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The Utilisation of Electrical Resistivity Imaging (ERI) for Geological Structures Mapping in Rock Mass: A Review

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Abstract. Electrical Resistivity Imaging (ERI) is an in-situ geophysical method widely used in environmental, engineering and hydrogeological explorations due to cost, time, and data coverage efficiency. Traditionally, geotechnical parameters such as discontinuities properties are obtained from rock samples acquired from a borehole. However, it only provides a single information point, costly and time-consuming. Thus, an approach using electrical resistivity to detect the presence of geological structure in a rock mass is an alternative method that can be applied. Discontinuities in rock mass include joints, bedding planes, blasting cracks, fractures, faults, and folds. This paper aims to present the utilisation of geoelectrical resistivity imaging for geological structures mapping in rock mass based on the review from previous research. The Electrical Resistivity Imaging (ERI) method is an effective tool to obtain structural differentiation of geological medium by interpreting 2D and even 3D electrical resistivity models. Electrical Resistivity Imaging (ERI) is an automated data acquisition system, inversion codes, non-invasive and user-friendly. The raw data received from data acquisition was analysed using Res2DINV software. The data inversion was done by applying the robust method and finite element grid to accommodate the steep topography. The data interpretation included numerical modelling to assess the suitability of all used electrode arrays in relation to the geological setting.

1. Introduction

Geological structures are formed from the tectonic forces within the earth's crust. These forces can fold and breaks rocks, create deep faults and build mountains. Geophysical surveys have become increasingly popular for detecting structural geology, especially in engineering and environmental studies. Ammar & Kamal [1] demonstrated that geophysical characterisation could help understand the present subsurface profile and expected structures.

According to [2], the stability and behaviour of both natural and manufactured rock slopes depend critically on geological structures like folds, faults, and discontinuities. The primary geotechnical factor in classifying rock mass quality is the rock quality designation (RQD) [3]. In general, RQD measures the general stability in the engineering rock mass. A severe challenge in geotechnical investigations is determining the quality of the rock mass because of the natural heterogeneity and the lack of data. Typically, these surveys mostly rely on standard drilling tests. However, such tests are time- and money-consuming, only provide point measurements, cannot be carried out in steep topography locations, and as a result, introduce uncertainties into the geological model [4]. Thus, both non-intrusive and cost-effective methods are reliable to decrease the need for costly drilling experiments to accurately establish the geomechanical factors that will determine whether or not built structures are successful.

The geophysical method is widely known for its low cost, economical, fast, extensive data coverage, and easy tools [5-6]. According to [7], the electrical resistivity method has improved its survey coverage,

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field measurement, processing techniques, and data collection for a subsurface profile. Besides that, the geophysical method is also used due to its non-invasive and non-destructive technologies, affordable price, rapid result, and compatibility with various materials in the subsurface [8]. The electrical resistivity method is widely used worldwide due to its non-invasive method and ability to cover extensive data [9] quickly. The electrical resistivity method is one of the in-situ geophysical methods that can measure physical features associated with lithological, hydrological, and geotechnical directly or indirectly [10]. The electrical resistivity method can also detect the contact between the sediment and bedrock in a fluvial system [11] and the thickness of bedrock in sedimentary layers [12]. Thus, this non-invasive method can provide a well-defined boundary and the estimation of sediment that covers bedrock.

2. Basic Theory of Resistivity Method

The electrical resistivity method is one of the most popular geophysical methods. This method investigates the subsurface condition by measuring the ground surface [13]. Ohm's law defines the relationship between electrical resistivity, current, and electrical potential. The equation for Ohm's law in vector form for current flow in a continuous medium is given by:

$$J = \sigma E \quad (1.1)$$

Where J is the current density, σ is the conductivity of the medium, and E is the electric field intensity. The potential on the surface or within the material can be determined if the resistivity distribution is known.

