VETIVER SYSTEM FOR INFRASTRUCTURE PROTECTION

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ABSTRACT

The use of vegetation as a bio-engineering tool for land reclamation, erosion control and slope stabilization have been implemented for centuries and its popularity has increased remarkably in the last decades. This is partly due to the fact that more knowledge and information on vegetation are now available for application in engineering designs, but also partly due to the cost-effectiveness and environment-friendliness of this "soft", bio-engineering approach.

Vetiver, a fast growing grass, possesses some unique features of both grasses and trees by having profusely grown, deep penetrating root system that can offer both erosion prevention and control of shallow movement of surface earth mass. Experiments revealed that vetiver grass roots are very strong with an average tensile strength of 75 MPa or one-sixth of ultimate strength of mild steel. The massive root system also increases the shear strength of soil, thereby appreciably enhances slope stability. In addition to its unique morphological characteristics, vetiver is also highly tolerant to adverse growing conditions such as extreme soil pH, temperatures and heavy metal toxicities.

Vetiver Grass Technology (VGT), or Vetiver System (VS), involves the correct application of this unique grass in erosion and sediment control, land reclamation, rehabilitation and stabilization etc. Having been introduced into Vietnam in 1999 by The International Vetiver Network (TVN) and the World Bank and since actively promoted by the Vietnam Vetiver Network (VNVN), the grass has become widely known throughout the country with numerous successful applications for road cut-slope stability enhancement, erosion/flood control of embankments, dykes, riverbanks, sand dune fixation as well as waste and leachate control etc.

1. INTRODUCTION

Land disturbance by construction activities has resulted in soil erosion increases from 2 to 40, 000 times the pre-construction rates with sediment being the principal transport mechanism for a range of pollutants entering water courses.

The use of vegetation as a bio-engineering tool for land reclamation, erosion control and slope stabilization have been implemented for centuries and its popularity has increased remarkably in the last decades. This is partly due to the fact that more knowledge and information on vegetation are now available for application in engineering designs, but also partly due to the cost-effectiveness and environment-friendliness of this "soft", bio-engineering approach.

Although vetiver grass (*Vetiveria zizanioides L.*) has been used first by Indian farmers for soil and water conservation more than 200 years ago, its real impact on land stabilization/reclamation, soil erosion and sediment control only started in the late 1980's following its promotion by the World Bank. While it still plays a vital role in agriculture, the unique morphological, physiological and ecological characteristics of the grass including its tolerance to highly adverse growing conditions and tolerance to high levels of toxicities provide an unique bio-engineering tool for other, non-agricultural applications such as land stabilization/reclamation, soil erosion and sediment control.

2. SPECIAL CHARACTERISTICS OF VETIVER GRASS SUITABLE FOR INFRATRUTURE PROTECTION PURPOSE

2.1 Morphological and Physiological Characteristics

Due to the following unique attributes Vetiver grass has been researched, tested and developed in to a very effective bioengineering tool:

- Extremely deep and massive finely structured root system, capable of reaching down to 2 to 3m in the first year. This extensive and thick root system binds the soil and at the same time makes it very difficult to be dislodged and extremely tolerant to drought.
- The tensile strength of vetiver roots varies between 40-180 Mpa. The mean design tensile strength is about 75 Mpa - **equivalent to approximately one sixth of mild steel**. This indicates that vetiver roots are as strong as, or even stronger than that of many hardwood species, which have been proven positive for root reinforcement in steep slopes.
- New roots are developed from nodes when buried by trapped sediment. Vetiver will continue to grow with the new ground level eventually forming terraces, if trapped sediment is not removed
- Stiff and erect stems which can stand up to relatively deep water flow (0.6-0.8m).
- Dense hedges when planted close together, reducing flow velocity, diverting runoff water and forming a very effective filter.
- Tolerance to extreme climatic variation such as prolonged drought, flood, submergence and extreme temperature from -14^{o}C to 55^{o}C.(Truong *et al*, 1996)
- Ability to re-grow very quickly after being affected by drought, frost, salt and other adverse soil conditions when the adverse effects are removed .
- High level of tolerance to soil acidity, salinity, sodicity and acid sulfate conditions, (Le and Truong 2003).

