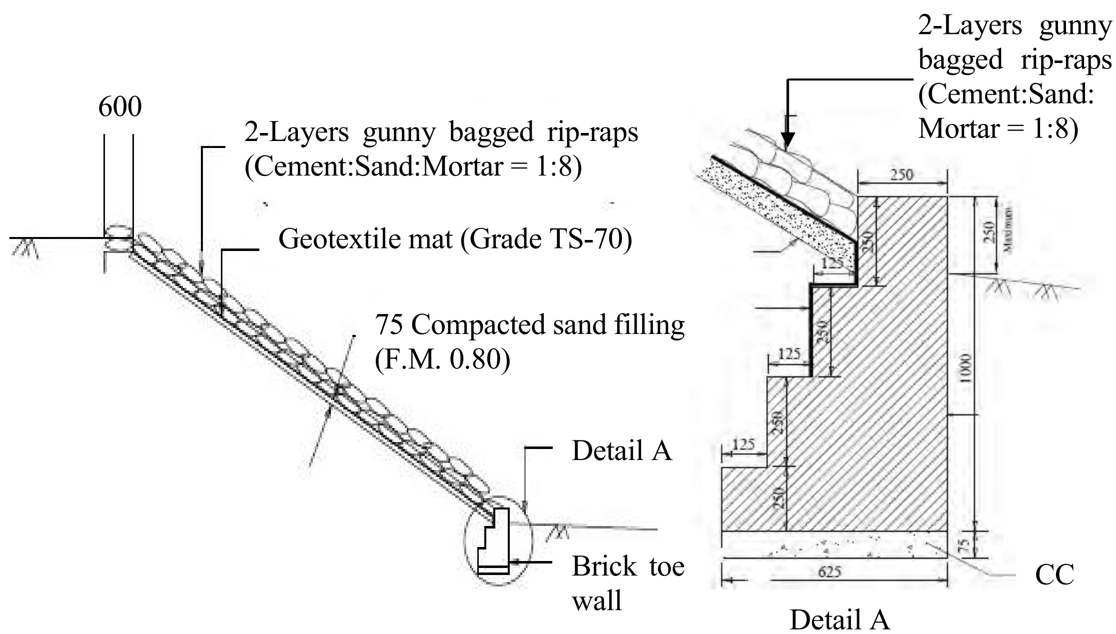
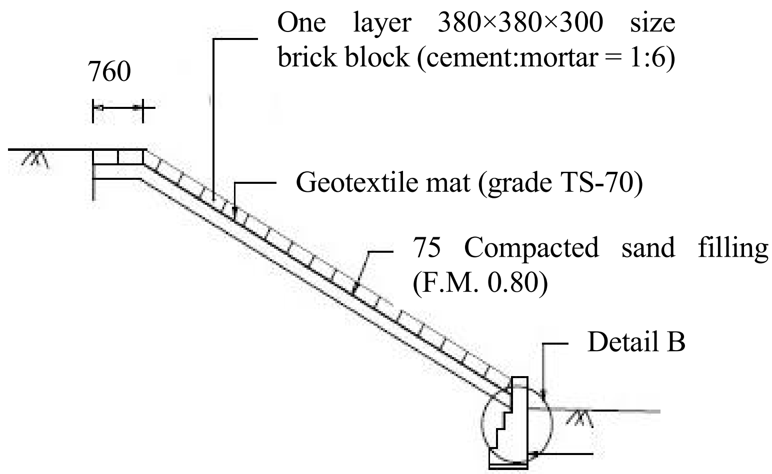
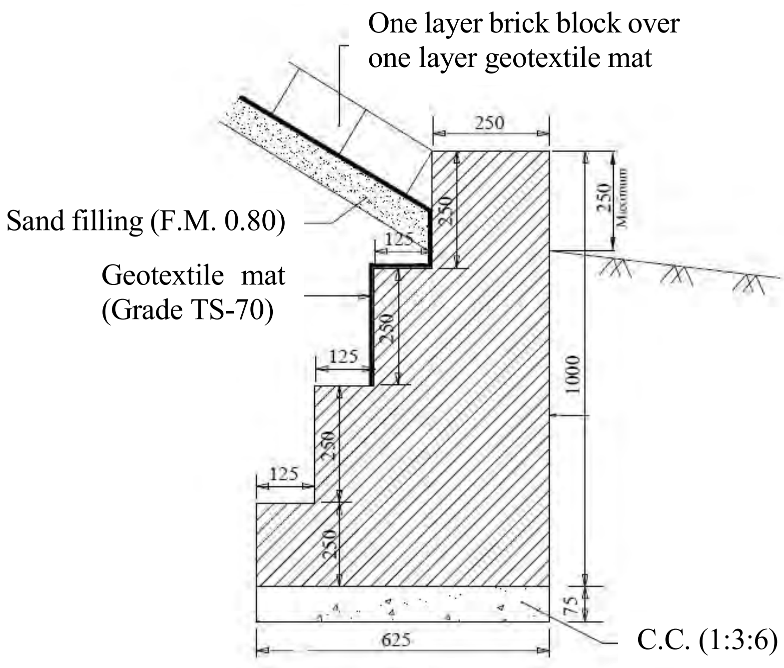


Figure 2.3 Conventional slope protection using brick toe with gunny bags and geotextile (Road Design Standards, LGED, 2005)





Detail B

Figure 2.4 Conventional slope protection brick toe with brick blocks and geotextile over the slope (Road Design Standards, LGED, 2005)

(a)

(b)

Figure 2.5 View of conventional slope protection methods in Bangladesh (a) CC block with vegetation; (b) geotextile over the embankment.

to grow but very effective in local applications. Use of vegetation for stability of slopes are described below. It also covers the effect of soil mass and roots of vegetation in slope stability.

2.5.1 Role of Vegetation in the Stability of Slopes

Surficial and mass stability greatly affected by the vegetation present over the slope (Ziemer, 1981). Type of vegetation and type of slope degradation process are the determinants of protective benefits of vegetation. In the case of mass stability, the protective benefits of woody vegetation range from mechanical and restraint by the roots and stems to modification of slope hydrology as a result of soil moisture extraction via evapotranspiration.

Vegetation has beneficial influence on the stability of slopes; however, it can occasionally affect stability adversely or have other undesirable impacts; for example, it can obstruct views, hinder slope inspection or interface with floor fighting operation on leaves.

It is very important to make right choice to vegetation for slope stability. A tight, dense cover of grass or herbaceous vegetation, e.g., provides one of the best protections against surficial rainfall and wind erosion. On the other hand, deep rooted, woody vegetation is more effective for mitigating or preventing shallow, mass stability failures. In a sense, soil bioengineering and biotechnical methods also can views as strategies or procedures for minimizing the liabilities of vegetation while capitalizing on it's benefits.

2.5.2 Influence on Slope Mass Protection

Vegetation has great effect on stabilizing mass of a sloped area (Ali, 2010). The main beneficial effects of woody vegetation on the mass stability of slopes are as follows:

(a) Root reinforcement: Roots mechanically reinforce a soil by transfer of shear in the soil to tensile resistance in the roots.

(b) Soil Moisture Depletion: Evapotranspiration and inspection in the foliage can limit build-up of positive pore water pressure.

(c) Buttressing and Archiving: Anchored and embedded stems can act as buttress piles or arch abutments to counteract downslope shear force.

(d) Surcharge: Weight of vegetation can, in certain instances, increase stability via increased confining (normal) stress on the failure surface.

The most obvious way in which woody vegetation enhances mass stability is via root reinforcement. Extensive laboratory studies (Gray and Ohashi, 1983) on fiber reinforced sands indicate that small amounts of fiber can provide substantial increases in shear strength. In addition, evapotranspiration by vegetation can reduce pore water pressure within the soil mantle on natural slopes, promoting stability (Brenner, 1973). The primary detrimental influence on mass stability associated with woody vegetation appears to be the concern loading and the danger of overturning or uprooting in high winds or currents (Tschantz and Weaver, 1988). This problem is likely to be critical for large trees growing on relatively small dams, levees or stream banks.

2.5.3 Analysis of the Role of Vegetation in Slope Stability

Slope stability is evaluated by the factor of safety (FS) which is defined as the ratio of resistance of the soil mass to shear along a potential slip plane to the shear force acting on that plane. Soil failures occurs when the ratio falls to unity.

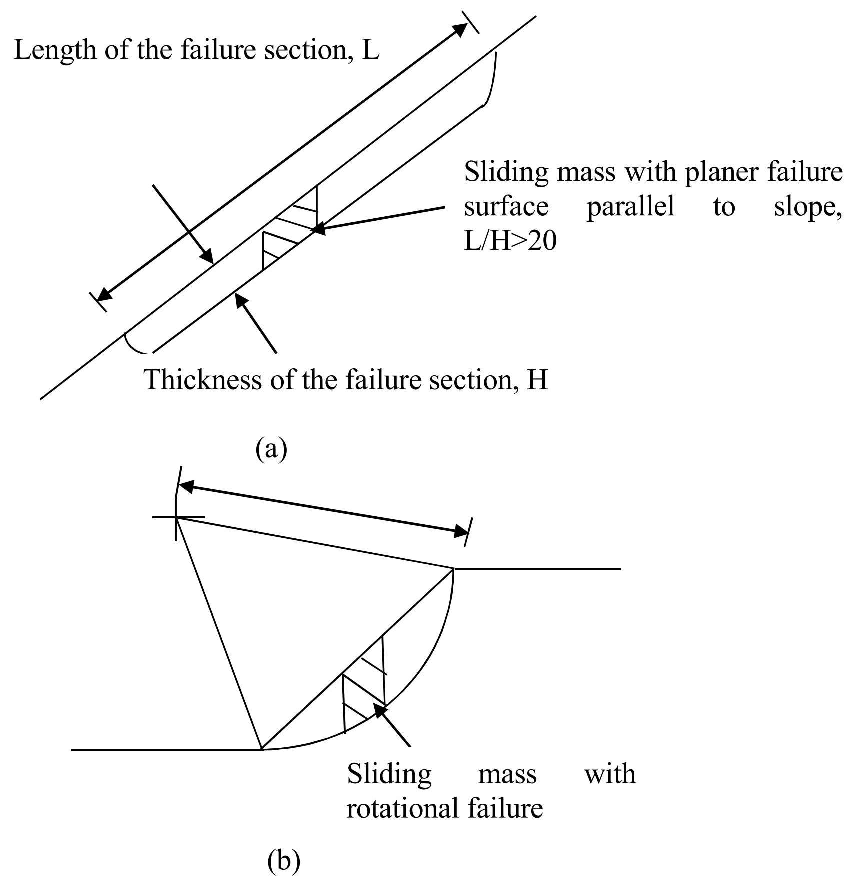


Figure 2.6 Mechanics of slope stability analysis; a) transitional failure; b) rotational failure, circular arc model (after Gray and Sotir, 1996)

The simple case of a transitional failure along a sliding surface parallel to the ground over a relatively long uniform slope can be analyzed by infinite slope analysis. In this case, a single element or segment (Figure 2.6) of the slope can be considered as representative of the whole and the head and top portions of the slope are ignored as being negligible in extent.

Using effective stress analysis, the factor of safety without vegetation can be defined by:

$$FS = \frac{c' + (\gamma z - \gamma w\, hw)\cos^2 \beta \ \tan \emptyset'}{\gamma z \sin \beta \ \cos \beta}$$

Where,

c′= effective soil cohesion, kN/m^3

γ = unit weight of soil, kN/m^3

z = vertical height of soil above slip plane, m

β = slope angle, degrees

γ_w = unit weight of water

h_w = vertical height of ground water table above slip plane, m and

ϕ = effective angle of friction of the soil, degrees

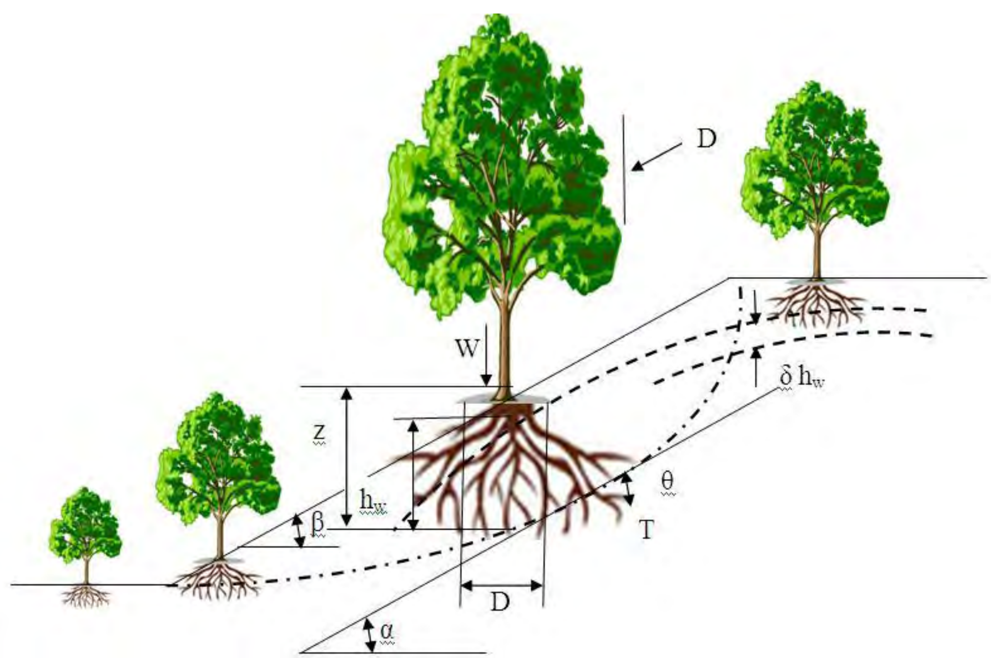


Figure 2.7 Influence of vegetation on slope stability (after Coppin and Richards, 1990) (Reproduced)

On the other hand using effective stress analysis, the factor of safety with vegetation can be defined by:

$$FS = \frac{(c' + c'R) + [\{(\gamma z - \gamma w\ hw) + W\} \cos^2 \beta + T \sin \theta]\ \tan \emptyset' + T\ cos\theta}{\{(\gamma z + W) \sin \beta + D\} \cos \beta}$$

Where,

- c' = Effective Soil Cohesion, kN/m^2
- γ = Unit weight of soil, kN/m^3
- z = Vertical height of soil above slip plane, m
- β = Slope angle, degrees
- γ_w = Unit weight of water, kN/m^3
- h_w = Vertical height of ground water table above slip plane, m
- ϕ' = Effective angle of internal friction of the soil
- c'_R = Enhanced effective soil cohesion due to soil reinforcement by roots, kN/m^2
- W = Surcharge due to weight of vegetation, kN/m^2
- h_v = Vertical height of ground water 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
- D = Wind loading force parallel to the slope, kN/m

Figure 2.7 shows the main influences of vegetation over factor of safety of slope stability. Here, c' is the effective soil cohesion in natural condition. But, c'_R is the enhanced cohesion due to addition of roots which acts as reinforcement in the soil. It is found that effective soil cohesion could be enhanced up to 33% to 55% depending on the other parameters (Nasrin, 2013). "T" is the tensile strength acting on the base of slip plane due to presence of roots from vegetation. θ is the angle between roots and slip plane when roots become longer. And "D" is the wind load which act parallel to the slope. Based on different values at different conditions of these parameters, factor of safety has been calculated for slope with presence of vegetation. During factor of safety calculation it has been considered that, for different slopes other factors remain same but change in the physical properties of soil. Effect of water were considered as standard stagnant water height during cultivation period.

2.5.4 Root Morphology and Strength

The root length and the type of root branching effects the way that root failure occurs. Three different modes of failure have been identified in hawthorn roots which relate to the root soil relationship which is shown in the shape of the roots and the shape of the failure curve. Roots which have no branches tend to fail in tension and pull straight out of the ground with minimal resistance. Roots which have multiple branches generally fail in stages as each branch breaks inside the soil. These roots can then separated into two different groups; 1) those that initially reach their maximum peak force and then maintain a high force that progressively decreases as the root branches fail after significant strain and 2) those that break with increasingly applied force. In a number of tests considerable adhesion between a segment of the root and the soil can be measured prior to the root eventually slipping out of the soil mass (Wikipedia).

Failure Type A (roots without branch)

Roots that do not have branches generally 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.

Failure Type B (roots with branch at peak resistance)

Type B failure occurs when branched roots initially reach their maximum peak resistance then sustain a high resistance which slowly reduces as the branches of the roots fail after significant strain. In some tests considerable adhesion between a section of the root and the soil mass can be measured before the root eventually slips out. Forked roots require a greater force to be pulled out as the cavity above the fork is thinner than the root which is trying to move through the cavity, this can then result in deformation of the soil as the root moves through the soil. Curving nature of roots also help soil improving bonding with soil. When this curvy roots also slips due to reaching in ultimate resistance power failure of slopes may happen.

Failure Type C (roots with multiple branches)

Roots that 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 there is no further interaction with soil and therefore no increase in soil strength is provided.

Root Growth Across Failure Planes

When roots grow across the plane of potential failure there is an increase in shear strength by binding particles. The roots anchor the unstable surficial soil into the deeper stable layers or bedrock. This most readily occurs when there is rapid deep growth (1.5m deep) of roots which last for more than two years. However it is important to note that the strength exerted by roots generally only extends down to 1m while most failures occur between 1.2 – 1.5m soil depth (Wikipedia).

Root Reinforcement Model

The root reinforced earth root model is the result of the root elongation across a potential slip plane which produces a tensile root force which is transferred to the soil by cohesive and frictional contacts between the root and the soil.

Tensile Strength and Pull Out Resistance

The pull out resistance of a root is the measured resistance of root structure to be pulled out of the ground and is likely to be only a little less than the measured tensile strength of the root which is the roots resistance to breaking as measured in the laboratory. In the cases where there is no pull out data available the tensile strength data may be used as a rough guide to the maximum pull out resistance available.

The tensile root strength of a range of diameters over a range of species has been tested in the laboratory and has been found to be approximately 5 – 75 MPa for 0.7 to 0.8 mm root diameter (Hengchaovanich. D. et al., 1996). In order for the root to actually enhance slope stability the root must have sufficient embedment and adhesion with the soil. The way that roots interact with the soil is intricate but for engineering purposes the available force contributions may be measured with in situ pull out tests. Root of vetiver grass are very strong in tensile force. It can provide up to 75 MPa of tensile strength (Hengchaovanich. D. et al., 1996).

Factors Affecting Root Pull Out Resistance of Root

Studies have shown that the pull out resistance of hawthorn and oak roots are affected by intra species differences, inter-species variations and root size (diameter) in a similar as way as root tensile strength varies (as measured in the laboratory). In the pull out test the applied force acting on the root acts across a larger root area, which involves multiple branches, longer lengths) than the short (approximately 150mm) length of root used in tensile strength tests. In pull out test the root is likely to fail at weak points such as branching points, nodes or damaged areas.

The studies also showed that there is a positive correlation between maximum root pull out resistance and root diameter for hawthorn and oat root. Smaller diameter roots had a lower pull out resistance or breaking force than the larger diameter roots.

Root Columns Acting as Piles

Trees and root columns can prevent shallow mass movement through acting as piles when there is buttressing and soil arching through a woody deep root system which has multiple sinker roots with embedded stems and laterals.

Controlling of Surface Erosion

Vegetation can also be used to control water erosion by limiting surface processes such as sheet wash and overland flow. Vegetation can provide a considerable contribution to the stability of slope through enhancing soil cohesion. This cohesion is dependent upon the morphological characteristics of root systems and the tensile strength of single roots.

There is considerable evidence of fine roots resisting surface erosion. The role of fine roots in general slope stability is not fully understood. It is thought that the fine roots help keep the surface soil together and prevent surface erosion. The fine root network may have an apparent enhanced cohesion which is comparable to geo-synthetic mesh elements. The limitation of surface erosion processes is particularly apparent in areas of shrub and grass where the fine root distribution is consistent and clearly defined, however cohesion is generally limited to the top 1m of soil. Root system of vegetation like vetiver can make up to 3 meters of fine roots below the soil surface (Source: www.vetiver.org/discus/messages/11/FactSheet_L34_Mar_02-862.pdf).