In practice, the measuring element is the electric field potential. Thus, in geophysical surveys the medium resistivity ρ, which equals to the reciprocal of conductivity ($\rho = 1/\sigma$), is more commonly used. So, the relationship between the electric potential and the field intensity is given by:

$$E = -\nabla\Phi \quad (1.2)$$

Thus, by combining equations (1.1) and (1.2);

$$J = -\sigma\nabla\Phi \quad (1.3)$$

For most all surveys, the current sources are presented in point sources. Thus, an elemental volume ΔV surrounding the current source *I*, and the relationship between the current density and the current is given by;

$$\nabla J = \left(\frac{I}{\Delta V}\right) \delta (x - x_s)\, \delta (y - y_s)\, \delta (z - z_s) \quad (1.4)$$

δ is the Dirac delta function. Thus, the equation can be written as;

$$-\nabla \bullet [\sigma(x,y,z)\, \nabla\Phi\, (x,y,z)] = \left(\frac{I}{\Delta V}\right) \delta (x - x_s)\, \delta (y - y_s)\, \delta (z - z_s) \quad (1.5)$$

This is the basic equation for potential distribution in the ground due to the point's current source. However, there have been many equations developed to solve the problems. Based on [13], the linear filter method is used for 1D cases, restricted to several horizontal layers, while for 2-D and 3-D cases, finite-difference and finite-element methods are used. Ohm's law also allows for the measurement of apparent resistance in a heterogeneous geological environment considering the geometric factor (K)

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between the two pairs of electrodes used to acquire the data. Thus, it is possible to determine the geological structures in the subsurface [13]. Figure 1 shows the schematic diagram for measuring a multi-electrode system to create a 2D pseudo section model.

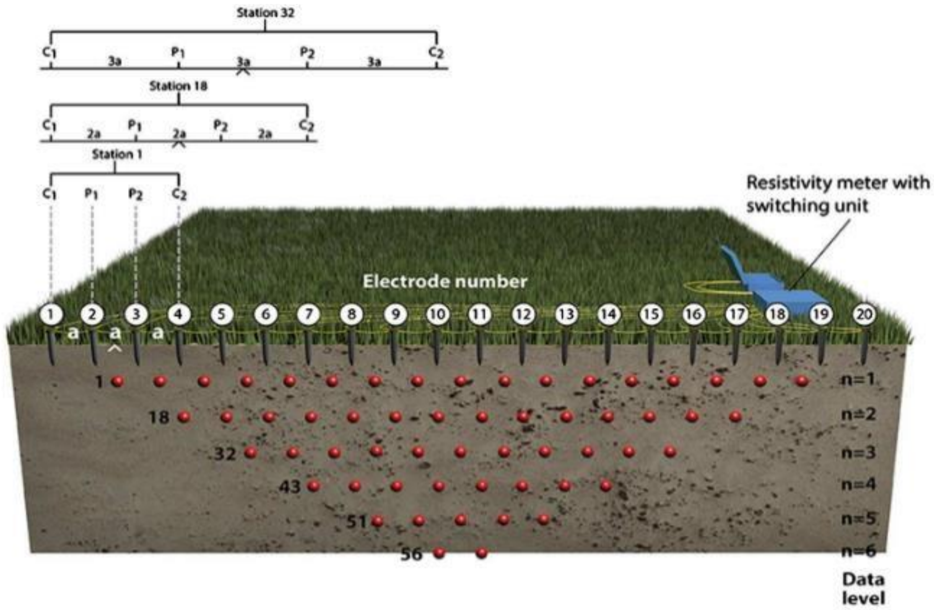

Figure 1. The schematic diagram for a multi-electrode system and possible sequence of measurements to create a 2D pseudo section [13].

3. The Geological Structures in Rock Mass

Based on [14], the discontinuities characteristics influence the rock mass behaviour and control rock mass stability, depending on their orientations. According to [15], rock mass stability depends on weathering degree, mineralogical composition, rock association, faults, fractures, rock deformation, and water infiltration. A recent study by [16] stated that rock mass classification is one of the most well-known empirical classifications for rock engineering, which is evaluated based on the crucial parameters that quantitatively describe the rock mass condition.

Discontinuities in rock mass include joints, bedding planes, blasting cracks, fractures, faults, folds, and other structural features. One of the stabilities of rock mass is weathering effect. Weathering rock masses can result in the breaking of intact rock, the fragmentation of larger blocks of intact material into smaller fragments, and the formation of infill material in discontinuities. Besides that, discontinuity also is a common feature in the rock mass. According to [17], factors such as orientation, spacing, persistence, aperture, surface roughness, and the presence of infill materials are the most important in discontinuity.

