APPLICATION OF GROUND-PENETRATING RADAR METHOD TO DETECT HIDDEN DEFECTS IN BANK REVETMENT

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ABSTRACT

The hidden defects in earthen levee and bank revetment may include surface crack, shallow cavity, deep cavity, seepage, piping, loose zone in base material, inhomogeneous density, and water content. Ground-Penetrating Radar (GPR) is a high-resolution geophysical method, which is based on the propagation of high-frequency electromagnetic waves. GPR transmits electromagnetic waves to penetrate the media under investigation and some reflected waves occurred at underground material interfaces are then picked up by receiving antenna when returning to the ground surface. In this article the results from a field investigation of the bank revetment located in the downstream of the Pin-Lin stream at Chungliao Township, Nantou County, Taiwan are presented and discussed. It is concluded that GPR surveys with proper data processing and image analysis can be effective in determining the scope of the hollowing region in the bank revetment.

Keywords: Flood mitigation, Revetment, Hidden defects, Ground Penetrating Radar (GPR)

INTRODUCTION

Due to global greenhouse effect, major flooding disasters occurred all over the world in recent years. In 2002, a 100-year flood caused by over a week of continuous heavy rains ravaged European countries including the Czech Republic, Austria, Germany, Slovakia, Poland, Hungary, Romania and Croatia. The 2005 European floods hit mainly Romania, Switzerland, Austria and Germany. In the same year, 80% of New Orleans, Louisiana, U.S. was flooded due to the failure of several floodwalls in the aftermath of Hurricane Katrina and 1,076 people also died because of the hurricane. In 2006, high Danube levels caused significant flooding in parts of Serbia, Bulgaria and the effects of high water were blamed on the poor levee systems in the affected countries. The 2007 Africa flood was reported to be one of the largest floods in recorded history in the continent of Africa with 14 countries affected. The 2007 Hunter region and Central Coast storms caused extensive flooding, damage and loss of life in New South Wales in Australia. The 2008 Indian floods were a series of floods in various states of India and countrywide death toll from floods was 2,404. The 2008 South China floods affected fifteen provinces in Eastern and Southern China and four rounds of torrential rains with landslides and flooding lasted for 20 days. The 2009 European floods are a series of natural disasters taking place in Central Europe. In the same year, typhoon Morakot wrought catastrophic damage in Taiwan, leaving 461 people dead and 192 others missing.

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In many countries across the world, rivers prone to floods are often carefully managed. Defences such as levees, bunds, reservoirs, and weirs are used to prevent rivers from bursting their banks. There are many factors directly or indirectly affecting the flood mitigation. Among these factors, levees and bank revetments are important hydro-structures to prevent flooding of the adjoining countryside also to confine the flow of the river. The hidden defects in earthen levee and bank revetment may include surface crack, shallow cavity, deep cavity, seepage, piping, loose zone in base material, inhomogeneous density, and water content. Up to now, investigations of existing levee structure in many countries are often carried out by visual inspection with some core drilling at a regular time interval in engineering practice. For instance, every section of levee structure is required to be examined once in two years. Based on the result of visual inspection which indicates possible defects, drilling holes into the structure and taking samples are then conducted in order to assess its structural condition. For section with possible defects, it is usually carried out at every three points for every kilometre of the levee structure.

Visual inspection with core drilling is not an effective method, because not only the properties of levee structure may vary drastically with every meter, but some hidden defects also may be overlooked by global visual inspection of the structure. In addition, from a viewpoint of management of a hydro-protection system, we do need a more effective investigation means other than visual inspection with core drilling by taking into consideration that the total length of levees plus revetments in every country may equal to thousands of kilometres.

Relevant research institutes are now making efforts to study the techniques for performing effective investigation of earthen levee and bank revetment from which hidden defects can be determined, and prompt maintenance and rehabilitation can be properly conducted. DEISTRUKT (2007) is a research project funded by the German Ministry for Education and Research dealing with the evaluation of geophysical methods for the structure investigation and flaw detection of river embankments. Standard methods as geoelectrics, Ground Penetrating Radar (GPR), refraction seismics were used as well as innovative techniques (e.g. Seismic Image Processing (SIP), Multichannel Analysis of Surface Waves (MASW), GPR arrays). Mydlikowski *et al.* (2007) presented results from the examination of flood embankments by means of three geophysical methods: GPR, mutual impedance of loop antennas measurements and D.C. resistivity method.

