An electromagnetic-based method for pinpointing leaks in buried pipes: a practical validation
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ABSTRACT

In this paper, a time domain reflectometry (TDR)-based solution for detecting water leaks in underground pipes is described and experimentally validated. The proposed method strongly reduces the inspection time that is typically required by traditional leak detection methods. In fact, it can successfully inspect pipes that are hundreds of meters long. In this work, two different configurations of the system are described: one can be used for detecting leaks in ‘already-installed’ metal pipes; whereas the other is suitable to be employed for detecting leaks in ‘newly-installed’ pipes made of any material. The performance of both these system configurations was assessed through an extensive, on-site experimental campaign, carried out with the collaboration of one of the largest European water operators, Acquedotto Pugliese S.p.A. (AQP). Representative results, related to both configurations, of three experimental cases (ECs) are reported and commented on. Finally, some practical considerations on the applicability of the system are provided.

INTRODUCTION

The individuation of leaks is extremely important for the optimization and rationalization of water resources (Farley & Trow 2005). Clearly, water losses have a highly negative impact both environmentally and economically.

In Fantozzi (2006), it was reported that, according to the Italian National Institute of Statistics, non-revenue water (NRW) levels in Italy range from 15 to 60% of total system input volumes, the average being 42%. Such a high percentage is mostly due to the fact that, in contrast to other European countries, in Italy the majority of water utilities only repair ‘reported’ leaks, and do not practise any active leakage control management (Lambert & Fantozzi 2005).

Additionally, leak detection campaigns are very time-consuming, costly and require highly-experienced personnel who must be capable of:

(i) choosing the most appropriate leak detection method to employ, according to the specific practical case that is being investigated (e.g., depending on the pipe material or on the environmental background noise);
(ii) correctly interpreting the acquired data.

The most commonly used methods for systematic leak detection are electroacoustic methods which, in spite of being widely adopted, can be affected by errors in the leak localization when the measurements cannot be performed in optimal operating conditions. Acoustic methods, in fact, typically require high hydraulic pressure in the pipeline, absence of environmental noise or interference and suitability of the pipe material for sound propagation. Non-acoustic methods for leak detection include the tracer gas technique, thermography and, recently, ground penetrating radar (GPR). However, their application is often hindered by their intrinsic difficulty to use and by the high costs. A comprehensive review of the state-of-the art methods for leak detection can be found in Puust et al. (2010).
To obtain reliable results in those situations that appear troublesome, it is good practice to employ different leak detection methods and to crosscheck the data.

As a consequence, the development of new leak detection methods and the enhancement of existing ones is considered as the key to improving the control and monitoring possibilities (Hunaidi 2000; Hunaidi et al. 2000).

In such a context, the company Acquedotto Pugliese S.p.A. (AQP), one of the largest European water operators, in collaboration with the Department of Engineering for Innovation of the University of Salento (Lecce, Italy), has been carrying out an on-site validation and practical implementation of an innovative system for leak detection in underground pipes. This system exploits an electromagnetic (EM) technique, namely microwave time domain reflectometry (TDR), which has never been employed before for these purposes. The proposed method strongly reduces the inspection time that is typically required by traditional leak detection methods; in fact, it can be successfully used to inspect pipes which are hundreds of meters long in a single measurement session.

As will be detailed in the following sections, the proposed method can be employed in two ‘configurations’ that correspond to different application scenarios:

1. Leak detection in metal pipes that are already installed and operating.
2. Leak detection in newly-installed pipes made of any material.

It is worth pointing out that the expression newly-installed refers to the fact that, for employing this system configuration, it is necessary to introduce some minor adjustments (which will be described later in this paper) at the time of installation of a new pipe. As will be detailed in the following sections, once this system is installed with the pipe, it can be used to periodically monitor the health status of the pipe in a very quick and effective way, as a proactive control approach.

