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IDENTIFICATION OF PIPELINES FROM THE SECONDARY REFLECT WAVE TRAVEL TIME OF GROUND-PENETRATING RADAR WAVES

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Key words: GPR, travel time, dielectric constants.

ABSTRACT

When using ground-penetrating radar to identify underground pipelines of similar dielectric constants (i.e. PE and PVC), misidentification is quite common. In this study, we apply reflected travel time of radar waves into the PE- and PVC- dielectric constants and the differentiation becomes possible. We have conducted the experiments using the non-metal PE- and PVC- pipelines as well as the heavy metal (iron) pipelines in a water environment. Based on a travel- time calculation, the dielectric constants of non-metal pipelines with similar composition (PE = 2.3 and PVC = 3.0) were quite close. The error between the experimental and theoretical values is acceptable in general engineering projects. It is also compliant with the standard error by the U.S. ASTMD4748-98 (the error range is about ± 0.2 inches or ± 0.508 cm). Therefore, the result of this study not only can be applied to detect the metal pipes, but also may be used to distinguish non-metallic pipes in a water environment.

I. INTRODUCTION

The concept of using ground-penetrating radar (GPR) to study subterranean structure began in the 1930s [9, 6] and was successfully applied to studies of ice thickness in the Arctic and Antarctic regions in 1960 [2]. After 1970, ground-penetrating radar was slowly adopted for widespread use in exploration [3, 4]. Ground-penetrating radar continued to develop in the 1980s using the electrical properties of different substances, such as dielectric constants, conductivity and resistance, to image soil and sedimentary layers (Table 1). The 1990s were the heyday of geological studies using ground-penetrating radar. Primary applications in the 1990s included investigation of buried objects, depth and saturation of groundwater, imaging of soil and sedimentary layers, and detection of damage in a dam. Although ground-penetrating radar appears to have wide applications, on the whole, it had only one purpose, to find target objects and resolve problems with regard to the environment and engineering.

Table 1. Commonly seen dielectric constants (adapted from Davis and Annan, 1989 [4], Ulriksen, 1982 [11]).

Material type	Dielectric constant	*T*/*D* (ns/m)
Air	1	6.5
Water	81	59
Iron	14	25
PE	2.3	11
PVC	3.0	12

Chou [1] and Lee [8] applied ground-penetrating radar to detect pipelines of two differing compositions (i.e. non-metal and metal) in physical models. As for the application of radar to the detection of subterranean pipelines of similar composition, it was used for detection of gas, water, telegraph, electrical, oil, and other pipelines [5, 7, 10]. On the other hand, we focused on the radar waves to analyze the dielectric constants of pipelines and differentiate between empty and full PVC pipelines submerged in water [12].

Radar waves can clearly detect individual pipelines or differentiate between subterranean pipelines of different compositions. However, when identifying pipelines of similar material (PE and PVC), radar wave is almost useless. As a result, we use reflected travel-times of the radar waves to calculate dielectric constants, and apply them to identify non-metal pipelines composed of PE and PVC plastics.

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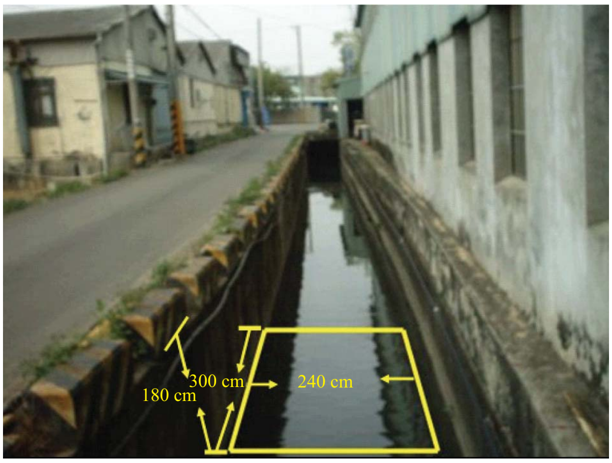

Fig. 1. The water surface was 180 cm below the surface of the road. The size of experiment: water depth 50 cm, length 300 cm and width 240 cm.

