# An Alternative Mitigation Method for Gerandi-Ella Reactivated Landslide

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**Abstract:**Gerandi-Ella, a former landslide area is currently under threat of reactivation. National Building Research Organization has implemented a surface and vertical well drainage system to stabilize it. However, vertical drainage system has failed,and an unexpected behavior of groundwater was observed due to presence of clay layers in the colluvium. An effective and economical alternative mitigation method is required to stabilize the area. A particular portion of the site,positioned such that it keeps the rest of the landslide mass intact, was chosen as the study area. Implementing a proper alternative mitigation methodto the study area may help to stabilize the landslide along with existing surface drainage system.Piezometric levels at two boreholes and rainfall data at the study area were analyzed. Stability analysis through the software SLOPE/W gave the current factor of safety as 0.965. A horizontal drain network with suitable design parameters was proposed to achieve a factor of safety of 1.206 by considering the effect of the matrix suction. A series of sand and gravel filled vertical holes capped with 100 cm clay layer are also proposed to expedite the water drawdown through impervious strata to horizontal drains.

**Keywords: Gerandi Ella, landslides, stability analysis, matrix suction, horizontal drainage**

## 1. Introduction

Being one of the most disastrous natural hazards experienced in Sri Lanka, landslides require due attention, especially when it is near a major transportation route.

Gerandi-Ella, a former landslide area located at the 41st kilometre post of Gampola – NuwaraEliya main road, was identified to be under threat of reactivation by National Building Research Organization (NBRO).

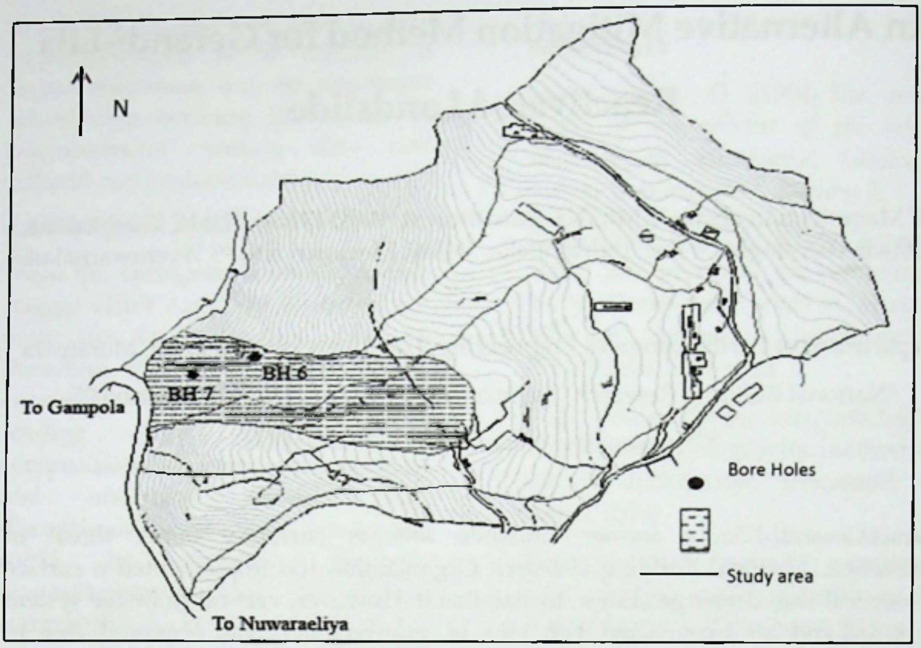


Figure 1: Selected study area of the Gerandi Ella landslide site by the Gampola - Nuwara Eliya main road and the borehole locations, BH6 and BH 7

Mitigation work, started in 2011, included a surface and vertical drainage system.

However, unexpected groundwater behaviour was observed during vertical well drainage due to clay layers present in the colluvium cover, and the vertical drainage system could not achieve the desired results. To suggest an effective and economical alternative to mitigate the landslide, a thorough and proper understanding of the hydrological and geological features of the site was required since no study related to such uncommon and complex behavioural patterns have been carried out for this site. The objective of this study was to carry out a suitable data analysis to identify an alternative mitigation option to stabilize theGerandi Ella landslide area.

