Application of Three-Dimensional Ground Penetrating Radar Imaging in Locating Wat Mo Khlan Archaeological Site in Nakhon Si Thammarat, Thailand

A. Chansane, W. Lohawijarn and B. Phongdara
Geophysics Laboratory, Department of Physics, Faculty of Science, Prince of Songkla University, Songkhla, 90112, Thailand

ABSTRACT

Three-dimensional ground penetrating radar imaging was used to map buried archaeological structures at the Wat Mo Klan archaeological site in Nakhon Si Thammarat Province. This ground penetrating radar survey used a 200-megaheartz central frequency antenna along 101 parallel lines in a 20-meter x 33-meter area. Time–slice maps and iso–amplitude surface maps revealed buried ancient walls, archaeological structural remains, and the interface between present and ancient surface soils. The presence of these features was confirmed by archaeological test pits.

KEYWORDS: Ground penetrating radar, archaeological application, three-dimensional image, time–slice map, iso–amplitude surface map

INTRODUCTION

Ground penetrating radar utilizes propagation and scattering of electromagnetic waves to image, locate, and quantitatively identify changes in electrical and magnetic properties in the ground. A pulse of radar energy is generated on a transmitting antenna dipole placed on the ground surface. This radar energy pulse propagates downward into the ground where a portion of it is reflected back to the surface at discontinuities created by changes in electrical properties of sediment or soil, variations in water content, lithologic changes, or changes in bulk density at stratigraphic interfaces. Reflection can also occur at the interface between anomalous archaeological features, buried pipes, and the surrounding soil or sediment. The greater the contrast in electrical properties between the two materials, the stronger the reflected signal.

The use of ground penetrating radar for archaeological investigations is increasing due to its non–destructive nature, fast operating time, and its high resolution images which allow buried features of relatively small size to be discovered. Another advantage is the possibility of processing data in the field so that the anomalies can be quickly identified. The ground penetrating radar method has been successfully used in archaeological prospecting for mapping shallow subsurface objects (Garcia and others, 2000; Hruska and Fuchs, 1999; Lohawijarn, 2005; Pattanaviriyapisan, 1999; Ranalli and others, 2004; and Sambuelli and others, 1999).

The goal of most ground penetrating radar surveys is to identify size, shape, depth, and location of buried remains and related stratigraphy. The straightforward way to accomplish this is by identifying and correlating important reflections within two-dimensional images where hyperbolic patterns reveal the presence of scattered buried objects. In standard two-dimensional profiles, the specific amplitudes within individual traces that contain important reflective information are usually difficult to visualize and interpret and may be sufficient only in case of simple buried features. Also, the interdependence between aligned views, not having been taken, increases the limitation of interpretation. To overcome this limitation, three-dimensional ground penetrating radar images have been recently applied on the data set of two-dimensional parallel profiles. The three-dimensional location of reflective anomalies can be derived from a computer analysis of all available two-dimensional profiles by correlating the reflections from profile to profile throughout a grid.

Three-dimensional visualization benefits the important information for archaeological applications by displaying complex data in an easily understandable fashion, thus improving the quality and efficiency of the archaeological interpretation. One of the sophisticated types of ground penetrating radar data manipulation is time–slice map analysis that creates maps of reflected wave amplitude differences within a grid. The arrangement of these amplitude slices in horizontal layers, representing real depths, is in a visual format familiar to archaeologists. These are analogous to excavation levels. Another way of three-dimensional image visualization is three-dimensional iso–amplitude surface maps where the reflection amplitude of ground penetrating radar data is defined in a three-dimensional cube representing the subsurface below the surveyed area. With this three-dimensional visualization technique, various threshold values of the reflection amplitude can be assigned in order to show the reflective subsurface object in a three-dimensional location. This makes understanding and interpretation easy.

Currently, three-dimensional ground penetrating radar imaging has been successfully employed in locating and detailed mapping in archaeological investigations (Arlsan and others, 1999; Leucci and Negri, 2006; Negri and Leucci, 2006; Shaaban and Shaaban, 2001; and Whiting and others, 2001). The same technique can be applied in shallow and small subsurface applications (Acqua and others, 2004) and for geological purposes (Beres and others, 1999; Grasmueck and others, 2005; Heincke and others, 2005; Sigurdsson and Overgaard, 1998; and Zeng and others, 2004).

In this work the ground penetrating radar survey was carried out at the Wat Mo Khlan archaeological site in Nakhon Si Thammarat, Thailand. The study aimed to apply ground penetrating radar measurements and display these as three-dimensional images by using three-dimensional ground penetrating radar imaging techniques. Doing this involved the use of time–slice, or depth–slice, maps and iso–amplitude surface maps to locate archaeological remains and structures in the subsurface. The findings of this study will be very helpful for archaeologists in later archaeological excavation.

SITE DESCRIPTION

The study area is located in the Wat Mo Khlan archaeological site, Tha Sala district, Nakhon Si Thammarat province, Thailand, at north latitude 8° 34' 46.8" and east longitude 99° 55' 48.8" (Figure 1).