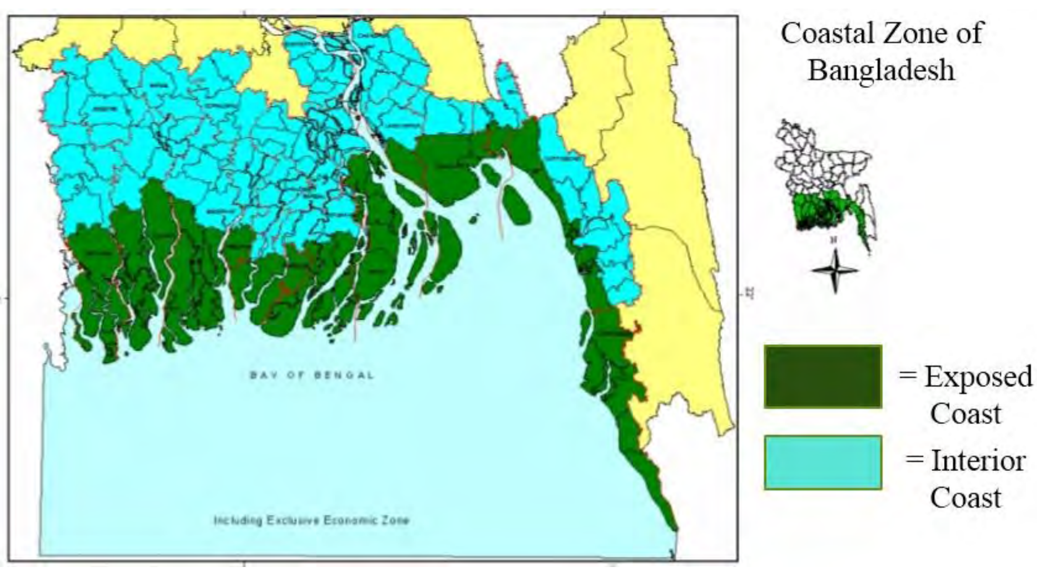


Figure 2.8 Coastal zone of Bangladesh (Source: Islam, 2004).

2.6 General Features of Coastal Zone

Salinity causes unfavorable environment and hydrological situation that restrict normal crop production throughout the year. The freshly deposited alluviums from upstream in the coastal areas of Bangladesh become saline as it comes in contact with the sea water and continues to be inundated during high tides and ingress of sea water through creeks. Figure 2.8 shows the coastal zone of Bangladesh which is shows as exposed coast and interior coast based on the location from Bay of Bengal. The factors which contribute significantly to the development of saline soils are, tidal flooding during wet season

(June-October), direct inundation by saline or brackish water and upward or lateral movement of saline ground water during dry season (November-May).

Observations in the recent past indicated that due to increasing degree of salinity of some areas and expansion of salt affected area as a cause of further intrusion of saline water, normal crop production becomes more restricted. In general, soil salinity is believed to be mainly responsible for low land use as well as cropping intensity in the area (Rahman & Ahsan, 2001). Salinity in the country received very little attention in the past. Increased pressure of growing population demand more food. Thus it has become increasingly important to explore the possibilities of increasing the potential of these (saline) lands for increased production of crops. It necessitates an appraisal of the present state of land areas affected by salinity.

2.6.1 Physiography of the Coastal Area

Tidal and estuarine floodplains cover almost 98% of the coastal area. Small areas (2%) with river floodplains and peat basins are found in the northern part of the coastal area. Tidal floodplains occur in Satkhira, Khulna, Bagerhat, Pirozpur, Jhalukhati, Barisal, Patuakhali, Chittagong and Cox's Bazar district. They cover a total of 18,65,000 ha or about 65% of the coastal area. Estuarine floodplains occur in Noakhali, Bhola and Patuakhali districts and in the north-western part of Chittagong district. They cover about 9,37,000 ha or about 33% of the coastal area (Haque, 2006).

2.6.2 Land Characteristics and Hydrology of the Coastal Region

The coastal saline area lies about 1.5 to 11.8 meters above the mean sea level. The Ganges river meander floodplain systems are standing higher than the adjoining tidal lands. The tidal floodplain has a distinctive, almost level landscape crossed by innumerable interconnecting tidal rivers and creeks. The estuarine islands are constantly changing shape and position as a result of river erosion and new alluvial deposition. Peat basins are located in some of the lowlying areas between the Ganges river floodplains and tidal floodplains occurring in the western part of Khulna (Karim *et al.*, 1982). These areas are subject to flooding in the monsoon season and waterlogging in parts of the basin areas in the dry season. Tidal flooding through a network of tidal creeks and drainage channels connected to the main river system inundates the soil and impregnates them with soluble salts thereby rendering both the top and subsoil saline. The most significant feature of hydrology in relation to agricultural development is the seasonal shallow flooding (up to 90 cm) which affects about 64% of the total area. In these areas flood water recedes from October to late December. Depending on topographical position and drainage facilities, water recede from about 24% area within October, from about 53% area in November and mid-December and from about 23% area in late December (Haque, 2006).

2.6.3 Tidal Effect

The effect of the tides is manifested in a regular alternation of rise and fall of the water level of the sea and the estuarine/tidal channels and creeks. The flow repeatedly inundates the soils and impregnates them with soluble salts, thereby rendering the soils and subsoil water saline. The high tide during summer rises up to 1.3 meter above the general ground level. On the east coast of the Sunderbans, the highest tidecould inundate lands up to a depth of 2.0 meter, where protective bunds were not erected.

2.6.4 Salinity Built-up

The main obstacle to intensification of crop production in the coastal areas is seasonally high content of salts in the root zone of the soil. The salts enter inland through rivers and channels, especially during the latter part of the dry (winter) season, when the downstream flow of fresh water becomes very low. During this period, the salinity of the river water increases. The salts enter the soil by flooding with saline river water or by seepage from the rivers, and the salts become concentrated in the surface layers through evaporation. The saline river water may also cause an increase in salinity of the ground water and make it unsuitable for irrigation. The increase in water salinity of these areas has created suitable habitat for shrimp cultivation. Along with other factors, shrimp cultivation played a major role to increase salinity, particularly in the southwestern coastal regions. In greater Khulna alone, about 31,200 ha of land in 1982-1983 and about 94,850 ha of land in 1993-1994 were brought under shrimp cultivation.

2.6.5 Extent of Salinity

Coastal saline soils occur in the river deltas along the sea coast, a few kilometers to 180 kilometers. The landscapes are low-lying land, estuaries and inland along the seacoast of Bangladesh. According to salinity survey findings and salinity monitoring information, about 1.02 million ha (about 70%) of the cultivated lands are affected by varying degrees of soil salinity (Haque, 2006). About 0.282, 0.297, 0.191, 0.450 and 0.087 million hectares of lands are affected by very slight (S1), slight (S2), moderate strong (S3) and very strong (S4) salinity respectively. Table 2.1 shows salinity affected areas in the coastal and offshore regions of Bangladesh at a glance. Cropping intensity may be increased in very slight and slightly alkaline areas by adopting proper soil and water management practices with introduction of salt tolerant varieties of different crops. To mitigate the demand of fresh water for irrigation, especial emphasis may be given to adopt rain water harvest technology.

Table 2.1: Salinity affected areas in the coastal and offshore regions of Bangladesh (Source: Soil salinity in Bangladesh (SRDI), 2000)

Description	**Total cultivated area (ha)**	**Saline area**	**Area of each salinity class (ha) (dS/m)**				
			S1 (2.0 - 4.0)	S2 (4.1-8.0)	S3 (8.1-12.0)	S4 (12.1-16.0)	S5 (>16.0)
Non-saline with very slightly saline	425490	115370 (27%)	82260 (72%)	31590 (27%)	1520 (1%)	0	0
Very slightly saline with slightly saline	420420	309190 (73%)	170380 (55%)	110390 (35%)	29420 (10%)	0	0
Slightly saline with moderately saline	257270	240220 (93%)	35490 (15%)	113890 (47%)	61240 (26%)	25870 (11%)	2650 (1%)
Moderately saline with strongly saline	198890	198890 (100%)	1630 (1%)	36060 (18%)	73400 (37%)	55130 (28%)	32750 (16%)

Note: S1 = Very slight salinity; S2 = Slight salinity; S3 = Moderate salinity; S4 = Strong salinity and S5 = Very strong salinity.

2.7 Past Researches

Vetiver grass is used for many purposes like slope stability, soil erosion, agriculture improvement, disaster mitigation, prevention and treatment of contaminated water and land etc. Many researches have been conducted in home and abroad to know the propagation of vetiver, performance of vetiver grass against climatic change, slope protection, embankment protection, soil erosion control etc. A few research papers relevant to this thesis are presented here.

2.7.1 Researches Conducted in Abroad

The vetiver network international (TVNI) is an international NGO, with members in over 100 countries promoting the worldwide use of the vetiver system (VS) for a sustainable environment particularly in relation to land and water. This network tries to establish the vetiver as a biotechnical solution for slope stability, soil erosion, agriculture improvement, disaster mitigation, prevention and treatment of contaminated land and water etc.

Hengehaovanich et al. (1996) studied the strength properties of vetiver grass roots in relation to slope stabilization. They observed that the tensile strength of vetiver roots is as strong as, or even stronger, than of many hardwoods. In fact, it is better than many types of trees because of it's long (2.0 to 3.5m) and massive root networks which are also very fast-growing and essential for embankment stabilization. He observed the strength vs. diameter curve of vetiver root and found that, the strength derived from 0.66 mm diameter is about 80 MPa. According to his observation he mentioned that the high mean tensile strength of vetiver root is 75 MPa or approximately 1/6th of strength of mild steel.

Carey (2000) and Chomchalow (2003) showed the different techniques of vetiver propagation by using different parts, ground propagation and given planting and maintenance tips. The suggested cutting the tops of the vetiver slips to 200 mm length and the roots to 50 mm and fertilize by sprinkling each pot with approximately 5 g of DAP (di-ammonium phosphate). They also suggested plant well-rooted slips or bare root plants 150 to 200 mm apart to ensure a close hedge within 12 months of planting.

Truong et al. (2002) worked with growing of vetiver under saline condition. It was found that vetiver can grow under extreme saline condition and particularly effective where saline high water table is the causal effect. In his study, it was found that vetiver even can grow in very high saline soil who's EC was as high as 31.8 dsm^{-1}. Figure 2.9 shows effect of salinity on growth of vetiver grass. It clearly represents the less growth of vetiver with the increase of salinity. This test were performed in a salinity range of 14.9 to 31.8 dsm^{-1} and vetiver survived, where we found maximum 12.37 dsm^{-1} in Bashkhali area. Thus vetiver could also survived in saline zone of Bangladesh. Truong also found that it can also be used for soil and water conservation, and sediment control particularly where gully and stream bank erosion is a problem.

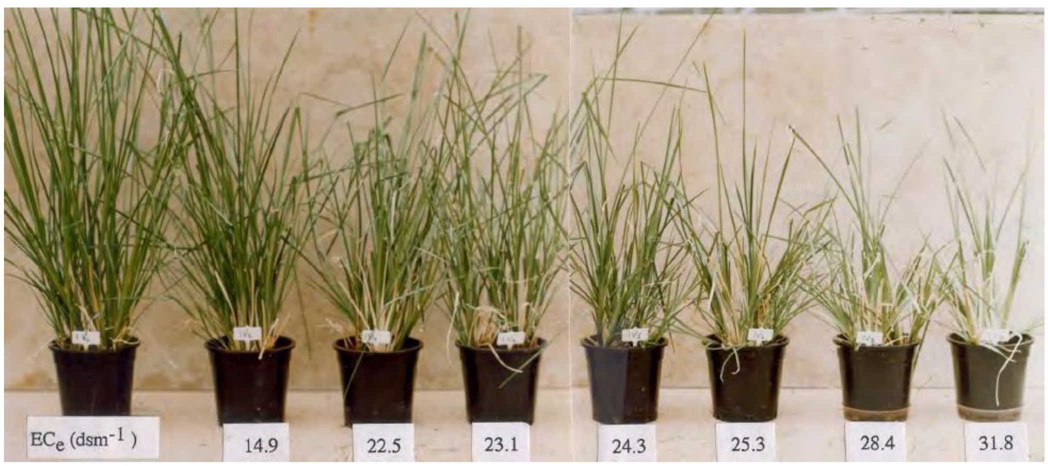


Figure 2.9 Influence of salinity on vetiver grass (after Truong et al., 2002)

Ke et al. (2003) tested vetiver as a protection measure on several test sites (in Australia, China, Philippines and Vietnam). Their tests showed promising results for the use of vetiver grass as a bank protection measure.

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

Troung et al. (2007) explained the differences between species of vetiver, four common ways (splitting mature tillers from vetiver clump or mother plants, using various parts of a mother vetiver plant, bud multiplication and tissue culture) to propagate vetiver and applications of vetiver.

Verhagen et al. (2008) conducted different laboratory and model tests on influence of soil type and phreatic level on vetiver grass, effect of vetiver grass against protection of bank due to vessel-induced load and use of vetiver grass as an armour layer on a dyke under wave attack. They found that, growth rate of vetiver grass in non-cohesive soil is 40-50% higher than cohesive soil. It was also found that, growth rate of root is high in low ground water level rather than water close to root itself. Beside this, model experiment showed that, vetiver grass in river bank with cohesive soil could reduce erosion up to 8-10 times than without having any vetiver on that river bank. Another experiment performed by Verhagen et al. (2008) upon use of vetiver grass as run-up reducer showed that, single layer of hedge of vetiver grass could reduce run up volume by 55%. Use of multiple layer of vetiver grass in row pattern along the dyke would reduce run up volume significantly more than 55%. Thus vetiver was found sustainable and innovative solution for protecting dykes of coastal region as vetiver was able to establish a full stop of bank erosion caused by rapid downtown.

James et al. (2011) evaluated the method to mitigate erosion due to plunging water by strengthening the soil with ground modification. They used vetiver plant and polyhedral Oligomeric Silsesquioxanes (POSS) as ground modifiers used in this test and showed that both POSS and the vetiver were effective in reducing erosion. But vetiver showed higher resistance to erosion by plunging water, but required time to achieve a well established root/stem system.

2.7.2 Researches Conducted in Bangladesh

Few researches have also been conducted in Bangladesh on vetiver in last 10 years. Recently some research works are conducted at BUET. Some of these researches are briefly discussed as below.

Rahman et al. (1996a) survey on vetiver grass in Bangladesh. The survey records information on the ecological distribution, morphological variation and the use of vetiver grass. They collected vetiver grass from many districts of Bangladesh and found mainly one species of vetiver that is *Vetiveria zizaniodes* by microscopically analysis of flowering material and DNA fingerprinting. They found that, it is able to survive in submerge condition for 3 to 4 months a year during monsoon and it could be spread from seeds. They also found that vetiver grass does not survive in saline zone. They showed various socio economic, cultural and many other uses of vetiver grass in Bangladesh like forage, thatch and roofing materials, fire wood, raw materials in cottage industry, an ingredient of medicine, soil stabilizer etc. they suggested to use that vetiver grass as road protection, protection for irrigation channels, water dams, to stabilize waste land and to use as an ingredient of paper and perfume manufactured.

Rahman et al. (1996b) also showed that vetiver could grow in highly acidic (pH: 4) and alkaline (pH: 8) soil. It can withstand climatic change. It can grow on sites where annual rainfall ranges from 200 to 5000 mm.

Work on erosion control in cultivated land had been conducted by Bangladesh Water Development Board (BWDB) in available places in Bangladesh (Thomas et al., 2002). They found that vetiver is very common about 40% (in the division of Chittagong, Dhaka and Rajshahi) of the total land area of Bangladesh and common in the Khulna, Sylhet Division and other parts of Bangladesh which is about 45% of the total land area of Bangladesh. There are some districts of Bangladesh like Barguna, Bagerhat, Bhola, Jamalpur, Pirojpur and Shatkhira where vetiver is rare and about 15% of the total area of Bangladesh.

Islam (2003) worked on the performance of vetiver grass over the coastal polders around eighty seven kilometers of earthen coastal embankment of Bangladesh during 2000 to 2001. It was observed that, main problem behind maintain those earthen embankments are water borne erosion. Causes of these are both surface runoff and wave action. Human and animal interferences, seasonal variations in soil moisture content and coastal peculiarities like changing sea water level, salinity, threat of washing away by cyclones or tidal surges etc. also affect the performance of vetiver grass.

Moula et al. (2008) studied on the nursery performance of vetiver grass from June 2000 to June 2001 with different number of tillers. Optimum numbers of tillers had been investigated per clump for the better propagation of vetiver grass. He 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) was 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 the double tillers. According to this observation, it is revealed that propagation of vetiver clump was found with the double tillers is better than single and triple tillers.

Huq (2010) studied on types of vetiver grass in Bangladesh and their propagation in different soil and climatic condition. According to his observation, five types of vetiver grass like Bennashoba (vetiver), KhusKhus (Vetiveria zizanioides), Gondhabena (vetiver), Ecorban (vetiver), Vetiveria zizanioides (dwaf ecotype) are available in Bangladesh and able to propagate in our soil and climate condition.

Islam and Arifuzzaman, (2011) developed a device to determine the in-situ shear strength of the vetiver rooted soil matrix for silty and sandy soil in coastal zone. They tested block samples (approx.. 29×15×19 cm^3) at different depths under different normal loads at the field to know the in-situ shear strength of vetiver rooted soil matrix. They found that for a particular normal stress the shear strength of vetiver rooted soil is 87% higher than that of a bared soil. Again, the failure strain is 770% higher than that of bared soil. He also compared factor of safety between bared and rooted slope by using different methods of slope stability.

Islam et al. (2010) determined the soil characteristics of coastal regions of Bangladesh. In-situ shear strength of vetiver rooted soil and un-rooted soil, and it's effectiveness for protecting the embankments against erosion and surge.

Islam et al. (2011) studied availability and sustainability of vetiver grass in the climatic and soil condition of Bangladesh. They also determined the factor of safety of slopes by using the vetiver gras in the basis of in-situ shear strength of vetiver rooted soil matrix and found that for a particular soil the factor of safety of vetiver orrted soil slope is 1.8 to 2.1 times higher than the beared soil and compared the cost of vetiver with other traditional methods.

Islam et al. (2013a) used vegetation and geo-jute for slope protection in different regions of Bangladesh. They conducted the in-situ test and also conducted direct shear test on laboratory reconstitute soil samples at different root content to know the shear strength of vetiver grass. Laboratory results were also compared with that of the field test.

Islam et al. (2013b) conducted field trials in road embankment and slope protection with vetiver at different sites. Slope stability analysis showed that vegetation increases the 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 is cost effective than other methods.

Islam et al. (2014) used vetiver as bio engineering solution to protect slope in various parts of Bangladesh. They found that, earthen blocks made with the mixing of vetiver straw was resilient to earthquake. Through in situ shear strength it was also found showed increment in shear strength and deformation capacity of soil significantly. They also started field trial of using vetiver along the 12 coastal district to see the effectiveness of it under CCRIP project.

After going through the above list of work upon vetiver grass it can be found that, availability, growth, root strength had been studied based on plane land and no study had been conducted on the saline zone of Bangladesh which is 24% of our total land. Considering the contribution of coastal region of Bangladesh it was sought to study the characteristics of vetiver grass over that region and find a suitable sustainable solution.

2.8 Available Vegetation in Coastal Regions

There were very little or no natural mangroves in the Coastal Circle. There was a very good natural mangrove forest named Chakaria Sundarbans in 1970's, but by 1980's, the vegetation is replaced by Shrimp Farms.