Ground penetrating radar (GPR) is one of the newer geophysical methods. It has been used for the past 20 years for a variety of applications to investigate many civil structures, such as pipe line, pavement, bridge, rock field, and vandose zone. Early utilization of this method for engineering applications were given by Morey (1974), Annan and Davis (1976), and Ulriksen (1982). An extensive overview of the method is given by Davis and Annan (1989). The principle of GPR is that an oscillatory electromagnetic wave (EM wave) of 10~2500 MHz is launched from the transmitting antenna into the structure under examination. The electromagnetic waves interact with features inside the structure. The waves are reflected, transmitted, absorbed and refracted. When a certain interface or object changes the conductivity or dielectric constant, a partial radar wave is reflected to the ground surface (Fig. 1). The image is then displayed on the screen and, after processing, the signal can be plotted into a Distance-Time diagram which can be used to determine the position of abnormal underground electromagnetic waves as well as to estimate the relevant stratum interface. By exploiting the wave propagation characteristics of electromagnetic fields, GPR provides a very high resolution sub-surface mapping method.

The long-term purpose of the article was to study the applicability of GPR to detect hidden defects in levee structure and bank revetment via a series of field testing, so that an effective testing system of hidden defects can be established for long-term safety evaluation, tracking and comparison as well as maintenance and rehabilitation.

EXPERIMENT DESCRIPTION

In this article the results from a field investigation of the bank revetment (Fig. 2) located in the downstream of the Pin-Lin stream at Chungliao Township of Nantou County in Taiwan are presented and discussed. The bank revetment consisits of concrete plates and vertical concrete beams between two plates. There is no steel reinforcement in the structure. The width of each plate is 4 meters, its height is 8 meters , and the thickness of each plate is in the range of 20~25 cm. The slope of revetment is about 55^0 measured from the horizotal line. A SIR-3000 GPR data acquisition system (Fig. 3) manufactured by GSSI (Geophysical Survey System, Inc., USA) with 400 MHz bistatic antenna was used. Three test lines were undertaken to examine the GPR images for a concrete plate under which there is a existing cavity (Fig. 4). Their line codes are LT1, LT2, and LT3 (Fig. 5) with their lengths eqaul to 8 meters. The distance between each test line is one meter. For the easy of conducting the GPR test, each test line was undertaken by moving antenna from the bottom to the top of the concrete plate. It is noted that in addition to a cavity under the concrete plate, there is a surface crack at the top of the plate with its length about 1 meter (Fig. 6) which is located between test lines LT1 and LT2.

