Resistivity profiles and foundation structure of Central Tower in Bayon Temple, Angkor Thom

Koichi NAKAGAWA(1), Yoshinori IWASAKI(2) Makoto ARAYA(3)
Shunsuke YAMADA(3), Ichita SHIMODA(4), Takeshi NAKAGAWA(3)
and Tomofumi KOYAMA(4)

(1)Faculty of Science, Osaka City University,
E-mail:knaka@sci.osaka-cu.ac.jp
(2)Geo Research Institute, (3)Waseda University,
(4)University of Tsukuba, (5)Kansai University

Abstract

Electric exploration survey was conducted to study the foundation structure of the Central Tower of stone masonry in the Bayon Temple, Angkor Thom. Masonry structures were constructed upon manmade filled terrace with three different levels. The Central Tower of 31m in height stands upon the top level of the terrace of 11m in height from the ground. Several borings which consist of vertical, oblique and horizontal drillings under the central tower area preceded the electric study to grasp the foundation features. Past studies in this area have clarified the outline of the underground structure. By those results, it is known that the filled terrace of the tower foundation consists of compacted soil, artificially sundried laterite and floor sandstone above natural Holocene ground. The laterite block is more rigid mechanically than the compacted soils or the original soils in the area.

Four poles type measurement technique for the electrical survey was adopted at several sites. The measurement lines were set on the upper terrace radially and circularly to the axis of the Central Tower.

A unit spacing for the electrodes was 1.5 meter. A piece of aluminum foil with conductive paste was applied to surfaces of the floor stone as an electrode. Magnitude of the resistivity obtained from all measurement ranges in common values from order of 10 to 1000 ohm meter. The resistivity profiles were carried out by the inversion in terms of the finite element method.

The higher resistivity parts were corresponding to the laterite blocks. The resistivity profiles and the boring core correlation were rather consistent. Those results lead a hypothesis that a donut-shaped laterite mass with about 36 meters in outer diameter, 28 meters in inner diameter and 6 meters in thickness should exist beneath the sub-tower and gallery zone surrounding the central tower.

One of the present objects is to confirm the feature of the existing laterite ring structure. The profile along the circular measurement line above the laterite ring suggests that the distribution of laterite block is not uniform shape and the laterite blocks lack under the east part of the sub-tower and the gallery. This result may give important information to the discussion on the stability problem to restore the foundation mound supporting considerable loads of the stone towers.

Keywords: Electrical survey, Resistivity, Foundation structure, Bayon Temple

1. Introduction

The Bayon located in 10km north of Siem Reap is renowned as one of the most famous Angkor temples. The most distinctive feature of the temple is a unique architectural display of giant stone carvings of faces on the many towers which jut out from the upper terrace and cluster around its central peak (fig.1).

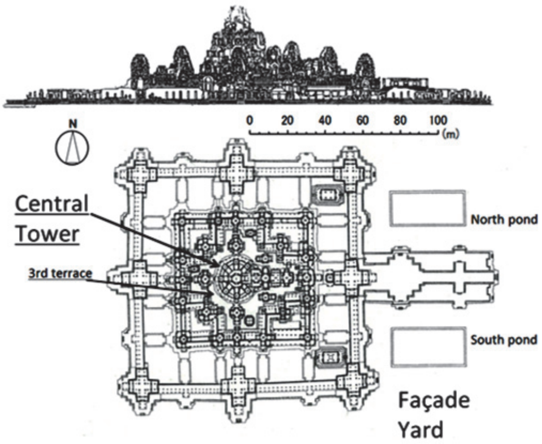


Fig.1 General Plan and Section of Bayon

Those monuments are in half ruined condition with suffering from the deformation of the foundation and the damage by weathering. Accordingly, JSA (Japanese Government Team for Safeguarding Angkor) has been engaged in the conservation and restoration work for the Angkor Thom.

Seven drillings with one vertical, two oblique and four horizontal axes were performed inside the inner gallery in 2011 to 2012 to examine the geotechnical conditions of the ground (Fig, 2). Those drillings suggest an extent of laterite mass with thickness of six meter beneath flagstones that were laid on the surface.