Coastal area is composed mainly of three halophytic tree species of which Sundri (*Heritiera fomes*) is dominant. There is a range of tolerance level of these plants. Of the three common plants Sundri is freshwater (FW) loving, Gewa (*Excoecariaagallocha*) tolerates moderately saltwater, while Kewra (*Sonneratia apetala*) tolerates polyhaline condition. These trees and other halophytic species form forest types. Three major forest types are Sundri, Sundri-Gewa and Gewa-Sundri.

Table 2.2: Types of forest in coastal area of Bangladesh. (After Aziz, 2009)

Forest Types	**Area (%)**	
	1959	**1983**
Suindri	31.6	21
Sundri-Gewa	24.4	29.7
Gewa-Sundri	15.6	14.8

A comparison of the types observed by Forestal (1960) with that of Chaffey *et al.* (1985) is shown in Table 2.2. Several types of forest is also available in coastal regions. Among them Durva Grass (*Cynodon dactylon)* is most common.

2.9 Vetever System

The vetiver System (VS), which is based on the application of vetiver grass (*Vetiveria zizanioid* L Nash, now reclassified as *Chrysopogon zizanioides* LRoberty), was first developed by the World Bank for soil and water conservation in India in the mid-1980s. While this application still plays a vital role in agricultural land management, R&D conducted in the last 20 years has clearly demonstrated that, due to vetiver grass extraordinary characteristics, VS is now being used as a bioengineering technique for steep slope stabilization, wastewater disposal, phyto remediation of contaminated land and water, and other environmental protection purposes.

Vetiver System is a very simple, practical, inexpensive, low maintenance and very effective means of soil and water conservation, sediment control, land stabilizations and rehabilitation, and phyto-remediation. Being vegetative it is also environmental friendly.

When planted in single rows vetiver plants will form a hedge which is very effective in slowing and spreading run off water, reducing soil erosion, conserving soil moisture and trapping sediment and farm chemicals on site.

Although any hedges can do that, vetiver grass, due to its extraordinary and unique morphological and physiological characteristics mentioned below, can do it better than all other systems tested.

In addition, the extremely deep and massively thick root system of vetiver binds the soil and at the same time makes it very difficult for it to be dislodged under high velocity water flows. This very deep and fast growing root system also makes vetiver very drought tolerant and highly suitable for steep slope stabilization.

Biological Characteristics of Vetiver

Vetiver has many outstanding characteristics. Its main biological characteristics used for antislide and anti-scour engineering are as follows.

If reasonable design and correct planting in regions of the middle and lower reaches of Yangtze 350 River, its stiff and upright stems and leaves can grow up to 1.5 m high after 2-3 months, forming a dense hedgerow to effectively slow down surface runoff, filter and to trap eroded sediments. It can reduce 60-73% runoff and trap90-98% sediments (Kon and Lim, 1991; Xia *et al.*, 1996).

It has a vigorous and massive root system that can penetrate 5 cm thick layer of asphalt concrete (Hengchaovanich, 1998). In regions of the middle and lower reaches of Yangtze River, its roots can reach 1.3 m deep 3 months after planting, and reach 2-4 m one year after planting. The strong root system like rows of biological piles penetrating into the soil layer and thus it can largely enforce shear strength of soil body.

The stiff shoots and strong roots can keep the plant stand steadily in water with 0.6-0.8 m deep and 3.5 m/s velocity of water flow. Thus it can reduce scouring energy of strong flow, and protect safety of dyke or riverbank.

It grows rapidly and has strong vitality, long life, and strong resistance to drought and submergence.

Special Characteristics of Vetiver Grass

Morphological Characteristics

Vetiver grasses poses some strong morphological characteristics. Some of these are presented below:

(a) Vetiver grass does not have stolon or rhizome. Its massive finely structured root system that can grow very fast, in some applications rooting depth can reach 3-4m in the first year. This deep root system makes vetiver plant extremely drought tolerant and difficult to dislodge by strong current.
(b) Stiff and erect stems, which can stand up to relatively deep water flow. Figure 2.10 shows the erect and stiff stems of vetiver grass when planted closely.
(c) Highly resistance to pests, diseases and fire.
(d) A dense hedge is formed when planted close together acting as a very effective sediment filter and water spreader.

(e) New shoots develop from the underground crown making vetiver resistant to fire, frosts, traffic and heavy grazing pressure.

(f) New roots grow from nodes when buried by trapped sediment. Vetiver will continue to grow up with the deposited silt eventually forming terraces, if trapped sediment is not removed.

(a) (b)

Figure 2.10 Erect and stiff stems form a dense hedge when planted close together (a) close view; and (b) long view

(a) (b)

Figure 2.11 View of vetiver grass surviving the forest fire in Australia (a) just after fire; and (b) two months after fire.

Physiological Characteristics

Vetiver grass is well known for it's tolerance level and survive capability. Some of the dominating physical characteristics are as follows:

(a) Tolerance to extreme climatic variation such as prolonged drought, flood, submergence and extreme temperature from -14°C to +55°C. Figure 2.11 shows the existence of vetiver grass even after fire attack at Australia.

(b) Ability to re-grow very quickly after being affected by drought, frosts, salinity and adverse conditions after the weather improves or soil ameliorants added
(c) Tolerance to wide range of soil pH from 3.3 to 12.5 without soil amendment.
(d) High level of tolerance to herbicides and pesticides.
(e) Highly efficient in absorbing dissolved nutrients such as N and P and heavy metals in polluted water.
(f) Highly tolerant to growing medium high in acidity, alkalinity, salinity, sodicity and magnesium.
(g) Highly tolerant to Al, Mn and heavy metals such as As, Cd, Cr, Ni, Pb, Hg, Se and Zn in the soils.

Ecological Characteristics

Although vetiver is very tolerant to some extreme soil and climatic conditions mentioned above, as typical tropical grass, it is intolerant to shading. Shading will reduce its growth and in extreme cases, may even eliminate vetiver in the long term.
Vetiver grows best in the open and weed free environment, weed control may be needed during establishment phase. On erodible or unstable ground vetiver first reduces erosion, stabilizes the erodible ground (particularly steep slopes), then because of nutrient and moisture conservation, improves its microenvironment so other volunteered or sown plants can establish later. Because of these characteristics vetiver can be considered as a nurse plant on disturbed lands.

Cold Weather Tolerance of Vetiver Grass

Although vetiver is a tropical grass, it can survive and thrive under extremely cold conditions. Under frosty weather its top growth dies back or becomes dormant and 'purple' in colour under frost conditions but its underground growing points survived. In Australia, vetiver growth was not affected by severe frost at –14°C and it survived for a short period at –22°C (-8°F) in northern China. In Georgia (USA), vetiver survived in soil temperature of -10°C but not at –15°C. Recent research showed that 25°C was optimal soil temperature for root growth, but vetiver roots continued to grow at 13°C.

Table 2.3: Adaptability range of vetiver grass in Australia and other countries (Truong, 1999)

Condition characteristic	Australia	Other Countries
Adverse Soil Conditions Acidity (pH) Salinity (50% yield reduction) Salinity (survived) Aluminium level (Al Sat. %) Manganese level Sodicity Magnesicity	 3.3-9.5 17.5 mScm-1 47.5 mScm-1 Between 68% - 87% > 578 mgkg-1 48% (exchange Na) 2400 mgkg-1 (Mg)	 4.2-12.5 (high level soluble Al)
Fertilizer Vetiver can be established on very infertile soil due to its strong association with mycorrhiza	 N and P (300 kg/ha DAP)	 N and P, farm manure
Heavy Metals Arsenic (As) Cadmium (Cd) Copper (Cu) Chromium (Cr) Nickel (Ni) Mercury (Hg) Lead (Pb) Selenium (Se) Zinc (Zn)	 100 - 250 mgkg-1 20 mgkg-1 35 - 50 mgkg-1 200 - 600 mgkg-1 50 - 100 mgkg-1 > 6 mgkg-1 > 1500 mgkg-1 > 74 mgkg-1 >750 mgkg-1	
Location	15^0S to 37^0S	41^0N - 38^0S
Climate Annual Rainfall (mm) Frost (ground temp.) Heat wave Drought (no effective rain)	 450 - 4000 -110C 450C 15 months	250 - 5000 -22^0C 55^0C
Palatability	Dairy cows, cattle, horse, rabbits, sheep, kangaroo	Cows, cattle, goats, sheep, pigs, carp
Nutritional Value	N = 1.1 % P = 0.17% K = 2.2%	Crude protein 3.3% Crude fat 0.4% Crude fibre 7.1%

Although very little shoot growth occurred at the soil temperature range of 15°C (day) and 13°C root growth continued at the rate of 12.6cm/day, indicating that vetiver grass was not dormant at this temperature and extrapolation suggested that root dormancy occurred at about 5°C.The summary of vetiver adaptability range is shown on Table 2.3.

Weed potential

Vetiver grass cultivars derived from south Indian accessions are non-aggressive; they produce neither stolons nor rhizomes and have to be established vegetative by root (crown) subdivisions. It is imperative that any plants used for bioengineering purposes will not become a weed in the local environment; therefore sterile Vetiver cultivars (such as Monto, Sunshine, Karnataka, Fiji and Madupatty) from south Indian accessions are ideal for this application. In Fiji, where Vetiver grass was introduced for thatching more than 100 years ago, it has been widely used for soil and water conservation purposes in the sugar industry for over 50 years without showing any signs of invasiveness.

2.10 Use of Vetiver Grass for Slope Protection

Vetiver is becoming very popular day by day and it is cultivated around 70 countries over the world (NRC, 1993). In recent past vetiver has been widely used in Australia, Bangladesh, China, Chile, Colombia, El Salvador, Indonesia, Malaysia, South Africa, Thailand, Vietnam, Venezuela, USA and many other countries.

Multiple use of this grass is possible such as forage, thatch and roofing materials, fencing materials, shedding materials, firewood, raw materials in cottage industries and medicinal herbs (Kirtikar and Basu, 1986), soil conservation and in perfume industry (Bor, 1960).

Vetiver has 11 species around the world. Among them, five species are endemic to Australia, Two are from Africa, one is the member of Southeast Asia and one is endemic to Mauritius and neighboring island of Rodrigues in the indian Ocean (Rahman et al., 1996). Out of the remaining two species, *Vetiveria lawsonii* is endemic to southern India and *Vetiveria zizaniodes* occurs in Northern Indian and Bangladesh.

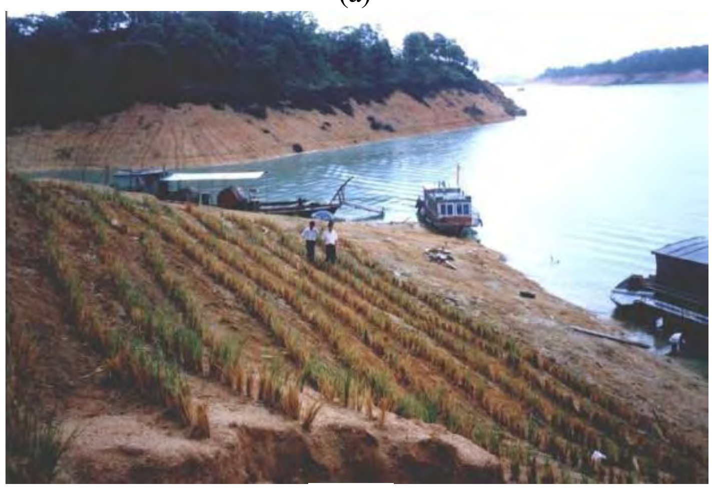
As mentioned earlier, as vetiver becomes more widely adopted globally, the implementation will need to be improved in accordance with practice on the ground. Sanguankaew *et al*. (2003) describe the experience of the Thai Department of Highways

(a)

(b)

Figure 2.12 Views of vetiver application at highway of Fuzhou, China. (a) before plantation of vetiver; (b) after plantation of vetiver. (Source: http://www.vetiver.org/CHN_Fuzhou_highway.htm)

(a)

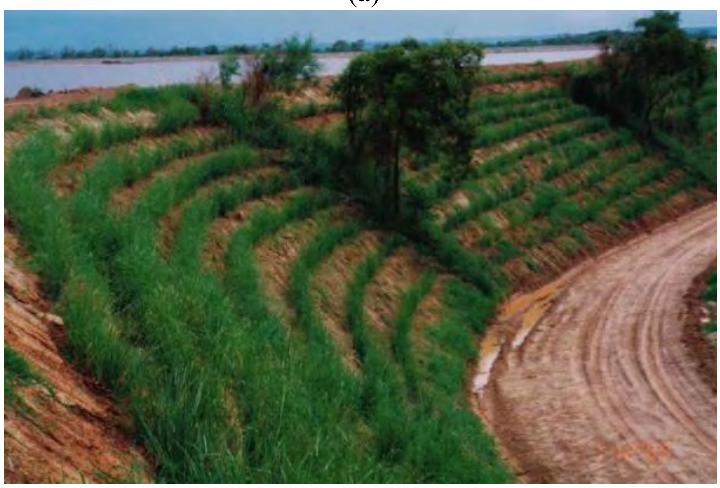


(b)

(c)

Figure 2.13 River slope erosion control using vetiver at Guangdong, China (a) eroded condition before application, (b) view after two months of vetiver plantation and (c) view of site after three years of plantation. (Source: Truong., 2010)

(a)



(b)

(c)

Figure 2.14 Dam wall repair using vetiver grass in Australia (a) before vetiver application, (b) six months after vetiver plantation and (c) two and half years after vetiver plantation. (Source: Truong., 2010)

(a)

(b)

(c)

Figure 2.15 Shrimp pond dyke protection in Mekong Delta, Vietnam (a) dyke slope before vetiver application, (b) eight yearss after vetiver plantation and (c) burning of vetiver in dry season to control weed. (Source: Truong., 2015) in implementing the vetiver slope protection works on mountainous highways in the North, Northeast and South Thailand. Standard drawings detailing the quality of slips, planting procedures and maintenance techniques, planting patterns for various types of situation: on slopes, end of drainage lines, at bridge approaches, etc have been prepared to aid field practice. Training to highway officials involved in vetiver implementation was provided to ensure satisfactory performance. Some cautionary note was hinted in the conflict between timing in planting and construction period, which needs to be ironed out.

The use of vetiver for highway slope stabilization has progressed by leaps and bounds in recent years, especially in China, taking the view that the cost of embankment stabilization compared with conventional engineering methods can be reduced by 90% when vetiver is chosen as an alternative. Chinese government planted vetiver in Fuzhou city of China beside highway. It was a very steep slope and finally vetiver worked very

(a)

(b)

Figure 2.16 River bank slope protection using vetiver grass at Tra Khuc River, Vietnam (a) before vetiver application, (b) four months after vetiver plantation (Source: http://www.vetiver.org/TVN-Handbook%20series/TVN-series2-1-infrastructure.htm)

(a)

(b)

(c)

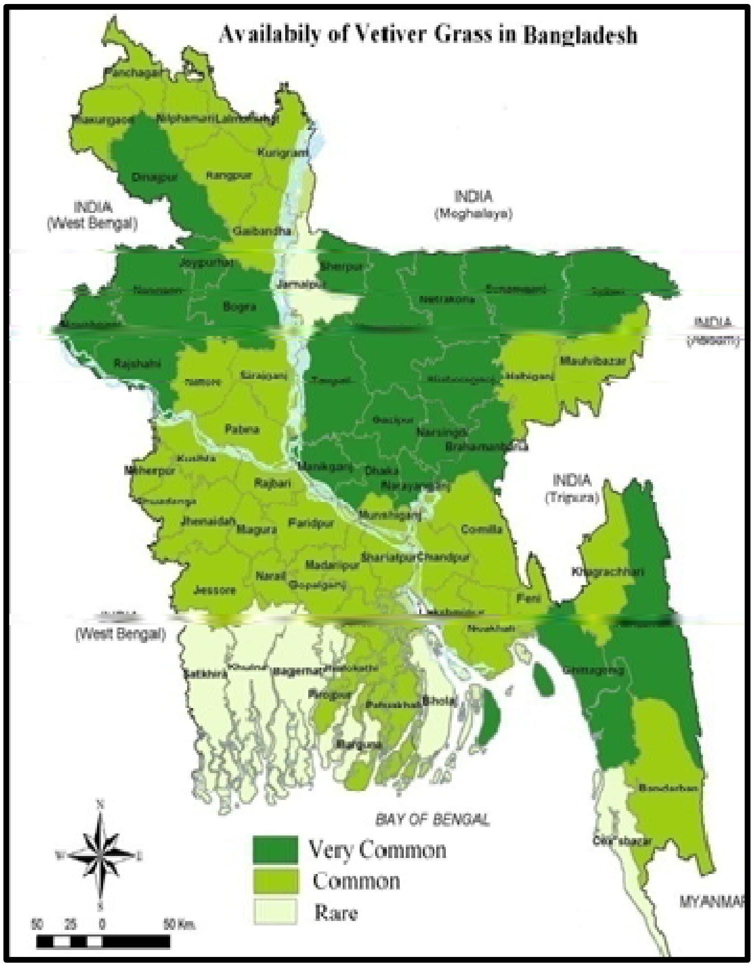
Figure 2.17 River bank slope protection using vetiver grass at Kolong river of Assam, India (a) river bank before vetiver application, (b) vetiver plantation at grid pattern, (c) slope with grown vetiver (Source: Bhattacharyya, 2010).

well there where as performance of concrete protection was not satisfactory. It was planted by Madam Zhang under the finance of World Bank. Figure 2.12 shows before and after condition of vetiver plantation over the slope at Fuzhou, china. Figure 2.13 shows the use of vetiver for river slope erosion control at Guangdong, China. Before application of vetiver this river bank amount of erosion was very high. To mitigate the issue, vetiver was plated on 2001 and it was found that, just after three years of plantation the slope was successfully free from erosion and become highly stable one.

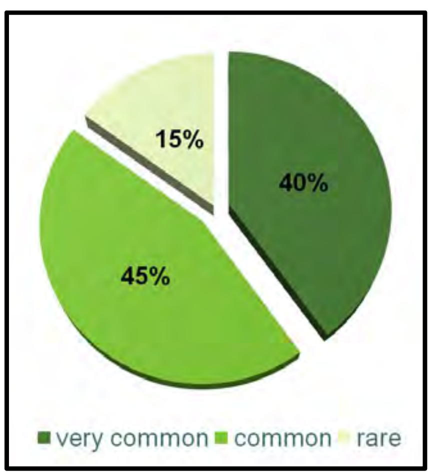
Figure 2.14 shows condition of cyclone affected dam at Gove, Northern Territory, Australia which were protected by application of vetiver grass. Figure 2.14(a) shows the condition of dam after cyclone attack which was in very loose and erodible condition. This slope made stable by application of vetiver grass in row pattern which formed a very dense hedge within two and half years.

On farmlands where topography is mostly gentle or rolling with about 10-15% gradient; however, there are occasional instances where steep slopes may be encountered such as banks of fish farm ponds in Northeast Thailand. With their soils being sandy and saline, erosion is a major problem, with sediments tending to make ponds shallower and water quality poorer. By introducing 3 rows of Songkhla-3 ecotype vetiver on a 45-degree inner pond bank, at 30 cm spacing between rows, it was found (Panchaban *et al*., 2003) that soil sediments have significantly reduced and thereby bring about better water quality.

Figure 2.15 shows the application of vetiver grass to protect the dykes of shrimp pond in Mekong Delta, Vietnam. Due to flat topography, those shrimp farming ponds were vulnerable to daily tidal movements, king tides, tidal surge during rainy season and occasional typhoons. Vetiver were planted in 2007 to protect the side slopes and it was found very effective around the year. Figure 2.15(a) shows the slope before plantation of vetiver and Figure 2.15(b) shows the slope condition after eight years in 2015. Vetiver grew very well during this period and protect slopes from natural calamities by all means. Every year during dry season these vetiver burns in fire to protect it from weeds. Figure 2.15(c) shows condition of vetiver grasses after burning. It was found that, vetiver system was very effective in establishing and protecting dykes from adverse elements commonly experienced in coastal zone.



