

SUSTAINABLE VETIVER SYSTEM IN EROSION CONTROL AND STABILIZATION FOR HIGHWAYS SLOPES IN THAILAND

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Abstract

After His Majesty the King of Thailand's initiative, since 1993, each year over 4.5 millions slips has been planted for erosion control and stabilization in highway construction and maintenance projects. Vetiver grass technology for erosion control and stabilization of highway slopes is a specific technique and has a degree of difficulty in establishing on highway slopes. Therefore, it should be considered to be a particular field of technology which need to be improved and developed as a separate body of knowledge. The Department of Highways developed sustainable vetiver system detailing the quality of slips, planting procedures and maintenance techniques, unit rates, planting patterns for various types of situation and seriousness of erosion, interplanting with *Arachis* 'Pinto' (*Leguminosae*) for sustainability and saving of maintenance cost. These will be beneficial techniques for applied on bioengineering slope stabilization works in Thailand.

The application of vetiver system on bare slopes that vetiver becomes pioneer plant, produced an effective measures for erosion control and stabilization of highway slopes. In addition, for applying closely-spaced plantations, it shows high efficiency in the evapotranspiration rates. It is appropriate to set soil moisture condition within saturated-soil slopes. Consequently, the slope is stabilized and prevented earthflows.

Keywords: Erosion, Slope stabilization, *Arachis*'Pinto', Bioengineering, Shallow-seated failure, Earthflows.

1.0 INTRODUCTION

After His Majesty the King of Thailand's initiative in 1993, the first application of vetiver system was applied for erosion control and stabilization on highway slope in Northern region of Thailand under the Royal Initiative. Department of Highways (DOH) has concentrated on the important role of soil and water conservation. It aim to reduce environmental impact, not only for a highway construction projects, but also in the existing highway erosion-control projects. Each year over 4.5 millions slips has been planted for erosion control and stabilization on mountainous highway construction and maintenance projects.

By His Majesty's suggestion, experience in implementing and research on vetiver slope protection works on mountainous highways, the vetiver system has been improved and developed to achieve maximum benefit and sustainability. The Department of Highways developed sustainable vetiver system. This system includes the optimum planting and maintenance techniques, unit rates, planting patterns for various type of situation and seriousness of erosion, and interplanting with *Arachis* 'Pinto' (*Leguminosae*) for saving of maintenance cost and sustainability.

2.0 SLOPE EROSION CONTROL AND STABILIZATION MECHANISM BY VETIVER

The factors contributing to the stability of slope by vegetation are root reinforcement and evapotranspiration, that pore pressure being reduced and soil shear strength being

increased which contributes to the apparent cohesion and internal friction angle (Hengchaovanich, 1998).

Vetiver contributing to erosion control and stability of slope by slow down runoff, evapotranspiration and its root reinforcement. Hengchaovanich *et al.*(1996) study the tensile root strength properties of vetiver in its resistance to shallow mass stability and surficial erosion. According to the study, vetiver roots are very strong with high mean tensile strength about 75 MPa. at 0.7- 0.8 mm. root diameter. It was obvious that the penetration of vetiver roots in a soil profile increased the shear strength of the soil significantly.

Vetiver, long (2-3.5 m.) and strong massive root networks, can reduce soil erosion and stabilize soil slope if planted in row across the slope. With the high nutrients soils the vetiver slips can develop a completely dense hedgerow in rainy season that to be effective function able after 4 months (Sanguankaeo *et al.*, 2006). The vetiver hedgerows act as a living wall which stands against and slows down runoff, and the eroded soil is deposited behind the vegetative barrier. Vetiver hedgerows have been found to be able to resist scouring of water flow 0.028 m³/s (Huang *et al.*, 2003). Compared with bare soil, vetiver was able to control runoff and total eroded soil (soil loss) 20-73% and 50-98 % reduction, respectively (Kon *et al.*,1991; Rodriguez, 1993). Under the vetiver hedgerows the root system interact with the soil in which it is grown, a new composite material comprising roots with high tensile strength and adhesion embedded in a matrix of lower tensile strength is formed. Vetiver roots reinforce a soil by transfer of shear stress in the soil matrix to tensile inclusions (Hengchaovanich, 2006). In other words, the shear strength of the upper soil layer (1-2 m.) is enhanced and stabilized by root system.

The vetiver stabilize the soil slopes not only root reinforcement but by getting soil to dry by evapotranspiration. High soil moisture zone under the vetiver hedgerows was restricted at the depth less than 50 centimeters (Hengchaovanich,1998 ; Babolola *et al.*, 2003 ; Singhatat, 1994). In water-saturation soil or slope of high watertable , if vetiver is planted the massive and deep root could water rise up through capillary to deplete moisture in the soil thus lowering pore water pressure (Chomchalow, 2010; Hengchaovanich,1998). This situation will have beneficial effects on slope stability, especially for the 1 - 2 m. depth soil layer that is prone to slippage (shallow-seated failure) or flows.

