TAO, Vol.4, No.2, 171-178, June 1993

Application of Ground Penetrating Radar to Locate Underground Pipes

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(Manuscript received 2 October 1992, in final form 28 May 1993)

ABSTRACT

In many situations, the governmental agency in charge of the underground pipes is unaware of the exact position of the pipes. The lack of efficient pipe management may potentially lead to the dangerous situation in which the underground pipes are destroyed during engineering excavation. The development of a non-destructive and efficient technique to locate underground pipes has therefore become important. The purpose of this study is to evaluate the applicability of ground penetrating radar (GPR) method in positing underground pipes by field tests on some different kinds of under-ground pipe. The reflections comes from an underground pipe is very particular diffraction pattern because the size of a pipe is normally small. The locations of underground pipes can be well delineated from the distribution of diffractions on the radar profile. The response of iron pipe is very obvious due to the strong reflection signal. Two closed iron pipes also can be distinguished from the radar profile. The sewer and drain pipes which are made of concrete also can be detected from the properties of multiple and flat reflections. It is difficult to detect the PVC pipe, because the reflected signals coming from a PVC pipe are very weak. The reflections coming from a PVC pipe can be enhanced if the background signal can be removed through measurement. The background removal technique can be added to detect PVC pipe.

1. INTRODUCTION

In many situations, the governmental agency in charge of the underground pipes is unaware of the exact position of pipes. The lack of efficient pipe management may potentially lead to the dangerous situation in which the underground pipes are destroyed during engineering excavation. Damage caused by destroying gas pipe, power line or water pipe during excavation are gradually increasing. This phenomenon reflects that it is necessary to efficiently locate the position of underground pipes before excavation.

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Many traditional methods employed for positing pipes are negatively affected by the surrounding noise and time-consumption factor. So, the development of an efficient, rapid, high-resolution and non-destructive technique to locate the underground pipes is important.

The concept of utilizing the reflections of electromagnetic waves for investigating sub-surface structure was first introduced by Melton (1937) and Donaldson (1953). This method was widely applied during the 1960s in probing underground structure of snow and ice in polar regions (Cook, 1960). Many non-ice explorations by using ground penetrating radar (GPR) were being attempted by the 1970's. GPR has been proved in many applications (Davis and Annan, 1989; Cook, 1975) to be a very useful tool in the soil and rock explorations.

GPR provides a substantially higher resolution internal image of the ground than the other conventional geophysical methods owing to the fact that high frequency radar waves are used. The rather high resolution image of ground produced by GPR makes it quite useful for engineering purposes. GPR has been primarily used historically in the area of mapping sub-geological structures. The electromagnetic waves which are reflected from an underground pipe along a survey line form a special diffraction pattern that can be easily distinguished from reflections created by geological boundaries or noise. So, GPR has also been recently applied in non-destructive probing the positions of a buried pipe because of the rapid measurement and high resolution.

Since the papers discussing the use of GPR method in positing pipes are few, a brief overview of the GPR method is presented in this paper. Some results of field tests on positing different kinds of pipes are also discussed in order to evaluate the applicability of the GPR method in probing underground pipes.

2. CONCEPTS AND INSTRUMENTATION OF GROUND PENETRATING RADAR

The principle of GPR is similar to reflection seismics and sonar techniques. The energy of reflected wave depends on the reflection coefficient of the differing boundaries. For the natural strata, the reflection coefficient is defined as:

$$\Upsilon = \frac{\sqrt{\varepsilon 1} - \sqrt{\varepsilon 2}}{\sqrt{\varepsilon 1} + \sqrt{\varepsilon 1}},$$

where Υ is the reflection coefficient; $\varepsilon 1$ is the dielectric constant of the upper layer; and $\varepsilon 2$ is the dielectric constant of the lower layer.

The basic operation of GPR is illustrated in Figure 1. A short burst of high frequency radar wave, typically in 1 to 1000 MHz frequency range, is transmitted into the ground. The reflections are produced by electrical property changes, i.e. the boundaries between different stratigraphic units, groundwater table, cavity or buried pipe. The reflected wave can be detected by a sensitive antenna, digitized and stored on video tape for post processing and display. The energy of reflected wave and penetrating depth depends on the electrical properties, dielectric constant, electrical conductivity, velocity and attenuation of the ground. A summary of typical velocities and attenuations for common materials is presented in Table 1, which are primarily derived from field investigations undertaken by Annan and Cosway (1991).

