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ABSTRACT

Slope failures often occur in highways located in the mountainous terrain of Northern Thailand. There are several factors which induce those failures. The construction material consists of cohesionless decomposed granite. The highway embankment is steep over 30 m in height. The rainfall is very high during the monsoon season. Due to limitation of right of way, difficulty in the reconstruction and environmental consideration, geogrid reinforced embankment is introduced. The advantages of using the reinforced structure are to use less material because the very steep slope can be maintained and the vegetative cover is feasible. However, the method is expensive, economical design is necessary, i.e, very steep slope, wide spacing of geogrid and the minimum length of geogrid. The research was commenced on a selected failed slope repaired by using geogrid reinforcement. Borings were performed with soil samples taken to our laboratory to determine the engineering properties of the embankment materials as well as the soil profile of the foundation. The design and construction was verified by installing several geotechnical instruments, i.e., inclinometers, piezometers, observation wells, surface settlement plates and pressure cells. Long term monitoring data were recorded and analyzed. The FEM model was established and calibrated with measuring data. The analysis results indicated that surface runoff and seepage were the major causes of the failure. In order to prevent the future failure, good surface drainage is required to eliminate the surface runoff and the horizontal drainage pipes are needed to reduce the amount of underground water. The FEM analysis shows that using the geogrid reinforcement improves the slope stability; however, the length of geogrid should be long enough in order to fully develop the anchorage end.

INTRODUCTION

In Thailand, sloped embankment failure could be seen in many places, especially in the northern and southern parts, which are mountainous areas.It causes problems of safety and inconvenience to the road user as well as financial burden to the Department of Highways. After the sloped embankment fails, most of the repair work is based on a conventional practice, which the reconstruction of the embankment is commenced. The repaired slope embankment could not stand very long, because the same condition is remained, particularly the high embankment where the reconstruction process is difficult resulting in substandard construction. Reinforced embankment is introduced. However, because the method is expensive, economical design is commenced. The geometry of the design and design parameters for the design as well as the construction technique are among the factors of success in using the reinforced embankment for the failed slope. Therefore, the Bureau of Road Research and Development under the Department of Highways has conducted the study by installing instruments at a test reinforced embankment, monitoring the performance of the embankment, predicting the performance of the embankment by analytical model and finally evaluate appropriateness of the design and construction.

TEST SITE AND FAILURE CHARACTERISTICS

A test site with sloped embankment failure was selected and the failure characteristic is shown in Figure 1 and Figure 2. The failure occurred on December 2005 after the big raining. The failure occurred from the side slope in which the toe slope started to move. Then everything above including the road embankment was collapsed. One traffic lane disappeared causing difficulty and danger to road users. Thailand Department of Highways had the budget for the repair work and the reconstruction had begun.

