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Application of Ground-Penetrating Radar to Archaeological Remains in Wat Phra Si Sanphet, Central Thailand

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Abstract: The application of ground-penetrating radar was executed at Wat Phra Si Sanphet, located to the south of the Ayutthaya Royal Palace on the western bank of Koh Muang, Ayutthaya city. The aim of this study was to prove archaeologists' assumptions about the areas which expected that on the pathway of the western side of the temple and Wiharn Chaturamuk is the original area of the chapel. The GPR survey used the SIR 300 system connected to a 400 MHz antenna. The area under examination covered 28×16 m on the western side of the temple. A total of 24 GPR profiles was presented as time slice maps in 2D and 3D to identify the underground structures. The anomalies of GPR were confirmed by the excavation of the test units, revealing the archaeological remains at depths of 0.2 to 3 m DTL. The underground structures appear as a long brick pathway in the west-east orientation with a length of 5 m and connected to the base of the Wiharn.

Key words: Ground-penetrating radar, archaeological remains, 2D/3D GPR profile slices map, GPR reflection, Ayutthaya world heritage

INTRODUCTION

Wat Phra Si Sanphet is one of the best known Buddhist temples in Ayutthaya Province, central Thailand. It is located at 14°21' N latitude and 100°33' E longitude near the west bank of the Chao Phraya River (Fig. 1). It was constructed in 1448 AD within the Royal Palace grounds of the Ayutthaya Kingdom. Since, the middle ages until the end of the Ayutthaya Kingdom, it was an important royal temple where the King and his successors performed religious ceremonies. In addition, Wat Phra Si Sanphet is considered to be a model for the Temple of the Emerald Buddha in Bangkok.

In the western area of the Wat Phra Si Sanphet, archaeological remains were found which, according to the archaeologists, assumed that the modifications had been established in the late Ayutthaya period. In 1973, the Fine Art Department has archaeological excavations in the Royal Palace and Wat Phra Si Sanphet, there are points of interest assumed the walking path of Wiharns and Pagoda. Contributing to the assumed that the succesion of the building will happen two times (Kaewsaisoon, 2004). Next in 1983, Rungrujee (1983) has examined the premise around the structure of this pathway. The southwest of Wat Phra Si Sanphet between Wiharn Chaturamuk with the Pagoda found the remains of the pathway. It is expected to be connected the western group of Pagoda and Wiharn Chaturamuk. The construction made from bricks and improved two times, first at 1.2 m depth arranged in the north-south and second at 1.40 m depth arranged in the northeast-southwest. Aumthong *et al.* (1996) research in the excavation project ancient palace in Ayutthaya since, 1983-1996 describe the feature of the western walls and topless door of a wall called Patu Chongkoot which is in the middle, the western side of Wat Phra Si Sanphet. The walls have a width of 5.50 m and topless door of a wall height of 1.80 m.

The 3rd Regional Office of Fine Arts (1997) found the remains of the water supply system such as flume, storage tank, water pipe are parallel to the city walls in the north and the west. Which includes the diversion of water from the Lopburi river to the north side use for the Royal Palace. The Archaeologists estimate that the infrastructure of water supply system begins in the reign of King Narai the Great (since, 1656-1688). In fiscal year 2004 of the Bureau of Archaeology, Ruengted (2004) excavations found the brick drainage ditch at 1.0 m depth in the west and the east side transverse of the western wall, to utilize to drain out of the wall. The drainage system is coherent with the water supply system might come about simultaneously.

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Fig. 1(a-c): (a) Located map of Koh Muang, Ayutthaya, (b) General topography visualization in Ayutthaya and (c) Aerial view of Wat Phra Si Sanphet

The west area led to the forms of infrastructure planning such as the water supply system, the drainage system, a pathway for the entry and connect within the Royal Palace and Wat Phra Si Sanphet. In which surveys and excavations in this area have not used the geophysical studies. Tharaphong (1993), the director's office of archaeology explains the features of geophysical applications in archaeology which can be applied to work more conveniently in limited spaces. The optimal performance occurs at depths of more than 1-5 m and GPR is a method usually employed in archaeological studies. In Thailand, there is no conclusive evidence concerning the commencement of the use of the technique. At present, however, GPR is being used to detect artifacts at archaeological sites in Thailand in a number of interesting projects. The survey is a project that is initiating the use of geophysical method applied to the archaeological study. The expected to be beneficial to the development of the further exploration.

