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LARGE-SCALE IMPLEMENTATION OF A NEW TDR-BASED SYSTEM FOR THE MONITORING OF PIPE LEAKS

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Abstract - In this paper, the practical implementation of an innovative time domain reflectometry (TDR)-based system for leak detection in underground water pipes is presented. This system, which had been previously developed and experimented on pilot plants, has now been installed (for the first time) on a large scale, in 10 km of pipes. The present work describes all the practical aspects and technical details (from the design to the functional tests), related to the implementation of the system.

Keywords: Leak detection, time domain reflectometry, underground pipes, water leakages

1. INTRODUCTION

The localization of leaks in underground pipes is one of the crucial steps for the optimization of the use of water resources [1]. Traditional leak detection methods, such as noise loggers and correlators, are based on acoustic methods [2]; nevertheless, despite the extensive use of these systems, their performance can be severely compromised in case of low hydraulic pressure in the pipes, in presence of high environmental acoustic noise, in case of unsuitable sound propagation condition [3], etc. Additionally, their performance is also influenced by the material and diameter of the pipes.

On such bases, recently, an innovative time domain reflectometry (TDR)-based system for the localization of leaks in underground pipes has been developed by the Authors [4, 5, 6, 7]. Because this system is based on an electromagnetic measurement technique (rather than acoustic), it overcomes all the limitations that typically affect the performance of traditional leak detection systems. Furthermore, the developed TDR-based system can be used to localize leaks on pipes made of any material and also on non-pressurized pipes: these aspects make it a viable solution also for leak detection in sewer pipes.

The effectiveness of the proposed TDR-based system has been proven through an extensive experimental campaign carried out on several pilot pipes. Based on the positive results obtained during the experimentation, the company Acquedotto Pugliese S.p.A. (the largest European water operator) has decided to move on to the realization of the very first large-scale implementation of the proposed TDR-based system, and to install it on 10 km of underground water pipes. In this regard, the present work describes all the operational activities that were carried out and all the technical aspects that were considered for the aforementioned large-scale deployment of the TDR-based leak detection system.

2. BACKGROUND AND DESCRIPTION OF THE MEASUREMENT APPARATUS

As aforementioned, the proposed leak detection sytem is based on the use of TDR technique. TDR had been originally developed mainly for the localization of faults in electric wires; however, thanks to its adaptability, TDR has progressively established itself as an appealing solution in the most diverse application contexts, such as moisture content measurements in porous materials [8], soil moisture measurement [9, 10], liquid level monitoring [11], etc.

Generally, in TDR measurements, a step-like electromagnetic signal propagates along a sensing element (SE) inserted in the system to be monitored. The response of the system, acquired in terms of reflected signal, is used to retrieve the desired information on the system under test. With regards to the TDR-based leak detection, the basic principles have been described in [6, 7]. However, for the sake of clarity, the important details are also recalled herein.

The top image of Fig. 1 shows a simplified schematization of the measurement apparatus. The proposed system requires that, during the installation of new pipes, a wire-like SE be buried along the pipe to be monitored. The SE is laid on the pipe and remains permanently buried with it. The beginning of the SE is connected to a coaxial cable, which emerges through an inspection well. For checking for the possible presence of leaks on a SE-equipped underground pipe, it suffices to connect the TDR measurement instrument to the beginning of the coaxial

