Data Acquisition of 2D Geophysical Resistivity Methods with Dipole-Dipole Configuration for Identification the Subsurface Brick Stone Sites of Kadipaten Terung Sidoarjo

A Widodo\textsuperscript{1}, F Syaifuddin\textsuperscript{1*}, Vinca\textsuperscript{1}, D D Warnana\textsuperscript{1}, J P G N Rochman\textsuperscript{1}, N Ariyanti\textsuperscript{1}, W Lestari\textsuperscript{1}

\textsuperscript{1}Geophysical Engineering Department, Faculty of Civil Engineering, Environmental and Geoengineering, Institut Teknologi Sepuluh Nopember, Surabaya

*Corresponding author : firmansyaifuddinakbar@gmail.com

Abstract. The discovery of the "J" letter-shaped brick structure (also called the Terung Temple) in Terung Wetan Village in 2012 is thought to be a heritage of the Majapahit Kingdom era. However, there is no further research to figure out the distribution of structures in the area. Geophysical surveys with 2D resistivity geoelectric methods-dipole-dipole configuration were carried out in the Site of Kadipaten Terung, Terung Wetan Village, Krian, Sidoarjo Regency to map the distribution of existing subsurface structures. Judging from the location of the Terung Temple, line 1 with the north-south direction on the west side with a length of 62 meters had a resistivity anomaly value of 13.2-60 Ωm at a depth of 1-3.67 m; line 2 with the southwest-northeast direction on the northwest side with a length of 46.5 meters had a resistivity anomaly value of 13.8-75 Ωm at a depth of 1-2.75 meters; line 3 with the northwest-southeast direction on the southwest side with a length of 46.5 meters had a resistivity anomaly value of 12.7 - 75 µm at a depth of 1-2.75 meters; line 4 with the east-west direction on the south side had a resistivity anomaly value of 15-75 Ωm; and line 5 with north-south direction on the east side with a length of 62 meters had a resistivity anomaly value of 15.7-100 Ωm. These anomalies are indicated as subsurface brick structures scattered throughout the research trajectories and it had been the continuity of the Terung Temple into the west and south.

Keywords: dipole-dipole configuration, 2D resistivity method, subsurface brick structure, Terung.

1. Introduction
The Terung Area is located in Krian Subdistrict, Sidoarjo and it are divided into two villages namely Terung Wetan Village and Terung Kulon Village. There are many relics that have been found in the heritage area. The discovery of the J-shaped brick structures, which was named the Terung Temple in Terung Wetan Village in 2012. Geoelectrical is one of the geophysical exploration methods to investigate subsurface conditions using rock electrical properties, one of which is resistivity. Moreover, subsurface conditions can be investigated by utilizing differences in rock resistivity properties through the geoelectrical method. The difference in the value of resistivity from the geoelectrical method used in this study will describe the subsurface of Kadipaten Terung Site. Several research have been carried out to map the patterns of site distribution using the resistivity method like application of Geoelectrical Method for identification of archaeological sites in Pulau Laut, Natuna [1].
The dipole-dipole configuration is the most sensitive arrangement of horizontal resistivity variations in each pair of dipoles, but relatively insensitive to vertical resistivity variations [2][3]. Thus, dipole-dipole 2D resistivity configuration is appropriate for mapping subsurface structures found on the Terung Site. Based on the background described earlier, the problem statement in this study is about how to map the subsurface brick structures distribution in the Terung Site which implemented the measurements of dipole-dipole 2D resistivity methods. The research coverage area is in Terung Site, precisely in Terung Wetan Village, Krian, Sidoarjo Regency. Measurements were only carried out by 2D dipole-dipole configuration resistivity method without age analysis of rocks on the Terung Site.

Based on the background and formulation of the problems described earlier, this study aims to determine the distribution map of the subsurface brick structure in the Terung Site based on the measurement results of the dipole-dipole 2D resistivity method.

