Design of a utility scanning testing ground on the UTwente campus

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Summary

The Dutch infrastructure sector uses various GPR types and brands for detection of buried infrastructure. Most of these require specialist knowledge and can be used for distinctive types of soil investigation. There are, however, also ongoing developments on a radar system that is tailored to utility detection. Since the quality testing of GPR systems currently takes place implicitly 'on the job' while utility surveyors experience the real operating conditions of a GPR, it is more difficult for GPR-developers to gain credibility with potential end users. To increase the validity and reliability of the implicit testing processes, this study proposes the development of an outdoor testing facility on which various systems can be compared. This testing facility buried distinctive utility types in known locations. This allows researchers to test what under what conditions developed GPR systems can detect utilities. This article specifies the technical details of the designed testing facility of the University of Twente Campus. It elaborates the various utility types, soil types, and surface coverage that will be installed in this facility to systematically test and compare radar systems. We further outline the possible use cases and future extensions of the lab and argue that both the facility and the quality testing process eventually contribute to the adoption and effective use of the GPR in the field.

Key words: Ground penetration radar, Test site facility, Utility detection

Introduction

Civil engineers use various tools to help them inspect the inner structures of the earth with the ultimate goal to make assessments about, for example, subsoil conditions and ground stability. Geophysical methods like seismology, gravity, magnetic, and ground penetration radar (GPR) assist them in achieving this goal. These methods that are used to study the subsurface have been applied within the various contexts in civil engineering. Tunneling, mining, road construction, and utility mapping are examples of these contexts. From the geophysical methods, GPR is superior as it, unlike the other methods, is a non-destructive test (NDT) which is able to detect both metallic and non-metallic objects, while it is capable of determining the depth and relatively easy to train and use. GPR emits electromagnetic-wave (EM) pulses in the microwave band to detect subsurface structures (Jol, 2009). It uses a transmitter and a receiver antenna and moves over the surfaces to detect signal reflections from the ground. These reflections from anomalies like cables, pipes, tree roots, metal plates, and others objects that have different permittivity and electrical conductivity create a hyperbolic signature on the output of a GPR, a so-called radargram (Reynolds, 2012). Although this method has great benefits, due to lack of experience and trust in the abilities of the method by civil engineers, this method is not used as a common practice in the Netherlands utility and road sector yet.

Thus, GPR needs to gain credibility for the sake of potential end-users. This is particularly valid in the context of utility detection and mapping; which is a field that is becoming increasingly relevant in during the large infrastructural Energy Transition that takes place in the Netherlands and requires major reconstruction of the underground space. Accordingly, the validity and reliability of GPR should be increased by developing testing methods. To date, a few international organizations for testing materials have tried to establish guidelines for GPR applications. However, a standard protocol to validate the quality of these systems in detecting utilities is still missing. This, in turn, reduces trust in the technology.

An outdoor testing facility containing accurately installed buried utilities at known locations would enable developing a standard protocol. A tailored geophysical test site would enable validation of GPR solutions for subsurface utility mapping. In addition, it can serve as a facility for training and research field for of utility surveyors and geophysicists. To assess GPR equipment and train practitioners, such a facility should represent the Netherlands' physical situation and also represent conditions that comply with Dutch utility engineering standards.

Therefore, the goal of this study was to review existing literature on geophysical test sites, consult Dutch utility design standards and propose a test geophysical site that should be built on the campus of the University of Twente. The purpose of our shallow geophysical site design is to provide a facility for training GPR users and assess various GPR equipment for infrastructure applications. In this design, cable, and pipes are placed according to the most common the Dutch cities' infrastructure. The advantage of having a purposefully designed geophysical site is that the true soil conditions – including the location of cables and pipelines - are registered accurately after construction. This enables researchers and instructors to verify whether detected buried objects from experiments and surveys indeed are represented accurately on a GPR scan. This advantage does not exist in other existing spaces, where underground conditions have not been registered and are often inaccurate, imprecise or even unknown (Pajewski, 2017).