Electrical survey was recognized as one of the useful tools to study underground structure in Angkor. Some electrical surveys in this area have been carried out (Sugimoto et al., 2007, Nakagawa et al., 2012). In the previous studies, an applicability of electrical survey to on the flagstone nondestructively and a general pattern of the resistivity distribution under the Bayon temple were examined. The results from those studies showed that a significant electrical prospecting on the flagstone becomes adequately possible by adapting sheet type electrode to stone surface and the laterite block has a higher resistivity than that of natural soil or compacted soil. In addition, a ring-shape structure of the laterite in the foundation surrounding the central tower was assumed from considering the correlation between the resistivity profile and drilling core data. In the present study, the electrical prospecting was planned to clarify the underground structure, especially, the configuration of the laterite ring body which is important to discuss on the stability of the foundation.

2. Measurement

Four poles type measurement techniques called Wenner's and Eltran's techniques were adopted at the all measurement sites. Electrode array pattern of

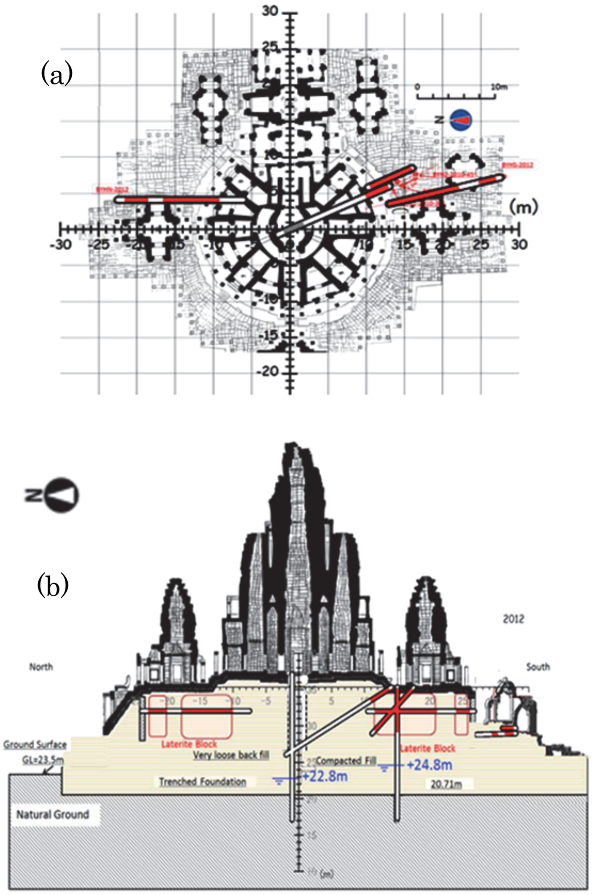


Fig. 2 Plan (a) and North-South section (b) of the area of tower cluster and gallery, and the distribution of laterite bodies estimated by the directive drilling correlation (Red segments show lateritic part of the core).

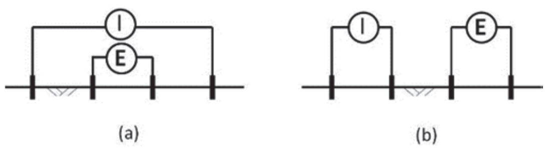


Fig. 3 Electrode array of typical four poles technique (a) Wenner's technique (b) Eltran's technique Symbol; I: electrodes to measure the current, E: electrodes to measure the potential

those techniques is shown in Fig. 3. The Wenner's technique is adequate to extract the continuity component of the underground structure. Contrastively, the Eltran's technique is adequate to extract discontinuous component. The resistivity profiles were analyzed by inversion in terms of the finite element method. The minimum interval of the electrodes, that is, unit spacing is 1.5 meter. Number of electrode is twenty four and the length for a measurement line, therefore, is 34.5 meter.

Locations of these survey lines are shown in Fig. 4. In order to inspect the continuity and configuration of the laterite mass, survey lines were set across or along the top terrace where the laterite block was confirmed its existence beneath the flagstone by the drilling survey.

Electrodes of aluminum foil with conductive paste were used. Conductive paste was made by wheat flour with saline water. This electrode setting must be useful to decrease the contact resistance between electrode and stone surface.

