Evaluation of a Geogrid Reinforced Slope Structure of a Highway Rehabilitation Project: Field Experience in Thailand.

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ABSTRACT
This paper describes the successfulness and the use of knitted polyester geogrids with polymeric coating for slope reinforcement of a highway rehabilitation project in Northern part of Thailand. The knitted polyester geogrids were installed with suitable local materials. The fine grain soil was compacted layer by layer as backfills. The quality of the backfills were supervised and monitored during construction followed by specification and special provision. The in-situ soil density test was performed regularly to conform the reinforced slope structure. The finished slope shows less lateral and vertical movement after open to the traffic. Significantly, sub-drainage systems were designed and installed behind the reinforced zone to intercept water table from existing soil. The reinforced slope was monitored and evaluated during and post construction comparing to numerical analysis. The statistic data of slope rehabilitation by soil reinforcement project in Thailand will be recorded and use for future development.

Keywords: Knitted polyester Geogrids, Local backfills, Lateral and Vertical movement, Sub-drainage, Numerical,

1. INTRODUCTION

Slope failures were typically occurred in Northern and Southern of Kingdom of Thailand. At Northern part especially in Maehongsorn Province, since year 2005there were more than 30 areas and many of them obstructed the traffic. TheBureau of Road Research and Development, Department of Highways (DOH) was approached to study and develop as a sustainable of landslide rehabilitation. One of the projects was earth reinforcement. DOH has been using geosynthetics to reinforce soil slope (RSS) for several years. Due to some problems of its implementation, It was necessary to improve and set up a standard construction and quality control procedures. Ultimately, by using geosynthetics in highway application, it would be providing safety of work life, save of maintenance yearly budget.

In 2006, Bureau of Road Research and Development, DOH started a project in slope stabilizing to find out a cost-effective method of repairing slope failure and movement. The methodology was begun from typical of slope repairing using geosynthetics to be reinforced soil slope. In order to ensure a safe and stable structure, a performance of RSS is monitored. The geotechnical instruments were applied to monitor vertical, lateral movement, water table, water pressure. The in-situ result will be compared with the numerical analysis program.

The present paper was studied on highway route no. 1095, km. 178+950. Its failure was located near Amphur Muang, Maehongsorn Province. This route is quite important because many travelers used it to commute to Amphur Pai, one of most famous area in Maehongsorn. Many locals earn their livings by tourists who come and traveled around Pai and its vicinity.

2. THEORY AND PRELIMINARY DESIGN

Soil is strong under compression but weak under tension. Reinforcement can carry tensile stresses. Tensile stresses are transferred to the soil along common interfaces with reinforcement. The end result is a structure that can sustain both compression and tension. The benefits of soil slope reinforcement are area increasing, less imported soil by using local materials and cost-effective compared to conventional concrete retaining wall. In Thailand, there are many cases use the geosynthetics to reinforced soil as embankment, to replace the retaining wall, road widening, side slope repair as shown in Figure 1.

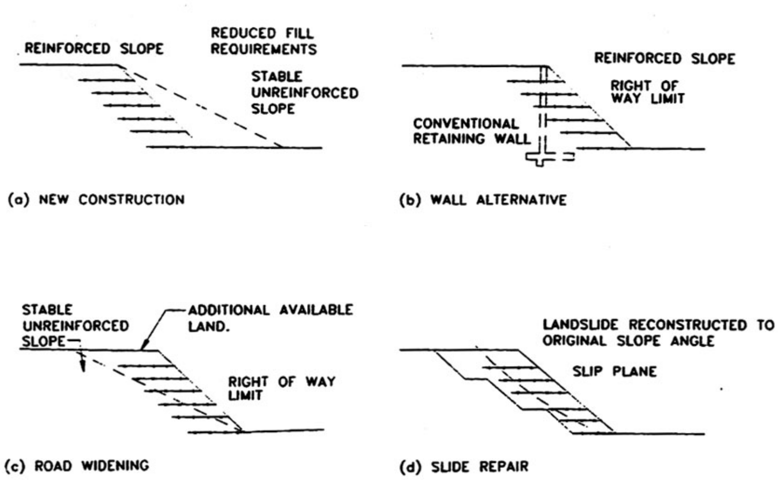


Figure 1 Typical soil reinforcement (FHWA, 1997)

The compacted soil can be local material that can compress to achieve high compressive stress. The reinforcement is used to increase the tensile resistance by inserting both inextensible and extensible material. A high tensile strength and good friction interface with soil to restrict horizontal/tension movement was created. The metal strip and polymeric material will be considered as reinforcement in soil structure.

2.1 The criteria of compiling soil reinforcement structure

2.1.1 Reinforced soil fill

The compacted soil fill for reinforced slope structure must meet the following requirements; they shall meet specified particle size distribution, maximum dry density and shear strength, respectively.

