Relevance of ERT to the Detection of Ancient City Basement Wall in Khao Daeng, the Old Town of Songkhla

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ABSTRACT

In the past, Songkhla prospered as a prosperous port city. However, this era of prosperity ended in 1680. There are moats, some parts of city wall, and fortress still presenting. However, most of ancient city wall evidence is disappearing according to the city map drawn by Monsieur de Lamare in 1687. Therefore, the aim of this study was to locate the ancient city wall basement using 2D electrical resistivity tomography (ERT) method. The survey lines were set and oriented perpendicular to the expected location of the old city wall which connecting between the forts. ERT dipole-dipole array was conducted by Lund imaging system and ABEM Terameter SAS1000 with 1.0 m of smallest electrode spacing for the target depth of about 5.5 m. There are 16 resistivity survey lines, which were inverted by Res2Dinv software for subsurface resistivity distribution sections. The results of all resistivity sections show a similar pattern of three separated layers: (1) the upper layer with higher resistivity values, interpreted as topsoil or sand dune, (2) the second layer with low resistivity values, interpreted as saturated or clay layer and (3) the third layer of high resistivity values, interpreted as sand layer. The locations with the pattern of high resistivity of the upper layer submerges into the low resistivity layer on the survey lines F0903 and F0904 are possibly the foundation of ancient city wall or other forms of structure. For the low resistivity pattern close to the surface on the west side of the high resistivity foundation, found on the survey lines F0201 and F0202, are probably an old city moat. ERT results have demonstrated its ability to map the possible location of the ancient city wall and will be useful for future archaeological excavation.

Keywords: electrical resistivity tomography (ERT), archaeology, Songkhla

1. INTRODUCTION

The old city of Songkhla (Hua Khao Daeng) locates in the area of Hua Khao subdistrict, Mueang district, Songkhla province. In the past, it was called "Singora" [1] and was a prosperous city during the 22nd century of the Ayutthaya Kingdom, until Songkhla city grew stronger and vied with Ayutthaya. This led Ayutthaya to send forces to suppress and conquer until succeeding in the early 23rd century.

In the year 1687 AD, a French engineer named Monsieur de Lamare created an urban plan of the old city of Songkhla (Hua Khao Daeng). This plan depicted the city as a rectangular shape with the forts and the city walls (Fig. 1) [2]. The city had forts and walls in the north, east, and west sides, while natural walls, Khao Daeng and Khao Khai Mueang, protected the in southern side. The current remains of these structures include fragments of the fortifications and some parts of the city walls. The fortifications have found 18 forts correctly with reference to the city plan drawn by Monsieur de Lamare and the city walls were the lines connecting to the forts (Fig. 2). However, the old city wall is still appeared in the area close to fort number 1, while the evidence of ancient city wall in other areas are disappearing. If there were the city walls connecting between the forts, there should be remnants of the base of the city wall buried beneath the subsurface. To identify the position of the city wall, a geophysical survey such as electrical resistivity tomography (ERT) would be helping to determine the precise location and clear structure of the city wall.

The aim of this research was to study the location and foundational structure of the inner layer of the city wall of the old city of Songkhla (Hua Khao Daeng), buried beneath the subsurface. ERT method, a non-destructive technique (NDT), has been conducted for the resistivity distribution image and the obtained data could be useful for future archaeological excavations.