MATERIALS AND METHODS

Equipment and survey

Equipment: Ground-Penetrating Radar (GPR) is a geophysical method that basically uses radar pulses (high frequency electromagnetic waves) to visualize the subsurface construction. The aim of this's results section is to use the GPR images to document and enhance the internal structures of the natural and archaeological soil profiles. The GPR was undertaken at Wat Phra Si Sanphet, Ayutthaya, central Thailand during March 2012.

This study was based on the measurements from the SIR-3000 of Geophysical Survey Systems, Inc. (GSSI) using an antenna frequency of 400 MHz (the monitor of SIR-3000 and GPR set is shown in Fig. 2). An antenna frequency of 400 MHz is an excellent compromise between depth (2 m) penetration and vertical resolution of the subsurface construction. The SIR-3000 consists of a 4 volt DC control unit with 8.4' full-color display and 800×600 resolution control cable, the system was powered by a 15 volt DC battery. The reflections were recorded in real time and displayed on a monitor in the field to provide real-time data quality. During the survey, traces were collected every 2 m. The use and operation of processed radar profiles were performed using ReflexW Software version 3.

The GPR data were collected from the reaction of the radar propagation, reflection and scattering of high frequency waves (generally in the range 10-1000 MHz) which were appropriate for the target object in a soil profile with a depth of less than 5 m. The GPR reflections are conceptually simple, the objective is to measure field amplitude versus time after the excitement. The essence of a GPR system is the timing unit which controls the generation and detection of signals and the boundaries between elements with contrasting dielectric properties. This depends on the grain size distribution (sorting, clay content), porosity, water content and the electrical properties of the particles themselves (Knight and Nur, 1987; Davis and Annan, 1989; Annan *et al*., 1991). Therefore, GPR results depend on the soil type and its conditions (saturation degree, compaction, mineralogy, etc.) and also on the frequency of the antennas used.

Survey: The GPR survey lines at Patu Chongkoot (gate) were located in the middle of the western side of Wat Phra Si Sanphet wall (Fig. 3). They were connected to the Patu Pom Mum Sakaeo (gate) in the Royal Palace which formed the gateway entrance and exit for lords and ladies attending rituals in Wat Phra Si Sanphet. The alignment of

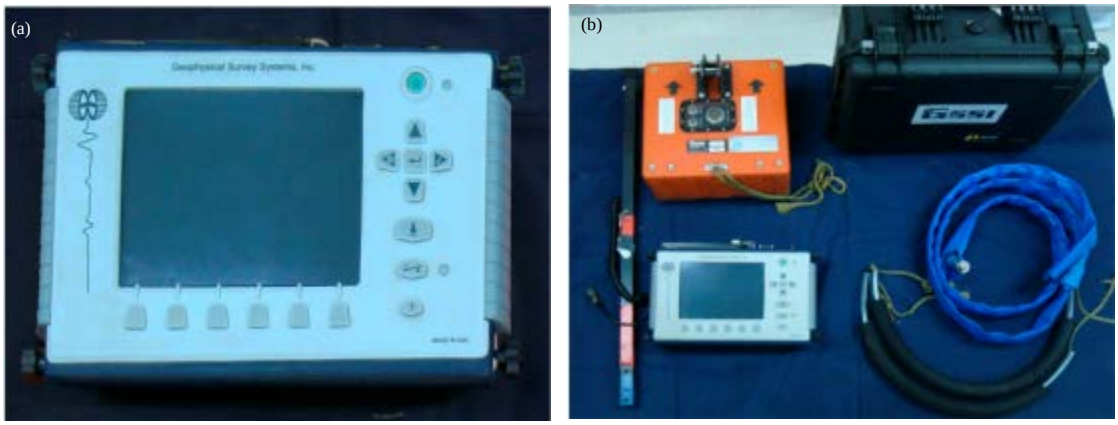

Fig. 2(a-b): (a) Monitor of GPR method (series SIR-3000), (b) GPR set with antenna 400 MHz

