Identification The Subsurface Structures of Kadipaten Terung Site Using Surface 3D Resistivity Methods

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Abstract. Measurements of the 3D resistivity method have been carried out in the Terung Site, Terung Wetan Village, Krian, Sidoarjo Regency. The study was conducted to determine the distribution pattern of the Terung Site subsurface structure. Many archaeological sites from ancient times have been buried or deliberately buried beneath the surface. The process of searching archaeological sites that have been carried out only based on the results of stories that developed in the community. The 3D resistivity method can be used as a method for conducting site searches. The 3D resistivity method gives the image of the resistivity distribution in a vertical and horizontal cross section therefore to produce a more resolutive image. Based on measurements with the 3D Wenner configuration resistivity method, there is a structured continuity of Kadipaten Terung Site in the depth of 1.5-3.5 meters with resistivity values of 30 Ωm - 80 Ωm.

Keywords: Kadipaten Terung site, 3D Resistivity, brick structures, Wenner

1. Introduction

Many archaeological sites from ancient times have been buried or deliberately buried beneath the surface. Studies of archeological sites need to be conducted to obtain information about social cultural behavior in ancient times. The lack of available information about archeological sites is an obstacle in the pursuit process that usually have been carried out only based on the results of stories that developed in the community [1]. The discovery of archaeological sites has mostly originated from the accidental process of residents who discovered the site's outcrops and then carried out the excavation process.

The Terung Site is located in Terung Wetan Village, Krian, Sidoarjo. The discovery of a J-shaped building structure named Terung Temple in Terung Wetan Village in 2012 was the main attraction for the area. Based on an explanation from the society who first examined this site, it was explained that the excavation seen on the surface at this time was only a small part of the site, because it was suspected that there were still continuity of sites around the area that had been excavated.

Several previous studies have been successfully carried out to identify patterns of site distribution using the resistivity method for example indentification the subsurface structure in the Belahan Temple complex [2] and application of 3D Geoelectrical Method to determine Salak Block Bitting archaeological site in Kutorenon Village, Sukodono, Lumajang District [3]. The 3D resistivity method will produce a more resolutive image compared to 2D resistivity because its data acquisition technique is more tight [4][5]. 3D resistivity have x-fields and y-fields when data acquisition is occured thus the available inversion results have three parts, namely, x-fields, y-fields and z-fields. Through the 3D
resistivity principle, it is expected to reach the optimized result of 3-dimensional subsurface resistivity imaging.

2. Electrical Property of Rock
Each rock has its own characteristics, one of which is resistivity ($\rho$) (type resistivity) which showed the ability of the material to conduct electric current [6]. If the resistivity value of a material become higher then it will be more difficult to conduct an electric current, and vice versa. Based on the resistivity price, rocks are classified into 3 categories, namely:

- Good conductors: $10^{-6} < \rho < 1 \ \Omega \text{m}$
- Medium conductor: $1 < \rho < 10 \ \Omega \text{m}$
- Insulator: $\rho > 107 \ \mu\Omega$

| Material          | Resistivity ($\Omega \text{m}$) |
|-------------------|----------------------------------|
| Clay Soil         | 1.5-3                            |
| Clay              | 3-15                             |
| Silt              | 15-150                           |
| Sandy Silt Soil   | 150-300                          |
| Weathered bedrock | 300                              |

There is a range of electrical values from each rock that exists and this will help in determining the type of rock based on the price of the resistivity or vice versa. Table 1 showed the range values based on each type of rock. This value does not only depend on the rock type but also the porosity and the fluid content [7].

3. 3D Resistivity
The 3D resistivity geoelectrical method is able to provide a 3D image from the subsurface of more detailed resistivity compared to 2D resistivity, therefore it not only gives the image of resistivity distribution in vertical crossings only but also in horizontal cross-sectional forms [8].

The 3D resistivity method is able to provide a detailed subsurface image of type resistance compared to 2D resistivity. However, 3D resistivity is rarely used because of the large costs and energy needed during many measurements, especially in large areas. At present there are two types of solutions that are being developed to overcome these problems. The first is the development of multi-channel resistivitimeters that can read data with a single injection of current therefore it reduces the time and energy needed. The second developed high-speed micro computer technology that is prepared to process large-scale data inversion with a wider survey plots in a shorter period of time.