3. Results

The resistivity profiles were obtained from the analysis of apparent resistivity by inversion in terms of the finite element method. Resistivity profiles obtained are shown in Fig. 5, 6 and 7. Fig.7 shows an example of different image by the result from different prospecting methods. All images in Fig. 6

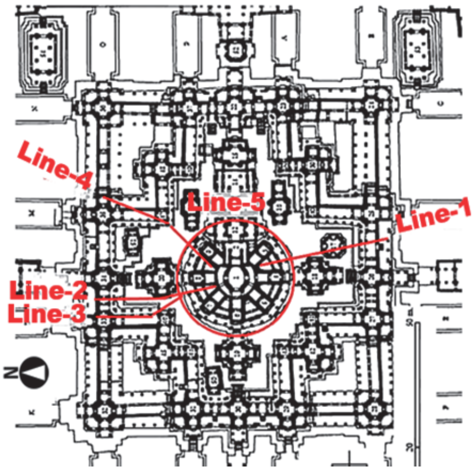


Fig.4 Layout of survey lines

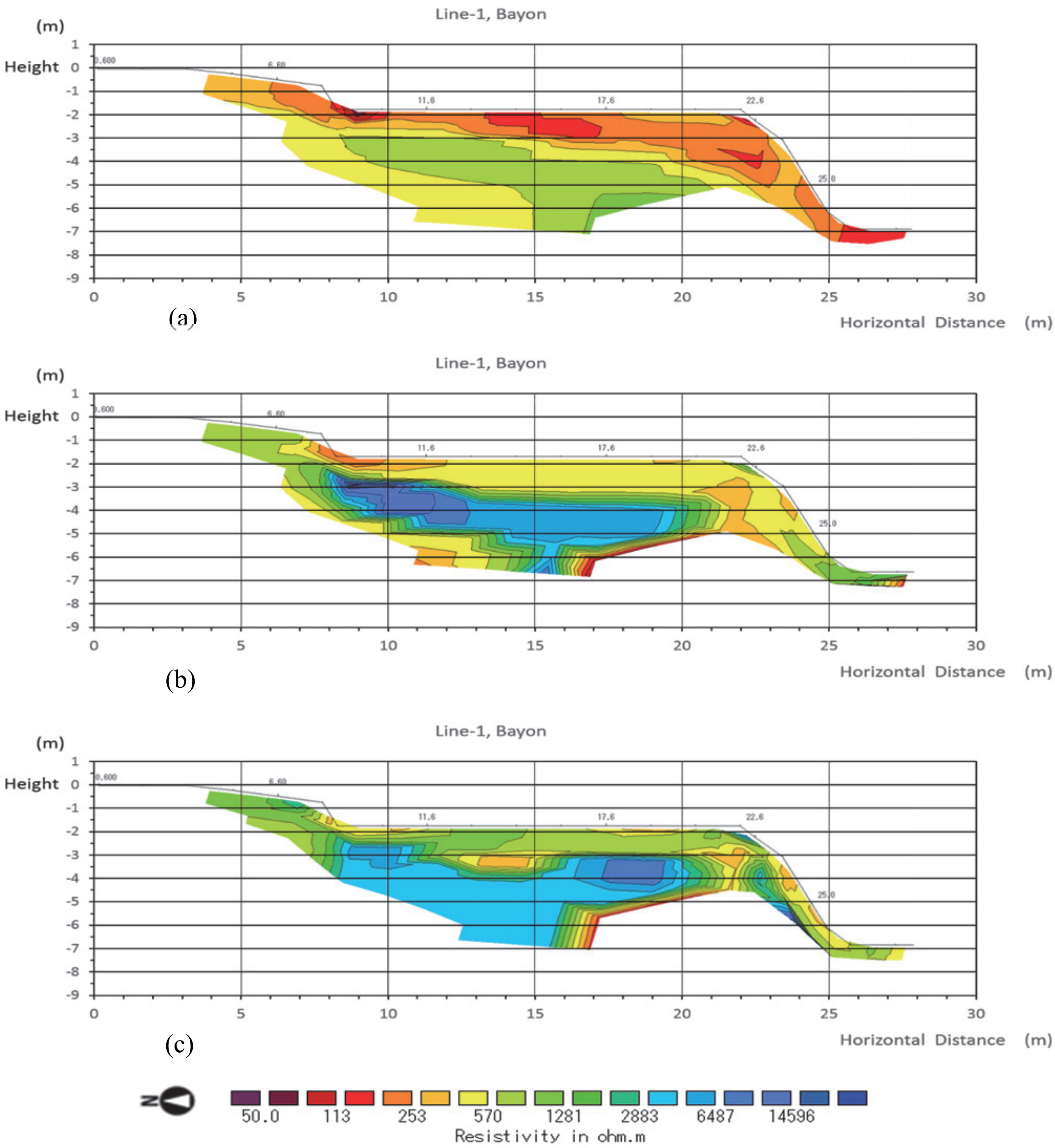


Fig. 5 Resistivity profiles determined from the different measurement methods
(a): Wenner's technique, (b): Eltran's technique, (c): Hybrid technique intergrading them