Table 1. A summary of typical velocities and attenuations for common materials (Annan and Cosway, 1991).

MATERIAL	Dielectric constant	Conductivity (m mho/m)	Velocity (m/ns)	Attenuation (dB/m)
Air	1	0	0.3	0
Distilled Water	80	0.01	0.033	0.002
Fresh Water	80	0.5	0.033	0.1
Sea Water	80	3000	0.01	1000
Dry Sand	3~5	0.01	0.15	0.01
Saturated Sand	20~30	0.1~1.0	0.06	0.03~0.3
Limestone	4~8	0.5~2.0	0.12	0.4~1
Shales	5~15	1~100	0.09	1~100
Silts	5~30	1~100	0.07	1~100
Clays	5~40	2~1000	0.06	1~300
Granite	4~6	0.01~1	0.13	0.01~1
Dry Salt	5~6	0.01~1	0.13	0.01~1
Ice	3~4	0.01	0.16	0.01

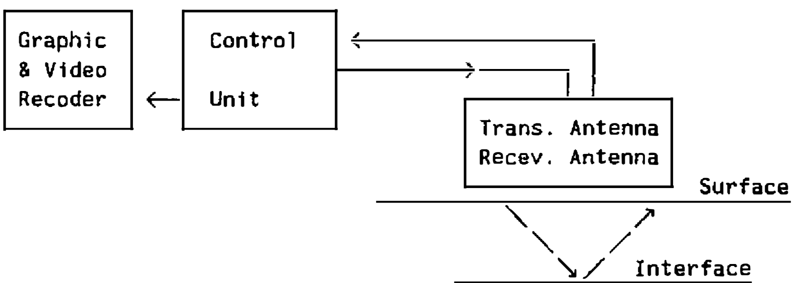

Fig. 1. Basic operation of ground penetrating radar.

3. PROCEDURE OF LOCATING PIPES

The distribution of underground pipes is often complicated. The characteristics of pipes are unknown before measurement is undertaken. A former survey design must be prepared so as to be able to perform an efficient survey. Some considerations are provided in the following which can assist the establishment of a proper survey plan.

(A) Estimation of the characteristics of pipe: Knowing the characteristics of underground pipes, i.e. their depth ranges, dimensions, and electrical properties is essential before a radar survey is performed. A proper survey plan can then be adequately estimated before the field work starts.

(B) Estimation of the ground velocity: Velocity of electromagnetic wave varies among different kinds of material. The properly recording time range can be estimated by referring to appropriate velocity of ground which is noted in Table 1 after maximum depth of investigation is decided.

(C) Selection of the appropriate antenna: Selection of a proper operating frequency for a GPR survey is critical. The resolution power is increasing and the penetrating power is decreasing as radar frequency increases. The 300 MHz and 500 MHz antennas are often used in positing pipes since the depth of buried pipes normally ranges from 0.1 to 4 meters.

(D) Conduction preliminary test lines: Before initiating all of the survey lines, some typical lines must be selected so as to test whether the survey parameters are properly set or not. The number of test lines depends on the size of the survey area and the electrical variety of the ground. Normally, the test lines should cover the whole survey area and the areas with different electric properties.

(E) Adjustment of the survey parameters for optimal data: The survey parameters, i.e. vertical filter, horizontal filter, time range, and gain, have to be adjusted during acquisition of data along the preliminary test lines. The purpose of this procedure is to enhance the reflection of underground pipes. A clear image of the subsurface can therefore be acquired.

(F) Acquisition of the data: The whole survey can be initiated once the survey parameters are properly set. The operator still has to monitor the quality of data during data acquisition. The readjustment of the survey parameters becomes necessary if the image of radar data has become not clear.

4. FIELD TESTS

Since the size of a pipe is relatively small, it will behave as a diffraction point when EM wave is propagated through the ground. The reflected wave coming from the pipe will form a special diffraction pattern. The shape of the diffraction pattern is primarily dependent upon the velocity of surrounding soil and the geometry of the pipe. The amplitude of reflected wave come from the pipe depends on the dielectric contrast between the pipe and soil. Underground pipes can be conventionally classified into four kinds, i.e. iron, PVC, sewer, and drain pipes. Some field tests are performed in order to understand the diffraction characteristic of each kind of pipe and to evaluate the applicability of GRP in locating these kinds of pipe.

