# Soil Nail Wall Design Optimization by Geotechnical Applications and Geophysical Techniques

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**Abstract**: Soil nailing is a soil reinforcement technique which is used to stabilize slopes by insertion of slender elements, called nails. When steep slopes are to be stabilized by soil nailing, practical problems are encountered related to subsurface investigations, as drilling machines cannot be placed on such slopes. Hence, bedrock levels cannot be determined in advance, which is disadvantageous to produce cost effective designs. This research was focused on studying the methods that can be used for soil nail wall design optimization by applying geotechnical and geophysical techniques. The study was based on an unstable slope situated near Victoria dam. The physical properties of soil were determined by direct shear tests, and stability analysis was done by means of "Slope-W" software. Determination of the profile of weathered quartzite layer, inter-beded with Charnokite bands was the major emphasis of this research. Three techniques were used: Ground Penetration Radar (GPR), Earth Resistivity Measurements and Geological Mapping. This investigation scientifically showed that the existing slope is unstable, and to be protected. Further, it was identified in advance that the basement rock cannot be encountered at designed depths of the soil nails, which was subcequently proven as correct by the ongoing drilling for soil nail installations.

**Keywords:** Geological Mapping, Ground Penetration Radar, Resistivity Survey, Soil Nailing, Slope Stability Analysis

## 1. Introduction

Soil nailing is a technique in which soil slopes, excavations or retaining walls are passively reinforced by insertion of relatively slender elements, normally steel reinforcing bars [1]. The introduction of soil nailing techniques to Sri Lanka has taken place in the late 1990s and has been subsequently adapted to the local conditions [2]. Soil nail walls can be considered as retaining structures for any permanent or temporary vertical or near-vertical cut construction, as they add stabilizing resistance in situations where other retaining structures such as anchor walls are commonly used and where ground conditions are suitable [3 and 4].

Although soil nailing is generally considered as a cost effective technique in the world, the cost effectiveness has not yet been achieved in most of the soil nailing applications in Sri Lanka. Due to lack of information on ground profiles and thickness of soil layers, the required soil nail lengths cannot be determined in advance, in most of the steep slopes. Without proper information on the depth at which the fresh rock is encountered, a cost effective soil nail wall design cannot be finalized.

When fresh rock strata is encountered, soil nails could be terminated after advancing at least 3.5 m into the in-situ rock, and confirming that it is not a boulder. Hence, the information on bed rock profile is advantageous to optimize the soil nail wall designs [5, 6 and 7].

### 1.1 Study Area

This study is based on an unstable slope that is to be stabilized using soil nailing techniques, which is situated near Victoria dam. The main observation gallery of the Victoria dam is situated on top of this slope, and the site map is given in Figure 1. At this location, a weathered Quartzite layer and a Charnokite layer are present. Here, the slope that is to be protected by soil nailing is very much steep, and hence a drilling machine cannot be mobilized to get the required information. However, the basically required subsurface information have been gathered by advancing three boreholes at the top of the slope and near the observation building up to which the drilling machines could be mobilized.

