Economizing the Soil Nailing Design by Drainage Improvement – Case History at Ginigathhena

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Abstract

As a tropical country which faces two monsoons with heavy precipitation, rainfall is identified as the major triggering factor for landslides in Sri Lanka. However, reactivation of ancient landslide is a major challenge faced by the Engineers in infrastructure developments in the hilly terrain of the country. Ancient landslide occurred at the Bridge No.48/2 in Avissavella – Hatton – Nuwaraeliya road was reactivated by excavation at the toe of the slope for the proposed widening of the bridge. This was further propagated by the extensive rainfall that occurred subsequently. The area under consideration is a sloping ground with undulating topography towards upper slope and in the form of a valley area formed by a prevision landslide. Mitigation of the landslide was done in order to accommodate the requirement of widening of the bridge and to minimize the risk of further activation by a critical design rainfall. Mitigation measures are mainly focused on three categories as; drainage improvement, slope modification and soil reinforcement. Soil nailing was used as the reinforcement technique. Surface and subsurface drainage improvement was used for economizing the nailing design. This study presents how the nailing design was optimized by using different drainage arrangements. GeoStudio SEEP/W and SLOPE/W software were used for seepage analysis and slope stability analysis respectively.

Keywords

Rain induced landslides, Mitigation, Soil nailing, Drainage improvement, Economizing the design

Introduction

Background

Sri Lankan landform has a very significant elevation difference within a shorter distance from costal area to the central regions. The elevation difference between the capital Colombo, which is at the sea level, to highest city of the country; NuwaraEliya, is about 2,000 m while the distance on the road is only 150 km. Many steep high slopes exist in and around the central region of the country due to variations in elevations.

Sri Lanka`s extensive road network connects the capital city Colombo to all regional cities in the country. This road network experiences significant variations in the elevations while traversing through the highly variable terrain in the central region. There are many requirements to widen and improve the current road network to accommodate the increasing demands of traffic flow due to economic development and population growth. Such road widening demands excavation into the slope in the hilly terrain.

Since the Bridge No. 48/2 on Avissawella – Hatton - NuwaraEliya Road near Ginigathhena area is narrow, there was a need of widening that bridge with the increasing traffic flow. However, the ancient landslide at that location got activated with the attempt to excavation in to the slope at the toe for the said bridge widening. Considering the social, economic and environmental importance, this Ginigathhena landslide was stabilized by extensive mitigation measures.

Mitigation measures are designed for stabilization of the slope while allocating space necessary for the widening. Drainage improvement, slope geometry modification and slope reinforcement are used as mitigation measures. There is a separate study done to identify the importance & effectiveness of the drainage improvement, requirement of combine mitigation measures and necessity of stage construction of landslide mitigation works. This study was done as a continuation to that and this paper is focused on the economizing of the soil nailing design by application of different drainage improvement measures.

Landslide in Sri Lanka

There are many reasons for activation of landslides and among those may reasons, rainfall is identified as the major triggering factor of landslides in Sri Lanka. Landslides triggered by rainfall are termed as rain induced landslides. There are several other facts contributes to the activation of rain induced landslides such as: human activities, natural weathering processes etc. Notably during the past few decades, rain induced landslides and cut slope failures have become a major natural disaster in Sri Lanka (Ratnayake & Herath, 2005).

Background knowledge

Residual soils, which are formed by weathering of parent rock have significant variations within a closer region due to different degree of weathering caused by the differences in the mineralogical composition of the parent rock. Colluvium soils are formed by down movement the residual soils and rock under gravity in previous landslides. Those colluvium soils also have variations in formation. Hydraulic and shear strength properties of those soils are significantly low and varying due to those variations in soil formations. Process of rain induced landslides are quite complex due to the variable soil properties brought under these conditions.

