R&D RESULTS ON UNIQUE CONTRIBUTES OF VETIVER APPLICABLE FOR ITS USE IN DISASTER MITIGATION PURPOSES IN VIETNAM

Tran Tan Van[1] and Paul Truong[2]
[1]Vietnam Coordinator Vietnam Vetiver Network
Email: van@rigmr.org.vn; trantv@gmail.com
[2]TVNI Director Responsible for Asia and South Pacific,
Brisbane, Australia
Email: truong@uqconnect.net

ABSTRACT

Extensive R&D results worldwide and in Vietnam in the last few years truly demonstrate that due to its various and unique characteristics, Vetiver grass is very suitable for mitigating different types of natural disasters, including slope instability, floods, bank erosion etc. The grass trunk and root systems are surprisingly extensive, which can, however, fully show its strength only when planted properly in rows and forming closed hedgerows. Among the most notable advantages of the grass are, for example, its tensile and shear strength, hydraulic excess pore pressure dissipation capacity, which are mobilized in one or another way, when applied for different types of natural disasters.

Keywords: Tensile and shear strength, hydraulic pore pressure, flow velocity

1. SPECIAL CHARACTERISTICS OF VETIVER GRASS SUITABLE FOR SLOPE STABILIZATION

1.1 Unique characteristics of Vetiver grass suitable for landslip mitigation

The following unique attributes of Vetiver grass have been researched, tested and developed into a very effective bioengineering tool for slope stabilization:

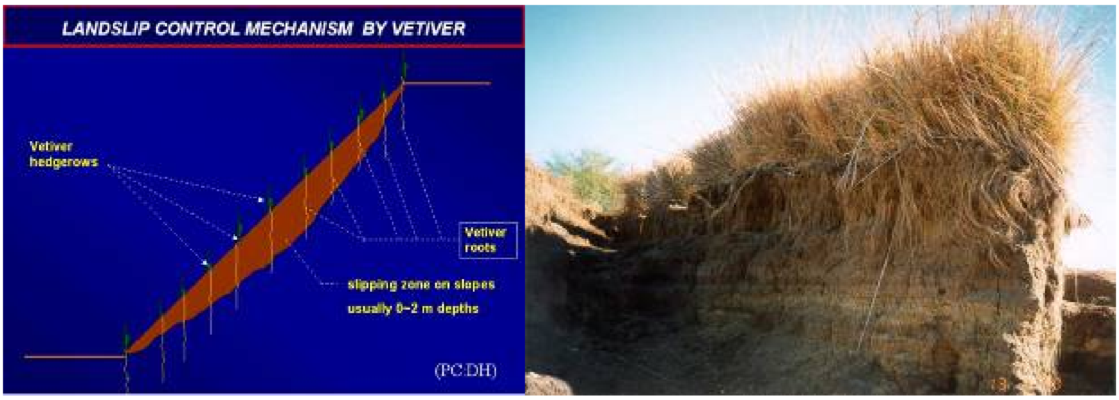
- Although classified as a grass, for land stabilization purposes, Vetiver plants behave more like fast growing trees or shrubs. Per unit area Vetiver roots are stronger than tree roots.
- Extremely deep and massive finely structured root system, capable of reaching down to 2 to 3m in the first year. Many experiments show Vetiver grass can reach 3.6m in the first 12 months on fill slope. 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 (Note that the grass certainly may not penetrate too far down into the groundwater table. Therefore at locations with high groundwater level, its root system may not be as long as in drier soil).
- Vetiver roots have very high tensile strength, which are as strong as, or even stronger than that of many hardwood species, which have been proven positive for root reinforcement in steep slopes.
- These roots have a mean design tensile strength of about 75 MPa, which is equivalent to 1/6 of mild steel reinforcement and a shear strength increment of 39% at 0.5m depth.
- Vetiver roots can penetrate compacted soil profile such as hardpan and blocky clay pan common in tropical soils, providing a good anchor for fill and topsoil.
- It forms dense hedges when planted close together, reducing flow velocity, spreading and diverting runoff water and forming a very effective filter for erosion control. The hedges slow down the flow, allowing more time for water to infiltrate into the ground.