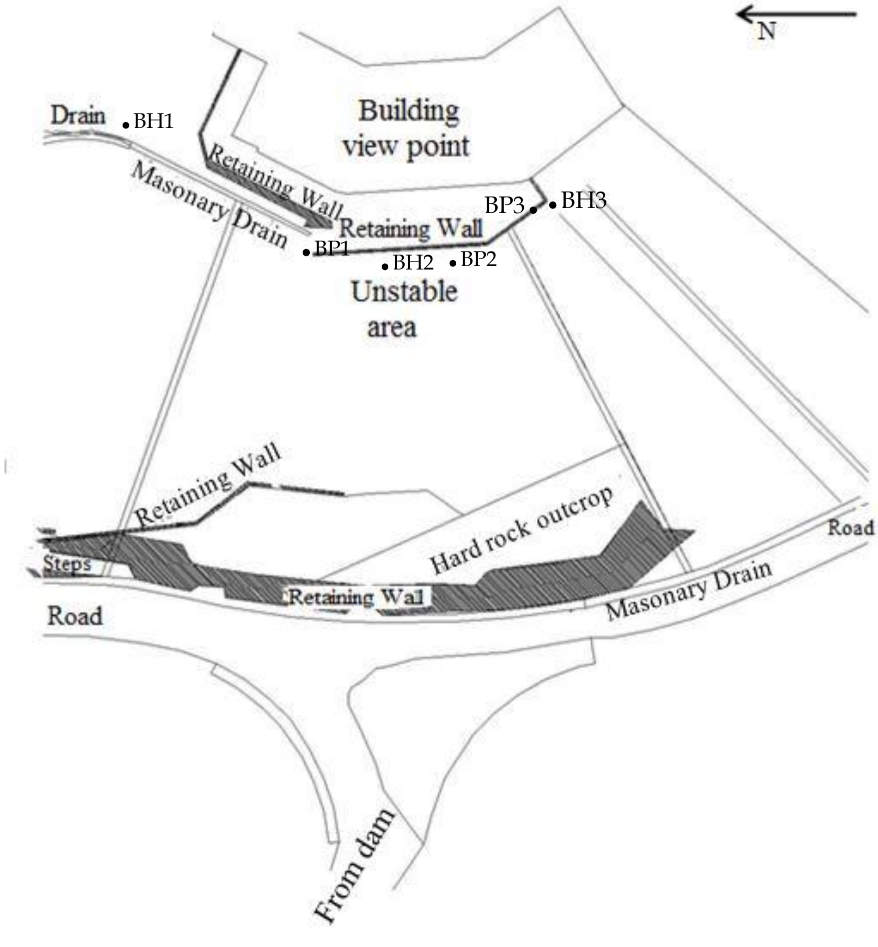


Figure 1 : Site map (Not to scale)

## 2. Methodology

### 2.1 Preliminary investigations

Identification of the site conditions was the first step of the project. The background information on the technical aspects of soil nailing were gathered through a literature survey. Further details were gathered using available topographical and geological maps, interpretations from contour survey and borehole investigations that had already been conducted by ELS Pvt. Ltd. The borehole locations BH1 to BH3 are illustrated in Figure 1.

### 2.2 Determination of physical properties of soil

Physical properties of soil at the site were determined by performing direct shear tests, on the undisturbed soil samples which were collected from the site.

### 2.3 Stability analysis

A few steepest slopes were selected and cross sections of the slopes were drawn. Slope stability analysis was carried out, assuming saturated conditions for the selected cross sections, and probable slip surfaces for each cross section were identified by means of "Slope/W" software analysis.

### 2.4 GPR surveys

GPR surveys were conducted on top of the slope as well as down the slope targeting interpretation of the bedrock levels. The reflected signal profiles were recorded for analysis of subsurface geology.

### 2.5 Earth resistivity surveys

Three resistivity surveys were carried out on top of the slope. Co-ordinates of the centre points are summerized in Table 1, and these locations are also given in Figure 1. Vertical Electrical Sounding (VES) method was utilized and the survey was carried out as per Shlumberger configuration of electrodes.

Table 1 : Resistivity Survey Locations

| | Base Point | X coordinate (m) | Y coordinate (m) |
|---|---|---|---|
| Survey 1 | BP1 | 476562 | 800520 |
| Survey 2 | BP2 | 476560 | 800506 |
| Survey 3 | BP3 | 476571 | 800491 |

The readings were interpreted using iX1D (Inteprex 1D) software, and the resistivity of subsurface layers along with the thickness of each layer were determined.

### 2.6 Geological mapping

Detailed geological mapping was carried out on this site using GPS.

The site map was georeferenced using ArcGIS with three known coordinates of the borehole locations.

As the general geological trend is into same direction, one cross section was selected in the middle of the slope joining two recorded points.

## 3. Results and Discussion

### 3.1 Physical properties of soil

According to the laboratory tests which were carried out, the following results were gathered on the physical properties of top soil layer.