4. Electrical Resistivity Imaging in Geological Structure Mapping

One of the oldest and most often utilised geophysical exploration methods is the electrical resistivity survey, commonly used in environmental and engineering studies [13]. Based on [18], the efficiency of the resistivity method in geological mapping is primarily determined by the resistivity contrast caused by the formation of rock discontinuity or a change in its physical condition. [19] added that the electrical resistivity technique is based on subsurface geological materials with a wide range of resistance values. The resistivity measurements can be used to determine the geological boundaries.

Structural geology in the geoelectrical method can be identified using the combination of engineering and geophysical study. The subsurface engineering geophysical studies illustrate a set of non-destructive geophysical technologies for determining the underground's geological structure and physicalmechanical features [20]. Electrical resistivity imaging (ERI) also has a wide range of resistivity values which demonstrates a strong link between electrical resistivity and a subsurface layer of lithology, provides the required depth of study, and analyses the subsurface using 2D and 3D imaging [20].

In the study of [21], the electrical resistivity approach has shown that it can find a broken zone and determine its width, dip direction, and depth extent. The theory behind the resistivity approach is that broken rocks have lower electrical resistivity because they are more porous and contain more water than undisturbed host rock. The modelling's findings demonstrate that the 2D resistivity method can accurately predict the depth extent of the weakness zone, the dip direction, and the width of the area close to the surface. As a result, a key finding is that the resistivity approach may locate weak points in crystalline bedrock and characterise them geometrically and mineralogically.

In another study by [22], ERI also can examine and detect subsurface parameters and characteristics such as soil qualities, bedrock depth, and topography beneath unconsolidated material, rock type, layer boundaries, depth of water table, and the presence of weak zones and expansive clays. The combination of geophysical and geotechnical measurements may be integrated to determine the in-situ properties of the subsurface. Therefore, the variety of these methods mainly concentrates on how soils and rocks behave and perform throughout the planning and building of civil, environmental, and mining engineering projects. In addition, these methods are crucial for identifying structural trends, lithologic borders and contacts, faults, dipping formations, and other features in basement rocks, as well as for identifying dipping formations and disruption in rock units [23].

The electrical resistivity method can also identify the development of karst features [24] and in a folded and fractured carbonate bedrock resulting from high contrast between high resistivity values and low resistivity values [25]. Structural features such as folds, and faults, can influence rock mass behaviour and affect the orientations and degree of rock slopes, significantly impacting unstable rock mass's stability [26][27]. Based on [28], the electrical resistivity method can map the presence of structural geology in highly weathered volcanic rock such as faults, folds, and quartz veins.

A high-resolution electrical resistivity method also is valuable in establishing the presence of geological features and structures. Electrical resistivity is a popular method for cavity detection [28]. According to [29], this method is usually used to examine the weak zones in ground subsidence under buildings, and [30] used the electrical resistivity method to identify the subsurface information and various underground voids such as crypts, cellars, and caves. Thus, [31] stated that the electrical resistivity method is the most suitable approach for identifying the subsurface cavities structures.

5. Data Processing in Pseudo sections

Res2Dinv (Geotomo Software) has been chosen as a data processing and inversion software once it is widely available and trendy in geophysical studies [28]. This software is designed to interpolate and invert electrical geophysical prospecting field data according to the mathematical model of ordinary least squares (OLS). This technique is responsible for smoothing the extreme values using block modelling and reducing differences between the measured and modelled resistivity.

A 2-D model with many rectangular cells is often utilised to analyse the data [29]. The resistivity cell may vary in one vertical and horizontal direction, but their size and position remain constant. The resistivity that produced the recorded potential measurements is reverse calculated using inverse methods. An optimisation method is utilised to alter the resistivity of the model cells iteratively to minimise the gap between the measured and computed apparent resistivity values. Generally, the inversion problem includes incomplete, inconsistent, and noisy data. The resistivity models are presented as 2D coloured sections with resistivity in a chromatic scale range defined to analyse the results better and identify contrasts between different geological materials.