- Acting as a very effective filter, Vetiver hedges help reducing the turbidity of surface run-off. 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. In addition, this sediment can also contain seeds of local plants hence facilitating the latter's growth.
- Tolerance to extreme climatic variation such as prolonged drought, flood, submergence and extreme temperature from -14°C to 55°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 Van Du and Truong, 2003).

Vetiver grass is very effective when planted closely enough in rows. Natural slopes, cut slopes and filled embankments can all be stabilized by planting Vetiver grass in contour lines. The deep, rigorous root system helps stabilize the slopes structurally while its shoot helps spread out the surface run-off, reduce erosion and trap sediments to facilitate the growth of native species.

Hengchaovanich (1998) also observed that Vetiver can grow vertically on slope steeper than 150% (~56°). It can grow faster and impart more reinforcement, making it a better candidate for slope stabilization than other plants. Another less well known characteristic which sets it apart from other tree roots is it power of penetration. Its 'innate' strength and vigor enable it to penetrate through difficult soil, hard pan or rocky layer with weak spots. It even managed to punch through asphalt concrete pavement. According to the author, indeed one can say that Vetiver roots basically behave like living soil nails or dowels of 2-3m depth, commonly used in 'hard approach' slope stabilization work. 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 (Fig.1).

Figure 1~~1~~: ***Left***: Principles of slope stabilisation by Vetiver; ***right:*** Vetiver roots reinforcing this dam wall kept it from being washed away by flood



1.2 Unique characteristics of Vetiver grass suitable for water disaster mitigation

To reduce water disasters such as flood, river bank and coastal erosion, dam and dike instability etc., Vetiver grass is planted in rows either parallel or across the water flow or wave direction. The following additional unique characteristics of the grass are also very useful:

- Due to its extraordinary root depth and strength, once fully established it is extremely resistant to high velocity flow. Experiences in north Queensland (Australia) show that Vetiver grass has withstood flow velocity higher than 3.5m/sec in river under flood conditions and up to 5m/sec in a drainage channel in southern Queensland.
- Under shallow or low velocity flow, the erect and stiff stems of Vetiver can act as a barrier to reduce flow velocity (i.e. increase hydraulic resistance) and trap eroded sediment. In fact, it can stand erect in the flow as deep as 0.6-0.8m.
- Under deep and high velocity flow Vetiver tops will bend down, providing extra protection to surface soil and at the same time reducing flow velocity.
- When planted on water retaining structures such as dams or dikes, Vetiver hedgerows help reduce the flow velocity, decrease wave run-up, over-topping and consequently the volume of water that may flow in the area protected by these structures. Vetiver hedgerows also help reduce the so-called retrogressive erosion that very often takes place when the water flow or wave retreats back after over-topping water retaining structures.
- Vetiver survives under prolonged submerged conditions as it is a wetland plant. Most recent trial on the Mekong River bank in Cambodia showed that vetiver can survive up to 15m deep and for at least 5 months under muddy water during flooding.

2. RESEARCH AND DEVELOPMENT ON VETIVER SYSTEM

2.1 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 at 0.7-0.8 mm root diameter which is the most common size for Vetiver roots (equivalent to approximately one sixth of mild steel). 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 (Fig.2 and Table 1).

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 (Fig.3). The authors explained that when a plant root penetrates across a potential shear surface in a soil profile, the distortion of the shear zone develops tension in the root; the component of this tension tangential to shear zone directly resists shear, while the normal component increases the confining pressure on the shear plane.