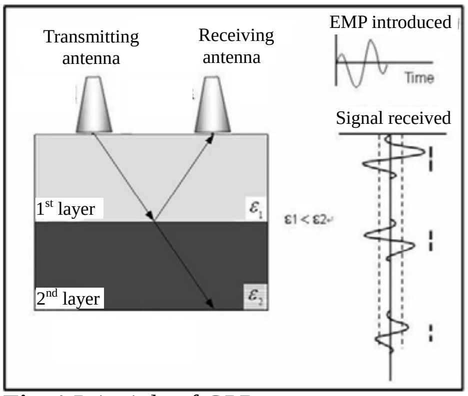

Fig. 1 Principle of GPR

Fig. 2 Map of test site from Google

Fig. 3 GPR data acquisition system used

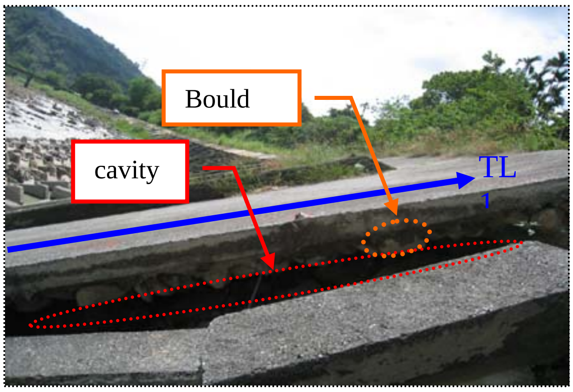

Fig. 4 Cavity and boulder under concrete revetment

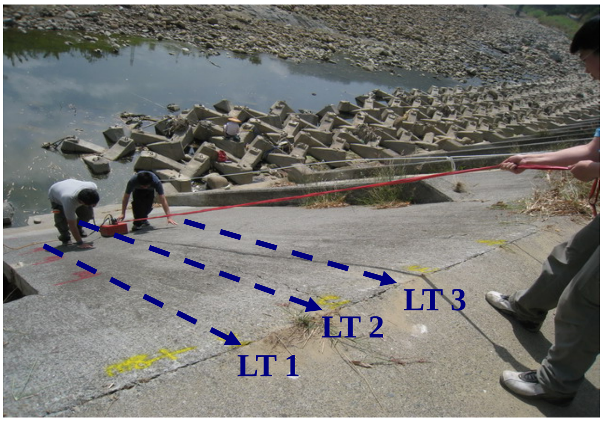

Fig. 5 Test site and three test lines

Fig. 6 Surface crack at test site

DATA PROCESSING

In order to effectively and rapidly detect the target, a successful GPR test must be undertaken with adequate settings and the in-situ pre-processing steps were taken as shown in Fig. 7. The influence of factors such as method of GPR recording, selection of monitoring system, type of underground interface and characteristics of wave transmission would generate differences between data and geotechnical space. In addition, diagrammatic distortion often occurs in the GPR raw data due to in-situ noise, so it may be difficult to make effective interpretation directly from the raw data. Therefore, post-processing was used to assist the diagrammatic interpretation as shown in Fig. 8. In this test, a low-pass boxcar FIR (Finite-duration Impulse Response) filter was applied, with which it passes low-frequency signals but attenuates signals with frequencies higher than the cut-off frequency which equals to center-frequency multiplied by 2. A high-pass boxcar FIR filter was also applied, with which it passes high-frequency signals but attenuates signals with frequencies lower than the cut-off frequency which equals to center-frequency divided by 6. Since some reverberation packets occur at the last portion of the raw data, some gain control was conducted to suppress them.

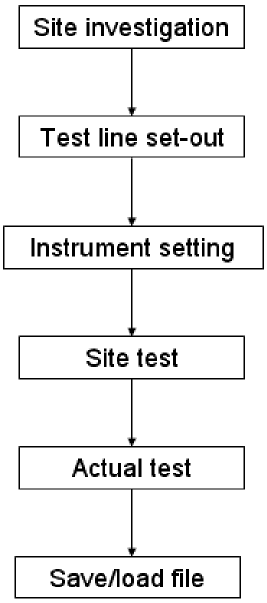

Fig. 7 Flowchart of pre-processing

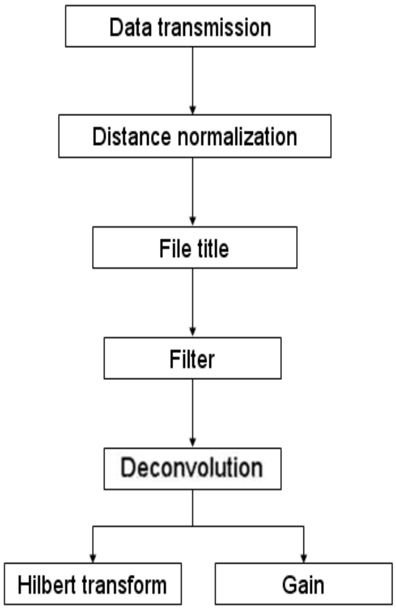

Fig. 8 Flowchart of post-processing

TEST RESULTS AND DISCUSSIONS

Fig. 9 shows the colormap diagram of raw data for test line TL1, where the horizontal axis is the tangential distance along the surface of the concrete plate. The distance of zero indicates the GPR data at the lowest side (water side) of the revetment and the distance of 8 meters indicates the data at the topmost side of the revetment. The vertical axis of raw data is the depth measured from the surface of the plate. After filtering and gain controlling mentioned aforehand, Fig. 10 is the processed image in grayscale mode of Fig. 9. By comparing raw data with processed data, there are three crucial perspectives can be drawn. First, due to multi-color display, more pseudo reflected interfaces can be found in colormap mode than in the grayscale mode. Second, the post-processing conducted in this study is robust regarding effectively suppressing the noise. Third, two strong interface reflections can be easily found in the processed images other than in the raw data.