Block modelling generates a standard deviation parameter called the root-mean-squared (RMS) factor that mainly represents the match between the calculated pseudo section and that obtained in the field, influenced by extreme values in the input data potentials postprocessing. The local topography is inserted into the model to avoid possible distortions in the resulting cross-section. Figure 2 and Figure

3 show the sequence to build up the pseudo section and resistivity datum points on the pseudo section, respectively.

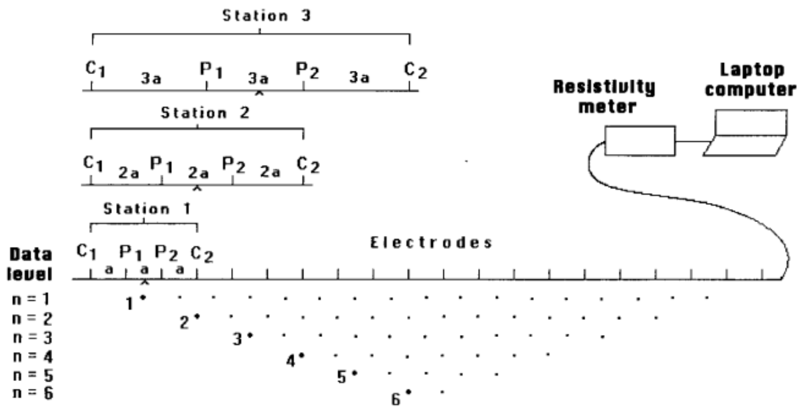

Figure 2. The sequence of measurements to build up pseudo section [29].

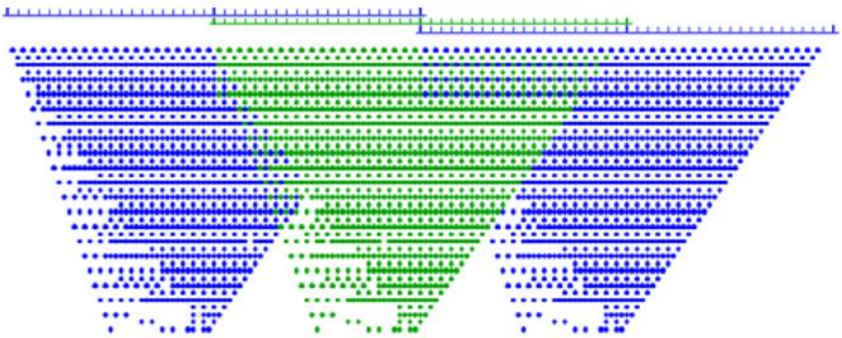

Figure 3. An example of 2D resistivity datum points to building up pseudo section [34].

6. Conclusion

To conclude, the study of electrical resistivity imaging (ERI) is widely applied, mainly in environmental and engineering studies. This review focuses on utilising electrical resistivity methods for geological structures mapping in rock mass. Geophysical methods are often used due to their low cost, fast data interpretation, and ease of handling. Compared to geotechnical techniques, they suffer drawbacks such as being costly and time-consuming and cannot be carried out in the steep topographic areas.

The geological structure can be identified based on the resistivity values data. A different contrast between high and low resistivity values can determine the structural features present. Thus, combining the geophysical method and geological mapping may be valuable in improving resistivity mapping [30]. In addition, the geological structure mapping offers better information regarding the earth's structures, such as the type of rocks, layers of investigate area, depth of bedrock, groundwater table, and the presence of structural geology in the study area.

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References

[1] Ammar, A. I., & Kamal, K. A. (2018). Resistivity method contribution in determining of fault zone and hydro-geophysical characteristics of carbonate aquifer, eastern desert, Egypt. *Applied Water Science*, **8**(1), 1–27.

[2] Stead, D., & Wolter, A. (2015). A critical review of rock slope failure mechanisms: The importance of structural geology. *Journal of Structural Geology*, **74**(December 2011), 1–23.

[3] Hasan, M., Shang, Y., Shao, P., Yi, X., & Meng, H. (2022). Geophysical Research on Rock Mass Quality Evaluation for Infrastructure Design. *Earth and Space Science*, **9**(1).