3.0 APPLICATION OF THE VETIVER SYSTEM IN HIGHWAY EROSION CONTROL AND STABILIZATION

Because of the excellent properties of vetiver system, the hedgerow can slow down runoff and the root system can stabilize the soil as deep as 3 meters ,so it is an effective measure for erosion control and stabilization against shallow-seated failure both in prevention and rehabilitation of highway slopes (Sanguankaeo *et al.*, 2000). According to Sanguankaeo *et al.* (2003) the benefits of application vetiver grassing for highway are in 6 formations.

3.1 Vetiver System is Applied for Highway Back Slope Protection

The Vetiver is planted both on slope face and bench slope (Fig.1). Some of the planting are not successful due to the hard and infertile soils.

3.2 Vetiver System is Applied for Highway Side Slope Protection

Planting on side slope can be efficiently and mostly successful (Fig.2). The first row of planting should be lower than the highway shoulder about 1 - 1.5 meter. This is for the good sight-distance, especially along the highway curves. In case of high slope, surface drainage system is required coupled with the vetiver planting.

3.3 Vetiver System is Applied for Stream Bank Along the Roadway

In this case , vetiver is planted over the rock filled or gabion wall (Fig.3).

3.4 Vetiver System is Applied for Highway Ditch Lining

In order to protect and stabilize the soil underneath and to trap the sediments to fill in the ditch (Fig.4).

3.5 Vetiver System is Applied on Shoulder Slope

At steep gradient of highway section, vetiver planting with suitable interval across and parallel the slope at highway shoulder and crest of shoulder slope respectively (Fig.5).

3.6 Vetiver System with Slope Protection Works

In this application vetiver is planted for erosion control and stabilization for existing eroding sites and rehabilitation works (Fig.6). Vetiver planting is associated with gabion wall, drainage structures etc. Vetiver is planted on the slope area above the gabion wall to stabilize the soil over the wall and also to prevent the slope failure and wall system.

Figure 1: Highway back slope (cut slope) was stabilized with vetiver.



Figure 2 : Highway side slope (embankment slope) was stabilized with vetiver.



Figure 3 : Stabilization with vetiver along the stream bank.



Figure 4: Vetiver planting at the side ditch lining.

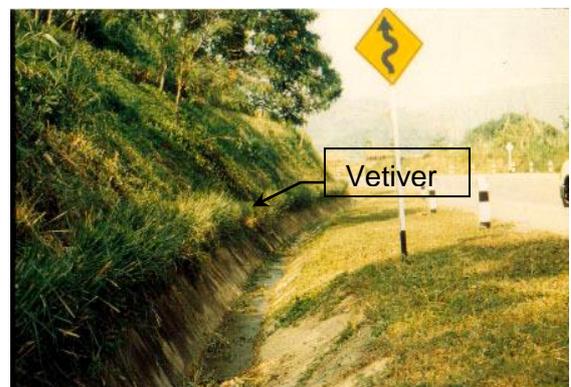


Figure 5 : Vetiver planting at steep gradient of highway shoulder to slow down runoff longitudinal.



Figure 6 : VS was associated with gabion wall in the rehabilitation work.



4.0 SUSTAINABLE VETIVER SYSTEM IN EROSION CONTROL AND STABILIZATION FOR HIGHWAY SLOPE

The climate of Thailand is tropical humid divided into a rainy season lasting from May to October, and a dry season. The rainfall in the country usually more than 1,500 mm, the temperature varies between 18-40 °C. In the Northern region the rainy season lasts from May to October. In Eastern coast and Andaman coast, the rainy season lasts from October to April and May to October, respectively. The Department of Highways has encountered with erosion problems and landslide damage to mountain roads along the Northern , Southern and Northeastern region.

Vetiver grass technology for erosion control and stabilization of highway slopes is a specific technique and has a degree of difficulty in establishing on highway slopes, because of infertile soil and steeper slopes (30-60 degrees or 60-180%) compare with gentler slope farmlands (seldom exceeds 8 degrees or 15%). Moreover, in some area the local weeds growth have been vigorous and replace the vetiver after 1 – 2 years of planting, which would then lead to the unsustainability of vetiver system. By His Majesty's suggestion, experience in implementing and research results obtained from Ban Rai – Ban I Thong, Kanchanaburi Province. Vetiver system for erosion control and stabilization of highways slopes had been reaffirmed and verity to achieve maximum benefit and sustainability (Sanguankaeo *et al.*, 2006).

4.1 Optimum Planting Techniques

4.1.1 Suitable planting materials

Aromatic vetiver (*Vetiveria zizanioides*) is usually used for roadworks. It should be nursery in poly-bagged (2x6 in.) for 45 – 60 days in order to produce “active tillers”. These poly-bagged active tillers at the age of 45 – 60 days are suitable vetiver tillers and should be applied. The poly-bagged active tillers give significantly better growth than bare slips vetiver.