4.1 Iron Pipe

Investigation of the iron pipe is relatively simpler than the other kinds of pipe. Amplitude of reflections from the iron pipe is obvious since the dielectric contrast between the iron pipe and surrounding soil is relatively substantial. Figure 2 shows a radar profile which is acquired at a petrochemical plant. The antenna frequency used is 500 MHz, and the time range used for recording reflections is 80 ns. The diffractions from two closed iron pipes are observed and quite clear from this record. Accurately locating the position of these two pipe therefore becomes quite easy.

Figure 2 also shows the applications of migration and Hilbert transformation. The true position of diffraction point can be obtained after data processing. The position of pipes can then be obviously defined from the processed record.

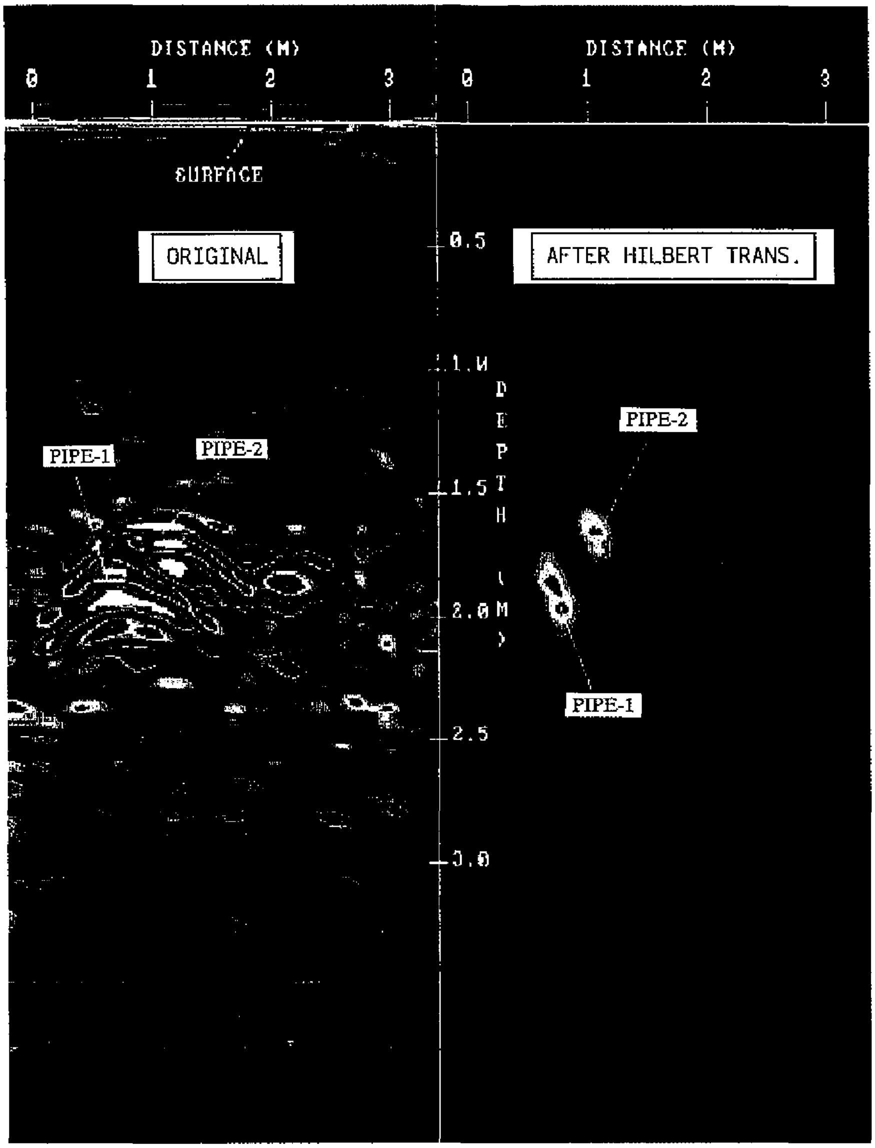

Fig. 2. Radar section illustrating diffractions from two closed iron pipes.