[4] Hasan, M., Shang, Y., Meng, H., Shao, P., & Yi, X. (2021). Application of electrical resistivity tomography (ERT) for rock mass quality evaluation. *Scientific Reports*, **11**(1), 1–19.

[5] Chambers, J. E., Kuras, O., Meldrum, P. I., Ogilvy, R. D., & Hollands, J. (2006). Electrical resistivity tomography applied to geologic, hydrogeologic, and engineering investigations at a former waste-disposal site. *Geophysics*, **71**(6), 231–239.

[6] Robinson, D. A., Binley, A., Crook, N., Day-Lewis, F. D., Ferre, T. P. A., Grauch, V. J. S., Knight, R., Knoll, M., Lakshmi, V., Nyquist, J., Pellerin, L., Singha, K., & Slater, L. (2008). Advancing process-based watershed hydrological research using near-surface geophysics: a vision for, and review of, electrical and magnetic geophysical methods. *Advancing PocessBased Watershed Hydrological Research*, **22**, 3604–3635.

[7] Hazreek, Z. A. M., Nizam, Z. M., Aziman, M., Md Dan, M. F., Shaylinda, M. Z. N., Faizal, T. B. M., Aishah, M. A. N., Ambak, K., Rosli, S., Rais, Y., Ashraf, M. I. M., & Alel, M. N. A. (2017). Mapping on Slope Seepage Problem using Electrical Resistivity Imaging (ERI). *Journal of Physics: Conference Series,* **995**(1).

[8] Lech, M., Skutnik, Z., Bajda, M., & Markowska-Lech, K. (2020). Applications of electrical resistivity surveys in solving selected geotechnical and environmental problems. *Applied Sciences (Switzerland)*, **10**(7), 1–19.

[9] Uhlemann, S., Chambers, J., Falck, W. E., Alonso, A. T., González, J. L. F., & de Gea, A. E. (2018). Applying electrical resistivity tomography in ornamental stone mining: Challenges and solutions. *Minerals*, **8**(11), 1–17.

[10] Perrone, A., Lapenna, V., & Piscitelli, S. (2014). Electrical resistivity tomography technique for landslide investigation: A review. *Earth-Science Reviews*, **135**, 65–82.

[11] Hsu, H. L., Yanites, B. J., Chen, C. chih, & Chen, Y. G. (2010). Bedrock detection using 2D electrical resistivity imaging along the Peikang River, central Taiwan. *Geomorphology*, **114**(3), 406–414.

[12] Jõeleht, A., Plado, J., & Sibul, I. (2017). Ground-penetrating radar and electrical resistivity tomography for mapping bedrock topography and fracture zones: a case study in ViruNigula, NE Estonia; pp. 142–151. *Estonian Journal of Earth Sciences*, **66**(3), 142–151.

[13] Loke, M. H., Chambers, J. E., Rucker, D. F., Kuras, O., & Wilkinson, P. B. (2013). Recent developments in the direct-current geoelectrical imaging method. *Journal of Applied Geophysics*, **95**, 135–156.

[14] Stead, D., & Wolter, A. (2015). A critical review of rock slope failure mechanisms: The importance of structural geology. *Journal of Structural Geology*, **74**(December 2011), 1–23.

[15] Elawadi, E., El-Qady, G., Salem, A., & Ushijima, K. (2001). Detection of cavities using pole-dipole resistivity technique. *Memoirs of the Faculty of Engineering, Kyushu University*, **61**(4), 101–112.

[16] Salmanfarsi, A. F., Awang, H., & Ali, M. I. (2020). Rock mass classification for rock slope stability assessment in Malaysia: A review. *IOP Conference Series: Materials Science and Engineering*, **712**(1).

[17] Tating, F., Hack, R., & Jetten, V. (2014). Weathering effects on discontinuity properties in sandstone in a tropical environment: case study at Kota Kinabalu, Sabah Malaysia. *Bulletin of Engineering Geology and the Environment*, **74**(2), 427–441.