Methodology

Various geophysical designs have been proposed by reviewing literature about geophysical test sites around the world, while respecting that the purpose of GPR testing protocol is to support the Dutch utility sector. While making the design, our goal is to balance between a complex and simple layout. It is essential to keep this design simple enough to be able to carefully examine and characterize different condition effects of soil conditions like soil moisture, soil contamination, cable and pipe diameter and the depth on GPR radargrams.

To design a test site facility, we searched systematically for literature. Moreover, we interviewed some experts. Based on the literature and discussions, some criteria for a test site design is derived, and eventually, the test site is designed, which we validate it with forward modeling.

Literature

Various existing geophysical test site exists around the world. As shown in the Table 1, some of the sites are specially constructed for experiments with the GPR methodology and its procedures (Pajewski, 2017). These test facilities are of different types with different purposes. The ultimate purpose of these facilities is divided into three main categories, the development of novel GPR instrumentation and the use of GPR in engineering, and organizing and offering training activities. Among these final purposes, utility detection, antenna testing, and research and training are the most similar activities to our project goal "Quality assessment of GPR". On the domain of utility detection, there are several facilities in Belgium, France, Italy, Spain, Ukraine, Hong Kong, and the united kingdom. For antenna testing purposes, there are two facilities in Belgium and the United kingdom. And From the perspective of research and training, Belgium, Hong Kong, Spain, and the United kingdom are the leading research centers.

But to the best of our knowledge, no facility design is documented that assesses the quality of GPR equipment in detecting utilities in Dutch (i.e. sandy and clayey) soil conditions. These GPR test sites and their area of applications are listed in Table 1.

Table 1. Application classification of GPR test facilities around the world

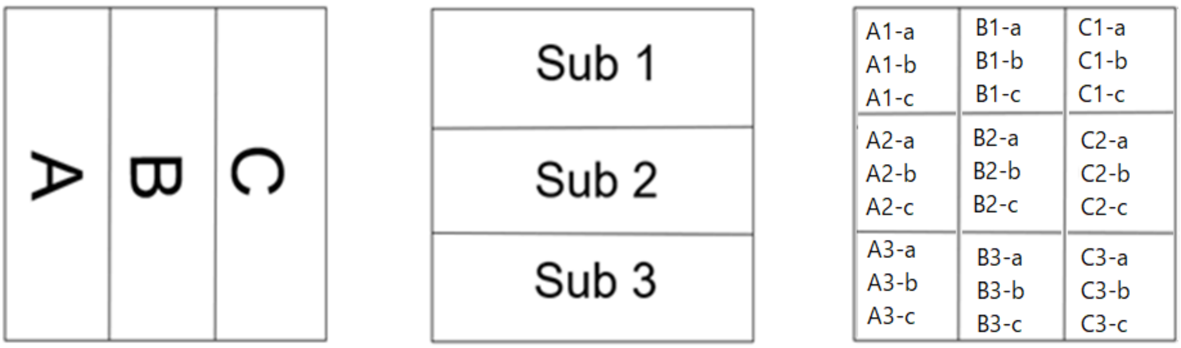
Test site (Country)	References	Cultural Heritage	Concrete	Roads	Railways	Hydro-geo	Landmines	Utilities	Research and trainings	Antenna testing	Boreholes
BRRC wavre (Belgium)	Pajewski, 2017			○					○		
UCLouvain (Belgium)	Pajewski, 2017							○	○	○	
CDV (Czech republic)	Pajewski, 2017		○								
ISTIMES (France)	Pajewski, 2017		○								
IFSTTAR (France)	Pajewski, 2017		○	○				○	○		
Université de Toulouse (France)	Pajewski, 2017		○	○							
BAM (Germany)	Pajewski, 2017		○	○							
The Hong Kong Polytechnic University	Pajewski, 2017		○	○				○	○		
CNR- IBAM (Italy)	Pajewski, 2017	○	○			○		○			
Sapienza University of Rome (Italy)	Pajewski, 2017						○				
Osaka (Japan)	Pajewski, 2017										○
Uinversity of Vigo (Spain)	Pajewski, 2017	○	○					○			
Polytechnic University of Catalonia (Spain)	Pajewski, 2017	○	○						○		
TRANSCIENT (Ukraine)	Pajewski, 2017							○			
NSGG (United kingdom)	www.nsgg.org.uk							○	○		
UKCRIC (United kingdom)	https://www.ukcric.com			○			○	○	○	○	
NBIF (United kingdom)	https://www.birmingham.ac.uk						○	○	○	○	

