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Case Study:
DETECTING THE REMAINING STRUCTURE FOUNDATION USING GROUND PENETRATING RADAR: THE OUTER WALL OF SMALL EAST GATE OF TAIWAN-FU, TAIWAN

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ABSTRACT

This study investigates the underground remaining foundation of the outer wall of the small east gate of Taiwan-FU at Tainan, Taiwan using the ground penetrating radar (GPR). The gate and the outer wall were torn down between 1912 and 1913. Before the geophysical detections, limited literature and photos in the 18th- and 19th-century referred the outer wall of the small east gate. In this study, the GPR detections along with the in-situ archaeological excavation give the location and the size of the outer wall. The investigations show that size of the outer wall of the small east gate is larger than the existing outer wall of the main south gate of the Taiwan-FU city. Therefore, the "small" east gate had a notable military use to protect the Taiwan-FU city during the 18th- to the 19th-century. In addition, GPR is a useful tool to identify the location and the depth of underground foundations before a new underground structure passes underneath the structure.

Key words: Non-destructive testing, underground, foundation, heritage.

1. INTRODUCTION

Tainan was the capital of Taiwan from the 17th- to the 19th-century and was the first Taiwanese city recorded in the world history when the Dutch built the first fort, Fort Zeelandia, to rule this island. In the 18th- and the 19th-century, the Chinese Ching emperor built the Taiwan-FU city with a large scale of city walls and gates to protect the political center. The regime changes, maintenance ignorance and improper city development damaged the old above-ground structures. The underground foundation of the architectural structure shows the existence of a building. Similar to other old capital cities such as Beijing of China, Kyoto of Japan, Rome of Italy, preserving the historic monuments is essential in the city modernization. The civil excavations in Tainan threat the remains when locating the underground culture heritages are unavailable. With the awareness of heritage preservation, the literature review and the in-situ detection using non-destructive testing technologies locate the underground remains. The detection of underground remains provides the indispensable references for the future civil engineering works.

Table 1 shows a development history of the Taiwan-FU city. The Ching emperor constructed the wooden city gates and thorny bamboo city fences of the Taiwan-FU in 1725. In 1736, the military demands improved the city gates to brick and stone structures. The cemented earth wall filling with compacted soil/rock inside replaced the thorny bamboo city wall in October 1788. In 1835, building the semi-circular outer walls at the main south gate, small south gate, main north gate, small north gate and small east gate increased the defense capability (Shih 2008). The Taiwan-FU was the largest city in Taiwan in the 18th- and the 19th-century (Shih 1985). Figure 1 shows the plan view of the city walls of Taiwan-FU in 1875. The hollow rectangles with the solid lines (Fig. 1) are the existing gates, which are the main east gate and the main south gate. Although some gates have semi-circular outlook (Figs. 2(a) to 2(e)) but the main east gate does not have a semi-circular outer wall (Fig. 2(f)), no further information ensures that the gates in Fig. 2 follow the actual outlook.

After the Sino-Japanese War in 1895, Japanese emperor ruled Taiwan. In the early 20th-century, tearing down the city walls and gates of Taiwan-FU urbanized the Tainan city. From 1907 to 1945, the Japanese royal troops camped on the west side of the small east gate and tore down the small east gate and the city wall on its south side between 1912 and 1913. After the World War II, the ROC (Taiwan) army also camped on the same place. In 1966, the National Cheng Kung University bought the camp as the Kuang-FU Campus (National Cheng Kung University 2017).

Classifying the outlook of the existing main gates as: (1) without outer wall: Main east gate (Fig. 3(a)), and (2) with outer wall: The main south gate (Fig. 3(b)). Figure 3(c) shows the semi-circular space between the outer wall and the city gate in the main south gate. The small east gate was in the east suburbs of Taiwan-FU city in the 19th- and the early 20th-century and is at the boundary of north and east districts of the Tainan city now (Fig. 4(a)). People forgot its exact shape, size, and location. In 2009, conducting ground penetrating radar (GPR) detections near the existing city wall of small east gate suggested the archeological trial excavations at TP1, TP2, and TP3 (Fig. 4(b)) to locate the remains of the small east gate of Taiwan-FU adjoining to the south end of the existing city wall. TP1 excavation (Fig. 5) showed the foundations of the outer wall, main city wall, and the small east gate, but the overall size of the outer wall was unclear. Therefore, this study attempted to determine the location and the exact size of the outer wall of the small east gate using GPR and the in-situ archeological excavations.

