Lowland Technology International June 2019; 21 (1): 14-22
International Association of Lowland Technology (IALT): ISSN 1344-9656

Research Paper

Combining Soil Nail and Vetiver Grass in A Slope Protection Project In Vietnam

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ARTICLE INFORMATION

Article history:

Received: 6 December, 2018
Received in revised form: 1 March, 2019
Accepted: 2 April, 2019
Publish on: 6 June, 2019

Keywords:

Soil Nail
Vetiver Grass
Green Environmental Solution

ABSTRACT

This paper presents a combination of soil nail and vetiver grass for slope protection in a project in center of Vietnam. The application of vetiver grass is considered as a green environmental solution for erosion surface control while soil nail with shotcrete is a traditional method for steep slope stabilization. The shotcrete surface of soil nail system will be replaced by vetiver grass for the combination of soil nail and vetiver grass. This is not only economic solution but also meets requirement for landscaping. This paper presents design and construction techniques and compares the construction cost with tradiional soil nail methods.

1. Introduction

1.1 Project Description

Laguna project located in the center of VietNam (**Fig.1**). This area has variable geometries including sea beach, river, and moutainous regions as shown in **Fig.2**. The mountainous regions having high slope angle from 40 to 80 degree, are covered by native plants. The center of Vietnam also subjects to average 5 tropical storms every year. It has the highest amount of raining water in Vietnam. Steep slope in combination with storm made many slope failures for this area as shown in **Fig.3**. There are several methods applied for slope protection in this project including: soil nail, concrete retaining wall, geocells,. Each method was carefully selected so that slopes could be kept stable and the natural beautiful landscape would not be changed. The mockup region within Laguna project was first proposed by Brothers E&C Ltd. with four slope protection methodssuch as traditional soil nail with shortcrete, soil nail with concrete beams, soil nail with gabion mat and soil nail in combination with vetiver grass. The fourth proposed solution was selected because of its economic and environmental solution.

Fig. 1. Location of Laguna project

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Note: Discussion on this paper is open until December 2019

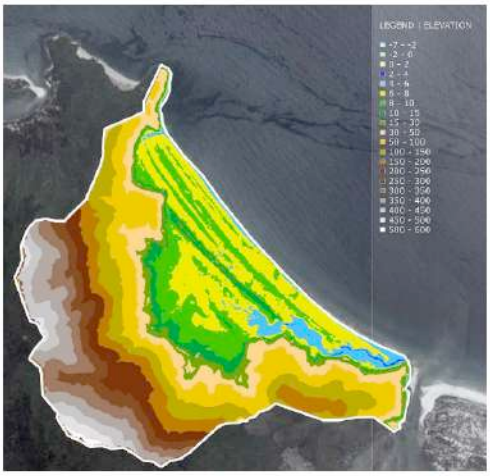

Fig. 2. Topographic of Laguna project

(a)

(b)

Fig. 3. A typical slope failure in Laguna project. (a) The cut slope for road in Laguna project; (b) The failure of the cut slope after a storm in 2011.

1.2 Vetiver grass

Vetiver grass is a unite tropical plant that has been proven and used in more than 100 countries for soil and water conservation, slope stabilization, land rehabilitation, pollution control, water quality improvement, disaster mitigation and many other environmental applications that can mitigate the impact of global warming and climate change. (Truong et al..2008). Vetiver grass has not only deep and high density root system but also can survive under extremely weather conditions such as fire, drout, flood and cold. The special root system make vetiver grass when growing in group can protect slope from erosion and instability.

In Viet Nam, vetiver grass has been extensively applied for natural disaster reduction and infrastructure protection such as sand dune protection in coastal province of Quang Binh, river bank erosion control in Da Nang city, Quang Ngai province and Mekong Delta, slope stabilization in Ho Chi Minh Highway (Van et al. 2002 ,2003a ,2003b). However, the maximum deep of vetiver root is only 3m. Therefore, the failure arc can occurred below 3m from the ground surface. Figure 4 shows a failure of slope in Ho Chi Minh highway with full growth of vetiver grass. (Van and Truong 2011)

Fig. 4. The failure a slope on Ho Chi Minh high way (Van and Truong 2011)

1.3 Combination of soil nail and vetiver grass

Soil nail and vetiver grass was selected to be combination support system for this project. Soil nail could protect deep slope failure arc when vetiver grass could protect surface erosion. The general layout and sections of this system are shown in **Fig 5**, **6** & **7**. The soil nail and vetiver grass distribution parameters were vertical spacing Sv = 2.0 m, horizontal spacing *Sh* = 2.0 m, Soil nail distribution in square pattern. The inclination of soil nail with the horizontal surface *i* = 15 degree, Nail have 3 types of length 7m (type C), 9m (type B) and 11m (type A), drill borehole *D* ≥ 120 mm, diameter of rebar steel *d* = 18 mm, nail head concrete bock 40cm wide and 25cm thick. Vetiver grass was planted with spacing of 11 cm to 15 cm spacing in a hedge row (The distance between rows is 1m level) and drainage slotted PVC pipes with diameter of 50mm and 8m length, and 10 degree upward.