2.1.2 Particle size distribution of soil

A suitable particle size distribution of soil was used in this project is shown in Table 1.

Table 1 Particle size distribution of soil used in soil reinforcement

Sieve Size	% Passing
100 mm	100-79
No. 4 (4.75 mm)	100-20
No.40 (0.425 mm)	0-60
No.200 (0.075 mm)	0-50

The Plasticity Index (PI) should not exceed 20%. If the soil has grain particles finer than sieve no.200, its structure will have poor drainage and increase in porewater pressure which is a major cause of structure failure.

2.1.3 Compaction

The compacted soil reinforcement was controlled as 95% standard proctor. The study shows that if the material is cohesive soil, the lift thickness would be around 15-20 cm. In term of granular material, we can compact soil up to 20-30 cm of lift thickness.

2.1.4 Shear strength

The peak shear strength was used to analyze the reinforced soil structure. In case of immediately after construction, we found that the suitable value of shear strength will be used from undrained direct shear or CU triaxial to analyze total stress parameter. But, the reinforced soil structure must stand for a long time. Thus, the long term design and analysis was executed from drained direct shear test or CD triaxial test to generate effective stress parameter.

The suitable of soil chemical property should have pH value around 3-9. The saturated unit weight was used for analysis but dry unit weight would be used in inspection of compaction.

2.1.5 Allowable of Tensile strength of Geosynthetics (TA)

The allowable tensile strength of geosynthetics calculated using reduction factors for creep reduction factor (RF_{CR}), installation damage (RF_{ID}), chemical degradation (RF_{CD}) and biological degradation (RF_{BD}). The tensile for long term tensile strength can be defined from equation 1 (Koerner, 1998).

$$T_A = \frac{T_{ULT}}{RF} \qquad (1)$$

Where RF = $RF_{CR} \times RF_{ID} \times RF_{CD} \times RF_{BD}$
T_{ULT} = Ultimate tensile strength (kN/m)

In general overall of factor of safety or reduction factor would be around 2.5-7.0 when used in low/high pH condition. The most important of reduction factor of reinforcement material is creep reduction factor. If creep test could not be performed, the highest RF_{CR} can be as high as 5.

2.1.6 Pullout resistance

Pullout resistance is important for soil reinforcement structure and cannot be neglected. Pullout capacity is an ability to resist design tensile load with a prescribed margin of safety. The pullout resistance was used as equation 2.

$$P_R = 2F^* \times \alpha \times \sigma_V' \times L_e \qquad (2)$$

Where L_e = Length of reinforcement behind failure plane (m)
F^* = Pullout Resistance Factor, $\frac{2}{3}\tan\phi$ for Geotextiles and $0.8\tan\phi$ for Geogrids
α = Scale Effect Correction Factor
σ_v' = Effective Overburden Pressure (kN/m^2)

2.1.7 Reinforced material

Geosynthetics reinforcements are required to carry tensile loads, at defined strains, over long design lives. They are available in a range of forms including strips, grids and sheets. For this particular project, geogrid reinforcement was selected. It is made from high tenacity polyester yarn coated with black polymeric, high molecular weight and low creep. The tensile strength is about 80-160 kN/m.

2.2 Design Criteria

2.2.1 External stability

In this project, we have concerned four externals stability as sliding, overturning, bearing capacity and global stability (see Figure 2).

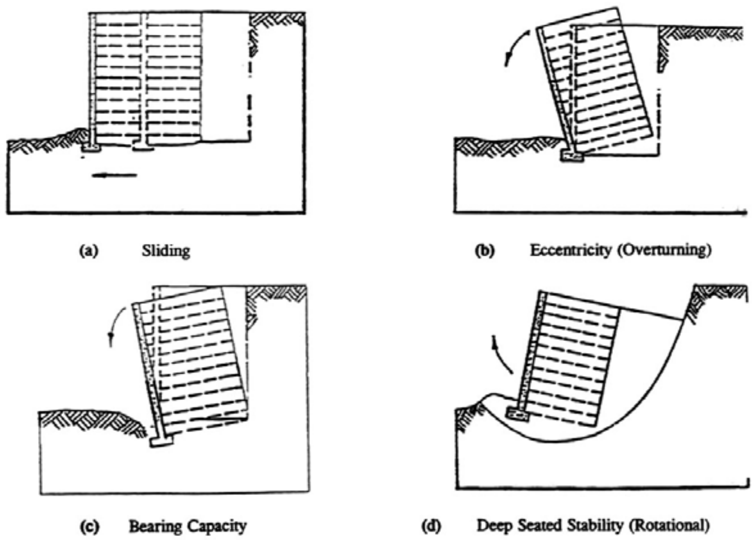


Figure 2 External stability (FHWA, 1997)

2.2.2 Internal stability

The internal stability is defined on two behaviors a) Pullout resistance and b) Tension failure, see Figure 3. From this paper, a design criteria was taken into consideration. They were controlling the length of anchorage to escaped failure from pullout, lifting optimum thickness of compaction to suit with wall/slope height. And the tensile stress would be less than allowable tensile strength.