2.2 Ecological Characteristics

Although vetiver is very tolerant to some extreme soil and climatic conditions, it is intolerant to shading. Shading will reduce its growth and in extreme cases, may even eliminate the grass. Therefore vetiver produces best growth in the open and weed control may be needed during establishment phase.

Vetiver grass can be eliminated easily either by spraying with glyphosate or uprooting and drying out.

2.3 Mechanical Characteristics

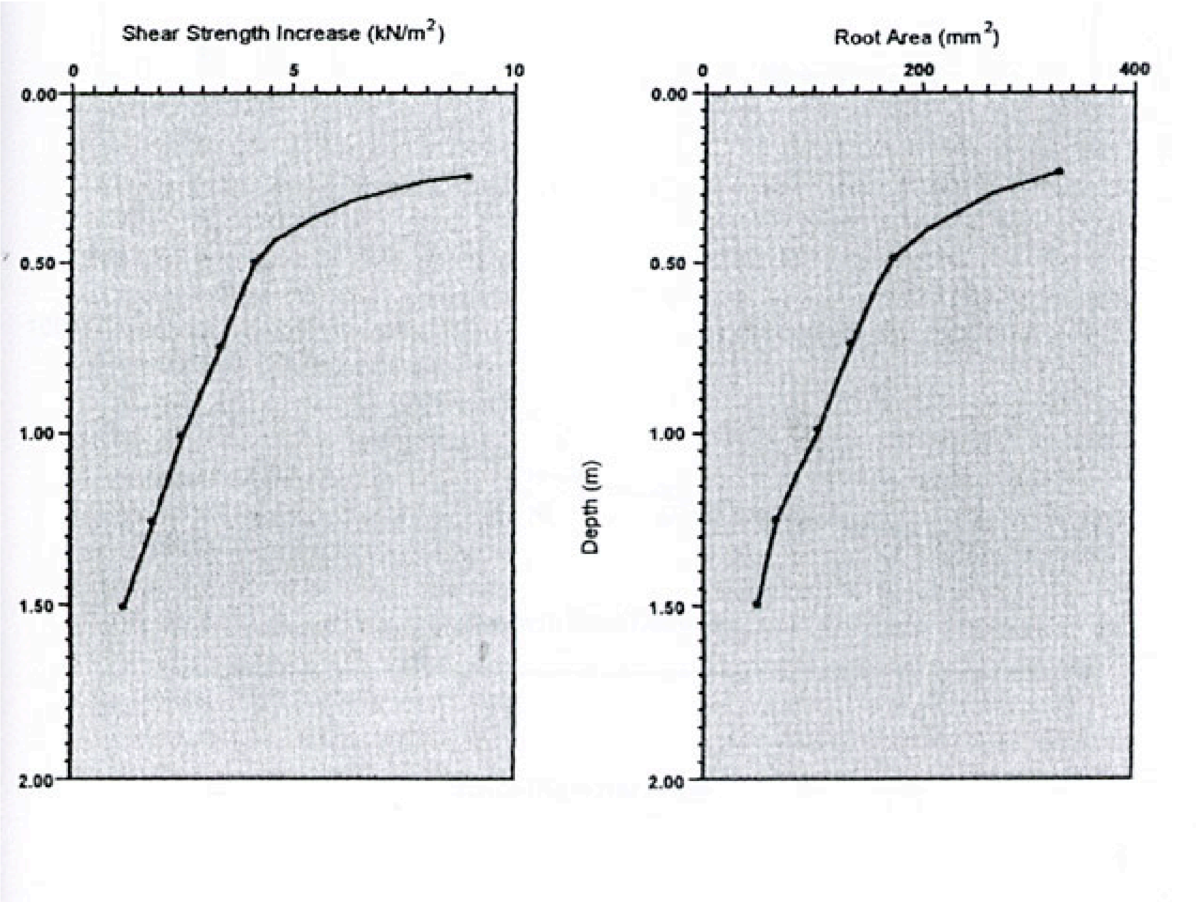
2.3.1. Tensile and shear strength of vetiver roots

