The Use of Vetiver Grass System for Erosion Control and Slope Stabilization along the Yadana Gas Pipeline Right of Way

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Abstract

The 238.5-km Yadana gas pipeline of the Petroleum Authority of Thailand (PTT) passed a 50-km strip of forest in which 20-m width was allowed for use during construction, amounting to an area of around 96 ha. Bare soil results from the construction was immediately exposed to erosion. Without any preventive measure, especially for the Slope Complex Soil Series in high mountain area, erosion rate may increase by 100 times.

To minimize environmental impact during construction and to achieve maximum effectiveness in rehabilitation, a construction strategy was formulated to create permanent soil erosion control structure with physical erosion design approach, i.e. soft plugs, diversion berms, and drainage system, combined with re-vegetation and agronomic erosion control methodology along the pipeline right of way. Vetiver grass was specifically introduced in high-risked erosion areas.

Erosion rating was calculated and classified into low risk (E_0), moderate risk (E_1), high risk (E_2) and very high risk (E_3). The mitigation measures at each area can be elaborated with the following details: E_1 areas - building permanent soil erosion control structure, re-vegetating with three kinds of leguminous covers, sowing of various grass species and immediate re-vegetation before the first rainy season; and E_2 and E_3 areas - building permanent soil erosion control structure including soft plugs and berms as well as vetiver grass planting, sowing of various grass and leguminous species before the first rainy season and re-vegetation before the second one.

Vetiver grass was planted in the E_2 and E_3 areas along the contour line, 10-15 cm apart, along the same contour furrow while hedgerows were spaced about 1-1.5 m, amounting to 1.5 million slips used in this project.

In the E_3 area with over 35^o slopes, berm construction may not effectively prevent erosion during the first rainy season; therefore, jute sacks filled with a mixture of soil and grass seeds were arranged in ladder-pattern, pegged with live stakes. Grass and legume seeds were sowed. Sacks were holed and planted with vetiver slips so that their roots grew into the soil while sacks naturally decayed. Those laddered jute sacks naturally formed permanent soil ladders covered with vetiver grass and other vegetation.

The vetiver grass system when utilized in conjunction with physical structures will play a significant role in erosion control and slope stabilization.

1. INTRODUCTION

The pipeline laying in the Yadana Gas Pipeline Project was necessitated to pass a distance of 50 km in the forest area with the construction right-of-way (R/W) of 20 m. Due to construction characteristics, strip surface clearing and construction resulted in bare soil after pipeline installation, thereby exposed to immediate soil erosion impact. The most effective application of rehabilitation measures must be implemented, based on environmental evaluation, engineering design / construction, and re-vegetation / agronomic control. Vetiver grass was thus introduced in the high-risked erosion areas.

Procedures and methods in integrating construction-engineering practices with botanical knowledge are summarized in the flow chart and the content of this document would subsequently follow the chart shown in Fig. 1.1.

2. PROJECT DESCRIPTION

During 1986 to early 1997, Thailand's commercial energy consumption, i.e. oil, coal/ lignite, natural gas and hydropower recorded a continuous growth, a three-fold rise from 300,000 barrels per day (crude oil equivalent) to 900,000-1,000,000 barrels per day. As indigenous energy sources were quite limited, able to be produced not over 30% of the demand, while the remaining must be imported, 60% of which is oil, in case of price fluctuation in global market, impact can be perceived. Therefore, additional procurement of natural gas was urged especially for power generation. More importantly, natural gas among petroleum fuels is cleaner. The Yadana Gas Pipeline Project was thus originated.

2.1 Yadana Gas Pipeline Project

The Petroleum Authority of Thailand (PTT) constructed the Yadana Gas Pipeline Project from the Thailand-Myanmar border at Ban I Tong, Thong Pha Phum district, Kanchanaburi province to transmit natural gas to fuel the Ratchaburi Power Plant of the Electricity Generating Authority of Thailand (EGAT) as well as Independent Power Producers (IPP). The 238.5-km pipeline passed a 50-km strip of forest in which 20-m width was allowed for construction space, amounting to an area of around 96 ha.

The construction of this 105-cm diameter pipeline, like other pipeline construction, was involved with digging of 2.50-m wide and 2.50-m deep trench. Pipelines were welded, strung together and installed. In the forest area, delivery of construction materials restricted within pipeline R/W and existing original mining roads in which necessary upgrading was done. However, during operation phase, along the pipeline route in forest areas, no permanent road was built.

