Preliminary result of electrical resistivity and electromagnetic methods to determine the bedrock

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Abstract. Infrastructure development such as buildings, especially in multi-story buildings, really requires strong foundation support. In the construction of a multi-story building, usually using a pile that is embedded into a zone that has a hard rock arrangement or bedrock to support the building above it. This is a challenge for multi-story buildings in areas of volcanic deposits or pyroclastic deposits. The rock layer below the surface in this area is dominated by less dense rocks such as tuff. This rock layer has more challenging when using for building foundations because it tends to be permeable, so a special method is needed to obtain information on hard rock or bedrock for building foundation needs. In other hand, the presence of weak zones, below the surface can cause sudden land subsidence which of course will damage the buildings on it. This study aims to determine the depth of the bedrock zone, in the pyroclastic deposit area using the integration of geophysical methods, resistivity and electromagnetic (EM) method. The resistivity method is more sensitive for areas that have large types of resistance or areas that are resistive, such as rocks that have low porosity and permeability such as igneous rocks. Meanwhile, the EM method is more sensitive in layers that have high porosity and permeability values or in conductive areas such as sediment layers. Nevertheless, the conductor layer is also influenced by the mineral content in the rock, so a good understanding of geology is needed in matching the data and conditions in the field. This is expected to be a reference in designing building structures, especially in pyroclastic deposit.

Keywords: Bedrock, EM, Groundwater, Resistivity, Conductivity

1. Introduction

Infrastructure development such as building is necessary to support economic growth. Therefore, infrastructure development is needed not only in terms of quantity but also in terms of quality. As in building construction, especially multi-story buildings, a strong foundation is needed. The building foundation is a part of walls, piers, and columns in direct contact to the ground and the one transmitting loads to the ground. The size and depth of the foundation is largely determined by the structure and size of the building as well as the nature of the soil bearing capacity that supports the foundation structure [1].

In the last decades geophysical method involvement in civil and environmental engineering has become a promising approach, unfortunately, questions about the quality of building foundations are often answered at a late stage when earthquake damage has occurred [2]. In the case of building construction, geophysics can be applied in order to provide useful information regarding early detection of potentially dangerous subsurface conditions. In this study we apply the electrical resistivity and electromagnetic method to study the characteristics of the subsurface as information for the depth of the building foundation.
Hard rock or bedrock is generally a watertight layer or impermeable. To get information about the rock layers, it can be done by direct drilling. This method certainly requires more costs and takes a long time. The different depths of the bedrock in an area are caused by complex soil layers or complex geological conditions. Geophysical methods have been widely used to determine bedrock such as using resistivity method [3,4] and electromagnetics method [5]. The electrical resistivity and electromagnetics method can measure variation of the resistivity or conductivity of the rock or material including bedrock. The resistivity and conductivity values of rocks can vary depending on geology such as minerals contained in rocks, fluids, porosity and degree of air saturation in rocks [6].

Electrical resistivity and electromagnetics (EM) method have become a powerful method to investigate subsurface shallow structures and geology for various environmental and engineering applications [7,8]. They have been widely applied in various studies related to the building construction and hazard such as fault [9], soil characteristics [10,11] and for the purposes of building construction[12,13]. Therefore, in this research, we employ 2D electrical resistivity method using Wenner configuration to analyze the subsurface structures in the building construction area in Institut Teknologi Sumatera campus (Figure 1) and compare with EM method to determined layers that have high porosity and permeability values or in conductive areas.

Figure 1. Research location, visible measurement trajectory (yellow and red).

