

The Application of the Vetiver System in Erosion Control and Stabilization for Highways Construction and Maintenance in Thailand

Surapol Sanguankaeo, Surachai Chaisintarakul, and Ekawit Veerapunth

Department of Highways, Bangkok, Thailand

Abstract

Since 1993, The Vetiver System (VS) has been applied both in construction and maintenance projects of mountain roads in the Northern , Northeastern , and Southern regions of Thailand. Over 2.5 million slips are planted each year. The Department of Highways (1994) has prepared a Standard Drawing [SP-204 1994 and SP-206 (Revision) 1999,“ Vetiver grass planting for highway slope protection”] that consists of detail of the pattern of planting on back slope, side slope and bridge slope. The drawing covers planting at high erodible area, side ditch lining, bank protection. It also includes suitable slips, hole digging and ground preparation, planting, period for plant, planting caring , leaf trimming and fertilizing application. This drawing is used as a guideline in development of other engineering departments.

The VS plays an importance role and replaces other techniques for erosion control, and solves highway slopes damage caused by erosion or scouring at the curved section of road, surface slope, the end of surface drainage systems and toe slope. Vetiver slips have been planted depending on the seriousness and tendency of erosion. Their growth on side slope was usually better than back slope. Slips were obtained from : The Highway District's multiplication plots, Land Development Department and other agencies. Polybagged slips kept in the nursery are recommended and fertilizer should be applied at the bottom of the planting holes.

The VS has been proven and accepted to be an effective and low-cost technique for erosion protection in roadworks, suitable for a sustainable economy with limited budget. Some defects of the vetiver planting in the roadworks are found in the Northern region of the country where some local weeds grow more rapidly than the vetiver. So, in the first year, more care is needed. Suitable period for planting is limited in the rainy season that is not correlated well with construction that takes place in dry season.

1. Introduction

The Department of Highways has encountered with erosion problems and landslide damage to mountain roads. Estimated annual cost for erosion control and rehabilitation of highway slopes is about 100 millions Baths. By His Majesty the King of Thailand's initiative, in 1993, the first application of VS was applied for erosion control and slope stabilization on Highway Route No.1089: Mae Chan - Tha Torn Chiangrai province in Northern region of Thailand, where about 440,000 of

vetiver slips were planted. The Department of Highways is aware of the importance of soil and water conservation not only in highway construction projects, but also in existing highway erosion-control and rehabilitation projects. Over 2.5 million slips are planted each year on highly erodible soil of back slopes (cut slopes) and side slopes (fill slopes or highway embankments) in the Northern, Southern and Northeastern regions.

2. Geologic and Physiographic Factors of Erosion Control

2.1 Climate

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 18-34 °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.

2.2 Geology and Physiography

Physiography of Thailand is classified into 8 regions (DMR,2001). There are 3 regions that geologic condition and physiography encourage erosion, that are:-

2.2.1 Northern and Upper Western Regions. The region mainly consists of North-south and Northwest - Southeast trend high mountain ranges, usually more than 2,000 meters above MSL, valley plains and fluvial plains. The main country rocks are granitic rocks of Cretaceous and Triassic Period (DMR, 2001)

2.2.2 Lower Western and Southern Region. The region consist of the mountain ranges and submergent shoreline at the Western and emergent shoreline at the Eastern part of the region (DMR, 2001). This region is underlain chiefly by granitic rocks of Cretaceous to Tertiary and Triassic Period (Nakapadungrat,et al.1982 and Beckinsale, et al. 1979)

2.2.3 The Khorat Plateau. The Northeastern region of the country is high plateau with 130-250 meters. elevation above MSL., that contain sub-basin, flood plains and non-flood plains. The Plateau was surround by siltstone and sandstone mountain ranges of Mesozoic Era.