(a)



(b)

Figure 2.18 Vetiver grass availability in Bangladesh, (a) vetiver availability map of Bangladesh; (b) pie chart of percentage of availability. (Source: Thomas et al., 2002)

Figure 2.16 shows protection of river bank with vetiver application at Tra Khuc river of Vietnam. Earlier this river bank was erosion prone and after application of vetiver grass by the local community it turns into an intact slope even after flood season.

Vetiver worked very well in Assam for river erosion and slope protection. PWD of Assam used vetiver in many places to asses it's potentiality and found that it has great power to control erosion at river bank at other areas. Figure 2.17 shows stages application of vetiver grass at the bank of river Kholong at Assam. Vetiver were planted in row pattern there which helps protecting wave attack directly. Being the tributary of river Brahmaputra river bank soil was silty in condition. Thus it proves that vetiver grows well in silty condition also.

From the above successful practical application of vetiver grass for various protection measures around the world encourages us to implement these in Bangladesh. Climate and soil characteristics of both Vietnam and Assam are similar to Bangladesh which also is a good sign as vetiver grows and results very well in application for those countries. Thus application of vetiver grass to solve erosion, slope protection issues in Bangladesh could be study extensively

2.11 Availability of Vetiver in Bangladesh

As per study carried by Rahman et al. (1996) and Thomas et al. (2002) vetiver grass is available almost all districts of Bangladesh. But these grasses are found in abandoned places and no extra care had been taken for these. From the study it can be said that vetiver is available over 85% area of Bangladesh. Figure 2.18a shows the vetiver availability map of Bangladesh which shows that vetiver is mostly available at northern part of our country. It also shows that vetiver is not common in coastal region of Bangladesh. Figure 2.18b shows the pie chart of percentage of availability in Bangladesh. Vetiver used for study of Islam (2013) and Nasreen (2014) were collected from Pubail of Gazipur district. It is also considerably available in Kuakata and Haor area.

2.12 Summary

Stability of slopes of dykes, embankments, river banks are often disturbed by natural disasters/forces like rainfall, wave action, cyclone etc. Conventional methods of protection by CC blocks, geo-textile are costly. Application of bio-engineering through vegetation to protect these dykes could be suitable, cost effective and sustainable solution. This chapter mainly covers the causes of erosion, conventional methods used for protection, use of vegetation to protect the slopes, stability of slopes due to root morphology, salinity condition of Bangladesh, past researches both in local and abroad, vetiver system, characteristics, current use at different countries and availability in Bangladesh.

Causes of erosion are mainly due to natural forces and human interferences. Rainfall, wave action, turbulent water currents are the main natural forces act over the slopes. On the other hand, travel path for men and cattle, agricultural practices, cattle grazing, public cuts, unplanned afforestation, uncontrolled animal activity and improper design and construction techniques covered under cause of erosion due to human interferences.

Few reasons of slope failures are steepness of the slope, water and drainage, soil composition, uncovered slope, bedding planes, joints and fractures and sudden shocks.

In Bangladesh RC cantilever wall, reinforced earth wall, RC wall with footing, CC block and palisading, brick toe with gunny bags are common practice to protect slope against failure and erosion. But these are costly in nature. Stability of slopes could be increased using vegetation and for this analysis basic parameters to asses factor of safety has been discussed based on equation provided by Coppin and Richards (1990).

Root with branch system enhance the stability through growing the roots along surface plane, increasing tensile strength, increasing root pull out resistance and root columns acting as piles.

Coastal area mainly covers the southern part of Bangladesh. Tidal and estuarine floodplains cover almost 98% of this area and it lies 1.5 to 11.8 meters above the main sea level. The high tide during summer rises up to 1.3 meter above the general ground level and this increase salinity in the ground water which make it unsuitable for irrigation. Around 1.02 million ha (about 70% of total cultivated land) of the cultivated land are affected by various degree of soil salinity.

Various researches had been conducted over application of vetiver grass both in abroad and Bangladesh. But, effectiveness and growth of vetiver in coastal region were not covered by others. Thus study had been conducted over the growth and application of vetiver grass to protect dykes in saline zone.

Vetiver system is currently used around 70 countries of the world. It is very simple, practical, inexpensive, low maintenance and very effective means of soil and water conservation. It's morphological, physical and ecological characters shows that it has excellent root system with high tolerance level against wide range of pH level, heavy metals, alkalinity, salinity etc. it also has great weed potential.

Currently vetiver is widely used in Australia, Bangladesh, China, Chile, Colombia, El Salvador, Indonesia, Malaysia, South Africa, Thailand, Vietnam, Venezuela, USA and many other countries. Practical photos of use of vetiver grass in highway of Fuzhou, China; in river slope erosion control at Guangdogn, China; Dam wall repair in Australia, river bank slope protection at Tra Khuc River, Vietnam and river bank slope protection at Kolong river of Assam, India has been presented in this chapter.

Vetiver is available in 85% area of Bangladesh. Among this, it is very common in 40% area of Bangladesh and common for 45% of total area. It is rare in rest of the 15% area which is mostly southern part of Bangladesh i.e. coastal region of Bangladesh.

Considering all the features and availability of vetiver grass in Bangladesh it can be realized that this would be a best option for slope stabilization in coastal areas which would be low in cost and sustainable also.

Moreover, this vegetation also serve the purpose of green revolution over the country to reduce the effect of global warming. Thus this research has been conducted to study the use of vetiver grass application in saline zone and it's application procedure to get the best result in the context of Bangladesh.

Chapter Three

EXPERIMENTAL PROGRAM

3.1 Introduction

Both field trial and laboratory tests were conducted to achieve the objectives of this study. Model study was also conducted at BUET premises. Soil condition and salinity affects the growth and behavior of the vegetation. Field trials and test procedures are the main features of this chapter.

3.2 Plant Selection Methodology

Considering the physical, biological, morphological, ecological and experience of application of past occasions, *Vetiveria zizanioides* seems the perfect vegetation for our research. Apart from the root morphology, vetiver is the grass which can survive under extreme soil condition. Table 3.1 shows that vetiver grass has the highest salt tolerance level among the other plans. Thus vetiver grass has been selected as our study subject under the saline zone. Collection procedure and storing procedure followed in the study is discussed as follows.

Table 3.1 Salt tolerance level of vetiver grass as compared with some crop and pasture species grown in Australia**.** (Shaw et al., 1987)

Species	**Soil EC_{se} (dSm^{-1})**	
	Saline Threshold	**50% Yield Reduction**
Bermuda Grass (*Cynodon dactylon)*	6.9	14.7
Rhodes Grass (C.V. Pioneer) (*Chloris*	7.0	22.5
guyana)	7.5	19.4
Tall Wheat Grass (*Thynopyron elongatum*)	7.7	17.3
Cotton (*Gossypium hirsutum*)	8.0	18.0
Barley (*Hordeum vulgare*)	**8.0**	**20.0**
Vetiver (*Vetiveria zizanioides*)		

3.2.1 Plant Collection Procedure

To keep the experiments rational for studying the characteristics of vetiver grass in different level of saline zone, source of these grasses kept same. Plants used in this study had been collected from Pubail of Gazipur area which is situated in North-East side of Dhaka city. A grown field had been chosen as source.

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

Figure 3.1 Vetiver grass collection procedure: (a) grasses are plucking form grown field; (b) extra soils are putting down from stems; (c) grasses before putting in sacks; (d) vetiver grass in sack bag.

To pluck grasses from this source field, watering were done one day before over it. This watering made the soil soft and wet so that grass can collect their necessary moistures. Shoots were cut down to 150 mm length so that transportation become easier. Garden hoe were used to pull up the stems of Vetiver grass. During uprooting necessary precautions were taken to keep the root long as possible. Initially soil tend to retain around the stem, but finally soils were loosen to get rid from the stem. It helps to keep the grasses lose some weight so that transportation become easier. After plucking from field, grasses kept in sacks for transport. It is found that a 50 kg sack can contain 1000 tillers of grown vetiver grass. These grasses can be transported by any means. Pickups or truck any transportation system will be ok for transporting this grasses. Thus collected grasses can be put in sacs for two days safely.

3.2.2 Plant Storing Procedure

After reaching at site, these grasses should be kept under shed. Watering might be done at this time which will keep these grasses moist. For long term use and store nursery could be made. For this purpose, nursery polybags could be used. Any garden soil would serve the purpose. No chemical fertilizer is needed for growing vetiver grasses. However, addition of organic fertilizer will enhance the growth rate. In a bag, 3~4 numbers of tillers could be planted. After planting in bags, watering should be done everyday basis. Placement of these grasses with bag are very important also. Sunlight plays a vital role in growing vetiver grass. Grasses should kept in a sunny area. At the initial stage grasses tends to die after becoming yellowish in color. But it is their natural form of growing new leafs. After 7 days new leaf start to grow. From now on, Vetiver grasses will keep growing and it can be used for any purpose.

3.3 Study Areas

Study areas were under Satkhira district which are situated on the South-West part of Bangladesh near to Bay of Bengal. Figure 3.2 shows the general condition of shrimp ponds in this district. Figure 3.3 shows the location of study areas. It has an area of 3817.29 km^2. It is bordered to the north by Jessore District, on the south by the Bay of Bengal, to the east by Khulna District, and to the west by 24 Pargana District of West Bengal, India. The annual average maximum temperature reaches 35.5 °C and minimum temperature is 12.5 °C. The annual rainfall is 1710 mm. The main rivers are the Kopotakhi river across Dorgapur union of Assasuni Upazila, Morichap River, Kholpotua River, Betna River, Raimangal River, Hariabhanga river, Ichamti river, Betrabati River and Kalindi-Jamuna River. Thus as costal region district satkhira has been selected. Field trial had been conducted in three locations of Satkhira district and they are Kaliganj, Baliapur and Nildumur.

According to saline content of the soil Kaligannj, Baliapur and Nildumur could be called as low saline zone, mid saline zone and high saline zone. A garden area had been selected for plantation in Kaliganj. Usually normal grass used to grow in this garden.

Figure 3.2 View of shrimp pond and dykes in Nildumur.

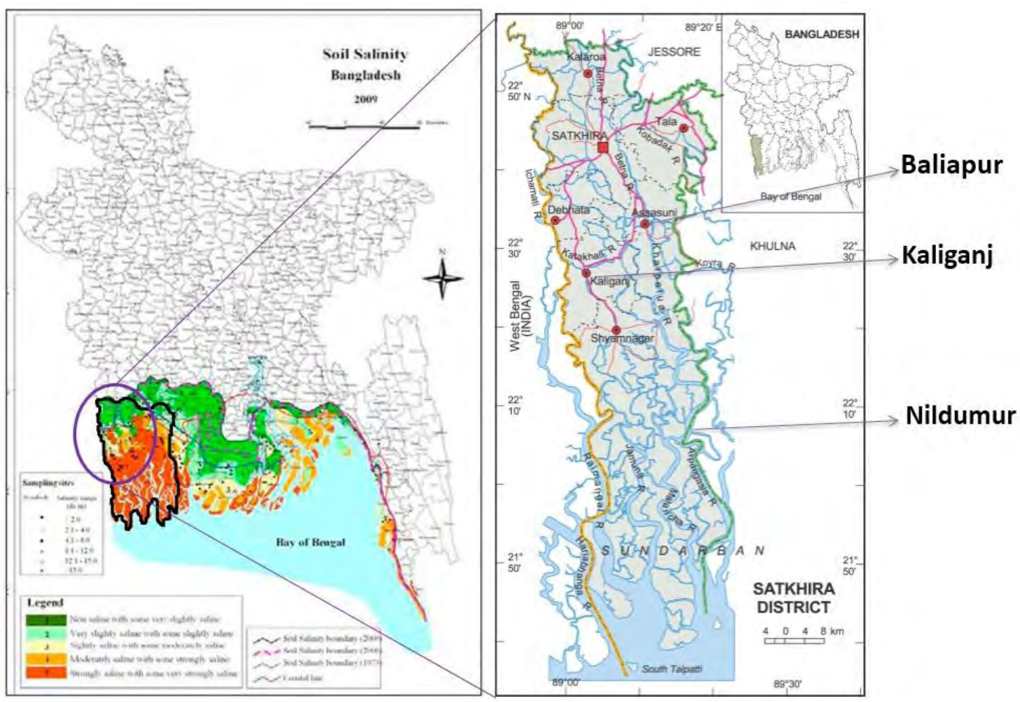


Figure 3.3 Map showing the study areas in the saline zone of Bangladesh.

Proper sunlight and water source were present for this plantation zone. On the other hand shrimp pond slope were selected in both Baliapur and Nildumur area. As a coastal belt area, cultivation of shrimp is the main source of income among the habitants. Here, flood tend to attack this region every 1~2 year and all the ponds become flooded. Moreover natural disaster like cyclone, high tide frequently attacks here. As result dykes become unstable and used to collapse. After leaving the flood water, farmers used to remake these dykes again and try to reset the whole system again. This had been a big setback for making more profit in this business for a country like Bangladesh.

3.4 Test Program

Laboratory test and model test were conducted for this study. For laboratory test, soil samples were collected from slopes of study areas. Model test had been conducted at BUET premises. Results obtained from these tests were used to relate with the behavior of vetiver grass growth and preparation of plantation guideline.

3.4.1 Soil Sample Collection

Two types of soil sample were used to do laboratory tests- disturbed and undisturbed soil samples. Undisturbed soil sample were collected using garden hoe. Polythene bag were used to store those soil sample so that moisture may also retain there. But, collection of undisturbed soil sample were different. To do this, PVC pipe of 7.5 cm diameter and 45 cm length were used. First, pipe was placed perpendicular to the slope and hammered so that it penetrates into the soil up to a at least 40 cm (Figure 3.4a). Then, surrounded soil was dug out to pull up the pipe and undisturbed soils inside (Figure 3.4b). During this pull out procedure proper care were taken so that soil cylinder

(a) (b)

Figure 3.4 Undisturbed soil sample collection procedure (a) insertion of PVC pipe and (b) taking out of PVC pipe with soil sample inside does not break inside. Muddy soil and polythene were used to seal the opening of the pipes so that moisture retains as it is.

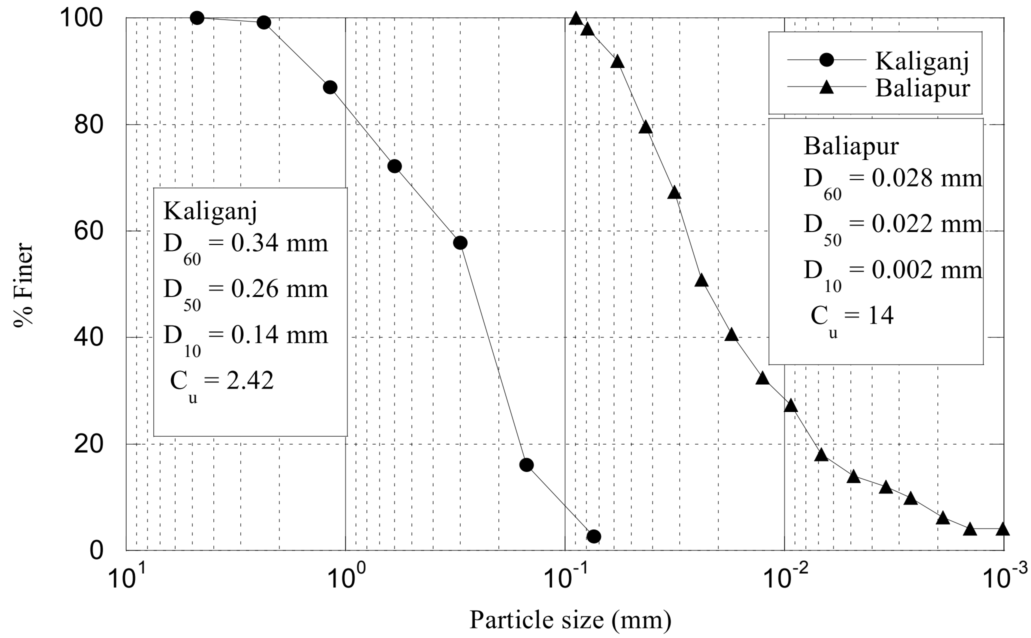


Figure 3.5 Grain size distribution of the soil samples collected from sites

3.4.2 Laboratory Tests

Samples collected from site were tested in the Geotechnical Engineering Laboratory of Bangladesh University of Engineering and Technology (BUET). The tests were conducted to ASTM standards. Index and strength properties were determined to evaluate the sub soil condition the study area. Atterberg limits, grain size distributions, specific gravity and direct shear test were conducted for all the study zones. Nutrient analysis of soil were conducted through SRDI (Soil Resource Development Institute) at their laboratory.

Table 3.2 List of conducted laboratory tests with their ASTM designations.

Name of Test	ASTM No.
Atterberg Limit Test	ASTM D 4318
Grain Size Analysis	ASTM D 422
Specific Gravity test	ASTM D854-14
Direct Shear test	ASTM D3080

3.4.2.1 Direct Shear Test

Direct shear test had been conducted over undisturbed soil samples. To do this, soil samples were taken out of PVC pipe very carefully in one piece. Then samples were cut down with knife like circular plates. These soil plates were used for specific gravity test as per ASTM D3080 standards.

3.4.3 Model Tests

Simulation study were conducted to determine the efficacy of the vegetation against wave action using a small scale model. For this purpose three wooden box (750 mm× 750 mm×750 mm) were made with different front slope.

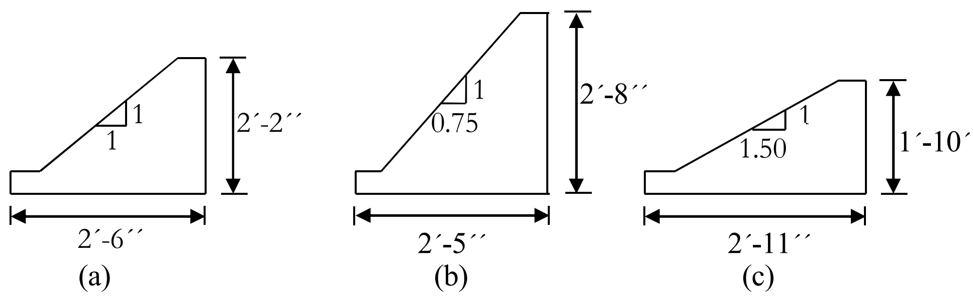


Figure 3.6 Schematic diagram of wooden boxes with three different slopes; (a) 1:1 slope, (b) 1:0.75 slope, (c) 1:1.5 slope.

These boxes were filled with soil collected from study area so that growth of grass would represent the saline soil growth. Figure 3.6 shows the measurements of the boxes used in this simulation test and Figure 3.7 shows the wooden boxes at real before and after soil filling. Vetiver grass were planted in these boxes at a distance of 100 mm c/c in both vertical and horizontal direction. At this stage it leave was left for three months. During these three months vetiver used to grow here at it's best level. These boxes were kept in a sunny location so that vetiver grasses could get adequate sunshine. Watering were done for first couple of weeks. Later no external watering were done. During this period weed protection were taken manually. Gardener used to clear the weeds to help it grow smoothly.

(a) (b)

Figure 3.7 Wooden boxes (a) before soil filling and (b) after soil filling

(a) (b)

Figure 3.8 Vetiver grass grown on models (a) 15 days after plantation; (b) three months after plantation.