[18] Verma, R. K., & Bandyopadhyay, T. K. (1983). Use of The Resistivity Method in Geological

Mapping-Case Histories From Raniganj Coalfield, India. *Geophysical Prospecting*, **31**(June 1982), 490–507
[19] Arjwech, R., & Everett, M. E. (2015). Application of 2D electrical resistivity tomography to engineering projects: Three case studies. *Songklanakarin Journal of Science and Technology*, **37**(6), 675–681.
[20] Kovacevic, M. S., Marcic, D., & Gazdek, M. (2013). Application of geophysical investigations in underground engineering. *Tehnicki Vjesnik*, **20**(6), 1111–1117.
[21] Rønning, J. S., Ganerød, G. V., Dalsegg, E., & Reiser, F. (2014). Resistivity mapping as a tool for identification and characterisation of weakness zones in crystalline bedrock: definition and testing of an interpretational model. *Bulletin of Engineering Geology and the Environment*, **73**(4), 1225–1244.
[22] Adebo, B., Layade, G., Otobrise, H., Ilugbo, S., & Hamzat, A. (2019). Mapping of Subsurface Geological Structures using Ground Magnetic and Electrical Resistivity Methods within Lead City University , Southwestern Mapping of Subsurface Geological Structures using Ground Magnetic and. *Kada Journal of Physics*, **2**(2).
[23] Ogundana, A. K., & Talabi, A. O. (2014). Geoelectric Characterisation of Aquiferous Units and its Implication on Groundwater Potential of Owo, Southwestern Nigeria. *American Journal of Water Resources*, **2**(2), 37–40.
[24] Chalikakis, K., Plagnes, V., Guerin, R., Valois, R., & Bosch, F. P. (2011). Contribution of geophysical methods to karst-system exploration: An overview. *Hydrogeology Journal*, **19**(6), 1169–1180.
[25] Waters, B., Doctor, D., & Maynard, J. (2018). Using Geophysics to Map Bedrock Faults, Dikes, and Surficial Geology in Relation to Karst Features in the Briery Branch Quadrangle, Rockingham County, Virginia. *15th Sinkhole Conference NCKRI Symposium 7*, 235–240.
[26] Stead, D., & Wolter, A. (2015). A critical review of rock slope failure mechanisms: The importance of structural geology. *Journal of Structural Geology*, **74**(December 2011), 1–23.
[27] Jacques Deparis, Denis Jongmans, Stephane Garambois, Clara Levy, Laurent Baillet, & Ombeline Meric. (2012). Geophysical detection and structural characterisation of discontinuities in rock slopes. *Rockfall Engineering, Wiley ISTE*, *1*(January), 1–38.
[28] Waters, B., Doctor, D., & Maynard, J. (2018). Using Geophysics to Map Bedrock Faults, Dikes, and Surficial Geology in Relation to Karst Features in the Briery Branch Quadrangle, Rockingham County, Virginia. *15th Sinkhole Conference NCKRI Symposium 7*, 235–240.
[29] Elawadi, E., El-Qady, G., Salem, A., & Ushijima, K. (2001). Detection of cavities using pole-dipole resistivity technique. *Memoirs of the Faculty of Engineering, Kyushu University*, **61**(4), 101–112.
[30] Putiška, R., Dostál, I., Kušnirák, D., & Nikolaj, M. (2012). Determination of cavities using electrical resistivity tomography. *Contributions to Geophysics and Geodesy*, **42**(2), 201–211.
[31] Doyoro, Y. G., Chang, P. Y., & Puntu, J. M. (2021). Uncertainty of the 2D resistivity survey on the subsurface cavities. *Applied Sciences (Switzerland)*, **11**(7).
[32] Mendoza, J. A., & Dahlin, T. (2008). Resistivity imaging in steep and weathered terrains. *Near Surface Geophysics*, **6**(2), 105–112.
[33] Loke, M. H., & Barker, R. D. (1995). Least-squares deconvolution of apparent resistivity pseudosections. *Geophysics*, **60**(6), 1682–1690.
[34] Nordiana, M. M., Rosli, S., Mokhtar, S. M., Nawawi, N. M. M., & Azwin, I. N. (2012). Imaging Subsurface Characterization at Bukit Bunuh Using 2D Resistivity Method: The Effectiveness of Enhancing Horizontal Resolution (EHR) Technique. *International Journal of Environmental Science and Development*, **3**(January), 569–573.