VETIVER SYSTEM FOR NATURAL DISASTER MITIGATION IN VIETNAM - SOME LESSONS LEARNED AFTER A DECADE OF APPLICATION

Tran Tan Van* and Paul Truong**
**TVNI Associate Director; Vietnam Institute of Geosciences and Mineral Resources, Ministry of Natural Resources and Environment, Thanh Xuan, Hanoi, Vietnam. Email: ttvan@monre.gov.vn.*
*** TVNI Director for Asia and Oceania, Brisbane, Australia*

ABSTRACT

The use of Vetiver System (VS) for infrastructure protection in Vietnam has become very popular after more than a decade when it has, for the first time in 1999, been introduced by Dr. Paul Truong into Vietnam and met with considerable skepticism at the beginning. The grass is now known throughout the country and is in use practically in nearly 40 out of 63 provinces. It is planted in a very wide range of soil types and climatic conditions, from very cold winter in the North, very hot summer-cold winter, pure sand in Central Vietnam to acid sulfate and saline soil in the Mekong Delta. The Ministry of Agriculture and Rural Development (MARD) and the Ministry of Transport (MOT) - the two most relevant ministries in terms of VS application - issued several guidances on the use of the grass for natural disaster mitigation (e.g. surface run-off soil erosion, coastal and river bank erosion, irrigation canal, river and sea dyke protection, landslide in mountainous areas, cut slope stabilisation along highway etc.). The Ministry of Science and Technology (MOST) funded a research project on the use of VS for tailing waste pollution control in mining areas. The Ministry of Natural Resources and Environment (MONRE) is going to fund another research project on the use of VS for waste water pollution control in craft villages etc. Tens of companies, NGOs, universities and institutions have been engaged in various pilot and mass applications of the VS and its promotion nation-wide. All these efforts have helped TVNI to compile in 2008 a very successful technical reference manual which has since been translated in 10 languages worldwide.

The widest application of the VS in Vietnam is for river bank, irrigation canal, river and sea dyke erosion control, cut slope stabilization along highways and erosion and pollution control in coal mining areas etc. Research results, successes and failures of numerous applications indicate that VS, having many advantages, is a very cost-effective, community-based and environment-friendly bio-engineering tool for natural disaster mitigation and infrastructure protection. However, to ensure successes and avoid failures, it is important that the VS be used with proper care. It is, therefore, the purpose of this paper to summarize some lessons learned from various applications of the VS in recent years in Vietnam to echo worldwide experience.

1. VS application for sand dune protection in Central Vietnam

1.1. The application

A vast area of more than 70,000 ha along the coastline of Central Vietnam is covered by sand dunes where the climatic and soil conditions are very severe. These sand dunes migrate westward into the inner, narrow coastal plain under the action of both wind and water (Fig.1). The government tries for years to mitigate this hazard by implementing forestation programs using varieties such as Casuarinas, wild pineapple, eucalyptus, acacia. When fully and well established, this measure can, however, only help reduce sand fly; there was no way yet to reduce sand flow.

In February 2002, with financial support from the Dutch Embassy and technical support from Elise Pinners and Pham Hong Duc Phuoc, the second author of this paper tried to fix this problem. Vetiver grass was planted in 3 rows along the contour lines on the slope of the sand dune, starting from the edge of the stream. After 4 months it formed closed hedgerows and the sand dune toe was stabilized.

The grass further surprised local people by surviving the coldest winter in ten years, with temperatures below 10^{o}C, forcing the farmers to replant twice their paddy rice and Casuarinas. After 2 years, local species such as Casuarinas, wild pineapple etc. re-established between Vetiver hedges; the grass itself faded away under the shade of these trees but it has accomplished its mission: dune sand flow was considerably reduced (Fig.2-7).

Fig.1. Sand flow in Le Thuy (Quang Binh) in 1999, exposing the foundation of a pumping station (left) and a 3-room brick house (right)

Fig.2. Left: The site; Right: April 2002 (1 month after planting); note mulching above uppermost row

Fig.3. Early July 2002 (4 months after) the hedge well established and effectively stabilized the dune

Fig.4. November 2002 (8 months after): Note establishment of Casuarinas in-between rows

Fig.5. Left: the nursery; right: mass planting in November 2002

Fig.6. Left: Vetiver grass for protection of bridge abutment along Nat. Highway nr.1; Right, December 2004: Vetiver grass is replaced by local species

Fig.7. Left: February 2003 (post-workshop field trip, Quang Binh); a new site established in October 2002: the grass survived the cold winter; Right: June 2003: nursery at home; a World Vision Vietnam-sponsored field trip for farmers from neighboring Quang Tri province

Following the success of this pilot project, a workshop was organized in early 2003 for more than 40 participants from local government departments, different NGOs and Universities of Central Vietnam's coastal provinces. The workshop helped both the authors of this paper and other participants draw useful lessons, especially on planting time, watering, fertilizing etc. After the event, also in 2003 World Vision Vietnam decided to fund another project for introducing Vetiver grass for sand dune fixation in the two Vinh Linh and Trieu Phong districts in Quang Tri province.