Fig. 5. Mockup area

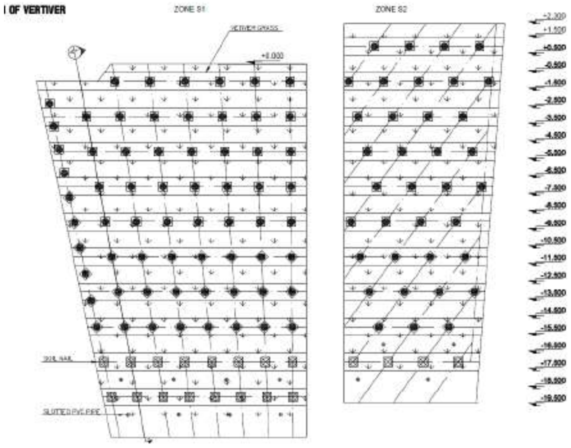

Fig. 6. General layout of soil nail and vetiver grass distribution

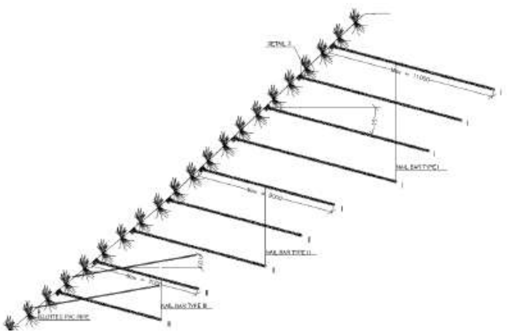

Fig. 7. Sections of soil nail and vetiver grass distribution

2. Design Criteria

2.1 Design criteria for soil nail

BS 8006:1995, FHWA(1998) and GEO(2000) were applied as design standard and reference manual for checking slope stability. Base on the standard, the checking external failure mode for slope reinforcement by soil nail were global stability, sliding stability and bearing capacity (**Fig. 8a**, **8b** & **8c**). Required factors of safety were 1.35, 1.5 and 3 for global stability, sliding stability and bearing capacity, respectively. The checking internal failure modes were pullout failure and nail tensile failure (**Fig 9a** & **9b**).

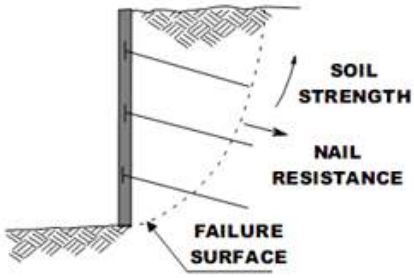

Fig. 8a. Global stability failure

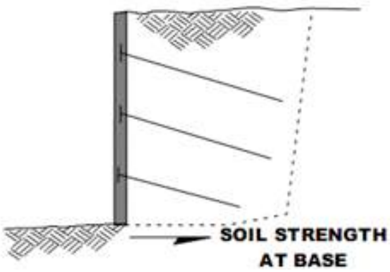

Fig. 8b. Sliding stability failure

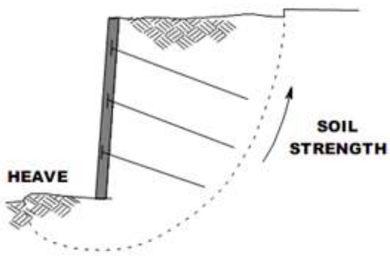

Fig.8c. Bearing failure

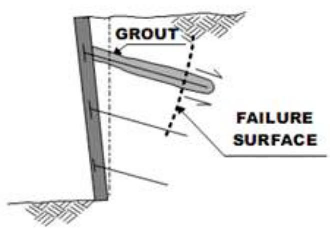

Fig. 9a. Pullout failure of grout

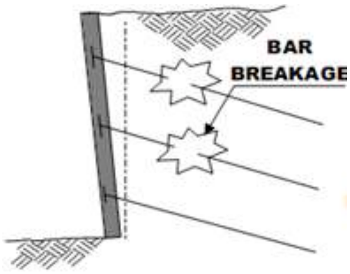

Fig. 9b. Nail tensile failure

Required factors of safety are 2 and 1.8 corresponding to pullout and tensile failure respectively.

