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SUBSURFACE CHARACTERIZATION FOR SLOPE STABILITY STUDY USING VERTICAL ELECTRICAL SOUNDING METHOD: A CASE STUDY

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Abstract

Vertical Electrical Sounding (VES) technique employing the Schlumberger depth sounding method was applied to investigate the subsurface characterization at Merhülietsa colony, Kohima. The interpretation shows differing lithology consisting of sandstone or shale with sandstone intercalation, fresh and fractured shales. Four geo-electric layers, comprising of the topsoil followed by alternate layers of weathered and fractured rocks is delineated by the sounding curves result. The analysis also confirms the presence of groundwater aquifer, which may be responsible for the accelerated weathering of the country rocks. The results obtained by this method confirms well with the available borehole data.

Keywords: Groundwater, Merhülietsa, Subsurface, Vertical Electrical Sounding (VES).

Introduction

Kohima town, which is located in the southern part of Nagaland state, hosts several major offices and institutions. It also facilitates as the main artery for the state of Manipur and several other towns, as the Trans-Asian Highway, AH 1, and National Highway, NH 2 pass through this town. Normal life for the people of this town is regularly disrupted due to frequent incidences of land instabilities. Some factors contributing to these are its geological setting and seasonal rainfall. Geologically, almost the entire region of Kohima town is dominated by the Tertiary Disang Group of rocks, consisting predominantly of shale with some siltstones and sandstones. The rocks are found to be folded, faulted, sheared, jointed, highly crumpled, crushed, and partially to completely weathered in many areas of the town [1-4]. The rock exposures are dark grey in color and splintery in nature and are found to be weathered to clay in many areas of the town and their interaction with water is responsible for several slope instabilities in the town [5-9]. The region receives copious amount of rainfall during the monsoon season, another factor that contributes to weathering of the rock mass, and the interaction of these weak rocks with water is one of the major factors that are responsible for slope failures in the town [10-13].

During the monsoon season, the town receives heavy rainfall, and the average rainfall recorded for the last 5 years (2019-2023) between the months of May to August ranges from 1000 mm to 1800 mm (Source: Department of Soil and Water conservation, Kohima, Nagaland). Continuous heavy rainfall and conditions of the slope materials are some of the factors that mainly contribute to the mass movements, as this facilitates easy infiltration of water into the weak rocks, leading to an increase of the groundwater table, and consequently saturating the weak

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materials, allowing a conducive condition for slope failures [14-17]. Weathered shales which has become clay-rich soil with very low shear strength, especially when saturated with water are often considered an important factor in the occurrence of landslides [18]. Shale and mudstone with minor beds of sandstone intercalation are also observed to be more prone to partial or total weathering of the rock mass. As a result of saturation, besides increasing in pore water pressure, the weight of the weathered materials also increases, thereby disturbing the balance of the slopes and causing instability [19-24].

Various methods were employed by several past workers for case studies related to landslides in and around Kohima town, to determine the influence of geology on the occurrence of landslides. Slope classification maps of Kohima town and its geotechnical reports were prepared by Sharda and Bhambay [25], significant information was also generated for landslide hazard zonation maps by researchers for this town [25-26].

One area within Kohima town that is often troubled by landslides is Merhülietsa colony. It is part of the Survey of India topographic sheet number 83K/2, and lies between 25°39'53" to 25°39'56" North latitudes and 94°05'41" to 94°05'45" East longitudes (Fig.1).

The use of the geo-electric method to investigate the subsurface lithology helps in the characterizations of the subsurface materials for slope stability study [27-34]. Hence, this study aims to evaluate the cause of land instabilities by identifying the inherent subsurface condition of the slope materials.