Both the configurations were tested through an extensive on-site campaign. In the present paper, first, a brief description of the theoretical background is given. Successively, for each of the aforementioned application scenarios, some interesting and representative experimental cases (ECs) are reported and thoroughly commented on.

## METHODS

### Theoretical background

The proposed system exploits the physical and operating principles of TDR-based investigation of materials. Generally, this kind of measurement relies on the analysis of the signal that is reflected when an appropriate EM signal (typically, a voltage step signal with very fast rise-time) is propagated along a probe (sensing element) inserted in the material under test (Topp et al. 1980). The reflected signal, in fact, carries useful information on the dielectric characteristics of the material in which the sensing element is inserted. Therefore, through suitable data processing, it is possible to retrieve other intrinsic (qualitative and quantitative) characteristics of the considered material (O’Connor & Dowding 1999; Agilent Technologies 2006).

In TDR measurements, the time-dependent reflection coefficient ($\rho$) of the material/device under test can be directly displayed as a function of the apparent distance ($d_{\text{app}}$) travelled by the signal that propagates along the sensing element. The quantity $d_{\text{app}}$ can be considered as the distance that would be travelled by the EM signal in the same interval of time, if the signal were propagating at $c$, which is the speed of light in a vacuum ($c \sim 3 \times 10^8$ m s$^{-1}$). The quantity $d_{\text{app}}$ can be associated to the ‘actual’ physical length ($d$) travelled by the signal, through the following equation:

$$d_{\text{app}} = \sqrt{\varepsilon_{\text{app}}} \cdot \frac{c \cdot t_i}{2}$$  \hspace{1cm} (1)

where $t_i$ is the travel time (round-trip time taken by the signal to travel the physical distance $d$) and $\varepsilon_{\text{app}}$ is referred to as the apparent relative dielectric permittivity of the medium in which the signal propagates (Agilent Technologies 2006). It is worth noting that for low-loss, low-dispersive materials, $\varepsilon_{\text{app}}$ can be considered practically constant in a wide frequency range (Robinson et al. 2003).

The behaviour of $\rho$ is strictly associated with the impedance variations along the electrical path travelled by the EM signal. A constant value of $\rho$ means that the dielectric characteristics in that ‘portion of path’ are practically uniform. Vice versa, variations of $\rho$ indicate that the dielectric
characteristics (and, hence, the electrical impedance) change along the travelled electrical path.

Additional practical and specific information on TDR and a comprehensive review of its major applications can be found in Cataldo & De Benedetto (2011).

On the other hand, with regard to the TDR-based leak detection application proposed herein, the experimental apparatus includes only a few pieces of equipment: a portable battery-powered TDR instrument; wires and cable; and a laptop for the automatic and real-time data processing (which is also the core of the system). In the following subsections, the system configurations for ‘already-installed’ pipes and for ‘newly-installed’ pipes are described in detail.

System for already-installed underground metal pipes

In this configuration of the system, the sensing element consists of a two-conductor transmission line (TL): the metal pipe acts as one of the electrodes and a metallic wire (laid down on the road surface corresponding, and parallel, to the pipe) acts as the second electrode. The reflectometric signal propagates along this two-conductor TL; as a result, the soil becomes the propagation medium.

In the presence of a water leak, there will be a local change of the dielectric characteristics of the soil (in fact, water has a high relative dielectric permittivity with respect to soil). Therefore, corresponding to a leak, there will be a change of the reflectogram (generally, a relative minimum is observed). The reflectogram directly provides the apparent position of the leak, \( L_{\text{app}} \); and, through suitable data processing, it is possible to find the actual position of the leak, \( L_{E} \) (Cataldo et al. 2012a).

Figure 1 shows a picture of the typical experimental setup. The capital letters indicate the most significant points of the apparatus.