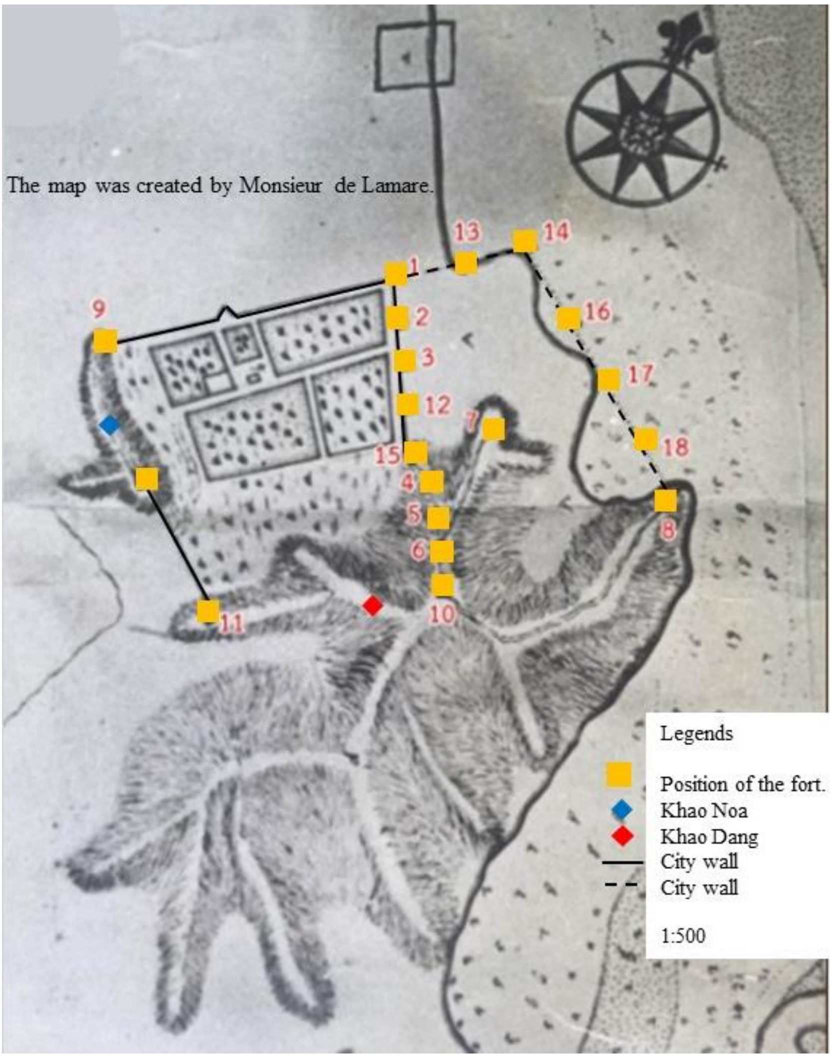

Fig. 1. Map of the Songkhla old town drawn by Monsieur de Lamare [2], the numbers 1 to 18 on the map were the forts of the town. The line connecting between the forts represents the ancient city wall.

Fig. 2. The current location of the forts on the Google Earth map.

2. MATERIALS AND METHODS

ERT is a geophysical imaging technology that is used to examine subsurface features and variations in ground electrical resistivity. ERT incorporates the underlying principle of direct-current (DC) resistivity exploration through electrodes and sensing the resulting voltages [3]. The apparent resistivity can then be calculated, and an inversion method can be used to generate a subsurface model of resistivity variation. The model of subsurface resistivity distribution can assist in determining geological features, locating buried items, and assessing material distribution underground. Environmental studies, civil engineering, archaeology, and other professions where knowing subsurface features is vital and ERT has been widely employed [4].

To acquiring ERT data, the Lund Imaging System [5] was used to specify the measurement sequence. ERT lines were oriented perpendicular to the line connecting between the forts. The longest length and the shortest length of the lines are 60 m and 32 m, respectively with the target depth of investigation about 5.50 m. The obtained data were inverted by Res2Dinv software for subsurface resistivity distribution sections.

2.1 Materials

Background geology in the Khao Daeng area: the rocks here appear to be sedimentary rocks from the Carboniferous period, primarily composed of sandstone. They are oriented in a northeast-southwest direction. Additionally, the subsurface area contains a sand dune with a long, flat expanse parallel to the seashore. This formation resulted from the accumulation of sand due to the influence of longshore currents and coastal waves. Over time, there has been both accumulation and erosion, leading to the formation of ridges and grooves. These features are frequently arranged parallel to the sea, following the coastal topography. The sediments have accumulated as loose sand, forming numerous successive layers [6].