2. Literature Review

2.1. Regional Geology

The Terung Site is administratively included in the Sidoarjo Regency but in regional geology it is included in the geological map of the Surabaya-Sapulu sheet [5] that is illustrated by figure 1. The research location is included in the alluvium deposit area (Qa). The spread of rocks in the Sidoarjo area is the alluvium plain. Alluvial deposits are scattered in the north, forming delta deposits known as Delta Brantas. Brantas Delta deposits are composed of sandy clay, gray sand and gravel [6].

![Figure 1. Kadipaten Terung Site Geological Map](image-url)
2.2. Current Condition of Terung Site
Terung Temple is a building composed of piles of bricks that was discovered around 2012. According to the Mbah Sahuri colleague named Jansen, this historic site had 15 bricks down. This brick building is arranged neatly down with the top forming the letter "J". The structure of the Terung Temple is at a depth of 1 meter from the surrounding surface and extends to 10.8 meters and 2.33 meters wide. On this rock site there are symbols of Lingga and Yoni. Seeing the shape and size of a large brick, the site is estimated to include the remains of the Majapahit era [4].

2.3. Resistivity Method
The resistivity method is based on Ohm's Law. The simple application is to cylindrical objects that have resistance type (ρ), electric current (I), then it will be proportional to the cross-sectional area (A) and the voltage between the edges (ΔV), however inversely proportional to the length (L). A simple equation used in the concept of resistivity is the number of resistance multiplied by the length of an object denoted in ρ in units of ohms meters (Ωm). Following is the writing of the equation:

$$\rho = \frac{RA}{L}$$

Resistivity method is an active method by flowing electric current into the earth through two current electrodes, while the potential is measured through two or more potential electrodes. Two C electrodes (C1 and C2) to inject surface electric current. The magnitude of the potential or voltage is measured by the electrodes P1 and P2 will be affected by the two electrodes. Following is the concept of the geoelectrical method in general according to Loke [7]:

2.3.1. Dipole-Dipole Configuration. The dipole-dipole configuration is a combination of profiling and depth sounding techniques, so this type of configuration is one of the configurations commonly used in geophysical exploration. In the dipole-dipole configuration, the two current electrodes and potential electrodes are separated by distance a. While the current electrode and the inner potential electrode are separate as far as na, with n are integers [8]. Variation n is used to get a certain range of depths, more greater the value of n, the greater depth obtained. The level of range sensitivity in the dipole-dipole configuration is influenced by the magnitude a and variation n.

The following dipole-dipole configuration scheme can be seen in Figure 3:

$$K = \pi na(1 + n)(2 + n)$$
2.3.2. Rock Resistivity Value. The references to rock and material resistivity values are as shown in the following table:

| Material Resistivity       | Ohm-meter | Material Resistivity          | Ohm-meter |
|----------------------------|-----------|------------------------------|-----------|
| Pyrite (Pirit)             | 0.01 – 100| Shales (Batu Tulis)          | 20 – 2,000|
| Quartz (Kwarsa)            | 500 – 800,000| Sand (Pasir)                | 1 – 1,000 |
| Calcite (Kalsit)           | 1x10^{12} – 1x10^{13}| Clay (Lempung)             | 1 – 100   |
| Rock Salt (Garam Batu)     | 30 – 1x10^{13} | Ground Water (Air Tanah)   | 0.5 – 300 |
| Granite (Granit)           | 200 – 100,000| Sea Water (Air Asin)        | 0.2       |
| Andesite (Andesit)         | 1.7x10^2 – 45x10^4 | Magnetite (Magnetit)    | 0.01 – 1,000|
| Basalt (Basal)             | 200 – 100,000| Dry Gravel (Kerikil Kering)| 600 – 10,000|
| Limestones (Gamping)       | 500 – 10,000 | Alluvium (Aluvium)       | 10 – 800  |
| Sandstones (Batu Pasir)    | 200 – 8,000  | Gravel (Kerikil)            | 100 – 600 |

3. Methodology
The design of the field acquisition made in the study in accordance with Figure 4 is used as many as 5 measurement lines that are spread in the Terung Site. Determination of the acquisition design referred to estimating the continuity of the structure of the Terung Temple, field conditions, track length, and other factors. Table 2 follows the measurement path data along with the trajectory coordinates of the study.