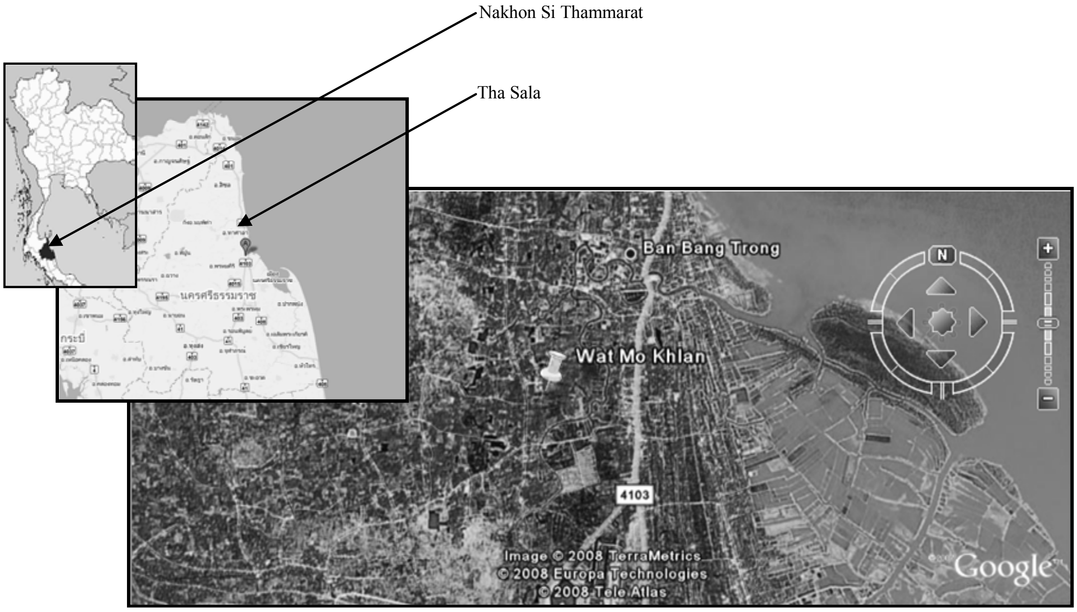
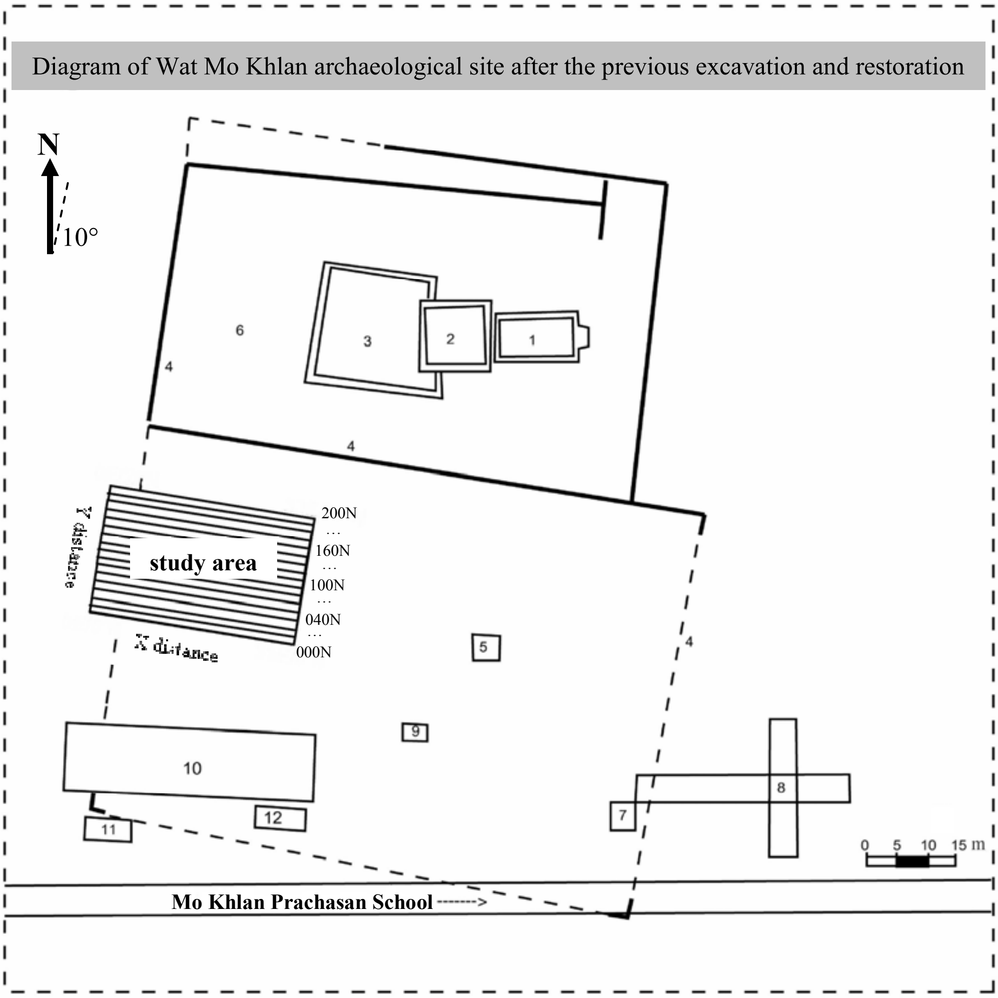


Figure 1. Wat Mo Khlan archaeological site in Tha Sala District, Nakhon Si Thammarat Province

The Wat Mo Khlan archeological site was registered as a national archaeological site in 1975. This site is one of the archaeological sites that are very important to the history and archaeology of Nakhon Si Thammarat province, where prehistoric humans settled about 6,500 years ago. There is much archaeological evidence of this settlement in this region.