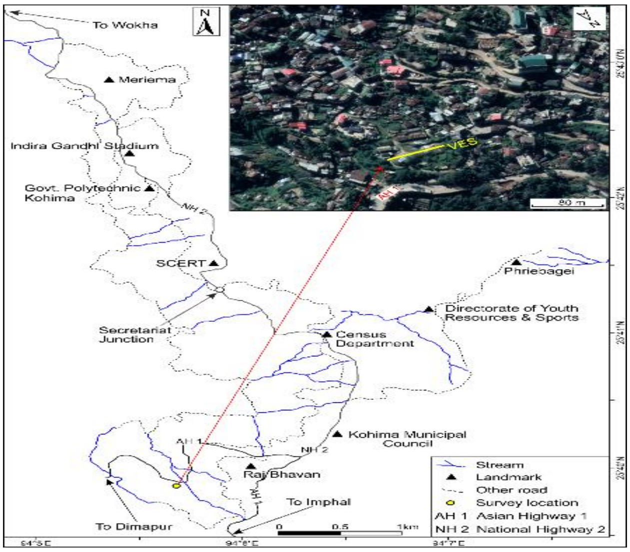

Fig. 1: Location map of the study area

Lithology of the study area

The study area is dominated by shales that are black, buff and greyish in colour, with interbedding of brown to reddish brown sandstone and minor siltstones. The exposed rocks are crumpled, weathered, jointed and fractured. Field photographs showing the exposed fractured and weathered shales are given in Fig. 2.

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Fig. 2: Rock exposures showing fractured and weathered shales.

Materials and methods

For assessing the subsurface conditions, Vertical Electrical Sounding (VES), which is based on the method of resistivity variations with depth was used [35-39]. This method is based on the estimation of the electrical resistivity of the medium, by a transmitting direct current that is induced artificially inside the ground using a pair of electrodes. This gives a measure of the electric potential between another pair of electrodes. The apparent resistivity (ρ_a) of geologic formation with depth thus is given as [40]:

$\rho_a = K\frac{\delta V}{I}$, where $K = \frac{\pi}{2}[(L/I)^2 - 1]$ is the geometrical spacing factor. (1)

Here, centre of the electrode is kept fixed and measurements are taken for various values of expanding current electrode. The current (I) is introduced between one pair of the current electrodes, say, A and B and the potential difference (δV) produced as a result of the current flow is measured with the help of the potential electrodes, say, M and N, with all four electrodes kept in a line (Fig. 3). Schlumberger configuration, which is employed for the present study follows the electrode spacing, $AB/2 \geq 5\ MN/2$ and this configuration gives a good resistivity contrast between the saturated and unsaturated layers for analysing the subsurface condition [41].

The four basic categories for subsurface layers with resistivity $\rho 1$, $\rho 2$, and $\rho 3$, with $\rho 1$ at the top followed by $\rho 2$ and $\rho 3$ is used for the analysis and is given by:

$\rho 1 < \rho 2 < \rho 3$: A-type

$\rho 1 < \rho 2 > \rho 3$: K-type

$\rho 1 > \rho 2 < \rho 3$: H-type

$\rho 1 > \rho 2 > \rho 3$: Q-type

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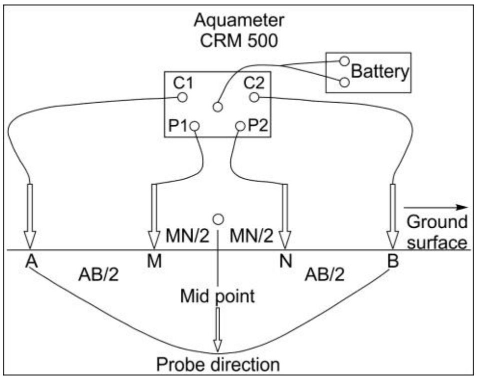

Fig. 3: Schematic diagram for the Schlumberger array.

A computerized resistivity meter, Aquameter CRM 500 was used for the field resistivity data, The apparent resistivity values were computed using equation (1) and the field data was interpreted using the iterative resistivity sounding interpretation software IPI2win [42-43]. The geographical co-ordinates of the VES and the borehole location selected along the colony to collect the field data is given in Table 1, the data obtained is then analysed for determining the resistivity layers.

Table 1: Geographical co-ordinates for the study area and borehole location

Location	**Geographical co-ordinates**	**Borehole Location**	**Geographical co-ordinates**
Merhülietsa (VES)	N 25°39'52.8" E 94°05'41.0"	Merhülietsa (BH)	N 25°39'50.28" E 94°05'41.20"

Results and discussion

Sounding curves of the types KH delineate to show four layers for the VES survey locations (Fig. 4). KH type show resistivity of the type ρ1 < ρ2 > ρ3 < ρ4. The thickness of the topsoil is 1.06 m with a resistivity value 51.8 Ωm, followed by a more compact rock layer comprising of sandstone or shale with sandstone intercalations with resistivity value 559 Ωm. The third layer indicates the presence of fractured shale/groundwater having resistivity value 1.02 Ωm with thickness of 2.96 m, followed by the region with fresh shale at greater depth (Table 2).