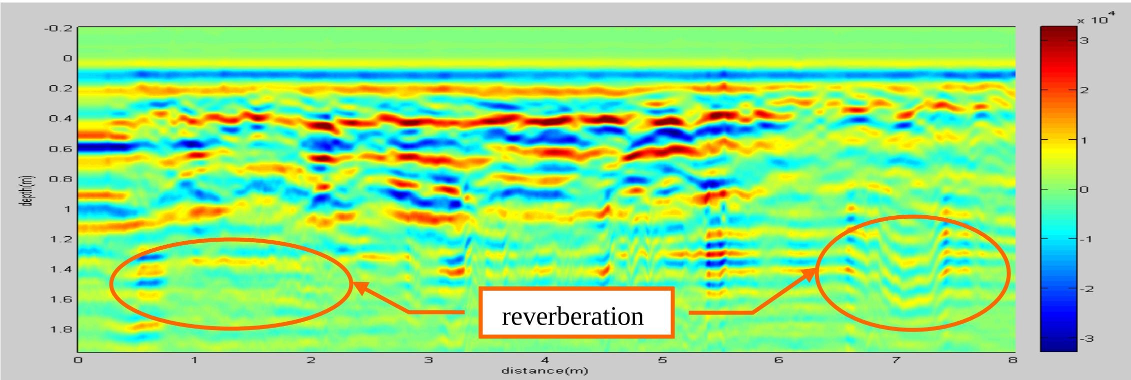

Fig. 9 Raw data of TL1

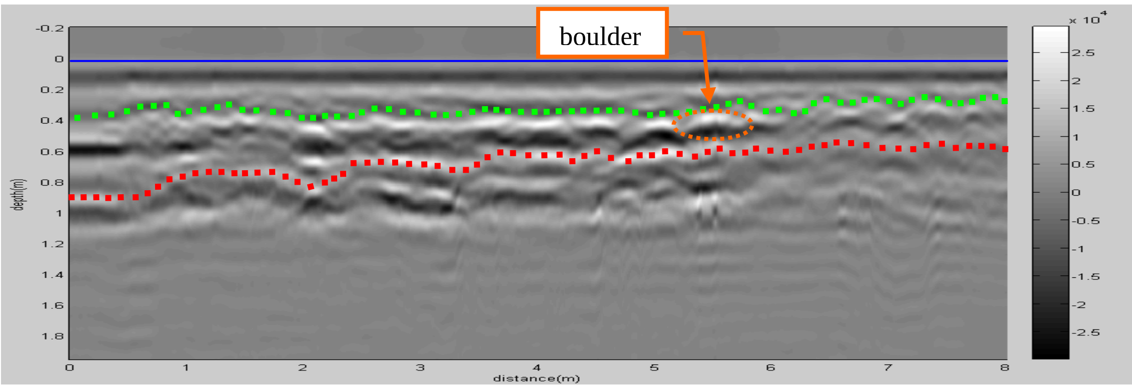

Fig. 10 Processed image of TL1, which indicates concrete surface (in blue), concrete-air interface (in green) and air-soil surface (in red)

A GPR reflection will be produced at a boundary between two different materials, where the dielectric constant suddenly changes. Higher dielectric contrast between the two materials, results in a stronger reflection. Davis and Annan (1989) reported typical dielectric constants for some geological media. In this study, the GPR antenna was placed directly on the surface of the concrete plate, instead of leaving an air gap. The signature of concrete plate at TL1 consists three portions: the first positive peak (white band at the depth of zero in Fig. 10), followed by a negative peak (black band), and then another positive peak. Thus, the blue line depicted in Fig. 10 represents the location of concrete surface which is inclined about 55^0 measured from the horizotal line in the test site. When the EM energy reaches the bottom of the concrete, a phase inversion occurs at a concrete-air interface because of the low dielectric of air (a value of one) as compared to the dielectric value of concrete (6~11). So instead of a positive/negative/positive (white/black/white) peak, the phase inverted sequence will be negative/positive/negative (black/white/black) for the concrete-air interface as shown by the green line in Fig. 10. Due to soil erosion under the concrete, there is a cavity beneath the bank revetment in the test site (Fig. 5). Consistently, some boulders stuck by cement to the bottom of the concrete plate can be seen as shown in Fig. 4. The signature of a boulder looks like an inverted V hyperbola as shown by orange circle in Fig. 10. The signature of an air-soil interface should be positive/negative/positive (white/black/white) peak because of the low dielectric of air (a value of one) as compared to the dielectric value of soil (3~30) as shown by the red line in Fig. 10. Hence the region between the green line and the red one in Fig. 10. represents the air-filled zone under the bank revetment. The cavity found in this article extends from the down side of the bank revetment to its top, and its height ranges approximately from 0.3m to 0.6m.