2.2 Methods

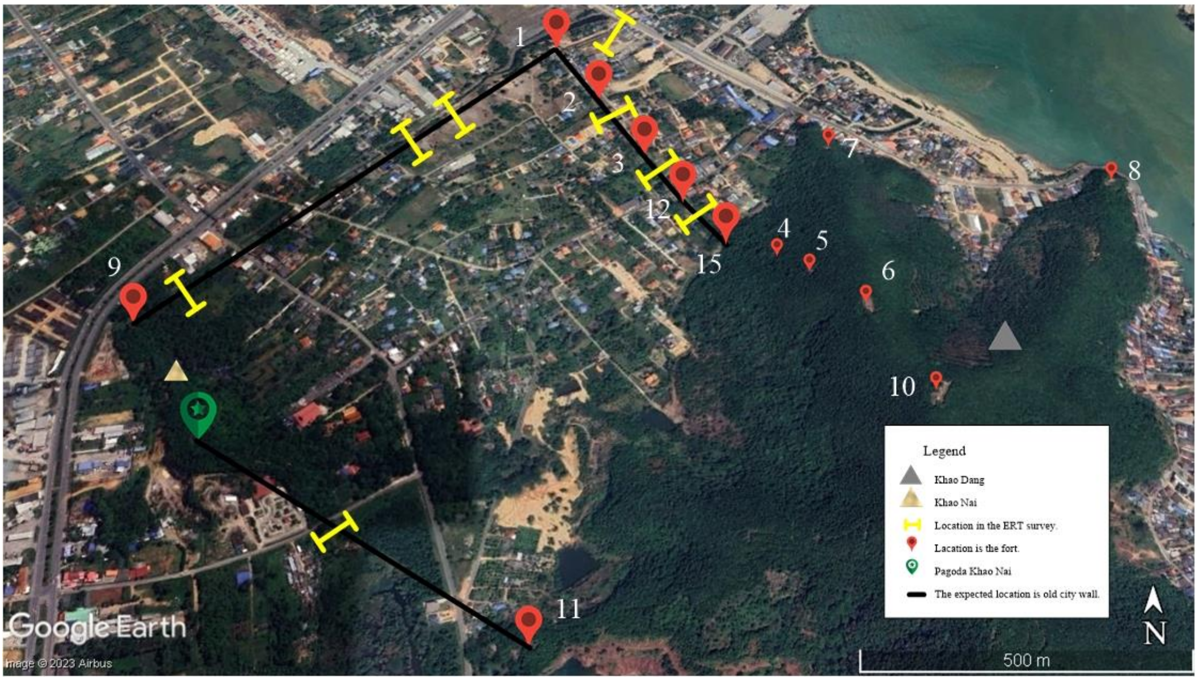

Fig. 3. Locations of ERT survey area (six zones) overlay on the Google Earth map. The yellow lines represent the two parallel survey lines in each zone. Only the zone 9, there are 6 survey lines.

In this study, the survey was designed based on the map drawn by Monsieur de Lamare. The survey area was then divided into six zones (Fig. 3): (1) F12, the area between Fort 12 and Fort 15; (2) F2, the area between Fort 2 and Fort 3; (3) F9, the area between Fort 9 and Fort 1; (4) F11, the area between Fort 11 and the pagoda Khao Noi; (5) F1, the area near the city wall remnants; and (6) F3 the area between Fort 3 and Fort 12. There are totally 16 survey lines. ERT data was performed by dipole-dipole array (Fig. 4) together with Lund Imaging System and ABEM Terameter SAS1000. The short-32-protocol file (Fig. 5) was used to conduct the measurement with the smallest electrode spacing distance between the dipole pair (C1C2 or P1P2), a = 1 - 3 and n = 1 - 6. This protocol gives 356 measuring points of apparent resistivity, and the vertical depths of plotting points are 0.416a, 0.697a, 0.962a,1.220a,1.476a, and 1.730a for n= 1- 6 respectively [7].

Fig. 4. Dipole-dipole array for resistivity measurement. C1 and C2 are current electrodes, P1 and P2 are the potential electrodes. The distance between the dipole pairs (C1C2 or P1P2) is a, whereas n is an integer equal to 1 - 6.