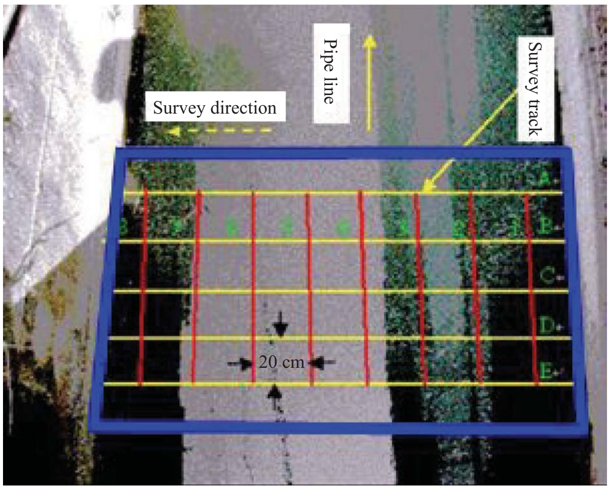

Fig. 2. The blue box is the survey area. The yellow lines are the measured profiles. In each line, there are 8 markers (the red lines), each separated by 20 cm.

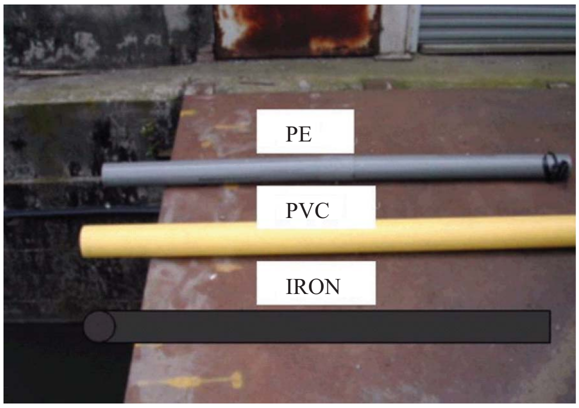

Fig. 3. There are three types of experimental material , iron, PVC and PE pipes with a length of 200 cm and diameter of 10 cm. The experiment is conducted under the water.

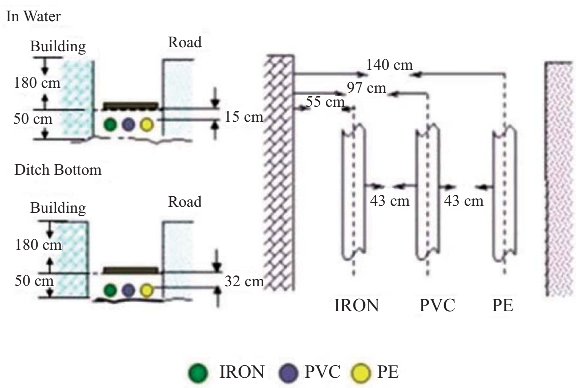

Fig. 4. The pipelines are placed in two configurations: suspended in the water and rested on the bottom of the ditch.

Therefore, this study provides a breakthrough in the application of ground-penetrating radars.

II. EXPERIMENT

The site for the experiment was a ditch next to an industrial road. The surface of the water was 180 cm below the surface of the road. The water's depth and width were 50 cm and 240 cm, respectively (Fig. 1). Iron, PVC, and PE pipes with a length of 200 cm and diameter of 10 cm were placed in the water (Fig. 2). Because radar waves propagating in water tend to suffer from serious energy reduction, the pipelines were divided into two configurations: suspension in water and resting on the bottom of the ditch (Figs. 3 and 4). Experimental results demonstrated that, perhaps because the water was only 50 cm in depth, energy reduction did not have a significant effect on these results.

Two tests, for pipes resting in water and on the bottom of the ditch, were conducted along five measured lines (yellow lines in Fig. 2) and used eight marked lines (red lines in Fig. 2). Measured and marked lines were each separated by 20 cm.