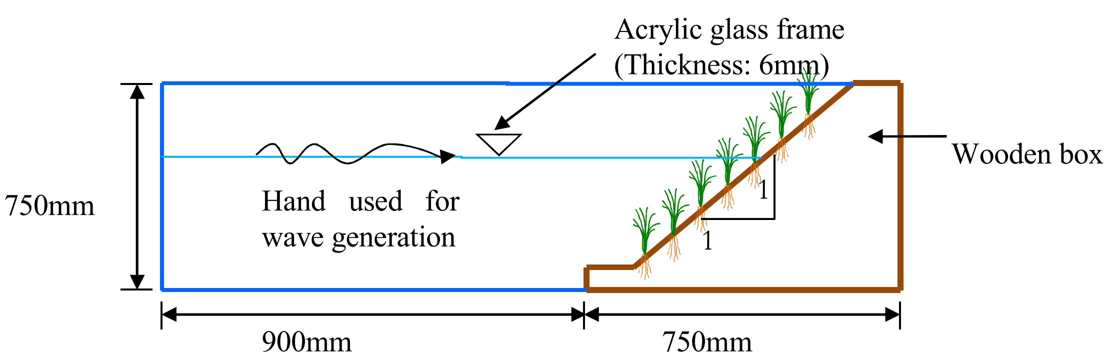


Figure 3.9 Schematic diagram of model constructed for studying the effect of wave action

(a)

(b)

Figure 3.10 Photos of model tests, (a) during water filling and (b) wave generation using hand.

After three months, these boxes with soil were ready for test. An acrylic glass box were made as water container. Figure 3.8 shows wooden box of vetiver 15 days and three months after vetiver plantation. Figure 3.9 shows the schematic diagram of the model setup. Then these two things were attached with angle framing along the outside. After proper waterproofing along the edges, water were poured in the box. This simulates shrimp pond condition. Figure 3.10 shows the actual condition of the model test. After that, hand were used to propagate into the water to generate wave. Those waves were acting as water force along the slope with vegetation. This action were done for 15 minutes. After that, eroded soil were calculated and condition of vetiver grass root were investigated. This was done for all three boxes. Analysis of slope protection using vetiver grass has been conducted using equation developed by Coppin and Richards, 1990 as stated in chapter two. The euation was as follows:

$$FS = \frac{(c' + c'R) + [\{(\gamma z - \gamma w\ hw) + W\} \cos^2 \beta + T \sin \theta]\ \tan \emptyset' + T\ cos\theta}{\{(\gamma z + W)\sin \beta + D\} \cos \beta}$$

Where,

- c' = Effective Soil Cohesion, kN/m^2
- γ = Unit weight of soil, kN/m^3
- z = Vertical height of soil above slip plane, m
- β = Slope angle, degrees
- γ_w = Unit weight of water, kN/m^3
- h_w = Vertical height of ground water table above slip plane, m
- ϕ' = Effective angle of internal friction of the soil
- c'_R = Enhanced effective soil cohesion due to soil reinforcement by roots, kN/m^2
- W = Surcharge due to weight of vegetation, kN/m^2
- h_v = Vertical height of ground water 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
- D = Wind loading force parallel to the slope, kN/m

3.5 SUMMARY

Kaliganj, Baliapur and Nildumur under Satkhira district were selected as study areas in the coastal zone. Vetiver grass were planted there as well as soil sample were collected to evaluate the physical and chemical properties. Laboratory tests and model test were conducted at the Geotechnical Laboratory of BUET. Slope stability analysis and cost analysis has been conducted. Results obtained from these experiments and analyses are presented in the next Chapter 4.

Chapter Four

RESULTS AND DISCUSSIONS

4.1 Introduction

The main objectives of this chapter is to present detail test results of the field and laboratory investigations obtained in the study. Growth of local vetiver grass was compared with that of collected from India and Thailand. Growth of vetiver grass was also compared with that of Kans. Both model study and field trials were conducted to investigate the effectiveness of vetiver grass in protecting dykes' slopes in the coastal zone of Bangladesh. Case studies were also taken into consideration for evaluating the efficacy of the proposed technique. Based on all these study an installation guideline for vetiver plantation for slope protection has been presented.

4.2 Study on Vetiver Growth

Growth of grasses depend on many factors. Characteristics of soil around itself is the most dominant. Moreover, sunlight and other factors also play vital roles. Several factors that plays roles on overall growth and performance of grass are presented in this section.

Several grasses are available in Bangladesh which grows high. But all these are not capable of holding soil particles to strengthen. Root length and morphology vary grasses to grasses. A comparative study on the growth of vetiver collected from different sources has been conducted at BUET ground.

Growth of local vetiver was compared with that of vetiver collected from India and Thailand. The local vetiver plant that was used for the comparative study, field trials was collected from the same place, Pubail of Gazipur District of Bangladesh.

Another plant named as *Kans* grass (*Saccharum spontaneum)* which is commonly found in Bangladesh similar to vetiver is also planted in the same place. It was found that among the planted vetiver grasses, the vetiver collected from Pubail grew best.

Figure 4.1 Photo showing different grasses planted at BUET premises

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

Figure 4.2 Comparative study on the growth of different plants at BUET field: (a) local vetiver (*Vetiveria zizaniodes)* from Pubail, Gazipur District, Bangladesh, (b) *Kans* grass (Saccharum *spontaneum)* from Pubail, Gazipur District, Bangladesh; (c) vetiver (*Vetiveria zizaniodes)* from Assam, India and (d) vetiver (*Vetiveria zizaniodes)* from Thailand

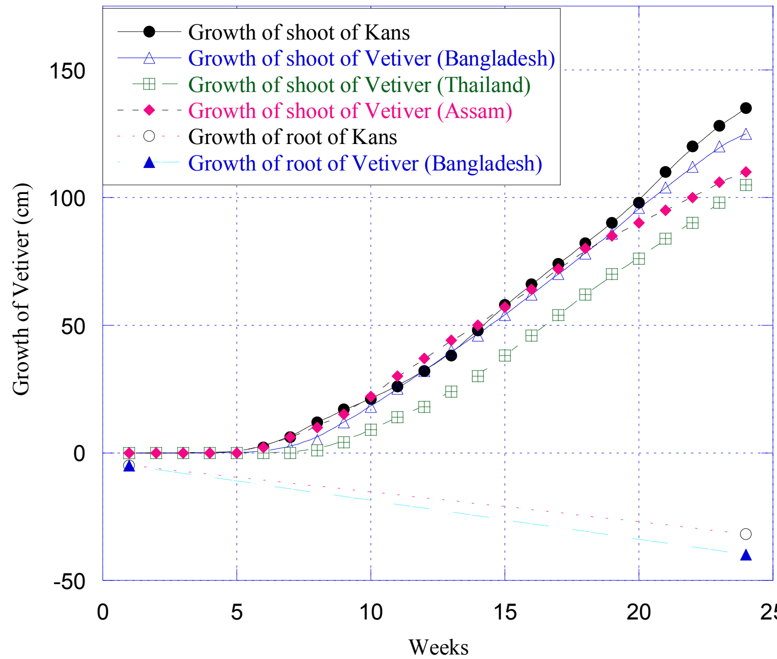


Figure 4.3 Comparative growth chart of root and shoot of different grasses at BUET premises

(a)

(b)

Figure 4.4 Root pattern and root length of plants; (a) vetiver (Bangladesh), (b) Kans

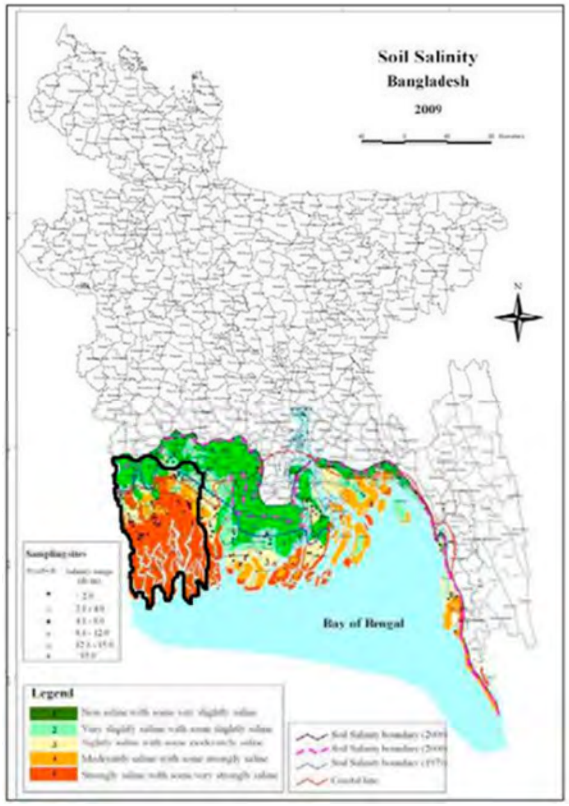
Figure 4.1 and 4.2 shows the photograph of vetiver planted at BUET ground. The study was conducted for six months.

This study shows that it took 1~1.5 months to grow green leafs of the grasses after plantation. Before that, all the grasses become yellowish within 2~3 days after plantation as if grasses are died. But after 1~1.5 months later, green leaves start to come out. It is found that, the shoot growth of the *Kans* grass (*Saccharum spontaneum)* better than vetiver grass. Comparative growth chart is given in Figure 4.3. But, growth of root of vetiver grass was better than Kans. Moreover root bindings and morphology of vetiver grass was found better than Kans. Figure 4.4 shows the length of root of vetiver grass against the root of Kans. From the figure it can easily be found out that, root pattern of vetiver grass was much better than Kans in terms of root morphology. As better root pattern and morphology give better shear strength and bonding to soil, vetiver grass (*Vetiveria zizaniodes)* had been selected for this study.

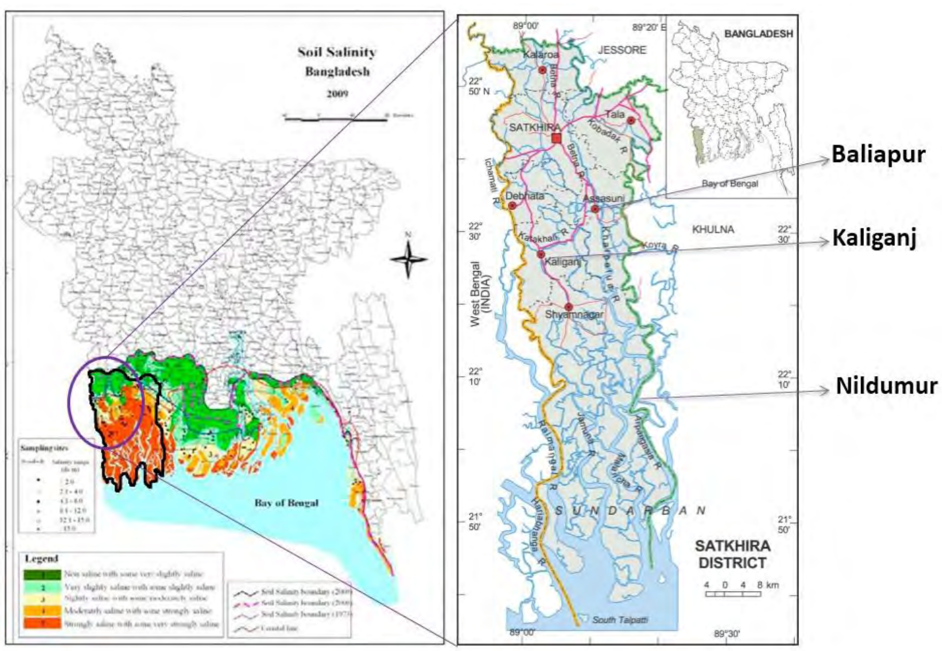
4.3 FIELD TRIALS

As a lot of factors play roles on the growth of vetiver grass. To get the actual scenario of the plantation field trials had been conducted. Study area were chosen in the saline zone of Bangladesh.

Field trials are conducted in Southern-Western coastal belt of Bangladesh. For this “Satkhira” district under Khulna division were chosen. Satkhira has “Jessore” district at it’s North, Bay of Bengal on South, Khulna district at East and, West Bengal of India at West. Kaliganj, Baliapur and Nildumur were chosen for this study depending on the salinity content of the soil. These area considered as low, mid and high saline zone respectively for our study. Distance of Bay of Bengal is decreasing from this places thus saline content is increasing. Location of the study area is shown on the salinity map of Bangladesh in Figure 4.5a. Study locations are marked on Figure 4.5b. The photographs showing the condition of the study area has been presented in Figure 4.3. From the photograph, it is seen that there is no vegetation or plants on the dykes in the saline zone. Very few plants and trees are seen in the area. These dykes are located in the low, mid and high saline zones. Generally, each year these dykes go under saline water during cyclonic tidal surge or flood water. Dyke erosion take place and farmers have to reconstruct the dykes every year at their own cost. This causes social instability between



(a)



(b)

Figure 4.5 (a) Study area on the salinity map of Bangladesh and (b) location of the study areas.

the farmers of the adjacent shrimp ponds. So a sustainable low cost technique for dyke slope protection is very important for this area.

4.3.1 Field Trial at Kaliganj

Kaliganj is located at the middle of Satkhira district and away from saline ponds. Location chosen for plantation was plane type of land. It used to be a grassy area before plantation took place. Vetiver grass were transported from Pubail of Gazipur to here through bus which was plucked 2 days before actual plantation at Kaliganj. During plucking, maximum length of root were tried to be kept, though average 50mm of root were found good for plantation. Shoots were also cut down to 100mm to 150mm for ease in transportation. First, necessary site preparation were taken at the garden area which included cleaning, levelling and ploughing. Then vetiver grasses were planted in a row with a spacing of 200 mm c/c. Row to row distance were kept around 450 mm c/c for proper breathing. A small stick were used to make holes in the soil which was around 75 mm deep. 3 to 4 clamps were planted in that hole at a time and roots were well buried beneath the soil. Proper watering were ensured after plantation. Figure 4.6 shows the site condition during plantation process. Then this site were sunder constant monitoring to record the growth rate of both roots and shoots. Few of the grasses were planted with exact 50mm roots and 75mm of shoots length for monitoring purpose. Monitoring were done weekly basis. From the Figure 4.7 it can be seen that growth rate of vetiver grass during monsoon season is higher than other seasons. Moreover it grows slowly during winter season. But growth of root does not have any seasonal affect. It grows rapidly during 4^{th} to 16^{th} week and then grows at a constant rate.

4.3.2 Field Trial at Baliapur, Satkhira

Baliapur is situated at northern side of Kaliganj and has a lot of shrimp pond in this side of the district. This site was chosen as pond site which is located far North than Kaliganj site which means also far away from direct saline water accumulation. Side of a shrimp pond were selected for plantation which were in sloped condition. This slope were near to 1: 2.5 in measurement. Figure 4.9 shows photos taken after initial plantation and on the 10^{th} month of monitoring.

(a) (b)

(c)

Figure 4.6 Field trials at Kaliganj, Satkhira (a) site preparation; (b) during vetiver plantation and (c) full grown vetiver just after 3 months of plantation.

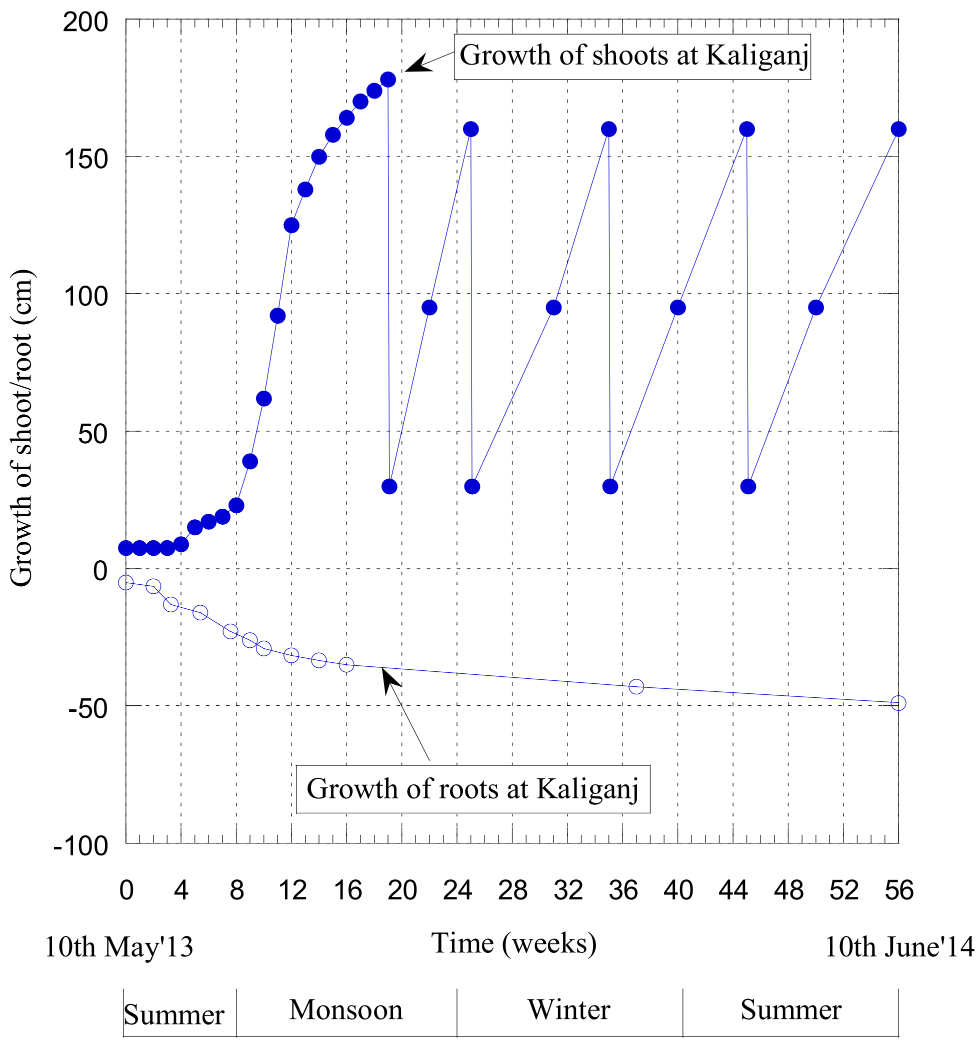


Figure 4.7 Growth chart of vetiver grass at Kaliganj, Satkhira (EC 1.57 ds/m).

From this Figure 4.7 it is clearly visible that growth rate of vetiver is faster in monsson season than any other season. As well as growth is slowest in winter season. growth of root is higher during first 12 weeks of plantation and then it become slower but steady. The drop in the curve of shoot grows denotes the curtailment of vetiver shoot to help it growing faster. Every time the shoot grows around 180 cm in length it were cut down and leaves were used to feed cattle around the area adjasent. These leaves could also be used in many other purposes. Growth were monitored for 56 weeks and necessary data were measured. Figure 4.8 shows the length of root after 9 months of plantation. root became 38.5 cm in length just after 9 months. Generally it can grows upto 2m in length below ground level. Root morphology of vetiver grass is such that it helps binding the soild particles to enhance the stability. To get the length of the root of planted vetiver, a round hole were dug around the plant. Then soil were taken out very carefully. As roots of grasses were spread very widely, necessary cautions were taken to take out the whole grass root system with care. Then the longest root were measured for growth measurement.

Figure 4.8 Length of vetiver root after 9 months ta Kaligonj, Satkhira.