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Table 1 Construction history of city walls of Taiwan-FU (Shih 1985)

Paling city gate and wall period	AD 1624-1732	AD 1624-1721	The late Ming emperor built the first city wall of Tainan in the form of bamboo fence around the Heliao Port Street. In the early Ching Dynasty, people, who would overturn Ching emperor and reinstate Ming emperor, may defend tenaciously depending on the city. The government did not construct the city walls or gates.
		AD 1721-1723	The Chu, I-KUI commanded the people and fought their way into prefecture government buildings. The Ching emperor changed the passive ruling to the active governing policy and constructed the paling as the Taiwan-FU city wall After repelling invasions.
		AD 1723-1732	In 1725, the magistrate Chou, Chung-Hsuan planned to build the paling city gates and the city walls. The construction included seven gates (the main gates of the east, south, west, and north, and, the small gates of the east, south, and north).
Brick/stone city gate and thorny bamboo wall period	AD 1732-1786	AD 1732-1736	After the Wu, Fu-Sheng event in 1732, the Ching emperor still rejected build brick-earth city wall and forts. Instead, the thorny bamboo was planted as fences.
		AD 1736-1775	The fulfilling defensive demands replaced the seven paling gates to the brick and stone ones. The completing city gates in 1739 are the remained in today's Tainan.
		AD 1775-1786	The prefecture magistrate Chiang, Yuan-Shu rebuilt the thorny bamboo city wall and constructed other forts, sheds, and military facilities. Then, build a small west gate in the south of Fu-an River. There were eight city gates in Taiwan-FU.
Brick/stone city gate and earth-stone wall period	AD 1786-1805	AD 1786-1788	The Lin, Shuang-Wen incident burned the paling city wall. The Ching emperor constructed the earth city walls to enhance the defensive capacity.
		AD 1788-1805	The Ching emperor replaced the original thorny bamboo wall to the cemented wall. The officers constructed the walls on the original positions on the east, south and north sides. On the west side, they moved the wall tens of meters to the west. The original perimeter of Taiwan-FU was 8064 m.
Additionally constructed outer wall period	AD 1805-1836	AD 1805-1835	Silting at the west shore expands an outer wall from the northwest to the southwest of the city. The limestones from the coral reefs at Peng-Hu islands replaced the original paling walls.
		AD 1836	Constructed the east outer wall with the paling fence. The total length of the city wall was 8640 m.