4.1.2 Soil fertility improvement

Bio-engineering highway slope stabilization works are relevant to lower soil profile (infertile of planting soil). The soil fertility improvement at the bottom of planting holes has strong effect on plant growth and the number of dead slips. It is obligatory to fertilize the soil at the bottom of planting holes with chicken manure (600 g.) or farmyard manure (2000 g.) mix with chemical fertilizer 15-15-15 (45-60 g.) per 1 meter of planting row (12 slips).

4.1.3 Planting during suitable period

The success of application vetiver system for highway slope protection depend largely on period for planting. The suitable period for planting is the beginning of the rainy season or should be done at least 2 months before the end of rainy season.

4.1.4 The pattern of the vetiver grassing on highway slope

The pattern of vetiver grassing can be classified into 2 categories according to the seriousness and the tendency of erosion.

4.1.4.1 On slopes where erosion is not severe

For the general preventive purpose on the maintenance and construction projects, that planting the vetiver in large scale area, the spacing between the planting rows should be 1 meter apart and 10 centimeters between the clumps.

4.1.4.2 On slopes where erosion is severe

For the erosion control and stabilization of the existing strongly eroding sites and collapsed slope for remedial works on rehabilitation for maintenance and construction projects. The slips are done in rows 0.5 meter apart and in clump space between 5 –10 centimeters, with

straw bundle installed behind the vetiver rows for temporary support and slowing down runoff.

4.1.5 Maintenance after planting

Maintenance after planting are strongly effect on growth situation and survival of vetiver in the longterm condition . Leaf trimming, weeds control and fertilization are necessary for 1-2 years after planting (Sanguankaeo *et al.*, 2006).

4.2 Influence of the site area on the growth of vetiver

4.2.1 The effect of land surface

In the mountain highway construction projects, the vetiver were planted as pioneer plant on barren land of back slope (cut slopes) and side slopes (fill slopes or highway embankments slope) Fig.7. On the planting site, in which vetiver were planted with the optimum planting techniques revealed that vetiver grow well and still survive after planting. Because of the negative effect, replacement of the vetiver by vigorous local weeds has been eliminated. It will lead to sustainability of the vetiver system at grassing sites. In accordance with His Majesty the King’s suggestion, results suggest that “for large-scale construction projects in which vast lands, especially hilly areas, are affected, vetiver should be used as a pioneering plant to effectively rehabilitate and restore the fertility of the areas” (Chomchalow,2010).

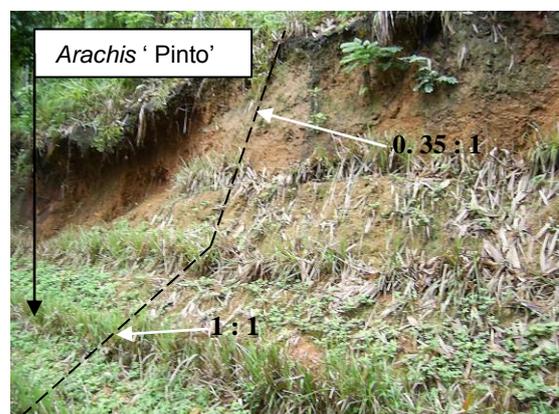
4.2.2 Effect of slope inclination

Sanguankaeo *et al.* (2006) study on growth situation and survival of vetiver on various slope inclinations. The study revealed that vetiver grow well on slopes which inclination less than 0.5:1 (H:V) and did not survived on inclination steeper than 0.35:1 (H:V) Fig.8.

Figure 7: Vetiver were planted as pioneer plant on barren land for highway construction project.



Figure 8 : Difference growth situation of the vetiver planted in steeply (>70°, 0.35 :1) and gently (<45°, 1:1) inclined slope portions.



4.2.3 Effect of shading

Shading played negative effect on vetiver, both height, tillering and total biomass considerably (Xu, 2000).

4.3 Mixed planting with suitable plant

Arachis 'Pinto' (Leguminosae : creeping forage peanut) is planted between the vetiver rows for coverage land area, in order to block or control weeds and provide nitrogenous fertilization to vetiver. It will lead to sustainability of the vetiver system. *Arachis 'Pinto'* is a creeper that grows closely to the ground surface with very dense mat-forming cover the land area. The covering were 40-60%, 60-80% and 80-90% in the land area within 5, 7 and 8 months respectively (Fig 9-10). In the case of planting the vetiver in combination with *Arachis 'Pinto'* at the beginning of rainy season, maintenance of weeds and

fertilization are not necessary or could be reduced to only 1 time (Sanguankaeo *et al.*, 2006).

Figure 9 : The approximate coverage of *Arachis* ‘Pinto’ 60-80% land area within 7 months.



Figure 10 : Efficiency of *Arachis* ‘Pinto’ to control weeds (covering 80-90% in land area within 8-12 months).



5.0 SLOPE OF HIGH WATERTABLE STABILIZED AGAINST EARTHFLAWS BY VETIVER

Since the vetiver system has been applied for erosion control and stabilization of highway slopes, it has been proved and accepted as a low-cost technique, effective measure for erosion control and prevent shallow-seated failure of highway slopes. Moreover, planting vetiver on the slopes of high groundwater table, which soil was in saturated condition and flowing down slope. After planting for 2 years, the vetiver reflected high efficiency in the evapotranspiration rates. It was appropriate to set soil moisture condition within this saturated-soil slopes. There were not any progressive soil movement or flow took places on these slopes (Fig.11-12).