1.2. Some lessons learned

The project proved that with proper care Vetiver grass could survive very hostile soil and climatic conditions:

- During the first pilot planting, several options were tried: Vetiver seedlings in poly-bags and bare-root; addition of green manure and good soil; addition of good soil only; and nothing added. Although the bare sand was very poor in nutrition, the grass could survive. For the subsequent mass planting during the next winter, only bare root seedlings were planted, and successfully, without any addition of nutrition. The conclusion is that VS can establish on poor sand dunes as long as its root can penetrate deeply enough into the sand to get water;
- Even though still young, the grass could survive both the harsh winter (<10^{o}C when other varieties e.g. paddy rice and casuarinas seedlings died) and the hot summer (>40-45^{o}C which is very usual in Central Vietnam during summer time). Under the latter condition, it is necessary to supply the grass with enough water, especially when the grass is still young (note that sometimes the farmers had to water the grass twice a day. They were also very creative to place dry mulching on-top and along the rows; first to help prevent the grass from being buried by hot sliding sand; and second to help distribute the supplied water evenly and gradually).

2. VS application for river bank erosion control

2.1. The application

2.1.1. VS application for river bank erosion control in Central Vietnam

Within the framework of the same Dutch Embassy project, Vetiver grass was planted to fix erosion of a river bank, bank of a shrimp pond and a road embankment in Da Nang City (Fig.8-10). Consequently, in October 2002 the local Dike Department also decided to mass plant the grass on more bank sections of several rivers.

Fig.8. Left: VS trial at a shrimp pond edge, where flood water drains into the river (March 2002); right: mass Vetiver planting combined with rock rip-rap along Vinh Dien River (Nov. 2002)

Fig.9. Left: Vetiver together with rock rip-rap in good shape already after 2 flood seasons (Da Nang, Dec. 2004); right: local farmers planted Vetiver grass to protect their shrimp ponds

Fig.1. Vetiver protecting a rock rip-rap (left), and a bend on Perfume Riverbank in Hue (right)

Also as a result of this pilot project, Vetiver grass was recommended for use in another natural disaster reduction project in Quang Ngai province, which was funded by AusAid. With technical support from Tran Tan Van, in July 2003, Vo Thanh Thuy and his co-workers from the provincial Agricultural Extension Center planted the grass at 4 locations, for sea water intrusion protection dike and irrigation canal in several districts. The grass grew well in all locations, and although at its young age, survived the flood in the same year.

Following these successful trials, the project has decided to mass plant the grass on other dike sections at 3 more districts, in combination with rock rip-rap measure. Some design modifications have been introduced to better adapt Vetiver grass to the local conditions. For example, mangrove fern and more salt tolerant grasses are planted on the lowest row to better withstand the high level of saline water and effectively protect the embankment toe. The grass is further introduced to local communities so that they themselves can protect their own land (Fig.11-14).

Fig.2. Left: Vetiver grass planted on river dike along Tra Bong River; right: on both sides of an anti-salinity estuary dike along the same river

Fig.3. Anti-salinity dike section upstream, with the old-fashioned concrete rip-rap facing the river (left) and along a section of the irrigation canal; note the poor shape of the opposite bank due to surface erosion (right)