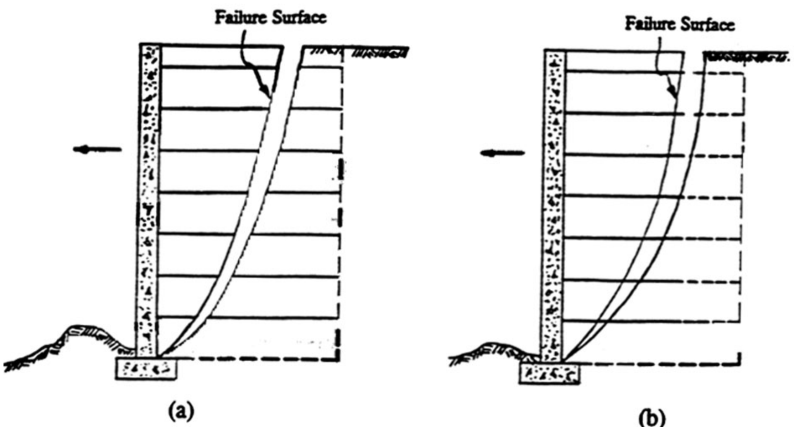


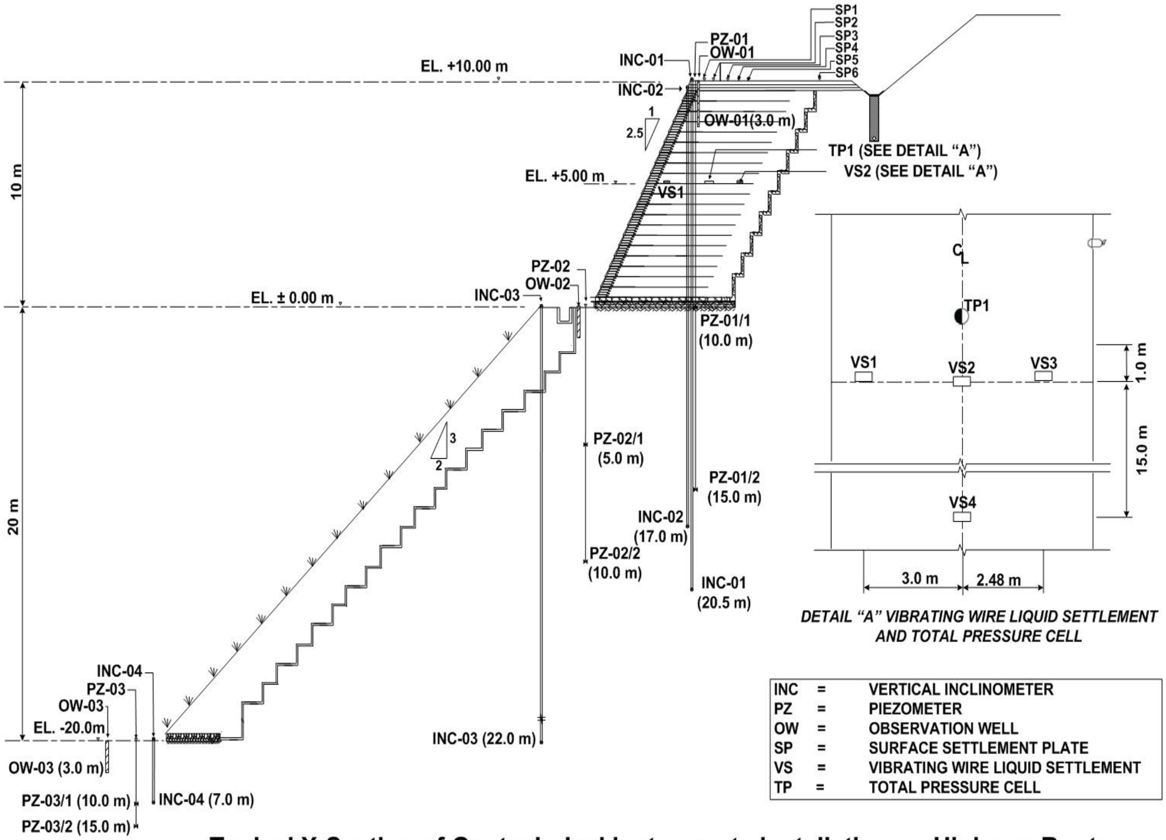
Figure 3 a) Tension Failure and b) Pullout (DiMaggio, 1999)

3. PROJECT LOCATION AND GEOTECHNICAL INSTRUMENTATION PROGRAM

This project is Slope Stabilization of highway located in route no. 1095 at km 178+950 Maehongsorn Province, Northern of Thailand. Due to right of way constraint, a typical slope is impracticable. The solution was chosen RSS method to make a steeped slope and to increase its factor of safety of slope stability. In addition, using in-situ soil is an economically way where selected backfills were neither difficult to find nor to transport to the site.