2.3 Target Areas for Vetiver Grass Planting

In the Northern, Western, Southern and Northeastern regions where soil is sandy, silty derived from decomposed granite, sandstone and siltstone contributing to the soil mass erosion potential. All these areas are subject to erosion problems and target area of vetiver grass planting of Department of Highways for erosion control and stabilization on highways construction and maintenance in Thailand. (Fig. 1)

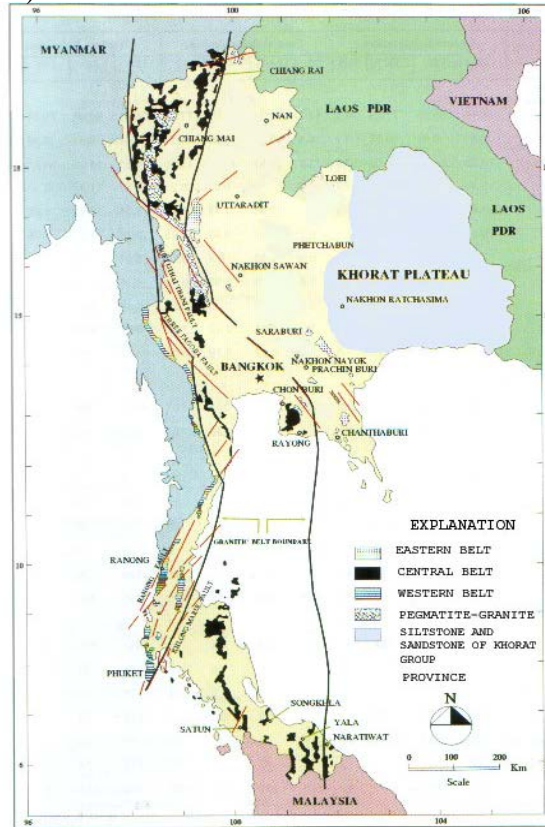


Fig. 1 Distribution of the Thai Granitic belts, siltstone and sandstone that are target area for vetiver grass planting (Modified from Putthapiban, 2002).

3. Erosion Problems in Highway Construction and Maintenance

In the mountain roads along the Northern, Southern and Northeastern regions, deep residual soil derived from decomposed granitic rocks, sandstone, siltstone is saturated by heavy rains and subsequently, excessive ground water and surface water flow. It is especially susceptible to erosion and shallow failure when highway slopes are over steep or insufficient of surface drainage systems, either due to stream channel cutting. The slopes with inadequate erosion protection or corrective measures in the long terms are induced to shallow mass movement of soils (shallow failure). The sliding mass blocks the traffic, transported to lowland, damage highway embankments, damage structures. Removal of the slide debris and repair of damage are the main impacts to mountain roads.

3.1 Erosion Types and Processes on Highway Slopes

Erosion types that lead to the problems in roadworks mainly are surface erosion (sheet erosion, gully erosion) and river erosion. Precipitation rain and river are the active factors. In the case of progressive or strong erosion, shallow mass movement of soils or shallow failure take place.

3.1.1 Erosion on Back Slope (Cut slope). The soil was transported or wash away to toe slope, blocking water flow in the side ditch which large block of soil mass block the traffic on the highway is the cause of damage on side embankment slopes. (Fig. 2)



Fig. 2 The strongly erosion on granitic soil back slope, sediments fill up ditch and damage embankment slopes.

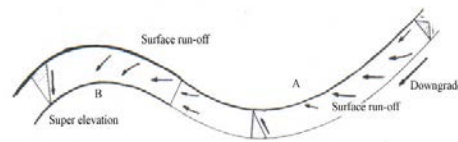


Fig. 3 Concentration of surface water on the surface of curved section.

3.1.2 Erosion on Side Slope (Fill slope). In the case of curved section of road where the cross fall of the road becomes a super-elevation, and where the surface run-off on the road is concentrated on such places as A and B as shown in Fig. 3, the water runs-off of the road when water volume exceeds the drainage capacity of inlets at A and B that results in the surface erosion of side slope.

3.1.3 Erosion at the End of Surface Drainage Systems. On the slopes that installation of surface drainage systems are not adequate and appropriate for erosion protection, especially at the end of drain chute and side ditch, large gully erosion is developed and progressive to shallow failure of highway slopes.(Fig. 4-5)

3.1.4 Erosion of Uncompacted Soil. Uncompacted sandy, silty soil on the surface of slope are frequently and easily subjected to erosion and progressive to surface failure especially after heavy rains, the sediment was transported to lowland becomes one of the environmental impact.(Fig. 6)

3.1.5 Stream Bank Erosion. Erosion along the stream channel way at the toe of embankment slope, finally the embankment slope fails.