Data acquisition is located in Terung Site, Terung Wetan Village, Krian, Sidoarjo Regency with the acquisition design as follows:

![Figure 4. Research Acquisition Design](image)

The stages in this study are generally found in the Figure 5. The equipments are used to support this final project research consists of hardware and software. Hardware consists of 2 sets of resistivitimeters, 2 meter rollers (100 m), 1 set of hammer, 8 roll cables, 64 electrodes, 1 GPS, digital multimeter, 2 batteries, geological map of Surabaya-Sapulu. While the Software consists of Microsoft Excel 2013, Notepad, Google earth, RES2DINV.
Table 2. Coordinate of Measurement Paths

| Line Number | Initial Coordinate (A) | Final Coordinate (B) | Space (m) | Length (m) |
|-------------|-------------------------|----------------------|-----------|------------|
| Line 1      | 7° 23' 42.04" LS        | 7° 23' 43.98" LS     | 2         | 62         |
|             | 112° 37' 11.93" BT      | 112° 37' 11.24" BT   |           |            |
| Line 2      | 7° 23' 42.94" LS        | 7° 23' 42.29" LS     | 1.5       | 46.5       |
|             | 112° 37' 11.17" BT      | 112° 37' 12.5" BT    |           |            |
| Line 3      | 7° 23' 42.47" LS        | 7° 23' 43.73" LS     | 1.5       | 46.5       |
|             | 112° 37' 11.32" BT      | 112° 37' 12.11" BT   |           |            |
| Line 4      | 7° 23' 43.01" LS        | 7° 23' 43.48" LS     | 1.5       | 46.5       |
|             | 112° 37' 11.28" BT      | 112° 37' 12.65" BT   |           |            |
| Line 5      | 7° 23' 41.86" LS        | 7° 23' 43.8" LS      | 2         | 62         |
|             | 112° 37' 12.9" BT       | 112° 37' 12.29" BT   |           |            |

Figure 5. Research Flow Chart
4. Result

4.1. Analysis of Line 1.

The inversion cross section of line 1 (Figure 6) showed a resistivity value of 1-8.57 Ωm which is interpreted as alluvium deposits in the form of rainwater saturated clay. Furthermore there are areas with high resistivity anomalies worth 13.2 - 60 μm at a distance 3-10 meters and 21-36 meters with a depths of 1 to 3.67 meters which are indicated as subsurface brick structures and are the continuity of the structure of the Terung Temple to the west. The inversion result also showed that there is a high resistivity from 38 to 59 meters with a resistivity value of 13.2-60 Ωm indicated as a subsurface brick structure.

![Figure 6. Resistivity Cross Section of Line 1](image)

4.2. Analysis of Line 2.

The inversion cross section of line 2 (Figure 7) showed a resistivity value of 1-8.87 Ωm which is alluvium deposits in the form of rainwater saturated clay. Then, the high resistivity anomaly at a distance of 2.25 - 21 and 24 - 44.25 meters with resistivity values of 13.8-75 Ωm at depths of 1 to 2.75 meters which are indicated as subsurface brick structures and the continuity of the structure into westward. Low resistivity anomaly is displayed at a distance of 21-24 meters with a depth of 2.75 meters and maximum resistivity value of 5.71 Ωm which is interpreted as an aquifer from a well found on Terung Site.

![Figure 7. Resistivity Cross Section of Line 2](image)
4.3. Analysis of Line 3.
The inversion cross section of line 3 (Figure 8) showed a resistivity value of 1 - 7.56 Ωm which is interpreted as an alluvium deposit in the form of rainwater saturated clay. Moreover, the high resistivity anomaly obtained in a distance of 4.5 - 44.25 with a resistivity value of 12.7-75 Ωm at depths of 1 to 2.75 meters which is indicated as a rock structure below the surface and continue into the west.