Geotechnical instrumentation program

The instrumentations layout used in a reinforced embankment behaviour are shown in the Figure 4 and details are in Table 2.



Typical X-Section of Geotechnical Instruments Installation on Highway Route No. 1095 Access to Ban-Maelana – Maehongsorn Municiple station 178+950

Figure 4 Cross section with instrumentation equipments

Table 2 Instrumentation equipment detail

Equipment	*No.*	*Remark*
Vertical Inclinometer	4	INC-01 at 20.5 m deep INC-02 at 17.0 m deep INC-03 at 22.0 m deep INC-04 at 7.0 m deep

Pneumatic Piezometer	3 holes	PZ-01 at 10.0 and 15.0 m deep PZ-02 at 5.0 and 10.0 m deep PZ-03 at 10.0 and 15.0 m deep
Surface Settlement Point	6	Install beneath the surface pavement
Observation Well	3	OW-01 at 3.0 m deep OW-02 at 3.0 m deep OW-03 at 3.0 m deep
Total Pressure Cell	1	At +5.0 m beneath embankment
VW Settlement Cell	4	At +5.0 m beneath embankment

4. TEST RESULT

4.1 Horizontal Displacement

A large amount of data from the instrumentation equipment is currently being analysed; some preliminary observation can be made:
The horizontal displacements are shown in 2 directions in perpendicular to longitudinal of road (A-axis) and parallel to the road (B-axis) as shown in Figure 5-8.