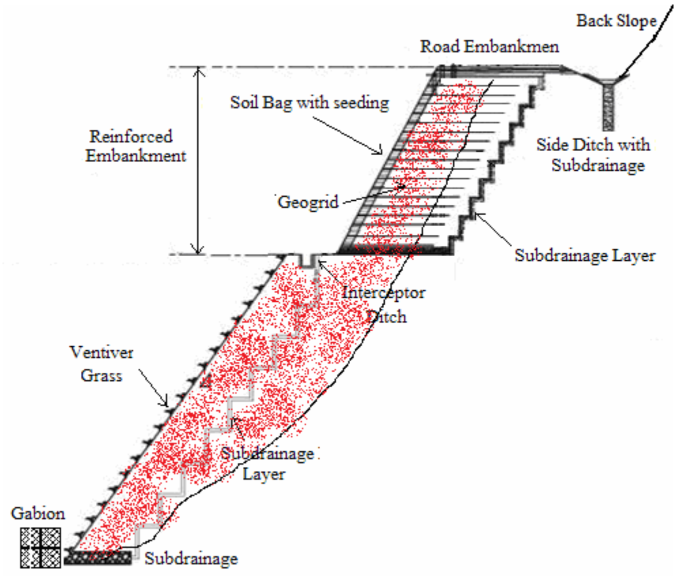

Figure 1: Cross Section of the Sloped Embankment Failure

Figure 2: Site with Sloped Embankment Failure

GEOTECHNICAL INSTRUMENTATIONS

In order to understand factors causing the failure, the Bureau of Road Research and Development hired a company to install geotechnical instruments at the site. The instruments are inclinometer, pneumatic piezometer, surface settlement plates, total pressure cell and observation well. The number and purpose of each instrument are shown in Table 1 and the layout of instrumentation is shown in Figure 3. In addition, the soil samples were collected and tested in the laboratory to determine some engineering properties

Table 1: List of Geotechnical Instruments Installed at the Test Site

Types	Number	Purpose
Vertical Inclinometer	3	To measure the horizontal movement at various depth
Pneumatic Piezometer	4	To measure the underground water pressure
Observation Well	3	To measure the water level near the surface
Surface Settlement Plate	5	To measure the vertical displacement
Total Pressure Cell	1	To measure the pressure due to weight of soil and other surcharges

The test site was approximately 100m long, in which the instruments were installed at the mid length. After the completion of installation, the long term test data were recorded and analyzed.

TEST DATA AND ANALYSIS

From the soil boring report, the engineering properties of each soil layers are shown in Table 2 and the geogrid used at this site has its EA = 500 kN/m.

Table 2: Engineering Properties of Each Soil Layer

Elevation	Identification	Type	$\gamma\ dry$ kN/m^3	$\gamma\ wet$ kN/m^3
+5.000 - +11.000	Decomposed Granite	Drained	18.5	20
+0.000 - +5.000	Decomposed Granite	Drained	19.0	21
-30.000 - +0.000	Decomposed Granite	Drained	19.0	21

Elevation	υ	E kN/m^3	C	ϕ	R_{inter}
+5.000 - +11.000	0.3	10000	-	30	0.7
+0.000 - +5.000	0.3	48000	-	40	0.7
-30.000 - +0.000	0.3	50000	-	40	0.7

The horizontal displacements from inclinometer INC-02 and INC-03 are shown in Figure 4 and Figure 5.