2. Material & Method
2.1. DC Electrical Resistivity
The basic physical law that used in resistivity surveys is Ohm's Law which regulates the flow of current in the ground. The equation for Ohm's Law in vector form for current flow in a continuous medium is given by:

\[ J = \sigma E \]  

(1)

where \( \sigma \) is the conductivity of the medium and \( J \) is current density dan \( E \) is the intensity of the electric field. In practice, the electric field potential is measured. In a geophysical survey the resistivity of a medium, which is the inverse of the conductivity of the medium. The relationship between potential and field intensity can be formulated as follows:

\[ E = -\nabla \Phi \]  

(2)
By combining equations 1 and 2, the result is:

\[ J = -\sigma \nabla \Phi \]  

(3)

where is the current flows radially from the source in half the globe (half-space), the current flow is perpendicular to the surface of the equipotential. The potential in this case is given by

\[ V = \frac{\rho I}{2\pi r} \]  

(4)

where \( r \) is the distance of a point in the medium (including ground level) from the electrode. In practice, the resistivity survey uses two electrode sources of positive and negative currents which are injected into the ground and then the potential difference is measured through another pair of electrodes. The potential value has a symmetrical pattern about the vertical spot at the midpoint between the two electrodes.

Field surveys are always carried out through non-homogeneous media where the subsurface resistivity has a 3-D distribution. The resistivity measurement is done by injecting a current into the ground through the two current electrodes (C1 and C2) and measuring the difference in voltage generated at the two potential electrodes (P1 and P2). The injected current (I) and the potential difference (\( \Delta V \)) are used to calculate the resistivity (\( \rho_a \)) [14]

\[ \rho_a = k \frac{\Delta V}{I} \]  

(5)

2.2. Electromagnetic Conductivity Meter Depth (CMD)

The electromagnetic CMD method (Electromagnetic Conductivity Meter Depth) is a tool that can quickly measure the conductivity of objects by utilizing electromagnetic induction from electromagnetic waves emitted into the ground with a certain frequency. This CMD instrument can measure the conductivity properties of subsurface materials which include soil, groundwater, rocks, and other materials. The work process of this CMD instrument is by sending a signal in the form of an electromagnetic wave that is created through a transmitter (Tx), the subsurface material responds to the electromagnetic waves and induces eddy currents. Secondary electromagnetic waves are magnetic field induction generated by Eddy currents. Then, on the surface, this secondary electromagnetic wave is received by the receiver (Rx). Eddy currents are directly proportional to the conductivity of rocks. So that in the measurement the value of the conductivity of the rock indirectly related to the eddy current [15].
The CMD instrument is manufactured by GeoModel Inc, has been used in several surveys with benefits, including fast and accurate, portable (the tool is very easy to carry around the location and used for various research purposes) and cost effective (affordable survey costs). The measurements can be done in two ways, namely horizontal dipole and vertical dipole. Illustration of wave propagation can be seen in Figure 2. The conductivity can be calculated [15]

\[
\frac{H_s}{H_p} = \frac{i \omega \mu_0 s^2 \sigma}{4}
\]

(6)

where:
- \(H_s\) = Secondary magnetic field in the receiving coil
- \(H_p\) = primary magnetic field in the receiving coil
- \(\omega = 2\pi f\) = frequency (Hz)
- \(\mu_0\) = vacuum permeability
- \(\sigma\) = conductivity
- \(s\) = inter-coil space
- \(i = \sqrt{-1}\)

So that the equation to get the conductivity value \((\sigma_a)\) of a medium is:

\[
\sigma_a = \left(\frac{H_s}{H_p}\right) \frac{4}{i \omega \mu_0 s^2}
\]

(7)
2.3. Resistivity and Conductivity of Rock

The resistivity and conductivity of rocks are related to various geological characteristics of an area. Several things that influence the resistivity or conductivity of the rock are the minerals contained in the rock, the fluid, the porosity and the degree of water saturation in the rock[6]. Figure 3 shows several types of rock and fluid with their resistivity values. Generally igneous and metamorphic rocks tend to have high resistivity values, on the other hand, sedimentary rocks usually have low resistivity values when compared to igneous and metamorphic rocks. This is because the texture of the sedimentary rock has a high porosity value and tends to absorb water. From this information, it enables geoelectric and electromagnetic methods to detect subsurface layers, such as bedrock and aquifer layers.