(a)

(b)

Figure 4.9 Field trial at Baliapur, Satkhira (a) Watering just after plantation ; (b) Grown vetiver after 10th month (with 15 weeks trimming interval)

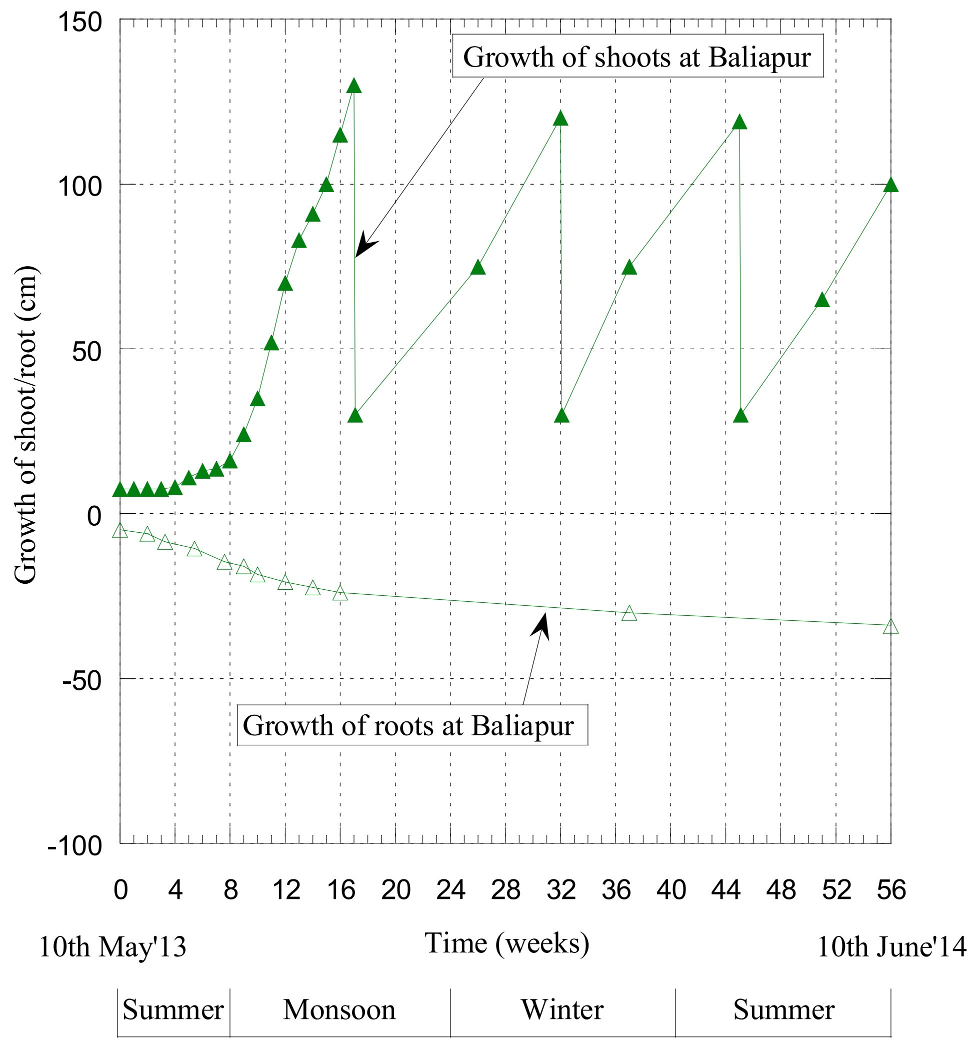


Figure 4.10 Growth chart of vetiver grass at Baliapur, Satkhira (EC 3.93 ds/m)

From Figure 4.10 it can be seen that growth of shoot is slower in winter season but faster in monsoon season. Moreover, the growth of both the shoot and root is lower than those of Kaliganj area. Hence come the question of other factors associated with the growth of vetiver grass. Chemical analysis of soil shows that salinity of Baliapur site is 3.93 dsm^{-1} and Kaliganj site is 1.57 dsm^{-1}. This means salinity is around 2.5 times higher in Baliapur site than Kaliganj site. This denotes that, growth of vetiver is slower in high saline zone which is similar to result found by Truong et al. (2002) as stated in chapter two. Due to slow growth shoots of this site had to cut after long periods. One significant point is to mention here that, sometimes shrimp pond water were directly used to watering the grasses.

4.3.3 Field Trial at Nildumur, Satkhira

Among the trial zones Nildumur is the southernmost area and much closer to Bay of Bengal. Thus this area has much salinity than other trial zones. A pond slope were selected for plantation. This time slope of the bank were much steeper and closer to 1:1.5. After plantation proper watering were ensured. Figure 4.11 shows the plantation of vetiver at Nildumur, Satkhira.

(a)

(b)

Figure 4.11 Field trial at Nildumur, Satkhira (a) Just after plantation ; (b) Grown vetiver after 5th month (without any trimming)

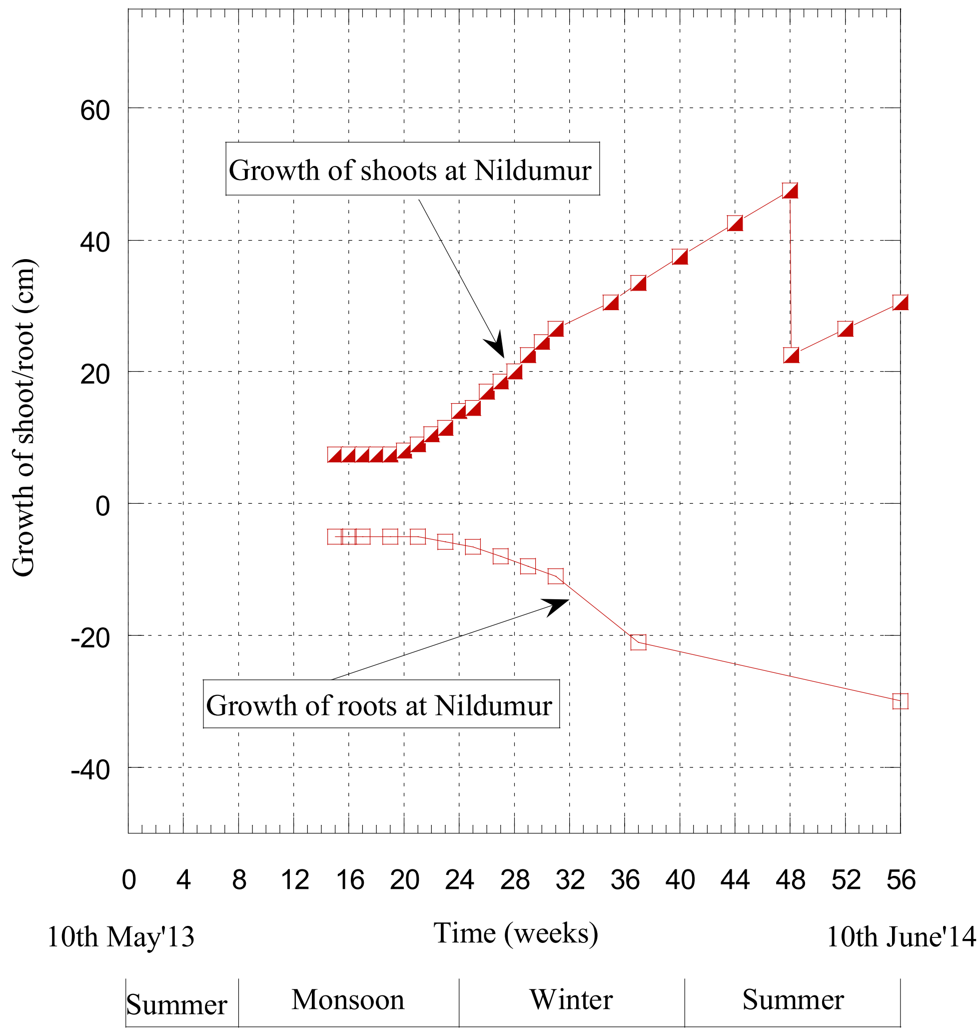


Figure 4.12 Growth chart of vetiver grass at Nildulur, Satkhira

Figure 4.12 shows the growth rate of roots and shoots of vetiver grass at Nildumur site. Rate of growth of roots were much slower than others. It grew only 30cm in 40 weeks. Monitoring of these plantation were done weekly basis. Kaliganj and Baliapur site were monitored for 56 weeks whereas Nildumur site were monitored for 41 weeks. It is here to mention that salinity of this area were 4.19 dsm^{-1} which is highest among the study area. From Figure 4.12 we also can see that initial growth of root were very slow where for other site we found that initial growth rate of roots were fast. Planting during monsoon season also could not help it growing fast. Thus it can be observed that, keeping the other parameters same (like monitoring, maintenance, weed protection) growth of vetiver vastly affected by salinity content of the soil.

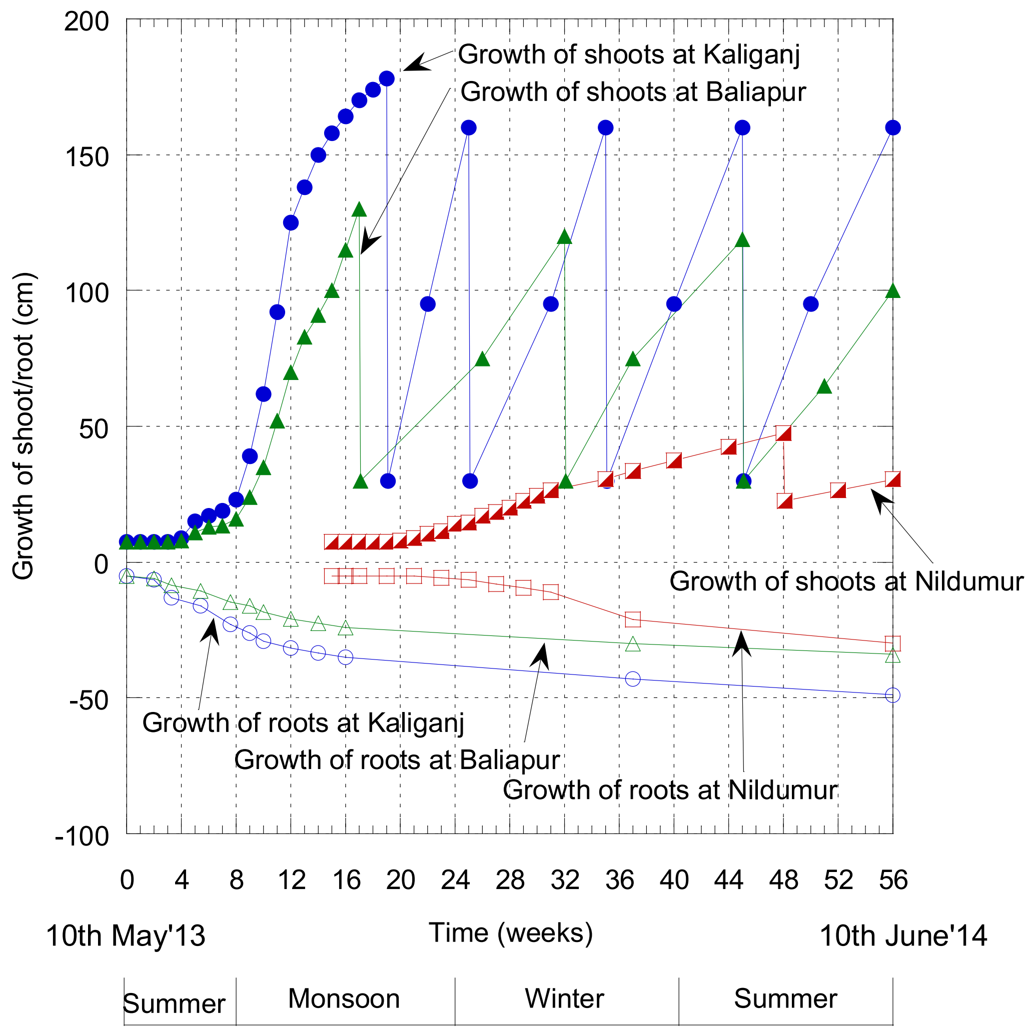


Figure 4.13 Growth of roots and shoots of Vetiver at field trial zones.

Figure 4.13 shows combined growth rate so that comparison become easier. From the above growth graph it is found that growth of vetiver grasses at Kaliganj is much faster and smoother than other areas. During these 56 weeks vetiver had to trimmed down to 300 mm when it passes above 1500 mm in length. In Baliapur, vetiver grass was trimmed after 1300 mm length for smooth growing.

From the graph it can also be found that, growth of vetiver has greatly depends on seasonal factors. In monsoon season growth rate is very fast than other time. Lowest rate of growth found in winter season.

To get more information about other factors of growth salinity information of water and soil were gathered. From Figure 4.14 it is found that water salinity concentration become maximum during the month of March-April i.e., at the end of winter season. And salinity remains minimum during the month of August to October i.e. end of monsoon season. Salinity of Nildumur is highest as it locates in the highest saline zone. Salinity in the water of Baliapur area varies between 5 to 17 ppt while the salinity of the water of Nildumur varies between 8 to 25 ppt. Thus seasonal growth can be related from these two graphs that high concentration of saline slower the growth of vetiver grass during winter season.

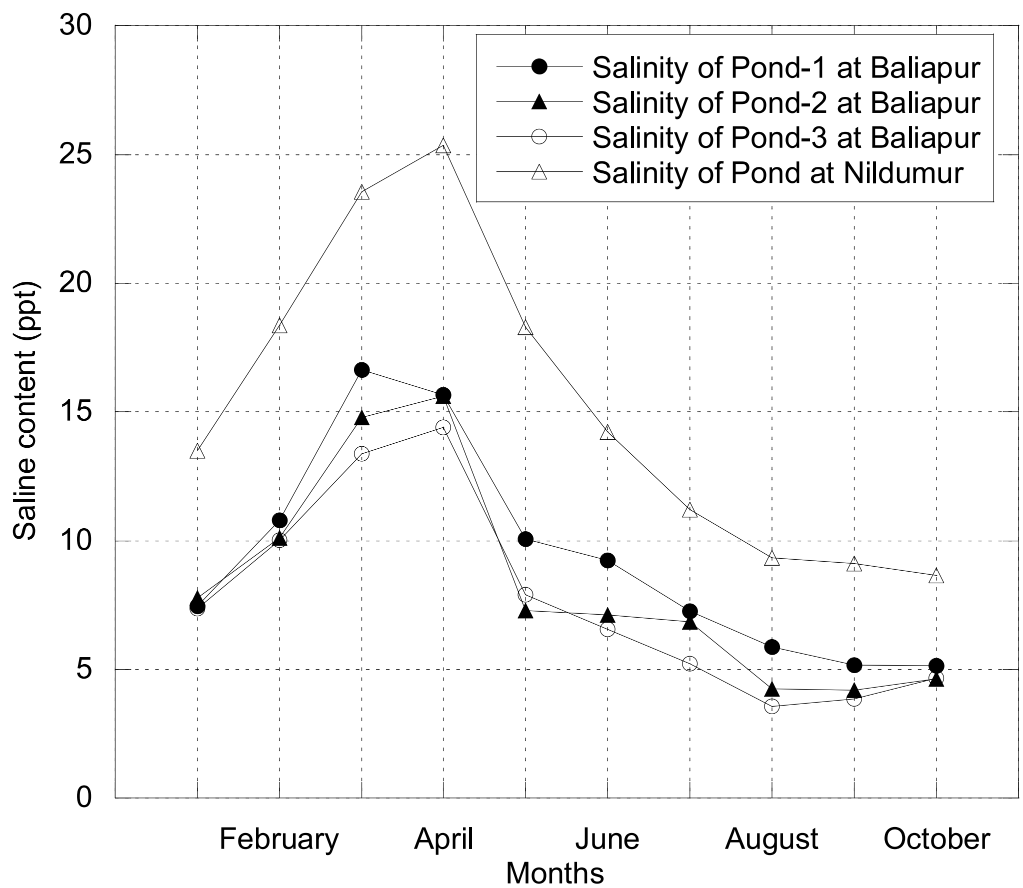


Figure 4.14 Salinity of water at ponds of Baliapur and Nildumur.

To be more precise, necessary soil properties are also investigated Atterberg limits and grain size distribution of the soil samples were determined. Consolidated undrained direct shear tests were also conducted to determine the shear strength properties of the soil samples collected from the dyke slopes.

Chemical properties of the soil samples collected from study areas are presented in Table 4.1, 4.2 and 4.3. It is seen that pH varies between 6.7 and 7.4. Salinity (EC) varies between 1.57 and 12.37 ds/m. Total nitrogen (TN) varies between 0.04 to 0.09%. Na content varies between 1.3 and 16.0 meq/100g soil. Zn content varies between 0.49 and 2.39 ppm. Cl varies in a very wide range between 363 to 4850 ppm.

Table 4.1 Index properties of soils collected from the study areas

Study Area Name	**OC (%)**	**G_s**	**LL (%)**	**PI (%)**	**Grain size**					**Group (According to ASTM D 2487)**
					Sand (%)	Silt (%)	Clay (%)	D_{50} (mm)	c_u	
Kaliganj	–	2.64	43.5	20.5	2	97	1	0.025	11.87	CL
Baliapur	10	2.19	60	37	16	81	3	0.005	4.00	CH
Nildumur	10	2.23	46	27	6	94	-	0.014	5.33	ML

Note: OC: Organic content; G_s: Specific gravity, LL: Liquid limit, PI: Plasticity index, D_{50}: mean grain size, c_u: uniformity coefficient, c: cohesion, ϕ: angle of internal friction

Table 4.2 Shear strength properties of soils collected from the study area

Study Area Name	**Cohesion, c (kN/m^2)**	**Angle of internal friction, ϕ°**
Baliapur	26	15
Nildumur	15	19

Table 4.3 Chemical properties of the soil samples collected from the study areas

Plantation Area	pH	EC (ds/m)	Salinity class	TN (%)	Na (meq/100g soil)	Zn (ppm)	Cl (ppm)
Kaliganj	6.70	1.57	Non-saline	0.07	1.3	2.39	363
Baliapur	7.40	3.93	Moderately saline	0.07	16.0	0.50	1039
Nildumur	7.40	4.19	Moderately saline	0.09	15.0	0.68	4850
Bashkhali	7.30	12.37	Strongly saline	0.04	13.0	0.49	2077

Note: EC: Electrical conductivity; TN: Total nitrogen

From the physical properties of soil it can be said that, all three trial zones poses same types of physical soil characteristics. These soils are silty in nature and has good cohesion among themselves. But form chemical properties of soil, it clearly shows that, Nildumur is much saline contained zone among the three. EC of Nildumur is more than twice of Kaliganj. Baliapur has twice EC than Kaliganj. Amount of Na and Cl are also much higher than kaliganj area. This explains the slow growth of vetiver in Baliapur and Nildumur.

On the other hand, roots of slow growth area remained same healthy as lower salinity contained area like Kaliganj. Thus, salinity does not affect the capacity of root. Figure 4.15 shows the root of vetiver at Nildumur area, which is alive and healthy.

Figure 4.15 Condition of roots at Nildumur after 6 months of plantation (root length is 20 cm).

4.4 Case Studies

Earlier to this plantation, vetiver had been planted in two different site of Bangladesh with different objectives. These are Keraniganj and Rajshahi. Fact and findings of these application are described below.

4.4.1 Case Study 1 (Keraniganj, Savar)

A road embankment named as Konakhola-Kholamura-Hazratpur-Itavara-Hemayetpur under Roads and Highway Department of Bangladesh was selected to investigate the effectiveness of vetiver at road side slope. The site is situated at Keraniganj under Savar Upazilla, Dhaka. Figure 4.16 shows the location of the site.

Figure 4.16 Location of Keraniganj, Savar site.

Total length of the road is 23.01km and average width is 3.80m. The chainage of the field trial is 17+700m to 17+800m. Annual Average Daily Traffic of the road is 71.38. Temperature and humidity of this area ranges between 14°C and 34°C and between 45% and 79%, respectively. Average annual rainfall is 1875mm.

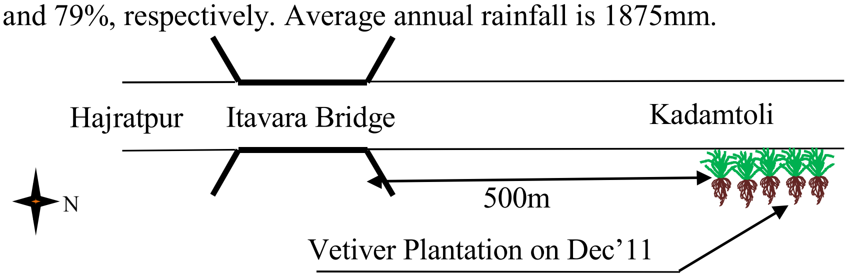


Figure 4.17 Location of Vetiver grass plantation on December 2011.

