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Correction of multi-frequency GPR wave velocity with distorted hyperbolic reflections from GPR surveys of underground utilities

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ABSTRACT

Estimation of Ground Penetrating Radar (GPR) wave velocity and the real part of dielectric permittivity (ε') play an important role when assessing the condition of buried objects because ε' is highly affected by moisture and void content in materials. However, errors in velocity occur due to the effect of oblique angles between the alignment of pipelines and GPR traverses during common offset survey. In this paper, field experiments on paving blocks and reinforced concrete were conducted in order to investigate errors caused by the effects of oblique angles on GPR wave velocity. GPR traverses were designed to travel along several oblique angles (θ = 30°, 45°, 60°,75°, 90°, 105°, 120°, 135° and 150°) relative to the alignment of a ductile iron (DI) pipe. Antennas with various nominal centre frequencies (IDS 200/600, GSSI 400/900 and Sensor & Software 250 MHz) were applied in order to compare the effects. It was found that wider and flatter hyperbolic reflections are obtained and the estimated GPR wave velocity is higher if the included angle between the alignment of the DI pipe and GPR traverse changes from being perpendicular to oblique. The relative error of velocities estimated at oblique angles when compared to that estimated in perpendicular cases can be as much as 44%. Specific steps were taken to correct the errors. It is believed that this study suggests a method whereby the measurement accuracy of velocity estimation for GPR condition surveys of underground utilities can be increased.

1. Introduction

1.1. GPR wave velocity analysis

Ground Penetrating Radar (GPR) is a well-known non-destructive method for subsurface exploration. Major applications include condition assessment of underground utilities (Costello et al., 2007; Hao et al., 2012), for example to identify water seepage/leakage and to characterize the dielectric properties/water content of materials (Lai et al., 2011; Lai et al., 2012; Lai et al., 2009; Lai et al., 2016), for which GPR wave velocity estimation always plays an most important role. The real part of complex dielectric permittivity of a dielectric material, denoted as ε', primarily determines the GPR wave velocity when the signal travels through such dielectric material, which can be commonly formulated as (Balanis, 2012):

$$v = \frac{c}{\sqrt{\varepsilon'}} \tag{1}$$

where c is EM wave travelling velocity in free space and ε' the real part of complex dielectric permittivity.

In addition to Eq. (1), several other major methods can be used for GPR wave velocity estimation, such as depth to known reflector, velocity sounding and hyperbolic fitting. The depth to known reflector method utilizes a target reflector with known depth to calculate the velocity by two-way travel time t, but it is difficult to find such perfect targets on site during underground utility surveys. Also, this method only provides us with a single estimated velocity, which is not accurate enough ("ASTM D6432-11," 2011). For the velocity sounding method in multi-offset configuration, transmitting and receiving antennas are sequentially moved away in opposite directions from the original position and at known distance increments ("ASTM D6432-11," 2011). By measuring the reflection and refraction time, the velocity can be calculated. This method is only applicable for GPRs with separate transmitter and receiver setting antennas but not with common offset configurations. For the hyperbolic fitting method in common offset configuration, velocity is obtained by a curve-fitting process that overlays a typical hyperbolic curve on a user-selected reflection in the radargram ("ASTM D6432-11," 2011; Kohl et al., 2003; Kohl, Krause, Maierhofer and Wöstmann, 2005). Obviously, the result of hyperbolic fitting can be easily biased as the overlay procedure significantly relies upon the operator's judgement and perception of vague colour contrasts within the radargram. Chen and Cohn (2010 May 2010 July) have