A coaxial cable (with an approximate length of 3 m) is connected to the TDR output port; in turn, the start of the metallic wire is connected to the signal pin of the coaxial cable (point B). A short wire is used to connect the outer conductor of the TDR output port to the valve stem of the underground metal pipe. The length of the metallic wire must be chosen accordingly to the length of pipe that is being inspected; in fact, the length of this wire is the length of the sensing element \( (L_{\text{se}}) \). The end of the sensing element (which, for reasons of perspective, is not visible in Figure 1) is the distal end of the wire and it is left open-ended: in the following paragraphs, this point will be referred to as point D.

Figure 2 shows the schematization of a typical reflectogram in the presence of a leak. The position of the leak is referred to as point E. The abscissa \( d_{\text{app}} \) indicates the apparent distances as directly displayed in the waveform; the quantities \( L_{\text{app}} \) and \( L_{\text{app}}^{E} \) indicate the apparent length of the sensing element and the apparent distance of the leak from point B.
As can be seen from the schematized TDR signal of Figure 2, under normal operating conditions of the pipe (i.e., if no leak is present), \( \rho \) would have a constant value along the length of the sensing element. On the other hand, the presence of water associated with a leak causes a local variation of the measured \( \rho \) (typically associated with the presence of a relative minimum of the amplitude of the reflected signal). In fact, as mentioned above, the variation in \( \rho \) is at the basis of the method to determine the presence of the leak as well as its position \( (L_E) \).

As reported in Cataldo et al. (2012c), the physical position of the leak is individuated through the following equation:

\[
L_E = \frac{L_{se}}{\sqrt{\varepsilon_{app}}} = \frac{L_{app}}{I_{se}}
\]

(2)

To calculate the position of the leak from Equation (2), it is necessary to determine \( L_{E}^{app} = d_{E}^{app} - d_{app}^{D} \) and \( L_{se}^{app} = d_{E}^{app} - d_{B}^{app} \). The quantities \( d_{B}^{app} \), \( d_{D}^{app} \), and \( d_{E}^{app} \) represent the abscissae at the beginning of points B, D, and E, respectively and are taken from the TDR waveform.

It is worth mentioning that the accurate evaluation of these quantities may not be straightforward; in this regard, a detailed description of the procedure for individuating them is reported in Cataldo et al. (2012a).

System for detecting leaks in newly-installed pipes made of any material

The operating principle of this system configuration is similar to the one described for the ‘already-installed’ pipes: the leakage of water is sensed as a local variation of the dielectric characteristics of the surrounding soil.

However, in this case, the sensing element consists of a twin lead (similar to those used for speakers) that is attached to the pipe and extends through all its length. A twin lead consists of two copper wires that are isolated from and run parallel to each other. Basically, the copper wires represent the two electrodes of a bifilar line. The sheath of the twin lead and the surrounding soil represent the propagation medium of the twin lead; the plastic housing also provides the mechanical stability for the twin lead (especially in terms of maintaining the parallelism between the two wires).

It goes without saying that, since the twin lead must be positioned close to the pipe, it is necessary to place the twin lead at the time of installation of the pipe; hence, the suitability of this system configuration for ‘newly-installed pipes’.

RESULTS AND DISCUSSION

All the TDR measurements reported herein were performed through the Hyperlabs HL1500; a low-cost, portable unit, particularly suitable for on-site applications. The HL1500 generates a step-like signal with a rise time of 200 ps; the amplitude of the signal is 250 mV. The output port has a BNC (Bayonet Neill–Concelman) connector, and the output impedance is 50 Ω. Each TDR measurement reported herein was acquired with 2,048 measurement points and was the result of 128 automatic averages.

Results on already-installed underground metal pipes

This set of experiments consisted in an on-site measurement campaign, performed on already-installed metal pipes. In practice, a leak detection crew had individuated the possible presence of leaks in a number of pipes (the crew had used traditional methods: listening rod, geophones and correlators). In this section, some of the most representative ECs are reported (EC1, EC2, EC3, EC4).