The Wat Mo Khlan archaeological site was explored in 1992 and 1993 in order to do restoration (Figure 2). At that time, fractions of limestone and sandstone sculptural art, such as door frames, rectangular rocks, and pedestal pillars, were found. Other archaeological evidence found included metal earrings, obsolete coins, ancient pottery, ancient bricks, broken Siva–lingas, and broken Siva–linga pedestals. With this information and collateral evidence, archaeologists believed that there should be other ancient remains, such as walls and building structures, buried southwest of the excavated and restored Wat Mo Khlan archaeological site (Figure 2). Because this southwesterly area was quite extensive, archaeological excavation within it could be quite time consuming and expensive. Therefore, use of geophysical techniques could reduce the time and expense of locating archeological remains. A case study of this was in the abandoned Tumpung temple (Lohawijarn, 2005).



1 Archaeological building no.1
2 Archaeological building no.2
3 Archaeological building no.3
4 Walls
5 Archaeological pits
6 Bricked floor
7 Archaeological pits
8 Archaeological pits
9 Housing
10 School building
11 School toilets
12 Water tank

Figure 2. Location of ground penetrating radar profiles in the Wat Mo Khlan archeological site

The most common geophysical methods are electrical, magnetic, electromagnetic, and ground penetrating radar. The use of ground penetrating radar in archaeological investigations is increasingly used due to its non–destructive nature, fast operating time, and high resolution images that permit buried features of relatively small size to be quickly recognized. The locations, alignments, and depths of burial obtained from ground penetrating radar measurements can be very useful for planning archaeological excavations.

FIELD INSTRUMENTATION AND DATA ACQUISITION

The RAMAC ground penetrating radar system, with a 200-megaheartz center frequency antenna, was used in this study. Ground penetrating radar measurements were made along 101 parallel lines trending N 80^o W within a 20-meter x 33-meter area (Figure 2). Acquisition measurement parameters used were: 0.6-meter common antennae offset; 0.2-meter line spacing; 0.1-meter trace spacing; sampling frequencies of 1654.381779 megaheartz and 3124.943360 megaheartz; 256 samples per scan; and recording time window of 154.74 nanosecond.

DATA ANALYSIS

Processing steps applied to the ground penetrating radar data so that anomalies could be observed clearly on recorded sections were:

1. Resampling: Since three-dimensional imaging requires equal time increments, ground penetrating radar data of different profiles with different sampling time intervals were re-sampled to the same time increment (Sandmeier and others, 2007).

2. Trace editing: Shifts in recorded traces are probably caused by an unstable condition of field equipment and resulted in sawtooth ground penetrating radar time sections, as shown in Figure 3a. Trace editing is then necessary to shift all traces to the same starting time, as shown in Figure 3b.

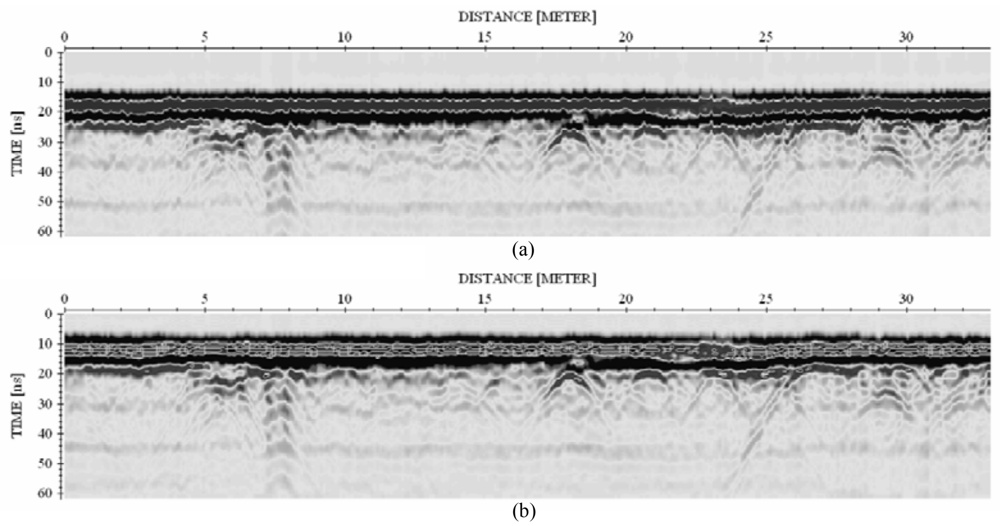


Figure 3. Ground penetrating radar section of profile 168N, (a) before and (b) after trace shift processing

3. Dewow: A dewow filter eliminates a possible low frequency part of the recording signal.

4. Set time zero: In this processing step, the first arrival time of the radar pulse at receiver is set to time zero.

5. Background removal: This processing step eliminates temporally consistent noise from the whole profile and possibly makes signals previously covered by noise visible.