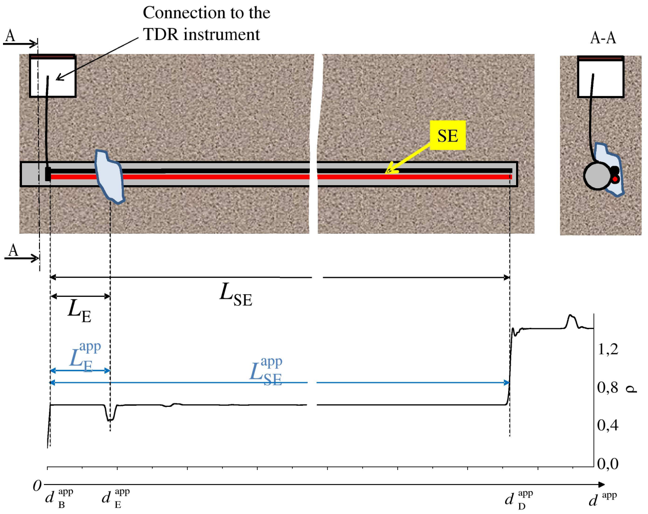


Fig. 1. Schematization of the measurement apparatus (top image) and schematizatin of the corresponding reflectogram (bottom image).

cable. Each single SE can be up to 200 m-long and can follow the topology of the pipe network.

The direct output of the measurement is a reflectogram, which shows the reflection coefficient (ρ) as a function of the apparent distance (d^{app}) traveled by the EM signal along the SE. The bottom image of Fig. 1 shows the schematization of a possible reflectogram associated to the pipe condition depicted in the top image of the same figure. It can be seen that, if a leak is present, the reflectogram will show a local minimum in correspondence of the position of the leak. In fact, the presence of water associated to a leak causes a local (but significant) variation of the measured ρ(typically associated to the presence of a relative minimum of the amplitude of the reflected signal). This is due to the fact that water has a high relative dielectric permittivity (approximately equal to 78), which is significantly higher than the typical relative dielectric permittivity of the soil (which is in the order of 3-5). The variation in ρ is at the basis of the method to determine the position of the leak.

As detailed in [6, 7], the position of the leak (L_E) is evaluated as the distance from the beginning of the SE, through the following equation:

$$L_E = (L_E^{app})/(L_{SE}^{app}/L_{SE}) \tag{1}$$

where L_E^{app} is the apparent distance of the leak (directly measured from the TDR reflectogram as reported in [12]; and L_{SE}^{app} and L_{SE} are the apparent and the actual length of the SE, respectively.

As will be detailed in the full-version of this paper, (1) has been implemented in an algorithm (specifically developed by the authors) that provides in real time the position of the leak, L_E.

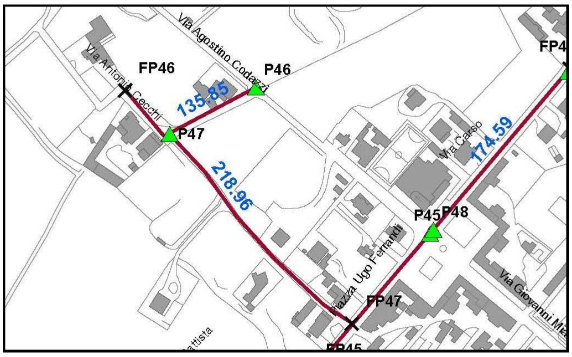


Fig. 2. Excerpt of the blueprint with the details on the installation of the sensing elements.

3. DESCRIPTION OF THE IMPLEMENTATION STEPS

This section describes in detail all the steps that were followed for the practical implementation of the system on 10 km of new pipes.

3.1. Design of the optimal disposition of the SEs

The very first step for the large-scale deployment of the system is to establish, in the blueprints, the optimal positioning of the SE's. In this step, the length of each SE and the position of the corresponding inspection well are decided. It goes without saying it that these decisions are made with the goal of expediting the installation, minimizing the costs of installation, and maximizing the efficiency in the subsequent use of the leak-localization system.