4.2 PVC Pipe

The reflection coefficient between PVC pipe and soil is small since the dielectric contrast between the PVC pipe and surrounding soil is relatively weak. The amplitude of the reflected waves probably have the same magnitude as surrounding noise. Locating such kinds of pipe consequently becomes more difficult. Finding the PVC pipes is, meanwhile, possible; that is, if a careful survey design is attempted. A test on locating the buried PVC pipes is performed. In this study, a 500 MHz antenna is used and the time range is set to be 20 ns. The radar profile is shown in Figure 3.. For enhancement of the diffractions from pipe, background

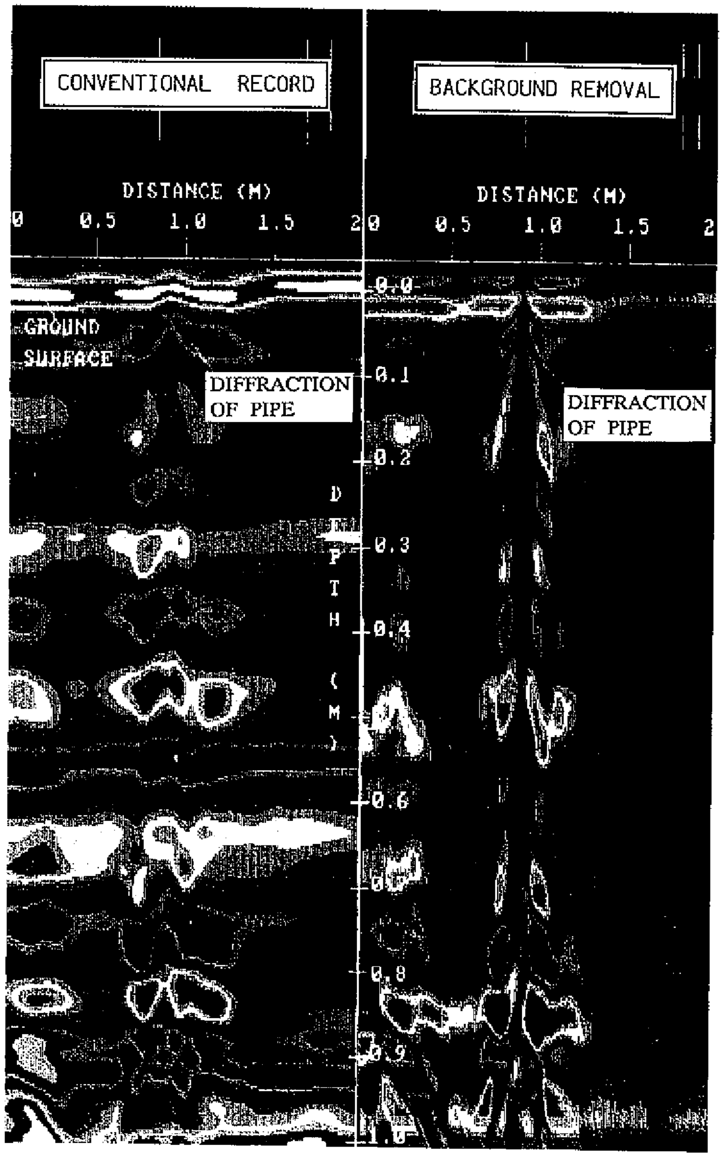

Fig. 3. Radar section illustrating reflections from a PVC pipe.

noise is memorized and removed during data acquisition so as to emphasize the weak amplitude of diffractions by filtering out the steady background signal. Utilizing such a manner to acquire GPR data provides evidence that the position of PVC pipes can also be found.

4.3 Sewer Pipe

Sewer pipes are normally made of concrete. The dielectric contrast is obviously large enough to make a reflected wave since both water and air are filled in the pipe. A GPR profile acquired for positing a sewer pipe is provided in Figure 4. Multiple reflections become induced when an electromagnetic wave is propagated into the pipe as a consequence