2.2 Design criteria for vetiver grass

The shotcrete surface was replaced by vetiver grass when the combination of soil nail and vetiver grass were proposed. Therefore, the failure surface modes were failure of ground around nail, nail bearing failure and local failure between soil nail (**Fig.10a**, **10b** and **10c**). The required factor of safety for failure of round around nail, nail bearing failure and local failure between soil nail were 1.35, 1.5 and 1.35 respectively.

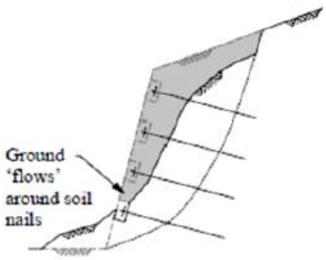

Fig.10a. Failure of ground around nail

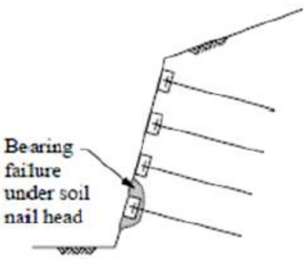

Fig. 10b. Nail head bearing failure

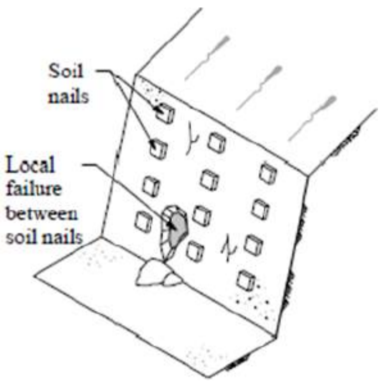

Fig. 10c. Local failure between soil nail

3. Stability Analysis

3.1 Soil profile

The soil parameters were summarized based on the following soil investigation reports:

The soil investigation report (1st stage) had been done from April to October, 2008, i.e. dry season and completed at the beginning of rainy season. The total numbers of boreholes were 136 nodes.

The site investigation report (2nd stage) had been done from March to April, 2011 in dry season. The total numbers of boreholes were 18.

Based on the observation with index tests, the soil profile in this area consists of following residual soil layers:

- Layer 1 - Sandy clay, medium to stiff, reddish brown. Soil parameters are as follows:
$\gamma = 19.4\text{kN/m}^3$, $S_u = 41kPa$; $c' = 17kPa$; $\varphi' = 29^o$; $E_s = 20.5MPa$; $k = 5.77 \times 10^{-4}$ cm/s.
- Layer 2 - Clayey sand with gravel, light yellow into reddish brown, in medium dense to dense state, weathered from granite bedrock with the coarse particle size increased with depth. Soil parameters are as follows:
$\gamma = 19.4\text{kN/m}^3$, $\varphi' = 33^o$; $E_s = 22.66MPa$; $k = 2.1 \times 10^{-3}$ cm/s.
- Layer 3 - Clayey sand at depth more than 6m; parameters are as follows:
$\gamma = 19.4\text{kN/m}^3$, $\varphi' = 37^o$; $E_s = 22.66MPa$; $k = 2.1 \times 10^{-3}$ cm/s.

3.2 Water run off analysis

In order to have long term slope stability during strong storm or heavy rain, the water run off analysis was carried out with SEEP/W and following initial parameters:

- Clay layer has hydraulic conductivity $k = 5.77 \times 10^{-4}$ cm/s
- Sand layer has hydraulic conductivity $k = 2.1 \times 10^{-3}$ cm/s
- The rain infiltration is 2mm/hr, taken from "Environmental water resource studies" Report. (August 15, 2008).

The analysis result is shown in **Fig. 11**, the increase of water table would be used as a input data for stability analysis.

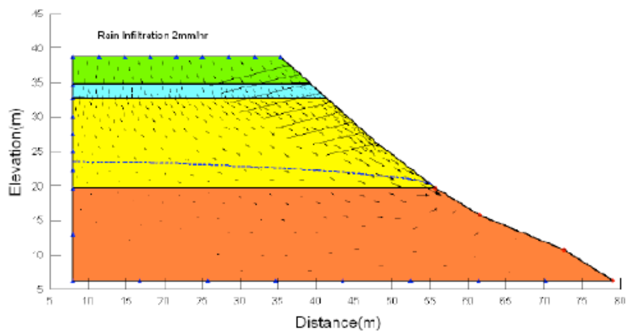

Fig.11. Water run off analysis

3.3 Global stability analysis

Global stability is controlled by soil nail because of deep slope failure plane. The analysis was carried out with

Geoslope/W. Soil parameters were taken from section 3.1, water table was given in section 3.2

The soil nails distribution was arranged to meet the requirement of factor of safety (*FS*) ≥ 1.35. Finally, the soil nails arrangement was selected as showing in **Fig. 6** & **7** with the factor of safety *FS* = 1.37 (**Fig.12**).