Figure 2: Root diameter distribution

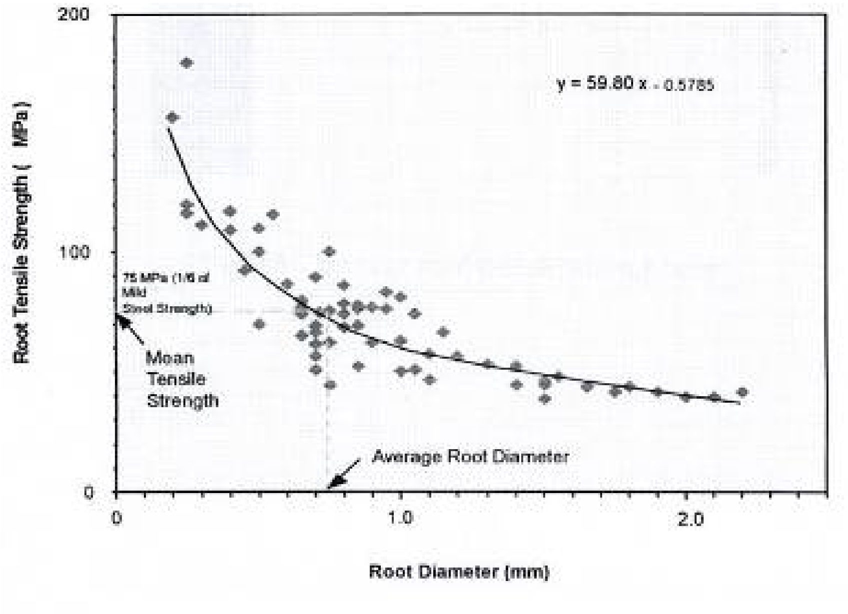


Table 1. Tensile strength of roots of some plants.

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 grasses as shown in Table 2. Although Vetiver has the second finest roots, its tensile strength is almost 3 times higher than all the plants tested.

2.2 Hydraulic characteristics

When planted in rows Vetiver plants will form thick hedges and with their stiff stems these hedges can stand up to at least 0.6-0.8m, forming a living barrier which slows and spreads runoff water. If properly 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.

Hydraulic characteristics of Vetiver hedges under deep flows were determined by flume tests at the University of Southern Queensland for the design and incorporation of Vetiver hedges into strip cropping layout for flood mitigation (Fig.4). There 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 (Dalton *et al*, 1996).