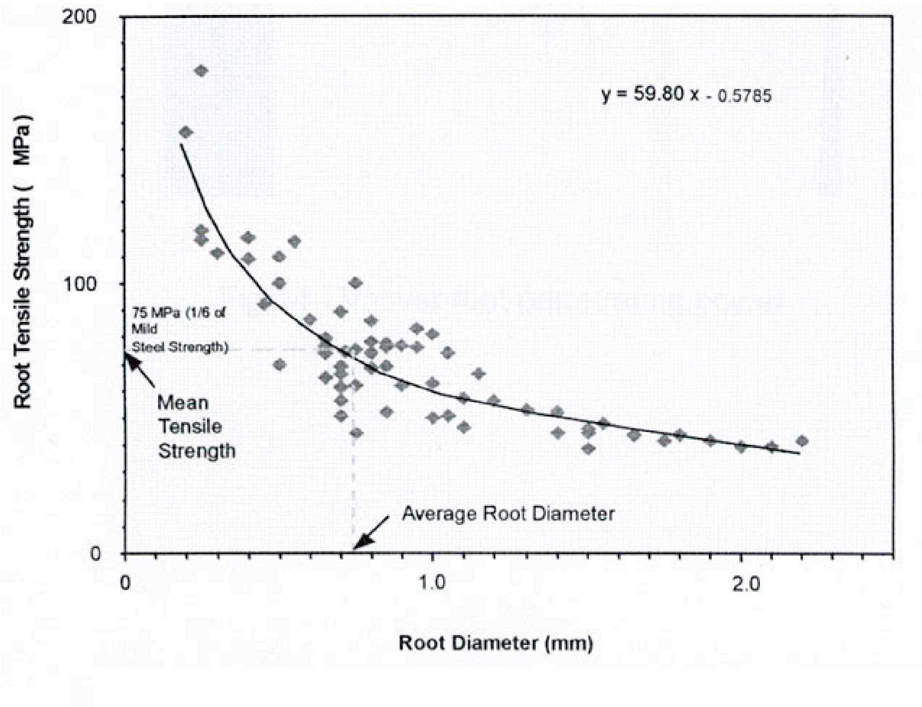
Hengchaovanich and Nilaweera (1996) showed that the tensile strength of vetiver roots increases with the reduction in root diameter, implying that stronger fine roots provide higher resistance than larger roots. The tensile strength of vetiver roots varies between 40-180 Mpa for the range of root diameter between 0.2-2.2 mm. The mean design tensile strength is about 75 Mpa (equivalent to approximately one sixth of mild steel) at 0.7-0.8

mm root diameter which is the most common size for vetiver roots. This indicates that vetiver roots are as strong as, or even stronger than those of many hardwood species which have been proven positive for slopes reinforcement.

In a soil block shear test, Hengchaovanich and Nilaweera (1996) also found that root penetration of a two year old Vetiver hedge with 15cm plant spacing can increase the shear strength of soil in adjacent 50 cm wide strip by 90% at 0.25 m depth. The increase was 39% at 0.50 m depth and gradually reduced to 12.5% at 1.0 m depth. Moreover, because of its dense and massive root system it offers better shear strength increase per unit fiber concentration (6-10 kPa/kg of root per cubic meter of soil) compared to 3.2-3.7 kPa/kg for tree roots.

Other less well known characteristics of Vetiver grass is it power of penetration. Its 'innate' strength and vigor enable it to penetrate through difficult soil, hard pan or rocky layers with weak spots. Vetiver roots basically behave like living soil nails or dowels of two to three meter depth. Together with its fast growing ability in difficult soil conditions, these characteristics make the grass a much better candidate for slope stabilization than other plants.





First intensive tensile strength research on vetiver roots was done by Diti Hengchaovanich. He showed that vetiver root strength is stronger than most trees and grass commonly used for steep slope stabilisation as shown in Table 1. (Hengchaovanich ,1998).