Figures 3(a) and 3(b) show the waveforms acquired in EC1 and EC2, respectively. In both cases, the length of wire \( (L_{se}) \) was approximately 60 m, as also reported in Table 1. Typically, the acquired reflectograms show a systematic presence of an initial peak, in the apparent distance range 0–20 m, which is due to the spurious reflections caused by the transition coaxial cable/wire (point B in Figure 1). Additionally, the termination of the sensing element is clearly associated with the characteristic final rising-edge of the reflectogram.

In particular, these figures show the portions of the waveform in which the presence of the local minima that correspond to the presence of a leak is apparent. It can be
seen that both the waveforms exhibit a significantly wide dip, occurring in both cases at approximately $d_{\text{app}} \approx 50$ m. In each waveform, the dip is clearly attributable to the presence of the leaked water.

From a ‘visual’ assessment of the TDR waveform, it is possible to deduce the effect of the leak, causing a significant inflection of the signal. The accurate localization of the leak position can be performed by searching the local minimum of the corresponding derivative curve (Cataldo et al. 2013a, b).

However, as aforementioned, to have a more accurate evaluation of the position of the leak and also in view of the final development of the commercial equipment (in which it is necessary to have a prompt and real-time response on the possible presence of a leak), the waveforms are processed through an algorithm, based on the wavelet transform, that allows the de-noised TDR waveform and its derivative to be obtained, useful for identifying the local minima corresponding to the leak position. The algorithm, along with the signal acquisition, is directly implemented on a LabView-based application, which facilitates the prompt individuation of points B, D, and E, directly applies Equation (2) and provides, as the final output, the estimated value of $L_E$.

As an example, Figure 4 shows two of the intermediate steps of the data processing. First, the reflectogram is windowed (excluding the portions of the signal that, based on the visual inspection, do not carry useful information); the windowed reflectogram is then filtered to reduce the effect of noise. Successively, the first derivative of the resulting reflectogram is calculated; and the points D and E are

![Figure 3](https://iwaponline.com/ws/article-pdf/13/4/966/415052/966.pdf)

**Figure 3** | Comparison between the TDR waveforms acquired before repair for the experimental cases EC1 (a) and EC2 (b).

<table>
<thead>
<tr>
<th>Experimental case</th>
<th>$L_E$ (m)</th>
<th>$L_{E-trad}$ (m)</th>
<th>$L_{E-eval}$ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC1</td>
<td>60.00</td>
<td>31</td>
<td>29.6</td>
</tr>
<tr>
<td>EC2</td>
<td>59.90</td>
<td>32</td>
<td>32.9</td>
</tr>
</tbody>
</table>

**Table 1** | Summarized data for EC1 and EC2

![Figure 4](https://iwaponline.com/ws/article-pdf/13/4/966/415052/966.pdf)

**Figure 4** | Windowed and filtered reflectogram and corresponding first derivative, as calculated through the implemented algorithm, for the individuation of points D and E.
individuated (as local maximum and local minimum of the first derivative, respectively) (Cataldo et al. 2022a, b).

In Table 1, the evaluated position of the leak \((L_{E-eval})\) is compared with the value that was estimated by the leak detection crew through traditional methods \((L_{E-trad})\). It can be seen that the proposed method, in association with the implemented algorithm, successfully estimates the position of the leak.

Figure 5 shows the measurement results obtained for two other ECs: EC3 and EC4. For these cases, an ex-post verification on the presence of the leaked water was also performed (through excavation at the time of repair of the pipe). The TDR measurements performed in the presence of the leak, both for EC3 and for EC4, present a similar trend: after a gradual signal decrease a local minimum, falling at approximately \(d_{app} \approx 75\) m and \(d_{app} \approx 82\) m, respectively, is clearly visible.