Slopes which have tendencies to fail during rainy period are generally in quite stable conditions during dry periods due to prevailing matric suctions under low ground water table conditions. However, with the infiltration during heavy rains, matric suction would be diminished and positive pore pressures may develop in the slope. Eventually the slope become unstable with the rainfall. If the stability of a slope is found to be insufficient during extreme conditions, mitigation measures are applied to enhance the stability to a required level. Rain induced landslides requires two types of analyses as seepage analysis to analyse the ground water regime variations and stability to analysis to evaluate the safety margins of the slope under those conditions. These two analyses are required to be coupled together to get realistic results. Semi coupled GeoStudio SEEP/W and SLOPE/W software are used for seepage and slope stability analyses respectively.

Drainage improvement and other structural mitigation measures are used for strengthening the slope susceptible for rain induced failures. There are main two types of drainage improvement as surface drainage improvement and subsurface drainage improvement. Surface drainage improvement is done mainly for reducing the infiltration and subsurface drains have capacity to lower the ground water table. Retaining walls, ground modification and soil reinforcement are some other types of slope strengthening measures.

Reinforcement by soil nailing is used for stabilization of most steep high cut slopes. Soil nailing is a technique of reinforcing in-situ soil by using passive intrusions from the facing proceeding in a top down construction sequence.

Soil Nailing systems are generally assed using two zone model, namely the active zone and the resistant zone, which are separated by a potential failure surface as shown in Fig. 1. The active zone is the region in front of the potential failure surface, where it tends to detach from the main slope. The resistant zone is the region behind the potential failure surface, where it remains more or less intact. The soil nails act to tie the active zone to the resistant zone (GEO, Hong Kong, 2008).

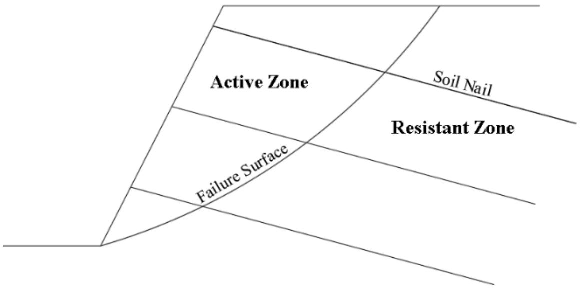

Fig. 1 Soil nailing system

Soil nails are functioning when the slope experiences some movement. Tensile stress developed in the soil nails which reduces the shear stress to be mobilized on the slip surface and increases the shear resistance force by increasing the normal stress on the failure surface. Both these phenomena increase the safety margin of a slope. For this to be effective, nails should extend to a sufficient distance beyond the failure surface (into the resistant zone) and should be capable of mobilizing a sufficiently large tensile force without getting pulled out.

Drainage improvement is considered as the primary mitigation measure in stabilization of rain induced landslides. It is a very important component in a soil nailing system. GEO, Hong Kong (2008) and Federal Highway Administration (2006) highlights the requirement of drainage improvement in soil nailing systems in terms of improving the performance of the soil nailing system, preventing local instabilities and overcoming difficulties due to high ground water table during construction. With the improvements achieved by drainage improvement, amount of soil nails required to maintain the stability of a particular slope would be less. In general, cost of drainage improvement is less than cost of soil nailing. Therefore, considerable amount of cost can be saved by application of drainage improvement measures in a soil nailing systems.

Economizing of the soil nailing design of Ginigathhena landslide by drainage improvement was studied at depth in this paper.

Ginigathhena landslide

Background

Avissavella – NuwaraEliya road is a major road which connects the capital Colombo to central region of the country. Bridge No. 48/2 on this road is very narrow. Also, the traffic demand on that road is increasing rapidly with economic and population growth in the area. Based on that, the bridge was proposed to be widen. Some excavation was done at the toe of upper slope of the bridge on the purpose of widening the bridge. Ancient landslide above the bridge got activated with this excavation and the failure was propagated to upper slope. It was reported that there was no rain at the time of the initial failure. With the occurrence of rainfall in the area later, failure was further activated. Fig. 2 and Fig. 3 shows the location map of the area and failure just after the rainfall event respectively.