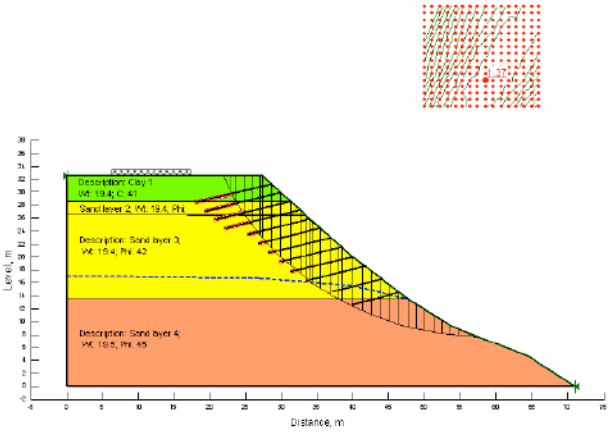

Fig.12. Global stability analysis

3.4 Stability analysis of mode failure by ground around nail head

Failure of ground around nail head would occur in the active zone which is treated by vetiver grassing. The effect of root system was increased the shear resistance within the rooted layer. The calculation was based on theory or semi-empirical (Waldron, 1977) as followings, respectively:

$$\Delta T = T_r \frac{A_r}{A}(\sin\theta + \cos\theta\tan\varphi) \quad [1]$$

$$\Delta T = 1.15 T_r \frac{A_r}{A}$$

Where:

- T_r is mean tensile strength of vetiver root of 75MPa;
- $\frac{A_r}{A}$ is the ration between root area with shear surface area
- θ and φ are angles of shear distortion and internal friction, respectively.

Applied the above equations, then the increase strength would be 19 kPa. During the first season, the empirical data by direct shear test was confirmed and the actual values were 3 times lower than the computed values. The increase shear strength would be 6 kPa for the first season, then it would be increased to maximum of 19 kPa.

The local stability analysis was shown in **Fig.13a** & **b**. The factor of safety for the first and second season were *FS* = 2.044 and *FS* =2.156 respectively.

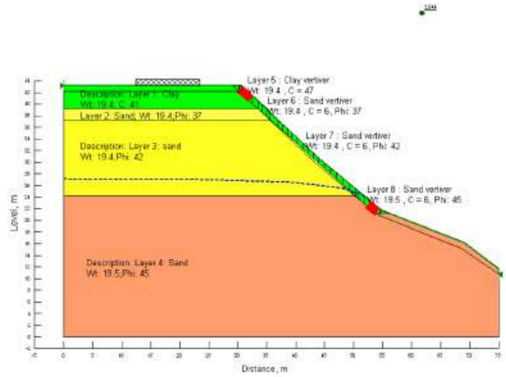

Fig. 13a. Stability analysis of ground around nail head in the first season

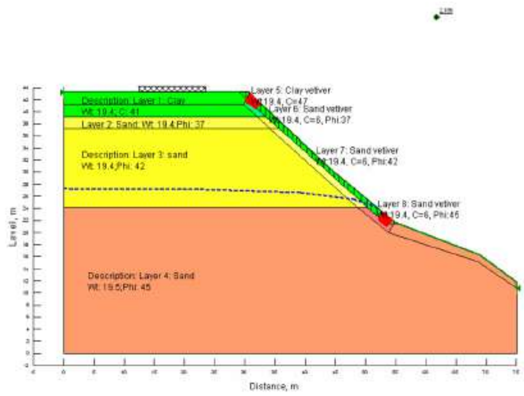

Fig.13b. The stability analysis of ground around nail head in the second season.

4. Constraction

4.1 Soil nail

The soil nail construction in the steep slope (45 degree) required high skill workers, experiences and safety protection methods (Brothers E&C 2012). The construction sequences are as followed:

1-Site clearance.

2-Drill the bore hole D120mm to the required length.

3-Install rebar steel d=18mm of soil nail.

4-Inject the grout by pressure grout pump.

5-Pullout tests

6-Install nail head width 40cm, thichness 25cm.

The construction soil nail are shown in **Fig.14a**, **b**, **c** & **d**.

Fig.14a. Drill bore hole D120mm

Fig.14b. Install rebar steel d=18mm

Fig.14c. Inject cement grout

Fig.14d. Pullout test soil nail

4.2 Vetiver grass

Vetiver grass was planted between nail head in rows in horizontal direction (**Fig.15**). The proposed distribution of vetiver grass helped to protect the slope from erosion.