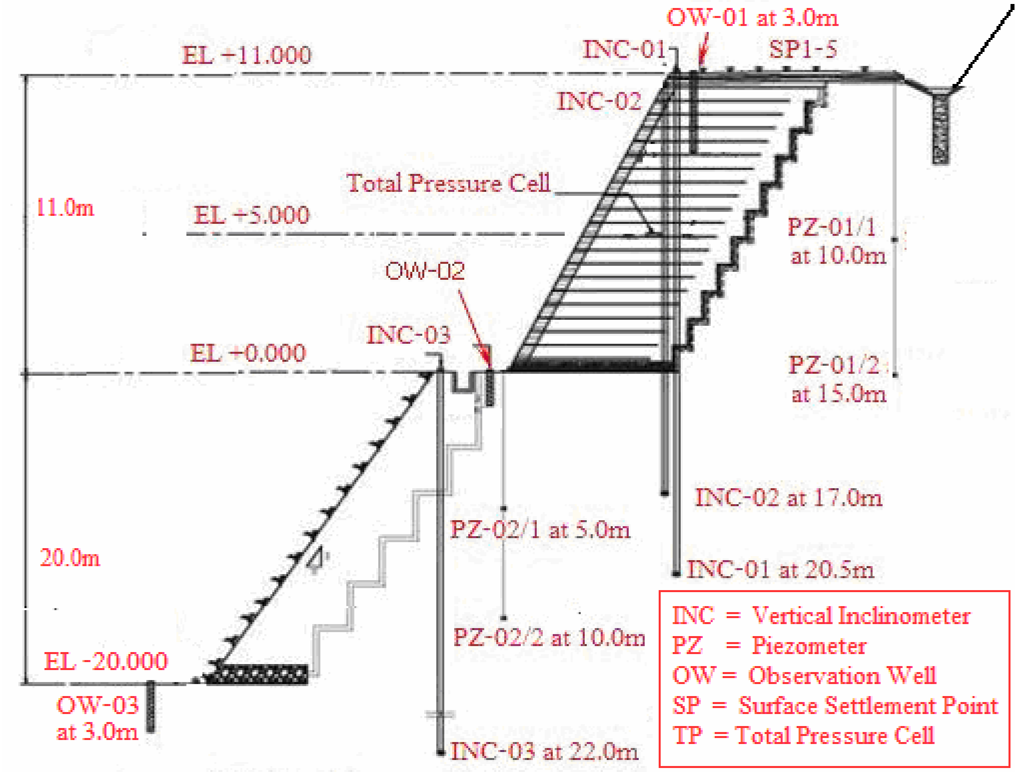

Figure 3: Cross Section of Instruments Installed at Test Site

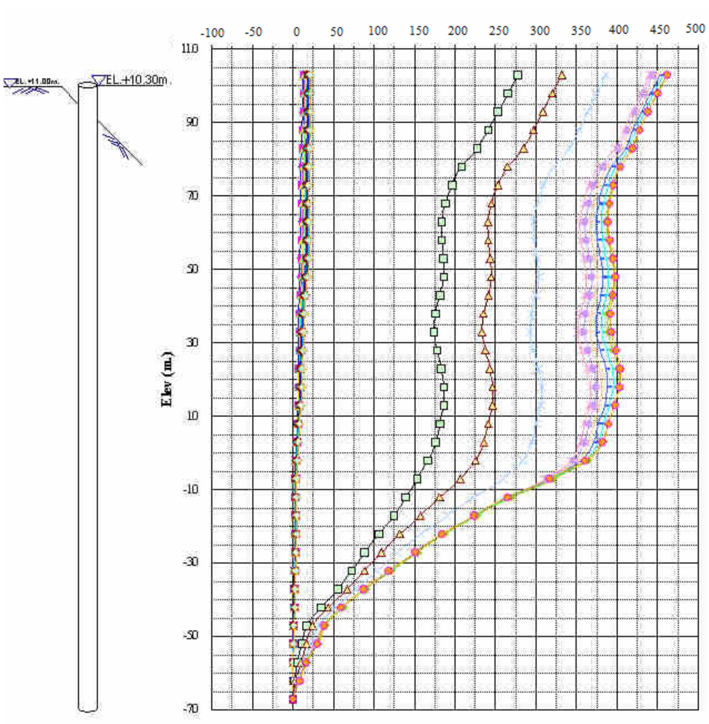

Figure 4: Horizontal Displacement of INC-02 in millimeter

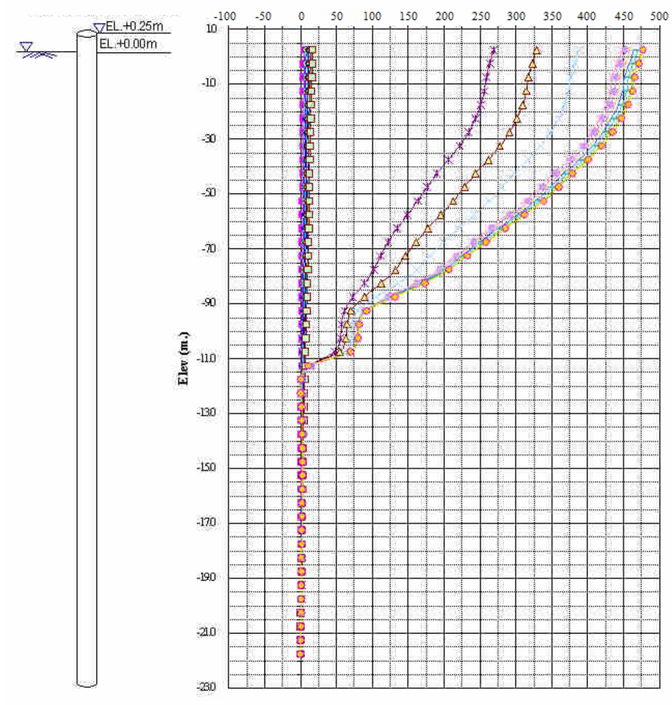

Figure 5: Horizontal Displacement of INC-03 in millimeter

At 9 months after the reconstruction, the maximum horizontal displacement of the top berm was about 470mm, which it was quite similar for the bottom berm. When considering