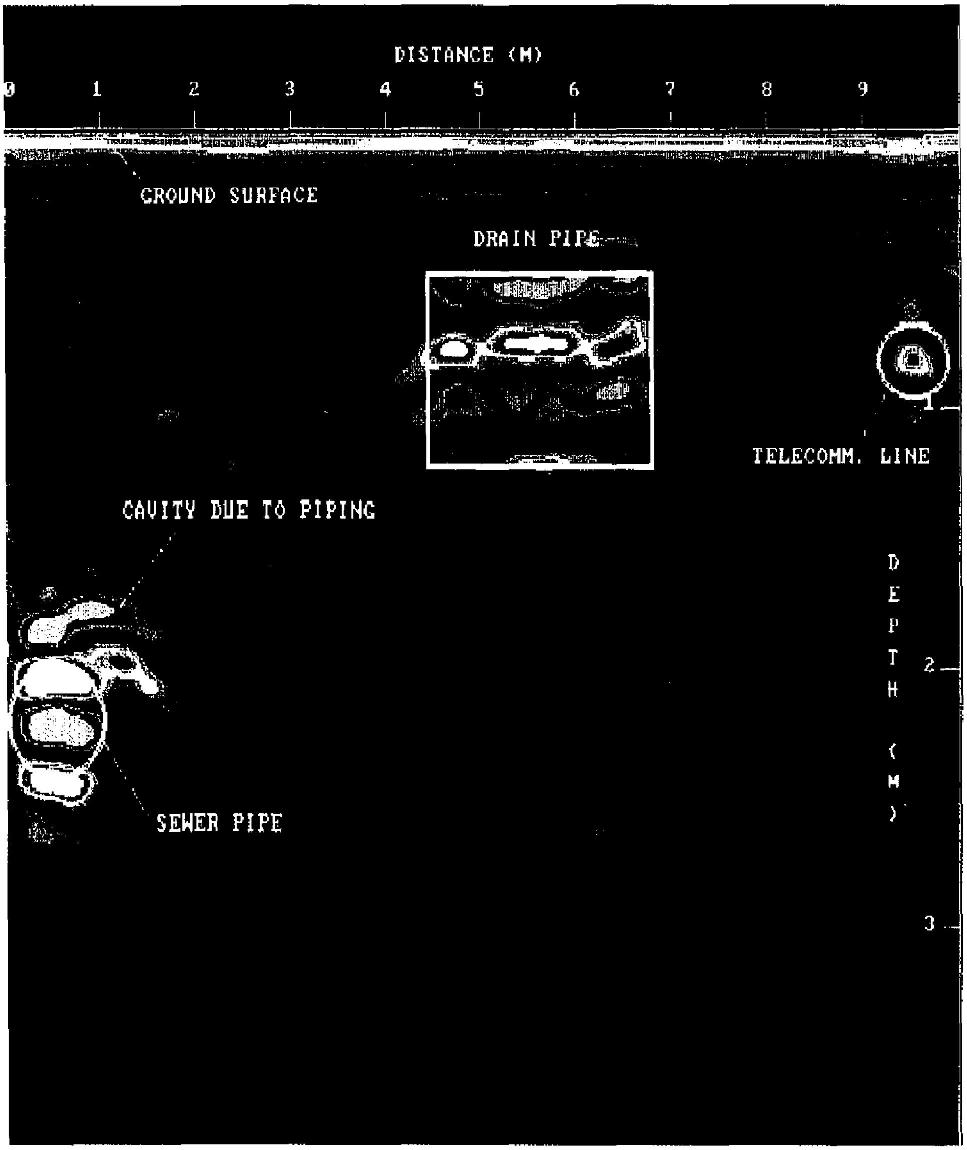

Fig. 4. Radar section along a line over buried sewer and drain pipes.

of the presence of water and air in the pipe which have different dielectric constants. The special multiple reflections can be a good indicator for identifying the sewer pipe.

4.4 Drain Pipe

The radar data along a line over a buried drain pipe are illustrated in Figure 4. The reflections from the top of the pipe are apparently flat since the width of a drain pipe ranges from 1 to 2 meters under normal conditions. From the obvious lateral amplitude changes, the position of the drain pipe is observed in Figure 4 to be well delineated.

5. CONCLUSION

Locating the position of underground pipes for engineering, environmental and geotechnical purposes is becoming increasingly important. Locating the position of underground pipes has therefore been a big problem in the past. GPR is a rather practical technique which provides a quite high resolution image of the ground. From the test results of this study, the following conclusions are obtained. The response of iron pipe is very obvious due to the strong reflection signal. Two closed iron pipes also can be distinguished from the radar profile. The sewer and drain pipes which are made of concrete also can be detected from the properties of multiple and flat reflections. It is difficult to detect PVC pipe, because the reflected signals coming from a PVC pipe are very weak. The reflections coming from a PVC pipe can be enhanced if the background signal can be removed through measurement.

Acknowledgements The author wishes to thank many companions of ERL, especially Mr. Yan-Tsong Hwang, Jin-Lang Chen, Jin-Chyuan Tsai and Bong-Kuo Chen, who assisted in the field work.

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