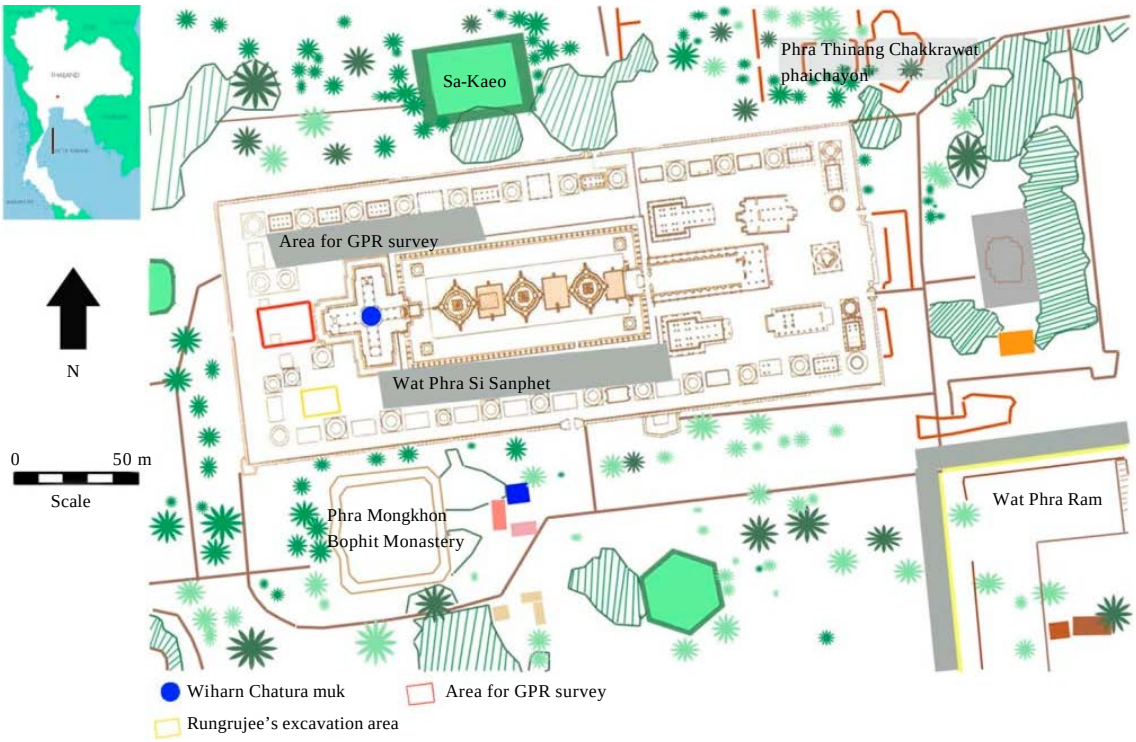

Fig. 3: A schematic drawing map showing the layout of Wat Phra Si Sanphet

survey lines in the north-south orientation were spaced 2 m apart and included 15 lines of 16 m in length. In the west-east orientation the spacing was 2 m with 9 lines of 28 m in length.

RESULTS

The general topography of Ayutthaya was a flood plain with an average height of about 7-12 m above mean sea level. The area was covered by a shallow marine clay which can be characterized as clay-rich sand/loam and wet, typical for the area under investigation. It has very high signal attenuation and the velocity of the signal is low. This makes the detection of GPR signals difficult (Hammon *et al*., 2000). Additionally, the high water content most likely resulted in a loss of resolution at greater depths (Theimer *et al*., 1994; Schultz, 2007).

The reflection of radar waves in the study area relies on the different types in the contrast between clay and brick. Figure 4a (left) shows the 2D time slice map rendering of the line 1-9 in the west-east orientation, length 28 m. Figure 4a (right) shows the 3D image which is the sum of the 9 lines with the pathway shown in purple and the Wiharn base indicated in the white zone in the longest continuous axial X. Figure 4b (left) shows the 2D time slice map rendering of the line 1-15 in the north-south orientation with a length of 16 m while Fig. 4b (right) shows the 3D image which is the sum of the 15 lines. The cross-sectional area of the pathway bricks is depicted in purple in the vertical of axis Y. The above image is a total reflection of the GPR profiles along the X and Y axis intersections of the 24 lines (axis Z) and can be described relative to the identification of the construction pattern at Patu Chongkoot (gate) in the excavated areas of underground structures (Fig. 5). The results of the 2D and 3D GPR profile slice maps showed that for the brick pathway in the west-east (alignment with survey lines), the depth ranged from 0.2-2 m, especially at high concentrations in the range 1-1.2 m DTL.