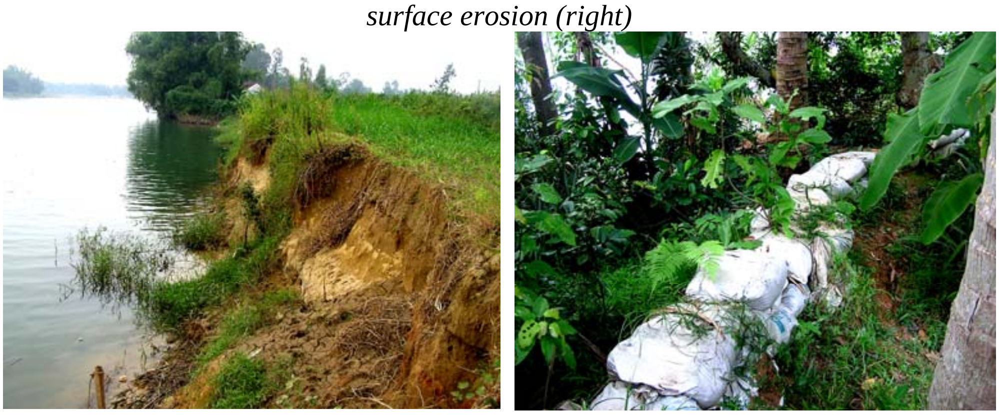


Fig.4. Another section of the poorly eroded bank at Binh Thoi Commune, Tra Khuc River (left) and the traditional, primitive protection by local farmers using sand bag (right)

Fig.5. Vetiver grass comes in with local participation (left) and the bank stays intact after the flood season in Nov. 2005

2.1.2. VS application for river bank erosion control and protection of flood-escaping communities in the Mekong Delta

With financial support from Donner Foundation and technical support from Paul Truong, Le Viet Dung and his colleagues at Can Tho University started works on river bank erosion control in the Mekong Delta. The area features long inundation (up to 3-5 months) during the flood season, with large (up to 4-5 m) difference in the water levels between dry and flood seasons, and strong water flow during the high water (flood) season. In addition, river banks are mostly made up of soils ranging from alluvial silt to loam, which are extremely erodible when wet. Due to the fast economic development in recent years, most boats traveling on rivers and canals now are motorized, in many cases with very powerful car engines. These boats aggravate the problem of river bank erosion further by generating strong waves. However, despite these negative factors, Vetiver grass withstands well, protecting large areas of invaluable farm land from erosion (Fig.15-16).

In An Giang and Tien Giang Provinces of the Mekong Delta of southern Vietnam major floods occur every year. These floods are usually up to 6-8m deep and can last up to 3-4 months. As a result unless houses are built inside the land protected by major dike systems, they are flooded every year. Therefore people cannot build their permanent homes, they have to rebuild every year causing extreme hardship to subsistent farmers.

To overcome this problem, local government select a relative high area and further top it up with soil from the surrounding land, high enough to escape the annual prolonged flood. These are called Flood-Escaping Communities or People Clusters. But the banks of these clusters are themselves highly erodible. They need to be protected from the strong current and waves during the flood season. Vetiver planting has been highly effective in protecting these clusters against flood erosion with the added benefit of treating the community effluent and waste water during the dry season.

A comprehensive Vetiver program has been carried out in An Giang Province, where annual flood can reach up to 6 m depth. The province 4,932 km long canal system needs maintenance and repair every year. In addition, a network of dikes, 4,600 km long, was built to protect 209,957 ha of prime farm land from flood. The erosion on these dikes is about 3.75 Mm^3/year and required USD 1.3 M to repair.

There are also 181 resettlement clusters built on dredged materials for people to live. These clusters also need erosion control measure from flood. Depending on the locations and flood depth Vetiver has been successfully used by itself or in combination with other vegetation. The total length of Vetiver planting for dike protection from 2002-05 is 61 km using 1.8 M polybags.

It was planned that for the next 5 years, 2006-2010, the 11 districts of An Giang province will plant 2,025 km of Vetiver hedges on 3,100 ha of dike surface. If unprotected by Vetiver, it is expected that 3,750 Mm^3 of soil will be eroded and 5 Mm^3 will have to be dredged from the canals. Based on the current cost, the total maintenance cost over this period would exceed USD 15.5 M for this province alone. In addition, application of VS in this rural region will provide extra income to the local people: men to plant and women and children to prepare Vetiver polybags. As a result, extensive use of Vetiver grass is now seen along the rigorous sea and river dike systems as well as along river bank, canals etc. in the Mekong Delta.