Fig. 11 and Fig. 12 are the raw data and processed image of TL2, respectively. Similar trends can be observed in the GPR image (Fig. 12) after processing: the blue line represents the concrete surface, the green line indicates the concrete-air interface of the concrete bottom, and the red line refers to the air-soil interface. The region between the green line and the red line represents the cavity under the bank revetment. It is noted that the signature of air-soil interface should produce white/black/white peak but it disappears at the left corner of Fig. 12 with a question mark. The missing interface may indicate the soil erosion stops at this point and the soil directly contacts with the bottom of concrete plate, so that weak reflection can no longer be detectable due to low dielectric contrast between the concrete and the soil.

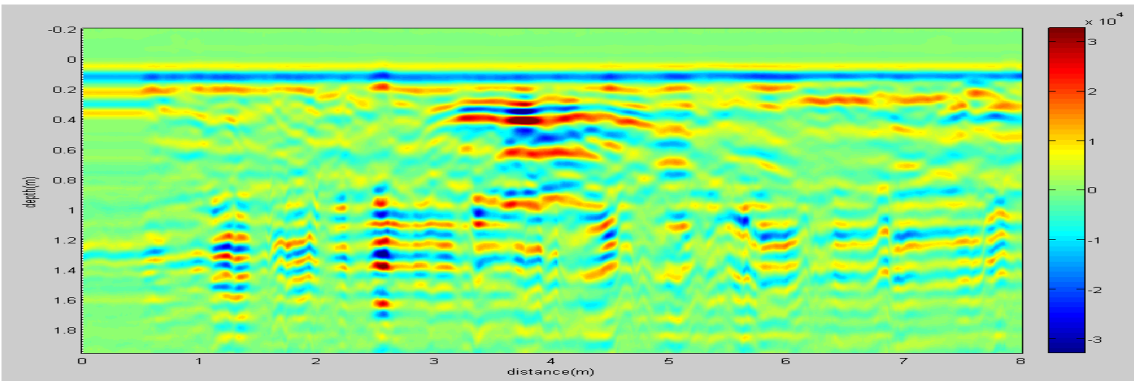

Fig. 11 Raw data of TL2

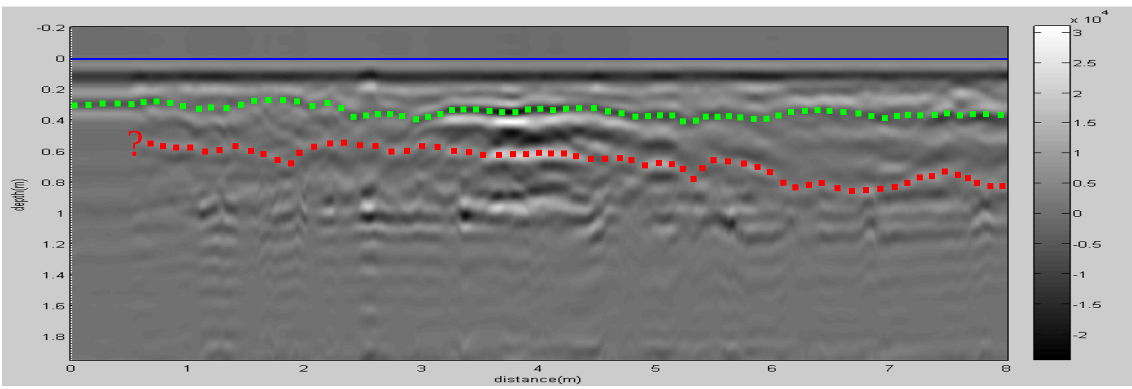

Fig. 12 Processed image of TL2, which indicates concrete surface (in blue), concrete-air interface (in green), air-soil surface (in red), and missing interface (within question marks).

Fig. 13 and Fig. 14 are the raw data and processed image of TL3, respectively. Similar signatures of three interfaces can be observed. The missing interface is now longer than that of TL2. As compared to TL1, there is less soil erosion in TL2 and the least soil erosion occurs in TL3. This results consist with the visual oberservation in the test site where the concrete plate is at the end of the whole bank revetment and TL1 is the test line closest to the edge of the bank revetment as shown in Fig. 4.