4.4. Analysis of Line 4.
The inversion cross section of line 4 (Figure 9) showed resistivity in this area has a value of 4.98 - 10.4 Ωm which is interpreted as alluvium deposits in the form of sandy clay saturated with rain water at depths of up to 1 meters. In addition, there is a high resistivity anomaly with a resistivity value of 15.0 - 75 Ωm at a distance of 2.25 - 44.25 meters which is indicated as a subsurface brick structure and continue into the south.

4.5. Analysis of Line 5.
The inversion cross section of line 5 (Figure 10) showed the resistivity value of 3 - 10.4 Ωm which is interpreted as alluvium deposits in the form of sandy clay saturated with rain water at depths of up to 1 meter. Then, there is a high resistivity anomaly with a resistivity value of 15.7 - 100 Ωm at a distance of 2.25 - 44.25 and a depth of 1 - 3.67 meters which is indicated as a subsurface brick structure.
Based on field observations and measurement of the dipole-dipole 2D resistivity geoelectrical data, it was interpreted that alluvium deposits in the research area were in the form of sandy clay with a resistivity value of $1 - 10.4 \, \Omega m$. The clay resistivity value which is obtained at the Terung Site indicated as a subsurface brick structure. The value of the resistivity anomaly is higher than the value of the resistivity of the sandy clay which is the sediment in the research location which is $12.7 - 100 \, \mu m$. Based on five of processing data, indications the distribution of the subsurface brick structures are in accordance with the continuity estimation of the Terung Temple structure, namely into the west and south. In addition, indications of the subsurface brick distribution are also found in all the research trajectories as many as 5 measurement lines as in Figure 11. Judging from the location of the Terung Temple structure, we can conclude that track 1 is on the west side, track 2 is on the northwest side, track 3 is on the southwest side, track 4 is on the south side, and track 5 is on the east side.

Based on the results of data analysis and interpretation, the distribution of subsurface brick structures on the Terung Site can be described as follows:

**Figure 10.** Resistivity Cross Section of Line 5

**Figure 11.** Distribution trend of subsurface brick structures in Kadipaten Terung Site
5. Conclusion
Based on the research that has been done, it can be concluded that the indication of the subsurface brick structure distribution of the Terung Temple are found in 5 research lines. Judging from the location of the Terung Temple structure, line 1 is on the west side, track 2 is on the northwest side, track 3 is on the southwest side, track 4 is on the south side, and track 5 is on the east side. The indication of the structure continuity is oriented west and south.

Acknowledgement
The researcher expressed his gratitude to the society of Terung Wetan Village for providing information and assistance to carry out this research.

References
[1] Pryambodo, D.G. dan Troa, R.A. (2016), "Aplikasi Metode Geolistrik untuk Identifikasi Situs Arkeologi di Pulau Laut, Natuna", KALPATARU, Vol.25, No.1.
[2] Dahlin, T. and Loke, M.H. (1997), "Quasi-3D resistivity imaging-mapping of three dimensional structures using two dimensional DC resistivity techniques", 3rd EEGS Meeting,.
[3] Telford, W.M., Geldart, L.P. dan Sheriff, R.E. (1990), Applied Geophysics, Cambridge University Press.
[4] Fitrotin, N.F. (2014), "KEDUDUKAN DAERAH TERUNG (KRIAN-SIDOARJO) PADA MASA MENJELANG AKHIR MAJAPAHIT (1478-1526)", Avatara, Vol.2, No.1.
[5] Supandjono, J.B., Hasan, K., Panggabean, H., Satria, D. dan Sukardi (1992), Peta Geologi Lembar Surabaya & Sapulu,.
[6] Sudarsono, U. dan Sujarwo, I.B. (2008), Buletin Geologi Tata Lingkungan (Bulletin of Environmental Geology), Vol.18, No.1.
[7] Waluyo dan Hartantyo, E. (2000), Teori dan Aplikasi Metode Resistivitas, Laboratorium Geoﬁsika, Program Studi Geoﬁsika, Jurusan Fisika FMIPA UGM, Yogyakarta.
[8] Loke, M.H. (1999), Electrical imaging surveys for environmental and engineering studies. A practical guide to 2-D and 3-D surveys.