Based on the various test site designs, we can derive that the following requirements are essential to the design of the utility test site:

- The test site should be constructed outdoor to monitor the effects of the weather on radargrams.
- The test site should be equipped with various temperature and moisture sensors.
- The test site should contain various soil types, cable, and pipes, with different depths and different planar and vertical configurations.
- The test site surface should be covered with grass, asphalt, and klinker.
- The should be no source of electromagnetic emission to avoid unwanted signals. For clay and sand, soil consolidation and compaction level should be calculated respectively, as they are two governing factors that may alter the output result.

Test Site Design

The geophysical site consists of three parts (a first pipe group, second pipe group and a composite group, respectively A, B and C in Figure 1a) that contain three subsections (1,2, and 3 in figure 1b), Each of these subsections are divided into three bays ('A1' to 'A3', 'B1' to 'B3', and 'C1' to 'C3', see figure 1c) that vary in pipe material and arrangement. Finally, the last subdivision is devoted for soil material differentiation (e.g.; A1-a , and A1-b are precisely the same in terms of pipe arrangement and material and the only difference is that the first group is buried in clay material, the second and third group host material are mix soil, and sand respectively). An overview of the geophysical site is presented in Figure 2.



(a) Pipe and cable groups (b)Different arrangement (c) Different soil composition

Figure 1. A guide for understanding the geophysical test site

The pipes in the first group are concrete, plastic, and copper, with various dimensions (20,40. 60, and 80 centimeters) buried in clay, sand, and a soil mixture that is common in the Netherlands (NEN-7171). The purpose of the first group is to monitor the diameter and material effects of the pipe. The second pipe section is dedicated to a survey of more complex pipe cross-sections. The goal of this second group is to investigate the effects of hyperbolic signatures of pipe overlapping. Therefore, we propose various more complex pipes arrangements. In this part, only plastic pipes with different overlaying arrangements and depths are used in three above-mentioned surrounding soil types. Finally, the third principal part is assigned to various cables (with 10, 5, and 2 cm diameter) and cables with pipes similar to the residential area. The goal of the third group is to monitor the effects of cable diameter and different vertical and horizontal configurations. Fig 2. And Fig 3. presents a sample cross-section and a 3D view of different designed groups, respectively.