6. Gain filter: This manual filter enhances the amplitude of signals.

7. Notch filter: This filter suppresses nearly mono–frequency noise, which in this study was 100 and 200 megaheartz signals.

8. Kirchhoff two-dimensional velocity migration: Velocity migration was done to trace back the reflection and diffraction energy to their source positions. In case of diffractions, migration contracts diffractions to their apexes.

RADAR WAVE PROPAGATION VELOCITY

Velocity is necessary for converting ground penetrating radar time sections to ground penetrating radar depth sections. In this study the velocity of radar propagation in the medium was obtained from the diffraction hyperbola analysis method. This method is supported by common radar software packages but should be applied if the diffraction hyperbola occurs at least at 20 radar scans (Luecci and Negri, 2006).

Hyperbolic reflections on a ground penetrating radar section and their velocity analysis are shown in Figure 5. The average velocity of radar pulse obtained from the study is about 0.13 meter/nanosecond.

DATA INTERPRETATION

A two-dimensional image of a selected profile, 100N, is shown in Figure 6. Most distinctive anomalies are clearly observed at 6 to 30 nanosecond two–way time, this being about 0.39 to 1.95 meters in depth. Similar anomalies appear in many of the profiles. According to shape and alignment, the anomalies labeled W were interpreted as archaeological structures, such as walls and other building structures. Moreover, a linear anomaly labeled L at 10 nanosecond to 14 nanosecond two–way time, about 0.65 to 0.91 meter, was interpreted as the interface between the present surface soil and an ancient surface soil.

THREE-DIMENSIONAL VISUALIZATION

Three-dimensional visualization of ground penetrating radar images was attempted in order to map continuation of anomalies observed in the study area. Two methods were employed, time–slice maps and iso–amplitude maps.

