Application of electrical resistivity tomography (ERT) in archaeological investigation of Chengsijiazi Ancient City ruins

Zhonghua Xin1, Lijia Liu1,2,*, Jiangtao Han1,2 and Huili Liang3

1 College of Geoexploration Science and Technology, Jilin University, Changchun, China
2 Key Laboratory of Applied Geophysics, Changchun, China
3 Jilin Provincial Institute of Cultural Relics and Archaeology, Changchun, China
E-mail: 505525448@qq.com

Abstract. The electrical resistivity tomography (ERT) has the characteristics of low cost, high efficiency, rich information, non-destructive exploration, and large detection depth. At present, it is being widely used in archaeological exploration. It can provide a more accurate result whether it is the preliminary survey delineation or the later detailed exploration. Chengsijiazi ancient city, located at the bank of Tao’er river, was built during the Liao and Jin dynasties. Except for the western wall destroyed by the river, the rest of the city walls were well preserved. The main target body of this survey is a part of wall foundation of an ancient building in the ancient city ruins. The ERT data are acquired along 55 survey lines and the horizontal differential field line method is introduced to interpret the inversion results of the measurement data. The horizontal differential field line method could more accurately describe the structure and boundary characteristics of the target body. The ancient building wall foundation is characterized by obvious high-gradient dense field line, so that we can accurately delineates the position of the wall base, which was excavated by archaeologists and has been verified.

1. Introduction
The traditional archaeological investigation mainly relies on identifying the soil brought by the Luoyang Shovel and the intuitional display information of the test pit. However, the formation, such as sandstone, gravel and water layer, will bring great difficulties to the traditional archaeological drilling, and the interpretation of samples obtained by Luoyang Shovel requires researchers with rich experience. The excavation of test pit is time-consuming, labor-intensive and lack of purpose.

Geophysical exploration has already been applied to the archaeological investigations since 1938 [1]. Because of low cost, high efficiency, rich information, non-destructive exploration, and large detection depth, it is currently widely used in archaeological surveys. Different detection methods can be implemented for different target bodies, which can accurately give the location, scale and framework of ancient architectural relics or tombs. It provides important clues for archaeological investigation.

The electrical resistivity tomography (ERT) is mainly based on the electrical differences between the remains and surrounding media, such as burial chambers and surrounding rocks, wood and soil, rammed soil and ordinary soil [2]. Therefore, the ERT shows its effectiveness in detecting the distribution of tomb Chambers, tomb passages and caves, the location of ancient architectural sites, ancient city walls, and ancient river channels [3]. Rammed soil is the major building material in
ancient China, such as city walls, palaces, and large mausoleums, especially their foundation parts, almost all of which are made of rammed soil [4]. Rammed soil refers to all kinds of compacted clays. Through artificial tamping, the rammed soil has lower porosity and lower water content than the surrounding soil, resulting in higher resistivity. The cavities, including the grave chamber and the grave road, also show obvious high-resistance characteristics in electrical properties. If it is backfilled with soil and filled with fluid, it shows low-resistance.

The study area is located in the Chensijiazi Ancient City site in Baicheng City. The exploration target is the historic building and the wall foundation, which is basically constructed of rammed soil. Combined with the known archaeological information, the location of the wall base was determined by the data from 55 ERT survey lines.

2. Overview of Chensijiazi ancient city ruins

Chensijiazi ancient city ruins is located in Deshun Mongolian township, Taobei district, Baicheng city, Jilin Province, as shown in Figure 1. It is one of the three ancient cities of the Liao and Jin period in Jilin Province and western Heilongjiang Province, located on the northern bank of Tao'er river, the river meanders from the northwest to the southeast [5]. The ancient city is roughly square, with a circumference of 5748 meters. A 5-7 meters wide artificial moat remains outside the city wall, which had been filled with the Tao'er River water, is dry now. Some parts of the moat are still faintly visible today. Except for the western wall which was destroyed by the river, the rest of city walls were mostly intact, with an average height of 5-9 meters, a top width of 1.5-2 meters, and the base width of the city walls ranging from 20 to 27 meters. They were built by tamping down loess and black soil (Yang, 2001). The flat ground in the city, which had been covered with bricks and ceramic fragments, is farmland now. On the ground, there are many soil mounts of varying sizes. They are spherical or ellipsoidal with the height of 0.5 to 3 meter [6].