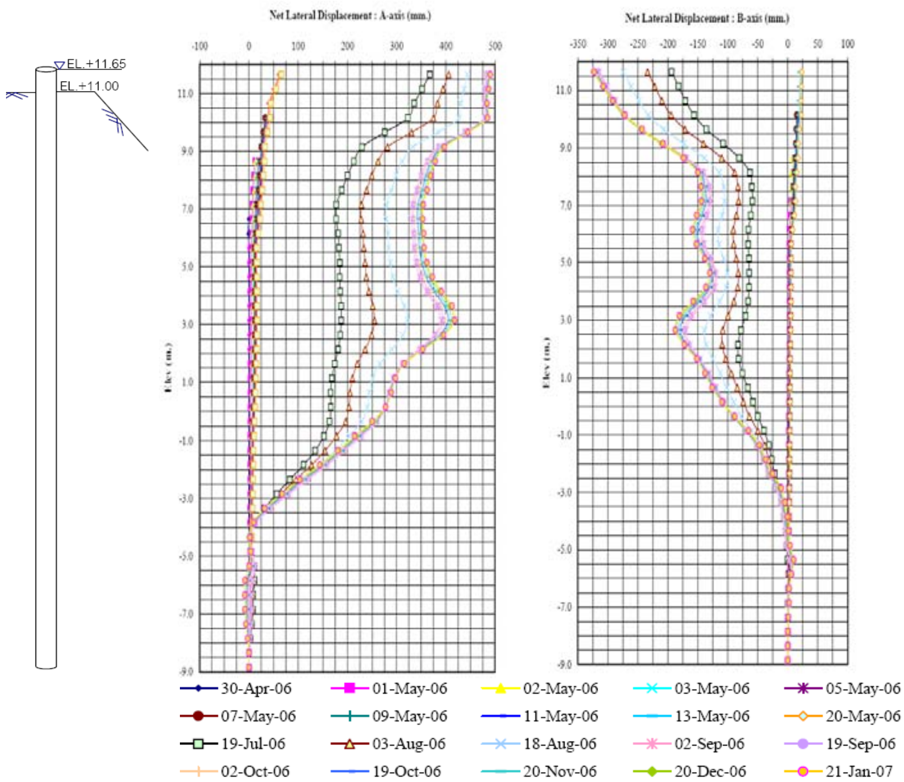


Figure 5 Horizontal displacement form Inclinometer INC-01

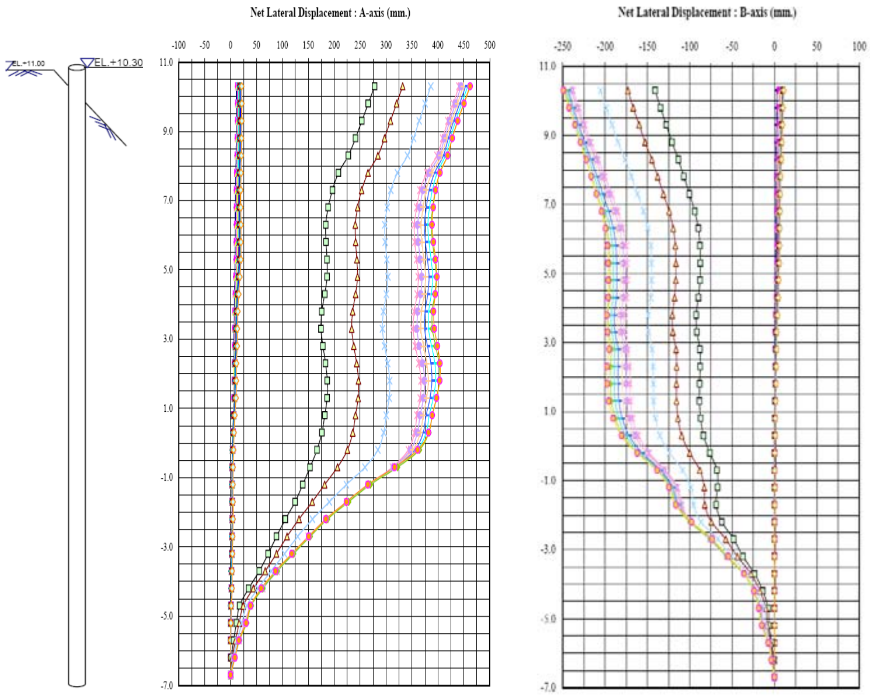


Figure 6 Horizontal displacement form Inclinometer INC-02

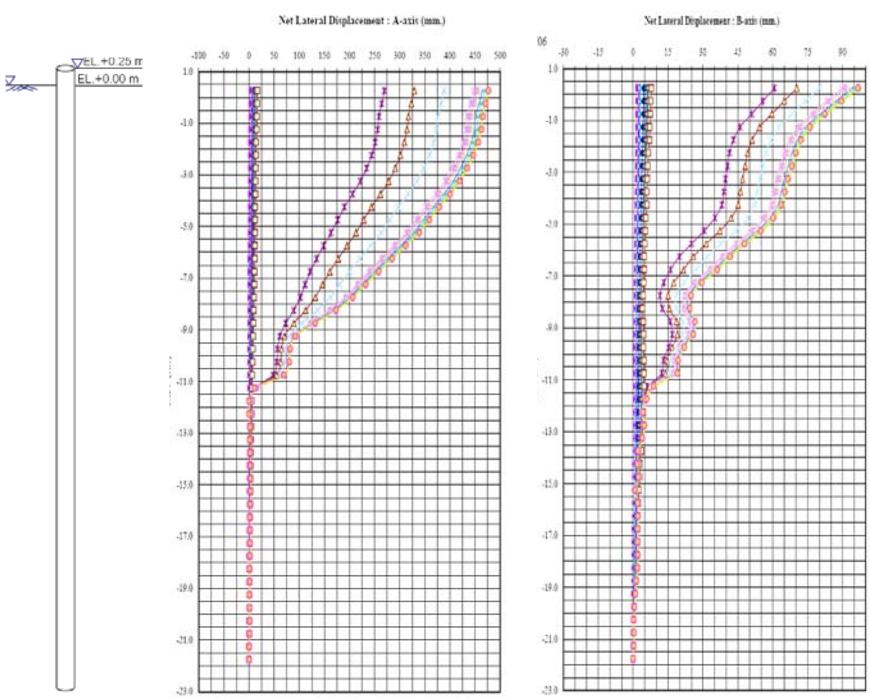


Figure 7 Horizontal displacement form Inclinometer INC-03

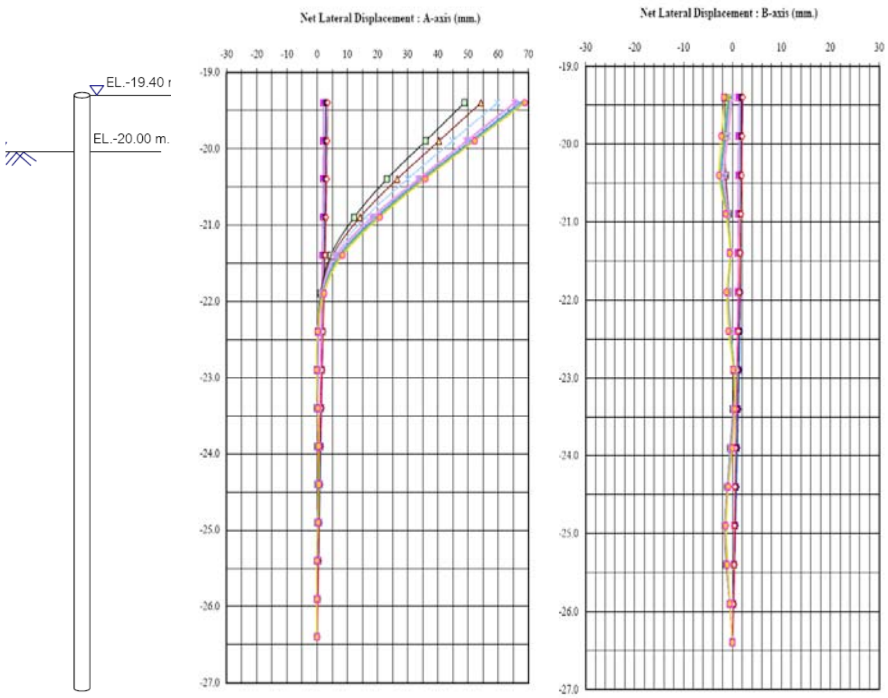


Figure 8 Horizontal displacement form Inclinometer INC-04

In general, the less horizontal displacements are shown during construction. When considered the elevation below elevation ±0.00, the lateral movements of reinforced slope vary with the embankment height, The maximum displacements are 275 and 375 mm in INC-01 and INC-02, respectively during construction. This is because the INC-02 is near to the side slope or shoulder. However, when considered the movement above elevation ±0.00, the incremental of lateral movement in reinforced zone is diminishing between the elevation of ±0.00 to +9.00 m. The maximum of movement is shown less than 500 mm. after 8 months open to the traffic.

It is found that the embankment underneath reinforced slope presented less lateral movement during construction. After open to the traffic, the lateral displacements seemed to be increased with time. The maximum displacements are 475 and 70 mm in INC-03 and INC-04, respectively.

4.2 Piezometer