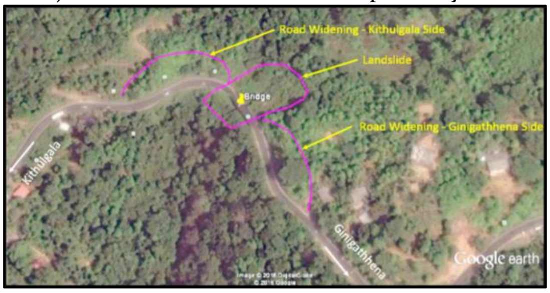

Fig. 2 Location map of the area

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Fig. 3 Failure after toe excavation

Geology and hydrology of the area

Landslide area is covered with thick colluvium deposit with boulders, which had been transported from the ancient landslide. This is underlaid by highly crystalline metamorphic bed rock. Main landslide area is a sloping ground with an undulating topography and just above the crest of the landslide there is a water logged marshy area which is the main reason for the prevailing high water table in the area. Water collected in the upper slope is flowing through the water stream at a side of the landslide. Fig. 4 and Fig. 5 shows the waterlogged marshy area at the top and the stream flowing at a side of the landslide respectively.

Mechanism of failure and justification of mitigation

With the high ground water table of the area, slope was already at a critical stable condition and with the removal of the toe support by the excavation at the toe, slope became unstable leading to reactivation of the landslide. With the rainfall that occurred in the area latter, landslide propagated further. After the failure, the unstable soil mass was supported by the bridge structure and slope was at critical stable condition. However, there was a possibility of further activation of this landslide as a deep-seated failure with heavy rainfall and such activation would have been led to a catastrophic failure damaging the bridge and the road. Also, there was a requirement for road widening. Therefore, it was decided to mitigate this landslide while accommodating the widening requirements.

Fig. 4 Marshy area at the top

Fig. 5 Stream beside the landslide

Investigation

Detail investigation of the landslide area was done including topographical survey and geotechnical investigation. Topographical survey included produced contour map of 1 m interval contour and slope cross sections (Fig. 6). Under the geotechnical investigation three boreholes were advanced with SPT`s followed by laboratory testing on recovered undisturbed samples. Subsoil profile from the geotechnical investigation is presented in Fig. 7.

Mitigation measures

Based on the investigation results, mitigation measures for the Ginigathhena landslide was designed focusing on three main categories as; drainage improvement, ground modifications and reinforcement. Under drainage improvement, surface drainage improvement was achieved by cut off drains, berm drains, trench drains & slope cover by vegetation. The subsurface drainage improvement was achieved by sub horizontal gravity drains. Propose road widening requires cutting in to the slope at the toe region and it reduces the safety margin of the slope. Therefore, slope reshaping was done to accommodate the required road widening. Since the required safety margin of this reshaped slope couldn`t be achieved only by the drainage improvement, reinforcements in the form of soil nailing were used for enhancing the safety margin of the slope. After several trails, stability of the slope was achieved by the nailing pattern presented in . This include;

- 5 nos. of 16 m long soil nails
- 2 nos. of 12 m long soil nails
- 4 nos. of 8 m long soil nails

All soil nails were installed in 2.0 m and 2.5 m spacing in horizontal and vertical direction respectively.