Figure 11 : Highway cut slope was stabilized with vetiver for stopping the earthflows on Highway Route No.107 (in 2007).



Figure 12 : Vetiver system was applied for stabilizing and stopping soil movement on highway slope (Route No.1249).



Earthflows are characterized by a relatively large semi-viscous and highly plastic mass resulting in a slow flowage of saturated earth. Many earthflows occur on gentle to moderate slopes (Varnes,1996 ; DMG,1997). Because of their viscous flows of saturated soils, earthflows are critical problems in actual highways maintenance.

Highway cut slope on Route No. 107 : Chiang Dao – Fang (Km.78+400 to Km.78+600) was constructed in 2004 on which landslide/earthflows occurred in the rainy season of 2005. Due to the flow of saturated soil in a thin zone, it appeared to be an essential element of this failure, in addition it was assigned to be the earthflows. The earthflows was 100 m. wide (Km.78+500 to Km.78+600) and 35 m. long. The soil was highly softened and walking over this earthflows ground was very difficult or impossible. With high groundwater table and seepages of wet ground were present, flowing mass blocked the traffic (Fig.11 and 13).

In 2006 (July – Aug.), 120,000 slips of vetiver were planted with the pattern for serious cases (planting in rows is 50 cm. apart and in clump 5 – 10 cm. spacing) on this earthflows. The earthflows was still active on the day of planting vetiver.

Figure 13 : Landslide / earthflows on highway cut slope of high groundwater table and seepages on Route No.107 (in 2005).

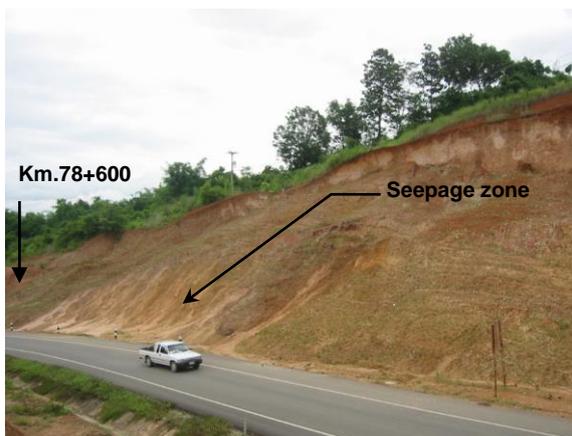


Figure 14 : VS in stabilization on water-saturated soil slope to stopped the flowage of earthflows (in 2008).



The soil investigation revealed that the soil is classified as CL(Silty clay) and CH (Inorganic clay) with low to high plasticity index (USCS, 2003). At the vetiver planting area or within the earthflows body, the lowering of the groundwater table occurred. As a consequence the soil was getting dry due to the evapotranspiration by vetiver. The soil moisture content at the vetiver planting area was contrary to non-planting vetiver area. The soil moisture content was 11% while the non-planting vetiver area was 15%. The slope was stabilized and stopped the flowage of soil by vetiver. (Fig.14).

For applying suitable closely- spaced plantations, it is appropriate to set soil moisture condition within saturated-soil slopes. The slopes should be able to be stabilized and prevented earthflows. Thammathworn *et al.* (2011) reported that vetiver has Kranz structure surrounding vascular bundles which confirmed high efficient photosynthetic rates. This indicate that vetiver has high efficiency evapotranspiration rates. Consequently, it reduce carbon dioxide in the atmosphere.

6.0 UNIT RATES OF VETIVER GRASS PLANTING FOR HIGHWAY SLOPE PROTECTION (Sanguankaeo *et al.* , 2006) .

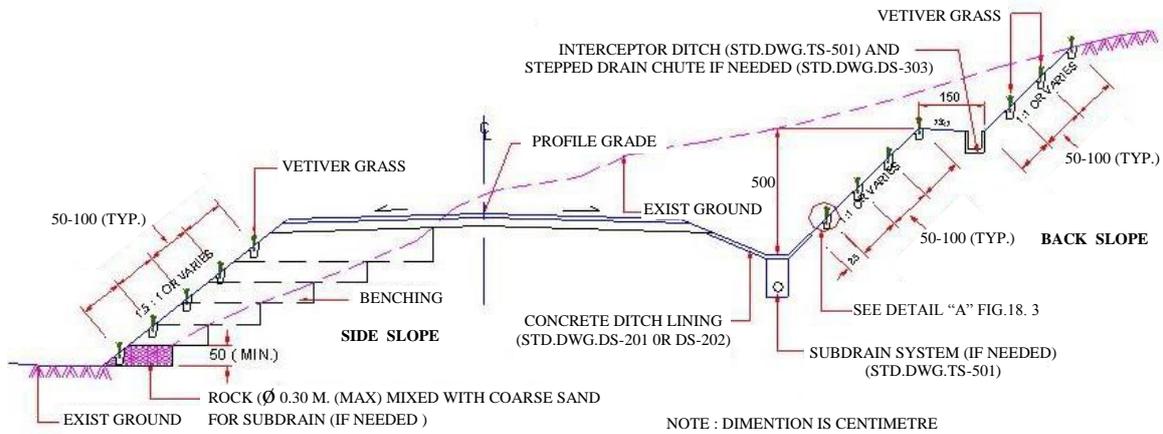
- The unit rates given in this paper are expressed in Baht. (THAI) and for Highways projects in mountainous area has shown in Plate 1.