PZ-01 at elevation ±0.00 or 10m deep from top of embankment was shown no water pressure. It was monitored 150 kPa porewater pressure during raining season time (August to September). It was shown that no water pressure at the elevation -5.00m in PZ-02 but 140 kPa at the elevation -10.00m. This is because water pressure dissipating with time due to the subdrainage system, that installed beneath the embankment. Water pressure of PZ-03 near toe slope was recorded 35 kPa at elevation -10m.

4.3 Observation well

OW-01 installed at Geogrid reinforcement zone was not found water table at elevation -3.0m after construction. The water table was monitored at elevation +0.75m during July – September that raining season and then decreased with subdrainage system. The result from OW-02 is shown the same.

The maximum of lateral movement from inclinometer was measured as 490.2 mm at elevation +11.7m of INC-01 and 426.3mm at elevation +10.3m of INC-02. The maximum of embankment beneath the reinforced structure was monitored 476.8 mm at elevation +0.3 m. The movement of toe slope is 68.9

mm at elevation -19.4m. The highest of water pressure was observed 164.5 kPa from PZ-01/1. The settlement of surface pavement is shown 0.32m. Soil stress at the highest embankment is 107.90 kPa.

5. NUMERICAL ANALYSIS

The Finite Element Method was analysed to fit with the result of instrumentation equipment. Most soil properties investigation contain 2m thickness silty Sand (SM), 2m clay layer and then silty Sand until bedrock 15.50 m (see Figure 9.). The soil model is shown in Table 3.