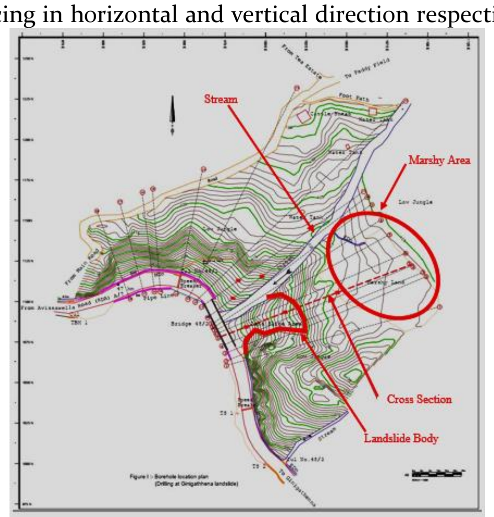

Fig. 6 Survey map

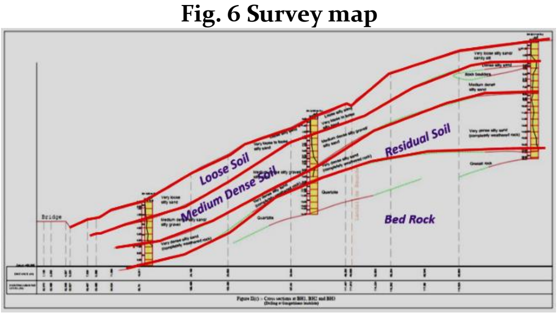

Fig. 7 Subsoil profile

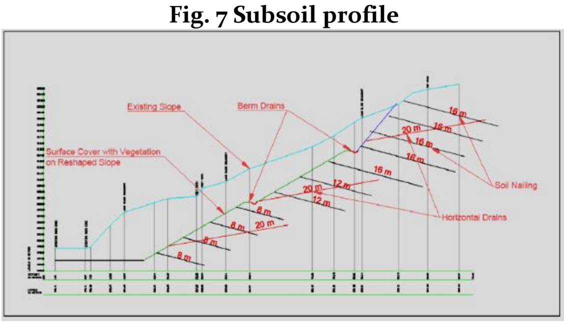

Fig. 8 Proposed mitigation measure – cross sectional view

Monitoring

During the application of mitigation measures, field monitoring scheme was established to monitor the behaviour of the slope with mitigation measures. This monitoring system consisted with three parts as; rainfall monitoring by manual rain gauge, ground water level monitoring by two observation wells and slope movement monitoring by number of fixed points established on the slope surface

Economizing the soil nailing design

Overview

Performance of the designed nailing pattern was assessed for different drainage conditions under the critical design rainfall condition and nailing pattern was revised if the required safety margins were not achieved. Following steps were followed in this study.

- Developing SLOPE/W & SEEP/W models
- Defining critical rainfall event
- Analyses for different drainage condition and revising the nailing pattern
- Cost comparison of different nailing patterns

Development of geotechnical computer models are not discussed here in depth. To give an overview; results of geotechnical investigation was used for developing the both SEEP/W & SLOPE/W models. Verification of the SLOPE/W model was done by simulating the failure occurred after toe excavation. SEEP/W model was verified by simulating an actual rainfall event on the model and comparing the results with actual ground water levels. Surface drainage improvement was modeled on the SEEP/W analysis by applying a thin layer of very low permeability on to the slope surface. In the modeling of subsurface drains, horizontal drains installed at some horizontal spacings were idealized to plain strain condition by a zero pressure boundary condition apply on to a reprenstative line of actual horizontal drains.

Drainage conditions

Three drainage conditions were considered in the analyses as *"No Drains"*, *"Only Surface Drains"* and *"Both Surface & Subsurface Drains"* conditions. Original design was done for *"Both Surface & Subsurface Drains"* condition. Therefore, conditions of; *"No Drains"* and *"Only Surface Drains"* were considered in this study and nailing patterns to maintain the required safety margin for those two drainage conditions were found.

Design Factor of Safety (FoS)

The slope is located on a major road and any failure of the slope would affect the lives & properties of users of this busy road, damage the bridge & road and disturb the traffic. Considering all those facts, design FoS was selected as 1.3.

Design critical rainfall event

Since the peak rainfall observed during the monitoring period is 300 mm/day, two days of 300 mm/day rainfall was selected as the critical rainfall followed by a 50 mm/day residual rainfall for seven days and initial dry period of five days (Fig. 9).