2.2 Gas Transmission Facilities

The overall gas transmission facilities consist of 12 block valve stations located along the pipeline and one Operation and Maintenance Center (O & M) in Ratchaburi province. The system is monitored and controlled via the Supervisory Control and Data Acquisition System (SCADA) from both O & M in Ratchaburi and the Operations Center in Chon Buri province. To control the pipeline, on-line information from the pipeline inlet and outlet, i.e. pressure, temperature, density and volumetric flow are monitored. On-line pipeline integrity monitoring software in the SCADA system performs overall pipeline mass balance, pipeline hydraulics and rate of change pressure calculations, including the detection for leakage or any abnormal operation.

2.3 Standards of Engineering Design and Equipment

Pipeline transmission is globally accepted as highly safe as pipes are fabricated with special steel, buried underground, and virtually separated from mass transportation system.

- The gas pipeline was designed and constructed according to the specifications of the American Society of Mechanical Engineers, standard ASME B 31.8.

- Rust protection was of international standards, both internally and externally coated by fusion bonded epoxy.
- The cathodic protection was applied to prevent corrosion around the clock.
- Every weld was 100% examined by radiographic method (X-ray).
- An electronic device called Intelligent PIG (Pipeline Inspection Gauge) undertook regular internal examination of pipeline operation.
- The earthquake parameter has been assigned to the pipe design and pipe classification selection. The engineering structure of the gas pipeline is in fact able to withstand tremors better than buildings and other structures as it is buried underground without binding foundation and is having better flexibility when strung together.
- The gas pipeline installed along the R/W of the roads of the Department of Highways was additionally covered with 10-cm concrete slabs.
- Warning signs were installed along the route.

2.4 Overall Project Implementation Schedule

The construction at site was started on 24 March 1997 and completed on 30 June 1998, which finished on schedule.

Table 2.1: Project implementation schedule

The implementation list	1992	1993	1994	1995	1996	1997	1998	1999
1. Cabinet resolution : natural gas procurement from both indigenous and foreign sources	29 June ▼							
2. Cabinet resolution : accelerate natural gas procurement in time for EGAT's power plant construction		5 Oct. ▼						
3. Cabinet resolution : procure natural gas for IPPs			31 May ▼					
4. Gas Sales Agreement signed				2 Feb. ▼				
5. Initial Environmental Examination (IEE) started			▼					
6. Environmental Impact Assessment (EIA) started				31 May ▼				
7. The Project approved in principle by the Cabinet					7 May ▼			
8. Technical Hearing						10-12 Feb ▼		
9. The National Environment Board approved the EIA						24 March ▼		
10. Construction started						24 March ▼		
11. Construction completed							30 June ▼	
12. Rehabilitation started							▼	
13. Rehabilitation monitored & repaired							▼	

Source: *The Yadana Gas Pipeline Project*

3. CONSIDERATION ON ALTERNATIVE ROUTES

Along the Thailand-Myanmar border, the dominant land use type is forest area, where the pipeline route has to pass. It is necessary to study the alternative routes and choose the one with minimum environmental impact.

3.1 Preliminary Surveys

PTT studied a route that pipeline may be installed along the R/W of the Highway 3272 (Thong Pha Phum - Ban I Tong). However, certain constraints were found and implementation was dropped:

- ♦ Engineering Constraint : The gas pipeline must be installed along side slope for a distance of 30 km. The area was thus liable to subsiding.
- ♦ Maintenance Constraint : With over 200 curves of the road some are sharp curves, the equipment for internal inspection of the pipeline may not be able to run smoothly.
- ♦ Environmental Constraint : The road was 6-8 m wide and was not sufficient for construction space. Mountain slopes must be cut in for another 8-m wide, leading to greater environmental damage and erosion.

3.2 Alternative Routes and Selection

Three potential alternative routes located in forest area were investigated. Three possible routes were identified as Alternative 1, 2 and 3 as shown in Fig. 3.2. The most appropriate route was selected based on the level of environmental impact and was subsequently studied for more details.

The gas pipeline route must pass national reserve forest (conservation forest area), national park and watershed class 1A areas. The following six factors were taken into consideration for environmental impact study: (i) forest resource, (ii) wildlife, (iii) socio-economic and community, (iv) hydrology, water quality and aquatic ecology, (v) local transportation, and (vi) aesthetic and cultural value.