Measuring of electrical resistivity with dipole-dipole array by injecting direct electrical currents into the ground via the pair of current electrodes and measuring the voltage difference (ΔV) between the pairs of potential electrodes. The apparent resistivity (ρ_a)data from the field investigation can be calculated from Eq. 1

$$\rho_a = \pi n(n+1)(n+2)a\left(\frac{\Delta V}{I}\right) \quad (1)$$

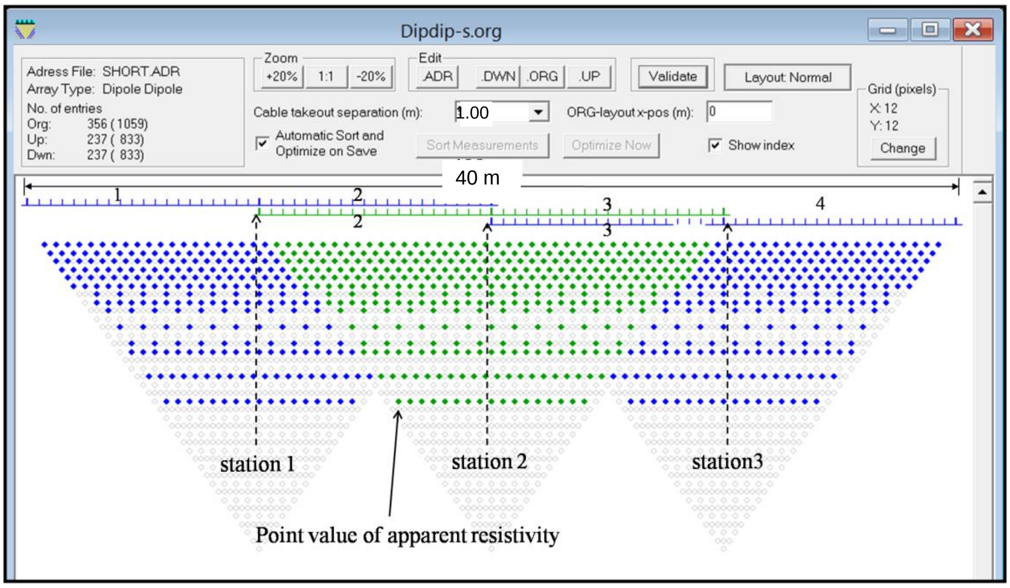

Fig. 5. Short protocol for dipole-dipole array resistivity measurement. Starting measurement with 2 spreads of electrodes (2 and 3), the measured apparent resistivity was then plotted in green points color. For an extension of resistivity data beneath the profiles (blue points color) the upward or downward spread needs to be performed.

Two-dimensional resistivity models were constructed using the inversion program RES2DINV version 3.41c [8]. This program creates a model of resistivity in a pseudosection and adjusts this model to fit the measured data by applying a non-linear least squares optimization technique [9],[10]. The resolution in the model is here decided by setting the thickness of the first layer of blocks at 0.9 times of the electrode spacing (a). The thickness of the subsequent deeper layer was set to increase by 10%. In the optimization procedure, the program tries to get the best fitting by adjusting the resistivity of the model blocks to minimize the root-mean square (RMS) error. We tried to force the program to calculate models with RMS error lower than 5%. The best possible models were considered when the RMS error did not change significantly, which usually occurred between the 5th and 9th iterations of calculation. However, models with small values of RMS error sometimes might not represent the best models of the geological features. Therefore, geological information in the area had an important role for the choice of the best model. For some models, the RMS error was never lower than 5% because of noises in the raw data. Nevertheless, all models have RMS errors lower than 5% and these model files were then saved for more sophisticated contouring by the program Surfer 8 [11].