## 1.1 Study area

The total landslide mass consists of two portions, upper region being held intact by a smaller lower region, which was selected as the study area (Figure.1). A proper mitigation option implemented for this smaller region is expected to stabilize the total landslide in conjunction with the already developed surface drainage system in the upper region. The slide mass was identified to have three major soil formations:

- a soil overburden
- an area between two weak zones
- weathered bedrock

## 2. Materials and Methods

Two boreholes BH6 and BH7, located as denoted in Fig.1 and each borehole attached with 3 piezometer probes were used to record and monitor the groundwater behaviour of the three soil formations at varying depths within the slide mass. A rain gauge installed at the GerandiElla site was used to obtain corresponding daily rainfall data.

Data collected during the monitoring period starting from 01.05.2014 to 30.11.2014 were visualized using data plots and furthersubjected to a statistical analysis. The piezometric level having the highest effect to trigger the landslide reactivation was determined.

Using the established ground water level the existing factor of safety (FOS) was calculated using the SLOPE/W software. The required soil parameters were obtained through NBRO.

The FOS was found to be less than 1.0 though the landslide mass currently stays intact. Matrix suction effect of the unsaturated region was thought to have caused the disparity. Stability analyses were carried out by reducing the water level and varying theoretical matrix suction values until a safe FOS value was resulted.

A horizontal drain network with suitable design parameters in conjunction with a measure to expedite the water draw down was proposed to stabilize the study area along with the already developed surface drainage system.

## 3. Results and Discussion

According to the borehole logs, the study area was found to be consisted of erratic behavior in soil strata. From the six piezometer probes attached to BH6 and BH7, one (BH6 P i) turned out to be dry over the monitoring period.

Table 4- Maximum depth fluctuation in response to highest and lowest rainfall occurrences within the monitoring period

| Piezometric probe | | Highest depth variation (m) | |
|---|---|---|---|
| | | 01/05 to 01/08 | 13/10 to 30/11 |
| BH7 | i | 0.51 | 2.45 |
| | ii | Insignificant | 2.01 |
| | iii | 2.4 | 0.73 |
| BH6 | ii | 2.16 | 0.74 |
| | iii | 1.36 | 0.68 |

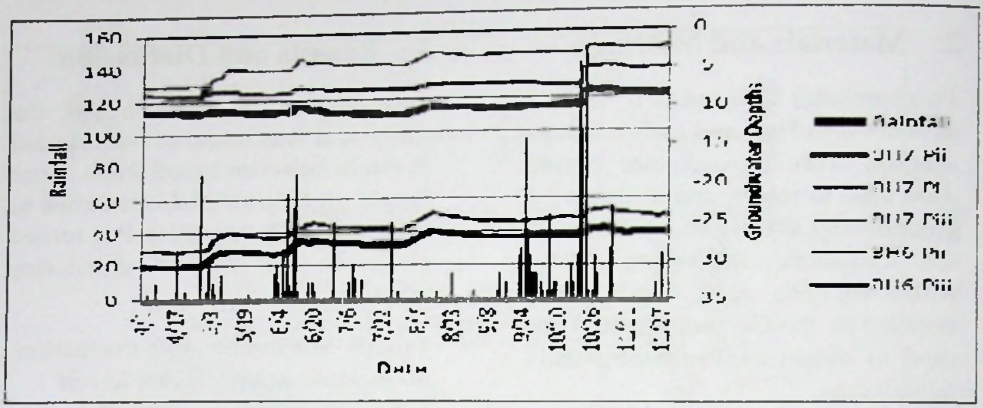


Figure 1 : Piezometric level variation with rainfall fluctuation from 11.04.2014

## 3.1 Data analysis

The data from the five piezometric probes BH6 Pii, BH6 Piii and BH7 Pi, BH7 Pii, BH7 Piii were plotted against the rainfall data (Fig. 2) while the maximum water level depth fluctuation in response to rainfall were also observed (Table 1).