the vertical settlement at the top of embankment, the reading from SP1-5 showed the maximum of 32cm settlement as shown in Figure 6.

The large horizontal movement and vertical settlement were expected to be due to the underground water, which lessened the soil strength. This was confirmed by the reading of the piezometers PZ-01 and PZ-02 as shown in Figure 7 and Figure 8.

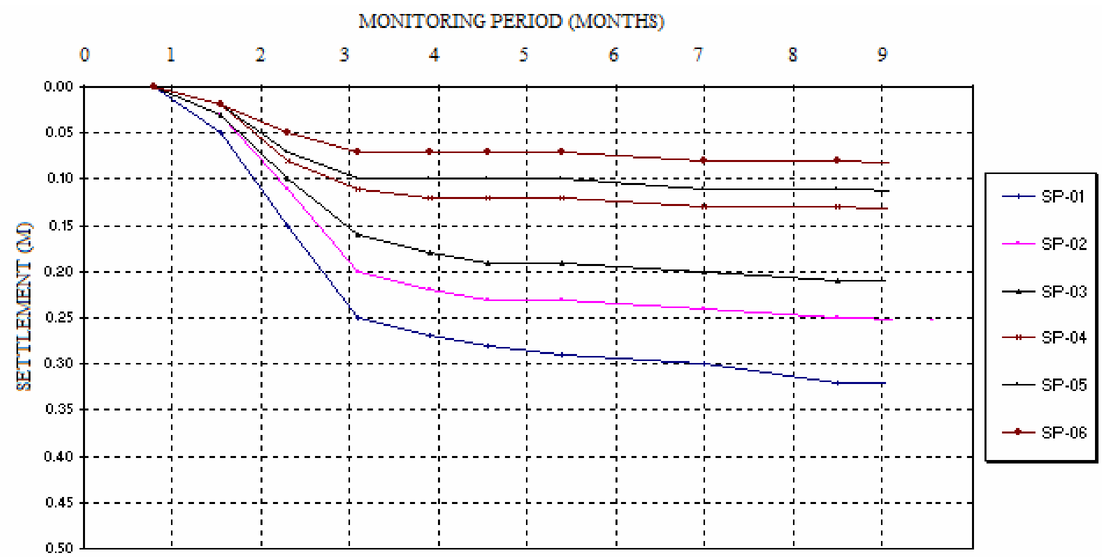

Figure 6: The Settlement at the top of Embankment (SP1-5)