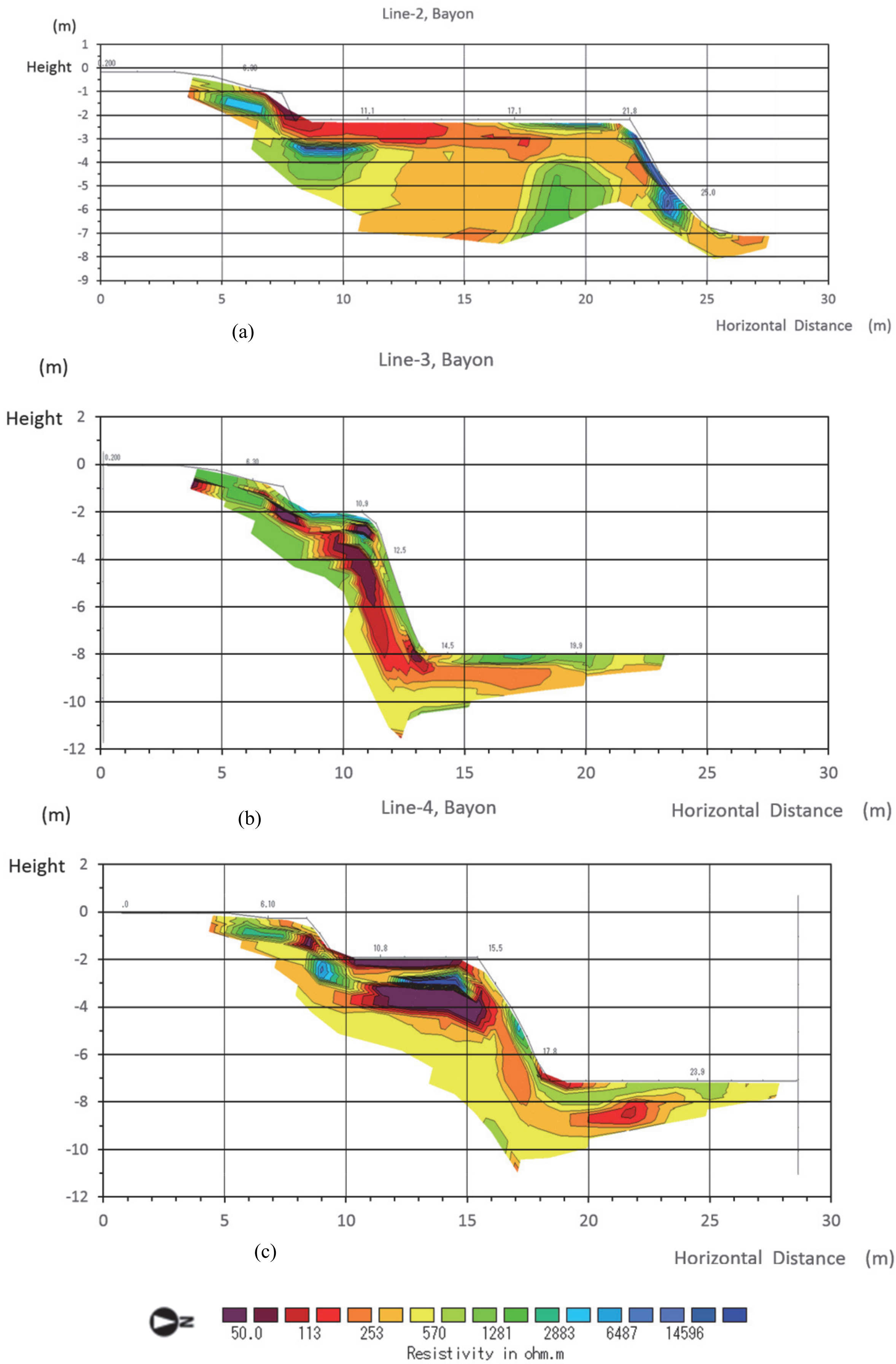


Fig. 6 Resistivity profile (a): Line-1, (b): Line-2, (c): Line3

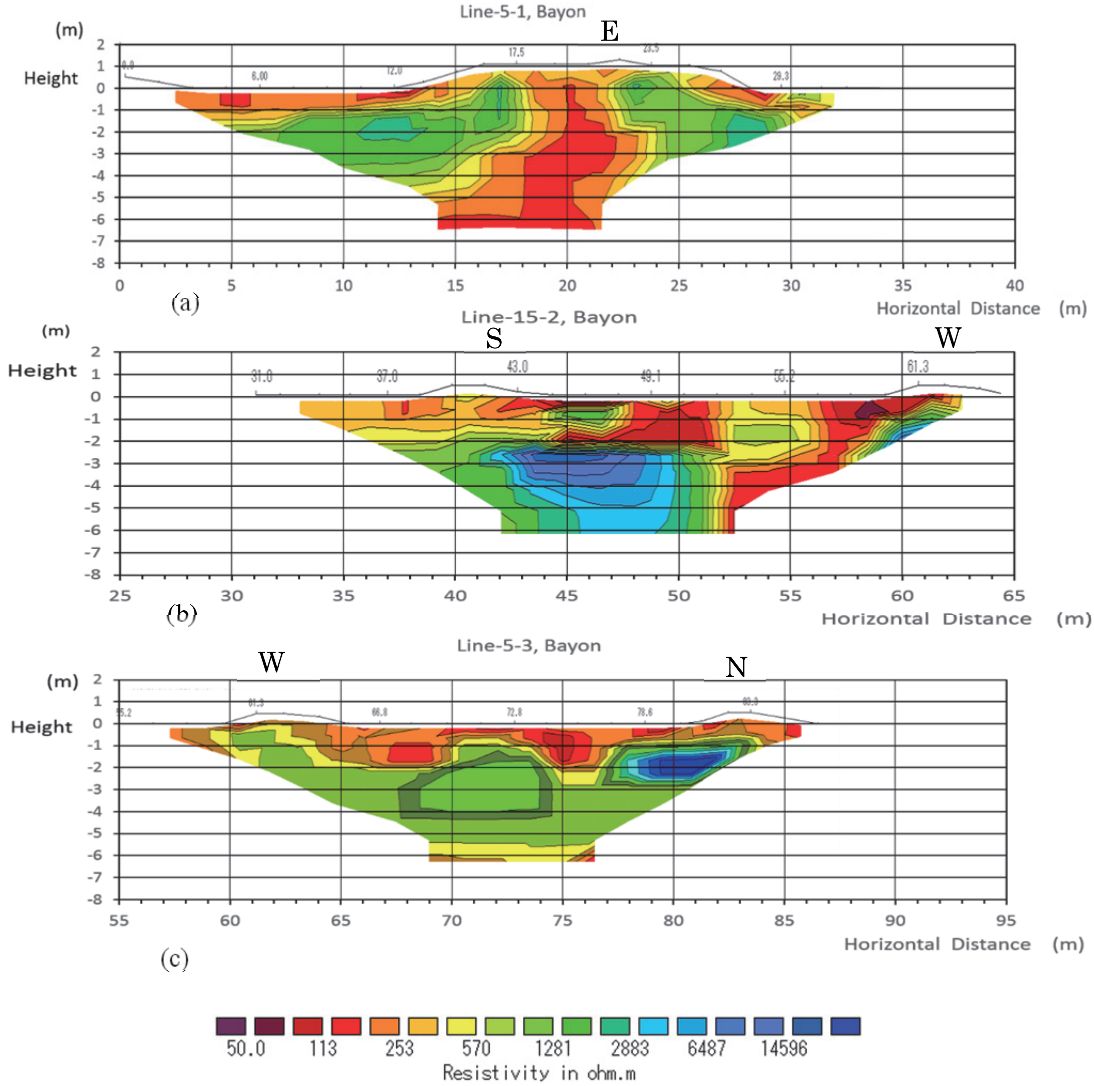


Fig. 7 Resistivity profile (a): Line-1, (b): Line-2, (c): Line3
The location of each profile is shown in Fig. 8.

