COST Action TU1208

Civil engineering applications of Ground Penetrating Radar

Catalogue of GPR test sites

1st edition

Lara Pajewski, Raffaele Persico, Xavier Derobert, Jean-Paul Balayssac, Satoshi Ebihara, Colette Grégoire, Volodymyr Ivashchuk, Thomas Kind, Lech Krysiński, Wallace Wai-Lok Lai, Sébastien Lambot, Sergio Negri, Salvatore Piro, Santo Prontera, Enzo Rizzo, Mercedes Solla, Josef Stryk.

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Preface

The *Catalogue of GPR test sites* aims to provide a list of the main available test sites and laboratories where Ground-Penetrating Radar (GPR) equipment, methodology and procedures can be tested. Most test sites presented in this volume are located in Europe; however, the catalogue also includes information about a few extra-European facilities. This publication is an outcome of the COST (European Cooperation in Science and Technology) Action TU1208 "Civil engineering applications of Ground Penetrating Radar" and is available for free download on the website of the Action (www.GPRadar.eu).

About COST

COST is the longest-running European framework supporting cooperation among scientists and researchers across Europe and beyond. Founded in 1971, it is currently integrated in the Horizon 2020 programme. It contributes to reducing fragmentation in European research investment, building the European Research Area (ERA) and opening it to worldwide cooperation. It also aims at constituting a "bridge" towards the scientific communities of emerging countries, increasing the mobility of researchers across Europe and fostering the establishment of excellence in key scientific domains. Gender balance, support to early-career investigators and inclusiveness are strategic priorities of the COST programme.

COST does not fund research itself, but provides support for activities carried out within Actions: these are bottom-up science and technology networks, centered around nationally funded research projects, with a four-year (or, exceptionally, slightly longer) duration and a minimum participation of five countries. The Actions are active through a range of networking tools, such as meetings, workshops, conferences, training schools, short- term scientific missions and dissemination activities. They are open to researchers and experts from universities, public and private research institutions, nongovernmental organizations, industry and small and medium-sized enterprises. By creating open spaces where people and ideas can grow, COST fosters the birth of new ideas and unlocks the full potential of science.

For more information about COST, please visit www.cost.eu.

About COST Action TU1208

COST Action TU1208 "Civil engineering applications of Ground Penetrating Radar" was running from April 2013 to October 2017. It involved more than 300 experts from 150 partner institutes in 28 COST countries (Austria, Belgium, Croatia, Czech Republic, Denmark, Estonia, Finland, France, former Yugoslav Republic of Macedonia, Germany, Greece, Ireland, Italy, Latvia, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, and the United Kingdom), a COST cooperating state (Israel), 6 COST near neighbor countries (Albania, Armenia, Egypt, Jordan, Russia, Ukraine) and 6 COST international partner countries (Australia, Colombia, Hong Kong, The Philippines, Rwanda, the United States). University researchers, software developers, civil and electronic engineers, archaeologists, geophysics experts, non-destructive testing equipment designers and manufacturers, end-users from private companies and public agencies participated in the Action.

The scientific structure of COST Action TU1208 included four Working Groups (WGs), which research activities covered all areas of the GPR technology, methodology, and applications.

WG 1 focused on the development of novel GPR instrumentation. Within this WG, novel equipment was designed, implemented and tested. Moreover, new tests were proposed for checking the performance and stability of GPR systems.

WG 2 focused on the use of GPR in civil engineering. This WG developed guidelines for GPR inspection of flexible pavements, utility detection in urban areas, and evaluation of concrete structures. Recommendations for a safe use of GPR were produced. Additionally, WG2 developed a wide series of case studies where GPR was successfully used in a plethora of different civil-engineering works.

WG 3 studied electromagnetic forward and inverse methods for the solution of near-field scattering problems by buried structures, imaging techniques and data processing algorithms. This WG released free software for electromagnetic modelling of GPR scenarios and processing of GPR data. A database of radargrams was composed and organized, which is openly available for researchers willing to use the proposed datasets to test and validate their electromagnetic forward- and inverse-scattering techniques, imaging and signal-processing methods.

WG 4 dealt with the applications of GPR outside from the civil engineering area; it investigated the combined use of GPR and complementary non-destructive testing methods, as well. The most interesting output of this WG is a wide series of case studies showing how GPR can be applied in different fields, both in well-established and emerging applications. Special attention was paid to the use of GPR for the management of cultural heritage.

All WGs were active in organizing and offering training activities (16 Training Schools were organized in four years) and jointly produced an open-access educational package for teaching GPR in the university.

For more information about COST Action TU1208, please visit www.GPRadar.eu.

About this catalogue

This catalogue represents, in our opinion, a useful tool for the GPR community. The information included in this publication will contribute to identifying new collaboration possibilities among European research teams and stimulate a stronger cooperation between academia and industry. The catalogue also clarifies which are the existing and missing testing facilities in the various European regions (with some prompt beyond Europe, too), thus highlighting and possibly addressing current and near-future research needs.

Scientists, GPR end-users and manufacturers can exploit the facilities listed in this catalogue to test and calibrate their equipment and inspection procedures, to investigate the feasibility of new applications, to plan and offer training activities, to verify and increase the level of their own experience with respect to specific applications, and more. This publication also represents a helpful reference for the preparation of new project proposals, as well as for the definition of the workplan of research initiatives and industrial ventures.

It is worth stressing that test sites are central to any future Quality Assurance/Control strategy to be developed in the GPR field. Furthermore, test sites are the only practical means of collecting experimental datasets in controlled conditions, to be analyzed and compared for the purposes of deriving knowledge about the performance of different GPR systems, antennas, procedures and algotithms.

The list of facilities provided in this publication is not exhaustive, of course. To the best of our knowledge, no previous efforts were done to produce a similar publication. Therefore, we did not have a basis to start from and possibly update. Nonetheless, thanks to the wide extension of the TU108 network, we were able to put together a good amount of information.

We hope that, in the future, this catalogue will progressively become more complete and we plan to update it on a regular basis; in particular, we are looking forward to enriching the list of facilities available outside Europe. The second edition of the catalogue is foreseen for Spring 2019 and will be presented during the 10th edition of the International Workshop on Advanced Ground Penetrating Radar (IWAGPR 2019, Rome, Italy, 3-5 July 2019). Scientists and professionals willing to contribute to the upcoming edition of this publication are welcome to take contact with us at tu1208@gpradar.eu.