The reflection of the GPR signal in Fig. 5 can be compared with the results of archaeological excavations as follows: Zone A is a 7×7 m Wiharn bases at 0.2-0.8 m depths, zone B is a cement water pipeline at 1.0 m depth, though to have been placed after the Wiharn had collapsed on the pathway at 1.0-1.2 m depths, zone C is the brick drainage ditch in the northeast with a length of 5 m, depth 0.3-0.8 m and zone D is the area that has not been excavated.

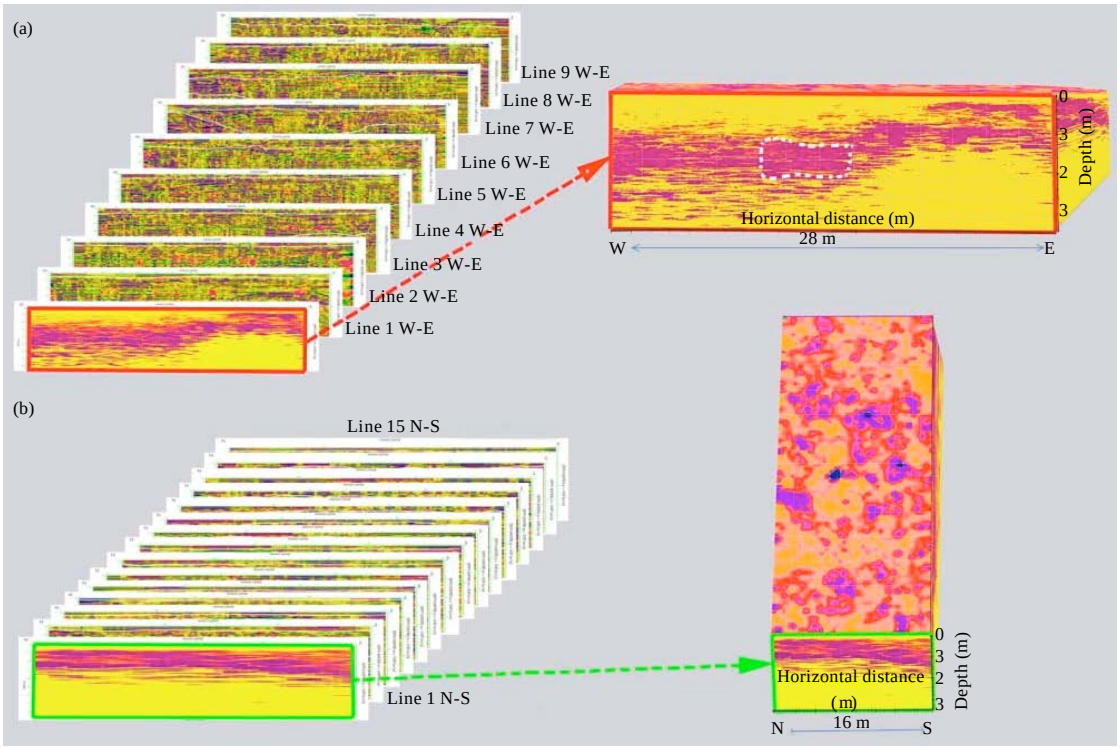

Fig. 4(a-b): GPR reflection image 2D (left) and 3D (right) models in the study area, (a) GPR profile along the west-east survey lines and (b) North-south survey lines