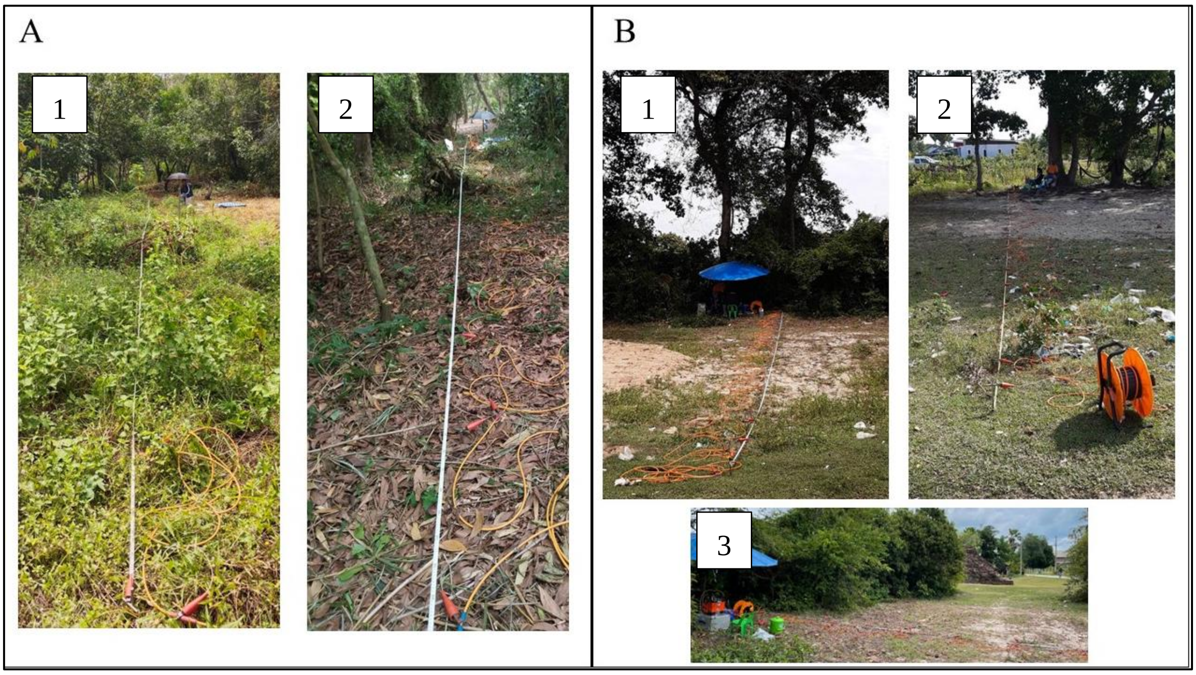

Fig. 6. Showing some survey lines in the study area: (A) zone F9, line F0903 (A1), line F0904 (A2) and (B) zone F2, line F0201 (B1), line F0202 (B2). The location of Fort 2 can be seen in Fig. B3.

3. RESULTS AND DISCUSSION (Example results)

The result from Zone F9, the area between Fort 1 and Fort 9, two inversion models of lines F0903 and F0904 are presented in Fig. 7. They found a similar pattern of subsurface resistivity distribution. The subsurface layer can be divided into three major layers. The first layer (1) is the topsoil layer from the surface down to green color or dash-line (630 Ohm.m) with a thickness about 0 - 2.7 m and a resistivity ranges from 1,000 to 800,000 Ohm.m. This layer is possibly a sand layer due to the sand dunes is presented in this area. The second layer (2) of lower resistivity (red - yellow colors) ranges from 20 to 250 ohm-m, is presented at a depth from 2.7 to 4.6 m. It expects to be water saturated layer. The third layer (3) of high resistivity (green - blue colors) at a depth equal and greater than 4.6 m. It is a layer beneath the bottom dashed line. The resistivity of this layer ranges from 2,000 to 10,000 Ohm.m, which should be represented by the resistivity of sand layer.