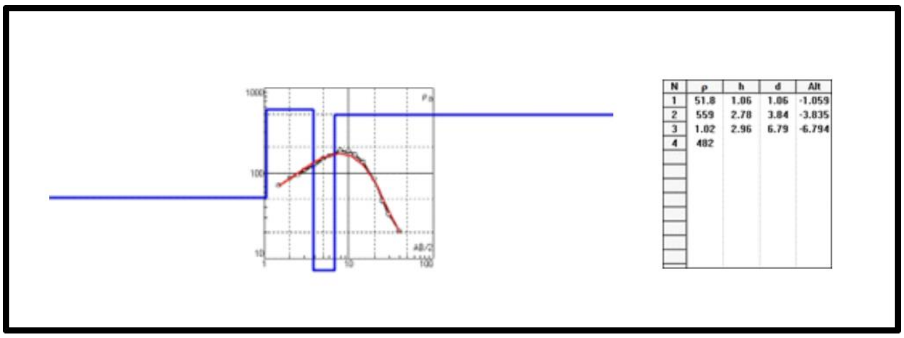

Fig. 4: VES Field curve

Table 2: Layer parameters for the VES

VES Station	Resistivity (Ωm)	Thickness h (m)	Depth d (m)	Inferred Lithology	Curve type
Merhülietsa	ρ1= 51.8	h1= 1.06	d1= 1.06	Topsoil/ weathered shale exposure	ρ1 < ρ2 > ρ3 < ρ4 **KH**
	ρ2= 559	h2= 2.78	d2= 3.84	Sandstone/ shale with sandstone intercalation	
	ρ3= 1.02	h3= 2.96	d3= 6.79	Groundwater	
	ρ4= 482	-	-	Fresh shale/ sandstone	

The VES results have confirmed the presence of viable aquifers at 6 m (approx). Besides generating pore pressure to build up on the slopes, these aquifers may be responsible for the weathering process of the country rocks. When there is continuous and heavy precipitation during the monsoon season, landslides on the slopes are usually seen and soils that are saturated tend to mobilize as debris flows. Shales, considered as weak rocks are easily weathered and weakened further, allows the slope to degrade further [44-46]. The analysis also confirms the presence of weathered and fractured shales, which can be another important factor for the slope instabilities. The presence of these weak rocks and aquifers are in consonance with available borehole data and were field-confirmed (Fig. 5).

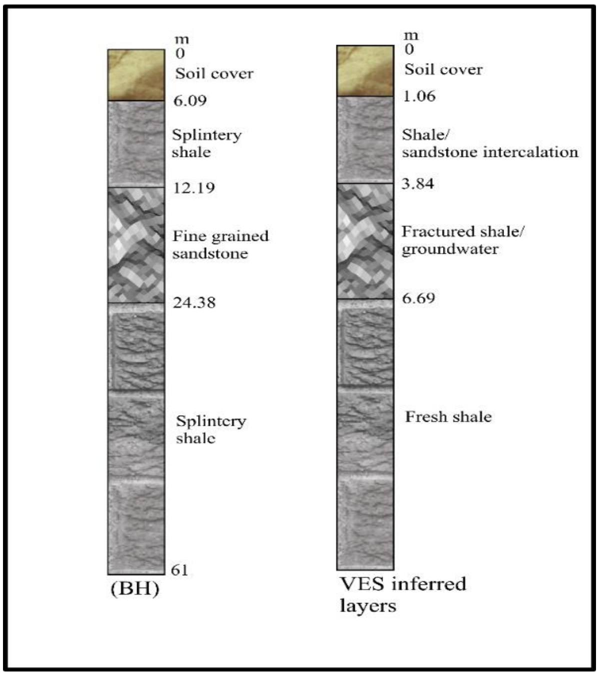

Fig. 5: Lithologic correlation of borehole (BH) and VES-inferred layers (Source for borehole data: Directorate of Geology and Mining, Dimapur, Nagaland)

Conclusion

Resistivity survey, utilizing the VES method and employing the Schlumberger configuration, was carried out at Merhülietsa colony, Kohima. The survey was conducted to determine the inherent subsurface condition of the slope materials and to analyse the cause of surface instabilities in the study area. Results of the study points to the presence of weathered and fractured rocks and are in consonance with local geology derived from available borehole data. The results also confirmed the presence of viable aquifers, which can accelerate weathering of the already weak subsurface materials. Thus, the resistivity survey provided valuable information about the subsurface conditions that might have caused the occurrence of landslides in the study area, and the results obtained may be used for future landslide investigations.

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