The study, the details of which appeared in the Environmental Impact Assessment (EIA), revealed that the Alternative 1 was the most appropriate, based on its least environmental impact compared to the other alternatives. In addition, it would pass the shortest distance of national reserve forest (conservation forest area) and watershed class 1A areas.

4. ENVIRONMENTAL EVALUATION

The EIA of the Yadana Gas Pipeline Project was started in 1995. The objectives of the study are as follows:

- Study existing characteristics of the environment prior to construction, and set up as baseline data,
- Assess environmental impact due to construction, and operation activities,
- Assess degree of the impact and prioritize the impact,

- Designate mitigation measures, monitoring program, and
- Specify construction strategies and techniques as well as rehabilitation approach.

Environmental evaluation was undertaken on two topics, i.e. existing environmental conditions and environmental impact assessment due to the construction. The former was used as references and baseline data while the latter was beneficial for the formulation of mitigation measures. The study on both topics covered the same 13 environmental issues, the details of which appeared in the EIA. Significant issues of the EIA due to the construction are as follows:

(1) Geology / Seismology: The construction procedure of the pipeline route includes digging up trenches to the average depth of about 2.0–2.5 m and generally at this depth the geological setting of the area receives no major disturbances.

The pipeline route from the gas delivery point at Ban I Tong to Ratchaburi province is near fault, of which magnitudes of earthquake recorded within 100-km radius around the site never exceeded 6.0 on the Richter scale. Such tremors would yield the maximum ground acceleration of 0.05 g. The pipeline structure of the Project, however, is designed at 0.2 g value, compared with the 0.1 g design value for dam construction in western Thailand.

(2) Hydrology and Erosion: The hydrological pattern around the project area may be temporarily altered due to the pipeline crossing. Most of the affected streams are intermittent and retain water only in the wet season. In addition, the crossing activities are often conducted in the dry season. Therefore, the hydrological pattern is likely not to be affected by pipe laying activities.

Erosion is strictly significant as the construction procedures include the clearing of 20-m wide area along the construction R/W. After the backfill, bare soil will directly affect erosion and immediately as soon as the rainy season arrives. Therefore, impact assessment must be undertaken on 'worst case', i.e. from Kilometer Post (KP) 0 to KP 27 that would be most affected by erosion. The assumption was made in the width of 50-m Right of Way after the construction, the soil was exposed without any mitigation measure. From that 'worst case' assumption, it was found that the overall maximum percentage of sediment to be washed from cleared R/W is about 1.285 % of the total sediment in Khwae Noi River close to the project area. Based on the impact resulting from the 'worst case' scenario assumption, the potential erosion affected by the construction of the Project can be minimized by indispensable mitigation measures.

(3) Water Quality: The impact on water quality, especially in streams and rivers due to the construction and related activities, is a result of:

- Workers at the Camp site, which however can be managed according to specified environmental standards together with proper examination.
- Appropriate construction standards and techniques, which are specified and chosen for all construction procedures from clearing, trenching, back-filling, open cut of streams/rivers in order to minimize impact on water quality. In the high-erosion area, in particular, construction was implemented in dry season. As all are in fact under the control and management, plus mitigation measures, impact on water quality was manageable.

(4) Aquatic Ecology: The impact on aquatic ecology was fairly low because the construction in forest area especially in watershed area is done in the dry season only when the water flow is minimized and several streams were seasonally dry.

(5) Soil: Soil was directly affected due to construction characteristics. After the back-filling, the soil was bare and erosion immediately occurred in the rainy season, especially from KP 0 to KP 50 in the high mountain area and the soil was in series of Tha Yang, Lat Ya, Mae Rim, and Slope Complex. With vegetation (prior to the construction), such soil series had the erosion rate of around 16-21 t/rai/year; however, as bare soil without vegetation, high erosion would be materialized with a rise to 69-2,000 t/rai/year. This would yield further impact, i.e. the loss of soil nutrients, water quality affecting community and especially the pipe itself.

(6) **Forest Resource:** As the construction required the clearing of 20-m wide R/W in the forest area for a distance of 50 km, trees along the line must be removed. However, they must be counted with the recording of sizes, species and number.