The test sites presented here are of different kinds and aimed at different purposes, ranging from purely academic research and training activities, to practical applications of GPR in civil-engineering (assessment of manmade structures, such as roads, railways, reinforced concrete walls and floors or pavements), cultural heritage (diagnostics of archaeological remains), hydrogeophysics, embedded utilities, and more. We classified the test sites according to their main applications in Table I. The aim of such Table is to help the Readers carrying out a first rough selection of the test sites, so that they can easily identify the facilities that best match their needs. This classification is sketchy and of course it does not prevent the possibility that a laboratory owning a particular test site might be interested in other applications, too.

After the above mentioned table, a short description of each test site is proposed. The test sites are grouped per country (and countries are listed in alphabetical order). For each test site some general information is given, including its geographical position and the full contact details of a reference person; this is followed by a short technical description of the experimental facilities; then, recent and ongoing research projects are briefly mentioned.

Let us specify that the presence of a test site in this catalogue does not mean that everybody can have access to it: we do not deal with the policies of the test-site owners. In particular, if a test site is listed here, this of course means that the managing scientific or industrial group is available for a dialogue with people who may be interested in using the presented facilities. However, it is up to the managing group to decide if and how facilities, resources, and data can be shared with other people.

The book is concluded with some recommendations for the design of a new GPR test site.

We would like to express our sincere thanks to all the authors of this catalogue, for their contributions and fruitful cooperation. We are immensely grateful to COST, European Cooperation in Science and Technology, for funding and supporting the Action TU1208 "Civil engineering applications of Ground Penetrating Radar" and the development of this publication. Finally, we thank TU1208 GPR Association for providing the ISBN and ISBN-A codes.

Lara Pajewski, Raffaele Persico, Xavier Derobert

TAB. I - TEST SITES VS. AREAS OF APPLICATION

Test site (Country)	**Main areas of application**									
	Cultural Heritage	Concrete	Roads	Railways	Hydrogeo	Land mines	Utilities	Research & Training[1]	Antenna testing	Borehole
BRRC Wavre *Road test site* (Belgium)			X					X		
Université catholique de Louvain *Sand box* (Belgium)							X	X	X	
CDV *Concrete slab* (Czech Republic)		X								
ISTIMES *Concrete beam* (France)		X								
IFSTTAR *Pavement fatigue carrousel* (France)			X					X		
IFSSTAR *SENSO* (France)		X								
Univ. of Toulose *LMDC 1* (France)		X								
Univ. of Toulose *LMDC 2* (France)			X							
IFSTTAR *Geophysical test site* (France)							X	X		

(1)The term "Research" here refers to purely academic experiments not strictly related to a specific application. Of course, all test sites are suitable to carry out research activities. Analogously, the term "Training" indicates that the test-site is particularly suitable (or was specifically conceived) for didactical purposes. Of course, training activities may take place in all test sites.

Test site (Country)	**Main areas of application**									
	Cultural Heritage	Concrete	Roads	Railways	Hydrogeo	Land mines	Utilities	Researc h & Training	Antenna testing	Borehole
BAM *Technical Safety test site* (Germany)		X	X							
BAM *Testing Hall* (Germany)		X								
The Hong Kong Polytechnic University *Underground Utility Survey Laboratory* (Hong Kong)		X	X				X	X		
CNR-IBAM *Concrete column* (Italy)	X	X								
CNR-IMAA *Hydrogeosite* (Italy)	X	X			X		X			
University of Salento *Applied Geophysics test site* (Italy)	X						X	X		
Sapienza University of Rome *Humanitarian Demining Lab* (Italy)						X				
GRS-Lab ITABC CNR (Italy)	X									

Test site (Country)	**Main areas of application**									
	Cultural Heritage	Concrete	Roads	Railways	Hydrogeo	Land mines	Utilities	Researc h & Training	Antenna testing	Borehole
Osaka electrocomm. University *Borehole test site* (Japan)										X
IBDIM *Reference asphalt pavement* (Poland)			X							
University of Vigo *Melide* (Spain)	X	X								
University of Vigo *Allariz* (Spain)							X			
Polytechnic University of Catalonia *EUETIB test site* (Spain)	X	X						X		
TRANSIENT LLC National University of Kyiv (Ukraine)							X			
NSGG Geological Society of London (United Kingdom)							X	X		

Belgium

BRRC Wavre – Road test site

General Information

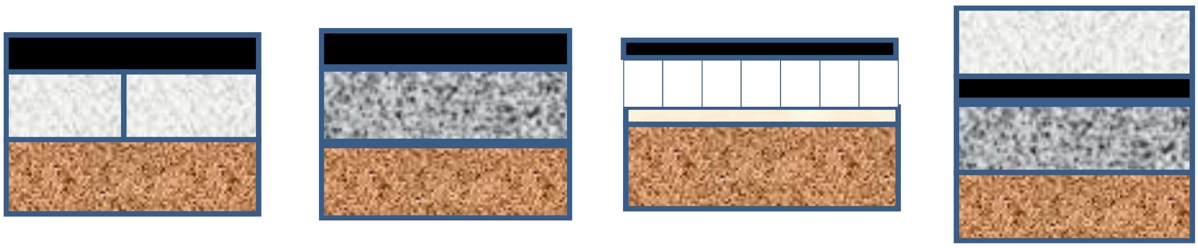
Test Site	**BRRC Wavre**
Country	Belgium
Institution	BRRC
Address	Av. Lavoisier 14, B-1300 Wavre
Website	www.brrc.be
Contact Person	Colette Grégoire
E-mail	c.gregoire@brrc.be
Tel	+32 2 766 03 19

Technical Description

Testing facilities, with technical characteristics

The test site is a stretch 23 m long and 2.7 m wide, indoor, including four different road structures that are commonly used in Belgium. Each section is equipped with strain gauges and temperature sensors.

The four different road configurations are: asphalt layer on concrete plates (1), asphalt layer on lean concrete (2), asphalt covering cobblestones (3) and concrete layer on lean concrete separated by a thin asphalt layer (4). The numbers here are related to the structure drawing. An unbound aggregate layer serves as a base layer. Heterogeneities (holes, voids, pipes, …) are buried in the structure.