Fig.6. Vetiver grass and river dike (left) and along a natural river bank (right) in An Giang

Fig.7. Left: Vetiver along the edge of flood resettlement centers; Right: see the red line, showing about 5 m of dry land being saved thanks to Vetiver grass

2.2. Some lessons learned

- Due to the highly fertile alluvial soil, planting of Vetiver grass along rivers is easiest compared to sand dunes, cut slopes or highly contaminated mining areas;
- Due to the more or less homogeneous nature of the river bank/embankment soil, shallow failure appears to take place more often than deep which is very appropriate for the VS to be applied;

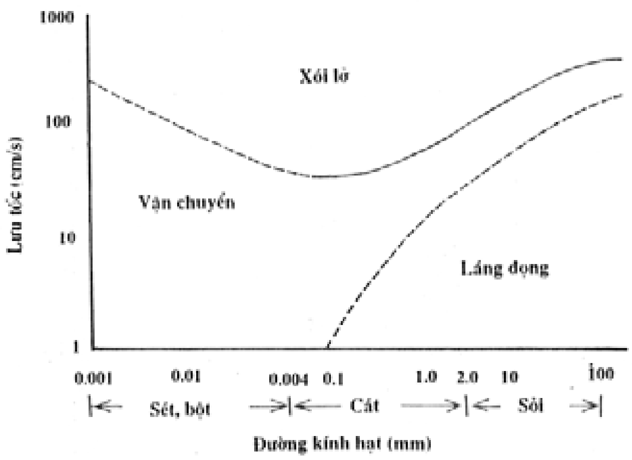


Fig.17. Erosion-transportation-deposition flow velocity boundaries for differently grain-sized soils

- As reported above, the young, 3-month-old grass was able to withstand the short (3-5 days) but fast flood (3-5m/s), most typical for short but steep rivers in Central Vietnam and in so being, was able to protect the vegetated bank/dyke. This confirmed a similar conclusion by the first author that the VS can withstand high velocity flow, retarding the water flow and by bending its stems to cover the soil underneath it helps protect the bank/dyke surface, and together with that, the stability of the latter as a whole (Fig.17);
- In his trials along the river dyke and irrigation canal, Vo Thanh Thuy et al. planted in between VS rows such grass as: guinea grass, Raflis trivialis/Chrysopogon grass (Cỏ may) or Pangola grass (Cỏ chỉ) which helped fully cover the soil surface. Along anti-salinity dyke, the lowermost row of Vetiver didn't establish well and the same authors tried successfully with local species e.g. Mangro ferns (Cây ráng) or Nypa palm (Cây dừa nước) which helped stabilize the upper Vetiver rows (Fig.18);

Fig.18a. Raflis trivialis/Chrysopogon grass

Fig.18b. Pangola grass

Fig.18c. Guinea grass in between Vetiver grass

Fig.18d. Nypa palm

Fig.18e. Mangro ferns

Fig.18f. Or both Nypa palm and mangrove ferns

3. VS application and promotion for coastal erosion control

3.1. The application

In 2001 with financial and technical supports from the Donner Foundation and Paul Truong respectively, Le Van Du from Ho Chi Minh City Agro-Forestry University initiated works on Acid Sulfate Soil to stabilize canal and irrigation channels and sea dike system in Go Cong province. Despite the poor embankment soil Vetiver grew rigorously in just a few months, helping to protect the sea dike, preventing surface erosion and facilitating endemic species to establish (Fig.19).

Fig.8. Planting Vetiver grass in Go Cong province, behind the natural mangrove on this Acid Sulfate Soil sea dike. Surface erosion is reduced and local grass re-established

In 2004, at the recommendation of Tran Tan Van, the Danish Red Cross funded a pilot project using Vetiver grass for sea dike protection in Hai Hau district, Nam Dinh province (Fig.20). The project implementers came in and to their surprise, they found out that Vetiver grass had already been planted 1-2 years earlier to effectively protect several km of the inner side of the local sea dike system. The effectiveness of Vetiver grass in reducing erosion of the sea dike was even more remarkable after typhoon No. 7 in September 2005, which even broke the sections rigorously protected by rock rip-rap.

Fig.20. Planting of Vetiver grass on the outer (left) and inner slope (right) of the sea dyke

Fig.21. Planting of Vetiver grass on anti-salinity dyke

Fig.22. Vetiver grass can establish along with local salt tolerant species but the latters are perennial

3.2. Some lessons learned

- The grass is planted more often on the inner side of the sea dyke. The outer side has less favorable conditions e.g. more salinity, higher impact of waves that also bring salty water;
- For both and especially the outer, sides sufficient watering should be provided when the grass is still young;
- Combination with other local salt tolerant species e.g. Aegiceras corniculatum (Cây sú); Brugiuera cylindrica (Cây vẹt), Rhizophora apiculata (Cây đước), Avicenniaceae (Cây mắm), Ipomoea pes-caprae (L.) Sweet (Cây Rau muống biển), Cyperales (Cây cói) etc. is good but as Vetiver grass is seasonal while the latters are perennial, Vetiver grass can fade away.
- Planting Vetiver grass where local species already establish or at the same time with local species may not be good because local species are more competitive;

4. VS application and promotion for road batter stabilization

4.1. The Ho Chi Minh Highway (HCMHW) - a brief introduction

The master plan for the HCMHW was approved by Vietnam's Government in 1997 and construction started in 2000 after the historic flood at the end of 1999 which disrupted for more than a month the North-South traffic on the National Route No.1 along Vietnam's coastline.