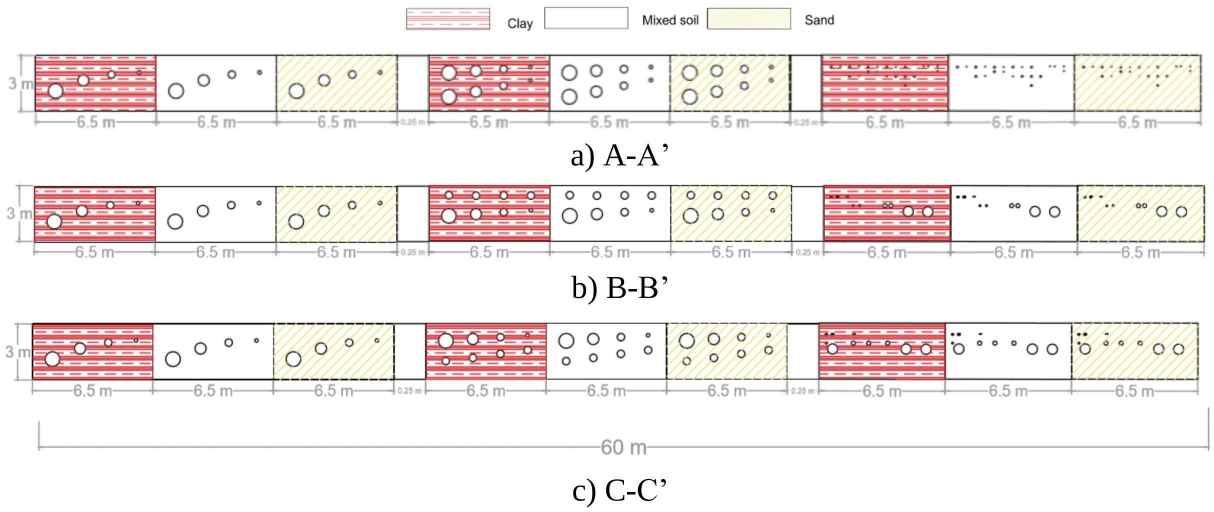


Figure 2. An overview of the geophysical site, a) A-A’ cross section b) B-B’ cross section c) C-C’ cross section

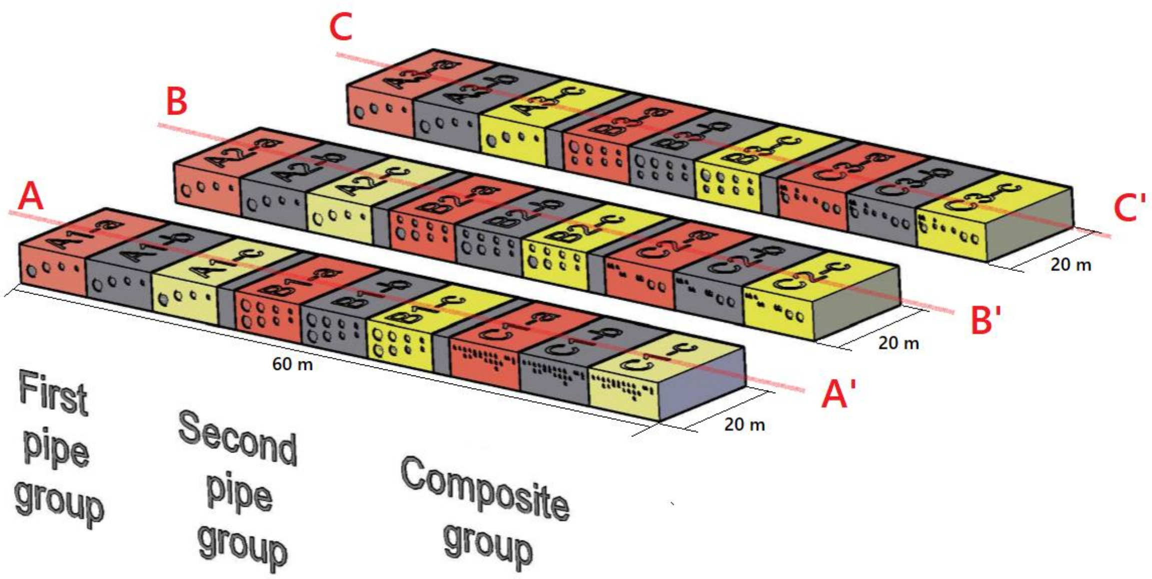


Figure 3. A 3D view of the geophysical site

The pipes and cables are placed to maximum 1.8, and 1 meter respectively (NEN-7171-2). The NEN-7171 is a Dutch utility guideline that specifies the cable and pipes depth, location, and the distances to any other underground infrastructure. The beforementioned depth values and utility diameter were in accordance with this guideline. Besides, the diameter of the utilities are determined with respect to common utility conditions in the Netherlands. The proper spacing between pipes and cables is selected, such that to prevent the hyperbolic signature covering. Moreover, plastic, concrete, and copper are chosen as pipe material to examine the effects of utility material on the radargram. Further, A number of simple utilities arrangement are chosen with respect to investigate the effects of various diameter overlaying each other. The test site design is kept simple as too complex condition would make the radargram to interpret.