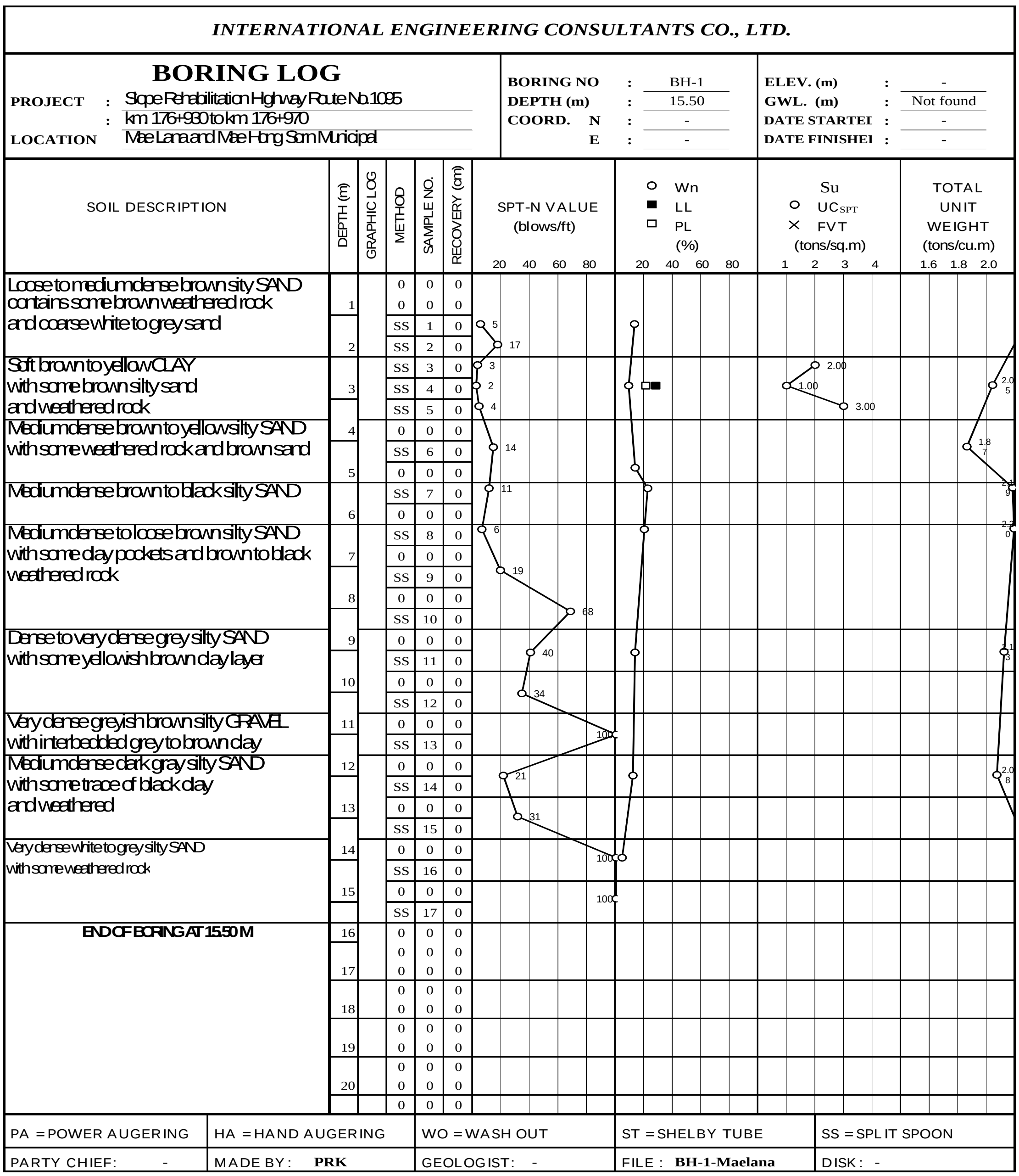


Figure 9 Soil boring log

Table 3 Soil model for FEM analysis

Soil	*Depth*	*Condition*	γ_t *(kN/m³)*	ν	*E (MPa)*	*c (kPa)*	ϕ *(°)*	R_{inter}
1st Silty Sand	0-4 m	Drained	18.0	0.3	5.0	10	30	1.0
2nd Silty Sand	4-8 m	Drained	19.0	0.3	10	10	35	1.0
3rd Silty Sand	8-20 m	Drained	20.0	0.3	15	10	40	1.0
Selected Backfill	-	Drained	20.0	0.3	3.5	30	35	1.0
Bed Rock	>20 m	Non Porous	25	0.3	50	500	-	-

The typical section of Geogrid soil reinforcement was designed 3 grades as tensile strength 50, 75 and 100 kN/m Miragrid GX 50/30, GX 75/30 and GX100/30 respectively. The anchorage length is 8m and 0.50m vertical spacing as shown in Figure 10.

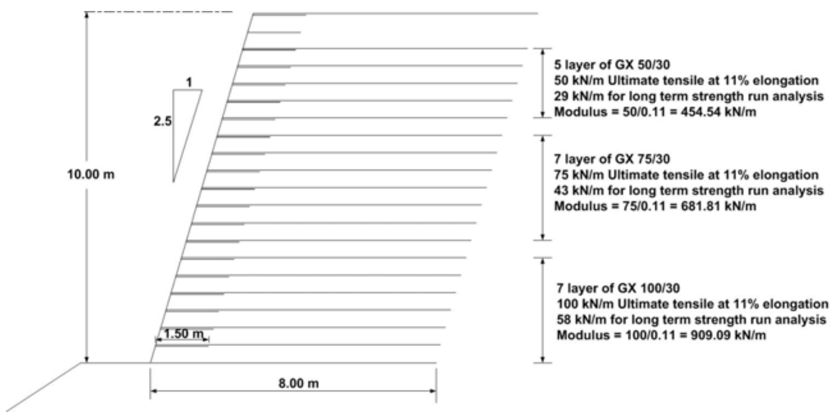


Figure 10 Typical section of Geogrid Reinforcement slope

Plaxis program was used to analyse the stability of Geogrid reinforced structure by Phi-C-Reduction method by deduct the strength parameter until failure. The proportion of decreased strength of soil to initial can be explained in term of factor of safety to failure. (see Figure 11.) The factor of safety is equal to 1.221 in overall stability case.