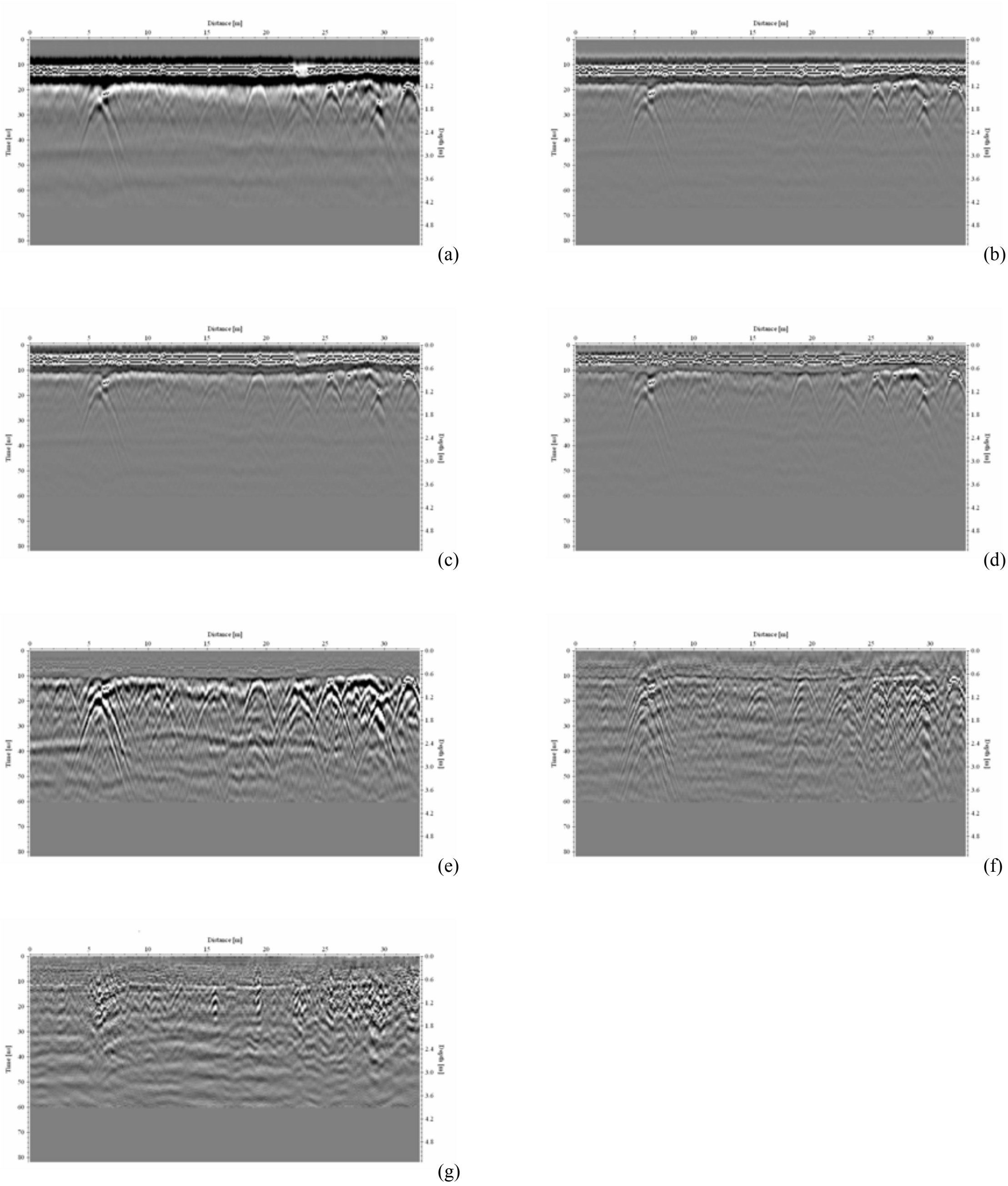


Figure 4. Processing steps applied to ground penetrating radar data of profile 100N, (a) raw data; (b) dewow; (c) set time zero; (d) background removal; (e) gain; (f) notch filter; and (g) migration

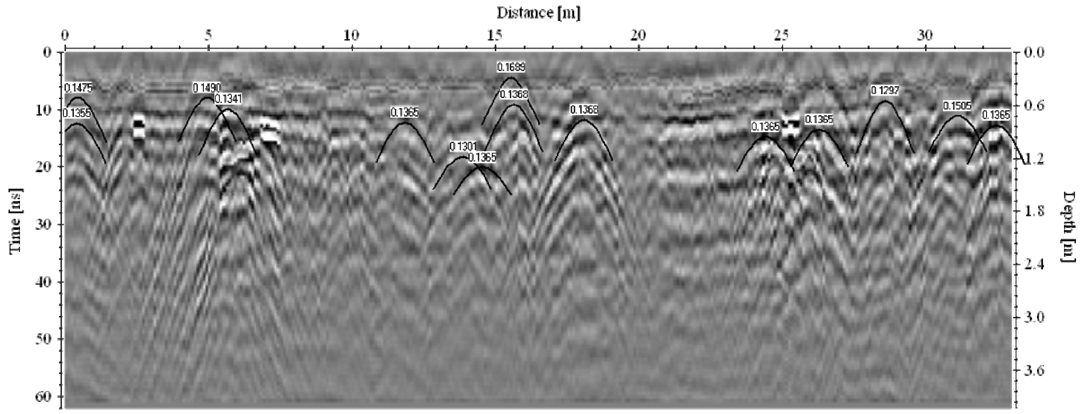


Figure 5 Velocity analyses with the diffraction hyperbolas method on the profile 160N. Labeled numbers over hyperbolas are their corresponding velocity values in m/ns

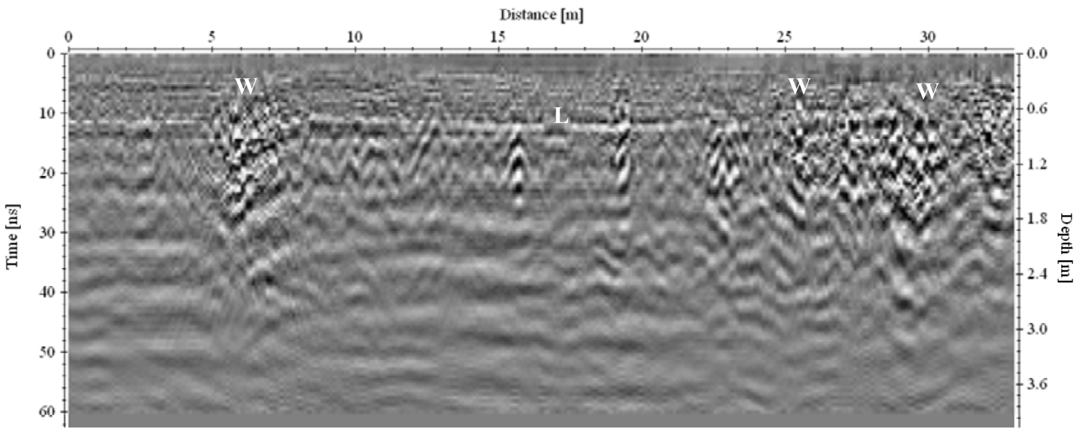


Figure 6. Two-dimensional image of processed ground penetrating radar data on profile 100N

TIME–SLICE MAPS

A time–slice map shows reflected wave amplitude distribution at a particular depth. In any one slice, low–amplitude variations indicate the presence of fairly homogeneous material and high amplitudes indicate significant subsurface discontinuities that, in many cases, relate to buried features. An abrupt change between an area of low and high amplitude can indicate the presence of a major buried interface between two media (Conyers, 2001).