4. Current Condition in Kadipaten Terung Site
Terung Temple was discovered around 2012. According to his colleague Mbah Huri named Jansen, this historic site has 15 bricks down. This brick building is arranged neatly down with the top forming the letter "J". There are symbols of Lingga and Yoni on the bricks site. The Lingga and Yoni symbols are on a pile of elongated bricks measuring 10.8 meters and 2.33 meters wide. The symbol was also found on bricks scattered around the excavation site. The Linga symbol is in the form of two long lines engraved on the brick. While the Yoni symbol is in the form of two lines that are curved upwards, resembling the letter U. Seeing the shape of a large brick, the site is estimated as the relic of the Majapahit era.

5. Methodology
The method used in this study is 3D resistivity-Wenner Configuration using the Multichannel FYA 1.0 instrument. The resulted data is the subsurface resistivity value. Configuration that used in this method is Wenner Custom (figure 1).
The Wenner Array Sequence of Measurement

The formula for the field data acquisition process used an overlay of 4 lines with an acquisition design located on the west of the site where the excavation has been carried out, as shown in Figure 2. This is because the excavation in the south has not been found. Acquisition due to the existence of stalls and community wells.

The length of the measurement path is 8 meters with respect to the x-field and 4 meters to the y-plane with a space between 1 meter electrodes and overlay on each 2 meter path to the x-plane and 2 meters to the y-plane. So that the total track length is 16 meters x 6 meters. The distance between each electrode is 1 meter and the overlay is from 4 tracks. The total length of overlays is 13 meters x 5 meters with a space between 1 meter electrodes with the total of data level (n) equal with 10 (figure 2). Thus it will make the data acquisition process are effective and efficient so that it is more quickly completed and reduces the expenditure budget.

Figure 1. The Wenner Array Sequence of Measurement

Figure 2. Acquisition Survey Design
The following will be given a flow diagram of the research (figure 3).

![Figure 3. Research Flow Diagram](image)

6. Result
The target of the measurement is the distribution pattern of the building structure below the site. The depth range that obtained in this measurement is 1.5-3.5 meters. The range of resistivity values that is used corresponds to the maximum and minimum data values for each track but the overall range is relatively the same. From the results of resistivity cross section can be seen the structure pattern distribution beneath the site surface. It can be known how the response of the resistivity value to the distribution pattern and the continuity of the site structure that has been found for excavation purposes. There are several parts of the field at the location of the study that can be explained to present the details of the resistivity value distribution.

Iterations were carried out 10 times and an error of 10.9% was obtained. The overlays of 4 tracks as shown in figure 4 resulted a depth around 4.7 meters. There are 3 parts of the field to be presented (x, y, z) and each has several incisions as shown in figure 5, figure 6 and figure 7. The three images are some of the few incisions that cannot be displayed because there are too many images of the incision section. The total point of the electrode are 84 points with the results of the illustration from the point of acquisition and the results of inversion are presented in Figure 3 where the north direction in the direction of field-y.

The resistivity value is quite high compared to the surrounding area, both the front, side or top of the bottom are indicated as the building blocks of subsurface buildings (sites). Anomalies with high resistivity values of around 30 Ωm - 80 Ωm are interpreted as site building bricks. Anomalies of
moderate resistivity values of around 10 Ωm are indicated as the surrounding lithology clay. While the low anomaly resistivity value less than 2 Ωm is assumed to be wet clay containing water.

**Figure 4.** Inversion Result from Resistivity Data

![Inversion Result from Resistivity Data](image)

It can be seen from the front field (figure 5) that the rock anomaly composing the site is at a distance of 1-11 x-fields with a depth of 1.5 - 3.5 meters. There are branching at a distance of 5-7 x-fields. In the side field (y), an anomaly is indicated as the site building rock at a distance of 0-5 y-field with a depth of 1.5-3.5 meters. The anomaly is not found at the beginning and end. Anomalies intersect at a distance of 3-5 fields-y then it looks full again. If observed in more detail, the constituent anomalies of the site slowly thin out at a distance of 3-5 fields-y.