Fig. 4 Erosion at the end of pipe culvert and drain chute.



Fig.5 Large gully erosion caused by the erosion at the end of side ditch.



Fig.6 Highly erosion of uncompacted sandy soils on surface of embankment slope.

4. Vetiver Grassing Promotion and Development Plan of the Department of Highways in Accordance with His Majesty The King's Project.

After His Majesty the King of Thailand's initiative, in 1993 the Department of Highways instructs its highway construction and maintenance units to plant vetiver grass on erodible highway slope. Each year over 2.5 million slips are planted for erosion control in highway construction projects, highway erosion-control and rehabilitation projects, some activities are:-

4.1 DOH Officials Training. At the beginning, it was found that officials at the implement sites needed to learn more about the knowledge of application VS for erosion control and stabilization highway slopes. There were four training courses for officials involving with the growing at the job site in 1999, total of 266 persons.(Fig. 7) After that, VS has been accepted as one of the effective technology for highway remedial and preventive measures.

4.2 Vetiver Grassing on Highway Slope. Road construction centers (construction units) and highway districts (maintenance units) have applied VS for erosion protection and stabilization on existing highways and under construction highways on steep and high slope, rehabilitation of collapsed slope, summarized in Table 1

Fiscal year	Highway Maintenance						Highway Construction		Total amount of slips
	Preventive			Rehabilitation			No.of Route	Amount of slips	
	No. of Route	No .of location	Amount of slips	No. of Route	No.of location	Amount of slips			
2001	7	>10	658,998	10	10	757,700	4	786,220	2,202,915
2002	12	>16	320,680	6	18	615,500	8	1,610,940	2,547,120
2003	9	>10	1,135,750	18	22	1,023,600	2	500,000	2,659,350

Table 1 Summary of the vetiver grassing for highway maintenances and constructions in 2001-2003

4.3 Production and Propagation of Slips. The Department of Highways instructs its highway maintenance units to propagates the vetiver slips in large multiplication plots. There are 6 multiplication plots at Chiangmai 3 , Prayao 1, Loei 1, Loei 2, Nakornsithamarat 2 and Narativat Highway Districts. (Fig. 8)

The production and propagation of slips for erosion control and stabilization of highway slope are performed in three methods.

4.3.1 Vetiver slips from other Departments and Agencies. Vetiver slips in small plastic bags are nursed for 20-45 days and planted in places.

4.3.2 Propagation in large Plastic bags. Planting soil must be well drained soil. Sand and burnt rice husk in a proportion of 1:2:1 gives the best result.

4.3.3 Multiplication in cultivated plot.

Method of 4.3.1 and 4.3.3 are most useful and practically for roadworks. The production and propagation of slips are shown in Fig.9

5. Application of the Vetiver System in Erosion Control and Stabilization for Highway Slopes.

The Department of Highways (1994) has prepared a Standard Drawing [SP-204, 1994 and SP- 206 (Revision) 1999, “ Vetiver grass planting for highways slope protection”].The purposes of the design are for directing, helping the maintenance and construction units to utilized the vetiver grassing for erosion control correctly and perfectly through out the country. The drawing includes detail of the pattern of planting on back slope, side slope, and bridge slope, planting at high erodible

area, side ditch lining and bank protection. It also includes suitable slips, hole digging and ground preparation, planting, period for plant, planting caring, leaf trimming and fertilizing. This drawing is used as a guideline in development of other engineering departments, summarized and showed in Fig. 10

5.1 Suitable Period for Planting. The success of application VS for highway slope protection depends largely on period for planting. The suitable period for planting is the beginning of the rainy season or planting should be done in the period of rainy season at least 1 month in the period of rainy season is needed for growing. Consequently, the period for planting is from late April to September in the Northern and Northeastern regions. In the Southern region, October to March in Eastern coast and May to September in Andaman coast.