Table 4.1: Number of trees counted with recording of sizes

Diameter, greater than (cm)	16	32	48	64	80	95	111	127	143	159	175	Total
No.of trees counted (for the area, 20 m x 50 km)	2,602	1,205	520	200	117	62	44	31	7	20	6	4,812

Source: *The Yadana Gas Pipeline Project*

In economic terms, most of these trees were dry evergreen forest with lower economic value compared with teak, while their ecological values were indeterminate. The characteristics of area utilization, however, did not permanently change the ecological system with potential recovery. The designated mitigation measures during the construction period and rehabilitation (such as encircling trees, realigning the pipeline route, utilizing specific technology and equipment to reduce the number of trees cut) during the operation must be immediately applied.

(7) **Wildlife:** In the forest area inhabited by wildlife, their livelihood and food sources would be affected. However, the construction was constrained to be done within the 4-5-month dry season with interval construction digging, trenching and installation. The laying of pipeline on mountain area was done on the ridges, neither passing into any caves nor in parallel with streams. Wildlife also had temporary refuge in the nearby forest areas. After the back-filling, there was no permanent road along the pipeline route. Construction characteristics did not permanently change the ecological system of the forest area. It is believed that the impact was only temporary during the construction period.

(8) **Land Use:** Due to the characteristics of the gas pipeline system, after the installation, shallow-root crops, e.g. rice, sugarcane, corn, etc. are allowed to grow above the pipeline and paddy stubble or corncob can be burned. Growing of perennial trees and building of other permanent constructions above the pipeline, however, are not permitted.

(9) **Transportation:** The impact was only temporary during the construction period and was manageable with appropriate selection of construction techniques. Therefore, traffic along the roads, railways, and rivers passed by the pipeline construction was not affected. In case of open cut, construction with mitigation measures must be applied.

(10) **Compensation:** The compensation was fairly implemented in accordance with laws and regulations supervised by the Pricing Reconciliation Subcommittee chaired by the Governor of certain provinces. PTT / the Contractor have to follow their value specifications.

(11) **Socio-economic:** Local people / communities were positive with the Project as it would help with local economy during the construction and be beneficial to the country on the whole. However, negatively, they would be affected by various activities during the construction and were worried about the pipeline safety.

(12) **Public Health:** The impact was imminent during the construction period such as dust, noise and traffic, which would last about 2-3 months in each area. Safety measures and precaution must be held during construction in the R/W with hard bed rock that required blasting.

(13) Archaeology and Historical Value: The nearest archaeological and historical site, according to the study, is Wang Krachae Cave, 0.5 km away from the pipeline. The impact was not anticipated.

5. MITIGATION MEASURES ESTABLISHMENT AND UTMOST IMPACT IDENTIFICATION

The 13 topics of the EIA due to the construction led to the formulation of detailed mitigation measures to accommodate the impact, as summarized below, of which details appeared in the EIA:

Topics	Mitigation measures
1. Seismology	– Gas transmission system designed to accommodate the impact.
2. Hydrology/Erosion 3. Water Quality 4. Aquatic Ecology 5. Soil	– Construction from KP 0 to KP 27 finished within one dry season. – Establish Physical Permanent Erosion Control Structure combined with Re-vegetation and Agronomic Erosion Control. – Use 1.5 million vetiver grass slips in high-risked erosion areas.
6. Forestry Resource 7. Wildlife	– Ball 3,600 trees and small plants, and re-plant them. – Realign the pipeline route, able to reduce 1,879 trees cut. (Counted 4,812/Actual cut 2,933) – Control the width of construction area by using Cable Crane technique. – Grow perennial trees 3 m from pipeline center, using 61,250 seedlings. – 10,000-Rai Reforestation Project along the pipeline route. – 30,000-Rai Forest Rehabilitation and Wildlife Preservation Project as wildlife inhabiting zone. – Establish Forestry Patrol Unit. – No permanent roads built along pipeline route in the forest area.
8. Transportation	– Utilize construction techniques: Directional Drill, Boring, Hydraulic Jacking, etc.
9. Land Use 10. Compensation 11. Socio-economic 12. Public Health	– As for community and social-related activities, the PTT Village Development Project was initiated as a fully integrated project for 30 villages along pipeline route from Kanchanaburi (21) to Ratchaburi (9). Activities included occupational promotion and marketing.