In particular, the position of the inspection wells is decided taking into account two major aspects:

i) trying to exploit the inspection wells that have been planned for routine maintenance of the pipe network (i.e. inspection wells that would have been installed even if the SE's had not to be installed); and

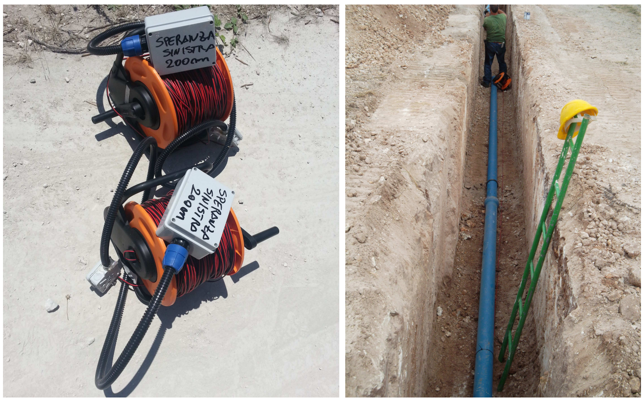
ii) trying to have SEs as long as possible, up to approximately 200 m and trying, when possible, to avoid street turns.

Fig. 2 shows an excerpt of the blueprint with the indication of the positioning of the SE's. In Fig. 2, each green triangle indicates an inspection well, whereas each purple line indicates the path of the sensing element. The numbers written as blue text indicate the length of each SE (starting from the point corresponding to the green triangle).

As will be clarified later, not only were these information used for the installation of the SE's, but they are also stored in a data-base and became part of the identification and geo-reference data of each inspection well/sensing element.

3.2. Installation of the SEs

Once the disposition of the SEs had been established, the next step regarded the installation phase. As already mentioned, the installation of the TDR SE's is carried out simultaneously with the installation of the pipe. Because the



(a) (b)

Fig. 3. (a) Picture of two SE's (already customized in length), ready to be unrolled and installed on the pipes; (b)Trench for the installation of the pipe.

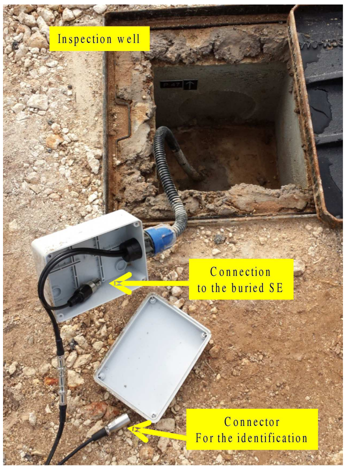


Fig. 4. Picture of an inspection well in which the plastic box is housed.

length of each SE had been established in the design-phase, each SE is already customized to be installed on a specific section of the pipe network. As can be seen from Fig. 3(a), each SE is equipped with a plastic box (used for protection from the environment), containing a BNC-type connector for the connection to the TDR instrument and another connector carrying an identification code.

The SE is rolled out along the pipe (Fig. 3(b)), and buried with the pipe.

For the sake of clarity, Fig. 4 shows an inspection well in which the plastic protection box is contained and the two aforementioned connectors (BNC and ID).

Finally, after each SE was positioned on the pipe, the GPS coordinates of the beginning and of the end of the SE were acquired and stored in a database. Also these data became part of the ID information.

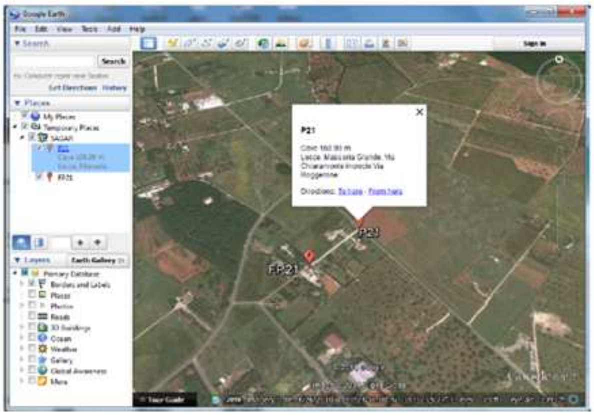


Fig. 5. Google Earth image showing the position of the pipe under inspection and the position of the leak.