The HCMHW, with cross-section width 40-100m, 2-8 lanes, is divided into several sections i.e.:

- Section 1 (Hanoi-Quang Binh): 500km in length;
- Section 2 (Quang Binh-Quang Nam) is divided into 2 branches i.e. East HCMHW, 364km in length; and West HCMHW, 514km in length;
- Section 3 (Quang Nam-HCM City): 825km in length;

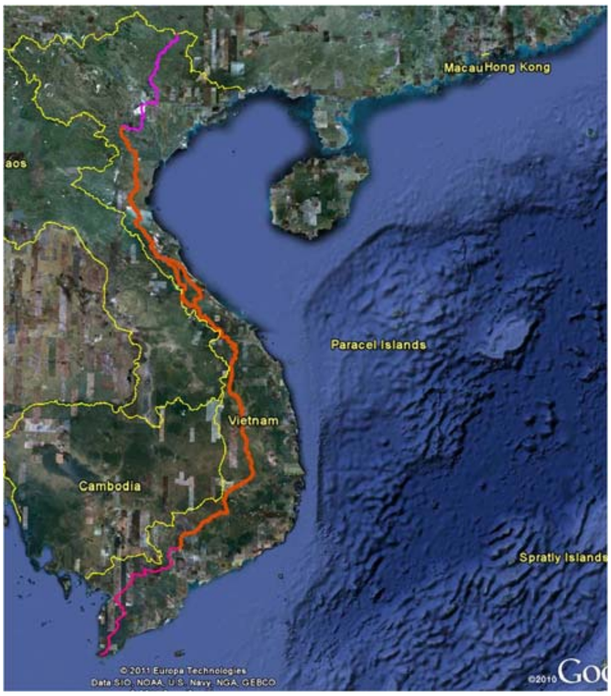


Fig.23. The HCMHW: Under construction (orange); Planned (pink)

According to plan, the HCMHW will connect the border province of Cao Bang in the North with Ca Mau Cape of Kien Giang province in the South, totaling in length 3,200km (Fig.23). In addition, it will connect with National Route No.1 by a network of 20 traverses totaling in length nearly 1,700km.

Fig.24. Starting with a small trail, at many locations completely new

Fig.25. Many cut slopes designed and constructed not to the standard, tens of m in height, very steep, often >60-75^o with rare or even without benches etc.

Fig.26. Ready to slide down during the rainy season

Construction of the HCMHW, especially its west branch, faced unprecedented difficulties as the road alignment never existed before and it had to go through rugged terrains. In addition, under time pressure, at many locations the primary aim was to get the road operate first, leaving behind many other aspects e.g. safety of cut slopes, waste disposal, environmental impacts, nature conservation etc. (Fig.24-26).

4.2. VS application for cut slope stabilization

In early 2002, Pham Hong Duc Phuoc (Ho Chi Minh City Agro-Forestry University) and Thien Sinh Co. tried for the first time the use of VS for a cut slope on the newly constructed HCMHW (Fig.27-28). Following the initial success of this trial, the Ministry of Transport made a bold move in 2003, allowing the wide use of VS for slope stabilization along hundreds of km of the same highway and other national, provincial roads.

Fig.27. Trial site at planting and visited by then Vietnam's President Tran Duc Luong

Fig.28. At planting and one year after

4.3. Some lessons learned after the first few years

The extensive use of VS for cut slope stabilization along the HCMHW brings in very good results e.g.:

- It helps increase the environmental friendliness of the road. Applied primarily for slope surface protection it greatly reduces surface erosion, which otherwise causes downstream hazards (Fig.29);
- By preventing shallow failures, it greatly stabilizes cut slopes and consequently helps reduce the number of deep slope failures. In some cases where the latter do occur, it still does a very good job in retarding the failures and reducing the failed mass. More on this follows in Section 4.4.