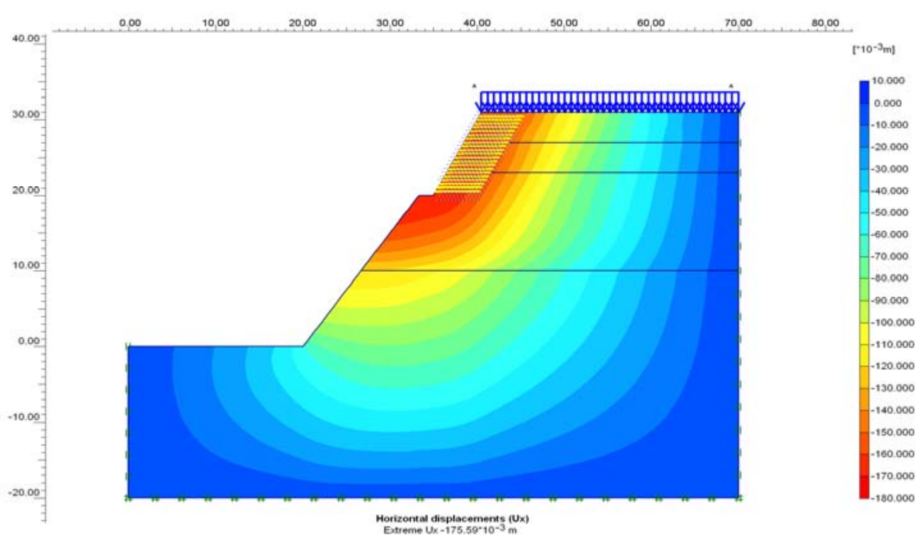


Figure 11 Safety analysis by FEM

The slope stability was also analyzed from Slide program. The slope stability was 2.790 (see Figure 12). From the FEM analysis, by using the geogrid reinforced structure, the factor of safety is greater than the stability of structure without geogrid. The factor of safety of unreinforced structure is 1.806.

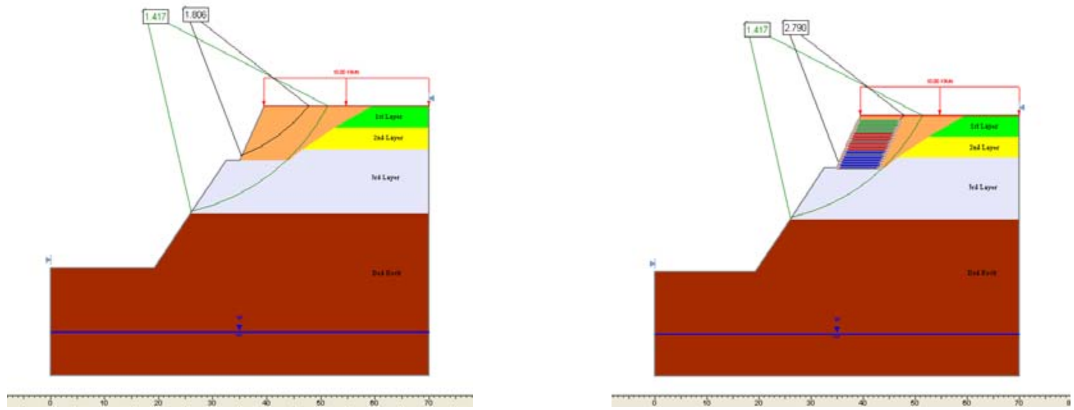


Figure 12 Factor of safety analysis from slide program (see Table 3 for properties of each soil layer)

6. CONCLUSION

The systematic of the design and construction of very high reinforced soil structures using geogrid, that have been implemented in large scale in highway embankment built in route no. 1095, KM 178+950, section Baan Maelana to Maehongsorn Municipality demonstrated the potential of the technique and the significant contribution of the quantitative of the Geogrid reinforcements. These aspects ratified the relevance of criteria of studies and constructive procedures, with particular emphasis in the determination of the material soil property for interface strength parameter in term of pullout resistance, effect of the confining pressure about the tensile behaviour of the Geogrid under service condition, and subdrainage system to gain strength with time.

This project has used the Geogrid to be reinforced soil structure. In the future, it would be more useful to monitor the tensile develop during and after construction period. We would be able to know the behaviour of the pullout resistance then compare to finite element analysis for future development of reinforcement material.

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