Table 5 - Time lags (days) for an autocorrelation coefficient of r=0 corresponding to the maximum and minimum rainfall events

| | BH7 | | | BH6 | |
|---|---|---|---|---|---|
| | i | ii | iii | ii | iii |
| 01/05-01/08 (days) | 14 | 19 | >30 | >30 | >30 |
| 13/10-30/11 (days) | 6 | 6 | 5 | 6 | 5 |
| Peak rainfall to peak water level rise (days) | 8 | 8 | 7 | 8 | 7 |

Autocorrelation analysis of the piezometric head data (for r=0), carried out representing the maximum and lowest rainfall occurrences of the monitoring period, was resulted as shown in Table 2

The data analysis results suggest that the weathered bedrock holds a confined aquifer with a considerable amount of connectivity over the 30m distance separating the BH6 and BH7. It was evident to have limited effect on the slope stability.

The vertical drainage has failed due to the very low interconnectivity among thesoil strata.

The rainfall infiltration is slow due to impermeable soil conditions. However the precipitated water ultimately seeps into the soil matrix and the aquifers within the soil mass get recharged by rainfall.

The slowly infiltrated water was found to be containedwithin the soil mass over the monitored time period in considerable amounts. Rainfall infiltration shows its full impact only after several days. Thus, increasing the surface protection methods could reduce the water seepage into the overburden.

## 3.2 Stability Analysis

The initial FOS was 0.965. The FOS when the water level is drawn down to the slip surface was 1.174. The FOS achieved through lowering the water table by 5m and incorporating the effect of matrix suction, may generally vary from 1.062 to 1.206 (Table 3) depending on the efficiency of the water table drawdown using the chosen mitigation method.

| Horizontal Drains | |
|---|---|
| Material | PVC tube |
| Length | 35m |
| Inclination | 10~ |
| Depth of installation | At road level |
| Drain spacing | 5m |
| **Vertical holes** | |
| Material | Sand/Gravel |
| Clay fill capped | 100cm |

## 3.2. Mitigation method

Horizontal drainage was considered as the mitigation method to stabilize the site. There are number of studies related to horizontal drainage, their applicability, effectiveness and feasibility for different slope stability cases with varying characteristics including Martin et. al (1994) and Raharjo and Leong (2002) which were adopted to decide on suitable design parameters for the drainage system. A 5m depth water drop is expected to be achieved through a horizontal drain network in conjunction with a series of sand and gravel filled vertical holes capped with 100cm thick clay layer having the following design parameters proposed based on the site conditions (Table 4 and Figure 3).

Table 3: The proposed design parameters for the mitigation

| $\Phi_b$ | Matrix suction | Achievable FOS |
|---|---|---|
| $\Phi_b=0.5\Phi'$ | 20kPa | 1.062 |
| | 30kPa | 1.092 |
| | 40kPa | 1.117 |
| | 50kPa | 1.143 |
| | 75kPa | 1.206 |
| $\Phi_b=\Phi'$ | 20kPa | 1.126 |
| | 30kPa | 1.179 |
| | 35kPa | 1.206 |

## 4. Conclusions

Introducing a horizontal drain system in conjunction with aseries of sand and gravel filled vertical holes could increase the FOS to a satisfactory level.The stability of the total landslide could be further increased by introducing additionalsurface drains to the upper regions of the slope.

## 5. Recommendations

More reliable data from longer monitoring periodsmay help in recommending a more suitable mitigation method.Stability of the slope in question was found entirely based on hydrological data.


Figure 2: Proposed Design horizontal drain network in conjunction with a series of sand and gravel filled vertical holes capped with 100cm thick clay laver

Landslide monitoring data from extensometers and inclinometers

should also be incorporated along with realistic matrix suction values to obtain a more realistic stability analysis.

## Acknowledgments

Authors wish to express their sincere gratitude to the academic and non-academic staff of the Department of Earth Resources Engineering, University of Moratuwa for their guidance and support, Dr.AsiriKarunawardane, Director General of NBRO and Mr. R.M.S Bandara, Head/Director, LRRMD, NBRO for granting permission and sharing data for the research study. Special thanks should go to Mr. N. I. C. Pieris, the officer-in-charge of NBRO regional office, Kandy and its staff for their valuable contribution to the research work.

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