5.2 Slip for Erosion Control on Highway Slopes. Slips are obtained from Highway District's multiplication plots, Land Development Department, other Departments and Agencies. Because of the long roots and being able to grow in a wide range of climates, altitude Aromatic vetiver (*Vetiveria Zizanioides* Nash) is usually used for roadworks. Polybagged slips give significantly better growth, hence the planting materials usually are 30 – 45 days vetiver nursery. Fertilizer should be applied at the bottom of the planting hole.



Fig.7 Training on vetiver for Bureau of Highway 2 officials in 1999.



Fig.8 Multiplication plot at Chiangmai 3 Highway District.

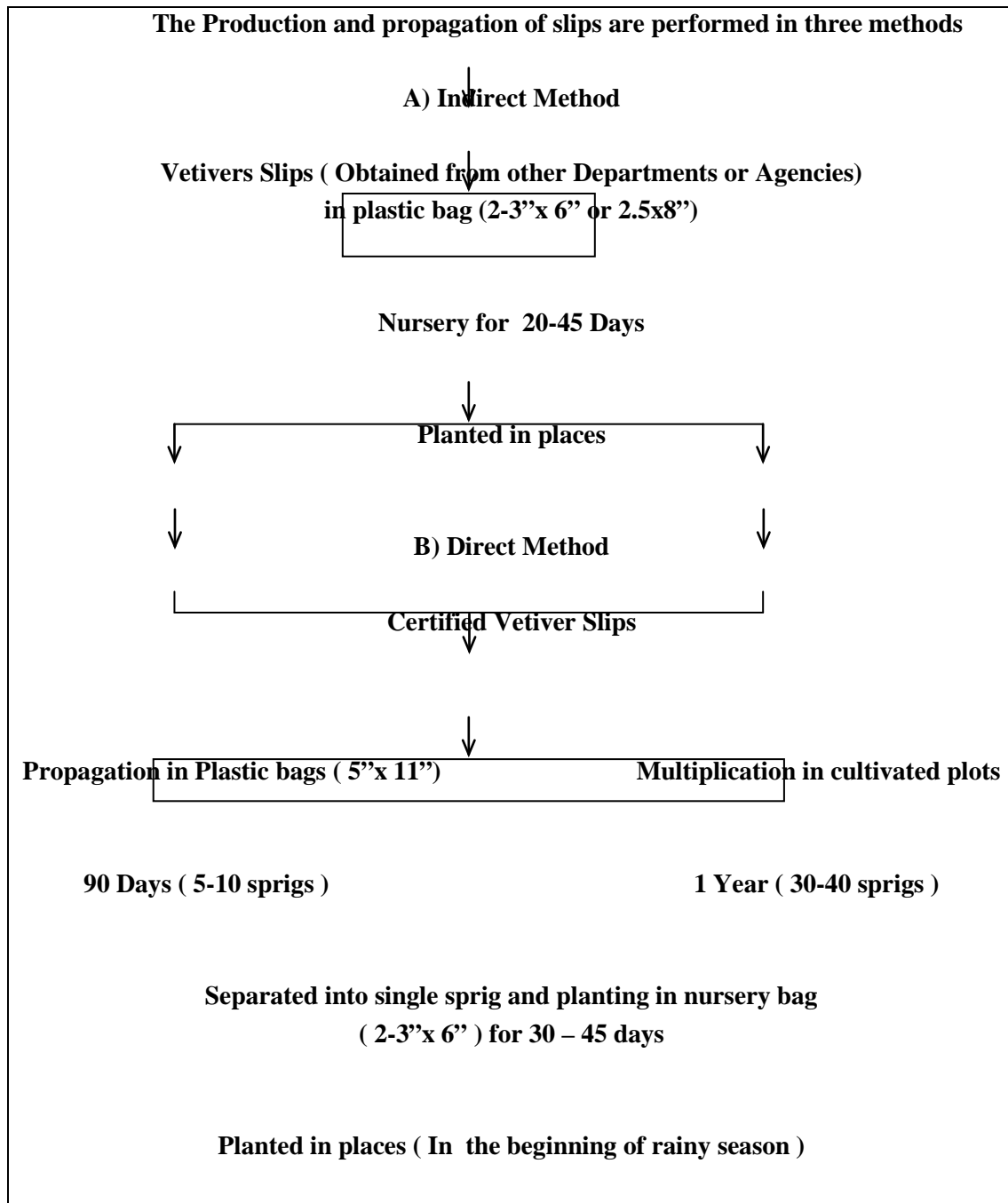


Fig. 9 Flow chart of production and propagation of slips for roadworks

Fig. 10 Vetiver grass planting for highways slope protection [SP-206(Revision) 1999].

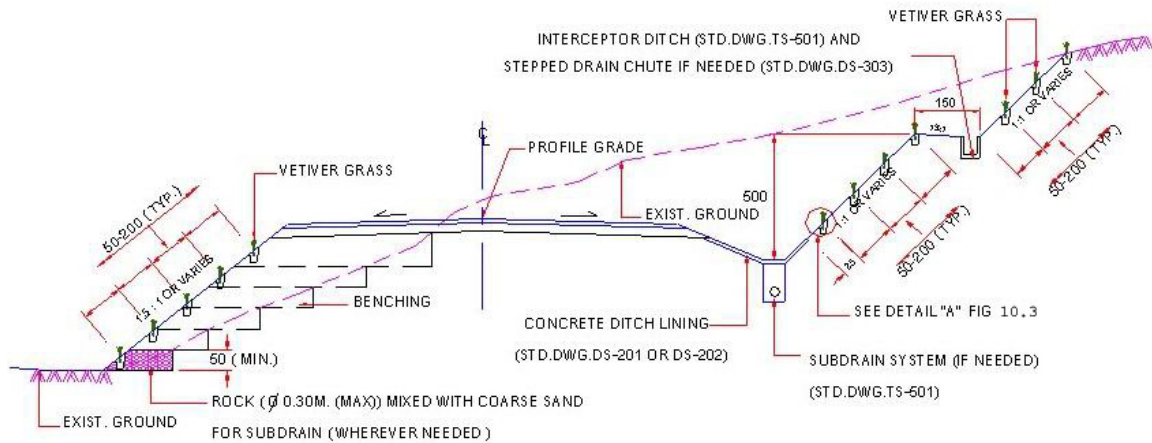


Fig 10.1 CROSS-SECTION : VETIVER GRASSING ON BACK SLOPE AND SIDE SLOPE

- SPACING OF VETIVER GRASS ROWS VARIES FROM 50-200 CM. AND IN CLUMP 5-15 CM. DEPEND ON THE FAILURE AND THE SOIL CONDITIONS.
- DRAINAGE SYSTEM i.e. INTERCEPTOR DITCH, DRAIN CHUTE, SUBDRAINS ARE ALSO NECESSARY

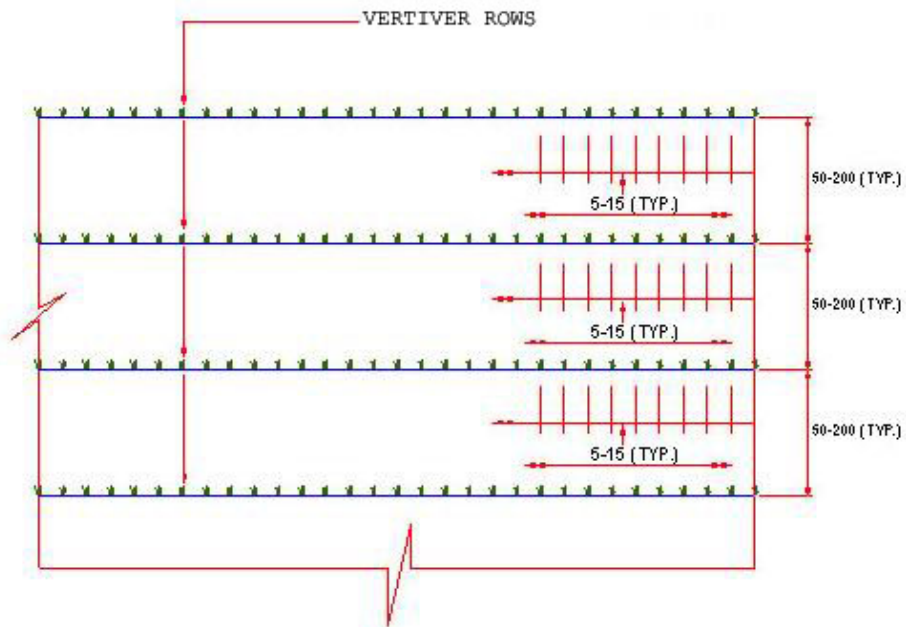
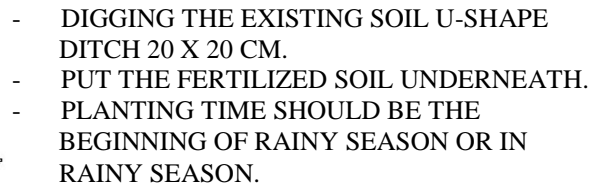