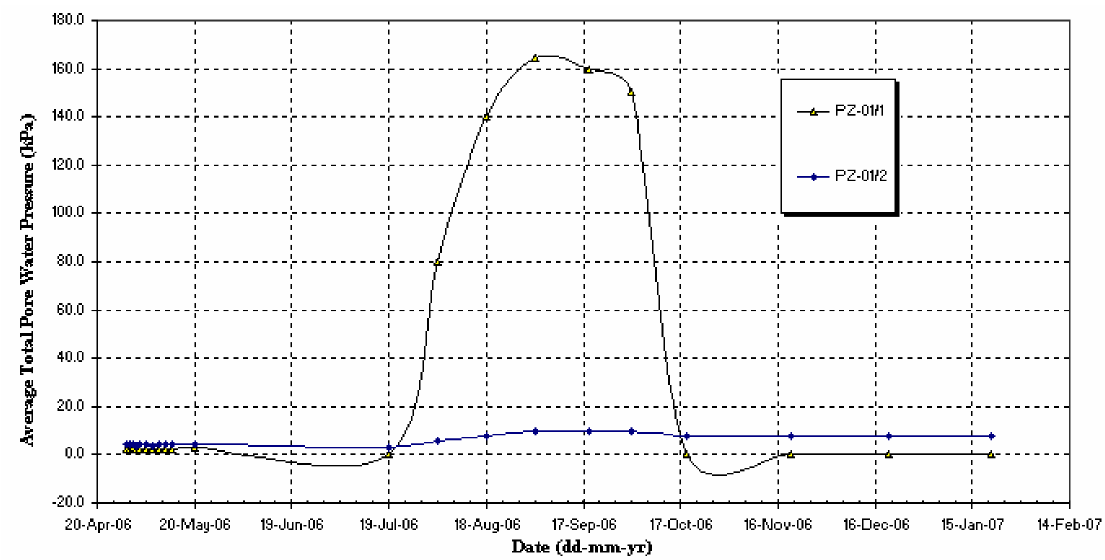

Figure 7: The Water Pressure in kPa from PZ-01/1 and PZ-01/2

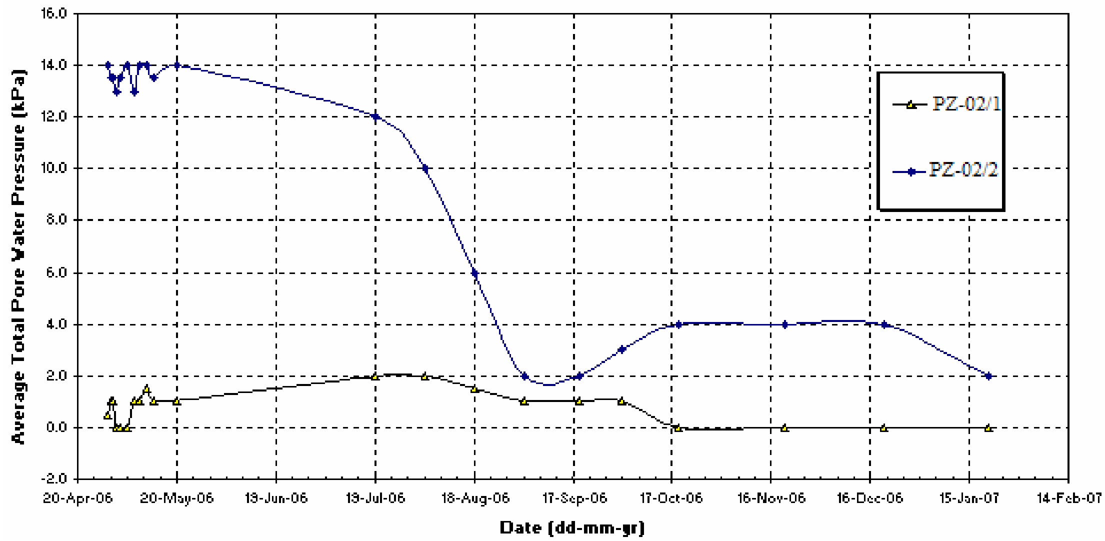

Figure 8: The Water Pressure in kPa from PZ-02/1 and PZ-02/2

In order to understand and predict the behavior of the sloped embankment, the finite element model (FEM) was modeled as shown in Figure 9.