Project name.....	Amount of tillers.....	Tillers
	Labour cost 212.00	Baht/day
	Diesel oil 26.00	Baht/lite
	All rates are on the basis of 12 Tillers/m ²	
	Exchange rate 1 \$ (USD) = 30 Bath	
A) Ground Preparation		
Cleared and Benching (Mini bench)		0.18 Baht/tiller
B) Materials Cost		
1] Materials for multiplication in plastic bags (2x6 in.)		
1.1 Cost of vetiver tiller (In case of bare root slip)		0.25 Baht/tiller
1.2 Soil and planting materials		0.23 Baht/tiller
1.3 Accelerating hormones		0.15 Baht/tiller
1.4 Plastic bag 2x6 in.		0.10 Baht/tiller
2] Cost of vetiver tiller (In case of tiller in plastic bag 2x6 in.)		1.50 Baht/tiller
3] Materials for basal application in bottom of planting hole		
3.1 Chicken manure (0.6 Kg./linear metre) or Farmyard manure (2.0 Kg./linear metre)		0.20 Baht/tiller
3.2 15-15-15 Fertilizer (60 g./linear metre)		0.05 Baht/tiller
4] Materials for maintenance ≈ 30-40 days after planting		
4.1 Urea fertilizer (30 g./linear metre)		0.12 Baht/tiller
C) Labour Cost		
1] Labour cost of nursery for 60 days		
1.1 Planting in plastic bag (325 bags/1 worker/day)		0.65 Baht/tiller
1.2 Watering (50,000 tillers/1worker/day)		0.25 Baht/tiller
2] Labour cost for planting at the target area		
2.1 Hole digging and basal application of manure (350 tillers/1 worker/day)		0.60 Baht/tiller
D] Transportation cost in mountainous area.		
1] In case of bare root slips		
1.1 Light truck or pick-up : 250-300 km.(20,000 slips/trip)		0.30 Baht/slip
1.2 Medium truck: 250-300 km.(400,000 slips/trip)		0.025 Baht/slip
2] In case of tiller in plastic bag 2x6 in.		
2.1 Medium truck: 250-300 km.(25,000 tillers/trip)		0.40 Baht/tiller
3] Transportation cost of tiller (in plastic bag) from vetiver nursery to target area		
3.1 Light truck (4,000 tillers/trip)		
- Distance 30 km.		0.125 Baht/tiller
- Distance 60 km.		0.25 Baht/tiller
3.2 Medium truck (25,000 tillers/trip)		
- Distance 30 km.		0.025 Baht/tiller
- Distance 60 km.		0.05 Baht/tiller
E) Maintenance cost for 1 year after planting		
1] Weeding (2 times)		0.10 Baht/tiller
2] Leaf trimming (2 times)		0.20 Baht/tiller
3] Fertilization (2 times)		0.20 Baht/tiller
F) Miscellaneous		
1] Fuel (For ≤ 100,000 tillers)		0.10 Baht/tiller
2] Other expenses (For ≤ 100,000 tillers)		0.15 Baht/tiller
G) In the case of interplanting with <i>Arachis</i> 'Pinto'		
1] Cost of 'Pinto' sprout(in plastic bag 2X6 in.)		0.75-1.00 Baht/sprout
2] Labour cost for planting (650 sprout/1 worker/day)		0.35 Baht/sprout

Plate 1 Unit rates of vetiver grass planting for highway slopes protection.

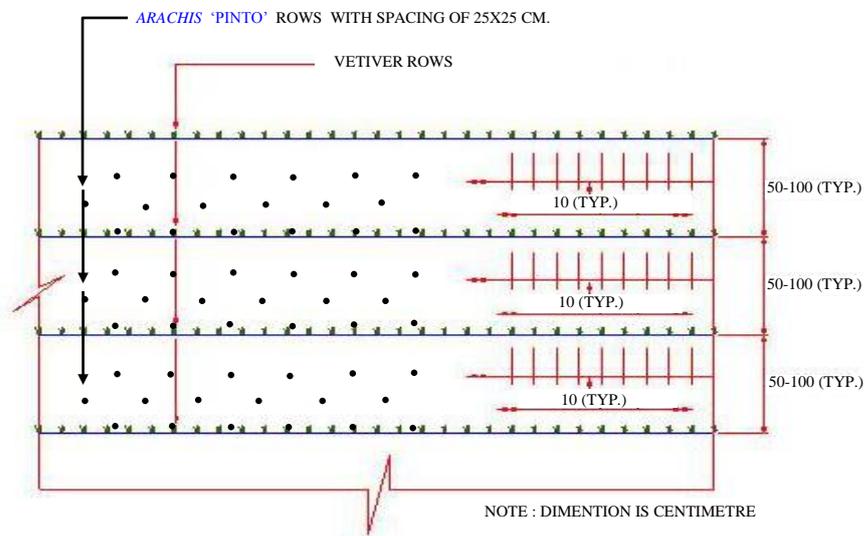
7.0 STANDARD DRAWING : VETIVER GRASS PLANTING FOR HIGHWAYS SLOPE PROTECTION (Sanguankao *et al.* , 2006) .