Fig 10.2 PLAN : VETIVER GRASSING ON BACK SLOPE AND SIDE SLOPE

- FOR NOT SERIOUS CASES, PLANTING IN ROWS VARIES FROM 1-2 M. APART AND IN CLUMP 10-15 CM. SPACING.
- FOR SERIOUS CASES, PLANTING IN ROWS VARIES FROM 50 -100 CM. APART AND IN CLUMP 5-10 CM. SPACING.



INTERCEPTOR DITCH (STD.DWG.TS-501) AND STEPPED DRAIN CHUTE IN NEEDED (STD.DWG.DS-203)

900 (MAX)

ERODED SLOPE

YETIYER GRASS

50x150

50x150

150

MINIBENCHING FOR YETIYER GRASS

RESHAPED SLOPE

PROFILE GRADE

CONCRETE DITCH LINING (STD.DWG.DS-201 OR DS-202)

SUBDRAIN SYSTEM (IF NEEDED) (STD.DWG.TS-501)

- RESHAPE THE ERODED BACK SLOPE.
- MAKE MINI BENCHING 50 CM. WIDE, 50 – 150 CM. HEIGHT.
- PLANT THE VETIVER GRASS ON THE BENCH.
- TOGETHER WITH DRAINAGE SYSTEMS.



CONSTRUCTION DETAILS

1. THE PLANTING MATERIALS : VETIVER (VETIVERIA ZIZANOIDES NASH) SHALL BE LOCAL KINDS OR OTHER APPROPRIATE ONES AS APPROVED BY THE DIVISION WHO INCHARGES THE CONSTRUCTION PROJECT , DEPARTMENT OF HIGHWAYS THE SHOOTS SHALL BE NURSERY VETIVER IN A POLY BAG WHICH HAS DIAMETER OF 2 INCHES AND THE LENGTH OF 5-6 INCHES (SIDE – FOLDED) BEFORE PLANTING. EACH BAG WHICH CONTAINS SOIL AND FERTILIZER IS TO SEVER 1-2 VETIVER SHOOTS. RESTED THE SHOOTS WILL BE IN BAGS FOR 1-1.5 MONTHS 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 HOLE WHICH IS 15 CM. WIDE AND 15 – 20 CM. DEEP. A GROOVE ALONG THE ROW OF VETIVER SHOULD BE MADE AND THE BOTTOM OF THE GROOVE SHOULD BE COVERED WITH 8 – 10 CM. OF EXISTING SOIL MIXED WITH BKK 2 (BANGKOK 2) FERTILIZER BY THE RATIO 1 : 1 OR DECAYED MANURE MIXED WITH CHEMICAL FERTILIZER (15 – 15 – 15 , 16 – 16 – 16) BY THE PROPORTION 100 GRAMS: 3 GRM/ SPRIG
3. PLANTING : THE SPACE BETWEEN ROWS IS AS SHOWN IN THE PLAN. THE DISTANCE BETWEEN TWO SHOOTS 5 – 15 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 PREPARED HOLES. FILL THE HOLE WITH THE PREPARED SOIL AS SHOWN ON FIGURE 10.3 AFTER 15-20 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. FILL THE HOLE WITH SOME EXISTING SOIL AND COMPACT TO MEET EXISTING SLOPE.
4. PERIOD FOR PLANTING : THE SUITABLE PERIOD SHALL BE 1 – 3 WEEKS BEFORE RAINY SEASON.
5. 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.
6. 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
7. LEAF TRIMMING AND FERTILIZING : THE VETIVER GRASS WILL BE TRIMMING AND FERTILIZED EVERY 4 MONTHS IN THE FIRST YEAR OF VETIVER GROWTH AND EVERY 6 MONTHS IN THE CONSECUTIVE YEARS. THE TRIMMING SHOULD LEAVE THE HIGH OF THE PLANT FOR 30 – 50 CM. AFTER THE SECOND LEAF TRIMMING, NPK FERTILIZER (15-15-15) SHOULD BE PUT ON THE GROUND IN THE PROPORTION 20 GRAMS PER METER OF VETIVER GRASS ROW.
8. VETIVER GRASSING ON DEEP CUT 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 SPRIGS AND ROWS SHALL 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.
9. DIMENSION ARE IN CENTIMETERS UNLESS OTHERWISE INDICATED.