Due to possible changes of velocity, both across the area and with depth, horizontal time slices must be considered as only approximate depth slices. In this study, the time–slice technique was used to display amplitude variations within consecutive soil layers approximately 0.25 meter thick between the surface and a depth of 2.5 meters. Depth slices are shown in Figure 7. High amplitude anomalies labeled W were interpreted as ancient walls or ancient building remains.

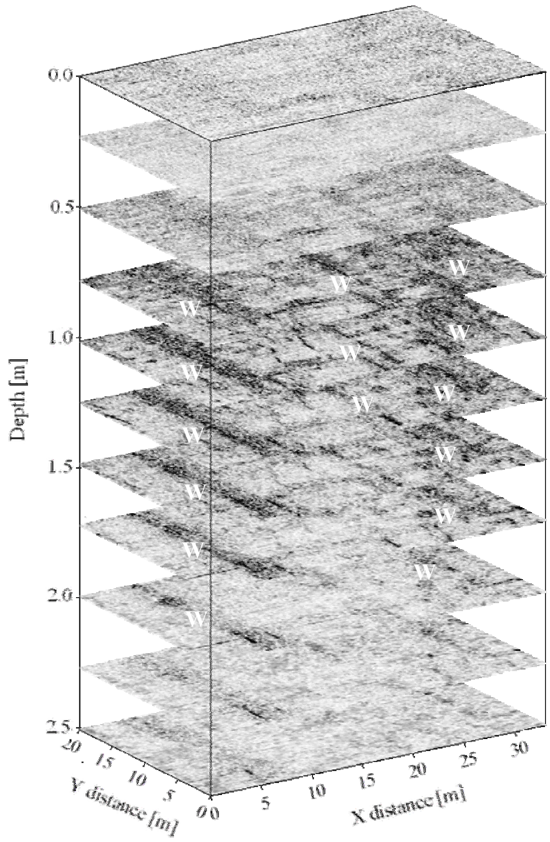


Figure 7. Ground penetrating radar depth slices; high amplitude anomalies labeled W are probably related to subsurface archaeological structures

ISO–AMPLITUDE SURFACE MAPS

In iso–amplitude surface map construction, the gridded data of trace amplitudes are converted to reflection strength. A threshold value is then set and all trace amplitudes greater than, or equal to, this threshold value are used for constructing three-dimensional iso–amplitude surface maps.

Iso–amplitude surface maps of threshold values 60, 70, 80, and 90 percent are shown in Figure 8. These maps show that the lower the threshold values, the more visible are large and small objects.

Most strong and continuous reflections associated with anomalies labeled W in Figure 7 appear clearly in depths between 0.6 and 1.75 meters in the three-dimensional cube threshold volume (Figure 8). Threshold values of 80 percent and 90 percent provide clearer subsurface pictures of archaeological targets than other threshold values. A side view, the x–z plane, and a top view, the x–y plane, of the 80 percent threshold value iso–amplitude surface maps were constructed to facilitate the interpretation (Figure 9). The shape and alignment of these strong anomalies were interpreted as subsurface archaeological walls or building structure remains.

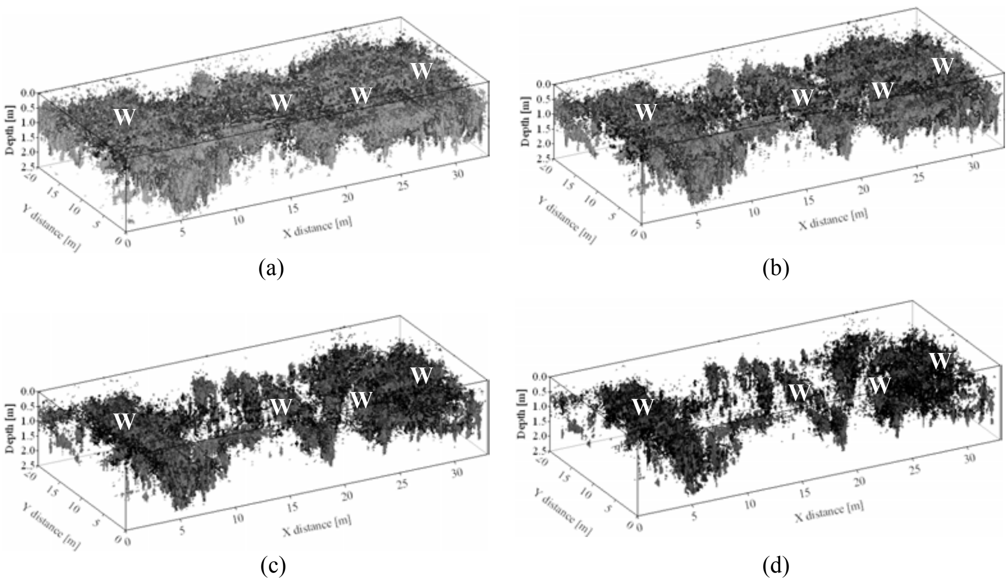


Figure 8. Three-dimensional visualization of ground penetrating radar data by means of iso–amplitude surfaces; views using different threshold values: (a) 60%; (b) 70%; (c) 80%; (d) 90%