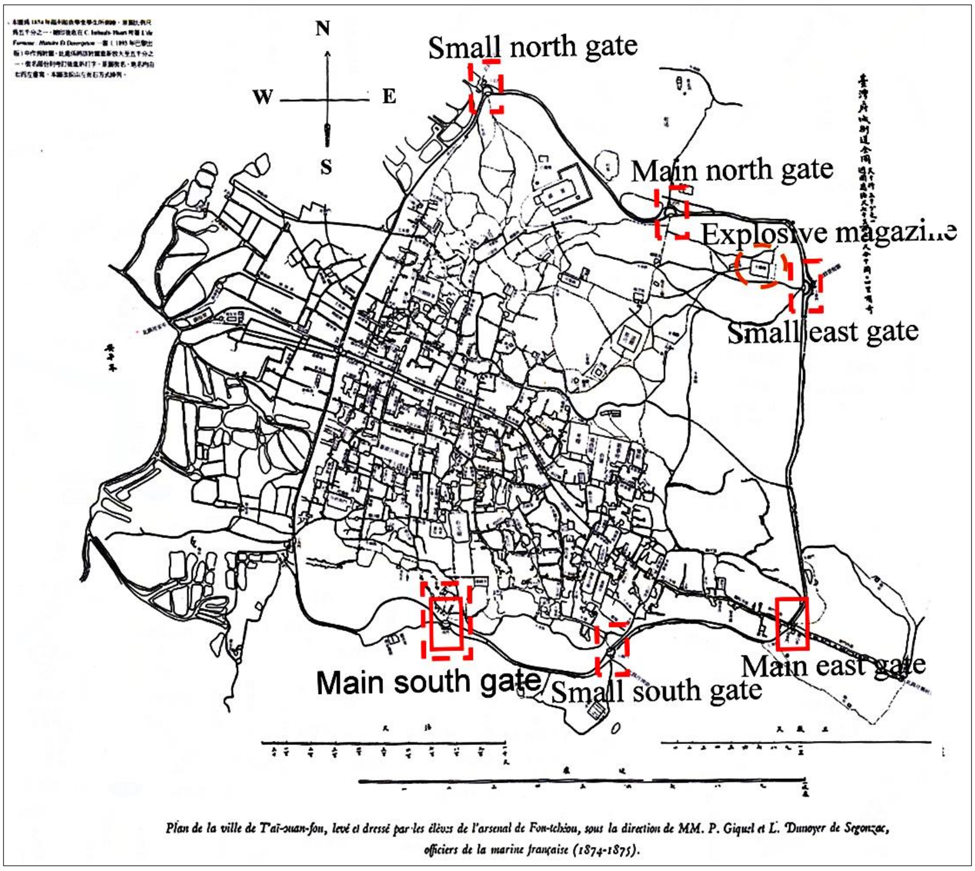


Fig. 1 Map of Taiwan-FU in 1875 (modified from Imbault-Huart and Cordier 1893)

(a) Small north gate

(b) Main north gate

(c) Small east gate

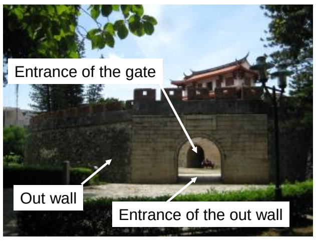
(d) Main south gate

(e) Small south gate

(f) Main east gate

Fig. 2 Shapes of gates marked in Fig. 1

(a) Main east gate without outer wall



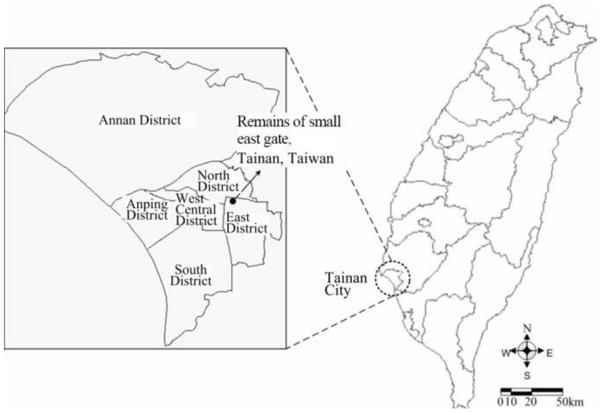
(b) Main south gate with outer wall

(c) Space between outer wall and city gate

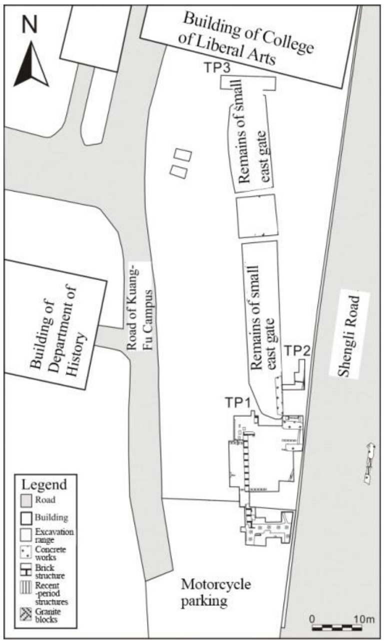
Fig. 3 Pictures of existing Taiwan-FU city gates

2. SMALL EAST GATE

The map of the Taiwan-FU (with the scale of 1:5000) in 1875 used the modern engineering surveying (Fig. 1) and showed the city walls, city gates, road system and important buildings. Based on the scale of the map (Figs. 1 and 2(c)), the outer diameter and the inner diameters of the outer wall of the small east gate can be 60 m and 47 m, and the thickness of the city wall of the outer wall is 6.5 meters. In addition, Lee *et al*. (2011) estimated that the outer diameter of the outer wall of the small east gate is between 49.84 m to 62.5 m, and the inner diameter is between 47 m to 51.3 m based on the archaeological excavations (Fig. 4) and the old aerial photo. The estimating diameter of the outer wall is even larger than the outer diameter (36 m) of the existing outer wall of the main south gate of Taiwan-FU (Fig. 3(c)).