This study used a GSSI-2000 main unit with a 400 MHz antenna, and repeatedly tested optimal parameters of the main instrument. The testing parameters are as follows:

(1) Sampling number of each trace: 512
(2) Trace number for each meter along a measured line: 30
(3) Distance between each measured line: 20 cm
(4) Band-pass filtering: 30~800 MHz
(5) Dielectric constant (water): 81
(6) Stacks: 4
(7) Testing depth: 100 cm

III. DATA PROCESSING

Radar data was processed by software developed by GSSI (Geophysical Survey System, Inc.). The raw sections of the radar waves were first processed using distance normalization to remove extraneous wave numbers. The radar sections

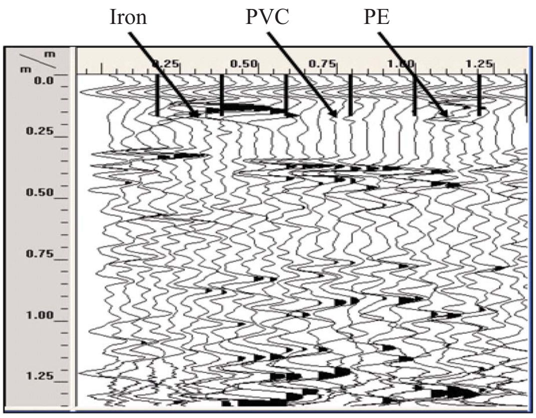

Fig. 5. The original profile of the water pipeline.

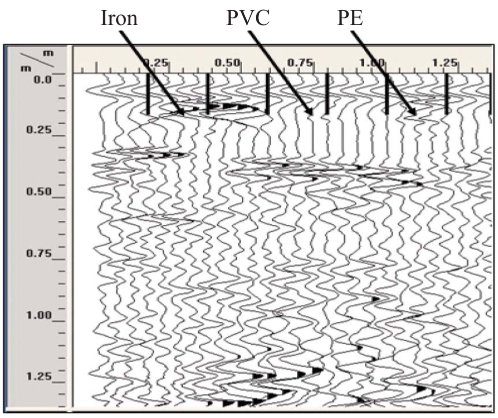

Fig. 6. The F-K filter processing of the water pipelines.

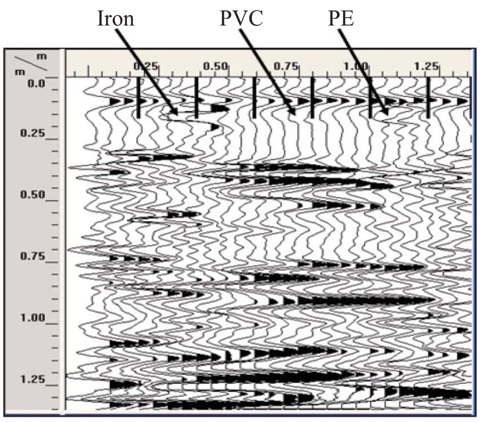

Fig. 7. The migration processing of the water pipelines.

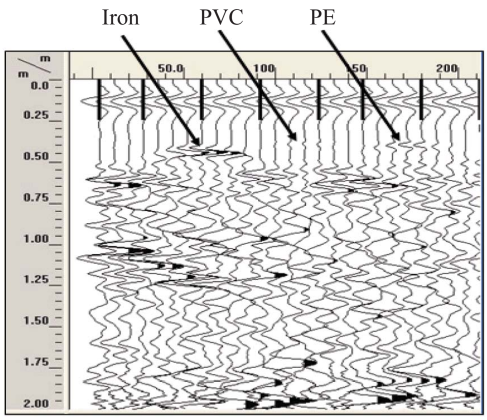

Fig. 8. The original profile of the bottom pipelines.

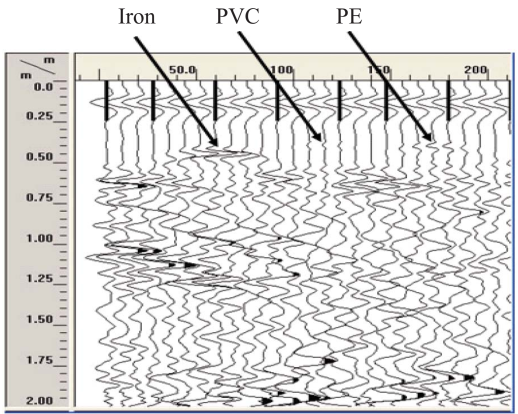

Fig. 9. The filter processing of the bottom pipelines.