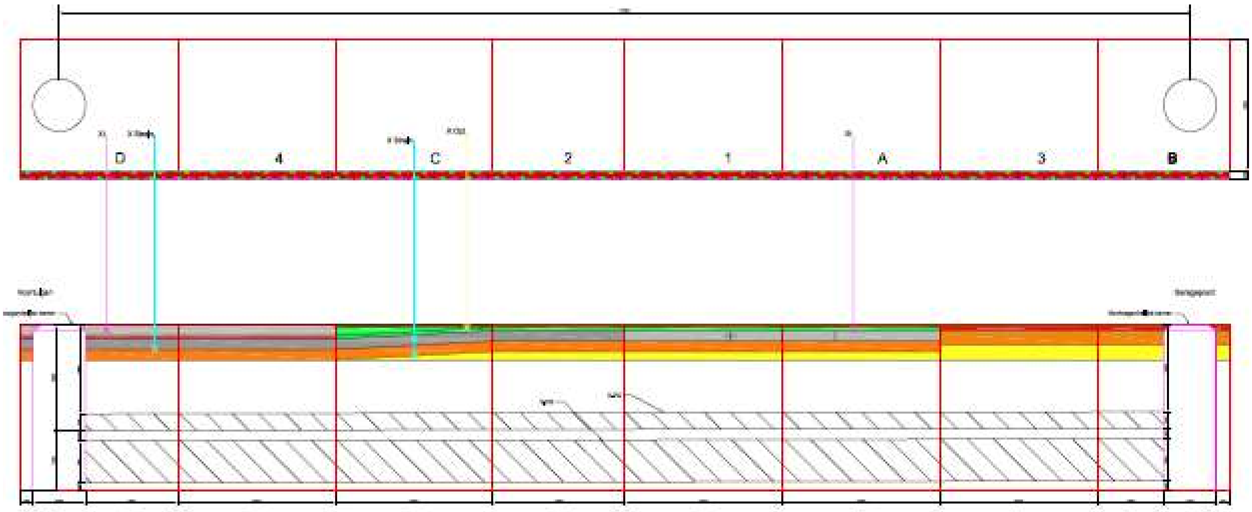
(1) (2) (3) (4)

Aggregates

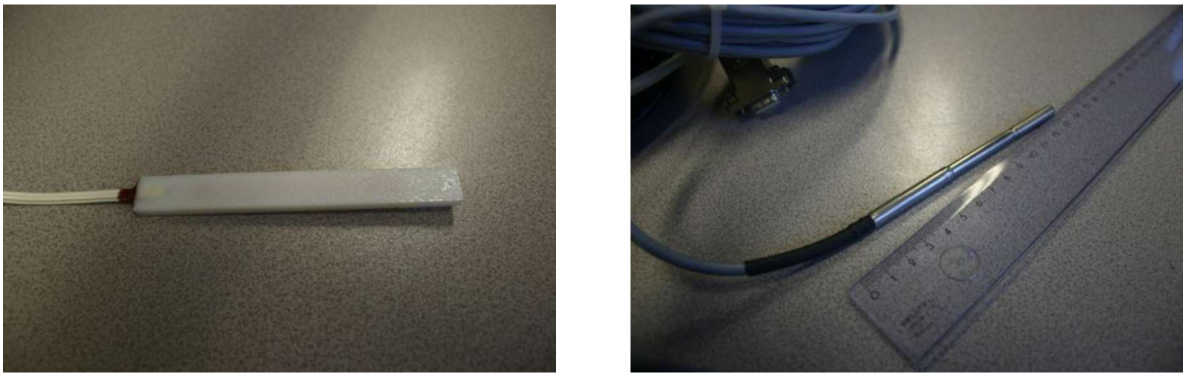
Concrete

Loan concrete

Photos taken during the construction of the test site



Lateral section of the test site (sketch)



KYOWA sensors (left photo: resistive force sensor; right photo: PT100 sensor)

Quantities/characteristics that can be tested: layer thickness, homogeneity, holes under concrete, pipes, interface and adhesion between asfalt layers.The site is instrumented with temperature and strain gauges. Also deflection measurements using a falling weight deflectometer are being performed on a regular basis on this test site.

Available equipment, with main specifications
GSSI control unit SIR 20, antennas: 1 and 2 GHz horn antennas, 400 MHz ground couple antenna. Falling Weight Deflectometer, ultrasonic tomograph.

Recent and Ongoing Research Studies

The test site is meant as a laboratory setting in order to develop descriptions of standard methods for the use of GPR on roads. These methods must cover the practical use on the road for determination of changes in the road structure, determination of layer thicknesses, and the detection of local defects or anomalies in road structures.

In the long term, the test site will also become a reference site in Belgium, for the verification of the good functioning of GPR equipment.

Sand Box

General Information	
Test Site	**Sand box**
Country	Belgium
Institution	Universitè catholique de Louvain (UCL)
Address	Croix du Sud 2 bte L7.05.02 1348 Louvain-la-Neuve belgium
Contact Person	Sébastien Lambot
E-mail	sebastien.lambot@uclouvain.be
Tel	+32 10 47 37 11

Technical Description

Testing facilities, with technical characteristics

The laboratory test site consists of a box (about 3 m × 3 m ×1 m) which can be filled with various materials. A copper plane is found at the bottom of the box. Radars can be set up on a XYZ automated scanner, which can sweep the box surface and allows us to obtain high resolution 2D and 3D images. Another copper plane situated near this equipment is available for antenna calibration. The GPR equipment is composed of GSSI SIR-20 with antennas ranging from 12.5 MHz to 900 MHz as well as a series of vector network analysers (2-4 ports) with antennas ranging from 200 MHz to 8.5 GHz. The test site is located in the geophysics laboratory of the Earth and Life Institute.

Structures/ materials/methods that can be tested or modelled

- Underground utilities detection and imaging
- Comparative tests of equipment
- Antenna calibration

Quantities/characteristics/properties that can be tested

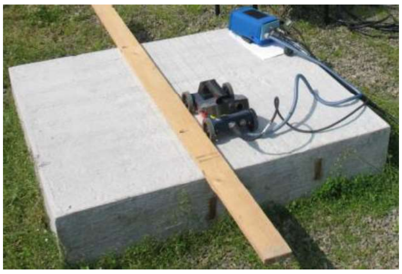
- Stability of measuring systems
- Reflection amplitudes, wave velocities, travel times, layer thickness
- Underground utilities depth

Uncertainty/reliability of the results + Qualification and quality assurance

- Numerous measurements were performed with this system
- Calibration procedure were validated
- Documentation for the various devices is available

Concrete Slab

General Information	
Test Site	**Concrete slab with 3 inbuild dowels in known positions**
Country	Czech Republic
Institution	CDV – Transport Research Centre
Address	Lisenska 33a 636 00 Brno
Website	www.cdv.cz
Contact Person	Josef Stryk
E-mail	josef.stryk@cdv.cz
Tel	+42 0 724 016 729



Technical Description

Testing facilities, with technical characteristics
For this experiment, a concrete slab 1.2-m long, 1-m wide, and 240-mm thick, was realized. Inside the slab, three dowels were placed in pre-set positions. The slab thickness corresponds to the standard thickness required for concrete pavement on motorways in Czech Republic.
For dowels positioning, the standard ČSN 73 6123-1 requirements were considered, where the maximum position deviation of rebar is specified. Two thin wooden boards were used for fixing dowels in required positions. One dowel was placed in ideal position without any translation and deflection in horizontal or vertical direction. The second and third dowel were placed out of the tolerance specified in the standard.