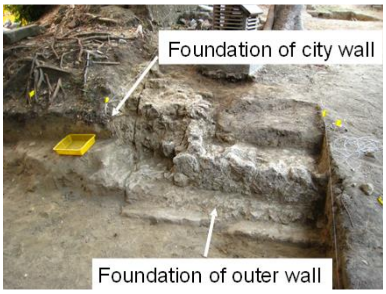


(a) Location of the investigating site

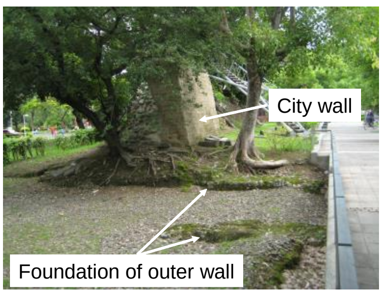


(b) Sketch of archaeological trial excavation pits

Fig. 4 Location of the archaeological site



(a) Discover the foundations



(b) Location of the discovered outer wall section

Fig. 5 The excavated outer wall of the small east gate

3. GROUND PENETRATION RADAR (GPR)

GPR detects the target and stratigraphic soil/rock formations according to the wave reflection of the high-frequency electromagnetic pulse. Several cases have shown that the GPR is a useful tool in archaeological investigations. Cezar *et al*. (2001) excavated an urn-like artifact with the height of 60 cm and the diameter of 45 cm by the GPR reflection signals in two-dimensional formation sectional image of the Serrano site in Brazil. Ranalli *et al*. (2004) detected the internal defects of walls in a limestone building built in L'Aquila, Italy in 1287. Leucci and Negri (2006) explored the underground stone remains in Mesagne, Italy using the signal amplitudes in the three-dimensional image. In the remains site, the cultural relics, such as ornaments, daily necessities, or ashes, can also be found. Perez-Gracia *et al*. (2008) investigated the internal structure and defects of the remains using the same technology in the Roman Theater in Valencia City, Spain. Ribolini *et al*. (2017) improved GPR interpretations to investigate different archaeological structures at Badia Pozzeveri, Italy.

The GPR instrument of the SIR-20 system is used. The system comprises antenna, data acquisition unit, and battery (Geophysical Survey Systems Inc. 1992) (Figs. 6(a) and 6(b)). A high-frequency GPR antenna (with a shorter wavelength) results in a high resolution of the detections but a shallow penetration depth. In this study, the 400 MHz radar antenna (Fig. 6(b)) is selected. The depth of penetration is 0 to 4 m (Geophysical Survey Systems Inc. 2017). The wavelength of the 400 MHz antenna in the concrete/soil is about 25 cm. The resolution of the detection is about 6 to 12 cm because the resolution is 0.25 to 0.5 of the wavelength (Ziani *et al*. 2011). The local wave velocity was 0.10 m/ns based on in-situ investigations technology (Lai *et al*. 2014). Table 2 shows the GPR acquisition parameters in this study. The range, which is the maximum two-way travel time of the antenna, was set at 50 ns to probe the maximum depth of 2.5 m.

In this study, interpreting the intensity of the reflection signals divides the RGB 256 color bar into 16 equal parts (Fig. 6(c)). The values between 0 and 128 represent negative reflection signals. The value of 0 is the strongest reflections and that of 128 is the weakest one. In addition, the values between 128 and 256 represent positive reflection signals. The value of 128 is the weakest reflection and that of 256 stands for the strongest one. Therefore, the color levels on the top (white) and bottom (gray) on the color bar (Fig. 6(c)) represent the very strong reflection signals; while the black shows very weak GPR reflections.

The GPR detection clarifies the underground conditions depending on the flatness, continuity, and reflection intensity of the reflection signals. The different dielectric coefficients of the underground remains and the surrounding soil result in different GPR reflections. Figure 6(c) shows the color bar for the GPR interpretations using the software of RADAN 5.0 (Geophysical Survey Systems Inc. 2003). Analyzing the Lines 1 to 3 (Fig. 7) adjoining to the TP1 and TP2 (Fig. 4(b)) verifying the GPR pattern to the outer wall foundation. Figure 8 shows the GPR images along Lines 1 to 3. The hollow rectangle with the dashed line locates the known outer wall foundation of the small east gate. Therefore, the outer wall foundations result in the strong GPF reflections (white color).