![Figure 1. Geographical location of Chensijiazi ancient city ruins.](image)

Since 2013, Jilin Provincial Institute of Cultural Relics and Archaeology has carried out multiple archaeological investigation on the sites. By drilling and excavations, a large number of ancient remains have been revealed. The remains mainly consist of historic building foundations, house courtyards, roads, etc., mostly constructed of rammed soil with some auxiliary materials such as blue bricks and stones.

At the intersection of the main roads leading to the four city gates, there is the largest soil mount in the city, which is also the highest point in the city. Through artificial drilling, it has been confirmed as
a compacted soil construction platform base, and its significance in the city site can be reflected from its scale and location. Therefore, we chose the front area of the mound to carry out the survey.

The surface fluctuation of this area is small and the nature of the remains is unknown. Artificial drilling in the past has preliminary learned that there are artificial relics such as roads. However, due to the poor preservation conditions, it is impossible to accurately grasp the pattern of artificial traces. In order to further understand the buried situation of the underground remains in the area, geophysical exploration was carried out in 2016. The geophysical exploration area is about 28,080 square meters, ranging from the southern edge of the building platform base in the north to the south gate of the city site in the south.

### 3. ERT data acquisition

The survey lines of ERT are arranged as perpendicular to the direction of the anomalous body as possible, and the line length is longer than the length of the survey area. Electrode spacing ensure that there are at least 1-2 observation points on an abnormal body. The detection depth is greater than the thickness of the Quaternary soil layer in the survey area. The line spacing is adjustable, but less than twice of the point spacing.

Based on the above principles, the survey lines are arranged in NE direction, which cut the suspected roads, courtyards, and buildings. We set up survey line 0 at first, and the survey lines on the north of line 0 is named by even number, respectively line 0, line 2 ... up to line 58, with a point spacing of 2m and a line spacing of 2m; the survey lines on the south of line 0 is named by odd number, respectively line 1, line 5 ... up to line 97, with a point spacing of 2m and a line spacing of 4m. There are 55 survey lines in total, and the position distribution of the test lines is shown in Figure 2. Each survey line is measured in two electrode arrays, Wenner array and dipole-dipole array, which have different device coefficient, and 55 × 2 groups of data are obtained.

![Survey lines distribution diagram](image)

**Figure 2.** Survey lines distribution diagram.

### 4. Horizontal differential field line method

The structure of geological bodies generally cannot be clearly distinguished by traditional inversion methods. In this context, we introduce horizontal differential field lines method to improve the abnormal body recognition.

The horizontal differential field line technology uses the distribution characteristics of the current
lines to describe the structure of the geological body on the premise of the Schlumberger array measurement. In the subsurface, the electrical field intensity direction of shallow point between electrodes M and N (the measurement area) can be regarded as horizontal, and the size is equal everywhere, as shown in Figure 3. If the underground is a homogeneous media, the current lines are evenly distributed. But if the current density has changed, it means that there is an abnormal body that interferes with the normal field.

The microscopic Ohm's law vector equation is expressed as:

\[ \vec{j} = \sigma \vec{E} \]

\( \vec{j} \) is the current density, \( \sigma \) is the media conductivity, and \( \vec{E} \) is the electric field intensity. When there is a high-resistivity body, the conductivity decreases, the electric field intensity is constant, and the current density is reduced. In the surrounding rock, the current density is relatively large, so a dense closed field line surrounds the high-resistance body. The low-resistivity body does not have the characteristics of field line surround, so as to distinguish the shape of the abnormal body.