Cohesion (c) = 14.66 kPa
Angle of Friction ($\phi$) = $45.9^0$
Bulk density ($\gamma$) = 1.612 g/cm$^3$

### 3.2 Stability analysis results

According to the "Slope/W" software analysis, under saturated conditions, a slip surface of the slope was identified as shown in Figure 2, with a factor of safety (FOS) = 1.21. (R= Radius of the failure slope)

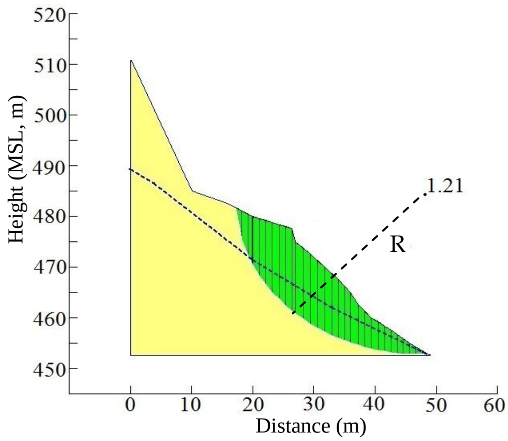


Figure 2 : Identified slip surface

### 3.3 GPR survey results

The depth of penetration of the GPR instrument was not sufficient to identify rock formation at any location of the GPR survey. However, the boundary between top soil layer and in-situ soil layer was identified by using GPR survey results.

### 3.4 Resistivity survey results

Table 2 : Results at BP1

| Layer No | Resistivity (Ωm) | Thickness(m) | Depth(m) |
|---|---|---|---|
| 1 | 984.05 | 0.93579 | 0.93579 |
| 2 | 585.97 | 8.1562 | 9.0920 |
| 3 | 58011.00 | - | - |

The depth to the bed rock level at Location BP1 was interpreted as 9 m.

Table 3 : Results at BP2

| Layer No | Resistivity (Ωm) | Thickness(m) | Depth(m) |
|---|---|---|---|
| 1 | 1.4520 | 0.26642 | 0.25542 |
| 2 | 3.3862 | - | - |

The resistivity values of both layers were too low, hence could not be taken to identify the depth to the bedrock at Location BP2.

Table 4 : Results at BP3

| Layer No | Resistivity (Ωm) | Thickness(m) | Depth(m) |
|---|---|---|---|
| 1 | 372.79 | 1.3736 | 1.3736 |
| 2 | 66.461 | 3.6877 | 5.0612 |
| 3 | 403.95 | - | - |

The depth to the bed rock level at Location BP3 was interpreted as 5 m.

### 3.5 Geological cross section

Geological cross section shows that the slope concerned is on a dip slope, having steep dip angle. The ridge area is mostly covered with quartzite but there are few interbeded Charnokite layers. (Figure 3)

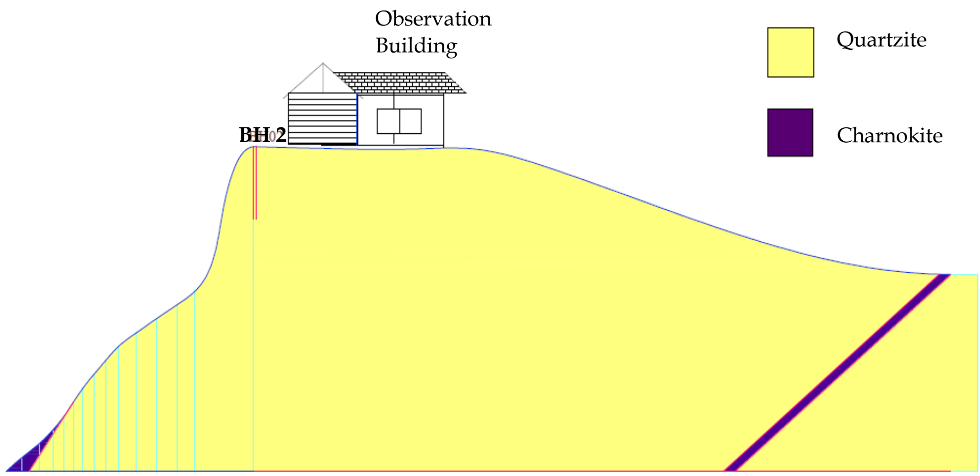


Figure 3: Geological cross section across the slope ( Scale = 1 : 1500)