13. Archaeology and Historical Value → – No impact

Among the 13 environmental impact issues, soil erosion is prioritized as the utmost immediate impact due to the following reasons:

(1) Characteristics of construction that immediately exposed soil to the erosion impact,

(2) Slope Complex Soil Series in the forest area along KP 0 to KP 27 erosion rate would increase by about 100 times compared with pre-construction conditions of the area,

(3) The impact on water quality, soil fertility, community and above all the pipe itself.

Measures to minimize impact from soil erosion are the most indispensable. Therefore, both construction strategies/techniques and rehabilitation have been taken into account. A special focus had been put on the selection of soil-holding vegetation in the areas with high risks of erosion.

6. CONSIDERATIONS ON CONSTRUCTION STRATEGIES AND TECHNIQUES

With a principal objective to effectively prevent soil erosion after pipeline installation, ranked as utmost immediate impact to the environment and pipe itself, a construction strategy was formulated with the construction of permanent physical erosion control structure as follows:

- *Important rules to follow during construction:* In the areas with Slope Complex Soil Series and in high mountain areas from KP 0 to KP 27, construction must be done and completed in one dry season.
- *Permanent physical erosion control structure:* Soft plugs, diversion berms, and drainage system are major permanent physical erosion control structures. However, other construction steps must be appropriately followed according to construction procedures as well.

  – *Clearing*: Sensitive and critical areas such as steep slopes or riverbanks, where stripping of vegetation can result in geo-technical instability, are left uncleared.

  – *Grading*: The formation of flat stable working surface is suitable for pipe installation activities with precaution given to provide adequate erosion control and avoid slope stability problems. Any slope cutting shall be maintained to a maximum grade of 1 : 1.5 (vertical : horizontal) or flatter; grading on filled slopes shall be restricted to its angle of repose or flatter. This is to ensure slope stability integrity, and limit the momentum gained by surface runoff.

  – *Trenching / Hard Plug & Soft Plug / Backfill*: Both sides of the trench shall have a slope of less than 60%. The hard plugs are needed when trenching at steep longitudinal slopes especially those greater than 10% gradient. Hard plugs are blocks of material that shall be left unexcavated in the trench line. Its function is to interrupt surface water flow and prevent scouring of the trench bottom. These hard plugs will be removed at the time of pipe lowering-in. Soft plugs or sack breakers, sand-filled plastic sacks, are impermeable barriers placed at regular intervals in the pipelines and facilities trench after pipe has been lowered in and before the trench is back filled as shown in Fig. 6.1. Soft plug forms an impermeable barrier, which can prevent mudslides or washout of the backfill material. Soft plugs shall be installed at slopes steeper than 10% gradient.

Diversion berms shall be placed immediately down slope of soft plugs to divert water off the R/W.

On completion of back-filling, a crown 0.5 to 1.0 m. high shall be left over the centerline of the pipe, which results in speeding up of water runoff from centerline R/W.

Berms, a temporary ridge of compacted native soil constructed at intervals across the R/W with sufficient grade to provide drainage, are a form of surface drainage control device to deflect surface water off the R/W. It is a major erosion control device for undulating and steep slopes.

Table 6.1: Minimum soft plug and diversion berm spacing (m)

Slope	Soil erosion potential		
	High (fine sand, silts)	Moderate (clays, coarse sand)	Low (gravel, exposed bed rock)
Gentle (under 5%)	45	60	-
Moderate (5 - 10%)	30	45	60
Steep (over 10%)	$\frac{305}{\%\ Grade}$	$\frac{305 \times 1.5}{\%\ Grade}$	$\frac{305 \times 2}{\%\ Grade}$

Remarks: *305 = a constant slope factor*
Source: *Construction Procedures of the Yadana Gas Pipeline Project*

Berm direction and orientation including pattern and spacing of the berms will be influenced by local topography, soils, adjacent vegetation cover, and drainage conditions, and shall be determined on site. Typical berm orientations are diagonal diversion berm, herringbone diversion berm, and horseshoe diversion berm.

After the diversion berm completion, permanent drainage system, i.e. riprap, pipe drain, drain channels shall be installed on the R/W immediately. Then, the "site" is reinstated back to the original topography and conditions, maintaining the slopes and general terrain characteristics. Surface runoff, especially, is not concentrated on a filled area where surface scouring and gully erosion can easily occur.