Fig.29. Improper rock/soil waste disposal which will be washed very far downstream

Fig.30. The slopes should first be internally stable, as the VS is not immediately effective

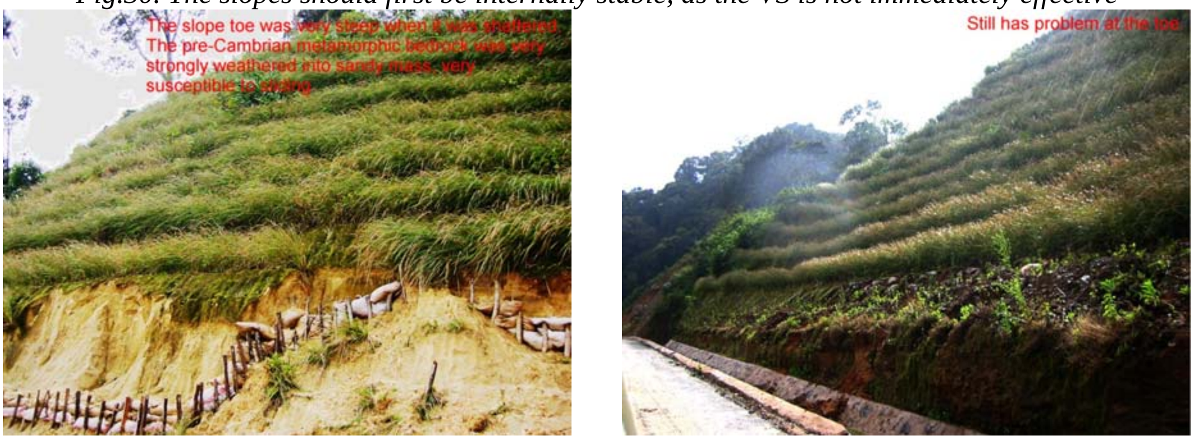


Fig.31. Protection of the slope toe is a must to ensure stability

Successes and failures of VS application along the Ho Chi Minh Highway also showed some lessons:

- The slopes should first be internally stable, as the VS is not immediately effective (slopes can fail before roots have established) (Fig.30). Stabilization may take place earliest 3-4 months after planting; hence timing is also very important to avoid slope failure in the first rainy season;
- Appropriate slope angle should not exceed 45^o (H:V = 1:1) to allow for successful establishment and visible effect of the grass on the slope stability;
- Good protection of the slope toe is a must even with Vetiver grass, be it alone or in combination with other structural measures (Fig.31); and
- Regular trimming is important to ensure further growth of the grass to achieve good, dense hedgerows etc.

4.4. A few more lessons learned after a recent field check

In a recent visit back to the Ho Chi Minh Highway by the second author (April 2011) the above mentioned lessons were once again confirmed. A few more remarks can be drawn out as follows:

- *Deep-seated failure*. A slope instability problem can exhibit itself in the following forms:

  1. Slow, gradual, either continuous or seasonal slope surface erosion;
  2. Shallow, small slide, having failure surface within 1-2 m below the slope surface; and
  3. Large, deep-seated slide, having failure surface sometimes exceeding a few m or even tens of m below the slope surface.

Fig.32. Slope surface erosion, developing into gullies and small, shallow landslides before large, deep-seated ones take place and Vetiver grass cannot help

Slope instability is usually progressive, starting just from invisible surface erosion, developing to gully and shallow, small slides long before deep slides take place. The latter can also happen suddenly but rarely, during extremely heavy meteorological events.

The HCMHW runs across several provinces of Vietnam which have the annual average rainfall intensity of 1,500-2,500mm. The rainy season accounts for up to 75% of the annual rainfall intensity. On the average there are 120-200 rainy days a year, 10-20 days a month during the rainy season and 5-15 during the dry season. Up to 130-170 days have more than 1mm rain but just only 6-8 days on the average have heavy (>50mm) rains. Extremely heavy rains (>100mm) happen even less, just 1-3 days a year. Observations confirm landslides and deep slope failures usually take place during these extreme events that follow prolonged (one week to ten days) smaller rains.

Vetiver grass can help prevent slope surface erosion, gully erosion or shallow, small slides and the slope can remain stable around the year, which may also result in false impression of the grass effectiveness. But it can hardly, even if well designed, established and maintained, prevent deep-seated failures. So it is very important that the slope be internally stable first and measures against deep-seated failures be taken before deciding to plant the grass as a supplementary bio-engineering measure. In other words, one should try to stay within the capacity of the grass if it is not to be blamed in case of deep-seated failures (Fig.32).