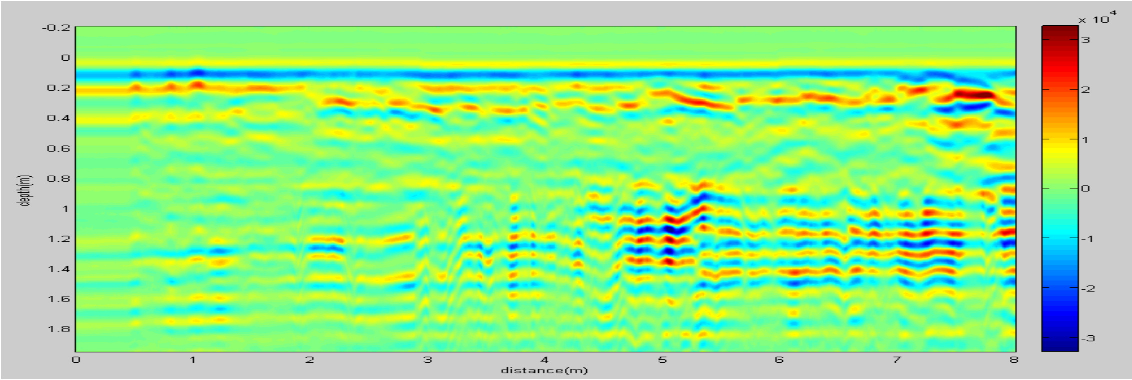

Fig. 13 Raw data of TL3

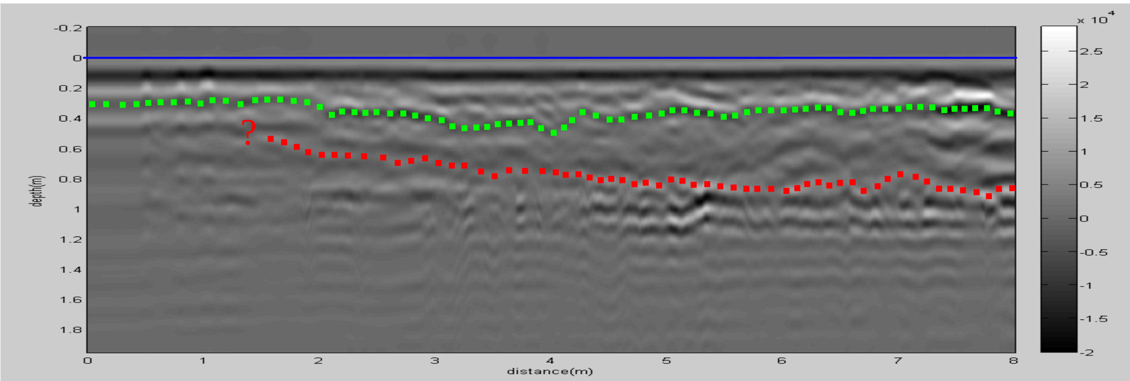

Fig.14 Processed image of TL3, which indicates concrete surface (in blue), concrete-air interface (in green) air-soil surface (in red), and missing interface (with a question mark).

The possible cause of the large cavity under the concrete plate of the test site is mainly due to river flow vortex, since this section under investigation is the last section of the whole bank revetment. The structure type of bank revetment like the test site is a common type of revetment in Taiwan. According to the experience of authors, in addition to surface crack at the top of the concrete plate, there are hidden defects under the bank revetment which may not be necessary located at the last section of bank revetment. For instance, Fig. 15 is a typical broken concrete plate which is located midway of a bank revetment in Taichung, Taiwan. Fig. 16 shows the cavity under the plate at that site. It is noted that both concrete plates located closely next to the broken plate, the soil under the plates may be subject to river flow vortex and some cavities may already occur. These hidden defects may not be identified simply by visual inspection, unless some large broken plate had occurred in the near section. Therefore, developing a systematic and non-destructive technique, such as GPR, is extremely important for performing effective investigation of earthen levee and bank revetment, and then prompt maintenance and rehabilitation can be properly conducted.

Fig. 15 Concrete plate broken at other site

Fig. 16 Cavity under concrete plate at other site

CONCLUSIONS

Because of numerous uncertain factors during GPR testing on site, some unknown noises and interferences may appear in the image, and the post-process (e.g. filter, de-convolution or gain) can be used to assist in interpreting the correct identification of images. From the test results and discussions conducted in this article, the following conclusions can be drawn:

1) The cavity found in this article extends from the down side of the bank revetment to its top, and its height ranges approximately from 0.3m to 0.6m.
2) The GPR with its fast, high-resolution and non-destructive characteristics has been proven to be very effective for detecting cavity under bank revetment.
3) The diagrammatic characteristics and skill of signal identification developed in this article can be used as important reference for future studies.

Although there have been many cases of successful GPR application and continuous improvement of technology (e.g. development of 3D image, image processing) incorporated with other non-destructive test methods, there is still room for developing both theoretical and in-situ studies in the future. Interested researchers are advised to continue with active development in this direction.

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