Figure15 : Standard Drawing “Vetiver grass planting for highways slope protection”



- Spacing of vetiver grass rows varies from 50-100 cm. and in clump 10 cm. which depend on severe erosion problems on soils.
- Drainage system i.e. interceptor ditch, drain chute, subdrains are also necessary.

Figure 15.1 : Cross-section : Vetiver grassing on back slope and side slope.



- **For not serious cases**, planting in rows is 1.00 m. apart and in clump 10 cm spacing.
- **For serious cases**, planting in rows is 50 cm. apart and in clump 10 cm spacing.
- **For minimal maintenance of weeds and fertilization**, *Arachis 'Pinto'* is planted between the rows of vetiver.

Figure 15.2 : Plan : Vetiver grassing on back slope and side slope.

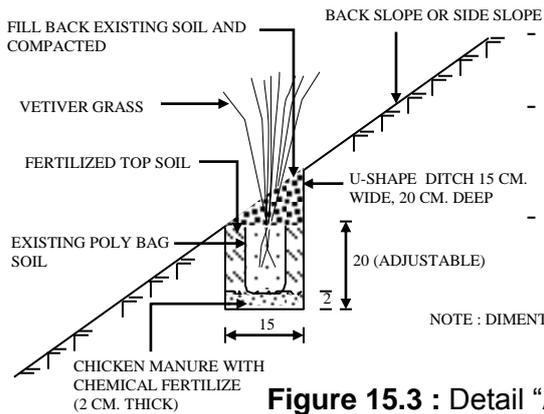
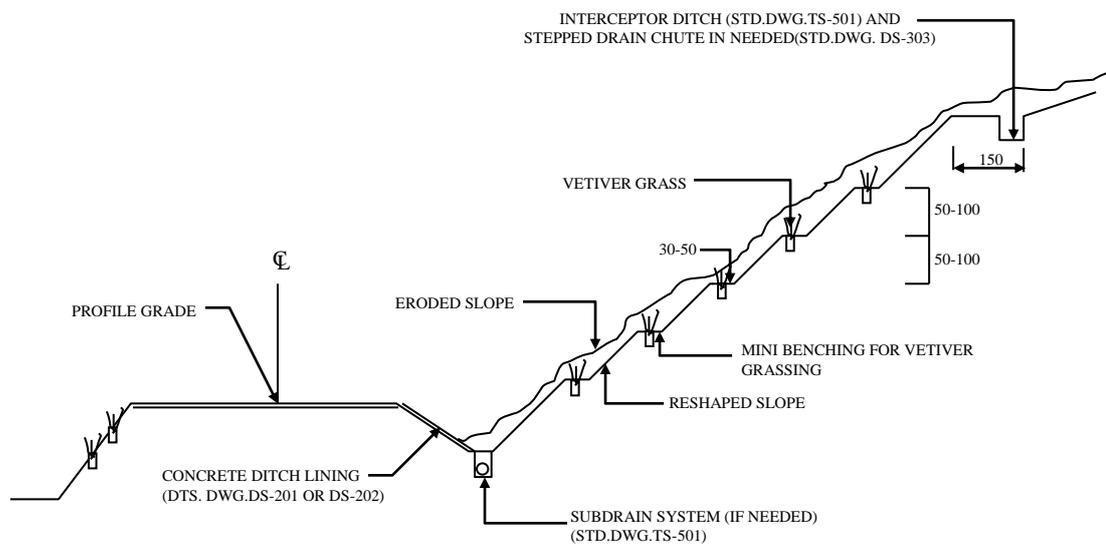


Figure 15.3 : Detail "A"