Table 2 GPR acquisition parameters for this study

Antenna frequency	400 MHz
Range	50 ns
Vertical high pass of the IIR filter	65 MHz
Vertical low pass filter of the IIR filter	800 MHz
Horizontal parameters	
Scans/second	100
Scans/unit (m)	100
Vertical parameters	
Samples/scan	256
Bits/sample	16

(a) SIR-20 system (b) 400 MHz antenna (c) RGB color bar

Fig. 6 The GPR instrument and signal color bar used for detection

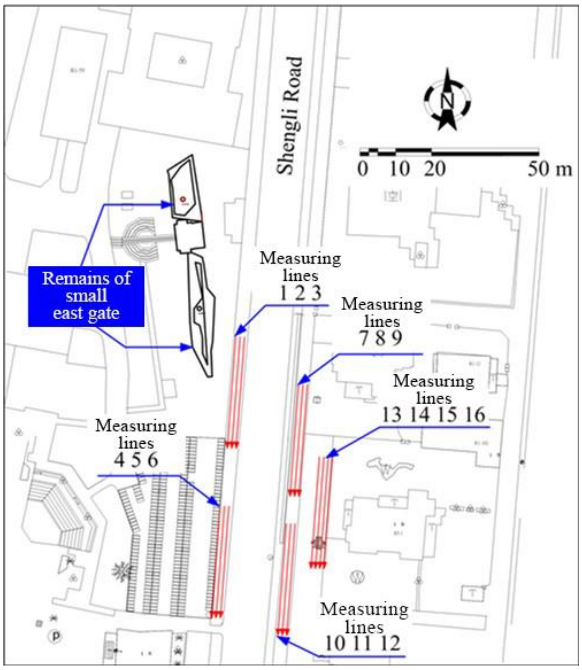


Fig. 7 Distribution of measuring lines to detect the outer wall foundation

4. IN-SITU DETECTION

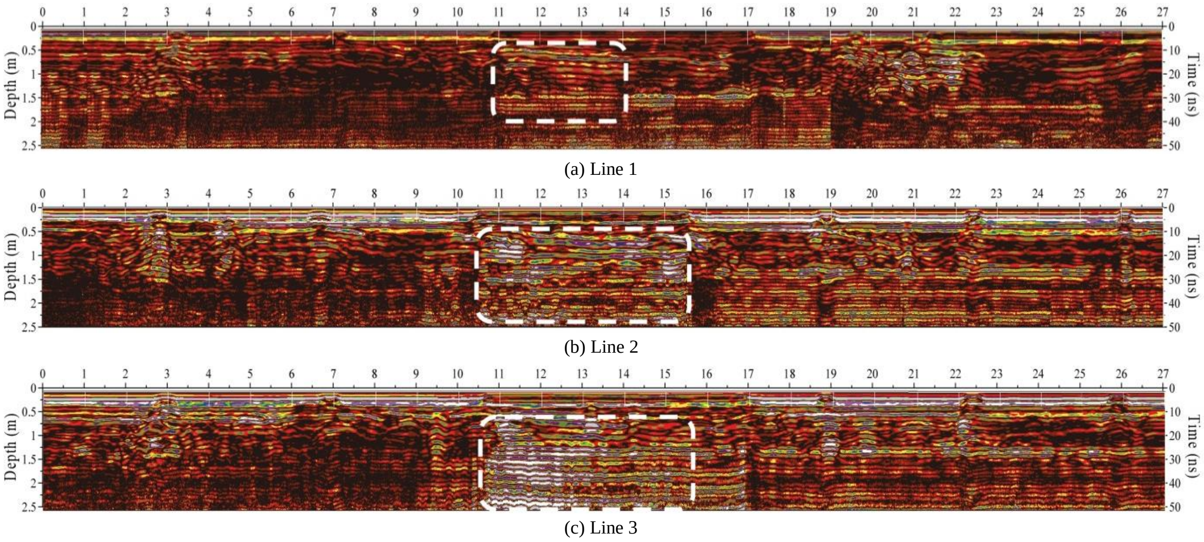
The estimating diameter of the outer wall by the Fig. 2(c) and by Lee *et al*. (2011) arranges additional detecting lines (Lines 4 to 16) in Fig. 7. The Lines 4 to 6 investigate the southern endpoint of the outer wall. The Lines 7 to 12 confirm the wings of the outer wall at the east sidewalk of Shengli road. Additionally, the Lines 13 to 16 explore the midpoint of the outer wall.