and Fig.7 are of the profiles analyzed from integrating with both methods of Wenner and Eltran. The magnitude of resistivity ranges from several tens to about two thousand ohm･meter

4. Discussions

There is a slight difference between profiles obtained from Wenner's and Eltran's techniques as shown in Fig. 7. The difference of absolute resistivity, however, is not so large, not more than a factor of two or three. A comparison of the present resistivity profiles with the distribution of laterite block of N-S section is shown in Fig. 9. As shown in the figure, absolute value of the resistivity in the northern section is lower than the southern section. It may relate to humidity of the ground depending with degree of sunshine. The correspondence between distributions of the resistivity and the laterite mass,

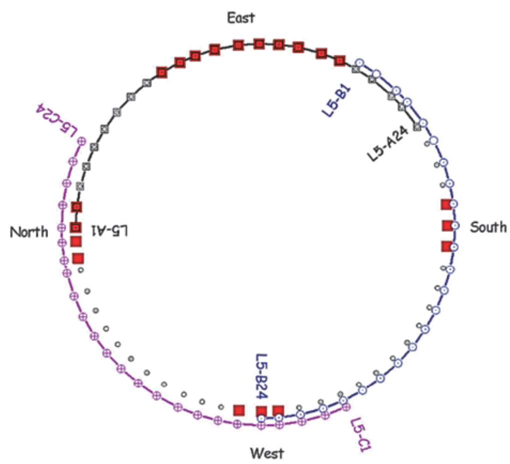


Fig. 8 Detailed layout of the survey line 5

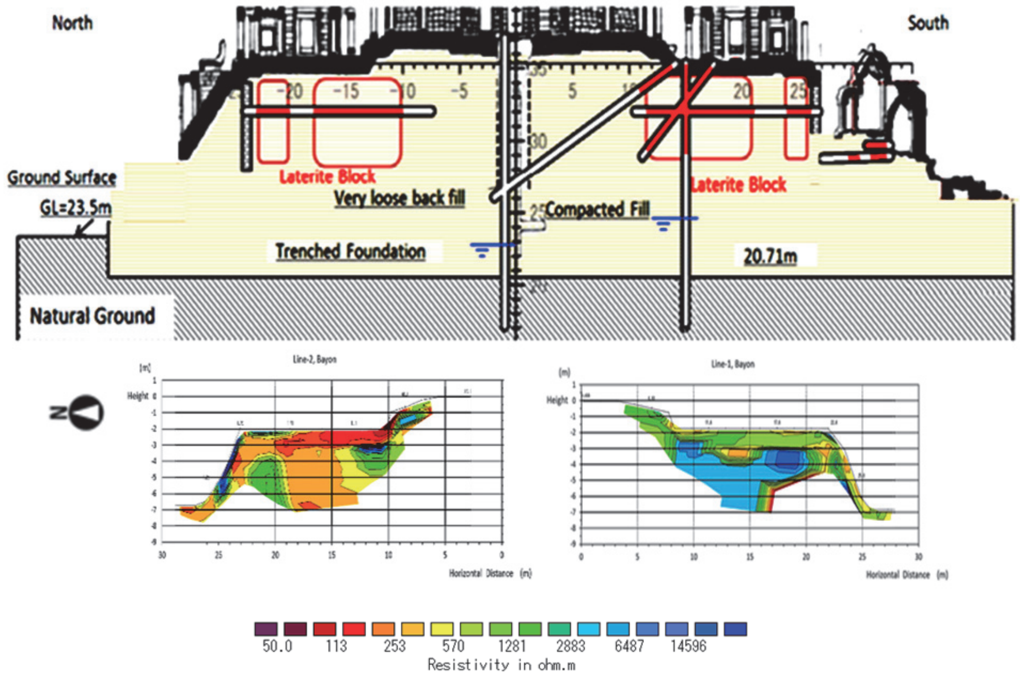


Fig. 9 Comparison between the geological section and the resistivity profile under upper terrace of the Bayon temple