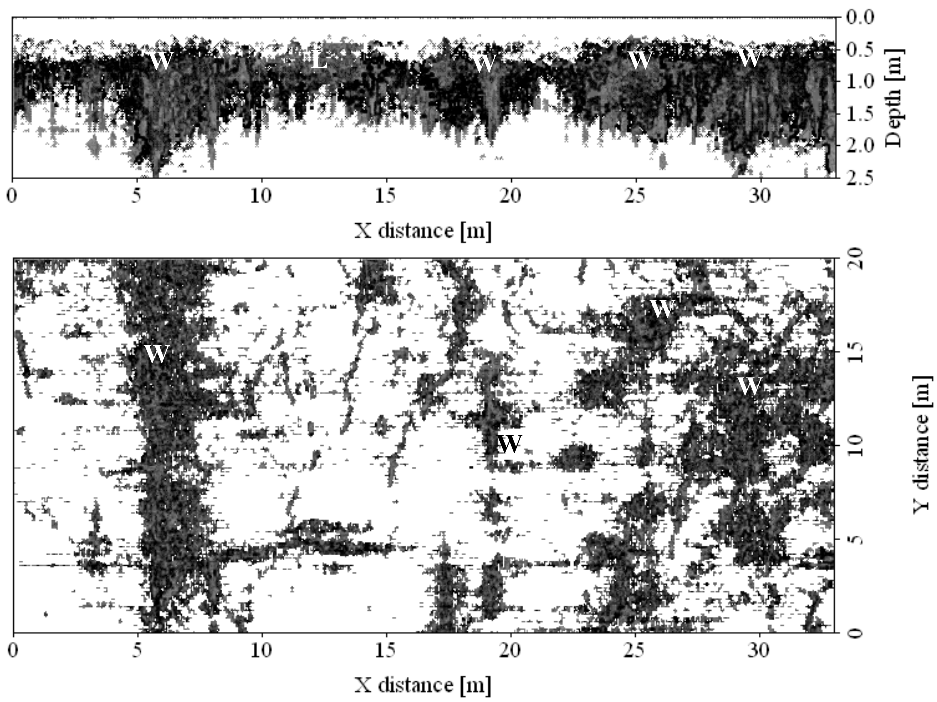


Figure 9. Side view x–z plane and top view x–y plane of ground penetrating radar data of threshold value 80%

Some archaeological test pits were dug in the study area in order to verify anomalies identified from ground penetrating radar measurements. Anomalies labeled W correspond to ancient walls and ancient building structure remains at estimated depths of 0.3 to 0.5 meter. Linear anomaly labeled L corresponds to a ground layer composed of sand and small pieces of ancient bricks (Figure 10).

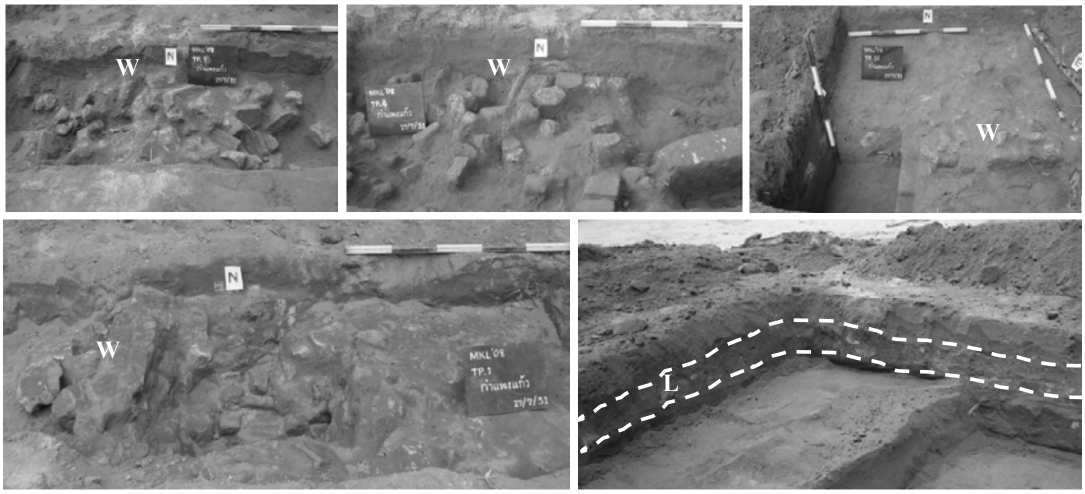


Figure 10. Archaeological test pits for verifying ground penetrating radar anomalies

CONCLUSION

Three-dimensional ground penetrating radar imaging was successfully used in mapping buried archaeological structures of the Wat Mo Klan archaeological site in Nakhon Si Thammarat Province. Buried ancient walls and archaeological structures show as groups of hyperbolic ground penetrating radar anomalies. These anomalies continue across many measuring lines at depths of 0.39 to 1.95 meters. Also on these lines is an interface between present and ancient surface soils. This interface appears as a nearly horizontal linear anomaly at depths of 0.65 to 0.91 meter. Archaeological test pits confirmed the interpretations. Three-dimensional ground penetrating radar imaging is, therefore, considered to be a useful tool in detailed archeological mapping and planning for archaeological excavation pits.

