Identification of Pipelines from the Secondary Reflect Wave Travel Time of Ground-Penetrating Radar Waves

Kun. Fa. Lee

Chinese Petroleum Corp. Exploration & Development Research Institute
Institute of Applied Geosciences, National Taiwan Ocean University
Department of Civil Engineering, Feng Chia University

Abstract
When using ground-penetrating radar to identify underground pipelines of similar dielectric constants (i.e. PE and PVC), misidentification of different pipelines is quite likely. In this study, by considering secondary-reflected travel-times theory of radar waves, we calculated dielectric constants of pipelines for which PE- and PVC-type non-metal pipelines were identified. An experiment by placing PE- and PVC-type non-metal pipelines and heavy metal (iron) pipelines in water were conducted. Based on the travel-time calculation, the dielectric constants of non-metal pipelines of similar composition (PE: 2.3 and PVC: 3.0) were quite close. The differences between experimental and theoretical values are acceptable in construction work and U.S.A.ASTM4748-98 standard error range on ± 0.2 in (0.508cm) completely Less than, it is qualified. As a result, not only can this study be used to detect metal pipelines, it can also be used to differentiate between non-metal pipelines submerged in water.

Keywords: Ground-Penetrating Radar (GPR), travel time, dielectric constants, PE, PVC

INTRODUCTION
The concept of using ground-penetrating radar to study subterranean structure began in the 1930s (Melton, 1937; Donaldson, 1953), and was successfully applied to studies of ice thickness in the Arctic and Antarctic regions in 1960 (Cook, 1960). After 1970, ground-penetrating radar was slowly adopted for widespread use in exploration (Cook, 1975; Davis and Annan, 1989). Ground-penetrating radar continued to be developed into the 1980s, and people began using the electrical properties of different substances, such as dielectric constants (Table 1), conductivity, and resistance, to image soil and sedimentary layers (Davis and Annan, 1989). 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 dam’s damage. Although ground-penetrating radar appears to have wide applications, on the whole it had only one purpose: to find target objects and resolve problems of environment and engineering.

Table I. Commonly seen dielectric constants

<table>
<thead>
<tr>
<th>Material</th>
<th>Dielectric Constant</th>
<th>T/D (ns/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>1</td>
<td>6.5</td>
</tr>
<tr>
<td>Water</td>
<td>81</td>
<td>59</td>
</tr>
<tr>
<td>PE</td>
<td>2.3</td>
<td>11</td>
</tr>
<tr>
<td>PVC</td>
<td>3.0</td>
<td>12</td>
</tr>
</tbody>
</table>

Source: (Adapted from Davis and Annan, 1989).

Chou (1998) and Li (1999) 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 detection of subterranean pipelines of similar composition, it was used for detection of gas, water, telegraph, electric, oil, and other pipelines (Tong, 1993; Huang, 1993; Deng, 1995). On the other hand, Zeng and McMechan (1997) focused on the radar waves to analyze the dielectric constants of pipelines and differentiate between empty and full PVC pipelines submerged in water.

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

EXPERIMENT
The site for the experiment was a preexisting ditch next to an industrial road. The surface of the water was 180 cm from the ground. The water’s depth and width were 50 cm and 240 cm, respectively (Figure 1). Iron, PVC, and PE pipes (Figure 3) with lengths of 200 cm and diameters of 10 cm were placed in the water. Lines Interval 20 cm (Figure 2). Because radar waves propagating in water tend to suffer from
serious energy reduction, the pipelines were divided into two circumstances: suspending in water and resting on the bottom of the ditch (Figure 4). Experimental results demonstrated that, perhaps because the water was only 50 cm deep, 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 Figure 2) and used eight marked lines (red lines in Figure 2). Measured and marked lines were each separated by 20 cm.

This study used a GSSI-3000 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

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 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).
Fig. 5-10 Separately in water (Fig. 5-7) and bottom (8-10) Pipeline. Source sectional of the Pipeline (Fig.5, Fig.8), Data Processing with through filter (Fig.6, Fig.9), and migration (Fig.7, Fig.10) the result.

It can clearly be seen from the radar-wave section of Figures 5-10 that the reflection and diffraction images of non-metal and metal piping can be readily distinguished, but PE and PVC pipes are indeed very difficult to tell apart. As a result, distinguish between sections of PE and PVC pipes is required further investigation. We magnified the processed sections (Figures 11–12) to better analyze and use secondary wave theory interpret them in order to identify PE and PVC separately.