(a)

(b)

(c)

(d)

Figure 4.18(a) View of site before plantation; (b), (c) View of site during plantation; (d) View of site after plantation.

Around 100m long embankment were taken for plantation purpose. After cleaning and necessary site preparation vetiver were planted in the eastern side of the road. Figure 4.17 shows the schematic diagram of vetiver grass plantation on December 2011.

Jute geotextile were used during plantation. Spacing of plantation vetiver grass were 200mm c/c both horizontal and vertical direction. Figure 4.18 showing some photos during initial plantation work.

(a) (b)

(c) (d)

Figure 4.19 (a), (b) View of site on Dec'12; (c) Condition of Jute Geotextile; (d) length of root of vetiver on Dec'12.

After initial plantation watering was ensured for 7 days. Then this site leave for natural growing. Gradually these vetiver grass were kept growing there. Figure 4.19 shows condition of site during Dec'12. There it is found that, vetiver grown very well. Roots become long enough and other vegetation were kept growing along with vetiver. As a bio degradable product, most of the jute geotextiles become degraded. Seeds were started to grown on month of December'12.

After 3.5 years of plantation another site visit was made to see the condition of embankment. Then it was found that, original vetiver planted slope become fully covered with green plants. Vetiver and other plants grown side by side. People of neighboring village used to cut this grass and feed their cattle. They also used to cut down these grasses to reduce the risk of hiding muggers at night time. Presence of vetiver stems were there very frequently. Another interesting matter is found there that, vetiver started to grow on the other side (i.e. western side) of the road. Though we didn't plant vetiver on that side, but it grows there with in full fledge. Some vetiver also found on the eastern side. Figure 4.20 shows the schematic figure of natural vetiver grown areas.

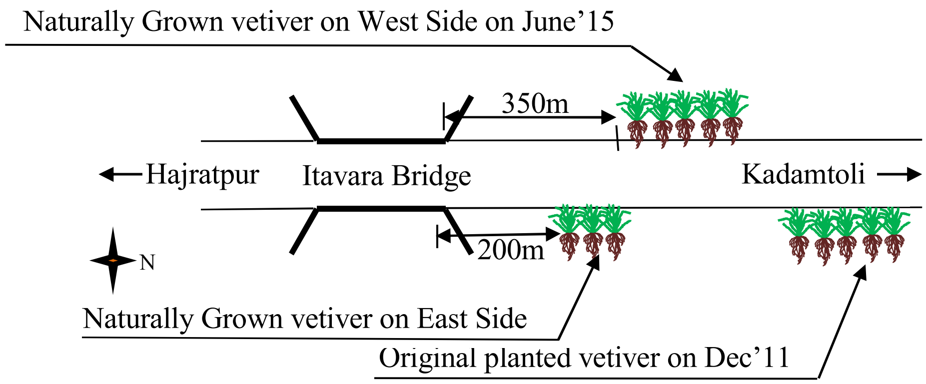


Figure 4.20 Location of original plantation and naturally grown vetiver of keraniganj, Savar.

(a)

(b)

(c)

(d)

Figure 4.21 (a), (b) Condition of grown vetiver on June'15; (c) Naturally grown vetiver on West side, (d)Naturally grown vetiver on East side of keraniganj, Savar.

In Figure 4.21 current condition of site is given which shows that natural vetiver grows either side of the road.

It seems that vetiver grows naturally on other side of the road due to transfer of seeds from the planted vetiver. Every year vetiver efflorescence used to grow and it flies around the air which helps spreading it in the adjacent areas.

Thus, finally it can be concluded that, in the original place, vetiver grew very well as well as it helps spreading it in other side of the road also.

4.4.2 Case Study 2 (Godagari, Rajshahi)

A pond was selected to evaluate the growth and effectiveness of vetiver grass to control erosion of pond bank soil. The pond was situated at Godagari Upazilla in Rajshahi District. The region consists of *Barindtract*, *Diara* and *Char* lands. Annual average temperature ranges between 11.2°C and 37.8°C. Average annual rainfall is 1862mm. Specific gravity of the slope soil is 2.64. Sand, silt and clay content of the soil are 13%, 75% and 12%, respectively. Mean grain size, D_{50} and coefficient of uniformity, C_u is 0.016mm and 7.4, respectively. According to percentage of contents the soil is sandy silt. It seems that the soil is erodible as well. Figure 4.22 shows the vetiver plantation work at Godagari, Rajshahi.

Figure 4.22 Vetiver plantation at Godagari, Rajshahi.

4.5 Model Study

Model study had been conducted at BUET premises to study the behavior of slope with vegetation against wave action. Three types of slope were used for this purpose 1:1, 1:0.75 and 1:1.5. these slopes were made at wooden boxes. After completing the experiment it was found that, each slopes acted differently. Figure 4.23 shows the model setup with wave propagation.

From the model study it was found that, vetiver grass at slope ratio 1:1.5 remained as it was before wave attack and eroded soil amount was very negligible. Same happened for slope ratio 1:1 though amount of eroded soil was a bit higher than 1:1.5 slope. But, amount of soil erosion for vetiver at slope 1:0.75 was higher than remaining two. Few tillers became displaced after wave attack in this slope. This result shows that, vetiver

(a)

(b)

Figure 4.23 Condition of slope against wave attack; (a) before wave attack, (b) after wave attack.

works fine at slope 1:15, 1:1 but don't work well in steep slope alone. We might use geo-jute for slope steeper than 1:1.

4.6 Factor of Safety Analysis

Factor of safety analysis of slope stability with and without vegetation has been conducted based on the respective soil properties. Slopes of Baliapur and Nildumur has been calculated for this purpose at various slope angle and dyke height. Shear strength properties used here had been collected from laboratory tests and studying the effect of vetiver root on soil properties. Some considerations also been taken from Nasrin (2013). Table 4.4 and 4.5 shows the factor of safety (both with and without vetiver plantation) for Baliapur and Nildumur slopes respectively at different slope angle and dyke heights. It can be seen here that, for Baliapur site, for 1 meter vertical height of dyke without vegetation factor of safety was 4.02 and it becomes 5.48 with the use of vegetation which is 36% higher. For a three meter height of dyke, factor of safety become 41% higher with the application of vetiver in slope. This increase in factor of safety become 45% when the dyke height become 5m. Thus it can be said that, application of vetiver grasses over the slope increases factor of safety around 35% ~ 45% for Baliapur site. On the other hand, in Nildumur site, for 1 meter vertical height of dyke without vegetation factor of safety was 2.58 and it becomes 4.24 with the use of vegetation which is 64% higher. For a three meter height of dyke, factor of safety become 60% higher with the application of vetiver in slope. This increase in factor of safety become 53% when the dyke height become 5m. Thus it can be said that, application of vetiver grasses over the slope increases factor of safety around 50% ~ 65% for Nildumur site. This increment of factor of safety depends on soil shear strength properties other than effect of root morphology of vetiver grass. Figure 4.24 and 4.25 represents the results in graphical form. In generally, it can be observed here that, factor of safety for slopes become higher with the presence of vetiver on the slope soil.

4.7 Cost Analysis

A comparative cost analysis over the general slope protection solutions has been done among five types of slope protection solution. These are i) Revetment Stone Protection solution; ii) Masonry Wall protection Solution; iii) Revetment stone with vegetation

Table 4.4 Factor of safety for different slope ratio and dyke height at Baliapur

		V. Height = 1m		**V. Height = 3m**		**V. Height = 4m**		**V. Height = 5m**	
Slope Ratio	**Angle of Slope**	**FS without Vetiver**	**FS with Vetiver**	**FS without Vetiver**	**FS with Vetiver**	**FS without Vetiver**	**FS with Vetiver**	**FS without Vetiver**	**FS with Vetiver**
1:0.5	63.43	3.72	4.88	1.33	1.78	1.03	1.39	0.85	1.15
1:0.75	53.13	3.17	4.2	1.19	1.62	0.94	1.3	0.79	1.1
1:1	45	3.10	4.15	1.21	1.68	0.97	1.37	0.83	1.18
1:1.25	38.66	3.22	4.34	1.3	1.81	1.06	1.49	0.91	1.3
1:1.5	33.69	3.44	4.66	1.41	1.99	1.16	1.65	1.01	1.45
1:1.75	29.74	3.71	5.05	1.55	2.19	1.28	1.83	1.12	1.62
1:2	26.56	4.02	5.48	1.7	2.41	1.41	2.02	1.23	1.79

Table 4.5 Factor of safety for different slope ratio and dyke height at Nildumur

		V. Height = 1m		**V. Height = 3m**		**V. Height = 4m**		**V. Height = 5m**	
Slope Ratio	**Angle of Slope**	**FS without Vetiver**	**FS with Vetiver**	**FS without Vetiver**	**FS with Vetiver**	**FS without Vetiver**	**FS with Vetiver**	**FS without Vetiver**	**FS with Vetiver**
1:0.5	63.43	2.21	3.54	0.85	1.38	0.68	1.09	0.58	0.91
1:0.75	53.13	1.92	3.11	0.81	1.3	0.67	1.07	0.59	0.92
1:1	45	1.92	3.12	0.87	1.39	0.74	1.17	0.66	1.02
1:1.25	38.66	2.02	3.3	0.96	1.54	0.83	1.32	0.75	1.15
1:1.5	33.69	2.18	3.57	1.07	1.72	0.93	1.48	0.85	1.31
1:1.75	29.74	2.37	3.89	1.19	1.92	1.05	1.66	0.96	1.47
1:2	26.56	2.58	4.24	1.32	2.12	1.16	1.85	1.07	1.64

protection; iv) Total vegetation with Geo-Jute solution and v) only vegetation solution. The revetment stone protection had been proposed by Hamid and Kabir. In general, a 300mm layer of stone is placed over geotextile. Vertical and horizontal anchor is also used to attach with ground. It is a hard nature solution and costs about 1874 Tk (US$24) per square meter slope protection. The cost analysis has been done based on rate schedule of 2011 from Public works Department; Government of Bangladesh and general protection height is taken as 4.5m at 1:2 slope. Another hard nature protection

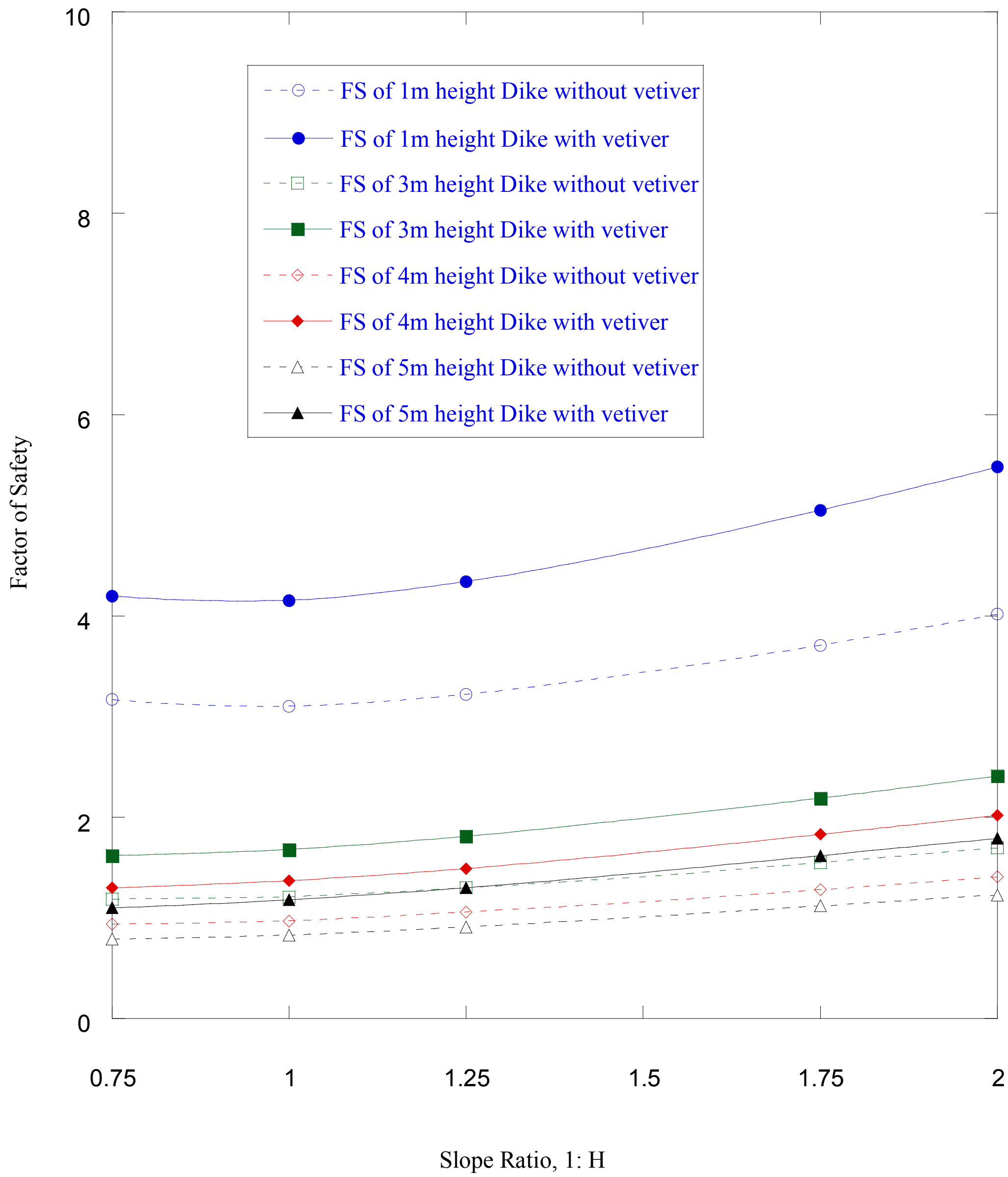


Figure 4.24 Factor of safety (with and without use of vetiver) at different slope ratio for Baliapur Site

system is “Masonry wall protection” system. It’s construction cost for per unit square meter is 4290 Tk (US$55). This solution is found as the most costly solution among the others. Another two protection solution is proposed here which are much less costly than the previous two. Vetiver grass is used with and without revetment structure. Protection including revetment stone will costs 855 Tk (US$11) per square meter and vetiver application with jeo-jute will costs 124 Tk (US$ 1.59) per square meter.

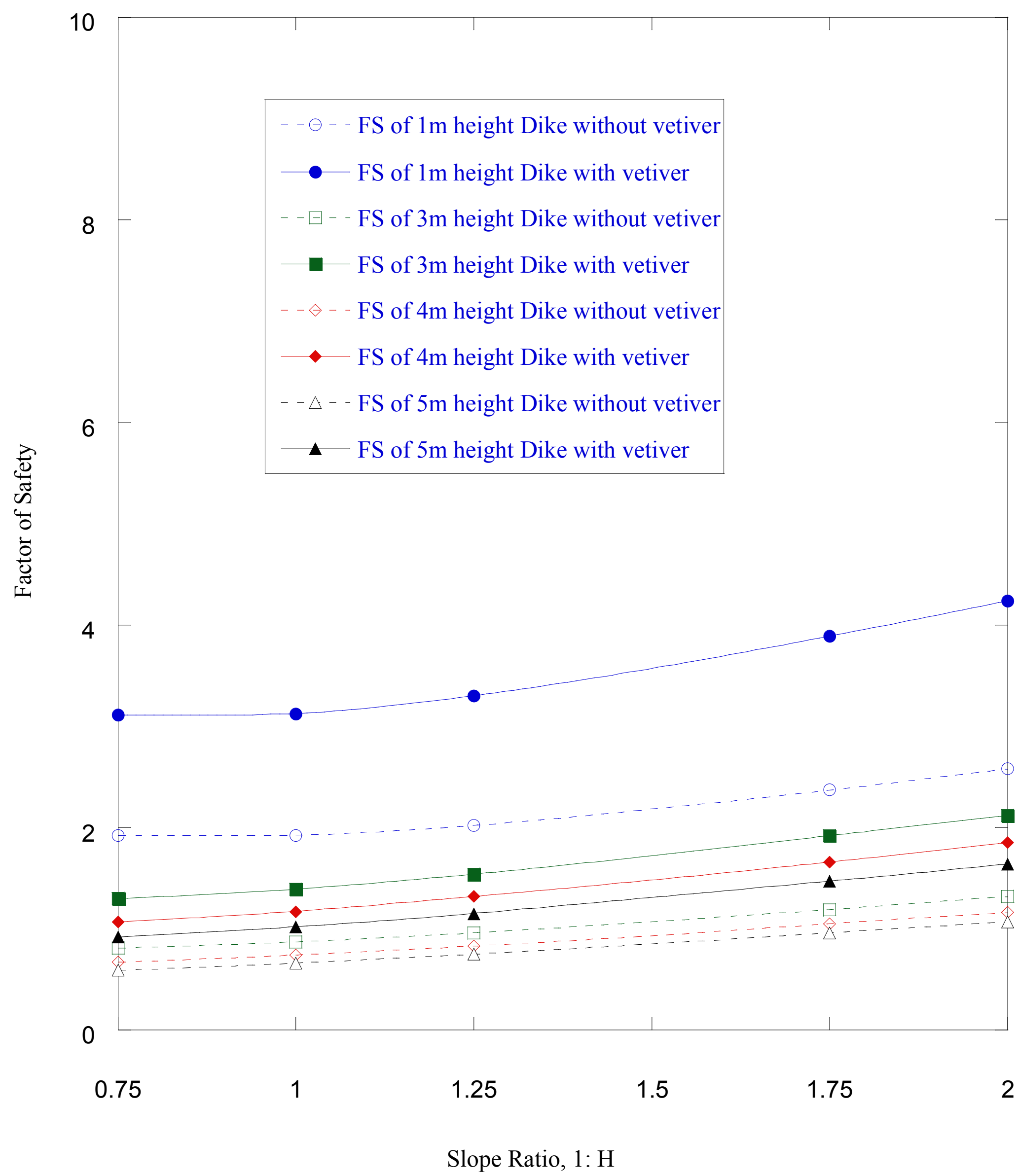
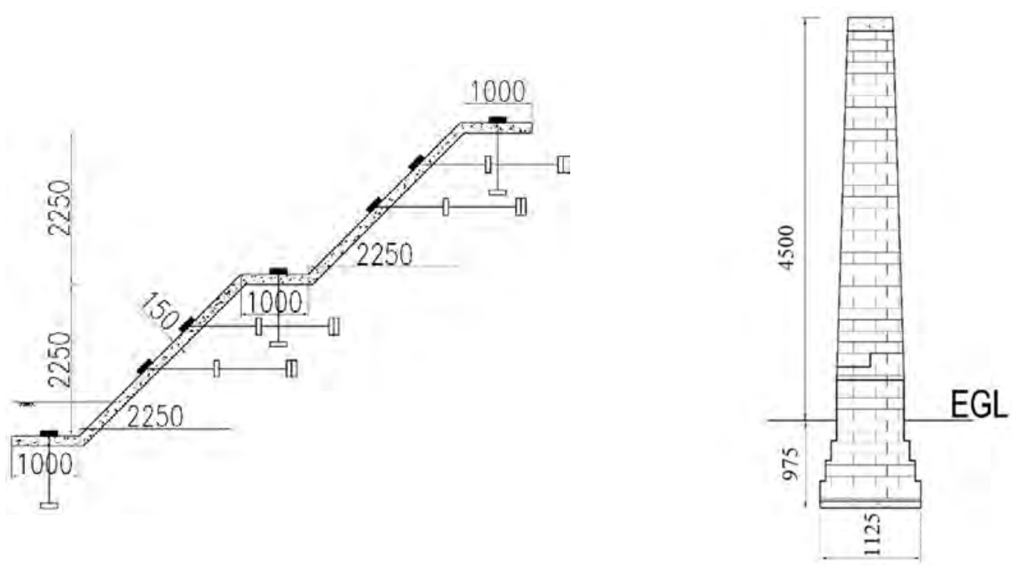


Figure 4.25 Factor of safety (with and without use of vetiver) at different slope ratio for Nildumur Site

Table 4.4 Costing of four types of slope protection solutions

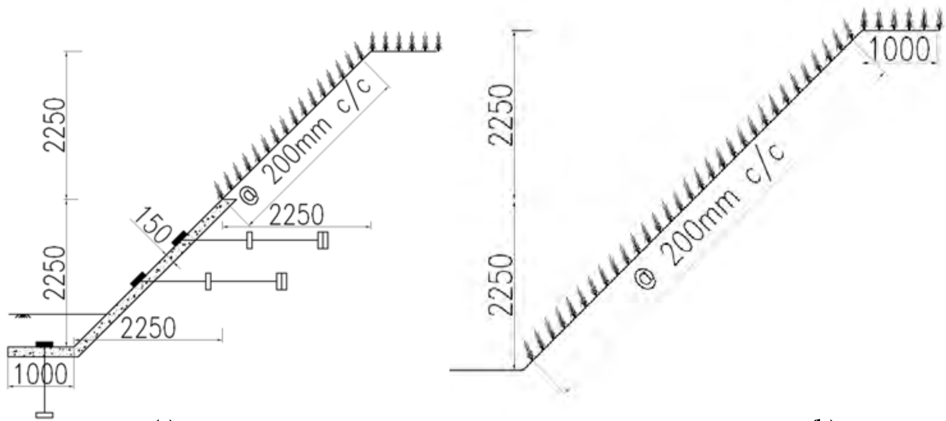
Type of Slope Protection	Cost per Square Meter (Tk)	Cost per Square Meter (US $)
Revetment Stone Protection	1874	24
Masonry Wall Protection	4290	55
Revetment Stone with Vegetation protection	855	11
Total Vegetation with geo-jute Protection	124	1.59
Protection only with vetiver grass	35	0.45

Protection with vetiver only will cost only 35 Tk (US$ 0.45) per square meter. Table 4.4 shows costing of various slope protection system. Considering the costing above costing of various types of protection work, protection with vativer is much feasible than others.