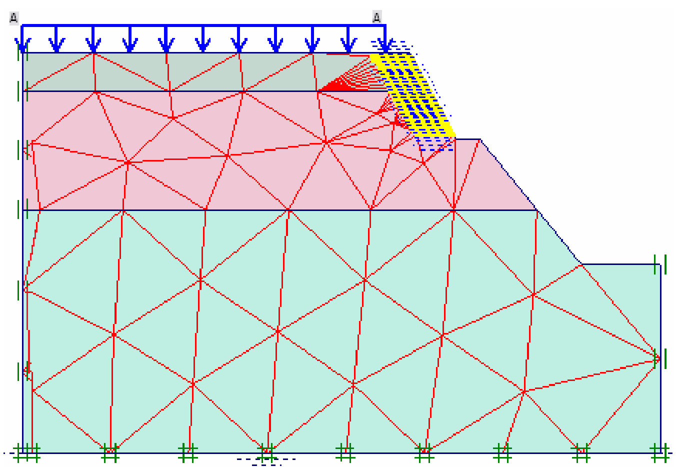

Figure 9: Finite Element Model (FEM) of the Sloped Embankment

The FEM model was calibrated with the measuring data. In the model, two experiments were conducted. The first one was the changing of ground water table, in order to see the effect of underground water on the horizontal movement of the slope. The FEM analysis showed that the higher the water table level, the higher the horizontal movement, especially when water table was higher than elevation -10.000m as shown in Figure 10 and Figure 11.

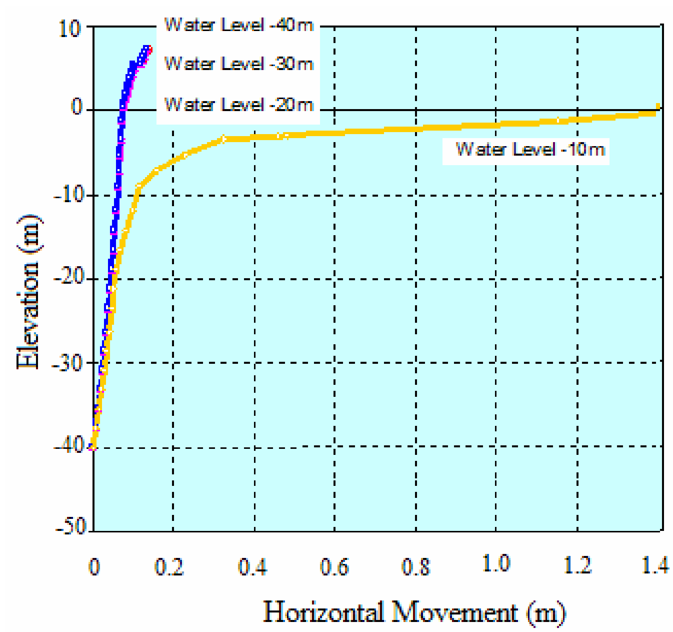

Figure 10: Horizontal Movement at INC-2 with Various Water Table

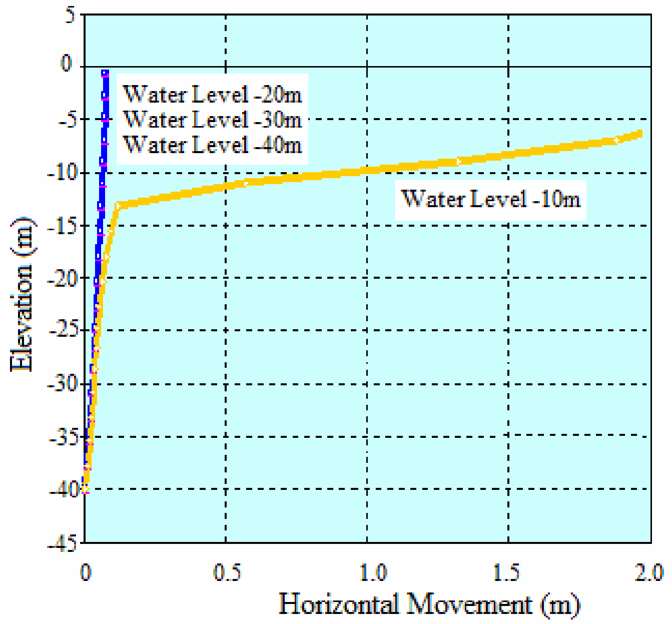

Figure 11: Horizontal Movement at INC-3 with Various Water Table

The second experiment was the changing of geogrid length. By increasing length of geogrid, it will increase length of anchorage zone. The FEM analysis showed that the horizontal movement could decrease about 10-30% by increasing the geogrid length from 5.0 – 9.0 m.