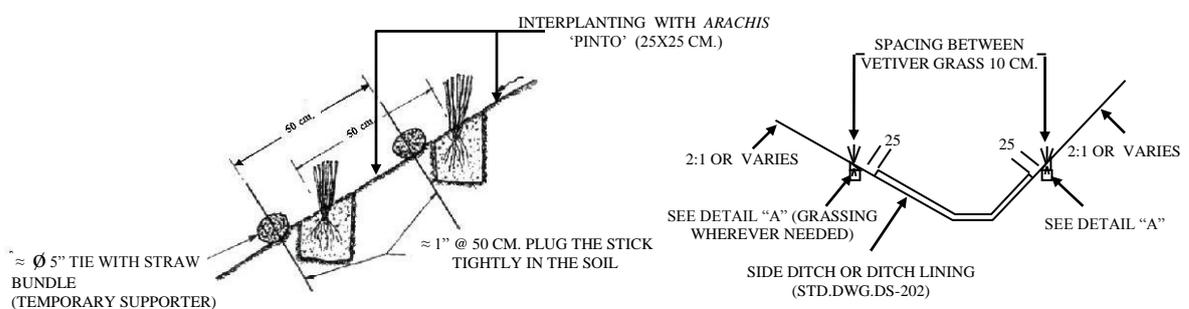
- Digging the existing soil U-shape ditch 15x20 cm.
- Basal with chicken manure (600 g.) or farmyard manure (2 kg.) + fertilizer 15-15-15(60 g.) per linear meter.
- Planting time should be the beginning of rainy season or at least 2 months before the end of rainy season.



NOTE : DIMENTION IS CENTIMETRE

- Reshape the eroded back slope
- Make mini benching 30-50 cm. wide, 50-100 cm. height
- Plant the vetiver grass on the bench
- Together with drainage systems

Figure 15.4 : Cross-section : Vetiver grassing on existing eroded back slope.



NOTE : DIMENTION IS CENTIMETRE

Figure 15.5 : Vetiver grassing on high erosible area and side ditch.

CONSTRUCTION DETAILS

1. THE PLANTING MATERIALS : VETIVER (VETIVERIA ZIZAIODES NASH) SHOULD BE LOCAL KINDS OR OTHER APPROPRIATE ONES AS APPROVED BY THE DIVISION WHO INCHARGES THE CONSTRUCTION PROJECT, DEPARTMENT OF HIGHWAYS. THE SHOOTS SHOULD BE NURSERY VETIVER IN A POLY BAG WHICH HAS DIAMETER OF 2 INCHES AND THE LENGTH OF 5-6 INCHES (SIDE – FOLDED). EACH BAG WHICH CONTAINS SOIL AND FERTILIZER IS TO SEVER 1-2 VETIVER SHOOTS. RESTED THE SHOOTS WILL BE IN BAGS FOR 45-60 DAYS BEING TAKEN TO THE PREPARED SOIL.
2. HOLE DIGGING AND GROUND PREPARATION : AFTER THE WORKS FOR BACK SLOPE, SIDE SLOPE, ARE FINISHED ACCORDING TO THE CONSTRUCTION PLAN, GROUND PREPARATION FOR VETIVER PLANTING SHOULD BE STARTED BY DIGGING A U-SHAPE DITCH WHICH IS 15 CM. WIDE AND 15 – 20 CM. DEEP.
3. SOIL FERTILITY IMPROVEMENT CHICKEN MANURE (600 G.) OR FARMYARD MANURE (2 KG.) MIX WITH FERTILIZER 15-15-15 (60 G.) PER LINEAR METRE OF PLANTING APPLIED AT THE BOTTOM OF PLANTING HOLES.
4. PLANTING : THE SPACING BETWEEN ROWS IS AS SHOWN IN THE PLAN. THE DISTANCE BETWEEN SHOOTS IS 10 CM. TRIM AND LEAVE THE LEAVES OF THE SHOOTS FOR 20 CM. BEFORE PLANTING, CUT OFF THE BOTTOM PART OF THE BAG AND LET 10 CM. OF THE ROOT BE SHOWN. TAKE OFF THE BAG AND PUT THE VETIVER SHOOT ON THE TOP OF IMPROVED SOIL IN ITEM 3. FILL THE HOLE WITH THE PREPARED SOIL AS SHOWN ON FIGURE 18.3 AND COMPACT TO MEET EXISTING SLOPE.
5. PERIOD FOR PLANTING : THE SUITABLE PERIOD SHALL BE ON MID APRIL – JULY, EXCLUDING IN EASTERN COAST REGION SHALL BE ON OCTOBER-FEBRUARY.
6. PLANT CARING : THE RATE OF SURVIVAL OF VETIVER GRASS SHOULD BE NOT LESS THAN 95 % AFTER 2 MONTHS OF PLANTING IF LESS, THE CONTRACTOR HAS TO REDO THE PLANTING WITHIN 15 DAYS. THE NEW PLANTING WILL BE RECHECKED ANOTHER 2 MONTHS.
7. THE SHOOTS : OTHER THAN THE LOCAL SHOOTS, THE CONTRACTOR MAY USE ANY SHOOTS REPRODUCED THROUGH VARIOUS WAYS, SUCH AS BY TISSUE CULTURE BUT THE QUALITY OF THE SHOOTS NEED TO BE APPROVED BY THE DIVISION WHO INCHARGES THE CONSTRUCTION PROJECT, DEPARTMENT OF HIGHWAYS
8. LEAF TRIMMING, WEEDING AND FERTILIZING : AFTER 30 DAYS OF PLANTING , POUR HALF A TEA-SPOON OF AMMONIAM SULPHATE FERTILIZER (21 : 0 : 0) OR ONE-FOURTH OF TEA-SPOON OF UREA FERTILIZER (40 : 0 : 0) OVER EACH HOLE AND OVER EACH SPACE BETWEEN HOLES. THE VETIVER GRASS WILL BE TRIMMING, WEEDING AND FERTILIZING ON MAY AND SEPTEMBER BUT ON NOVEMBER AND MARCH IN THE EASTERN COAST REGION. THE TRIMMING SHOULD LEAVE THE HIGH OF THE PLANT FOR 20 – 30 CM.FOR FERTILIZING NPK FERTILIZER (15-15-15) SHOULD BE PUT ON THE GROUND IN THE PROPORTION 20 GRAMS PER METER OF VETIVER GRASS ROW.
9. MINIMAL MAINTENANCE IN THE CASE OF PLANTING THE VETIVER IN COMBINATION WITH *ARACHIS* 'PINTO' IN THE SUITABLE PERIOD OF PLANTING AS MENTION IN ITEM 5, LEAF TRIMMING IN ITEM 8 CAN ONLY BE DONE, THE WEEDING AND FERTILIZING ARE NOT NECESSARY.
10. VETIVER GRASSING ON DEEP CUT AND HIGH FILL SLOPE : IN CASE OF PLANTING THE VETIVER GRASS ON DEEP CUT SLOPE OR HIGH FILL SLOPE OF THE HIGHWAYS SHOULD BE NEEDED MORE CARE , CLOSED SPACING BETWEEN CLUMPS AND ROWS SHOULD BE APPLIED, AND THE COMBINATION WITH SURFACE DRAINAGE STRUCTURAL WORKS FOR EXAMPLE INTERCEPTOR DITCH , DRAIN CHUTE ARE ALSO NECESSARY AS DIRECTED BY THE ENGINEER OR AS PARTICULAR DESIGNED FOR THE INDIVIDUAL SITE.
11. DIMENSION ARE IN CENTIMETERS UNLESS OTHERWISE INDICATED.