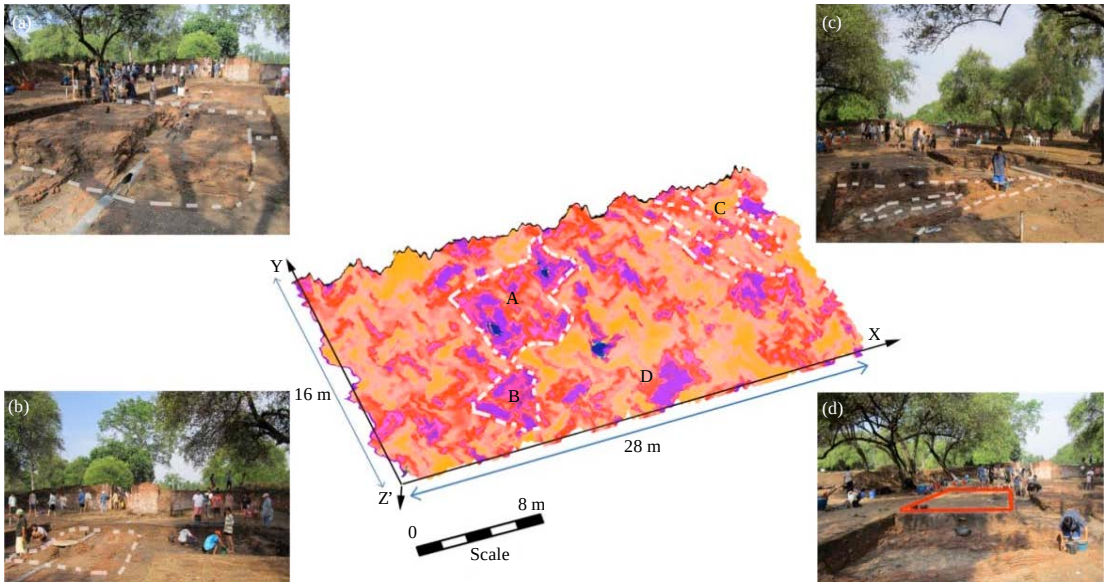

Fig. 5(a-d): Anomalies of the GPR 3D model compared with the excavation area, (a) Wiharn base, (b) Water pipeline, (c) Brick drainage ditch and (d) Non-excavated area

DISCUSSION

The problem of the soil in the study area is wet clay, also, in 2011, the entire area of the central plain was flooded, so the water is still trapped in clay particles causing attenuation of the radar signal. A velocity spectrum was made in the study area based on first arrivals with an average radar velocity in ~0.09 m ns^{-1}, through which the soil profile was defined to be a water-saturated clay. The researcher needs to recognize the general characteristics of the study area to determine to the basic factors behind the exploration and the technical aspects of the application process. The cross-sectional survey design has the advantage of making 3D models. As the GPR survey will lead to incorrect identifications then this could hinder investigations (Mellett, 1996). The parameters defined a common offset survey are GPR centre frequency, the recording time window, the time-sampling interval, the station spacing, the antenna spacing, the line separation spacing and the antenna orientation.

The estimated location of targets and structures under the surface with the GPR method can be accurately identified the located in the interest excavations for the archaeologists. Nevertheless, the problem of the depth estimation which involves wet clay to make the depth discrepancy is corrected by setting the velocity of the radar signal according to the study was previously performed. The pathway level for the study of Rungrujee (1983) arrived at the excavation near the study area (in the southeast), constitute the pathway at 1.20 m depth. The depth of the water supply system and the brick drainage ditch studies of The 3rd Regional Office of Fine Arts (1997) and Ruengted (2004) in the west region of the Royal Palace at about 1.0 m that result was in this study are consistent and comparable all the research mentioned above.

CONCLUSION

In the present study, we describe the discovery of the archaeological remains at Wat Phra Si Sanphet, Ayutthaya, central Thailand using the GPR method. The dependability of the GPR method can be assessed on the pathway in the middle of the western side of Wat Phra Si Sanphet wall. This provides coherent and interpretable images of the near surface structure in the study area. It is an efficient method to separate between the soil layer and the obvious brick components. In order to map the 3D distribution of the archaeological remains and determine their size, surveys have carried out in a grid manner. This permitted us to discover the architecture of the study area in fine point, proving that the archaeological remains are buried under 0.2-3 m of thick alluvial sediment consisting of clay with organic matter. Based on this evidence, it can be seen that the previous excavation strategies were not focused on recovering anything below the Wiharn base and the pathway. This allowed the archaeologists to excavate on the site, resulting in a long brick on a pathway in the west-east direction which is connected to the Wiharn base. The water pipeline is consistent with the pathway while in the northwest-southeast orientation from the water pipeline is the brick drainage ditch 5 m in length.

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