## 4. Conclusions

Based on the research outcomes of this study, following conclusions can be made:

- The slip surface was identified to be at an intermediate height, with a factor of safety of 1.21, under wet conditions. Although it is greater than one, it cannot be concluded as the slope is stable. Also, the cracks on the building floor and minor landslides which have already taken place recently prove that the slope needs to be stabilized
- The area is mainly comprised of quartzite with thin bands of Charnokite. Information gathered from borehole investigations have not been sufficient to clearly identify basement rock.
- Charnokite rock will not be encountered from any of the drill holes which will be drilled for installation of soil nails.
- Eventhough fresh quartzite layer could be interpreted based on borehole data, termination of soil nails in the same strata cannot be recommended, as the rock strength is low and would not be able to bear the design load of the soil nails.
- The soil nail design optimization could be achieved by integrating data from geological mapping, conduct of GPR survey and advancing a minimum number of boreholes on a slope proposed to be protected by soil nailing.

## 5. Recommendations

As per the findings of this research, the following subsurface investigation steps could be recommended to optimize a soil nail wall design and project management of the construction:

(a) A desk Study

(b) Reconnaissance survey followed by a geological mapping across the slope which is to be stabilized and the associated area.

(c) A GPR survey down the slope and also laterally along the berms, in order to precisely interpret the basement rocks and boulders

(d) A minimum number of borehole investigations based on results from (a) – (c), and also comprised of inclined drill holes

(e) Testing of undisturbed soil samples to determine design parameters: c , $\phi$ and $\gamma$ values

(f) Stability analysis and soil nail design by a suitable software followed by design optimization by means of findings from step (c)

## Acknowledgements

The authors are thankful to Eng. S. R. K. Aruppola (Project Director – DSWRP Project) of Mahaweli Authority and Eng. E. M. S. Bandara (Chief Engineer, Victoria Dam Site), Eng. W. A. A. W. Bandara, Director of ELS Pvt. Ltd for providing necessary data and laboratory facilities free of charge, Eng. Tiran Jayasinghe, (Material Engineer) of ELS Pvt. Ltd, for helping with laboratory testing of soils, Access Engineering PLC along with Eng. B.H.T.P. Peiris for providing GPR instrument and helping with our field work, academic and non-academic staff of the Department of Earth Resources Engineering, University of Moratuwa, for their guidance and support, especially to Mr. P. R. D. C. Fernando (Systems Analyst), Mrs. P. R. Dissanayaka (technical officer) and Mr. S. D. Sumith (Laboratory attendant) for their assistance during the field visits, and all the other individuals and organizations who contributed for the successful completion of this research project.

## References

[1] Prashant, A. and Mukherjee, M. (2010) Soil nailing for stabilization of steep slopes near railway tracks

[2] Kulathilaka, S. A. S. and Mettananda, D. C. A. (2005) Use of soil nailing technique for stabilization of slopes, Geotechnical Journal, 3(1) : 17-19

[3] Ortigao, J. A. R., Palmeira, E. M. and Zirlis, A. C. (1995) Experience with soil nailing in Brazil : 1970 -1994, Geotechnical Engineering Advisory Panel Paper 10584 : 93 – 106

[4] Sivakumar Babu, G. L. (2009) Case studies in soil nailing

[5] John, P. T. and Wayne, G. J. (2005) Landslide stabilization using soil nail and Mechanically stabilized Earth walls: case study, Journal of geotechnical and geoenvironmental engineering ASCE : 141-150

[6] Thompson, S. R. and Miller, I. R. (1990) Design, construction and performance of a soil nailed wall in Seattle, Washington. Geotechnical publication No. 25, 1990 : 629 – 643

[7] Turner, J. P. and Jensen, W. G. (2001) Performance of soil nail and MSE wall for stabilization of the Elbow fill slide. Fedaral Highway Administration and Wyoming Department of Transportation, Wyo.