Figure 3: Shear strength of Vetiver root

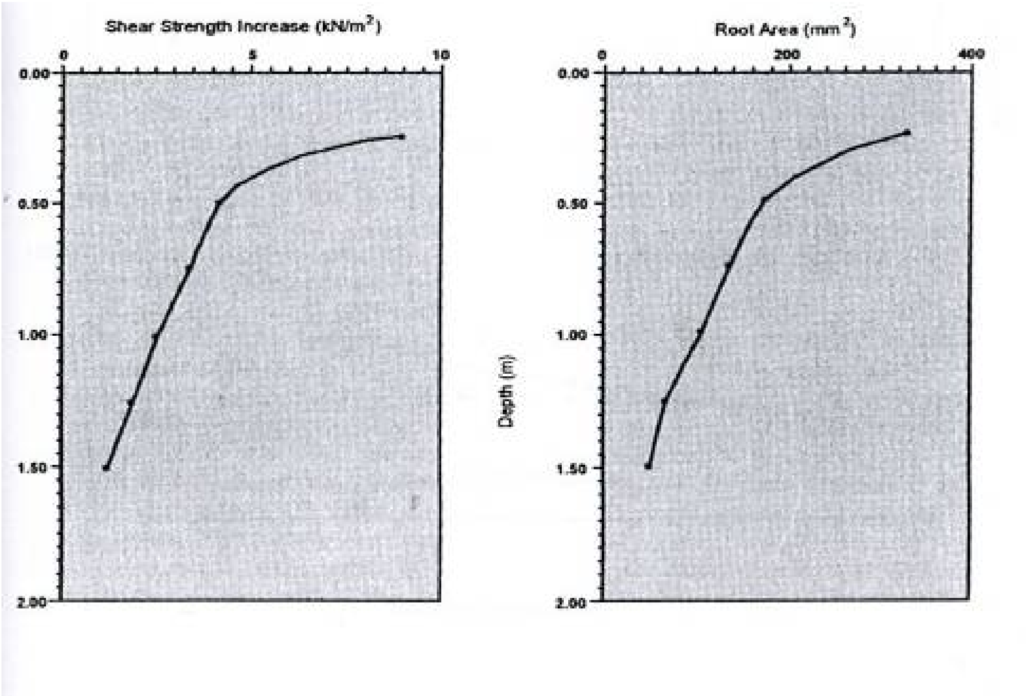


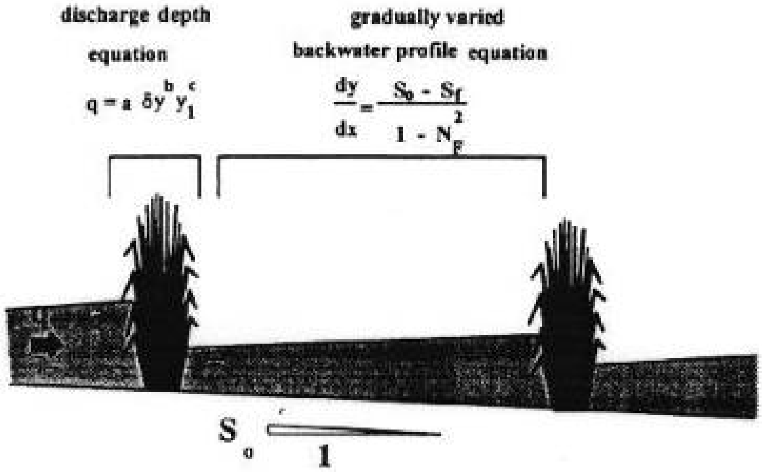
Table 2. Diameter and tensile strength of root of various herbs.

Grass	Mean diameter 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

2.3 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.

Figure 4: Hydraulic model of flooding through Vetiver hedges



Where:
q = discharge per unit width
y = depth of flow y_1 = depth upstream
S_o = land slope S_f = energy slope N_F = the Froude number of flow

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).

3. SOME APPLICATIONS OF VS IN NATURAL DISASTER MITIGATION AND INFRASTRUCTURE PROTECTION

Because of the above characteristics, in general Vetiver grass is very effective in erosion control of both cut and fill batters and other slopes associated with road construction. It is particularly effective in highly erodible and dispersible soils such as sodic, alkaline, acidic and acid sulfate soils. Vetiver planting has been very effective in erosion control or stabilization of the following cases:

- Slope stabilization along highways, railways etc., especially effective for mountainous rural roads, where there is not enough funding for road slope stabilization and where the local community often takes part in road construction;
- Dike and dam stabilization, reduction of canal, river bank and coastal erosion etc., and protection of hard structures themselves e.g. rock rip-rap, concrete embankment, gabion etc.;
- Slope above culvert inlets and outlets;
- Interface between cement and rock structures and erodible soil surface;

- As filter strip to trap sediment at culvert inlets;
- As energy reducer at culvert outlets;
- Gully head erosion can be effectively stabilized by Vetiver hedges, when planted on contour lines above gully heads;
- Erosion by wave action can be eliminated by planting a few rows of Vetiver on the edge of the high water mark on big farm dam walls or river banks;
- In forest plantation, Vetiver has been used successfully to stabilize shoulders of driving tracks on very slopes as well as gullies developed following harvests.

Also because of the above-mentioned characteristics, Vetiver grass is very effective in controlling water disasters such as flood, coastal and river bank erosion, dam and dike erosion and instability in general and for protection of bridge, culvert abutments and the interface between concrete/rock structures and soil in particular. Vetiver is particularly effective in cases the embankment fill is highly erodible and dispersible, such as sodic, alkaline, acidic including acid sulfate soils.

4. SOME TYPES OF NATURAL DISASTERS THAT CAN BE REDUCED BY USING VETIVER SYSTEM (VS)

Besides soil erosion, many other types of natural disasters can be reduced by using Vetiver System (VS), e.g. landslides, road batter instability, erosion of river banks, canals or coastline, erosion of dikes, dam etc. Each of these types represents some sort of slope failure or mass wasting, which is the down slope movement, either slow or rapid, of rock debris and soil in response to gravitational stresses. Below are some basic principles of slope failure, on which basis proper application of the VS could fully mobilize its unique characteristics for and slope stabilization.