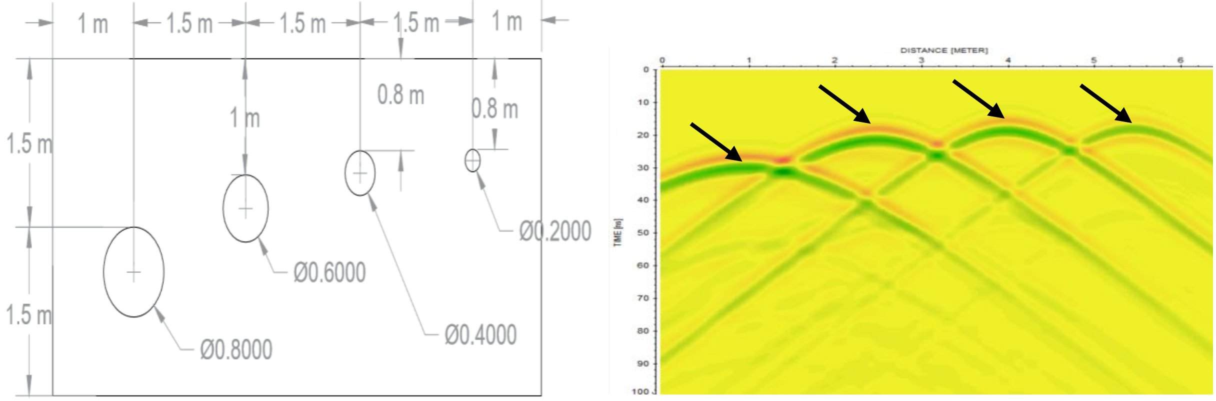
Any material that is not mentioned in this design should be avoided in the construction stage, as debris may cause soil heterogeneity. This ‘media heterogeneity’ (due to presence of tree roots, rocks, metal nails, gravels, voids, and cavities). leads to unwanted echoes in radargram signals Finally, a weather station and soil moisture instrument should be installed between bays to register the conditions in which the various measurements with GPR equipment have been conducted.

Detectability of utilities in the design

To safeguard that the designed utilities can indeed be detected and mapped using GPR equipment, we ran electromagnetic forward modeling simulations that produce – based on modeled physical properties of the GPR and ground – a synthetic GPR scan.

Forward modelling is used to identify the earth's responses to electromagnetic waves. Specifically, it helps the designer to estimate the GPR radargram output:, the response from the utilities that will be buried on the test site. . Fig 4. shows the designed cross-section of each utility group (left) and the related forward modeling output (right). It can be seen that some hyperbola related to deeper, smaller and utilities overlapped by larger objects are less visible or occluded. This can be explained by the phenomenon of signal loss and scattering (Fig .4). The Vertical and horizontal axis on the right-hand side images of figure 4 is time (ns) and distance(m), respectively. The signal attenuation will be corrected in post signal processing whenever it is needed. As shown in Fig 4, pipes in the first row are visible in all radargrams (a,b,c,d), each hyperbola demonstrates one pipeline as indicated by the black arrow. But the pipes that are buried beneath the other pipes are only distinguishable when their diameter is larger or the same as the overlaid pipeline, indicated by a red arrow. Dashed red arrow symbolized for the pipes that are visible but masked with signals from other pipes. As Fig 4 (c) shows, smaller pipes that are covered by larger pipes in radargrams are not visible, and advanced signal processing is required to visualize them (indicated by black box). Although if the diameter differences are small, pipes underlaid by larger ones can be distinguishable (Fig 4 (d), indicated by the blue arrow).