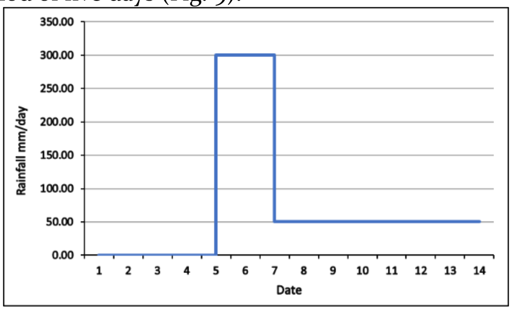

Fig. 9 Design rainfall event

Analysis

Analysis for "No Drains" condition

Critical design rainfall event was simulated on the SEEP/W model and it was analyzed for *"No Drains"* condition. Results from seepage analysis was given as input to the slope stability analysis. SLOPE/W analysis with the original design showed that the minimum FoS value will occur just after the peak rainfall of design rainfall event. The resultant FoS was 1.042 (Fig. 10). Therefore, soil nailing pattern was modified to achieve the required FoS of 1.3 against the critical rainfall (Fig. 11). Since the increasing the nailing length beyond 16 m was not practical and effective, nail grid was densified while increasing length of some 12 m nails to 16 m. After several trials, following nailing pattern was obtained;

- 12 nos. of 16 m long nails in 1.5 m horizontal and 1.5 m vertical spacing
- 4 nos. of 8 m long nails in 2.0 m horizontal and 2.5 m vertical spacing

Nailing arrangement at the lower part of the slope was not changed since the critical slip surface was not passing through that nails area.

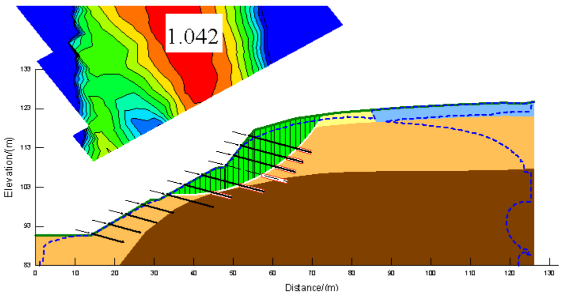

Fig. 10 "No Drains" – Original design

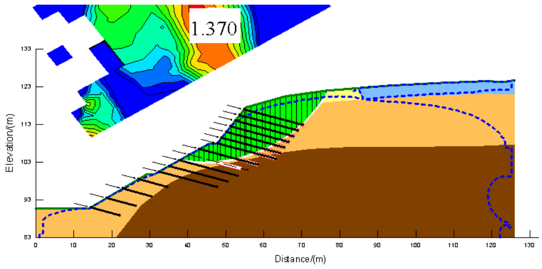

Fig. 11 "No Drains" – Modified design

As such, if no drainage improvement is done total number of nails and nail lengths will be increased very significantly. Thus the, total nailing length was increased to 3,112 m from 1,624 m of the original design. Further, facing arrangement of soil nailing system is required to be modified due to densification of the grid and increasing of the number of nails.

Analysis for "Only Surface Drains" condition

As similar to the previous case analysis was done for *"Only Surface Drains"* condition and the resulting FoS of the original design after peak rainfall was 1.124 (Fig. 12). Therefore, soil nailing pattern was modified to achieve the design FoS (Fig. 13). After several trials, following nailing pattern was obtained;

- 9 nos. of 16 m long nails in 1.5 m horizontal and 2.0 m vertical spacing
- 4 nos. of 8 m long nails in 2.0 m horizontal and 2.5 m vertical spacing

Bottom nailing arrangement was not changed since the critical slip surface was not passing through that nails area.

