Parametric study of a reinforced highway slope in Thailand

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ABSTRACT: Highways constructed in mountainous area are often experienced high potential risk to slope failures. In 2005 alone, 30 high fill slopes in Mae Hong Sorn province in northern Thailand, were reported collapsing during the prolonged rainfall. A failed slope repaired with geogrid was selected among those reported failed slopes for the study. Parameters affecting performance of the geogrid-reinforced slope were investigated using finite element and limit analysis simulations. The results of the simulations revealed the effectiveness of the repair technique and parameter-influenced behaviors of the repaired slope.

1 INTRODUCTION

The failure of earth slope is widely known as "the movement of a mass of rock, debris or earth down a slope". Causes of failure involve various internal and external stimuli such as earthquake shaking, intense rainfall, storm waves, stream erosion, etc. These activities can cause a rapid increase in driving shear stress or decrease in resisting shear strength of slope forming materials.

The causal factor of such failures may contribute to short and long term variation on the slopes such as vegetation cover, drainage conditions, climate and weathering. Human activities (e.g., construction), also play a major role in making the slope susceptible to failure (Popescu 1994).

Effective managements of slope could dramatically reduce losses such as use of restriction of land use, design codes (e.g., excavation, grading, landscaping, and construction), preventive measures and warning systems. Prioritization regarding severity, elements at risk, and loss that may occur could be judiciously used to remedy these landslides more effectively (Pensomboon 2006).

Highways located in mountainous area, especially in Northern of Thailand, are critical to slope instability problems. The causal factors were the direct effects of a long and harsh monsoon season. In Mae Hong Sorn province in Thailand's Northern region, more than 30 failed cases were reported in 2005 (BRRD 2007). Failed debris had blocked the roads causing economic loss throughout the region. Later, Bureau of Road Research and Development, Department of Highways, have proposed the standard design for routine maintenance practices of the failed slopes in the region.

One of physical measures to prevent landslide that has been widely adopted in Thailand is use of geosynthetics such as geogrid to stabilize slopes. Geosynthetics have a wide range of applications in civil engineering works. They have been used in conjunction with soil, rock and/or other construction materials. Types and their basic functions can be found in literature elsewhere.

In typical slope repair using geogrid, multiple layers of geogrid are usually placed within the compacted backfill material with desired reinforcing lengths. Properly installed geosynthetics in the direction and along the line of action of the major principal tensile strain can dramatically increase shearing and strain resistance in the reinforced slopes (Shukla 2002).

This paper presents the parametric study of the reconstructed slope on the highway route number 1095 at kilometer post of 178+950 in Mae Hong Sorn province. The parametric studies revealed the effectiveness of slope repaired with geosynthetic techniques. Some parameters that may affect the performance of the repaired slope were discussed.

2 SITE CONDITIONS

Subsoil encountered at the failure site composed of mixed layers of low plastic clay to silty sand to the depth of first 4 m. Thereafter, the layer of silty sand was encountered to the depth of 15.50 m where the underneath material was the weathered gray shale. The blow count (n-value) showed that soil strength was increase with depths.

The apparent soil layers at the site were believed to form by weathering of shale. Highways constructed with cut-and-fill technique through shale are subjected to failure during high precipitating season because shale material becomes degraded and slippery (Jamnongpipatkul et al. 2008). Ground water level at the failed site was below the toe of the slope at the investigation period. It is believed that the ground water level may vary greatly during rainy season.

3 FINITE ELEMENT ANALYSIS AND PARAMETRIC SETTING

For finite element analysis, PLAXIS 2D (Brinkgreve et al. 2006) has been used under plane strain condition of 15 node elements. The subsoil condition was simulated as indicated in Table 1 while the elastic parameters used in the analysis were adopted from the correlation of n-value proposed by Das (1990). The mesh generated from the program for the analysis is illustrated in fig. 1.

The long-term performance of the repaired slope was investigated by the comparison of use of three different types of geogrids as shown in Table 2. The reinforcement lengths of the geogrids were assumed to be 8 m with vertical spacing of 0.50 m.

Initial Condition is to simulate the settlement of the model due to weight of the soil layers; Geogrid Construction is to simulate the construction of the geogrid as built on the reinforced slope; Traffic Condition is to simulate the traffic load on the reinforced embankment.