The following signal process in Lines 4 and 5 interprets the GPR signals to locate the buried outer wall foundation:

1. After getting the raw GPR data (Fig. 9(a)), filter the air signal near the ground surface (Fig. 9(b)) because the GPR antenna may sometimes not tight to the ground surface. The air-ground interface results in the signal reflection as the noise.
2. Remove the background noise in the GPR image (Fig. 9(c)). Then, the strong reflection signals locate the buried wall foundation at the horizontal distance between 12 and 22 m.
3. The hollow rectangles with pink and green dashed lines in Fig. 10 are out of the possible location of the buried wall foundation. Select 5 to 10 GPR signals in each investigating rectangle for the frequency analysis. The dominant frequency is between 340 and 405 MHz.
4. Conduct frequency analysis to the referring buried wall foundation section with strong GPR images (yellow hollow rectangles) between 12 and 22 m (white rectangles in Fig. 11). Select 5 to 10 strong GPR signals in each investigating section for the frequency analysis. A dominant frequency is between 465 and 600 MHz.
5. The GPR images and the dominant frequency differs the ground conditions in a horizontal distance between 0 and 12 m and that between 12 and 22 m. The archaeological excavations (Fig. 12) discover the buried outer wall foundation at the possible location between 12 and 22 m.

Then, the outer wall foundation (Fig. 13) is located by the GPR data (Lines 6 to 16). Connect the possible locations of the outer wall foundation in GPR to a half ring in Fig. 13. The outer and inner diameters of the outer wall are 61.8 m and 50.8 m, respectively.

The GPR images (Fig. 13) result in the successful in-situ archaeological excavations. The investigations discover the north wing (Fig. 14(a)), the mid point (Fig. 14(b)), and the south wing (Fig. 14(c)) of the outer wall foundation. The measuring inner and the outer diameters of the outer wall of the small east gate are 51 m and 62 m from the archaeological excavation outcomes. It is surprising that the size of the outer wall of the small east gate is larger than the main south gate of Taiwan-FU of the 26 m inner diameter and the 36 m outer diameter. The name of the "small" east gate show less important than the "main" south gate. But, the size of the outer wall highlights the military importance of small east gate to safeguard the city of Taiwan-FU in the 18th- and the 19th-century. Also, an explosive magazine (the dashed circle in Fig. 1) shows another important military facility near the small east gate of the Taiwan-FU city. The west side of the small east gate had been the military camp until the National Cheng Kung University took it in 1966.