It is interesting to point out some differences between EC1 and EC2, related to a specific urban area, and EC3 and EC4, related to another area. When comparing Figure 3 and Figure 5, it can be seen that in the former curves, there is a ‘sharp’ and bigger change of the reflection coefficient corresponding to the leak; whereas in the latter curves, the change of the reflection coefficient is slower and the dip is milder. This is most attributable to the different nature of the soils. In EC1 and EC2 the soil was thin- to medium-bedded limestone, thus leading to a ‘more localized’ presence of water around the leak point (hence, the presence of a sharp variation of \(\rho\)). On the other hand, in EC3 and EC4, the soil was calcareous sand with intercalated mud, thus allowing a larger horizontal diffusion of water.

In order to highlight the difference between the presence and absence of the leak, for EC3 and EC4, TDR measurements were also repeated approximately one month after the leak had been repaired (curves with dots in Figure 5). It can be seen that, since the soil has started to dry up, the reflection coefficient curve has shifted towards higher values and the dips that were present before the repair have almost disappeared. On the other hand, the residual dips and small variations are attributable to the residual presence of water which still remained at the time of after-repair measurements.

As for the leak localization procedure, the EC3 and EC4 waveforms (acquired before repair) were processed through the aforementioned algorithm. Table 2 compares the \(L_{E-eval}\) values calculated through the algorithm and the actual position of the leaks \((L_{E-act})\) as verified during the excavation. There is a very good agreement between the values, thus confirming the accuracy of the procedure.

**Measurements on a newly-installed water pipe**

To test this system configuration, an 85 m-long iron pipe was installed approximately 1 m underground and connected to...
the water distribution system (EC5). A picture of the installation is shown in Figure 6(a). A hole was (intentionally) made at a known reference point, \( L_E = 22.5 \) m; a twin lead was attached to the pipe (each copper wire contained in the twin lead had a diameter of 1 mm). The twin lead ran close to the hole, as shown in Figure 6(b). One end of the twin lead was connected to a coaxial cable; and, finally, the pipe was buried. The far end of the coaxial cable, in turn, was left out of the soil, so as to allow connection to the TDR instrument. The length of the twin lead was \( L_{se} = 84.7 \) m.

After installation and before letting water run through the pipe, a TDR waveform was acquired (curve with circles of Figure 7).

It can be seen that, after some initial spurious reflections, due to the transition between the twin lead and the coaxial cable, \( \rho \) remains practically constant until the open-circuited termination. Basically, this waveform represents the ‘signature’ of the pipe in normal operating conditions, i.e., without leaks.

In practical applications, the acquisition of a TDR waveform right after the installation of the pipe, would be a major advantage; in fact, for each pipe, such a waveform could be stored in a database and used as a reference to which successive TDR measurements on the same pipe could be compared. This would facilitate the individuation of possible leaks and would enhance the accuracy in the evaluation of their exact location.

Successively, water was let run through the pipe; as a result, water also began escaping from the hole. The curve with squares in Figure 7 was acquired approximately 1 hour after the water had started leaking. For this reason, the volume of escaped water was not large, thus resulting in an ‘incipient leak’ condition. In this case, as discussed in detail in Cataldo et al. (2012b), the processing algorithm localizes accurately the actual position of the leak in correspondence with the local minimum of the TDR waveform; the corresponding data and results are summarized in Table 3.

As can be seen from the reported results, this system configuration can also successfully individuate incipient leaks. In fact, from the reflectograms in Figure 7, it can be seen that the presence of the leak is detectable just 1 hour after water leaked out from a 3 mm diameter hole, and the corresponding variation in the reflectogram is already evident.