Available equipment, with main specifications
GSSI SIR-20, antennas with central transmission frequencies of 1.6 GHz and 2.6 GHz.

Structures/ materials/methods that can be tested or modelled
Jointed unreinforced concrete pavements (slabs with inbuild dowels and tie-bars)

Quantities/characteristics/properties that can be tested
Accuracy of localization of built-in dowels in horizontal and vertical direction

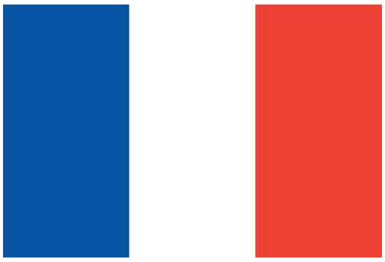
Uncertainty/reliability of the results
The real position of in-build reinforcement is known with accuracy +/- 1 mm.

Qualification and quality assurance
The position of dowels was fixed in two wooden boards.

Main Ongoing Research Studies

A GPR procedure for in-situ measurement of the position of dowels and tie bars in concrete pavement was optimised based on the laboratory experiments. The work was mainly focused on three aspects: production of a two channel GPR hand cart, realization of a sufficiently extensive set of measurements on motorways covering different rebar misalignments, and finally in-situ GPR comparative measurements test allowing to check the accuracy of GPR measurements with respect to the known positions of rebar.

France



IFSTTAR – Concrete beam ISTIMES

General Information

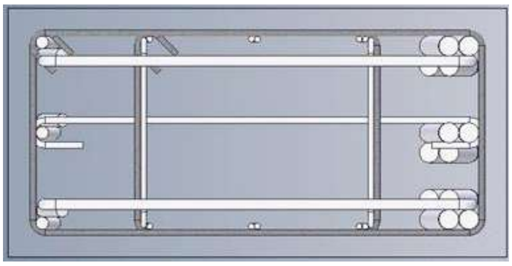
Test Site	**Concrete beam ISTIMES**
Country	France
Institution	IFSTTAR Nantes-site
Address	Route de Bouaye – CS4 44344 Bouguenais
Website	www.ifsttar.fr
Contact Person	Xavier Dérobert
E-mail	xavier.derobert@ifsttar.fr
Tel	+33 0 2 40 84 56 24

Technical Description

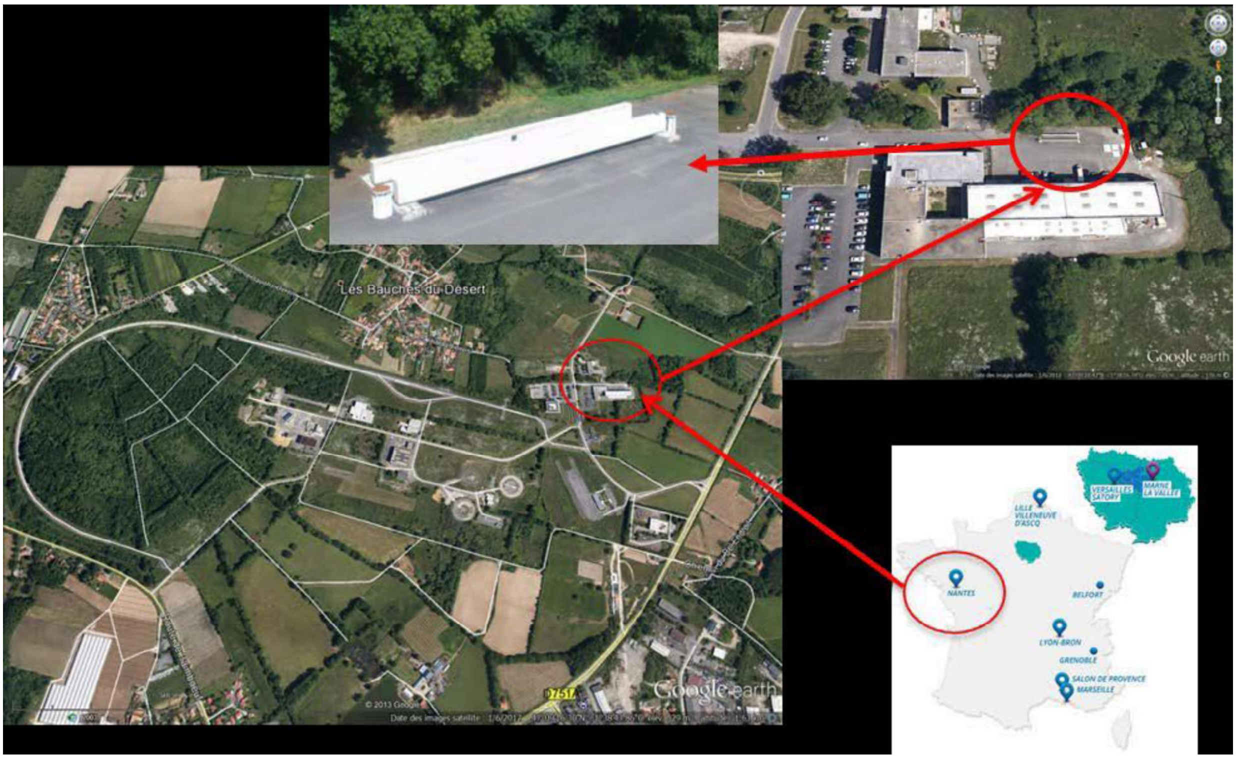
Testing facilities, with technical characteristics

Reinforced concrete beam – Scale 1:1

In the framework of the ISTIMES project (FP7), a reinforced concrete beam was designed to test damage quantification evolution methods during several high energetic mechanichal impacts (produced by a few tons objects dropped directly from few meters). Two beams were built, one was damaged by sucessive impacts and the other one was not damaged. The inner of the sound beam is equipped with thermocouples and strain gauges. Finally, in-situ weather parameters are also followed with time. The beams are 16 m long, 0.5 m wide and 1 m high, for a total weight of 21 T, and their metallic inner structure is sketched belove. Such a structure is made by longitudinal bars, with a diameter equal to 30 mm and spatial offset of 0.175 m, and by secondary transversal and longitudinal bars, with a diameter of 10 mm, and spaced 0.2 m from one another. The damaged structure presents various level of cracks, and an area of 1 m^2 of spallling.



Scheme of the structure, with he reinforcement.



Geographical location of the test site.

Photos of the test site.