![Figure 3. The resistivity and conductivity values of several types of rock and fluid][17]

This research was conducted around the ITERA campus area which is a pyroclastic deposition area using resistivity and electromagnetic geoelectric methods. Both methods will be measured at the same location (Figure 3). It is hoped that the combination of these two methods can provide an overview of the structure of the subsurface layer. In this area also visible outcrops with a depth of ± 10 meters, which will later be correlated with measurement data.

Data acquisition for electrical resistivity methods using ARES instruments. This tool is a multi-channel, using 48 electrodes which are then connected by multi-core cables. In this study, 10 meters of electrode spacing will be used for 5 measurement paths. This tool is equipped with a switchbox that functions for automatic measurement. In the main unit, first set the configuration that will be used, and the amount of current that will be injected into the ground when measuring. Next, to start measuring, first check to make sure all components are connected properly. The data from the measurement results will be automatically stored in the memory on the main unit. The data that has been stored is then downloaded to a computer and then analyzed and processed.
Table 1. parameters used in geoelectric measurements

| Parameter                  | Value setting                      |
|----------------------------|------------------------------------|
| Electrode configuration    | Wenner & Wenner Schlumberger       |
| Spacing between electrodes | 10 m                               |
| Maximum standard deviation | 5                                  |
| Maximum Stack              | 5                                  |
| Minimum Stack              | 4                                  |
| Voltage                    | 600 and 830 V                      |

The instrument used for the CMD electromagnetic survey consists of two coils, one receiving coil and one coil for the transmitter, which are separated by a certain distance using a connecting cable with a certain distance. The CMD-Duo has several different inter-coils spacing for different depth ranges [18]. The CMD instrument which consists of a transmitter and receiver parts is connected using a connecting cable as shown in Figure 4. The cable that has been connected to each coil is then hooked up with a rope with the hanging cable that is on the connecting cable. In the CMD-Duo instrument there are 3 (three) cables of different lengths 10, 20, and 40 m respectively. All three aim to achieve different measurement penetration depths. For effective depths of 15, 30 and 60 m, with cable lengths of 10, 20, and 40 m respectively, the measurement is carried out in the Hi (horizontal) position, while for the effective depth of 7.5, 15, or 30 m, the measurement is carried out in the position Lo (vertical). The two connected coils, receiver and transmitter, are then connected to the control unit via a wireless network (Bluetooth). It is from this control unit that the CMD-Duo is controlled for measurement.

![Figure 4 How to install the CMD-Duo instrument][18]

2.4. Processing and Interpretation

The resistivity data processing was performed using Res2Dinv software. The results of the inversion of the two software will be compared and then analyzed for further interpretation. Conductivity is the main parameter measured on the CMD-Duo instrument; this is due to the induction of electromagnetic waves below the earth's surface which is conductive. The second parameter that is measured is In-Phase which is measured simultaneously with the conductivity. In-Phase is a real component that is in phase with the primary wave. In-phase is defined as the deep relative quantity of the primary magnetic field. This is closely related to the measured magnetic susceptibility of the material, so that the distribution map In-Phase becomes the data that supports the interpretation of the conductivity map to distinguish rock structures.

3. Geologic Setting

Tectonically, the Sumatra island can be divided into 5 areas, namely the outer arc ridge, the arc face basin, the back-arc basin, the Barisan mountains along the Sumatran Fault, and the intra-arc basin that develops along the Barisan Range [19]. Quaternary volcanism dominates the Barisan Range, represented by 50 volcanic centers along the Sumatra Fault zone [20]. The relationship between volcanism and tectonic activity of the Sumatran Fault is poorly understood, as only a few volcanisms are in the active fault zone, while most of them are distributed within.
Based on the geological map of the Tanjung Karang sheet (Figure 5), the research location is located in the Lampung Formation, which is dominated by layers of tuff pumice, rhyolitic tuff, tuff clay and tuff sandstone on the surface. In the lower layer it is estimated that there is a complex formation of an inseparable Kasih mountain, which generally contains a stinging schist and a few gneiss [21].