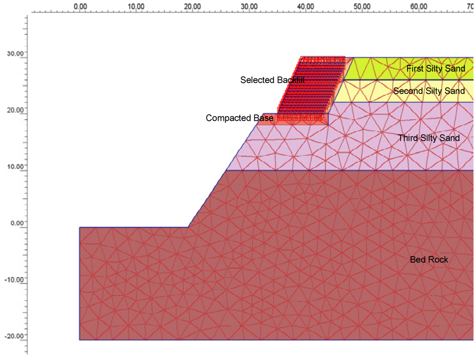

Figure 1. Finite element mesh used for the analysis.

Table 2. Geogrid's paremeters in the analysis.

Material	Layer number	Property	Tensile strength (kN/m)	EA (kN/m)
Geogrid 1	1-5	Elastic	29	264
Geogrid 2	6-12	Elastic	43	391
Geogrid 3	13-19	Elastic	58	527

4 PARAMETRIC STUDY ON SLOPE MOVEMENTS

The effect of the environment that may influence the repaired slope was investigated by simulation of 3 environment conditions. The effects of variations of (i) stiffness of the backfill material, (ii) stiffness of underlying compacted base, and (iii) ground water levels were investigated.

4.1 *Stiffness of the backfill material*

According to DOH standards, the properties of backfill material used for reinforced slope must be controlled as follows: LL<30, PI<6, $\phi' > 32^{o}$ and %passing #200<15 (Department of Highways 2007).

Even though, the backfill materials have met the standards, achieving the desired stiffness may encounter some technical difficulties. The parametric analysis regarding the variation in elastic stiffness of the backfills was investigated. Fig. 2 shows the effect

Table 1. Subsoil condition used for analysis.

Soil	Depth	Condition	γ_t (kN/m^3)	υ	E (MPa)	c' (kPa)	ϕ' (°)
1st Silty Sand	0-4 m	Drained	18.0	0.3	5.0	10	30
2nd Silty Sand	4-8 m	Drained	19.0	0.3	10	10	35
3rd Silty Sand	8-20 m	Drained	20.0	0.3	15	10	40
Selected Backfill	-	Drained	20.0	0.3	5.5	30	35
Compacted Base Layer	-	Drained	19.0	0.3	15	10	35
Bed Rock	>20 m	Non Porous	25.0	0.3	50	500	-

of variation in stiffness. It revealed that once the stiffness was reduced by 50%, the crest settlement will be increases by 200 mm or by 70% of the original value.

The FEM results were compared with the monitored settlement. It revealed that the stiffness of the constructed slope may be reduced following the decrease in soil stiffness according to stiffness nonlinearity which can be obtained from sophisticated laboratory test (Sukolrat 2007).

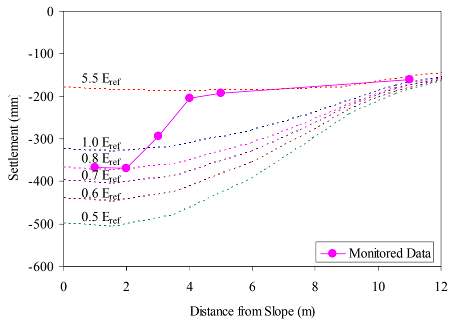

Figure. 2 Effect of stiffness of the backfill material to slope movement.

4.2 *Stiffness of underlying compacted base*

The movement of the reinforced slope also depends on the stiffness of the base. Soft base may cause high movement at the crest slope. The FEM analysis revealed the variation of the base stiffness that may affect the reinforced slope movement. The results of the investigations are shown in fig. 3. In the case that the compactive effort of the base material is not reached the designed value, the soil stiffness is then reduced. The result of the FEM simulation shows that although the base material was softened, the movement of the slope is not as much as the effect from the backfill material.

4.3 *Ground water level*

Heighten ground water put an additional weight to the reinforced slope, which become less stable thus causing greater movement. In this paper, ground water variations of 3 locations were studies including (i) no effect of ground water, (i) at the bottom, (iii) on the top of the reinforced slope. Fig. 4 shows that increase of ground water has less effect on the overall settlement at the crest of the slope.

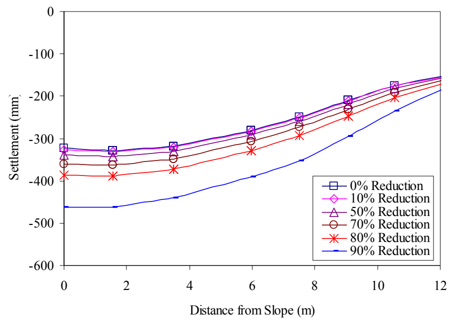

Figure 3. Effect of underlying compacted base to slope movement.