Pavement fatigue carrousel

General Information	
Test Site	**Pavement fatigue carrousel**
Country	France
Institution	IFSTTAR Nantes-site
Address	Route de Bouaye – CS4 44344 Bouguenais
Website	www.ifsttar.fr
Contact Person	Xavier Dérobert
E-mail	xavier.derobert@ifsttar.fr
Tel	+33 0 2 40 84 56 24

IFSTTAR

Technical Description

Testing facilities, with technical characteristics

This is a large scale circular outdoor test facility, unique in Europe by its size (120 m long) and loading capabilities (maximum loading speed of 100 km/h equating to a loading rate of one million cycles per month). The circular test track is divided into several different test sections, loaded simultaneously. A 25 m long pavement section has been dedicated to study detection of defects at interface between layers with NDT methods. Pavement consists of two bituminous layers (8 cm thick base layer, and 6 cm thick wearing course), over a granular sub-base. A fatigue experimentation has been performed to follow any evolution of the defects under controled traffic. This experiment included 300 000 applications of standard French axle load (65 kN dual wheel load). The test area is now at disposal for NDT measurements.

fig.2a

Debonded interface defects:		
Defect zones	Type	Dimensions (m) (length × width)
I-1	Sand	0.5 × 2 m
I-2	Textile	0.5 × 2 m
I-3	Tack coat free	0.5 × 2 m
I-4 to I-9	Textile	0.5 × 0.5 m
I-10	Textile	3 × 1 m
I-11	Sand	1.5 × 2 m
I-12	Textile	1.5 × 2 m
I-13	Tack coat free	1.5 × 2 m

Available equipment, with main specifications
GSSI SIR-3000 radar system with ground-coupled antennas (500 MHz (2) – 900 MHz (2), 1500 MHz (2), 2600 MHz (2))
Radan6.6 and ReflexW6.0.5 software

Structures/infrastructures/materials that can be tested
GPR systems, GPR softwares (modeling & processing), NDT systems

Quantities/characteristics that can be tested
GPR performances (accuracy of crack detection…)

Uncertainty/reliability of the results
GPR performances (accuracy of crack detection…)

Qualification and quality assurance
GPR training – GPR system qualification

Concrete beam SENSO

General Information	
Test Site	**Concrete beam SENSO**
Country	France
Institution	IFSTTAR Nantes-site
Address	Route de Bouaye – CS4 44344 Bouguenais
Website	www.ifsttar.fr
Contact Person	Xavier Dérobert
E-mail	xavier.derobert@ifsttar.fr
Tel	+33 0 2 40 84 56 24

Technical Description

Testing facilities, with technical characteristics

Reinforced concrete beam – Scale 1:1

At the end of a French National project (SENSO), a specific formwork, designed (by LMDC, univ. Toulouse, FR) for benchmarking, has been reused to build a reinforced concrete beam in order to test the effect of the reinforcement on NDT techniques on the concrete characterization by NDT techniques.

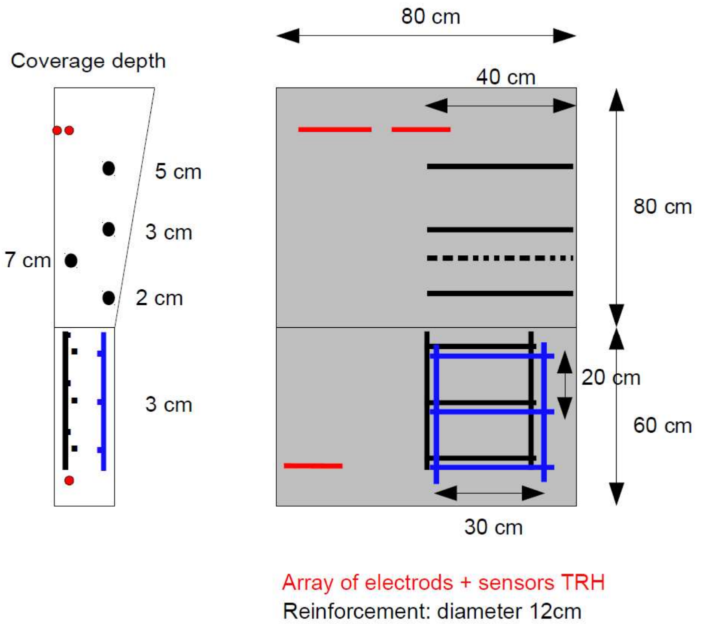
This wall (1.6 m high × 1.2 m width) is composed of two parts. The first one (left part of the middle image), which reinforcement meshes is presented below, leaving to parts without rebars, a zone with various depth reinforcement, and 4 meshes (20 × 30 cm).

The second zone, presenting a kind of diapason, is composed of a reinforced part and a posttensioned part separated by a notch. The piece of reinforced concrete will be used for the support in flexure of the post-tensioned part, via a threaded drawbar in order to seek the outer face until cracking.

The final objective of this zone is to monitor the evolution of a crack (~40 cm long) at the base of the post-tension part while gathering the two upper elements of the structure.

Some sensors (temperature and relative moisture - THR) have been embbeded in a representative area at various depths.

View and scheme and view of the reinforcement (diameter of rebars: 10 mm):



Available equipment, with main specifications
GSSI SIR-3000 radar system with ground-coupled antennas (500 MHz (2) – 900 MHz (2), 1500 MHz (2), 2600 MHz (2)) – StructureScan 2600 MHz Radan6.6 and ReflexW6.0.5 softwares

Structures/infrastructures/materials that can be tested
GPR systems, GPR softwares (modeling & processing), NDT systems

Quantities/characteristics that can be tested
GPR performances (depth penetration, accuracy of spatial detection…)

Uncertainty/reliability of the results
GPR performances (accuracy of spatial detection…)

LMDC 1

General Information	
Test Site	**LMDC 1**
Country	France
Institution	LMDC Université de Toulouse
Address	135 avenue de Rangueil 31077 TOULOUSE Cedex 04
Website	http://www-lmdc.insa-toulouse.fr
Contact Person	Jean-Paul Balayssac
E-mail	jean-paul.balayssac@insa-toulouse.fr
Tel	+33 5 67 04 88 79