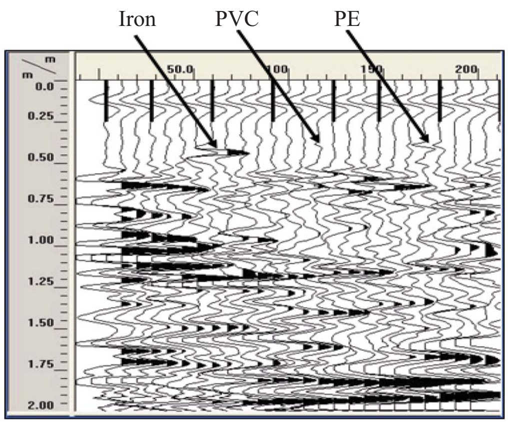

Fig. 10. The migration processing of the bottom pipelines.

were then filtered and migrated. If the radar signal was very weak, then a gain control was incorporated into each step to increase signal ratio (S/N).

There are two experiments in this study, the result from the water pipelines (Figs. 5-7) and the bottom pipelines (Figs. 8-10). Figs. 5 and 8 are the raw data from the survey. Figs. 6 and 9 represent the results from a F-K filter processing in which the filter box is continuously shifted along the profile. Figs. 7 and 10 are the final results from the migration processing. The processes have made the identification much easier.

Accurate identification of PE and PVC pipe sections requires further investigation. We magnified the processed sections (Figs. 11-12) to better analyze and interpret them in order to identify PE and PVC separately.

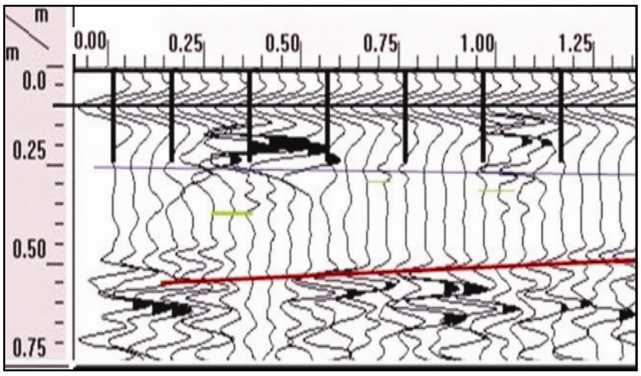

Fig. 11. Incorporated images of pipes placed in the water. Gray indicates the top of the piping, red denotes the bottom of the piping and yellow represents reflections of radar waves from the bottom of the piping.

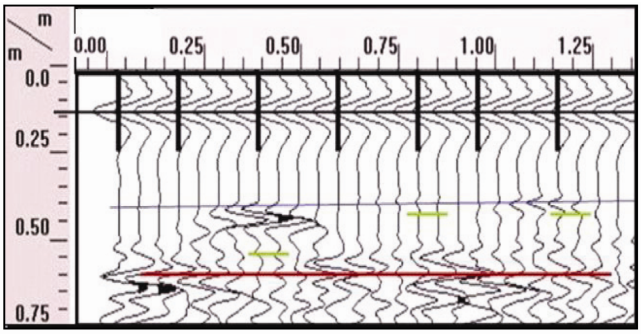

Fig. 12. Incorporated images of pipes placed in the the bottom. Gray indicates the top of the piping, red denotes the bottom of the piping and yellow represents reflections of radar waves from the bottom of the piping.

IV. DATA ANALYSIS

Although the speed of a radar wave propagating in water is constant, the radar-wave speeds through different pipelines are:

$$V = C/\sqrt{\varepsilon} \tag{1}$$

where C: light speed (0.3 m/ns) and ε: relative dielectric constant.

Since the relationship between radar speed and travel time is:

$$D = VT/2 \tag{2}$$

where D: depth (m), V: radar wave speed (m/ns), and T: travel time (ns).

To consider (1) and (2), dielectric constants of different pipes (Table 2) can be calculated from:

$$\varepsilon = \left(\frac{C}{2}\frac{T}{D}\right)^2 \tag{3}$$

Table 2. C Electrical constants of PE and PVC pipes.