### Table 2 | Summarized data for EC3 and EC4

<table>
<thead>
<tr>
<th>Experimental case</th>
<th>( L_{se} ) (m)</th>
<th>( L_{E\text{-act}} ) (m)</th>
<th>( L_{E\text{-eval}} ) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC3</td>
<td>83.00</td>
<td>53</td>
<td>53.3</td>
</tr>
<tr>
<td>EC4</td>
<td>83.00</td>
<td>50</td>
<td>50.8</td>
</tr>
</tbody>
</table>

### Table 3 | Summarized data and results for EC5

<table>
<thead>
<tr>
<th>Experimental case</th>
<th>( L_{se} ) (m)</th>
<th>( L_{E\text{-act}} ) (m)</th>
<th>( L_{E\text{-eval}} ) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC5</td>
<td>83.00</td>
<td>22.5</td>
<td>21.8</td>
</tr>
</tbody>
</table>
Measurements on a newly-installed sewer pipe

The system configuration for scenario #2 was also tested on a ceramic sewer pipe (Figure 8), EC6. Similar to the previous case, a leak was intentionally generated, and two (independent) twin leads were positioned on the pipe, attached to it through cable ties. One twin lead ran parallel along the pipes, in close proximity to the hole; whereas the other twin lead was attached on the pipe along the direction diametrically opposite to the position of the hole. The beginning of each twin lead was connected to the connection coaxial cable. After installation, the pipe and the twin leads were buried and the ends of the coaxial cables emerged from underground through the inspection well, so as to allow connection to the measurement instrument.

The total length of the pipe was 5.7 m. The actual distance of the hole from the beginning of the twin leads was approximately \( L_{E,\text{act}} = 2.7 \text{ m} \). In the following, the results related to the twin lead closer to the hole are reported (results related to the other twin lead were similar).

First, before letting water run through the pipe, a reflectogram was acquired (\( m_0 \), curve with squares in Figure 9): as aforementioned, this reflectogram represents the signature of the pipe in normal operating conditions. Figure 9 also shows the reflectogram acquired approximately 2.5 hours later (curve with circles). It can be seen that corresponding to the leakage point, the reflectogram shows the typical dip associated with the presence of leaked water.

Considerations for practical applications of the proposed system

Considerations on possible influence of rainwater

For the practical use of the system, it is worth addressing a few aspects related to the possibility of employing the proposed system in the presence (or after) heavy rain. It goes without saying that how the system performs after rain depends on how much the soil gets soaked with water; as a general consideration, it can be stated that the system works correctly as long as the permittivity of the soil in proximity of the leak is sufficiently different from the
The permittivity of the surrounding soil. Clearly, given the variety of soils and soil textures, it is impossible to establish in advance a universal limit for the method, however, it is possible to make some consideration that allows assessment of the applicability (and, hence, the reliability) of the system.

However, it should be pointed out that the aforementioned aspect may represent a problem only with reference to the system configuration for scenario #1. In fact, in the application of the leak detection system in scenario #2, it is good practice to acquire a reflectogram right after a pipe has been installed (m0-reflectogram). This reflectogram can be stored in a database and used as a reference. Any subsequent measurement (performed on the same pipe) can be readily compared with the m0-reflectogram and any effect (due to rain or to other factors) could be easily spotted.

With regard to the system configuration for scenario #1, the presence of rainwater may represent an issue, but there are ways to understand how, in rainy conditions, this system configuration may provide accurate results.

First of all, in practice, if the road surface is asphalt or concrete, rainwater usually does not penetrate excessively underground and the proposed system still provides accurate results.

If the road surface is soil (for example, in countryside areas) then the penetration of rainwater might be considerable (depending on the soil texture) and the performance of the system, in such circumstances, may not be adequate. However, in this case, it is possible to perform TDR measurement of the moisture content of the soil (and, hence, of its permittivity), thus establishing whether it is advisable to carry out the water leak detection activities. The moisture content/dielectric permittivity estimation can be performed through the same TDR instrument that is being used for water leak detection, by employing a multirod probe (the cost of which is approximately 50 euros) as reported in Piuzzi et al. (2010).