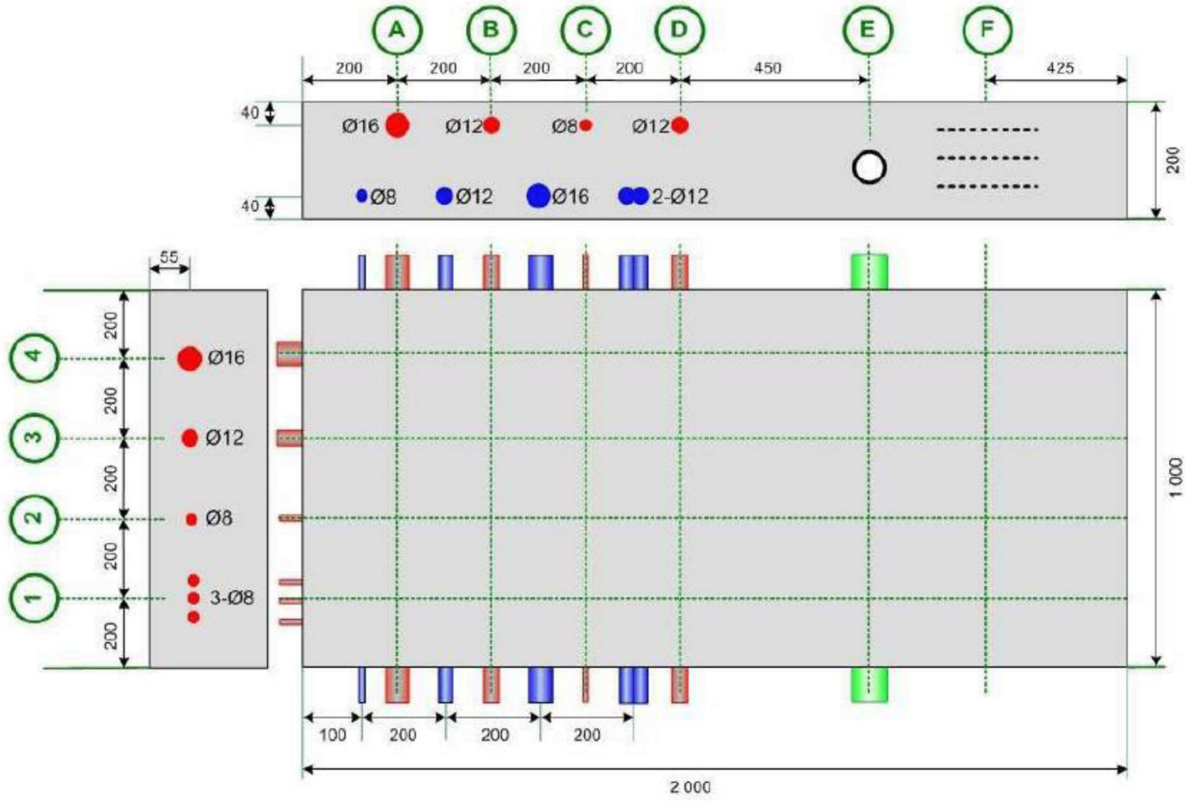
Technical Description

Testing facilities, with technical characteristics
Outdoor slab with size 2 m × 1 m × 0.20 m, placed on the ground, with accessible upper face.

Available equipment, with main specifications
GPR GSSI SIR 20 with two 1.5 GHz antennas and two 2.6 GHz antennas.

Structures that can be tested
Concrete, reinforcement, voids, delamination.

Quantities/characteristics/properties that can be tested
Depth of reinforcement, void and delamination properties.



Scheme of the slab.

LMDC 2

General Information	
Test Site	**LMD 2**
Country	France
Institution	LMDC Université de Toulouse
Address	135 avenue de Rangueil 31077 TOULOUSE Cedex 04
Website	http://www-lmdc.insa-toulouse.fr
Contact Person	Jean-Paul Balayssac
E-mail	jean-paul.balayssac@insa-toulouse.fr
Tel	+33 5 67 04 88 79

Université de Toulouse

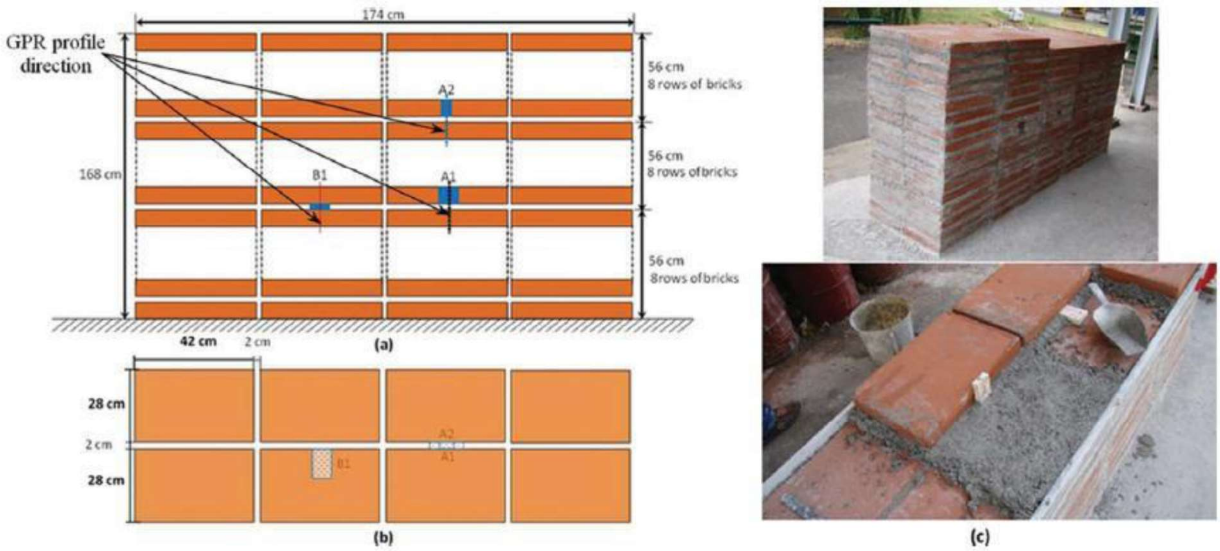
Technical Description

Testing facilities, with technical characteristics
Brick masonry wall with jointing defects inside. The positions of the defects are well known and the electromagnetic properties of the materials (brick and mortar) are also known.

Available equipment, with main specifications
GPR GSSI SIR 20 with two 1.5 GHz antennas and two 2.6 GHz antennas.

Structures that can be tested
Jointing defects (5 cm × 5 cm × 2 cm, vertical or horizontal).

Quantities/characteristics/properties that can be tested
Localisation of the defects.



Scheme of the wall and photos

Recent and Ongoing Research Studies

The results of recent studies were published on the following scientific paper:

Rani Hamrouche, Gilles Klysz, Jean-Paul Balayssac, Jamal Rhazi & Gérard Ballivy, Numerical Simulations and Laboratory Tests to Explore the Potential of Ground-Penetrating Radar (GPR) in Detecting Unfilled Joints in Brick Masonry Structures, International Journal of Architectural Heritage: Conservation, Analysis, and Restoration, 6:6, 648-664, 2012, http://dx.doi.org/10.1080/15583058.2011.597484.