(a) Pipes in water

Material type	T/D (ns/m)	Dielectric constant (ε)
PE	10.6	2.6
PVC	11.7	3.2

(b) Pipes on the ditch bottom

Material type	T/D (ns/m)	Dielectric constant (ε)
PE	12.6	3.6
PVC	13.5	4.2

if the depths of pipes (D) are evaluated and reflected travel-times from the top of the pipes are manually selected based on the radar-wave sections.

V. DATA INTERPRETATION

To increase the resolution of the radar-wave sections and to aid in data interpretation of metal and non-metal pipes, Figs. 6 and 9 were zoomed into Figs. 11 and 12, respectively.

Fig. 11 is the zoomed image of piping placed in the water. The gray and red lines in the image indicate the top and the bottom of the piping, respectively. The yellow lines denote reflections of radar waves from the bottom of the piping. Fig. 12 is the zoomed image of piping placed at the bottom of the ditch. Lines in Fig. 12 represent the same things as in Fig. 11.

We observe that the two-way travel-time curves of non-metal (PE and PVC) piping are all weaker than those of metal (iron) piping (Figs. 11 and 12). The following is the comparison of the travel-time curves among the metal and non-metal (PE and PVC) pipes.

1. Comparison of the Travel-Time Curves of Metal and Non-Metal Pipes

1) Metal (Iron) Pipe

The size of the reflected signal delivery time and interface depth level is proportional to, the size of the reflection signal of the dielectric regular number (Table 1) difference between process level about (water and pipe), namely medium of dielectric power often number the greater, the antenna can amount more concentrated waves, the better ability to penetrate its groove depth of 50 cm, so the minority due to water attenuation, the wave energy of a large part of the penetration. So the vast majority (90%) of radar-wave energy reflected from the top of the piping, only less than 10% energy penetrated the top of the iron pipe. Because the transmitted energy was weak, the radar-wave speed decreased after passing through the iron pipe.

2) Non-Metal (PE & PVC) Pipes

On the other hand, the vast majority of radar-wave energy passed through the non-metal (PE & PVC) pipes, with less than 10% being reflected back by the top of the pipes. As a

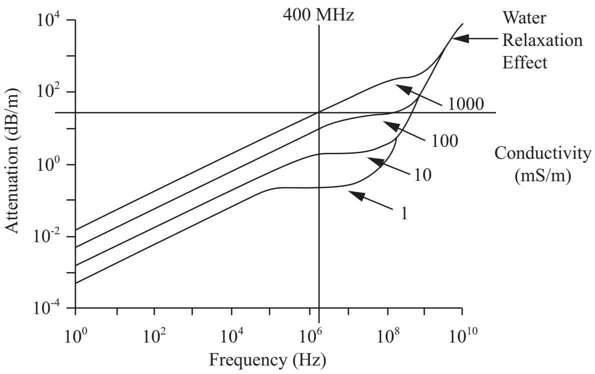

Fig. 13. Weakening and Frequency Relationship (Davis and Annan, 1989).

result, the reflection horizons indicated very weak signals. Since most of the energy (above 90%) penetrated the non-metal pipes, then travel time decreased and the wave speed increased after wave passing through the non-metal pipes.

2. Comparison of the Travel-Time Curves of PE and PVC Pipes

Comparison of two-way travel-time curves of the PE and PVC pipes clearly shows that the travel-time difference (Table 2) in radar-wave propagation can be seen despite the similarity in their polyethylene composition.

Although there were errors in calculation of the dielectric constants of suspended pipelines (Fig. 11) and submerged pipelines (Fig. 12) based on the radar-wave sections, the results are still allowable. We find that the experimental (Table 2) and accepted (Table 1) dielectric constants are extremely close. In particular, errors of dielectric constant are all 0.3 for suspended PE and PVC pipelines. Similarly, errors of dielectric constants are 1.3 and 1.2 for submerged PE and PVC pipelines, respectively.