Table 1: Tensile Strength of Roots of Some Plants

Botanical name	***Common name***	Tensile strength (MPa)
Salix *spp*	Willow	9-36*
Populus spp	Poplars	5-38*
Alnus spp	Alders	4-74*
Pseudotsuga spp	Douglas fir	19-61*
Acer sacharinum	Silver maple	15-30*
Tsuga heterophylia	Western hemlock	27*
Vaccinum spp	Huckleberry	16*
Hordeum vulgare	Barley Grass, forbs Moss	15-31* 2-20* 2-7kPa*
Vetiveria zizanioides	Vetiver grass	40-120 (Average 75**)

Cheng *et al* (2003) supplemented the Diti Hengchaovanich's root strength research by conducting further tests on other herbs (grasses) as shown in Table 2. Although Vetiver has trhe second finest roots, its tensile strength is amost 3 times higher than on the plant tested.

Table 2: Diameter and tensile strength of root of various herbs

Grass	Mean diam. of roots (mm)	Mean tensile strength (MPa)
Late Juncellus	0.38±0.43	24.50±4.2
Dallis grass	0.92±0.28	19.74±3.00
White Clover	0.91±0.11	24.64±3.36
Vetiver	0.66±0.32	85.10±31.2
Common Centipede grass	0.66±0.05	27.30±1.74
Bahia grass	0.73±0.07	19.23±3.59
Manila grass	0.77±0.67	17.55±2.85
Bermuda grass	0.99±0.17	13.45±2.18

More recently a software developed by Claudio Amati, PE with the University of Milan to determine the additional sheer strength provided to soil by Vetiver roots in various soils under vetiver hedges treatments. This software is particularly suitable to assess the contribution of vetiver roots needed for the application of VS on steep batter stabilisation particularly earthen levees, where vetiver hedgerows will protect and consolidate the slopes and therefore the levees themselves.

2.3.2. Pore Water Pressure

Increase in water infiltration is one of the major effects of vegetation cover on sloping lands and there has been concern that the extra water will increase the pore water pressure in the soil which could lead to slope instability. However, field observations show much better counter-effects. First, planted on contour lines or modified patterns of lines which would trap and spread runoff water on the slope, the extensive root system of vetiver grass helps prevent localized accumulation of surplus water and distribute it more evenly and gradually. Second, the possible increased infiltration is also balanced by a higher, and again, gradually rate of soil water depletion by the grass.

Research in soil moisture competition in crops in Australia (Dalton *et al*, 1996) indicated that under low rainfall condition this depletion would reduce soil moisture up to 1.5m from the hedges thus increasing water infiltration in that zone leading to the reduction of runoff water and erosion rate. From geotechnical perspective, these conditions will have beneficial effects on slope stability. On steep (30-60^o) slopes the space between rows at 1m VI (Vertical Interval) is very close, this moisture depletion would be greater therefore further improve the slope stabilization process. However, in the very high rainfall areas, to reduce this potentially negative effect of vetiver grass on steep slopes, as an extra protection, vetiver hedges could be planted on a gradient of about 0.5% as in graded contour terraces to divert the extra water to stable drainage outlets (Hengchaovanich, 1998).

2.4 Hydraulic Characteristics

Hydraulic characteristics of vetiver hedges under deep flow were determined by flume tests at the University of Southern Queensland, Australia for flood mitigation on the flood plain of Queensland (Dalton *et al*, 1996) (Fig.1).

Where: q = discharge per unit width; y = depth of flow; y1 = depth upstream; So = land slope; Sf = energy slope; NF = the Froude number of flow.