– *Retarding failure*: Nevertheless, even in cases of large, deep-seated failures, Vetiver grass, when it establishes, can play a very useful role in retarding failure, which is well illustrated at many locations along the Ho Chi Minh Highway (Fig.33-36):

Fig.33. Without Vetiver grass, the slope constructed out on strongly crushed rock/soil along a fault zone at Deo Da Deo Pass (Quang Binh province) continuously fails even though it has been very gently flattened down to the natural slope angle (photos taken 8/2004)

Fig.34. Under the same condition, a combination of Vetiver grass and rock groins did a better job even though at the other end still couldn't prevent a massive failure to occur (photos taken 1/2005)

– *Slope drainage and dissipation of excessive pore pressure*: In slope engineering it is well-known that water is number one enemy of the slope (Fig.37). Vetiver grass, with its unique characteristics and coupled with proper design, does a very good job in draining away surface run-off, dissipating excessive pore pressure and reducing infiltration (Fig.38). In so doing, Vetiver grass also help stabilizing the slope almost around the year. But in case of extreme meteorological events, sooner or later the slope will get soaked and saturated when the infiltration rate exceeds the grass's evapo-transpiration capacity. Also during prolonged rains the excessive pore pressure can eventually dissipate without needing the assistance of the grass extensive root system.

Fig.35. (Same location). Planted just in 6/2004 (left photo taken 8/2004), the grass couldn't help prevent a deep failure in 9/2004 during the rainy season (right photo taken 1/2005)

Fig.36. But when established it helped restore the local vegetative cover and strongly retard the failure even though eventually a by-pass had to be made a few meters down (photos taken 4/2011)

Some other slopes can have such unfavorable condition that the water table is much deeper than the depth that the Vetiver roots can reach and such water table continuously drains out on the slope surface, saturating and weakening the slope rock/soil. Vetiver grass alone may not be fully effective also in this case.

It is, therefore, also very important that a slope is well designed and constructed in terms of water drainage before Vetiver grass can come in as a supplementary measure.


Fig.37. Improper drainage is an important cause of slope failure: Left photo taken in 8/2004 at Deo Da Deo Pass (Quang Binh province) at the beginning of the rainy season; Right photo taken in 4/2011 at Deo Sa Mui Pass (Quang Tri province) during the dry season


Fig.38. With proper design, Vetiver rows can help greatly divert the surface run-off, reduce infiltration and stabilize the slopes (photos taken in 8/2004 in Vu Quang, Ha Tinh province)

– *Understanding the geology, especially the weathering profile of cut slopes*:

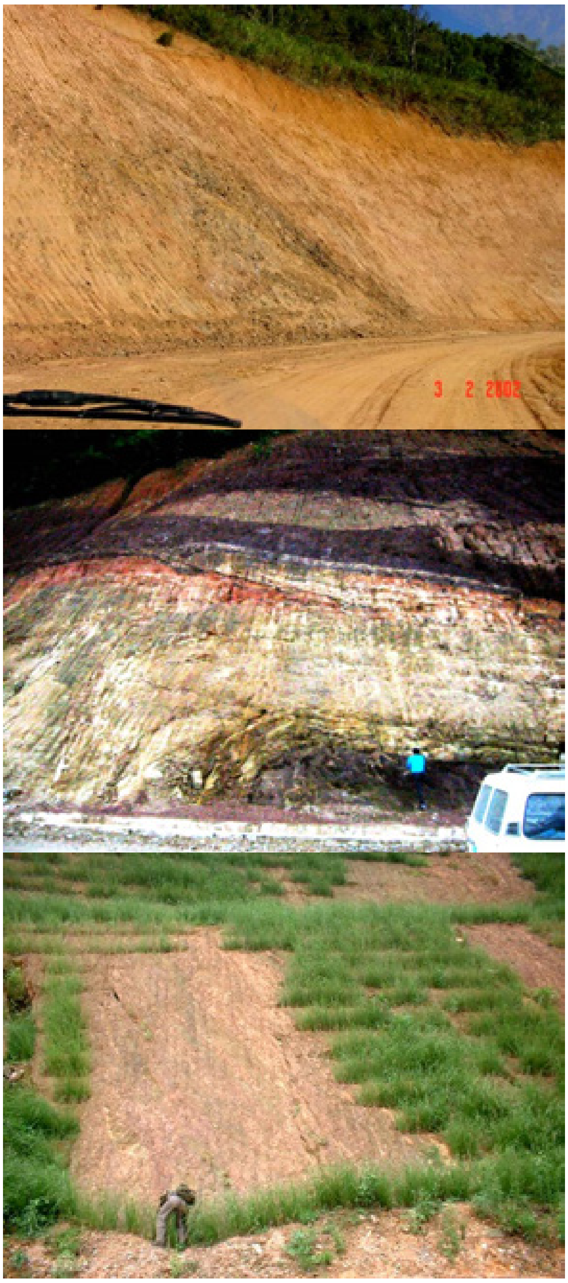
Different parts of a cut slope may differ greatly in composition, due either to the weathering process or to the original bedrock lithology and structure. Understanding the regional and the slope geology and particularly its weathering profile is, therefore, a must if proper design and construction is desired. In any case, for a completely weathered cut slope, or at least it's completely weathered part, it is advisable not to exceed 45^o (H:V = 1:1). Moreover, although Vetiver grass appears versatile enough to grow on different soil types, this difference may also influence the growth of the grass on one and the same slope and may need to be taken into account. Even though some parts of the slope can be soft enough to allow digging a ditch, the mottled rock composition there would not allow further growth of the grass down beyond the soft and fertile soil that is provided during the planting (Fig.39).