IFSTTAR Geophysical test site

General Information

Test Site	**Geophysical test site**
Country	France
Institution	IFSTTAR Nantes-site
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IFSTTAR

Technical Description

Testing facilities, with technical characteristics

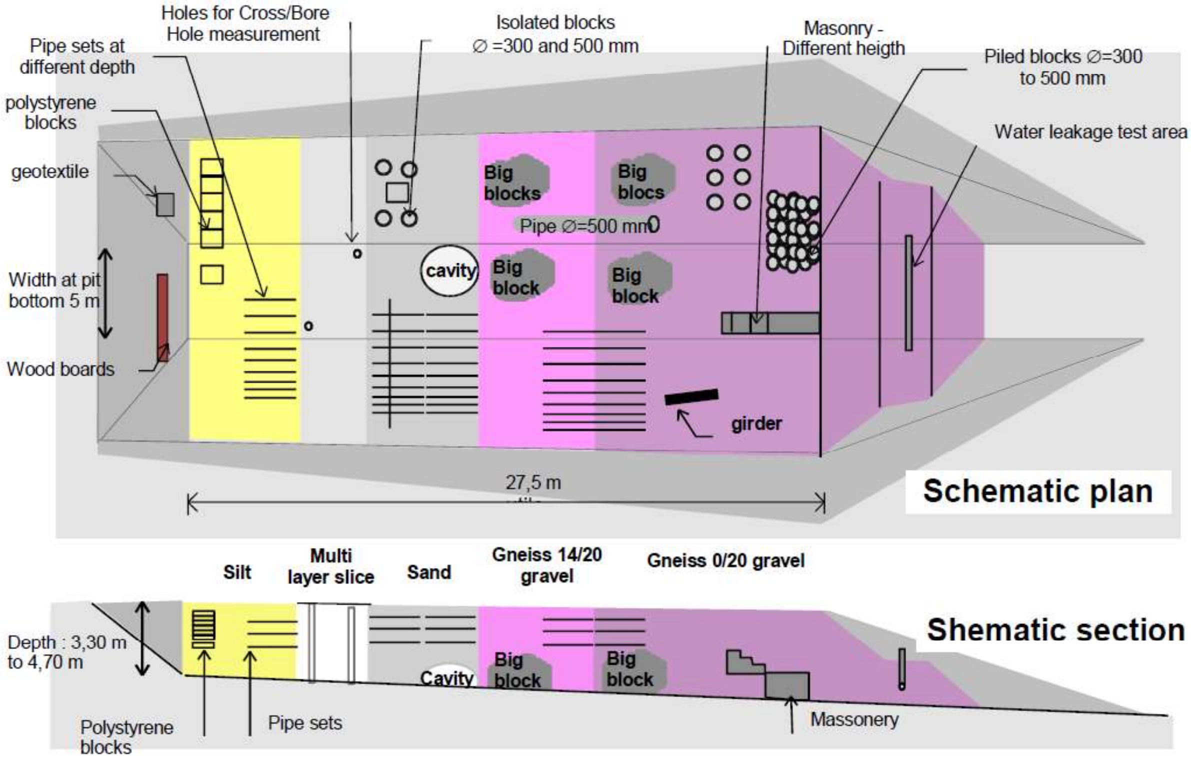
Geophysical test site – Scale 1:1

This site is constituted essentially by a pit length of 30 m and 5 m in width in bottom with sides sloping to 2/1. Useful depth varies from 3.30 to 4.70 m. This pit is filled with various materials arranged in horizontal compacted slices separated by a vertical interface and water-tighted in surface:
a silt trench (5 m width) / a multilayer trench (2.5 m width) / a limestone sand trench (5 m width) / a gravel gneiss 14/20 trench (5 m width) / a gneiss 0/20 trench (10 m width)

Embedded Objects:

- Pipes (3 depths : 1 m – 1.5 m – 2 m / 3 natures: metal – PVC(air) – PVC(water)),
- Polystyren hollows (few depths : 0.65 m to 2.3 m), cavity (depth: 3.47 m ~ 2 m large)
- Boulders (various size/various depths : from 0.9 m to 3.3 m),
- Masonry (depth: from 1.5 m to 3.5 m)

These objects were identified consistently in local coordinates at construction to constitute a database of their position (see the scheme of the test site).

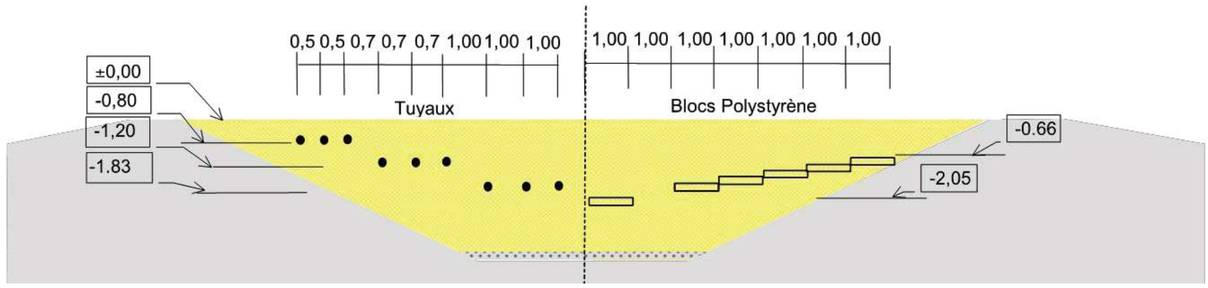


Schematic plan and section of the entire test site.