DATA ANALYSIS

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

\[ V = \frac{C}{\sqrt{\varepsilon}} \]  

(1)

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

Since the relationship between radar speed and travel time is

\[ D = \frac{VT}{2} \]  

(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

\[ \varepsilon = \left( \frac{C}{2D} \right) T \]  

(3)

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

Table 2. Electrical constants of PE and PVC pipes

(a) In water

<table>
<thead>
<tr>
<th>Material Type</th>
<th>T/D (ns/m)</th>
<th>Dielectric constant (ε)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE</td>
<td>10.6</td>
<td>2.6</td>
</tr>
<tr>
<td>PVC</td>
<td>11.7</td>
<td>3.2</td>
</tr>
</tbody>
</table>

(b) On the ditch bottom

<table>
<thead>
<tr>
<th>Material Type</th>
<th>T/D (ns/m)</th>
<th>Dielectric constant (ε)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE</td>
<td>12.6</td>
<td>3.6</td>
</tr>
<tr>
<td>PVC</td>
<td>13.5</td>
<td>4.2</td>
</tr>
</tbody>
</table>

DATA INTERPRETATION

To increase the resolution of the radar-wave sections and to aid in data interpretation and of metal and non-metal pipes, Figures 6 and 9 were zoomed into Figures 11 and 12, respectively, and secondary reflect travel time wave theory (Figures 13).
Fig. 11 and 12 respectively in water (Fig. 11) and bottom (Fig. 12) with zoom Pipeline and secondary reflect travel time. From can color not different labelled to see (dust, yellow, red) Line, its differentiate expression; Grey: The pipeline top, red: The pipeline bottom, Yellow: In the pipeline of secondary reflecting theory of radar wave.

Figure 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. Figure 12 is the zoomed image of piping placed at the bottom of the ditch. Lines in Figure 12 represent the same things as in Figure 11.

Fig. 13 secondary reflect wave travel time theory

We observe that the secondary reflect wave two-way travel-time theory curves (Figures 13) of non-metal (PE and PVC) piping are all weaker than those of metal (iron) piping (Figures 11 and 12). The following is the comparison of the travel-time curves among the metal and non-mental (PE and PVC) pipes.

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

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

Comparison of the Secondary Reflect Travel-Time Theory Curves of PE and PVC Pipes

Comparison of secondary reflect two-way travel-time theory curves of the PE and PVC pipes clearly shows that the travel-time difference (Table 2) in radar-wave propagation can be seen despite of the similarity in their polyethylene composition. Although there were errors in calculation of the dielectric constants of suspended pipelines (Figure 11) and submerged pipelines (Figure 12) based on the secondary reflect 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 constants are 0.3 and 0.2 for suspended PE and PVC pipelines, respectively. Similarly, errors of dielectric constants are 1.3 and 1.2 for submerged PE and PVC pipelines, respectively.

Suspended pipeline dielectric constant error:
PE 2.6-2.3=0.3, PVC 3.3-3.0=0.3
Submerged pipeline dielectric constant error:
PE 3.6-2.3=1.3, PVC 4.2-3.0=1.2

From calculation of submerged and suspended pipelines, we see that the error of dielectric constants associated with PE is 0.3~1.3, and the error of dielectric constants associated with PVC is 0.3~1.2. From Figure 14, which describes the weakening and frequencies of radar waves, we see that the depth of the water is the confounding variable although it is a homogenous solution. This weakening and error is acceptable in construction engineering, especially since construction primarily requires knowledge of the pipeline’s offset and depth. Since the pipeline’s type can also be determined in this manner, such error is acceptable.

GPR radar reflection travel time to the second theory, we calculate the PE and PVC-based non-metallic pipe lines is consistent with the dielectric constant of the error can be used as a reference for future research.
For most construction work, except for pipelines having a diameter over 10 inches (such as sewage pipelines and oil 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 acceptability range of construction work, so this technique is applicable.

CONCLUSION

Construction work requires nothing more than time-effectiveness and accuracy. The GPR technique used in the underwater study is light, convenient, fast, nondestructive, and is not subject to geographical influence. This technique can be used to readily and quickly determine the dielectric constants of submerged and suspended pipelines. With regard to accuracy, it can be seen that experimental and theoretical values do not differ much – such error is acceptable for construction work. Our underwater GPR technique leads to the following results:

1. This technique is not only fast, it can also differentiate between underwater pipelines of almost identical composition. As a result, this study raises the applicability of ground-penetrating radar to underwater detection.
2. The differences between experimental and theoretical values are acceptable in construction work and U.S.A. ASTM D4748-98 standard error range on ± 0.2 in (0.508cm) completelyLess than, it is qualified.

REFERENCES