Construction Techniques

Special and state-of-the-art techniques were chosen for the construction to minimize environmental impact.

- *Hydraulic Jacking, Boring, Horizontal Directional Drill are techniques for crossing roads, railways and rivers, able to be undertaken during active traffic; no impact thus occurs. The Horizontal Directional Drill of Mae Klong River, for instance, was finished within two weeks. The Horizontal Directional Drill can be done for a distance of 1 km and at the depth of 30 m.*
- *Cable Crane introduced for the strip of KP 0 to KP 27 is the construction technique used in high slope mountainous area, able to decrease the construction R/W and minimize tree felling.*
- *Special Equipment: Padding Machine is used in high mountain area to crush rocks with appropriate sizes for back-filling. Trenching Machine is used in areas adjacent to*

residential community. Small pipeline truck has a special size for transporting pipes in forestry area R/W.

Despite the utilization of special techniques, conventional system such as Open Cut must be carried out under stringent mitigation measures, as well as in several areas with hard rocks, blasting was unavoidable constrained by time limit.

7. CONSIDERATIONS ON REHABILITATION

With the characteristics of Slope Complex Soil Series, after the construction with bare soil, the EIA report indicated that the high erosion was 100 times increased, though in terms of engineering construction, permanent physical erosion control structure had been installed. An important one was diversion berms which served to deflect water off the R/W. However, without vegetation, these structures would be eventually perished by water runoff. *Despite the presence of vegetation, in the high-erosion area, those ordinary shallow-root vegetation species were unable to resist water runoff. Therefore, in areas with high-risk erosion, vetiver grass was introduced to stabilize the area and berms which ultimately became natural permanent stabilized structure.*

7.1 Important Rehabilitation Rules

Vegetation must be carried out instantly after the reinstatement, and vetiver grass must be planted according to technical principles.

7.2 Strategic Approach for Agronomic and Re-vegetation Erosion Control

A mixture of vegetation was planted along the R/W:

Grasses: *Brachiaria ruziziensis*, *Panicum maximum*
Legumes: *Centrosema pubescens, Pueraria phaseloides, Calopogonium muconoides*

This would allow for better chances of vegetation to grow and cover the soil in diversified area characteristics.

- Recover and enhance the richness of soil.
- Maintain and enhance the moisture of soil / environment and stimulate the growth of local flora species.
- Prevent soil erosion.

Grow 1.5 million vetiver grass slips in areas with high risk of erosion: With remarkable characteristics given below, vetiver grass is appropriately qualified to create Permanent Physical Erosion Control Structure into Natural Permanent Stabilized Structure:

- When planted correctly, *Vetiveria zizanioides* will quickly form a dense, permanent hedge.
- It has a strong fibrous root system that penetrates and binds the soil to a depth of up to 3 m and can withstand the effects of trenching and cracking.
- It is perennial and requires minimal maintenance.
- It is practically sterile, and because it produces no stolons or rhizomes, it will not become a weed.
- Its crown is below the surface, which protects the plant against fire and overgrazing.
- Its leaves and roots have demonstrated a resistance to most diseases.

- It is extremely appropriate for construction areas. It is both a xerophyte and a hydrophyte, and once established, it can withstand drought, flood and long period of water logging. It grows in a wide range of climates. It is known to grow in areas with average annual rainfall between 200 and 6,000 mm and with temperatures ranging from -9^o to 45^{o}C. Most importantly, it grows in all types of soil, regardless of fertility, pH, or salinity. This includes sands, shales, gravels, and even soils with aluminum toxicity, thereby matching the pipeline construction area along KP 0 to KP 20, which was tin and wolfram mines having soil of low pH (3-5) and low fertility.

The above characteristics of vetiver grass have been continuously disseminated through the study and demonstration of various Royal Projects in accordance with His Majesty the King's initiatives. Vetiver grass was thus selected and applied in high-risked erosion areas of the Yadana Gas Pipeline Project as follows :

- Grow vetiver grass according to technical principles with a distance of 10-15 cm between slips along the contour line and 1-m distance between each row. Each row of vetiver grass will instantly serve to prevent soil erosion.
- Vetiver grass will grow with expansion of its root system to the depth of 1-2 m to stabilize soil. Vetiver grass bush will grow and serve as natural walls to prevent and decrease water runoff as well as filtering silts. This also helps with the stabilization of diversion berm.
- Enhance the stability of permanent physical erosion control structure to become natural permanent stabilized structure.