ACKNOWLEDGEMENTS

The authors thank the Graduate School of Prince of Songkla University for the scholarship to carry out this study. Thanks to the IPPS of Uppsala University, Sweden, for the research equipment and interpretation software. Very special thanks to the 14th Regional Office of the Fine Arts Departmant, Nakhon Si Thammarat, for permission to conduct research and for providing related archaeological information and excavation in the study area. The authors also express their gratitude to the graduate geophysics students at Prince of Songkla University who helped with the fieldwork.

REFERENCES

Acqua, A. D., Sarti, A., Tubaro S., and Zanzi, L. 2004. Detection of linear objects in ground penetrating radar data. *Signal Processing* **84**, 785–799.

Arlsan, E., Biella, G., Boniolo, G., Caporusso, D., Franco, R., Lozej, A. and Veronese, L. 1999. Geophysical investigations of the Olonium Roman site Northern Como Lake. *Journal of Applied Geophysics* **41**, 169–188.

Beres, M., Huggenberger, P., Green, A.G. and Horstmeyer, H. 1999. Using two– and three–dimensional georadar methods to characterize glaciofluvial architecture. *Sedimentary Geology* **129**, 1–24.

Conyers, L. B. 2001. Ground penetrating radar. Encyclopedia of Imaging Science and Technology,New York,USA. 463–476.

Gracia, V.P., Canas, J.A., Pujades, L.G., Clapes, J., Caselles, O., Garcia, F. and Osorio, R. 2000. Ground penetrating radarr survey to confirm the location of ancient structures under the Valencian Cathedral Spain. *Journal of Applied Geophysics* 43, 167–174.

Grasmueck, M., Weger, R. and Horstmeyer, H. 2005. Full–resolution three-dimensional ground penetrating radar imaging. *Geophysics* **70**, K12–K19.

Heincke, B., Green, A.G., Kruk, J. and Horstmeyer, H. 2005. Acquisition and processing strategies for three-dimensional georadar surveying a region characterized by rugged topography. *Geophysics* **70**, K53–K61.

Hruska, J. and Fuchs, G. 1999. Ground penetrating radar prospection in ancient Ephesos. *Journal of Applied Geophysics* **41**, 293–312.

Leucci, G. and Negri, S. 2006. Use of ground penetrating radar to map subsurface archaeological features in an urban area. *Journal of Archaeological Science* **33**, 502–512.

Lohawijarn, W. 2005. Geophysical Investigation at some archaeological sites of Nakhon Si Thammarat province in Peninsular Thailand. Proceeding of the *Seminar on Thailand–Malaysia: Malay Penninsula Archaeology Programme*, 4–10 September 2004, Thailand and Malaysia, 125–132.

Negri, S. and Leucci, G. 2006. Geophysical investigation of the Temple of Apollo (Hierapolis, Turkey). *Journal of Archaeological Science* **33**, 1505–1513.

Pattanaviriyapisan, A. 1999. A study of Archaeology Morphology with High Frequency Electromagnetic Wave, Hat Yai. M.Sc. Thesis, Prince of Songkla University. 157 p. (in Thai)

Ranalli, D., Scozzafava, M. and Tallini, M. 2004. Ground penetrating radar investigations for the restoration of historic buildings: the case study of the Collemaggio Basilica (L'Aquila, Italy). *Journal of Cultural Heritage* **5**, 91–99.

Sambuelli, L., Socco, L.V. and Brecciaroli, L. 1999. Acquisition and processing of electric, magnetic and ground penetrating radar data on a Roman site Victimulae, Salussola, Biella. *Journal of Applied Geophysics* **41**, 189–204.

Sandmeier, K.J. 2007. Reflexw Version 4.5 manual, Sandmeier Software, Zipser Strabe 1, D–76227 Karlsruhe, Germany.

Shaaban, F.F. and Shaaban, F.A. 2001. Use of two–dimensional electric resistivity and ground penetrating radar for archaeological prospecting at the ancient capital of Egypt. *Journal of African Earth Sciences* **33**, 661–671.

Sigurdsson, T. and Overgaard, T. 1998. Application of ground penetrating radar for 3–D visualization of geological and structural variation in a limestone formation. *Journal of Applied Geophysics* **40**, 29–36.

Whiting, B.M., McFarland, D.P., and Hackenberger, S. 2001. Three-dimensional ground penetrating radar study of a prehistoric site in Barbados, West Indies. *Journal of Applied Geophysics* **47**, 217–226.

Zeng, X., McMechan, G.A., Bhattacharya, J.P., Aiken, C.L.V., Xu, X., Hammon, W.S. and Corbeanu, R.M. 2004. Three-dimensional imaging of a reservoir analogue in point bar deposits in the Ferron Sandstone, Utah, using ground–penetrating radar. *Geophysical Prospecting* **52**, 151-163.