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Figure 15.6 : Construction details.

8.0 CONCLUSIONS

- Optimum Planting Techniques.
 - Poly-bagged active vetiver tillers at the age of 45-60days should be applied.
 - It is obligatory to fertilize the soil at the bottom of planting holes with chicken manure (600 g.) or farmyard manure (2000 g.) mix with chemical fertilizers 15-15-15 (45-60 g.) per 1 meter of planting row.
 - The suitable period for planting vetiver is the beginning of rainy season (mid April – July) or should be done at least 2 months before the end of rainy season.
 - The pattern of the vetiver grassing can be classified into 2 categories according to the seriousness and tendency of erosion.
 - Maintenance of weeds and fertilization are necessary at least 1 year after planting.

- In the case of planting the vetiver in combination with *Arachis* 'Pinto' in April – July, maintenance of weeds and fertilization are not necessary or could be reduced to 1 time of weeding.
 - Vetiver slips can develop a completely dense hedgerow within 3-4 months.
 - Vetiver grows well on slopes which inclination is less than 0.5 : 1 (H : V) and did not survive on inclination steeper than 0.35 : 1 (H : V)
 - Shading played a negative effect on vetiver growth.
- Planting the vetiver as a pioneer plant on barren land, the vetiver grows well and still survives after planting. It will lead to the sustainability of the Vetiver System at grassing sites.
- *Arachis* 'Pinto' has efficiency to control weeds. The coverings were 40-60%, 60-80 % and 80-90 % in land area within 5, 7 and 8-12 months respectively. *Arachis* 'Pinto' planting with vetiver could significantly reduce the cost of weeding and increase soil fertility for vetiver plants. This planting technique will lead to the sustainability of the Vetiver System.
- Vetiver System is multi-technology, a mixed planting technique combining vetiver with other suitable plants should be studied and applied for improving efficiency of the Vetiver System in the long run.
- Vetiver shows high efficiency in evapotranspiration rates. It is appropriate to set soil moisture conditions within saturated-soil slopes. This situation will have beneficial effects on slope stability. Furthermore, it contributed to the reduction of carbon dioxide in the atmosphere.
- Vetiver stabilizes the soil slope not only by root reinforcement but by getting soil to dry by evapotranspiration. In the case of planting the vetiver with suitable closely spacing, the roots of vetiver could cause water to rise up through capillary action to deplete moisture in the soil thus lowering pore water pressure and lowering the groundwater table on slopes.
- Vetiver System has been proven to be an effective measure for erosion control and stabilization against shallow-seated failure and earthflows of saturated soil slopes.

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A Brief Introduction to the First Author

Mr.Surapol Sanguankao is a senior expert engineering geologist of the Department of Highways, Thailand. His past experiences included a variety phase of problems in erosion control and stability analysis of highway slopes in mountainous area. He has published 27 technical papers in the fields of slope stability analysis and construction materials. He creatively initiated the application of VS in erosion control and stabilization for highway slopes in Thailand. He is currently a member of the committee on Development and Promotion of the Utilization of the Vetiver Grass, Thailand.

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