The implementation results of planting vetiver grass confirmed its suitability in preventing soil erosion, which will be publicized more extensively.

Plant 61,250 perennial trees at the distance of 3 m from pipeline center: Perennial (21 species) and fruit trees (7 species):

- In over-three-year period, perennial and fruit trees will take over the duties from vegetation plants in creating the construction R/W into natural permanent stabilized structure eventually.
- Become inhabiting areas and food resources of wildlife.

7.3 Techniques

Various techniques were introduced to help with the growth of vegetation and enhance the stability of physical erosion control structure.

- *Riprap:* Rocks/stones are arranged along the ridge of streams to prevent erosion and stabilize the area whilst preserving moisture for the growth of vegetation seeds to become permanent erosion control eventually.
- *Woven bamboo fence:* Install woven bamboo fences in front of diversion berm to protect soil and vegetation seeds whilst preserving moisture for better growth of seeds.
- *Live stake:* Live stake, a growing plant stake, was pegged to hold the soil-filled just sacks for their stability that can eventually grow into perennial trees.
- *Soil-filled jute sacks:* Arranged as ladder ridge and diversion berm upon which vegetation seeds can be sown and grow. They can also be holed in which vetiver

grass slips can be grown. These sacks would gradually decay in one year and become ridges covered by vetiver grass and other grasses.

8. FORMULATION OF COMBINED STRATEGY FOR IMPLEMENTATION PLAN

Construction strategy that combines the use of physical permanent erosion control structure with agronomic and re-vegetation erosion control can be summarized as follows:

8.1 Methodology

Erosion rating of a particular stretch of the R/W is classified according to the rate of possible soil loss. The soil loss is calculated under the worst conditions: i.e. loosened topsoil, bare and with no protection or measures. The amount of soil losses is calculated by the Universal Soil Loss Equation. The classification for each rating E_0 to E_3 is shown in Table 8.1.

Table 8.1: The classification of rating code according to the Soil Loss potential

Soil Loss (t / rai* / yr.)	Rating Code	Erosion Rating Risk
0 – 16	E_0	Low Risk
17 – 64	E_1	Moderate Risk
65 – 112	E_2	High Risk
113 above	E_3	Very High Risk

** 1 ha = 6.25 rai*

Source: *Construction Procedures of the Yadana Gas Pipeline Project*

8.2 Application

Permanent physical erosion control structure, and agronomic and re-vegetation erosion control are appropriately applied to each erosion rating risk. In the areas classified as high risks in particular, vetiver grass was applied as tabulated in Table 2.

Table 8.2: Physical permanent erosion control structure combined with agronomic and re-vegetation erosion control

Areas / condition	Grass + legume	Tree	Vetiver grass	Soft plugs & berm and drainage system	Special technique
E_0	✔	✔	-	-	-
E_1	✔	✔	-	-	-
E_2	✔	✔	✔	✔	-

E_3	✔	✔	✔	✔	✔

Remarks: *In E_0 areas, trees may not be planted*

9. IMPLEMENTATION AND EVALUATION

The 50-km R/W in the forest area was classified into E0, E1, E2 and E3 areas, of which rehabilitation program was applied according to the application. Above all, the mitigation measures must be stringently observed. The performance evaluation must be obtained after the first and second rainy seasons.

9.1 Implementation

The physical erosion control structure must be finished by June at the latest, after which the re-vegetation and agronomic erosion control must be immediately implemented. The results of its implementation according to the application along the 50-km R/W consist of six areas for E_3, and 44 areas for $E_{2,}$ and the rest are E_1 and E_0. Those overall 50-km implemented results are plotted in Fig. 9.1.

9.2 Evaluation

Rehabilitation performance would be taken into consideration: how much and how quick the R/W in forestry areas has been recovered back to its original state.

Evaluation Concept: The universal soil loss equation was used in evaluating soil loss by considering multiplication results of cropping management factor, or C factor, i.e. physical erosion control structure, and erosion control practice, or P factor, i.e. agronomic and re-vegetation erosion control, while other param (rainfall erosion index, soil erodibility factor, slope length factor, slope steepness factor) are treated as constant terms. Multiplication results of C and P factors are index of rehabilitation performance.