![Geologic Map](image)

**Figure 5.** Geological map of the study area. ITERA is in the Lampung formation which is dominated by tuff (modified from the geological map of the Tanjungkarang sheet [21])

4. Results and Discussion

This research is conducted in the Sumatra Institute of Technology which is based on the geological map into the Lampung Formation with rock lithology which is dominated by tuff rocks. In general, tufa has a relatively high resistivity value, but under certain conditions tuff can have a low resistivity value. Several things can be caused by these conditions such as the water saturation factor contained in the rock body [14]. The following is a classification of resistivity values in rocks around the research area that have been studied and used as a reference in the data interpretation process.
Table 2. The rock resistivity value around the study area from the previous research [22,23]

| No | Rock Type        | Range Resistivity value (Ohm.m) |
|----|------------------|---------------------------------|
| 1  | Clay tuff        | < 20                            |
| 2  | Sand tuff        | 20-80                           |
| 3  | Tuff             | 80-150                          |
| 4  | Tuff             | > 150                           |
| 5  | Clay tuff (wet)  | 4.5-15                          |
| 6  | Tuff (wet)       | 15-50                           |
| 7  | Clay tuff (dry)  | 93-292                          |
| 8  | Tuff (dry)       | 76-268                          |

The subsurface 2D model along line 1 with a length of 470 m uses the Wenner configuration and reaches a depth of 78.8 meters (Figure 6). Field measurements were carried out in humid conditions and sunny weather throughout the day. From the results obtained on the track first seen the value of the resistivity varies from a low resistivity value < 10 Ohm.m to a high resistivity value of about 200 Ohm.m with a percentage error (error) 26.3% to 5 iterations. On this trajectory, the distribution of resistivity values is quite diverse but is still dominated by layers with relatively low to moderate resistivity values. In general, the resistivity value < 15 Ohm.m. The presumed tuff clays based on Table 2 above were found at varying depths in the length of the track from 2.5 m to about 50 m. Furthermore, the moderate resistivity value of 15 - 85 Ohm.m is thought to be the sandy tuff layer found in 2 different layers, namely a depth of 0-25 m and a depth of > 30 m. Whereas for high resistivity values > 85 Ohm.m is a tuff layer.

Figure 6. Subsurface resistivity 2D section line 1

Figure 7 shows a 2D model of line 2 with a length of 470 m with the Wenner configuration and reaching a depth of 78.8 meters. The measurements are the same as line 1 with sunny weather conditions throughout the day. From the results obtained on Tracks 2 looks variation in resistivity, of low resistivity values < 10 Ohm.m to a high resistivity value of about 200 Ohm.m with a percentage error (errors) 39% to 5 iterations. This line is dominated by layers with medium to high resistivity values. Based on the references from Table 2 above, then they are grouped into several ranges of resistivity values. Resistivity value < 15 Ohm.m. suspected tuff clays were found at varying depths and extended the trajectory from the surface to a depth of about 78 m. Furthermore, the moderate resistivity value of 15 - 85 Ohm.m is thought to be the sandy tuff layer found in 2 different layers, namely a depth of 0-25 m and a depth of > 30 m. Whereas for high resistivity values > 85 Ohm.m, the tuff layers are grouped into 2, namely tuff with a resistivity of 85-150 Ohm.m which is found generally at shallow depths (0-30 m) and compact tuff with resistivity > 150 Ohm.m which is most of them are at depths > 40 m.
2D model of line 3 with a length of 470 m with the Wenner configuration reach to a depth of up to 78.8 meters (Figure 8). There are two variation resistivity values that vary with the percentage of errors (error) 40.3% to 5 iterations. In general, based on the references from Table 2 above, they are grouped into several ranges of resistivity values. Resistivity value <15 Ohm.m. suspected tuff clays were found at varying depths and extended the trajectory from the surface to a depth of about 78 m. Furthermore, the moderate resistivity value of 15 - 85 Ohm.m is thought to be the sandy tuff layer found in 2 different layers, namely a depth of 0-25 m and a depth of > 30 m. Whereas for high resistivity values > 85 Ohm.m, the tuff layers are grouped into 2, namely tuff with a resistivity of 85-150 Ohm.m which is found generally at shallow depths (0-30 m) and compact tuff with resistivity > 150 Ohm.m which is most of them are at depths > 30 m.