DESIGN BY Ekawit Veerapunth
Surapol Sanguankaew
28 OCTOBER 1999

Fig. 10.6 CONSTRUCTION DETAILS.

5.3 The Pattern of the Vetiver Grassing on Highway slope. The pattern of vetiver grassing are classified into two categories according to the seriousness and the tendency of erosion. (Fig. 10)

5.3.1 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 can be 1-2 meters apart and 10 – 15 centimeters between the clumps.

5.3.2 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 spaced between 0.5 – 1 meter and in clump space not more than 5 – 10 centimeters, with straw bundle installed behind the vetiver rows for temporary support and slowing down runoff.

5.4 Application of the Vetiver System in Highway Erosion Control and Stabilization.

Because of the excellent properties of VS that the hedgerow can slow down runoff and the root system can stabilize the soil as deep as 3 meters (National Research Council 1993; Grimshaw and Helfer 1995), so it is an effective measure for erosion control and stabilization against shallow failure both in prevention and rehabilitation of highway slopes (Sanguankao et al. 2000). The benefits of application vetiver grassing for highway are in 5 formations.

5.4.1 Vetiver System is Applied for Highway Back Slope protection. The Vetiver is planted both on slope face and bench slope (Fig.11). Some of the planting are not successful due to the hard and low nutrient soils.

5.4.2 Vetiver System is Applied for Highways Side Slope protection . Planting on side slope can be efficiently and mostly successful. 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 grass planting (Fig. 12-14)



Fig.11 Highway cut slope was stabilized with vetiver on Highway.



Fig.12 Highway embankment was stabilized with vetiver on Highway Route No.1149:

5.4.3 Vetiver System is Applied for Stream Bank along the Roadway. In this case , vetiver is planting over the rock filled, gabion wall.(Fig.15)

5.4.4 Vetiver System is Applied for Highway Ditch Lining. In order to protect and stabilized the soil underneath and to trap the sediments to fill in the ditch.(Fig. 16)

5.4.5. Vetiver System is Applied on Shoulder Slope. In case of steep gradient section, vetiver planting suitable interval across and parallel the slope at highway shoulder and crest of shoulder slope respectively. (Fig. 17)

5.4.6 Vetiver System with Slope Protection Works. In this application vetiver is planting for erosion control and stabilization for existing eroding sites and rehabilitation works. (Fig. 18-19)

1) Vetiver Planting is Associated with the Concrete Square grid (1X1meter) slope protection. On highly erodible soils, in this application the planting row in each grid shall be 3 rows.(Fig.18)

2) Vetiver Planting is Associated with Gabion Wall. 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 (Fig. 19)

Fig. 13 Vetiver system in the rehabilitation of embankment slope on Highway Route No.1149



Fig. 13.1 Repair of the collapsed embankment slope in Fig.4 and stabilized with vetiver.