Considerations on the effectiveness of the system

At the current stage of development of the system, it is difficult to provide an accurate and definitive estimate of the benefit/cost ratio. However, based on the factual data at hand, it is possible to make some considerations that clearly indicate the potential effectiveness of the system, both with respect to the costs involved and to the reliability of the system itself.

With regard to the instrumentation, the major cost is represented by the TDR unit; however, currently the approximate cost of a TDR unit (with adequate...
specifications for the proposed application) is generally much lower than the typical costs of correlator instruments.

As for the reliability of the system (in terms of uncertainty in the evaluation of the leak position), it is more meaningful to consider separately the two system configurations.

With regard to the system for scenario #1, it is clear that, currently, an intrinsic limitation is that it can be used only for metal pipes. Nevertheless, the most attractive advantage of the proposed system is that it can be employed in critical situations, where traditional methods fall short of providing conclusive results, if any at all. In fact, the very principle behind the measurement approach makes the proposed system practically immune to many of the factors that typically jeopardize the adoption of traditional methods (there is no need for high water pressure, environmental noise is not a problem, etc.). At the current stage of development, the system configuration for scenario #1 is not intended to replace (immediately) other well established leak detection techniques; on the contrary, it is intended to represent an additional tool to be used in conjunction with other leak detection methods.

Also, it is worth mentioning that the proposed system can be used very quickly. It allows rapid monitoring of long pipes in one operation. Hence, the TDR method can be used for a quick, preliminary assessment of the possible presence of leaks in long pipes; then, once specific areas with possible leaks have been individuated, a more localized inspection could be conducted by employing acoustic methods. To provide a rough idea of the speed of this system configuration, the experimental campaign showed that the system can be used to inspect approximately 2.5 km/day, which is comparable with the typical time required by traditional methods.

Finally, it is worth mentioning that, based on the experimental campaign conducted so far, the uncertainty in the evaluation of the leak position is in the order of 1.5 m which is of the same order of magnitude of the dimension of the excavation conducted for repairing the pipe.

With regard to the system for scenario #2 (newly-installed pipes), the proposed system is mostly effective, and the maximum absolute uncertainty in the estimation of the leak position is typically in the order of some tens of centimeters. Such low values of uncertainty make the proposed system a reliable and economically viable (and profitable) alternative to the traditional leak detection methods (provided that it is implemented in the ‘new pipes’). In fact, the possibility of having a permanent sensing element installed on the pipe and to interrogate it quickly and conclusively (it is enough to connect the TDR instrument to the connector in the inspection well), can potentially turn leak detection into a ‘pro-active’ activity: the easiness of performing the measurement would make it possible to check periodically on the health status of the pipes.

Finally, as mentioned above, an additional great advantage of this system configuration is that it can be applied to pipes made of any material; which allows the method to be used also for leak detection in sewer pipes.

CONCLUSIONS

In this work, an innovative method for pinpointing water leaks in underground pipes was presented.

Two system configurations were described: one for water leak detection for ‘already-installed’ underground metal pipes, and the other for water leak detection in underground pipes made of any material. Both these systems were tested and validated experimentally through an extensive on-site measurement campaign.

It was demonstrated that the proposed TDR-based system allows a quick and non-invasive inspection of underground pipes, thus showing great potential for practical implementation. In fact, the proposed system dramatically reduces inspection time required by traditional methods; furthermore, in contrast to state-of-the-art leak detection systems, the TDR-based system can be used under any operating conditions of the pipe.

With particular reference to the configuration for newly-installed pipes, it has two major appealing features. First, because it can be used on pipes made of any material, it can also be employed to pinpoint leaks in sewer and wastewater pipes. Furthermore, once the twin lead has been installed on a pipe, the search for leaks can be performed quickly and effectively. As a result, equipping the pipes with the proposed leak detection system would facilitate...
the possibility of carrying out periodic inspection and systematic monitoring activities on the pipes.

REFERENCES


First received 3 September 2012; accepted in revised form 4 January 2013