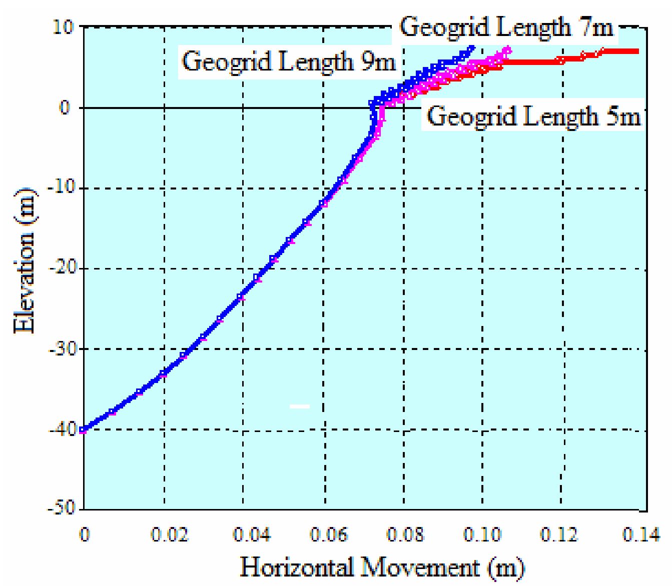

Figure 12: Horizontal Movement at INC-2 Changing with Geogrid Length

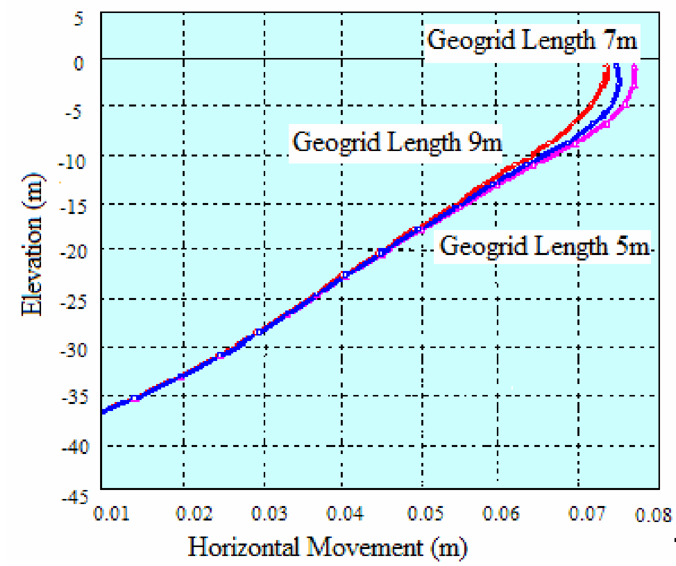

Figure 13: Horizontal Movement at INC-3 Changing with Geogrid Length

DISCUSSION AND CONCLUSION

Due to many failures of sloped embankment in Thailand, Thailand Department of Highways decided to conduct a study by installing geotechnical instruments at a reconstruction site. The geotechnical instruments were inclinometers, piezometers, observation wells, surface settlement plates and total pressure cell. The monitoring data indicated large horizontal movement and large vertical settlement. The expecting cause of large displacements was due to ground water between soil particles, which lessened the soil strength. This was confirmed from high water pressure monitored from piezometers and from the FEM analysis. From this study, the researchers suggested to install the horizontal drained pipes into the compacted embankment. They would help draining the underground water and reduce the excessive pore water pressure. In addition, the FEM analysis suggests putting longer geogrid. This will increase the anchorage length, which increasing the resistance force at the fixed end.