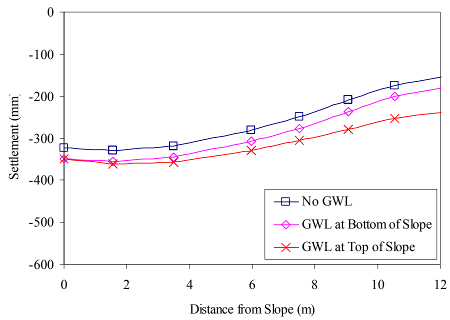

Figure 4. Effect of water level to slope movement.

5 PARAMETRIC STUDY ON SLOPE STABILITY

In the previous section, the FEM analysis showed that the parameters contributing to the undesired behavior of the reinforced slope is the properties of backfill. Variations of the strength parameters of the backfill were investigated and simulated using the reduction factor (r) in the range of 0 to 1, which applied to both material friction angle (ϕ') and cohesion (c').

Slope stability analysis was performed using simplified Bishop Method, and slope and load configuration as shown in fig. 5. The relationships of the reduced strength parameters versus factors of safety against local and global failures were illustrated in fig. 6. The local factor of safety refers to the range of safety factor that localizes the failure plane on the geogrid-reinforced zone. On the other hand, the global factor of safety localizes the failure plane beyond the reinforcing length of the geogrid.

The result shows that the reduction of backfill strength has high influence on the global factor of safety because the material itself cannot withstand shear stress due to its own weight and the applied traffic load. On the other hand, once the strength parameters of the backfill have been reduced, the geogrid still provide the interlock mechanism and tensile strength to the compacted backfill resisting the local failure developed by stress due to its own weight and traffic load.

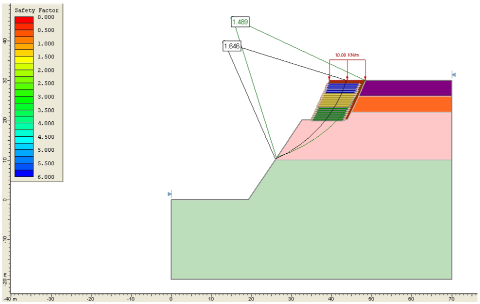

Figure 5. Slope stability analyses.

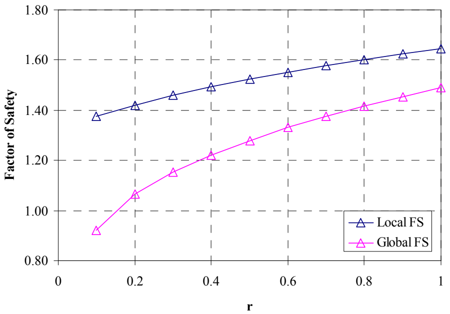

Figure 6. Factor of safety against strength reduction factor.

6 SUMMARY AND CONCLUSION

The parametric study of the failed slope repaired with geogrid has been conducted. The result of the study revealed that stiffness of the backfill controlled compaction plays a major role in controlling settlement of the slope. When the backfill material is poorly compacted or fail to achieve the desired backfill stiffness, the installed layers of geogrids will not fully mobilize to absorb the tensile strain developed in the repaired mass. This will later cause some movement in the reinforced portion.

In repairing a failed slope, the base underneath the repaired mass is compacted to provide the firm support for the repaired mass. Reduction of base stiffness will also affect the stiffness of the repaired mass and eventually cause settlement. The settlement caused by the effect of soften base is relatively less when compared with poor compacted backfill.

Fluctuation of ground water variations can soften the material and add more weight to the repaired slope. Ground water in the repaired slope can be effectively controlled by use of the selected free-drain material. However, in this study, fluctuation of ground water has less effect in comparison with the soften base and poorly controlled stiffness of backfill material.

The reduction strength parameter of the backfill directly impacts the stability of the repaired slope. Loss of backfill strength is likely to affect the global stability rather than local stability. At the same amount of the reduction of backfill strength, the repaired slope will reach the critical global stability before the local stability because interlocking mechanism and tensile strength of the installed geogrid have been mobilized to prevent the failure in the reinforced zone.

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