Suspended pipeline dielectric constant errors are:

$$\text{PE } 2.6\text{-}2.3 = 0.3, \text{ PVC } 3.3\text{-}3.0 = 0.3$$

Submerged pipeline dielectric constant errors are:

$$\text{PE } 3.6\text{-}2.3 = 1.3, \text{ PVC } 4.2\text{-}3.0 = 1.2$$

The errors of dielectric constants associated with PE are 0.3~1.3, and the errors of dielectric constants associated with PVC are 0.3~1.2. When we double check with the attenuation and frequency relationship between the radar frequencies (Fig. 13; David and Annan, 1989), it seems that the 400 MHz antenna, the radar frequency used in our survey, is small and acceptable. This is mostly due to the water depth in the experiment is relatively shallow (50 cm). This is well demonstrated in Fig. 13.

For most engineering work, except for pipelines having a diameter over 10 inches (such as sewage, oil and gas pipelines) which need to be buried quite deep (about 2~3 meters), most civilian pipelines (such as gas, electricity, telephone, and water pipelines) are buried more shallowly at about 0.5~1.5 m to facilitate speed and efficiency of renewal and repair. The dielectric constants and pipeline depths reached from the experiment described above fall within the acceptable range of construction work, so this technique is applicable.

VI. CONCLUSION

Engineering work requires time-effectiveness and location-accuracy. The GPR technique used in underwater study is light, convenient, fast, non-destructive, and is not subject to the geographical influence. This technique can be used to readily and quickly determine the dielectric constants of submerged and suspended pipelines. With regard to the accuracy, it can be seen that the experimental and theoretical values are minimums and, more importantly, the error is within the acceptable window.

Our underwater GPR technique suggests the following conclusion:

(1) This technique has been proven not only fast, but also can differentiate between the underwater pipelines of almost identical composition (such as the PE and PVC pipelines). As a result, this study improves the applications of ground-penetrating radar into the underwater detection.

(2) It is suggested that the experimental and theoretical errors in the engineering projects are acceptable, and in full compliance with the U.S., ASTMD4748-98 standard error range of ± 0.2 inches (± 0.508 cm). Therefore, the suggested experiment is not only useful to detect the metal pipes, but also may be applied to distinguish the non-metal pipes.

REFERENCES

1. Chiou, Y. H., *The Application of Ground-Penetrating Radar of the Tube Line Lnquisition*, Master Thesis, Graduate Institute of the Geophysics, National Central University, Taoyuan, Taiwan (1999).
2. Cook, J. C., “Proposed monocycle-pulse VHF radar for airborne ice and snow measurement,” *AIEE Transpotation, Communication and Electronics*, No. 79, pp. 588-594 (1960).
3. Cook, J. C., “Radar transparencies of mine and tunnel rocks,” *Geophysics*, Vol. 40, pp. 865-875 (1975).
4. David, J. L. and Annan, A. P., “Ground penetrating radar for high- resolution mapping of soil and rock stratigraphy,” *Geophysical Prospecting*, Vol. 37, pp. 531-551 (1989).
5. Deng, W. C., *The Research of Underground Pipe Model Investigation by Using Ground Penetrating Radar and Its Application*, Master Thesis, Graduate Institute of Applied Geology, National Central University, Taoyuan, Taiwan (1995).
6. Donaldson, C. A., *Underground Prospecting System*, U.S. Patent No. 2,657,380 (1953).
7. Huang, T. F. and Liang, S., “The application wears the ground penetrating radar technique to detect to lay to take care of the line in the ground,” *Journal of Chinese Soil and Water Conservation*, Vol. 24, pp. 15-21 (1993).

8. Lee, K. F., Hsiuan, T. H., and Wu, K. H., “Ground-penetrating radar the resolution technique,” *Exploration and Development Research Institute Report*, No. 22, pp. 319-340 (1999).
9. Melton, B. S., *Electromagnetic Prospecting Method*, U.S. Patent No. 2,077,707 (1937).
10. Tong, L. T., “Application of ground penetrating radar to locate underground pipes,” *TAO*, Vol. 4, No. 2, pp. 171-178 (1993).
11. Ulriksen, C. P. F., *Application of Impulse Radar to Civil Engineering*, Ph.D. Thesis, Department of Engineering Geology, Lund University of Technology (1982).
12. Zeng, X. and McMechan, G. A., “GPR characterization of buried tanks and pipes,” *Geophysics*, Vol. 62, pp. 797-806 (1997).