5. Discussions

In order to find the rammed soil foundation and other remains, which are buried shallowly, we select the horizontal slice of the results which can reflect the characteristics of the electrical abnormal bodies at the depth of 1-3m underground. The Wenner array has a higher resolution for the vertical change of resistivity, which can be processed by the differential field line method. The dipole-dipole array is more sensitive to the lateral change of resistivity [7], but does not meet the conditions of the differential field line method. So we select the horizontal slice of the apparent resistivity inversion result by the dipole-dipole array (Figure 4) and the horizontal slice of the differential field lines result by the Wenner array (Figure 5) to compare and analyze.

Figure 4 directly reflects the electrical distribution of the underground media, but the description of the shape and boundary of the anomalous body is fuzzy. Figure 5 describes the structural features of the underground in more detail and finely, and the horizontal distribution of the abnormality is more prominent.

The distribution of electrical features of Figure 4 and Figure 5 are coincident. In the survey area, the high-resistance anomalies and high-gradient field lines are obvious, which show a relatively regular geometric shape. The high-resistance strips are parallel which conforms to the layout of the buildings in the town site, and is likely to be the display of house foundation and wall site.

The northernmost part of the survey area is a banded anomaly in the NE direction, which is shown in both figures and is relatively continuous. It is located near the edge of the largest platform base in
the city, which may be a wall base of building or a road. The south is a series of rectangular frames surrounded by high-gradient strips. The structure is blurred in the apparent resistivity inversion slice, but the boundary is clear in the horizontal differential field line slice. It is presumed to be buildings such as houses, facing southeast, and there may be connectivity between buildings. There is a wide continuous strip with high gradient in the southernmost part, which is northeast trending, near the southern city wall. It is possible to be a rammed soil structure underground.

At the location of the wall foundation given by the interpretation of this paper, archaeological investigation was carried out in the later stage. Through the excavation of the exploratory pit, the target wall foundation was found at the conclusion position.

Figure 4. Horizontal slice of apparent resistivity inversion results by the dipole-dipole array.
6. Conclusion

This geophysical survey found out the underground structure of the survey area, and depicted the accurate location of the wall foundation. According to the horizontal slices by apparent resistivity inversion and horizontal differential field line method in the survey area, combined with the geological and geomorphological information, the following conclusions are drawn:

1. The continuous high-gradient strips in the northernmost of the survey area, which is northeast trending, may be roads or the wall foundation of buildings.
2. A series of rectangular frames surrounded by high-gradient strips in the middle of the survey area are speculated to be houses facing southeast, and there may be connectivity between each house.
3. The wide north-east high-gradient continuous strip near the south city wall may represent an abundant of rammed soil structure underground.
4. ERT can effectively detect the archaeological targets and give accurate results, and the horizontal differential field line method show its effectiveness in the description of the edge and trend of anomalies in shallow subsurface.

Acknowledgements

This work was supported by the field geophysical and archaeological exploration of Jilin Provincial Institute of Cultural Relics and Archaeology (3S318B564423), the National Key Research & Development Project (2017YFC0601305), Fundamental Research Funds for the Central Universities.

References

[1] Bevan B W 2000 An early geophysical survey at Williamsburg Archaeological Prospection 7(01) 51-58
[2] Yang H and Lv X 2008 Application of high density electrical and high precision magnetic method in archaeological field North China Earthquake Sciences (in Chinese) 26(3) 57-59
[3] Ma X, Yang L and Niu S 2017 Qicheng administration of cultural relics and CASS: a case study of the Qicheng site, Henan Cultural Relics of Central China (in Chinese) 02 92-99
[4] Yan Y, Di Q and Gao L 1998 Application of high density resistivity method in archaeological exploration Geophysical & Geochemical Exploration (in Chinese) 22(06) 53-58
[5] Liang H 2019 On Chengsijiazi the ancient city Northern Cultural Relics (in Chinese) 04 36-41
[6] Liang H, Zhang D and Xie F 2016, The excavation of the platform foundation of a building in the Chengsijiazi walled city site in Baicheng city, Jilin province Cultural Relics (in Chinese) 09 39-55+1
[7] Sun X and Wu H 2011 Comparison of different devices for high density resistivity method China New Technologies and Products (in Chinese) (09) 11