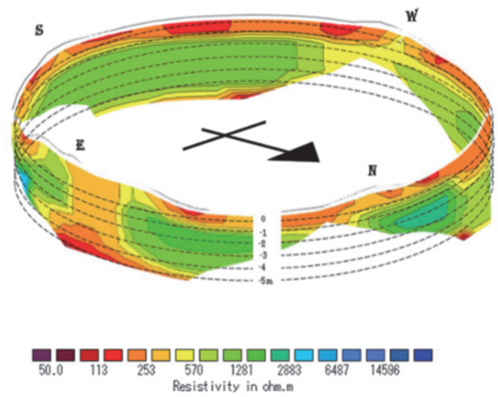
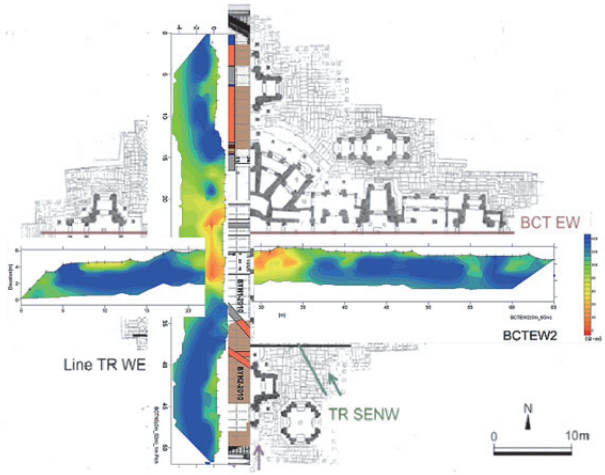


Fig. 10 A bird's eye view of the schematic resistivity profile image beneath the gallery surrounding the central tower obtained from analysis of the Wenner's array



Fig。11 Resistivity profiles of the N-S and E-W lines (from Nakagawa et al., 2012)

however, seems to be rather well. The laterite mass corresponds to relatively higher resistivity parts in the sections. The pattern of resistivity distribution in the N-S and E-W sections of the previous study (Fig.11 Nakagawa et al.) and Fig.9 suggested that underlain laterite mass is shaped into a ring structure. The present study performed to search the truthful shape of the laterite ring. The relating result is shown in Fig. 10 as a bird's eye image. As shown in the figure, a higher resistivity layer which seems to be laterite is underlain uniformly except the east segment of the region. It is possible that the ring is not a true circle but an ellipse so that layout of the whole monuments is non symmetric to the axis of central tower and the eastern buildings are grant with front gate. Accordingly, present measurement line may put out from the elliptic ring of laterite.

5. Conclusion

Electrical survey was conducted on the flagstone over the gallery surrounding the central tower of Bayon. Measurement lines were developed radially and circularly to the axis of the central tower. Those sites are underlain the laterite blocks. Results obtained by inversion analysis as follows;

(1) The practical Electrical prospecting is possible on the flagstone nondestructively.
(2) The correspondence between the resistivity profile obtained and the geologic structure from drilling data is rather consistent.
(3) Resistivity of the laterite block ranges order of 10^2 to 10^3 ohm・meter which is larger than the other kinds of soil at the site.
(4) The higher resistivity layer which is inferred to corresponding to the laterite block was not continuous uniformly in the section along circular measurement line on the gallery.
(5) There is a possible that the laterite ring structure is not circular, but elliptical.

Acknowledgment

A part of this work was supported financially by JSPS AKENHI Grant Number 26303010 (Grants-in-Aid for Scientific Research, Japan Society for the Promotion of Science; Principal Investigator: Tomofumi. Koyama).

References

Nakagawa, K., Shimoda, I., Yamada, S., Kanai, R., Ogawa, Y., Ohta, (Yasuda) Y., Fukuda, M., Jomori, A., Takahashi T. and Iwasaki Y. (2012): Resistivity profiles and foundation structure of Central Tower, Bayon in Angkor, Central Asian Geotechnical Symposium (IVth CAGS), Geoengineering for construction and conservation of cultural heritage and historical sites, Samarkand, pp333-338, ISBN 9789 94 31 1199 8

Iwasaki, Y., Fukuda, M., Haraguchi, T., Kitamura, A. Ide, Y., Tokunaga, T. and Mogi, K. (2013): Structure of Platform Mound of Central Tower Based upon Boring Information, JASA 2013 Report, 39p

Sugimoto, Y., Yamada, N., Tokunaga, T., Mohamed, N., Mogi, K., Ohnishi, K. and Iwasaki, Y. (2008): "Geophysical Prospecting Survey at the Bayon Complex" Annual Technical Report on the Survey of Angkor Monument, 2008, Safeguarding of Bayon Temple of Angkor Thom, JASA, published by JSA, Tokyo, pp.96-107