(a) (b)

Figure 4.26 Haor slope protection solution: (a) revetment stone protection proposed by Kabir et al. and (b) Masonry wall type protection.



(a) (b)

Figure 4.27. Slope protection using vetiver and geo-jute (a) Protection with combination of revetment and Vetiver grass, (b) Protection with Vetiver grass with geo-jute.

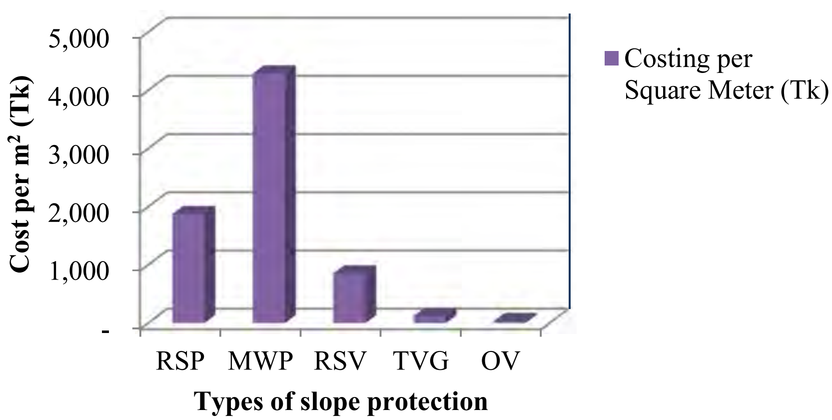


Figure 4.28 Graphical presentation of cost of four types of haor village slope protection solutions (RSP = Revetment stone protection, MWP = Masonry wall protection, RSV = Revetment stone protection with vetiver, TVG = vetiver with geo-jute, OV =only vetiver)

Figure 4.26 and 4.27 shows different types of slope protection system in sketch which is considering for costing purpose. Finally, Figure 4.28 shows the comparative costing of these protection systems. From this figure it is found that, protection with vetiver grass is the most easier and cheap protection solution. It can also be found here that, application of vetiver grass would be a cheaper solution for coastal embankment protection. Slopes of embankments could be covered with vetiver grass with specified density and it would work as natural protection in lieu of RC blocks.

4.8 Design Methodology

Vetiver grass helps to protect the slope from erosion. But initial application procedure of vetiver plant is not same for every places. It varies with the site condition. First of all if the plantation work is longer than 2~3 days then vetiver grasses need to protect from dried out. Watering to be done over the stored pile of vetivers. If it take longer than 10 days or more nursery should be prepared at site. If the application site is new one, slopes must be prepared evenly. In case of old site cleaning must be done properly along with filling of nay existing hole. Spacing of vetiver grasses in a dry embankment (which is vulnerable to rain and wind cut erosion) would be different than embankment with wave actions. Density of vetiver plantation would be higher in lower zone than upper in this type of embankment. On the other hand spacing of vetiver plant for Haor zone would be different than hilly area. Thus, design of vetiver plantation depends on surrounding factors and past experiences

4.9 Installation Guideline for Dykes

4.9.1 Site Preparation

Before application of vetiver grass over an embankment necessary site preparations are very important. If the embankment is newly constructed, first it is to decide whether geo-jute to be used or not for primary protection. If the slope is steeper than 1:2 and more, then geo-jute should be used before plantation. Moreover, if embankment is made of silty type soil or it is vulnerable to wave action of water from river/bills alongside it, geo-jute is also to be used. Before laying geo-jute, site must be leveled and any sort of weeds to be removed. Then geo-jute to be laid with metal "U" shaped hooks over the embankment with at least 300mm overlapping on sides. Figure 4.29 shows geo-jute laying procedure and metal hook insertion at site to lock geo-jute with soil. After that plantation could be done. If it is a older embankment but vulnerable to erosion, geo-jute should also be used before vetiver plantation. In case of mild slope, direct vetiver grass could be planted. In both cases site should be cleaned properly, weeds should be removed properly and leveled.

(a)

(b)

Figure 4.29 Geo-jute laying; (a) roll placing at site, (b) attaching geo-jute with U hook

1.10 4.9.2 Vetiver Grass Collection and Storage Systems

Vetiver grass could be collected either from existing grown land or nursery. To collect vetiver grasses from existing land some procedures to be maintained. If the land looks too dry, watering should be done before uprooting to wet the soil. Then, metal hoe could be used to uprooting the grass. Shoots could be trimmed leaving 6” ~ 8” with the roots.

(a)

(b)

Figure 4.30 Collection of vetiver grasses from naturally grown land, (a) separating from big stem, (b) uprooted vetiver grass

Extra soil should be cleaned before packing as it would increase the weight of the package. Figure 4.30 shows collection of vetiver grass from naturally grown field. These grasses could be transported in any type of bags keeping the natural temperature around itself. Storage of vetiver grass for a plantation site will depend on the length of plantation time. At site, if vetiver grass plantation could be completed within three or four days, temporary shed might be used to store the grasses closer to site. Sunshine is important for vetivers. So grasses must have sun shine during it's storage time. Watering could be done over the stored pile of grasses to keep them alive. On the other hand, if plantation procedure is periodical and time consuming then on site nursery could be made.

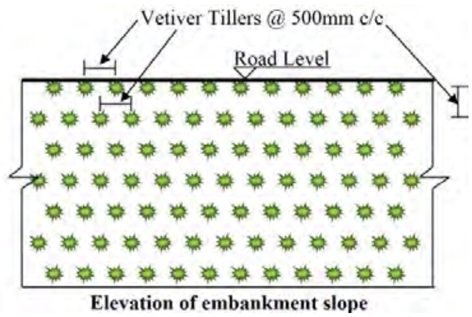
Figure 4.31 Vetiver transportation and storing, (a) Carrying vetiver grasses in bag (b) grown vetiver grasses in nursery

In this case, grasses needed to be separated from bigger crowns to smaller ones. Then these smaller grasses to be planted in polybag filled with soil and store them. Around 3200 tillers could be stored in 100 square feet area using polybag system. Figure 4.31 shows transported vetiver in a sack bag and stored vetiver in a nursery. Regular watering and sunshine is necessary at this stage. Within few days new leafs will produce and will be ready to be planted.

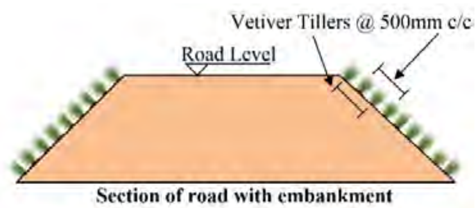
4.9.3 Plantation Procedure

Plantation of vetiver grass over the road embankment depends on its site condition. If a new embankment has been constructed and no watery action would hamper it, then vetiver grasses could be planted in rhombus pattern. Figure 4.32 shows the pattern of plantation in a road embankment. In this pattern horizontal and vertical both distance could be maintained at 500mm c/c.

To prevent the erosion from wave action of river/haor vetiver grass also to be planted in a rhombus pattern. But this time spacing should be reduced to 200 mm c/c in both direction. Figure 4.33 shows the pattern of plantation in a river/haor/saline zone embankment.

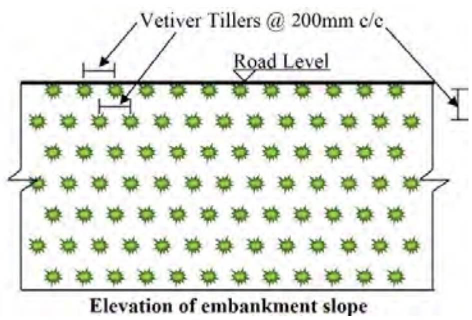


(a)

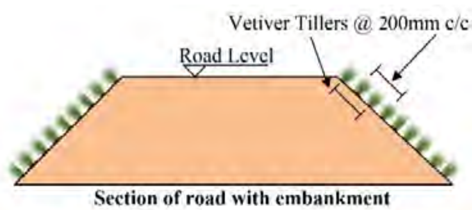


(b)

Figure 4.32 Vetiver plantation at road embankment slope: (a) elevation and (b) section



(a)



(b)

Figure 4.33 Vetiver plantation at river/haor/saline zone embankment slope: (a) elevation and (b) section

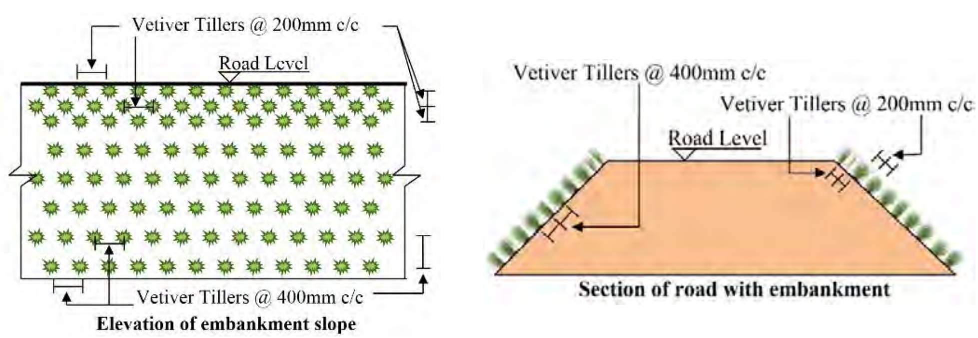


Figure 4.34 Vetiver plantation at embankment slope: elevation (left) and section (right)

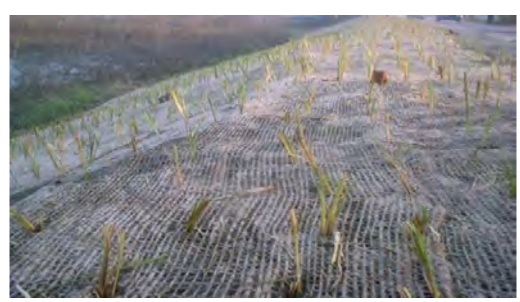


Figure 4.35 Vetiver plantation at embankment slope: plantation procedure and newly planted vetiver (right)

If the embankment is vulnerable to rain cut erosion then vetiver plantation to be done as per Figure 4.34 horizontal and vertical distance for tor rows of the embankment would be 200 mm c/c. rest of the plantation to be done at a spacing of 400 mm c/c distance. Figure 4.35 shows the plantation procedure at embankment slope.

4.9.4 Watering Procedure

Initially, watering is important for vetiver plantation. Watering to be done twice a day for next seven days after plantation. It is to note here that, within this seven days newly planted grasses become yellowish in color and seems to die. But after seven days new leaf start to grow from roots. Once new leaf start to grow, watering become optional. It will take only two months to grow full for these grasses.

4.9.5 Regular Maintenance Procedure

Maintenance is very small for vetiver grass which is also an advantage for planting it. After it's full growth within three months of initial plantation, shoots could be cut down to 300 mm which prevents unnecessary breaking of shoots. As growth become slower during winter season, two months of cutting period could be longer then. Inflorescence of vetiver is important for reproduction. It is advised to wait up to inflorescence period to be completed before cutting for first time.

4.10 Summary

Laboratory test and field tests were conducted to determine the soil properties and strength of soils. Growth of vetiver was studied at BUET premises. Both field trials and model studies were conducted to investigate the effectiveness of vetiver grass in slope protection especially for the saline zones of Bangladesh. The main findings of this study are:

(a) Field trials had been conducted at selected sites of Satkhira district which is under saline zone. Necessary physical and nutrient analysis test had been conducted for the soil samples collected from the study areas. From the results, it was found that, soils are silty in nature. Presence of clay and sand is very negligible in soil samples. Amount of electrical conductivity is also a main feature of this type of soil. Amount of EC for Kaliganj, Baliapur and Nildumur soils were 1.57, 3.93, 4.19 (ds/m) respectively.

(b) Main causes of slope failure of saline zone is found as wave action due to natural disaster. Frequently natural disaster attacks at coastal zone of Bangladesh and huge area become flooded which causes failure of slopes.

(c) Among the locally available grasses and vegetation vetiver (*Vetiveria zizaniodes*) is found suitable for saline zone for it's growth rate of root and composition of root morphology in the soil. Though growth rate of vetiver root is slower in high saline zone, it can survive in saline condition and serve the purpose of protection.

(d) Application of vetiver grass increases the factor of safety of the slope. Implementation of steeper slope is possible with the presence of vetiver grass application in proper manner. Thus it saves cost of land acquisition significantly.

(e) Plantation of vetiver grass in proper spacing over the embankment of saline zone of Bangladesh would be a solution for protection of embankment/dykes. For the embankments of saline zone (natural disaster prone zone), plantation of vetiver at 200 mm c/c distance in both vertical and horizontal direction works well. This system is much cheaper than other conventional systems. This costs only 35 Tk per square meter of plantation which is 53 times lower than the revetment stone protection.

(f) Application of vetiver grass would be different based on site condition. Installation procedure for new embankment to old one is different. Moreover spacing of vetiver grass would be different for Haor area, Hilly area, Saline area etc. An installation guideline has been developed in this study for vetiver grass plantation over embankments.

Chapter Five

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

Main purpose of this study was to develop a climate resilient slope protection method for saline zone of Bangladesh. Thus biotechnology using vetiver grass (*Vetiveria zizaniodes*) had been selected as a slope protection measure. This grass was chosen against *kans* for it's root morphology and better root growth rate. Field trials had been conducted to determine the effectiveness. Growth rate was analyzed against physical and chemical properties of soil of the saline zone. Model test had been conducted at BUET premises to determine the erosion of vetiver planted slopes. Cost analyses also done to compare the costing of vetiver plantation at embankment against other common systems. Finally, a guideline has been developed for plantation of vetiver grass for different types of embankments.

5.2 Findings of the Study

Main findings of the study obtained from field trials and laboratory tests are summarized below.

5.2.1 Characteristics of Soil and Causes of Slope Failure at Saline Zone

Field trials had been conducted at selected sites of Satkhira district which is under saline zone. Necessary physical and nutrient analysis test had been conducted for the soil samples collected from the study areas. From the results, it was found that, soils are silty (90%) in nature. Presence of clay and sand is very negligible in soil samples. Amount of electrical conductivity, EC is also a main feature of this type of soil. Amount of EC for Kaliganj, Baliapur and Nildumur soils were 1.57, 3.93, 4.19 (ds/m), respectively.

Main causes of slope failure in saline zone of Bangladesh are floods due to natural calamities like cyclone, typhoon, tidal surge etc. Lack of compaction, poor constriction, poor maintenance and unprotected steep slopes accelerate their failure.

5.2.2 Selection of Suitable Vegetation for Slope/Embankment Protection in Saline Zone

To select suitable vegetation, growth study had been conducted at BUET premises for vetiver grass (Vetiveria zizanioides) collected from different sources and Kans (Saccharum spontaneum). It is found that shoot growth of Kans was better but comparing growth and morphology of root for locally available vetiver grass (Vetiveria zizanioides) was best among them. Thus vetiver grass was selected as a suitable vegetation for plantation at dyke slope to protect it.

5.2.3 Sustainable Slope Protection for Dykes in Saline Zone of Bangladesh

It is found that growth of vetiver is different depending on amount of salinity presence in the soil. Vetiver grows very fast in the low saline zone (shoot grows 178cm in 19 weeks and root grows 49cm in 56 weeks), but growth rate was slow for high saline zone (shoot grows 47.5cm in 48 weeks and root grows 30cm in 56 weeks) and moderate saline zone (shoot grows 130cm in 17 weeks and root grows 34cm in 56 weeks).

Plantation of vetiver grass in proper spacing over the embankment of saline zone of Bangladesh would be a solution for protection of embankment/dykes. For the embankments of saline zone (natural disaster prone zone), plantation of vetiver at 200 mm c/c distance in both vertical and horizontal direction works well. It increases the factor of safety for stability of slopes by 36% to 65% depending on properties of soil. With the application of vetiver grass over the slopes, slopes could be steeper than conventional system. Moreover, this system is much cheaper than other conventional protection systems. This costs only BDT 35 per square meter of plantation which is at least 50 times lower than the common RC revetment structures.

5.2.4 Design Methodology/Installation Guideline for Slope Protection of Embankments/Dykes

Application of vetiver grass would be different based on site condition. Installation procedure for new embankment to old one is different. Moreover spacing of vetiver grass would be different for Haor area, Hilly area, Saline area etc. An installation guideline has been developed in this study for vetiver grass plantation over embankments.

Plantation of vetiver grass over the embankment as slope protection measure is sustainable for environment and low cost also. It can easily be applied depending on site condition with locally available labors. Less involvement of skilled manpower for this plantation makes it more suitable for remote places where regular protection could not reach due to lack of heavy budget sanction. Thus, vetiver plantation for slope protection has huge opportunity in Bangladesh and government can use this solution as climate resilient low cost sustainable solution for 21st century.

5.3 Future Recommendations

The main objectives of this research is to investigate the effectiveness of vetiver grass in protecting dykes/embankment slopes in the saline zone of Bangladesh where other vegetation rarely grows. During the study, it was felt that the following studies may be conducted in future:

(a) In this study, three study areas were taken in considerations, where more study area might show different growth rate.

(b) Plantation in the study area were done at the end of the monsoon when salinity in ponds were higher than other months. As salinity in the ponds become low in winter season, growth study could be done planting in winter.

(c) This study were conducted for saline zone. Plantation could be studied on other zone also like hilly area, haor area and reclaimed area.

(d) Extensive model analysis could be done against behavior of vetiver grass over steep slope in an embankment. Propagation of wave could be done using regulated motor to maintain the wave speed constant and measurable.

(e) Cost analysis were done based on PWD rate analysis. More detail analysis could be conducted using realistic unit cost.

(f) Study can be conducted to develop reclaimed land using contaminated soil cleaned with vetiver grass.

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