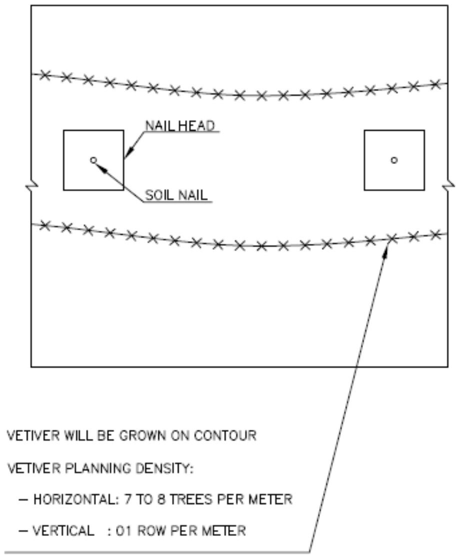

Fig.15. Distribution of vetiver grass

The vetiver grass had to be irrigated during first 3 months so that their root system can support themselves. Auto irriragtion system was also proposed by Brothers E&C as shown **Fig.16** .

Fig.16. Auto irigation system.

4.3 Maintenance process of vetiver grass

The process of grass growing is as followed:

1- The initial time of planing vetiver grass (**Fig.17**)

Fig.17. Planing vetiver grass

2- One month after planning, the vetiver grass showed the green leaf but they were extremely affected by sun light and watering process. The death grass was replaced by new one. (**Fig.18**)

Fig.18. Vetiver grass at one month growth

3- Three months after planning, the vetiver grass grew up to 40cm height (**Fig.19**). They could support themselves without irrigation.

Fig.19. Vetiver grass at three month growth

4- One year after planting, the vetiver grass was grown substantially. Vetiver grass developed its good function for surface erosion protection. It covered all the nail head and made the good slope surface and undisturbed natural beauty (**Fig. 20**)

Fig.20. Vetiver grass at one year growth

4.4 Construction cost

The construction cost for soil nail in combination with vetiver grass was 90,000 USD for an area about 500m2. Therefore the unit price for this method is 180 USD/m2. **Table 4.1** show the comparison in the construction cost between four slope protection methods. The traditional soil nail with shortcrete methods is the most expensive (268 USD/m2) while soil nail with concrete beam, soil nail with gabion mat and soil nail with vetiver grass have 236, 201 and 180 USD/m2 in construction cost, respectively. The soil nail with vetiver grass saved about 33% , 23% and 10% of total construction cost in comparison with soil nail with shortcrete, soil nail with beams and soil nail with gabion.

4.5 The effectiveness of the technique

The combination technique have been effetively proved by its stability and strong growth of vertiver grass (**Fig. 21**) since 5 years from the construction completation in 2012 to 2018, during that period, this region subjected at least 30 strong tropical storms which caused servesly damage to slope construction of other areas.

Table 4.1 Comparison in construction cost (at construction time 2012)

Soil nail with	Facing construction	Total cost USD	per m^2 USD
1-Shotcrete	Spray concrete Grassing cover the concrete surface	132,955	268
2-Concrete beam	Construct the beam connected between nails Grassing between the beam	117,000	236
3-Gabion mat	Construct the concrete at soil nail head Install the erosion control mat (ECM) with surface hydroseeded. ECM is PVC coated gabion of 60x80mm wire mesh with 2.7mm steel wire diameter.	99,600	201
4-Vetiver	Construct the concrete at soil nail head Planting the vetiver along the contour (every 1m level)	90,000	180

Fig. 21. Vetiver grass 10-01-2018

5. Conclusions and Recommendations

Based on the details provided in the previous sections, the following general conclusions were made:

1- Combination of soil nail and vetiver grass for slope protection was successfully applied for project in center of Vietnam. This is a green environmental and economic solution.

2- Design of soil nail and vetiver grass should include checking deep slope failure (Global stability) where soil nail govern design and checking the failure of ground around nail which vetiver grass govern design.

3- Construction steps of soil nail and vetiver grass were presented. Special attention for maintaining vetiver grass in the first month,the sunlight and watering can effect youth grass. After one year of planing, vetiver grass could protect the slope from erosion and created the beatiful landscape.

4- The construction cost of soil nail in combination with vetiver grass were smaller than soil nail with shortcrete, soil nail with beams and soil nail with gabion mat about 33%, 23% and 10% , repectively. Therefore soil nail in combination with vetiver grass is not only environmental solution but also an economic solution for slope protection. This method shall be widely apply in the near future.

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