Fort 2

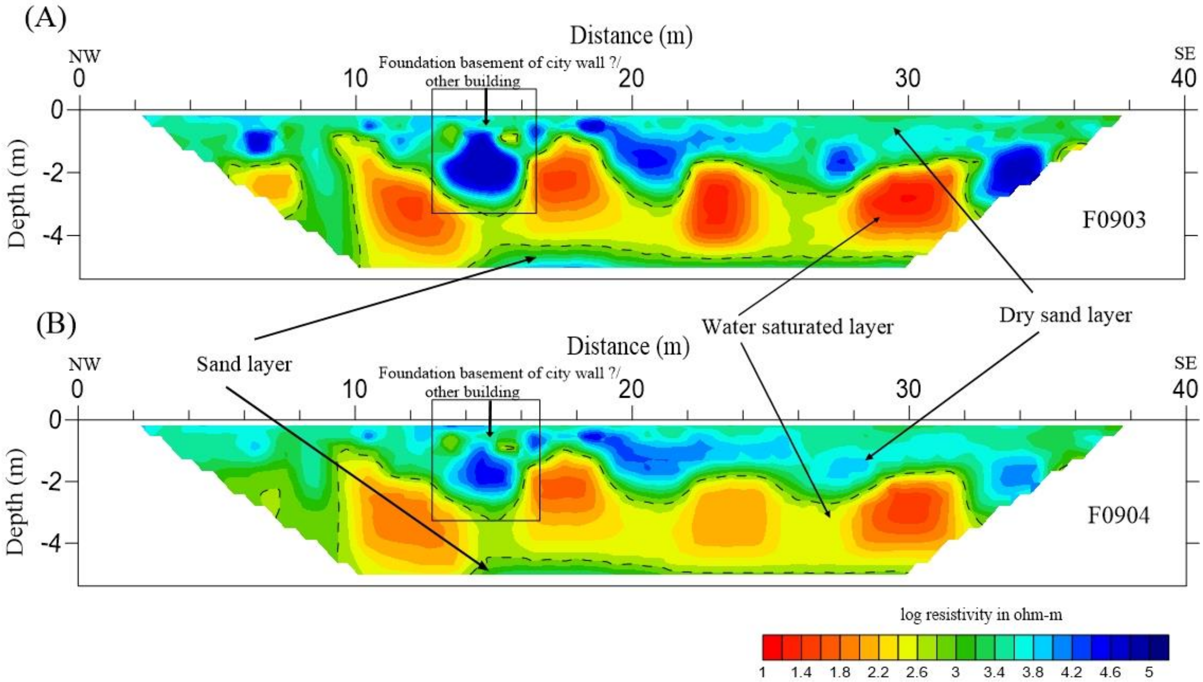

Fig. 7. Showing the inversion models of ERT dipole-dipole resistivity section in survey area F9, A) line F0903 and B) line F0904.

The pattern of high resistivity layer submerging into the low resistivity second layer is found at a distance of about 13 – 16 m on both lines F0903 and F0904 at a depth of about 2.5 m. This interesting pattern seems to be continuing from the lines F0903 to F0904 with interval about 30 m. It is thus possible to be the foundation basement of some kind of structures, which might be the footing of ancient city wall. At Fort 9, there is however no remaining evidence of ancient city wall such as brick or stone wall. It is probable that the city wall here might have been constructed with wooden logs. Therefore, these locations are recommended to be proved by archaeological excavation.

The result from Zone F2, the two parallel survey lines F0201 and F0202 located between Fort 2 and Fort 3 with an interval of 22 m. Their inverted resistivity models showed a similar pattern in Fig. 8. The subsurface here can be divided into two main layers. The first layer (1) of high resistivity, ranging from about 1,000 to 60,000 Ohm.m (green - blue colors) with a layer thickness about 0 - 2.7 m. The resistivity of this layer is probably represented the resistivity of sand, which is underlain by the second layer (2) of lower resistivity, ranging from about 18 to 250 Ohm.m (red - yellow colors). This low resistivity layer is thought to be completely saturated with water. The top of this layer is represented by the black dashed line.