4.1 Slope profile

Some slopes are gradually curved, while others are extremely steep. Profiles of naturally-eroded slopes are primarily dependent on climate and rock/soil type. For resistant rock/soil, especially in arid regions, the chemical weathering is slow while the physical weathering prevails. The crest of the slope is slightly convex to angular, the cliff face is nearly vertical, and a debris slope is present at an angle of repose of 30-35°, i.e. the maximum angle at which loose material is stable. Non-resistant rock/soil, especially in humid regions weathers rapidly and erodes easily. The resulting slope contains a thick soil cover. Its crest is convex, while its base is concave.

4.2 Slope stability

For upland natural slope, cut slope, road batter etc., their stability is based on the interplay between two types of forces, driving forces and resisting forces. Driving forces promote down slope movement of material, whereas resisting forces deter movement. When driving forces overcome resisting forces, these slopes become unstable.

For river bank, coastal erosion and instability of water retaining structures, some hydraulic engineers may argue that erosion of bank and instability of water retaining structures should be treated separately from other types of slope failure as the load on them is different. In our opinion, however, they are subject to one and the same interaction between the “driving forces” and the “resisting forces”, and failure will occur when the first overcome the later. In fact, erosion of bank and instability of water retaining structures is slightly more complicated, being the result of interactions between hydraulic forces acting at the bed and toe, and gravitational forces acting on the in-situ bank material. Failure occurs when erosion of the bank toe and the channel bed adjacent to the bank have increased the height and angle of the bank to the point that gravitational forces exceed the shear strength of the bank material. After failure, failed bank material may be delivered directly to the flow and deposited as bed material, or dispersed as wash load, or deposited along the toe of the bank as intact block, or as smaller, dispersed aggregates. Fluvial controlled processes of bank retreat are essentially twofold. Fluvial shear erosion of bank materials results in progressive incremental bank retreat. Additionally, increases in bank height due to near-bank bed degradation or increases in bank steepness due to fluvial erosion of the lower bank may act alone or together to decrease the stability of the bank with respect to mass failure. Depending on the constraints of the bank material properties and the geometry of the bank profile, they may fail by any one of several possible mechanisms, including planar, rotational, and cantilever type failures. Non-fluvial controlled mechanisms of bank retreat include the effects of wave wash, trampling, as well as piping- and sapping-type failures, associated with stratified banks and adverse groundwater conditions".

The main driving force is gravity which, however, does not act alone. Slope angle, climate, slope material, and especially water contribute to its effect:

- In the form of rivers and wave action, water erodes the base of slopes, removing support, which increases driving forces;
- Water can also increase the driving force by loading, i.e. filling previously empty pore spaces and fractures, adding to the total mass subjected to the force of gravity;
- The presence of water results in the so-called pore water pressure which reduces the shear strength of the slope material. More importantly, abrupt changes (both increase and decrease) in pore water pressure are believed to play the decisive role in causing slope failure;
- Interaction of water with surface rock and soil (Chemical weathering) slowly weakens slope material, reducing its shear strength, therefore reducing resisting forces.

The main resisting force is the material's shear strength, a function of cohesion (ability of particles to attract and hold each other together) and internal friction (friction between grains within a material), which acts oppositely of driving forces.

The ratio of resisting to driving forces is called the factor of safety (FS). If FS >1 the slope is stable, usually a FS of 1.2-1.3 is marginally acceptable. Depending on the importance of the slope and the potential losses associated with its failure, a higher FS should be ensured.

In short, slope stability is a function of: rock/soil type and its strength, slope geometry (height, angle), climate, vegetation and time. Each of these factors may play a significant role in controlling driving or resisting forces.

4.3 Types of slope failure

Depending on type of movement and material involved different types of slope failure may result as show in the Table 3.

Table 3. Different types of slope failure.