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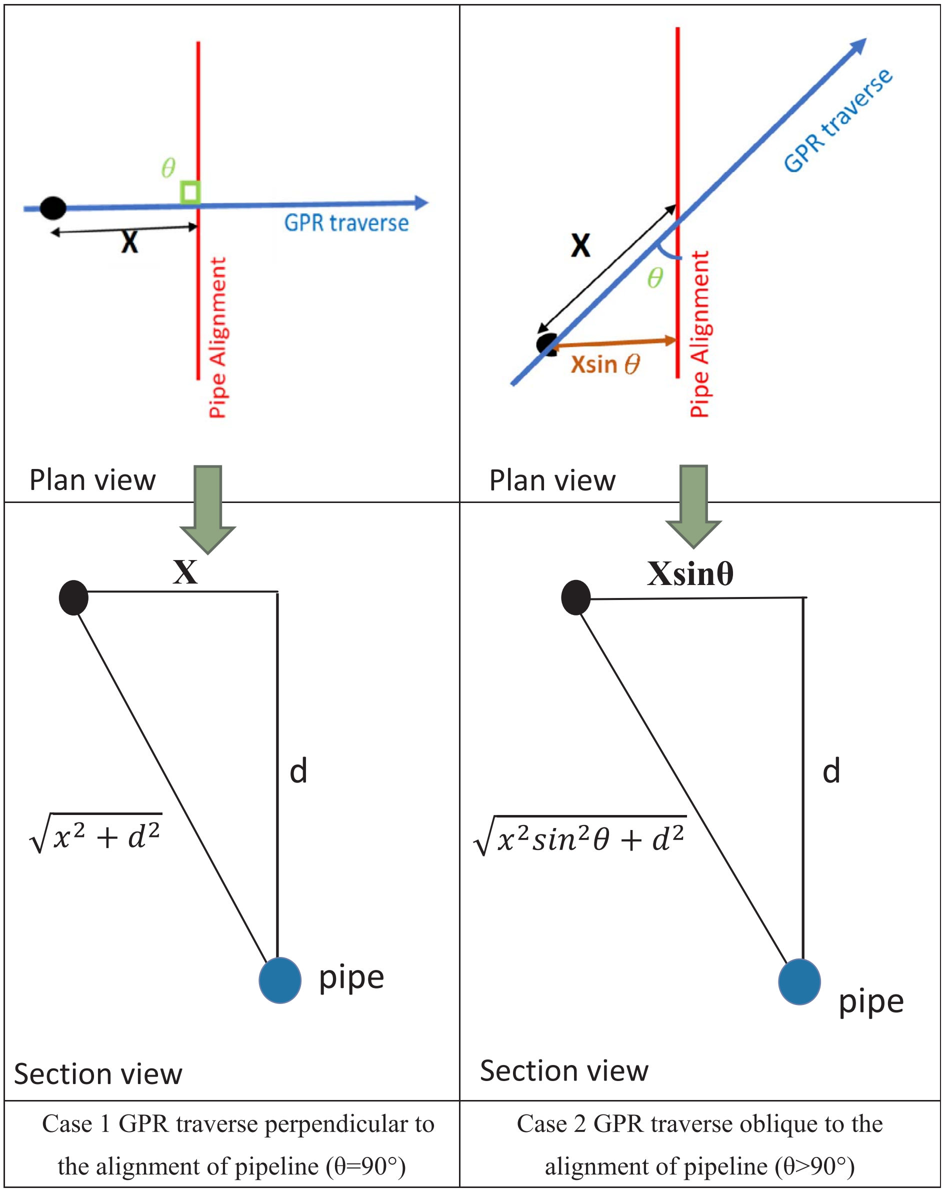

Fig. 1. Illustration of oblique angle on the GPR traverse.

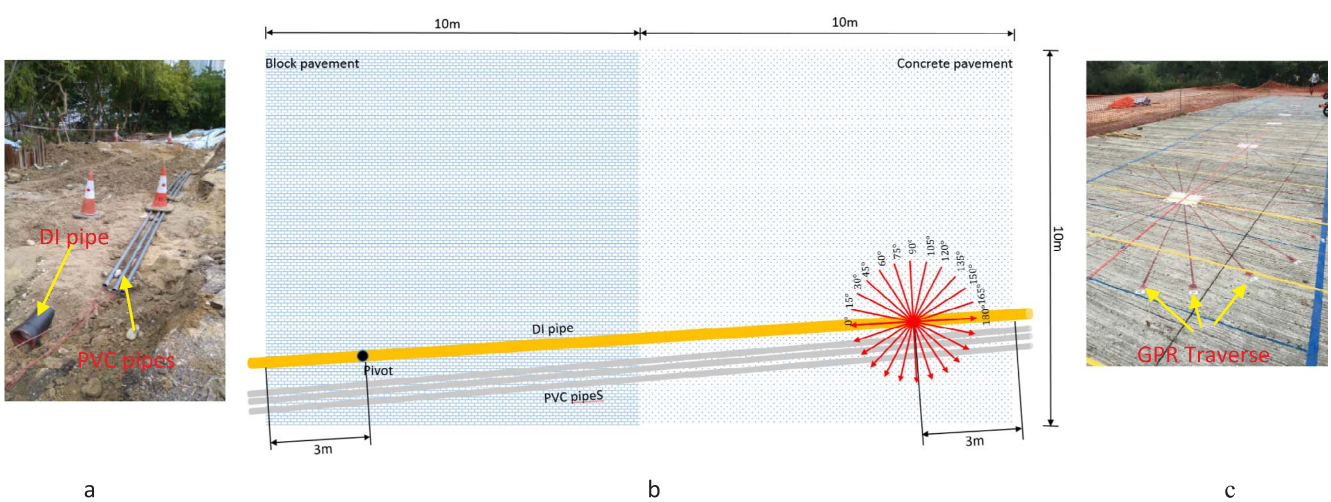

Fig. 2. Survey layout of the test site. Remark: the PVC bundle were put deliberately to observe the effects of small and weak scatterers on the reflection of D.I. pipe.