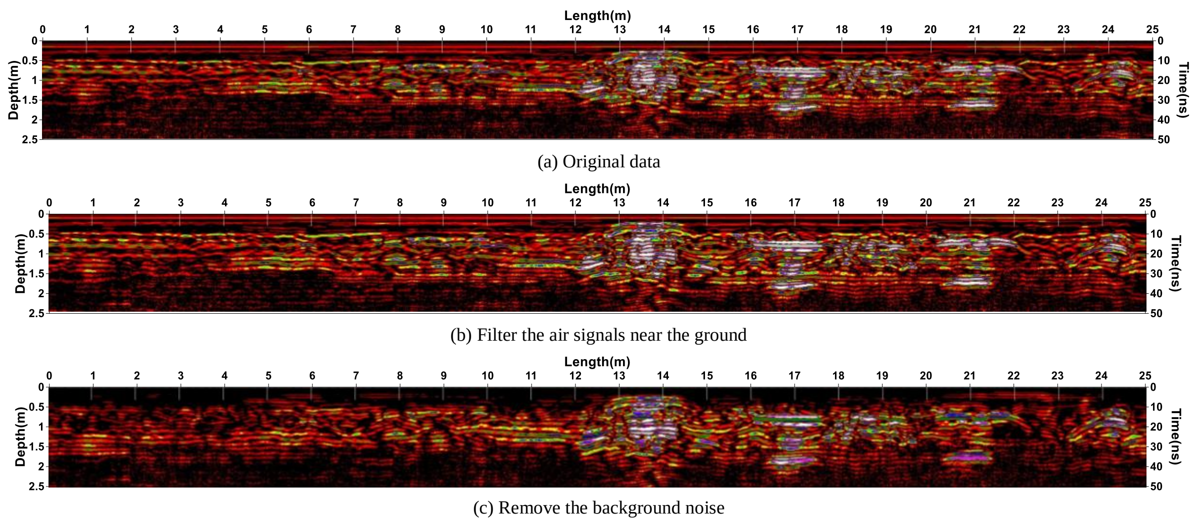


(a) Line 1

(b) Line 2

(c) Line 3

Fig. 8 GPR images of Lines 1 to 3



(a) Original data

(b) Filter the air signals near the ground

(c) Remove the background noise

Fig. 9 Signal filter process of Line 5

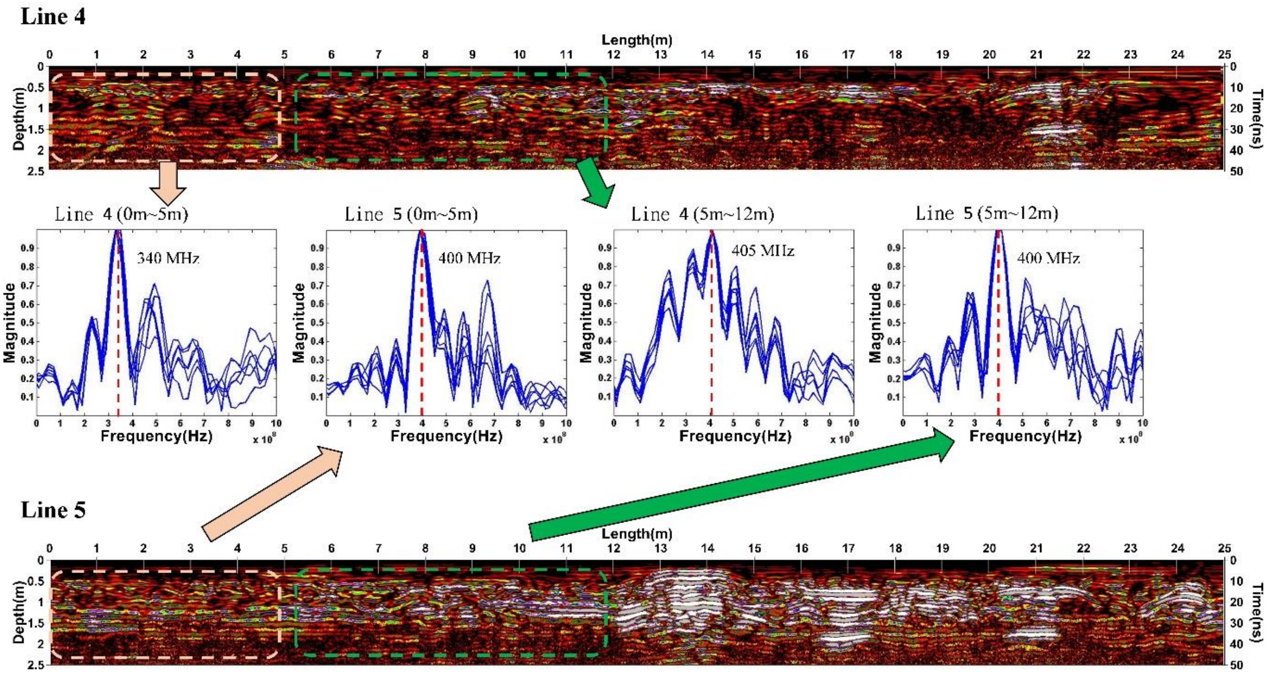


Fig. 10 Frequency distribution analysis at the locations out of the possible outer wall

