



Investigation of guided wave propagation and attenuation in pipe buried in sand



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ABSTRACT

Long-range guided wave testing is a well-established method for detection of corrosion defects in pipelines. The method is currently used routinely for above ground pipelines in a variety of industries, e.g. petrochemical and energy. When the method is applied to pipes buried in soil, test ranges tend to be significantly compromised and unpredictable due to attenuation of the guided wave resulting from energy leakage into the embedding soil. The attenuation characteristics of guided wave propagation in an 8 in. pipe buried in sand are investigated using a laboratory full-scale experimental rig and model predictions. We report measurements of attenuation of the $T(0,1)$ and $L(0,2)$ guided wave modes over a range of sand conditions, including loose, compacted, mechanically compacted, water saturated and drained. Attenuation values are found to be in the range of 1.65–5.5 dB/m and 0.98–3.2 dB/m for the torsional and longitudinal modes, respectively, over the frequency of 11–34 kHz. The application of overburden pressure modifies the compaction of the sand and increases the attenuation. Mechanical compaction of the sand yields similar attenuation values to those obtained with applied overburden pressure. The attenuation decreases in the fully water-saturated sand, and increases in drained sand to values comparable with those obtained for compacted sand. Attenuation measurements are compared with Disperse software model predictions and confirm that the attenuation phenomenon in buried pipes is essentially governed by the bulk shear velocity in the sand. The attenuation behaviour of the torsional guided wave mode is found not to be captured by a uniform soil model; comparison with predictions obtained with the Disperse software suggest that this is likely to be due to a layer of sand adhering to the surface of the pipe.

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1. Introduction

The inspection of pipelines by long-range Guided Wave Testing (GWT) has been routinely used for over a decade in a variety of applications in the petrochemical, power and nuclear industries [1–3]. The method employs ultrasonic signals guided by the inspected structure and offers the possibility of rapid screening over long lengths of pipework for the detection of corrosion and other defects. The common application of the method is to bare- or thinly epoxy-painted pipes. However, when the method is applied to pipes buried in soil, test ranges tend to be significantly reduced compared to bare pipes and unpredictable as the attenuation varies from case to case [4]. Buried pipes are generally tested by digging an

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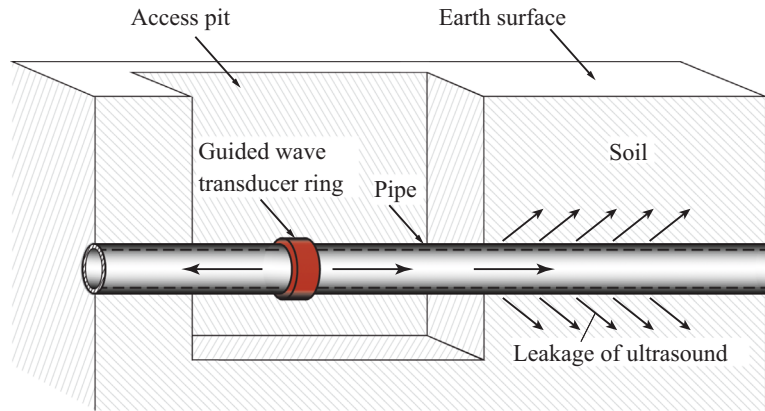


Fig. 1. Schematic of a pipe buried in soil. An access pit is excavated in order to perform guided wave inspection, where a guided wave transducer ring is attached to the pipe.

access pit to expose the pipe at the location where a transducer ring is to be attached as presented in Fig. 1. The testing scheme uses a pulse-echo arrangement from a single position on the inspected pipe. Waves are excited and received using a transducer ring comprising an array of dry-coupled piezoelectric elements equally spaced around the circumference of the pipe [5–7]. GWT typically requires frequencies below 100 kHz and employs the torsional ($T(0,1)$) or longitudinal ($L(0,2)$) modes. These modes are used since they are sensitive to cross-sectional loss at any location through the wall thickness or around the circumference, they are relatively easy to excite in their pure form and are generally non-dispersive over a wide frequency band [8–10]. The presence of soil in contact with the inspected pipe causes damping of the propagating guided wave modes since energy is leaking into the soil (Fig. 1), resulting in a dramatic reduction in test ranges. Moreover, the amount of leakage for a given mode depends on both the material properties of the pipe and the surrounding media, and in general is a function of frequency. The attenuation of these propagating modes may vary significantly from case to case since pipes are buried in different soil types and subjected to a variety of physical conditions, e.g. differences in water saturation of the soil along the pipe, soil compaction conditions and burial depths. The abundance of pipelines buried in the ground worldwide makes long-range GWT of these highly desirable and of high economic and environmental importance. Maximising the inspection range from a single access pit will minimise the number of access pits which have to be dug and reduce overall inspection costs significantly.

In the present study, we have conducted a comprehensive full-scale experimental investigation in order to characterise the damping of guided waves propagating in pipes buried in sand under a range of controlled physical conditions. Model predictions were used to reproduce the experimental results and to gain better understanding of the dominating physical mechanisms, with the aim of providing the scientific basis for the improved inspection of buried pipes.

The background on GWT in embedded cylinders is discussed in Section 2.1, the guided wave model is discussed in Section 2.2 and a review on soil acoustical properties is discussed in Section 2.3. The experimental apparatus and measurement method are described in Section 3. The experimental and model results are reported and discussed in Section 4 and the conclusion are provided in Section 5.

2. Background

2.1. Guided wave propagation in embedded cylinders

The propagation of acoustic waves along cylindrical structures has been studied extensively e.g. [11–15]. The use of ultrasonic GWT for the inspection of metallic structures is well established for several decades. For pipelines, GWT allows large pipe-lengths to be covered from a single transducer position, thus making it an economically attractive and time efficient technique. Many studies have focused on guided wave propagation in structures as means for detection and monitoring of defects and corrosion e.g. [1–10, 16–21].

However, although structures are commonly embedded or coated to provide insulation and corrosion protection in engineering applications, only a few studies have focused on these systems. In embedded or coated pipelines, the acoustic signal attenuates due to two mechanisms: damping by energy-absorbing materials of the waveguide system, and leakage of energy radiating out into the embedding material, resulting in a dramatic reduction of the test range. The rate of leakage depends on the material properties of both the pipe and the embedding material. For structures coated with materials having internal damping, e.g. bitumen, the attenuation is related to the amount of strain energy stored in the coating layer and is proportional to the frequency. As a consequence, there is a need for the understanding of the attenuation of guided waves propagating in pipes which are in direct contact with embedding or coating materials, in order to maximise the distance over which defects can be detected.

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