Fig. 13.2 Embankment slope was stabilized with vetiver for 1 year.



Fig. 14 High embankment was stabilized with vetiver coupled with surface drainage systems in the rehabilitation on Highway Route No.109: Fang – Tha Thon



Fig.15 Stabilization with vetiver along the stream bank on Highway Route No.107: Ban Pingkoke – Saphan Huai Tai.



Fig. 16 Vetiver planting at the side ditch lining.



Fig. 17 Vetiver planting on highway shoulder to slow down runoff longitudinal.



Fig.18 VS is applied with concrete square grid slope protection in the rehabilitation work on Route No.108: Hot – Mae Saring.



Fig.19 VS is associate with gabion wall in the rehabilitation work on Highway Route No 1451: Sec. Adj. to Phattalung Highway District's Area – JRT.Highway No. 403.

6. Conclusions

Vetiver system has been proven and accepted to be an effective measure for erosion control and prevent shallow failure of highway slopes, and low-cost technique which can readily be practiced. Highways Department highly satisfies the results of the application of VS in erosion control and stabilization for highways construction and maintenance, and replaces other techniques. The results of the application show that:-

- Aromatic vetiver (*Vetiveria Zizanioides* Nash) is suitable as planting material for roadworks, because it can grow better in wide range of climate and altitude.
- Polybagged slips give significantly better growth than bare slips vetiver.
- After planting vetiver, it may take 1-2 years to become fully effective.
- In the southern region of the country .The vetiver grow better than other regions due to longer rainy season.

- From the application of VS for rehabilitation of collapsed embankment slope at Highway Route No 1009: Chomthong- Doi Inthanon Km. 42+800 – 43+000 Chiangmai-3 District Highway, Northern region of Thailand. This location is 2,300 meters above MSL and temperature rang about – 3 to 20°C. Within this environment the vetiver is still adjustable itself and grow very well. This shows that vetiver can grow in a wide range of climates and altitude.

- The success of application VS for highway slope protection depends on:-
 - a) The suitable planting materials should be polybagged raised 30-45 days vetiver nursery and fertilizer should be applied.
 - b) Planting should be done in the period of rainy season or at least 1 month for growing in rainy season.
 - c) The carefulness is need for 1-2 years after planting, especially in the Northern regions.
- Some defects of the application of VS in the roadworks are:-
 - a) In the Northern region the local weeds grow rapidly than the vetiver.
 - b) Some of the planting on the back slope (cut slope) are not successful due to the hard and low nutrient soils, unlike planting on the side slope which are very successful.

c) Period for planting is limited in the rainy season. It is not correlated well with construction that takes place in the dry season.

7. References

- Beckinsale, R.D., Suensilpog, S., Nakapadungrat, S. and Walsh, J.N., 1979, Geochronology of Granite Magmatism in Thailand in Relation to Plate Tectonic Model, Journal of Geological Society of London, V. 136, P. 529-540.
- Department of Minerals Resources, 2001. Geology of Thailand, Bangkok.
- Department of Highways. 1994. Standard Drawing, Bangkok.
- Grimshaw, R.G. and Helfer, L. 1995. Vetiver Grass for Soil and water Conservation, Land Rehabilitation and Embankment Stabilization, Technical Paper No. 273, World Bank, Washington, DC.
- Sanguankaeo, S.; Sukhawan, C.; and Veerapunth, E.2000. The Role of Vetiver Grass in Erosion Control and Slope Stabilization Along the Highways of Thailand, Second International Conference on Vetiver, Phetchaburi, Thailand.
- National Research Council. 1993. Vetiver Grass: a Thin GREEN Line Against Erosion. National Academy Press. Washington, DC.
- Nakapadugrat, S., 1982, Geochronology and Geochemistry of the Thong Lang Granite Complex, Central Thailand, Ph.D. Thesis, University of London, 336 p.
- Puttapiban, P., 2002. Geology and Geochronology of the Igneous Rocks of Thailand, Symposium on Geology of Thailand, Bangkok, Thailand.
-