Evaluation Methodology: Direct examination at site along the R/W was undertaken after the first and second rainy seasons. On the other hand, the average C and P factors of each KP would be evaluated. Normally, the C and P factors are ranged between 1 and near zero. The more multiplication results of C and P factors are near zero, the less soil erosion rating will be. In other words, the areas are reinstated back to pre-construction conditions. This indicates better rehabilitation performance each year.

Initially, after pipeline installation, the soil was bare, berms were not built yet and without re-vegetation; P and C factors were equal to 1.0. However, when berms were in place with necessary drainage system and when vetiver grass, vegetation and perennial trees started to grow, the P and C factors gradually decreased. Characteristics of the P factor are slightly different from those of the C factor. That is, the P factor in the first year when the physical erosion control structure was just finished was slightly better than subsequent years by about 5-15%. The C factor would be better in accordance with the growth rate of the re-vegetation.

10. REHABILITATION PERFORMANCE

The evaluation of multiplication results of the C and P factors of each KP at the end of the first rainy season and the second rainy season was plotted in comparison with timing as shown in Fig.10.1, of which significance is as follows:

10.1 Overall Performance

- In the first year, after diversion berms and drainage system were installed, average multiplication results of the C and P factors for overall KPs (KP1 to KP 50) changed from 1 to 0.43. After re-vegetation and the first rainy season, they further reduced to 0.24 and improved in the second rainy season, decreasing to 0.13 close to pre-construction or natural conditions i.e. in the range of 0.1 to 0.003.

- KP 1 to KP 27 adjusted slower than KP 28 to KP 50, maybe due to quality of soil that previously underwent mining.

10.2 Significant Roles of Vetiver Grass

In using vetiver grass in high erosion area to prevent erosion and to conserve soil and water applied in pipeline route, the following significant issues were found:

- As soon as vetiver slips were (properly) planted, the row of vetiver grass would immediately serve to prevent erosion while other vegetation would take time to grow.
- When grown, with continuously expanding bushes, vetiver grass enhances and reinforces the physical erosion control structure constructed in areas with high risks of erosion to become natural permanent erosion control eventually.
- Vetiver grass kept soil moisture thereby helping perennial trees to grow back to their original state or better in a period of three years onwards.
- In case of erosion, the areas in which vetiver grass was grown would be easier for repair than the areas with vegetation alone.
- Local people in making handicrafts can use leaves of vetiver grass.

There were some points in which erosion occurred where vetiver grass had been grown, a result of improper and incomplete implementation of permanent erosion control structure. For example, berms were not continuous with the stabilized area, too steep degrees of berms. However, with proper execution and planting methods of vetiver grass, the physical erosion control structure would be naturally made into erosion control area within the first rainy season and would be even more stable after the second one.

The performance of utilizing vetiver grass in preventing soil erosion and creating soil moisture of this Project will be continuously monitored and disseminated to the public so that its usage can be further extended in both engineering and agricultural aspects even more.

11. FURTHER IMPLEMENTATION IN PTT'S REFORESTATION PROJECT

In the Reforestation Project of PTT, vetiver grass has been planted in appropriate areas. People around the Project are encouraged to learn how to use vetiver grass in conserving soil and water. The 9,972-Rai Reforestation Project of PTT is a part of the Kui Buri Forest

Conservation and Rehabilitation Project under His Majesty the King's Initiative. Vetiver grass has been incorporated into the Project in the following manners:

- ***Soil and Water Conservation:*** Plant vetiver grass in slope areas to prevent erosion; plant around reservoirs and their banks; plant on ridges of check dams to strengthen check dams and filter silts.
- ***Encourage people's learning:*** People around the Project learn how to reproduce and nurture vetiver grass, and the Project hires them to plant vetiver grass. Local people also use vetiver grass in their own lands for soil and water conservation. Concurrently, they learn handicraft skills by using vetiver grass as raw materials, which eventually can become their supplementary earning.

To encourage people to use vetiver grass in their own lands is beneficial to agriculturists themselves. Results achieved may be quite slow but are considerably useful in the long run, as it can reduce agricultural costs in accordance with His Majesty the King's concept granted on 29 May 1998:

"Conserve land by using vetiver grass because its root system is long and can sustain water to create moisture and improve soil."