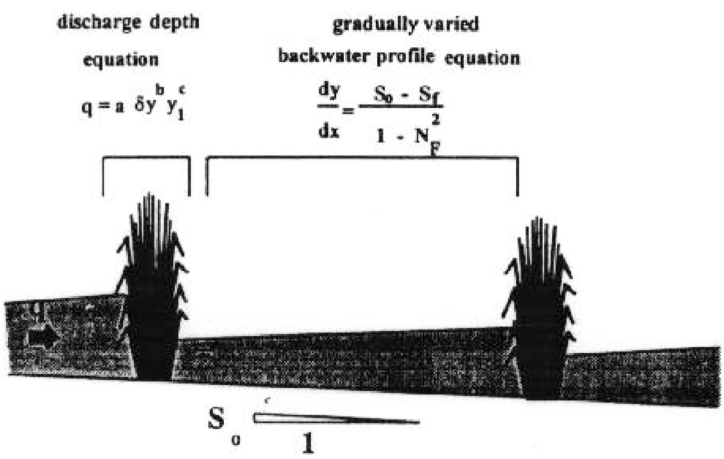


Fig. 1. Hydraulic model of flooding through Vetiver hedges (Dalton P. et al, 1998).

3. MAIN APPLICATIONS OF VGT IN CIVIL CONSTRUCTION

3.1 Batter Stabilisation

The main reasons for slope instability are surface erosion and structural weakness of the slope. While surface erosion often leads to rill and gully erosion, structural weakness will cause mass movement or land slip.

Normally a good vegetative cover provided by hydromulching is very effective against surface erosion and deep rooted plants such as trees and shrubs can provide the structural re-enforcement for the ground. However on newly constructed slopes, the surface layer is often not well consolidated, so rill and gully erosion often occurs on even well covered slopes. For these, structural re-enforcement is also needed very soon after construction, but trees are slow and often difficult to establish on such hostile environment. Vetiver grass is fast growing and with its very extensive and deep root system can provide the structural strength needed in a relatively short period of time. As mentioned above vetiver roots have been found to have average design tensile strength equivalent to one-sixth of mild steel. ***Therefore the role of vetiver in slope stabilisation should not be equated to that of hydromulching species and the cost of vetiver establishment should not be compared with that of hydromulching either.*** (Truong 1998)

3.2 River and stream bank stabilisation

The combination of the deep root system and thick growth of the vetiver hedges will protect the banks of river and stream under flood conditions. Its deep roots prevent it from being washed away while its thick top growth reduces flow velocity and its erosive power. In addition properly laid out hedges can be designed to direct water flow to appropriate areas.

Field trials using hydraulic characteristics determined by the above-mentioned tests (Dalton et al, 1996) showed that vetiver hedges were successful in reducing flood velocity and limiting soil movement, resulting in very little erosion in fallow strips and a young sorghum crop was completely protected from flood damage.

3.3 Runoff, Erosion Control, Water Diversion and Sediment Trapping

When planted in row, vetiver plants will form thick hedges and with their stiff stems these hedges can stand up to at least 0.6 m, forming a living porous barrier which slows and spreads runoff water. Appropriately laid out these hedges can act as very effective diversion structures spreading and diverting runoff water to stable areas or proper drains for safe disposal. As water flow slows down, its erosive power is reduced and any eroded material is trapped by the hedges. Therefore vetiver would be very effective in stabilizing table drains, gullies, creek banks and other drainage structures.

3.4 Protection of Concrete and Gabion Structures

The deep root system of the vetiver hedges will protect the ground surface next to the concrete structures such as culvert inlets and outlets, gabion structures or other solid barriers from scouring and erosion by high velocity flows. When planted upstream from the inlets, vetiver hedges will not only protect the inlets but they also trap the sediment outside the culverts where it can be easily cleaned if required.

4. ADVANTAGES AND DISADVANTAGES OF THE VS

The major advantage of VS over conventional engineering measures is its low cost. For slope stabilization in China for example, the saving is in the order of 85-90% (Xie, 1997 and Xia et al, 1999). Secondly, as with other bio-engineering technologies, VS provides a natural and environment friendly method of erosion control and land stabilization which 'softens' the harsh look often associated with conventional engineering measures such as concrete and rock structures. This is particularly important in urban and semi rural areas where the visual degradation of the environment caused by infrastructure development is often a major concern of local population. Thirdly, VS's maintenance costs are low in the long term. In contrast with conventional engineering structures, the efficiency of bio-engineering technology improves with time as the vegetative cover matures. VS requires a good maintenance program in the first 1-2 years but once established it is virtually maintenance free in the long term.