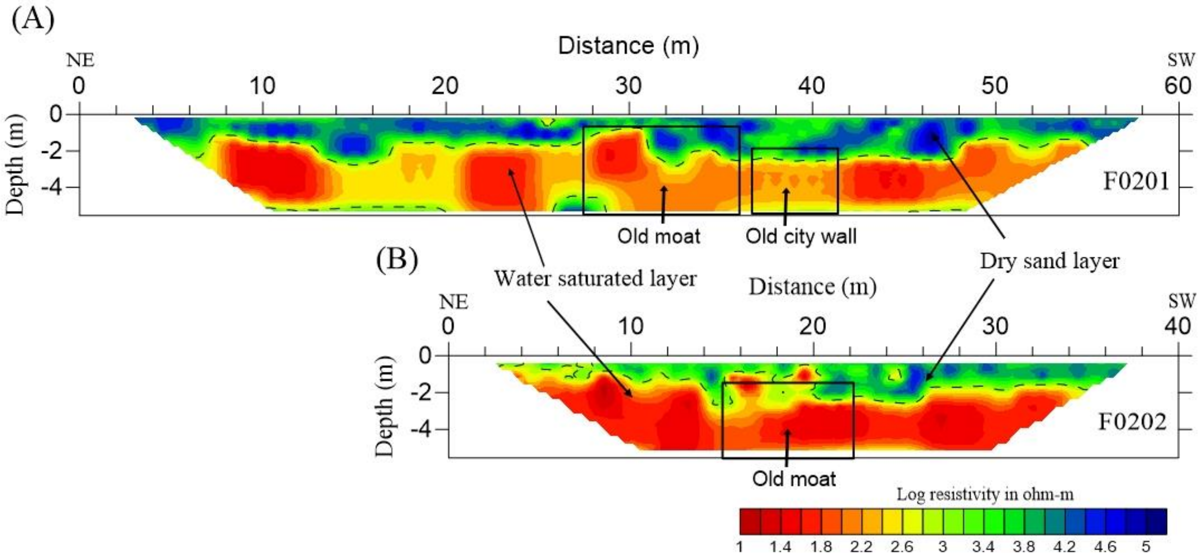

Fig. 8. Showing the inversion models of ERT dipole-dipole resistivity section in survey area F2, A) line F0201 and B) line F0202.

According to the subsurface resistivity distribution beneath the lines F0201 and F0202, the basement of ancient city wall at a distance of 37 - 41 m on the line F0201 can be determined. The resistivity pattern here is like a square block of 200 Ohm.m from depths about 2.7 – 4.3 m. It seems not to be disturbed underground zone. In addition, this kind of resistivity pattern could not be seen clearly on the line F0202. However, the similar pattern of low resistivity like a channel in the west side of the expected city wall can be seen on both survey lines at distance values of 27 - 36 m and 15 – 22 m on the line F0201 and F0202 respectively (square block). This channel pattern of low resistivity about 50 Ohm.m is probably the previous moat. This information coincides with archaeological evidence in the documents that provided by archaeologist at the 11th Regional Office of Fine Arts, Songkhla.

4. CONCLUSIONS

Geophysical surveys using electrical resistivity tomography (ERT) in the area of Khao Daeng, the old town of Songkhla were conducted. The results have demonstrated the ability of ERT to distinguish subsurface features, efficiently. The main target of investigation (basement of ancient city wall) and moat are expected to be mapped and the possible location can be located. The results of all resistivity sections show a similar pattern of three separated layers: (1) the first layer with higher resistivity values (1,000 – 800,000 Ohm.m), interpreted as topsoil or sand dune, (2) the second layer with low resistivity values (18 - 250 Ohm.m), interpreted as saturated or clay layer and (3) the third layer of high resistivity value, interpreted as sand layer (2,000 - 10,000 Ohm.m). The locations with the pattern of high resistivity of the upper layer submerges into the low resistivity layer on the survey lines F0903 and F0904 at a distance of about 13 – 16 m on both lines are possibly the foundation of ancient city wall or some kind of structures. For the low resistivity pattern close to the surface on the west side of the high resistivity foundation that found at 27 - 36 m and 15 – 22 m on the lines F0201 and F0202 respectively, are probably an old city moat.

Based on the evidence, the ancient city wall was mostly disappeared, and available information of city wall is limited. The results of this ERT study provide subsurface information related to archaeological evidence in the site, including possible location and depth, which will be useful for future archaeological excavation.

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