As can be seen from Fig 4 (e), each cable is not apparent in radargrams, and group cables that are next to each other create a non-symmetric hyperbola. GPR's with higher frequency and advanced signal processing will provide us the possibility of seeing them individually.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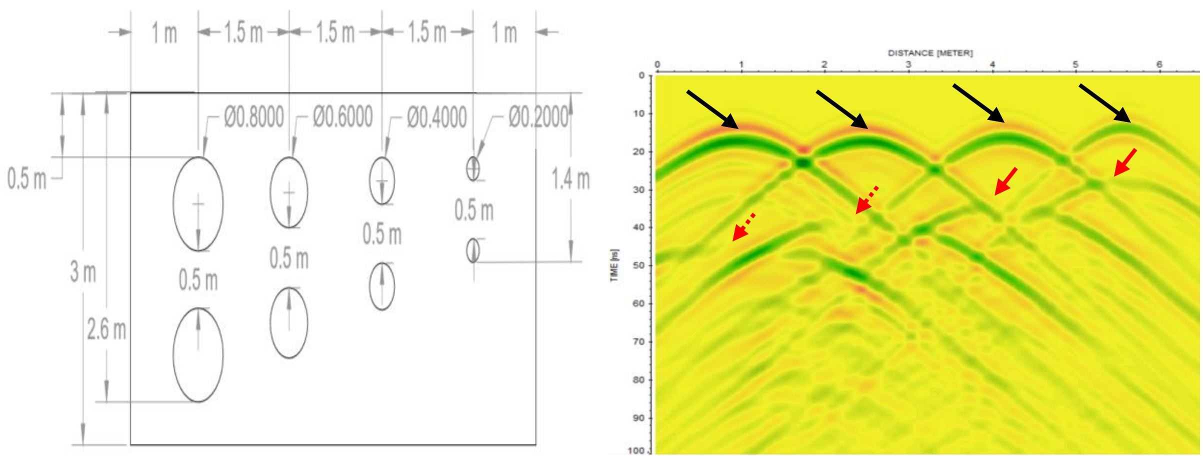
(a)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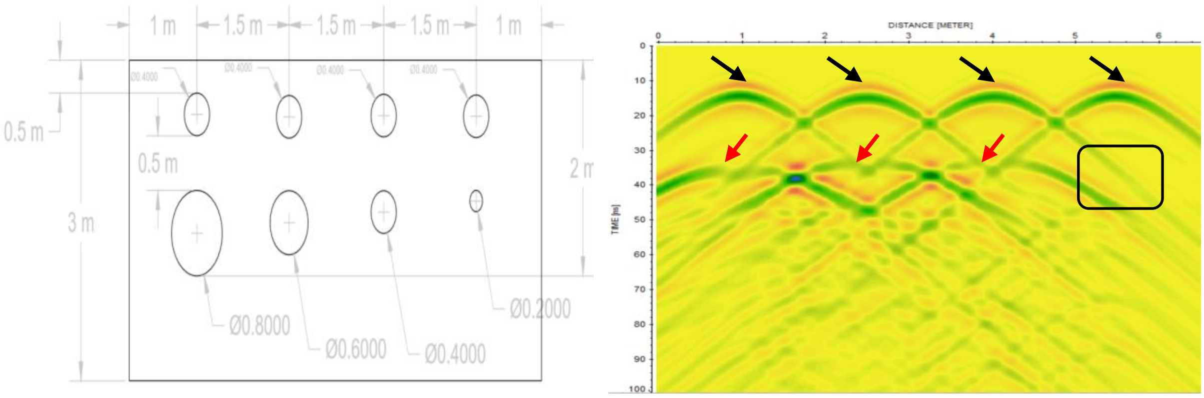
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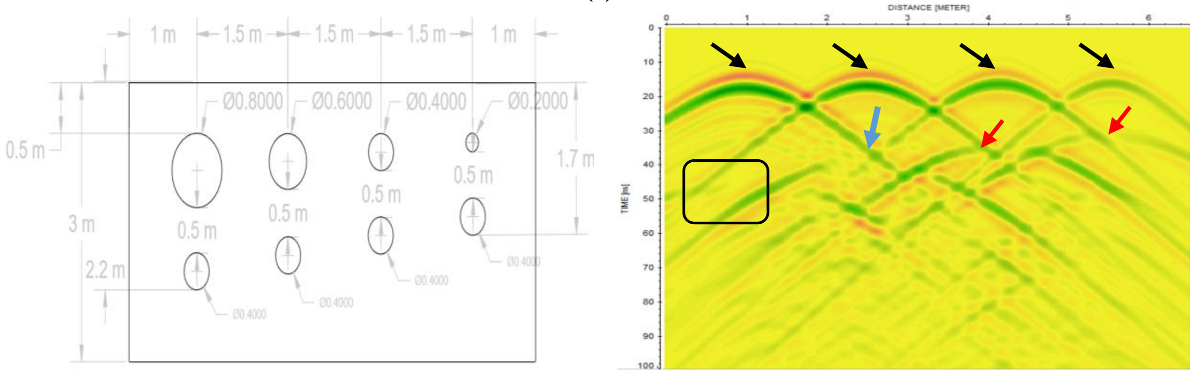
(c)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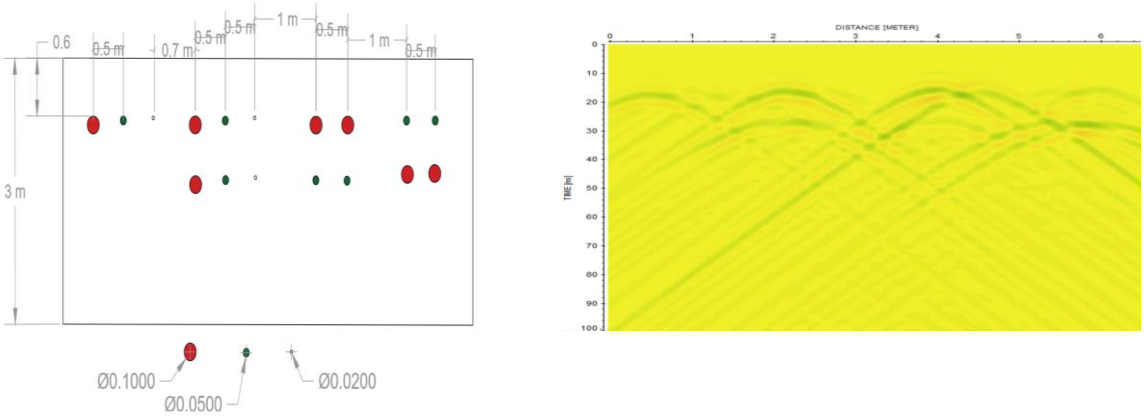
(d)