3.3. *Functional test of the system*

For each SE, after installation and burial of the pipe, the corresponding TDR reflectogram was acquired. This reflectogram serves two purposes. The first is that it allows to verify that the installation has been successful (e.g., that the SE was not broken). Secondly, acquiring the reflectogram right after the installation and storing it in a database associated to the specific pipe, serves as a reference to which compare the reflectograms acquired subsequently, during pipe inspection.

When carrying out the inspection of a pipe, while the BNC-type connector is connected to the TDR instrument, the ID connector is connected to the laptop and read through a specifically-developed software: in this way, the identification information are automatically retrieved (GPS position, length of the SE, name of the street, etc.). The software also automatically recalls also the reflectogram acquired, for that specific pipe, right after installation. As shown in Fig. 5, thanks to the GPS coordinates acquired during the installation phase, the developed software can directly launch a Google Earth view, displaying the map of the site. The software indicates with two markers in correspondence of the beginning and of the end of the SE. In presence of a leak, the software also displays a third marker in correspondence of the estimated GPS coordinates of the identified leak.

4. DESCRIPTION OF THE FUNCTIONAL TESTS ON A PIPE IN WHICH A LEAK WAS INTENTIONALLY PROVOKED

Finally, it is worth mentioning one of the experimental tests that were carried out. For the sake of carrying out tests and training courses for the operators, along one pipe portion, a gate valve was inserted between two section of pipes. By opening and closing this gate valve through a manhole, water was leaked (intentionally) from the pipe: this expedient allows to mimic the presence of a leak.

In this test, the gate valve was opened and water began to leak. After approximately half an hour, the reflectogram in presence of the leak was acquired,and the position of the leak was evaluated as it had been unknown. Fig. 6 shows the comparison between the reflectogram acquired before the leak was present (line with black squares) and in presence of the leak (line with red triagles). The reflectograms were acquired through the TDR istrument HL1500. It can be seen that, in the latter case, the typical minimum associated with the presence of leaked water appears. By processing the obtained reflectogram trough the developed algorithm (which also implemented (1)), the position of the leak was found to be at 113.5 m of distance from the inspection well; in optimal agreement with the (known) position of the gate valve that had caused the leak (which was 113.0 m distant from the inspection well).

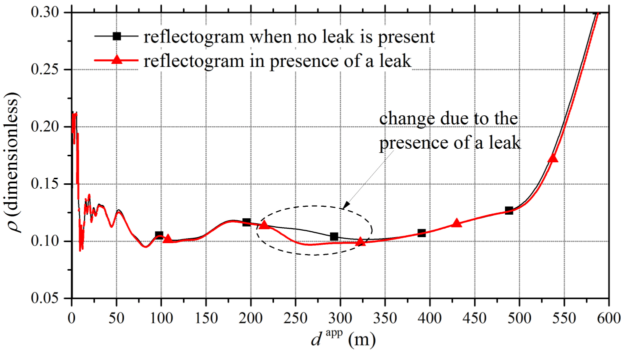


Fig. 6. Comparison between the reflectograms acquired for the same pipe, in presence and in absence of a leak.

4.1. *Practical considerations on the advantages of employing the proposed system*

It is worth mentioning that the installation of the SE's in the underground pipes brings another important advantage (in addition to the intrinsic advantage of the localization of leak when the infrastructure is in use). In fact, it is well known that, after the installation of the pipelines is complete, functional test have to be carried out to verify the correct installation of the pipes (e.g. no broken pipes after burial, no damaged seals between the pipes, etc.). In this regard, these functional tests can be carried out employing TDR and the installed SE's: in fact, TDR measurements will directly localize the position of possible pipe installation problems.

5. CONCLUSIONS

In this paper, all the practical steps for the large-scale implementation of a TDR-based system for water leak detection in underground pipes were presented. It was demonstrated that the proposed TDR system has met all the potential for practical implementation. In particular, thanks to a few specific operations (such as the design of the positioning of the SE in the blueprint and the present of the ID code), the proposed system has all the features that characterize a smart monitoring system.

ACKNOWLEDGMENTS

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