In Australia the cost advantage of VS versus conventional engineering methods ranges from 64% to 72%, depending on the method used (Braken and Truong 2001):

		USD
Culvert Protection		
Vetiver hedges		13.60
Grouted rock pitching		49.30
	Saving	**72%**
Road Shoulder Protection		
Vetiver hedges		11.60
Traditional concrete shoulder dykes		28.50
	Saving	**60%**
Table Drain Scour Protection		
Vetiver contour hedges		11.60
Traditional hard rock check dams		31.50
	Saving	**64%**
Miscellaneous Protection Work		
Vetiver hedges generally		11.60

Steel wire rock mattress	32.20
	Saving 64%

The main disadvantage of the VS applications is the intolerance to shading by the vetiver plants particularly in the establishment phase. Partial shading will reduce growth and severe shading can eliminate it in the long term by reducing its ability to compete with more shade tolerant species. However this weakness could be consider as a desirable characteristics in situations where a pioneer plant is needed to provide the initial stabilization, improve the micro environment for the introduction, either voluntarily or by planting of native endemic species.

Based on the above, it is clear that the advantages of using the VGT as a bio-engineering tool outweigh its disadvantages particularly when the vetiver plant is used as a pioneer species.

There is worldwide evidence to support the use of VS for embankment stabilization. Vetiver has been used successfully in Brazil, Central America, China, Ethiopia, India, Italy, Malaysia, Philippines, South Africa, Sri Lanka, Venezuela, Vietnam, and the West Indies for stabilization of roadsides. Vetiver has been used in conjunction with geotechnical applications for embankment stabilization in Nepal and South Africa

5. SOME MAJOR PROJECTS OF VS APPLICATIONS IN CIVIL CONSTRUCTIONS

5.1 Malaysia

The first and pioneer major highway work using vetiver as the main bio-engineering tool was conducted by Diti Hengchaovanich in Malaysia, on the East West Highway, which run through very steep mountainous and highly erodible terrain

5.2 Australia

A highway in the wet tropic of northern Australia, from Cooktown to Cape York Peninsular, was built on a very fragile and highly erodible soil. Major sections were washed out within 2-3 years, and all attempts of using conventional methods have failed, as a last resort, the conventionally trained engineers agreed to try VS. The result was so spectacular tthat they are now using VS for the whole highway of more tham 12 500km long.

5.3 Thailand

The Department of Highway in Thailand under the leadership of Mr.Surapol Sanguankaeo, has adopted VS as the main bio-engineering method for erosion and sediment control of the very extensive highway system in Thailand. Since 1993, The Vetiver System has been applied both in construction and maintenance projects of mountain roads in the Northern , Northeastern , and Southern regions of Thailand. The VS plays an importance role and replaces other techniques for erosion control, and solves highway slopes damage caused by erosion or scouring at the curved section of road, surface slope, the end of surface drainage systems and toe slope. Over 2.5 million slips are planted each year. The VS has been proven and accepted to be an effective and low-cost technique for erosion protection in roadworks, suitable for a sustainable economy with limited budget.

5.4 China

5.4.1 Highway stabilisation

China is a vast country, with a very extensive network of highways and railways connecting major population centers around the country. In the last 5 years the Chinese government has embarked on a very ambitious rail and road network, resulting in massive earth works and tunneling. Conventional engineering methods are not only very costly. they also very unstable themselves in mountainous regions due to very steep slope and highly erodible soils.

The total length of highways in China increased from 1,118,000 km in 1994 to 1,186,000 km in 1996. This was an annual increase of 34,000 km. However, due to financial limitations many highway embankments were not properly protected resulting in serious erosion.