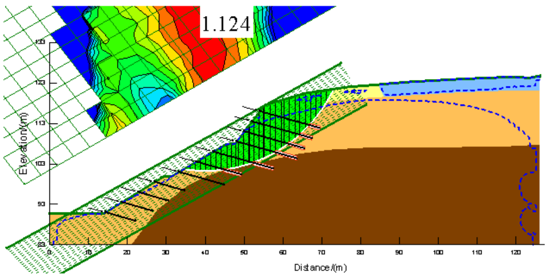

Fig. 12 "Only Surface Drains" – Original design

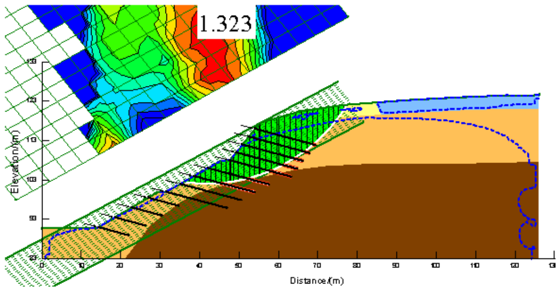

Fig. 13 "Only Surface Drains" – Modified design

The results show that total nailing length was increased to 2,624 m for *"Only Surface Drains"* condition. Further, facing arrangement of soil nailing system is required to be increased due to densification of the grid and increasing the number of nails.

Cost comparison

Construction cost for each drainage measures were calculated based on the average rates currently prevailing in the Sri Lankan industry. Tab. 1 presents the comparison of construction cost under different drainage conditions.

Cost of soil nailing also includes the cost of facing structure with nailheads connecting beams, high tensile mesh, coir mesh and vegetation. With the densifying the soil nailing, cost of facing structure also increased.

When the drainage measures are reduced a greater amount of nails have to be used to achieve the required safety margins. This causes significant cost increase.

Summary and conclusion

Summary

Total length of soil nailing was reduced and nail spacing was increased with the application of full drainage measures thus reducing the cost of nailing. But, drainage measures come with a cost. However, cost of drainage measures is less than the cost of nailing. As an example, in general, cost of nailing is about Rs. 8,500 per meter while the horizontal drain is about Rs. 4,500 per meter. Cost of excavation and associated works are remained unchanged. Therefore, total construction cost has reduced by application of drainage measures. Further, the process of nailing was made less complicated during the construction due to the lowered ground water table.

Construction cost without any drainage measures is Rs. 49.0 Mn. Cost saving by application of surface drainage is Rs. 1.3 Mn and it is a 2.65% saving. Cost saving by application of both surface and subsurface drainage is Rs. 7.1 Mn and it is 14.49% saving.

Above results illustrate how a soil nailing design can be economized by application of drainage measures. Therefore, it is important to have both surface and subsurface drainage improvement for economizing the nailing design.

Conclusion

Soil nailing technique can be used for stabilization of steep high slopes where other retaining structures are not feasible due to stability, economical and space constrains. Generally, soil nailing is applied when required safety margins couldn`t be achieved only through drainage improvement. However, drainage measures are used to optimize the nailing design.

In this study, typical rain induced landslide occurred in Ginigathhena area was selected as a case study. Results of the analysis highlighted the significant construction cost reduction can be achieved by application of drainage measures in soil nailing designs.

References

Federal Highway Administration, (2006). Soils and Foundations, Reference Manual. 1st ed. National Highway Institute, U.S. Department of Transportation, Federal Highway Administration. Washington, D.C.

GEO, Hong Kong, (2008). Guide to Soil Nail Design and Construction. 1st ed. Civil Engineering and Development Department, The Government of the Hong Kong Special Administrative Region, Hong Kong.

Lakruwan S O A D M, (2019) Enhancement of the Stability at the Site of an Ancient Landslide in a Road Cutting with Drainage and Reinforcement – Case History at Ginigathhena, M.Eng. thesis, Department of Civil Engineering, University of Moratuwa, Moratuwa, Sri Lanka.

Ratnayake U, Herath S, (2005) Changing rainfall and its impact on landslides in Sri Lanka. Journal of Mountain Science. 2(3): 218-224.

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Table 1 Construction cost comparison for different drainge measures

Drainage Condition	Cost of nailing and associated works (Rs. Mn)	Cost of drainage improvement (Rs. Mn)	Cost of excavation and other works (Rs. Mn)	Total cost (Rs. Mn)	Cost saving
No Drains	41.6	0	7.4	**49.0**	0.00%
Only Surface Drains	34.9	5.4	7.4	**47.7**	2.65%
Surface & Subsurface Drains	25.4	9.1	7.4	**41.9**	14.49%