Figure 9 shows a 2D model of line 4 with a length of 470 m with the Wenner configuration and reaching a depth of 67.5 meters. Resistivity values that vary from the results of low resistivity values <10 Ohm.m to a high resistivity value of about 200 Ohm.m with a percentage error (error) 64.6% to 5 iterations. This high error value is due to some problematic data, presumably due to damage to the equipment. Based on the references from Table 2 above, they are generally grouped into several ranges of resistivity values. Resistivity value <15 Ohm.m. presumed to be tuffaceous clays were found at varying depths which extended the trajectory from the surface to a depth of about 67.5 m. Furthermore, the moderate resistivity value of 15 - 85 Ohm.m is thought to be a sandy tuff layer which is found mostly at depths > 25 m. Whereas for high resistivity values > 85 Ohm.m, the tuff layers are grouped into 2, namely tuff with a resistivity of 85-150 Ohm.m and compact tuff with resistivity > 150 Ohm.m found at a depth of 0-48 m.
Figure 9. subsurface resistivity 2D section line 4

Figure 10 shows the results of the conductivity measurement, the apparent conductivity value varies with different spacing. Different spacing describes different depths, the greater the spacing between the coils, the deeper the depth will be achieved. At 10 m with an effective penetration depth of 7.5 m, a relatively small conductivity value can be seen, this indicates that the blood has a layer that has a large resistivity. This result is in accordance with the geoelectric data that the first layer is dominated by a tuff layer which tends to have moderate resistivity values. At a spacing of 20 with an effective depth of 15 m, a large conductivity value is seen which is in accordance with the geoelectric data where this layer is an aquifer layer that has a low resistivity value. Meanwhile, at an effective depth of about 30 meters, the conductivity value is low. These results confirm the presence of a hard layer of bedrock at that depth. These results are in accordance with geoelectric data with high resistivity values which are interpreted as tuff clay layers.

Figure 10. Iso conductivity combined from the four line.
Figure 11 shows the variation in resistivity values ranging from very low resistivity to high resistivity. Based on the resistivity value of rocks and minerals [14] and the resistivity range of ITERA rock lithology [22], the first layer is interpreted as a tuff layer with a resistivity value $> 150$ Ohm.m. This tuff rock is a rock with a fine and compact grain size. A layer with a resistivity value $< 85$ Ohm.m is interpreted as a sandy tuff layer and $< 15$ Ohm.m is suspected to be tuff clay. Sandstone tuff which contains sand with medium-coarse grain size and is permeable with good porosity can become an aquifer layer. This layer is an aquifer layer that can accommodate enough water reserves. Meanwhile, the tuffaceous clay layer is a layer that is able to store water but is difficult to pass it so it is not good as an aquifer. It is difficult to distinguish between these two layers properly; therefore, additional data is needed in the form of drill data to ascertain the actual material. The depth of the tap layer was identified with a high resistivity value of $> 150$ Ohm.m which was interpreted as a hard layer. Hard rock is solid/hard tuff, which is compact and impermeable, so that this layer is a water-unsaturated layer. The depth of this hard layer is about 30 m to 60 m or maybe more. Therefore, in carrying out development, it is necessary to consider the hard rock which is quite deep.

5. Conclusion and Recommendation

Based on the results of the resistivity and conductivity interpretation, the target in this study is to find the depth of the bedrock or hard rock which will be used as a reference for the foundation and the potential presence of groundwater aquifers or water-bearing layers seen from the two results obtained. The resistivity and conductivity
values are inseparable from the presence of groundwater that can be stored in rocks and highly dependent on the permeability and porosity of the rock. The high resistivity/low conductivity anomaly indicate the hard rock interpreted in the depth of 30 m approximately. The area with the low resistivity anomaly is interpret as tuffaceous sandstones/tuffaceous claystone with the high-water content.

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