For example, in Fujian Province 4,000 km of highways were built from 1992 to 1996. and in Guangdong Province in southern China, the highway construction has been up to 2900 km in the province by the end of 2005, increased by 1050 km or 56.8% compared with the year 2002. However, the construction and maintenance of highways has become more and more expensive. This is because many newly built highways go through mountain regions, which not only dig up mountains and excavate tunnels for their construction, but also must conduct steep slope stabilization work, usually using the "hard method". As a result, the construction cost has increased to about US$5~6.2 million/km, or even higher. Hence, cost reduction has been an important issue for highway departments and also their greatest concern. VS is just such a technique or "soft method" that can effectively abate construction fees of highways, especially those with steep slope stabilization. For example, one example, one company has done more than 100,000 m^2 of vetiver's slope stabilization projects along highways.

5.4.2 Dam wall stabilisation

In Guangdong Province alone, in the past two years, at least 5 vetiver projects in 5 different reservoirs and hydroelectric power stations. In one project in Guangxi, two batters with a total area of 6400 m^2 were executed with the Vetiver System. During the period of construction and maintenance in the second half of 2004, it experience very high temperature and long-term drought, with the monthly rainfalls from September 2004 through February 2005 were only 25.2, 0, 21.1, 10.9, 19.2, and 26.5 mm, respectively

As a result, almost all other species planted simultaneously with vetiver, such as *Ficus microcarpa*, *Hibiscus rosa-sinensis*, *Paspalum notatum*, and *Cynodon Dactylon*, were killed by high temperature or drought, but vetiver showed extremely strong vitality, and its survival rate exceeded 95%.

5.5 Vietnam

Vietnam is the latest successful story in VS application in infrastructure protection amongst other uses. Like China, Vietnam is also upgrading its transport system throughout the country, with new highways and roads etc.

5.5.1 *Ho Chi Minh highway*

This highway follows the old HCM trail, bordering the mountainous border between Vietnam and Laos, through numerous mountain passes and tropical jungles in the north and central sections. Therefore the terrain is extremely difficult and very costly to stabilise its batters and bridge abutments. While the southern section run passed extreme Acid Sulfate Soils, so the application of conventional engineering method is not an option due to its high cost of construction and maintenance, and also unstable themselves in mountainous regions due to very steep slope and highly erodible soils.

In 2003, after extensive trial in the central section, the Ministry of Transport approves the use of VS for slope stabilization in a series of National Highways, most notably along hundred of km of the Ho Chi Minh Highway. After more than 3 years, the results have been spectacular with hundreds of kilometers of batter covered by vetiver grass.

5.5.2 Mekong Delta flood control dike protection

The annual flood in the upper reach of the Mekong Delta, has caused misery to the population and crop destruction. To protect these, an extensive earthen dike system was built around population centers and fertile agricultural lands. When protected by trees and shrubs, these dikes are normally severely damaged but the flood, up to 3m a year. When vetiver grass was planted on the outside batter of these dikes no erosion occurred in the last 3 three years, often with record flood level.

5.5.3 River and canal bank stabilisation

- *Mekong Delta*

The heavy boat traffic in recent years caused severe erosion on the banks of rivers and canals in the Mekong Delta, threatening houses and road along these waterways. VS has been shown to be very effective in stabilising these banks.

- *Central Vietnam*

Flash flood in the rainy season and salt water intrusion are the natural phenomena in several provinces of coastal Vietnam. An Australian Aid project was initiated to mitigate these problems. Vetiver grass was exhaustively tested for 3 years 4 sites in Quang Ngai Province for riverbank, dyke erosion and flood control. In one occasion, despite the fact the grass was still at its young age, it managed to survive the flood season at the end of the same year and the results were so convincing that the Project Manager allowed for mass planting in many other sites of the province.

5.5.4 Coastal dune stabilisation

Coastal dune erosion by both wind and water in several coastal provinces of Vietnam, often destroyed valuable agricultural land and also roads and waterways in the region. Results to date are excellent and further details are presented by Dr Tran tan Van at his workshop.

6. CONCLUSION

From the results of research and the successes of numerous applications presented above, it is clear that we now have enough evidence that VS is a very effective and low cost bio-engineering tool for the stabilization and rehabilitation of disturbed lands caused by civil construction. ***However it must be emphasized that to provide an effective support for engineering structures, the two most important points are good quality of the planting material and the all-important appropriate design and correct planting techniques.***

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