Type of movement		Material involved	
		Rock	**Soil**
Falls		- rock fall	- soil fall
Slides	Rotational Translational	- rock slump block - rock slide	- soil slump blocks - debris slide
Flows	Slow Fast	- rock creep	- soil creep - saturated & unconsolidated material - earth flow - mudflow (up to 30% water) - debris flow - debris avalanche
Complex	Combination of two or more types of movement		

Usually in rock fall and translational slide (involving one or more planes of weakness) will occur. On the other hand, as soil is more homogenous, without any visible plane of weakness, rotational slide or flow often occur. In general, most mass wasting involves more than one type of movement, e.g. upper slump and lower flow, or upper soil slide and lower rock slide etc.

4.4 Human impact on slope failure

Landslides are natural occurring phenomena. Landslides, or slope failure, occur whether people are there or not! But, human land-use does have a major impact on slope processes. The combination of uncontrollable natural disasters (earthquakes, heavy rainstorms etc.) and unsustainable human activities (slope excavation, forest destruction, urbanization etc.) can result in disastrous slope failures.

4.5 Mitigation of slope failure

Minimizing slope failure requires three steps:

- identification of potentially unstable areas,
- prevention of slope failure, and
- corrective measures when a slope failure occurs. Proper understandings of geological conditions are of utmost importance for the best mitigation practice.

Identification is usually accomplished by scientists by:

- studying aerial photographs to determine sites of previous landslides or slope failures, and
- field investigations of potentially unstable slopes. Potential mass-wasting areas can be identified by steep slopes, bedding planes inclined toward valley floors, hummocky topography (irregular, lumpy-looking surface) covered by younger trees, water seeps, and

areas where landslides have previously occurred. The information is then used to generate a hazard map depicting the various landslide-prone areas.

Prevention of landslides and slope instability is much more cost effective than correction. Many methods are available for such purpose e.g. controlling drainage, reducing slope angle and slope height, providing vegetative cover, retaining wall, rock bolt, shotcrete (concrete but with finer grains/aggregate, so that you can use a powerful pump to apply; it contains admixture for fast solidifying). It is important to ensure that these methods are correctly and appropriately applied; applying them just as supporting and additional measures, ensuring first (at least temporary) that the slope is internally and structurally stable. All these again require a good understanding of the local geological conditions.

Correction of some landslides is possible by installing a drainage system, which reduces water pressure in the slope, thereby preventing further movement. On the other hand, slope instability problems along roads and other important places must be treated and this is usually very costly. If properly done, surface and subsurface drainage would be very effective but usually this is often neglected and instead, much more rigorous and expensive methods are used.

Rigid Engineering Structures

At present in Vietnam, the use of structural, rigid protection measures e.g. concrete or rock riprap bank revetment, groins, retaining walls etc. for slope stabilization, river bank and coastal erosion control is the most popular. These have been continuously used for several decades, but slopes continue to fail, erosion becomes more and more severe. So what are the main weaknesses of these measures?

- From an economic point of view, these measures are very expensive, as mentioned in the previous paper, and the State budget for such works can never be sufficient.
- From technical and environmental perspectives, one may notice the following concerns:
- Rock/concrete is mined/produced elsewhere, where it can cause environmental problems such as
    - o Localized structural, rigid measures do not absorb flow/wave energy
    - o Rigid structures are not compatible with the soft ground particularly on erodible soils
    - o Structural, rigid measures bring in considerable amount of stone, sand, cement into the river system
    - o Rigid structures like rock embankments are unsuitable for certain applications such as sand dune stabilization.
    - o Rigid structures can only temporarily reduce erosion but they can not help stabilize the bank in case of big landslides with deep failure surface.

Soft Bio-Engineering Vegetative Measures

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.

Under the impact of several factors mentioned above, a slope will become unstable due to:

- surface erosion; and

- internal structural weaknesses.

Surface erosion often leads to rill and gully erosion, which with time will deteriorate the slope stability, while structural weakness will cause mass movement or land slip. Thus, in the long run, surface erosion can also cause slope failure and, therefore, slope surface protection should be considered as important as other structural reinforcements. In a way, slope surface protection is a kind of preventive measures whereas the latter are corrective ones. In many cases, it is sufficient just to apply some preventive measures to ensure the slope stability, which always cost much less than corrective ones.