**Figure 5. Front Field**

![Front Field](image)

**Figure 6. Side Field (Y)**

![Side Field (Y)](image)

**Figure 7. Upper Field (Z)**

![Upper Field (Z)](image)

In the lower upper plane (z), there are several trees at a distance of 0-13 x-fields and 0-2 fields-y whose roots spread. At distances of 1-12 fields x and 0-3 fields-y are dominated by high resistivity values. It is indicated that solid clay is compressed and drier than the layers below it. Because at that point it is the road access that is used by the local people. At distances of 1-10 x-fields and 0-3 fields-y are dominated by low resistivity values which is indicated as wet clay containing water. Anomalies of high resistivity values are assumed by constituent rocks of the site appear to slowly begin at distances 1-4 and 8-11 x-fields, 3-5 fields-y and disappear long in the 0-y plane in the depth of 3.5 meters. Anomalies of constituent rock sites were completely lost in depths of more than 3.5 meters.

According to previous research about the 3D resistivity method for identifying subsurface structures of ancient relics made of bricks which site building rocks have a range of resistivity values of 33 Ωm to 92 Ωm that are identical to the value of resistivity.
The results of the 3-dimensional inversion process using 3D resistivity processing software are obtained in the form of a cross section of 3 fields, in the form of cross-sections x-fields, y-fields, and z-fields. The cross section of the field has resistivity values that are associated with different color images depending on the size of the resistivity value as shown in figure 5, figure 6 and figure 7. In the 3D resistivity inversion image showed each rock resistivity value which are seen from the cross-sectional color image of the subsurface structure. The distribution of resistivity values below the surface is indicated by the color image from data processing. Table 2 illustrated the types of soil layers or rocks found under the surface of the research location.

### Table 2. The scale of resistivity values in Kadipaten Terung Site

| Rock Types                | Scale | Resistivity (Ωm) |
|---------------------------|-------|------------------|
| Water saturated wet clay  | Very  | <2               |
| Wet Clay                  | Low   | 2-5              |
| Silty Clay                | Medium| 2-25             |
| Shaly Sand (Bricks)       | High  | 25-90            |

In general, the Terung Site is composed by the lithology of the sandy clay. The research area is paddy fields and plantation residents with a high enough water content cause water to be associated with clay so that the resistivity value is low. Resistivity data inversion results show scale classifications that can be interpreted as the constituent rock types shown in Table 2. Based on the 3D resistivity inversion profile, the contrast resistivity is quite high with the surrounding indicated as a rock structure that composes subsurface buildings. The cross-sectional distribution indicated as a subsurface structure is presented in the form of a 3-dimensional image in Figure 8. The distribution of subsurface structures is shown in brown color. Based on Table 2 and Figure 8, there is continuity from the site that has been interpreted, which is to the west of the site that has been located on a depth of 1.5-3.5 meters like Figure 8 brown with the expected shape of the structure as shown by the dashed white line.

![Figure 8. Subsurface Structures Distribution of Terung Site](image)

It can be seen clearly every subsurface layer that has a color contour with various types of resistivity distribution. The resistivity distribution showed different types of rock or its constituent soil. The subsurface conditions can be observed as well as observing a cube of subsurface so that it can be observed from various sides. This is an advantage of the 3D resistivity method which can provide more resolutive resistivity imaging in describing subsurface conditions.
Figure 9. Reconstruction of Terung Site

Based on the results of the resistivity distribution of subsurface structures site. Then reconstruction and possible continuity between existing sites and distribution results can be made (figure 9). Figure 9 showed the continuity between sites that are already visible with the distribution results forming a port dock pattern. This is reinforced that the measurement location close to the river.

The inversion resulted the resistivity values are from the range 1 Ωm - 80 Ωm. Each resistivity value has been represented by different color contours, making it easier to see the subsurface resistivity distribution. The geological condition of the study site was dominated by sandy clay soil, this was seen in the sealing of each incision shown in green. Site rocks that are bricks found below the surface are thought to be canals or distribution from excavated sites shown in red with resistivity values ranging from 25 Ωm - 80 Ωm. The resistivity values of Kadipaten Terung Site are shown in Table 2. Based on these results it can be seen that the application of the 3D resistivity method is able to interpret subsurface resistivity in 3 dimensions with resolutive results. Thus, in the two study locations, it is indicated that there are still subsurface structures that are still hidden.

7. Conclusion
Based on the results of data processing and interpretation, it was concluded that the location of The Terung Site had continuity with the existing sites at a depth of 1.5-3.5 meters and its resistivity values of 30 Ωm - 80 Ωm which are indicated as site building bricks dominated by blue as clay and light blue is water saturated wet clay, it is caused by the location of the research area in the plantation and rice fields where close to the river.

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