– *Vetiver grass vs. local species, or do we need long-term maintenance?*

At most locations the Vetiver rows are no longer maintained i.e. they are no longer watered, fertilized, trimmed or cut etc. As a result and because the grass is seasonal, it cannot compete with the local, perennial species (Fig.40). Whether or not it is better or worse remains a question but to the authors of this paper, it is better to provide long term and regular maintenance to ensure as deep root penetration, and together with that, slope stability, as possible. Another reason for doing so is to maintain the environmental friendliness of the measure.

– *Vetiver grass and negative slope side/embankment protection*:

It is pity to admit that although planted extensively along the Ho Chi Minh Highway, a major drawback of the campaign remains i.e. the technology is not used at all for the stabilization of the negative side of cut slopes or both sides of filled embankments although these provide much more favorable conditions than cut slopes for the VS to be applied. As shown above, the negative side of cut slopes can result in serious environmental concern. In addition, it too, can remain unstable and therefore, can threaten the road safety if it is not properly protected (Fig.41).



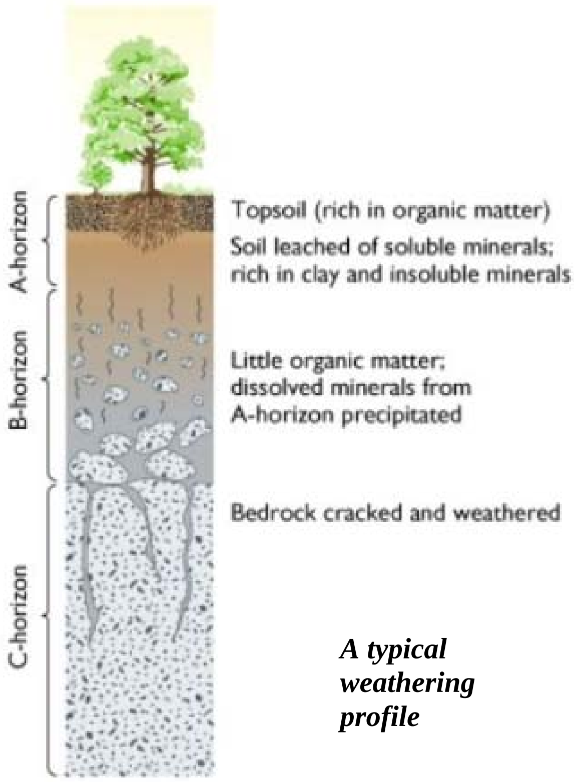


Fig.39. Different parts of a cut slope may be of different composition due either to the weathering process (upper left and right) or to the original bedrock lithology and structure (middle left) and the grass may not grow equally well on them (lower left photo)

5. Conclusions

From both the successes and failures of numerous applications presented above, it is clear that we now have enough evidence that VS, having many advantages and very few disadvantages, is a very cost-effective, community-based and environment-friendly bio-engineering tool for natural disaster mitigation and infrastructure protection. However it should be used with proper care, with lessons learned so as to achieve desirable results. Keeping the measure within its capacity and using it in combination with other proven measures, understanding geological and geotechnical conditions and providing long term maintenance etc. are probably the most important pre-requisite conditions.

Fig.40. As Vetiver is seasonal and no longer maintained, local, perennial species strongly come back to compete, penetrating even the rock rip-rap and wire mesh (lowermost photo, taken 4/2011)

Fig.41. Failure of the negative side of cut slopes and rigorous remedial measures

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