Normally a good vegetative cover provided by grass seeding or hydro seeding/hydro mulching is quite effective against surface erosion and small rill erosion and deep rooted plants such as trees and shrubs can provide some structural reinforcement for the ground. However, on newly constructed slopes the surface layer is often not well consolidated, so rill and gully erosion can still occur on even well vegetated slopes. Deep rooted trees are slow and often difficult to establish on such hostile environment. For these, engineers often blame the inefficiency of the vegetative cover and tend to apply structural re-enforcement soon after construction. In short, numerous experiences have shown that traditional slope surface protection by using local grass and trees, in many cases, can not ensure the needed stability. Tables 4 and 5 show some pros, cons and limitations of vegetative slope protection.

Along with rigid structural measures, softer solutions, using vegetation have also been tried in Vietnam, though to a much less extent. For river bank erosion control, the most popular bio-engineering method is probably the planting of bamboo, while for coastal erosion, mangrove, casuarinas, wild pineapple, nipa palm etc. are also being used. However, applications of these plants have shown some major weak points, for example:

Table 4. General physical effects of vegetation on slope stability.

Effect	Physical Characteristics
Beneficial	
Root reinforcement, soil arching, buttressing, anchorage, arresting the roll of loose boulders by trees	Root area ration, distribution and morphology; Tensile strength of roots; Spacing, diameter and embedment of trees, thickness and inclination of yielding strata; Shear strength properties of soils
Depletion of soil moisture and increase of soil suction by root uptake and transpiration	Moisture content of soil; Level of ground water; Pore pressure/soil suction
Interception of rainfall by foliage, including evaporative losses	Net rainfall on slope
Increase in the hydraulic resistance in irrigation and drainage canals	Manning's coefficient
Adverse	
Root wedging of near-surface rocks and boulders and uprooting in typhoon	Root area ration, distribution and morphology
Surcharging the slope by large (heavy) trees (sometimes beneficial depending on actual situations)	Mean weight of vegetation

Wind loading	Design wind speed for required return period; mean mature tree height for groups of trees
Maintaining infiltration capacity	Variation of moisture content of soil with depth

Table 5. Slope angle limitations on establishment of vegetation.

Slope angle (degrees)	**Vegetation type**	
	Grass	**Shrubs/trees**
0-30	Low in difficulty; routine planting techniques may be used	Low in difficulty; routine planting techniques may be used
30-45	Increasingly difficult for sprigging or turfing; routine application for hydro seeding	Increasingly difficult to plant
> 45	Special consideration required	Planting must generally on benches

5. APPROPRIATE DESIGNS AND TECHNIQUES

It should be stressed that VS is a new technology as any new technology it has to be learnt and applied appropriately for best results. Failure to do so will bring disappointing outcomes and some times adverse results. As a soil conservation technique and recently a bio-engineering tool, the application of VS requires the understanding of biology, soil science, hydraulic and hydrological as well as geotechnical principles. Therefore for medium to large scale operation, this technology is best implemented by experts, who have gained experiences in previous works rather than by local people themselves. But knowledge on participatory approach and community-based management are also very important. Thus, it is best for the technology be designed and implemented by experts in Vetiver application, a combination of an agronomist and a geotechnical engineer, with assistance from local farmers.

It has to be understood that Vetiver is a grass by botanical classification but it acts more like a tree with its extensive and deep root system. In addition, VS exploits its different characteristics for different applications, for example deep roots for land stabilization, thick growth for water spreading and sediment trapping and extraordinary tolerance to various chemicals for land rehabilitation etc.

Failures of VS in most cases can be attributed to bad applications rather than the grass itself or the technology recommended. Experience in Vietnam shows that the use of Vetiver is very successful when it is applied correctly, but improper applications may fail. Experiments in the Central Highlands of Vietnam show excellent protection of road embankment by using Vetiver grass. But mass applications along the Ho Chi Minh Highway, on very high and steep slopes without benches have witnessed some failures.

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