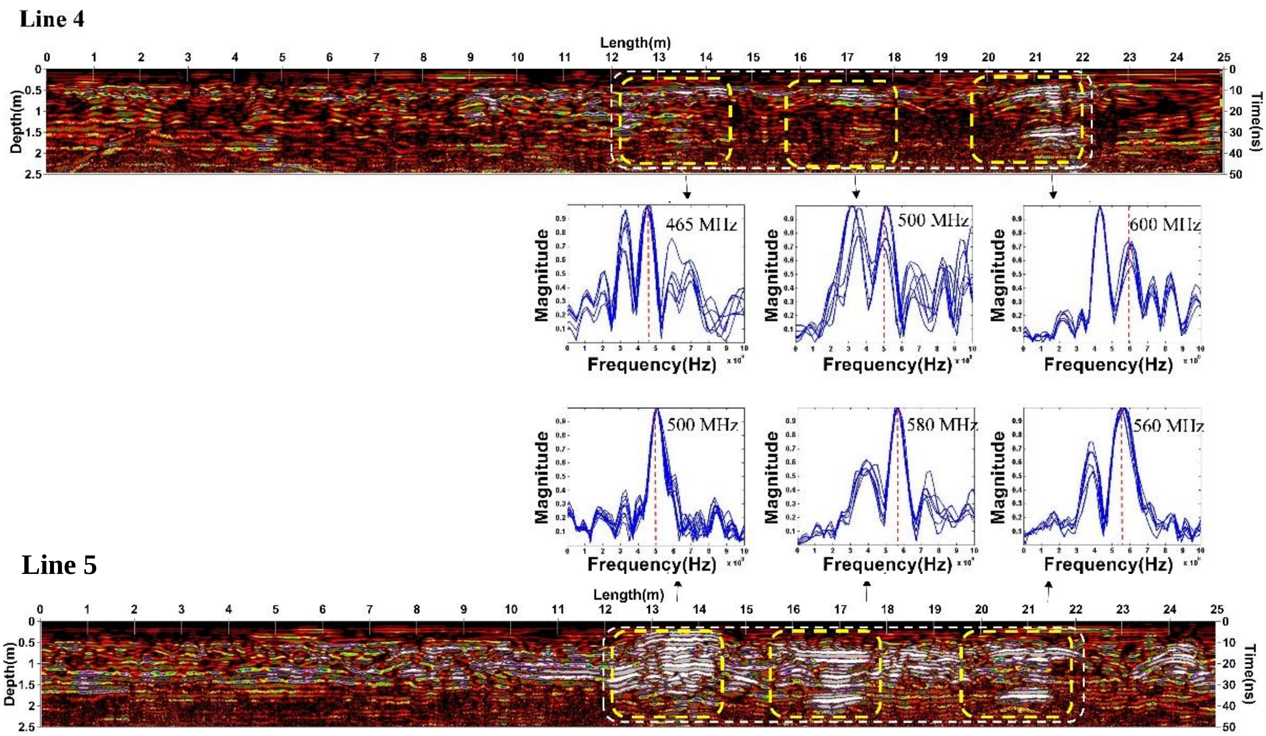


Fig. 11 Frequency distribution analysis at the possible outer wall locations

Fig. 12 Outer wall foundation discovered based on Line 4 and 5 GPR images

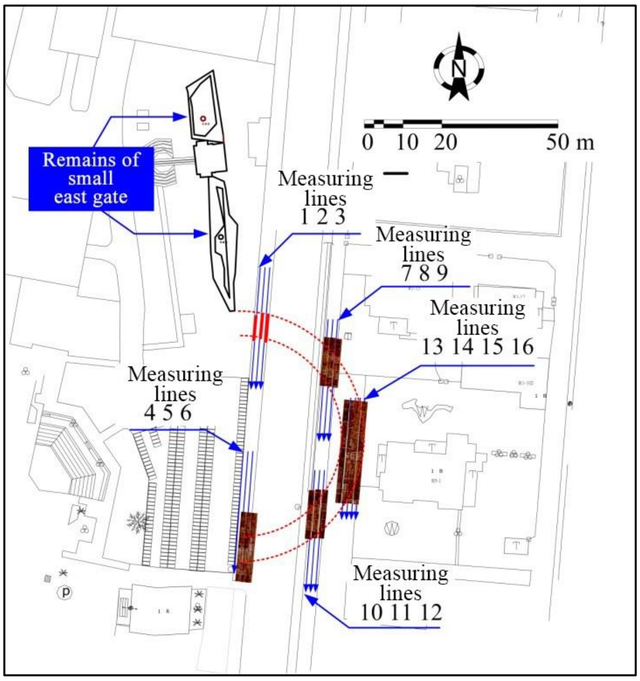


Fig. 13 Possible locations of the outer wall by GPR images

(a) North wing (Lines 7 to 9)

(b) East boundary (Lines 13 to 16)

(c) South wing (Lines 10 to 12)

Fig. 14 Underground outer wall foundations by in-situ excavations

5. CONCLUSIONS

This study investigated the underground remaining foundations of the outer wall of the small east gate of Taiwan-FU city in Tainan, Taiwan using GPR. The in-situ archaeological excavations confirm the location and the size of the outer wall. This study highlights the military importance of small east gate to secure the Taiwan-FU city in the 18th- and the 19th-century. Additionally, the existing main south gate is not the unique gate with the outer wall.

Locating buried foundation of other outer walls, city gates, and walls of the Taiwan-FU city is an urgent task to preserve the cultural heritage. In civil engineering, the GPR technique clarifies the location and depth of an old structure foundation before a new subway or pipeline passes underneath the building.

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