(e)

Figure 4. First group pipes cross-section (left) and related radargram (right)

(a) the first group, (b) the second group-pipes with same diameter, (c) the second group-pipes with different diameter-larger pipes overlaid by smaller ones (d) the second group-pipes with different diameter-smaller pipes overlaid by larger ones, (e) the third group- cables

Discussion

The propagated wave in the media, as shown in the forward modeling, indicates that the proposed buried utilities in test site is detectable and distinguishable and seems to be appropriately designed. Although detecting the signals might seems tricky in some parts of radargrams, for example; The deeper parts of the radrgram or where there bigger pipes are buried above the smaller ones. But, after signal processing, these radargrams will be more distinguishable. The abovementioned statements prove that the site is buildable. After the construction of the test site, It will be ready to conduct several GPR measurements for utility detection and various GPR apparatus assessment.

Conclusion

The Twente university geophysical test facility is designed to train people for GPR utility applications. The uniqueness of the Twente university geophysical test facility is that it covers the standard Dutch utility that exists in the cities, and also the design professionally compares various arrangements, utility geometry, material, and depth effects. With a design that utility is placed in known locations, the GPR practitioners have this ability to define the boundaries of the GPR system in terms of data acquisition, processing, and interpretation, which leads to effective use of the GPR in the field.

To achieve the goal of designing the optimum test site. After reviewing the literature and receiving feedbacks from GPR experts and related companies. The optimum design is proposed. The design looks as follows and contains three sections with different pipes and cables configuration that buried in sand, clay, and a soil mixture. The design based on the forward modeling seems to be realistic and constructible.

But of course, there might be some limitations because it needs to be exactly installed as designed to function properly. It is essential to mention that the design is kept simple, and very complex situations are avoided. Finally, the authors recommend the usage of this testing site to the industry to explore how GPR could be used.

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