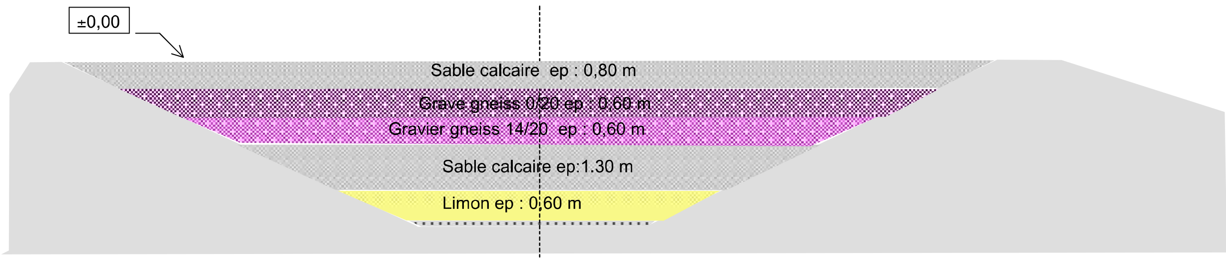




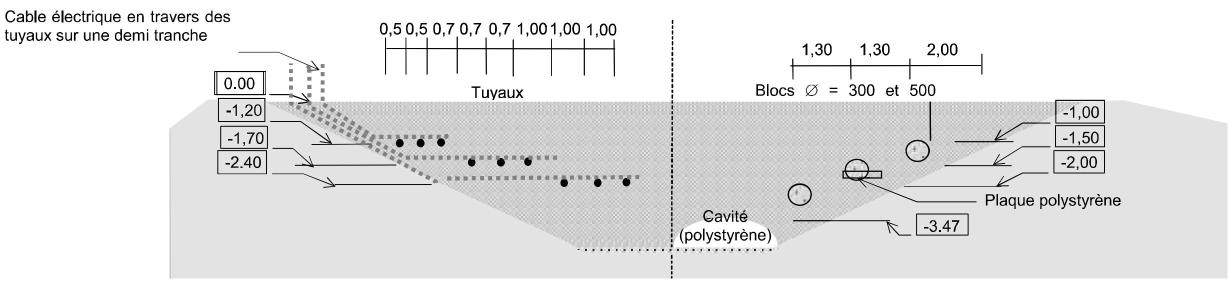

Photos taken during the realization of the test site.



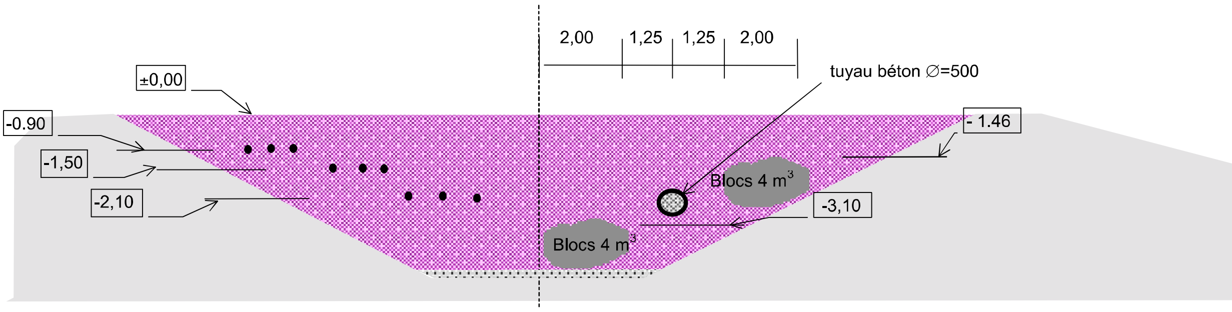
Transversal section of the silt region, with metallic pipes and polysterene blocks buried at different depths. In this region of the test site, GPR measurements were carried out with ground-coupled antennas having central frequencies of 200 MHz, 250 MHz, 400 MHz, 500 MHz, 800 MHz, and 900 MHz, by using different systems manufactured by different companies. All data are available for free download: they are included in the TU1208 open database of radargrams (www.GPRadar.eu/resources/database.html).



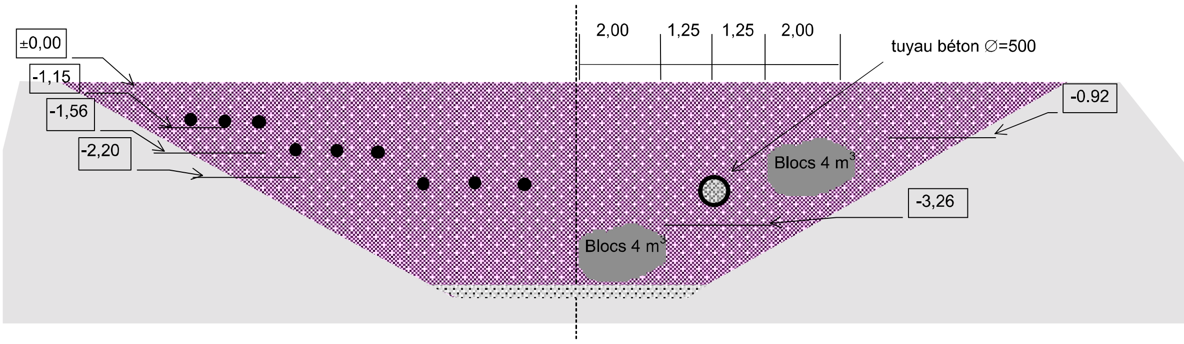
Transversal section of the multilayer region, with a stratification of different materials; holes are present (not shown in this scheme), which allow borehole measurements. In this region of the test site, GPR measurements were carried out with ground-coupled antennas having central frequencies of 250 MHz, 400 MHz, 500 MHz, and 900 MHz, by using different systems manufactured by different companies. All data are included in the TU1208 open database of radargrams.



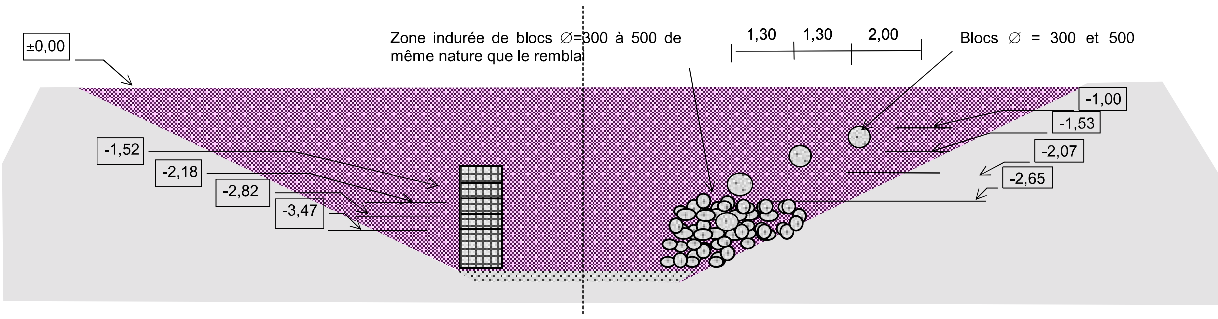
Transversal section of the sand region, with electrical cables, tubes buried at different depths, polysterene blocks and plaques. Here, GPR measurements were carried out with ground-coupled antennas having central frequencies of 200 MHz, 250 MHz, 400 MHz, 500 MHz, 800 MHz, and 900 MHz, by using different systems manufactured by different companies. All data are included in the TU1208 open database of radargrams.



Transversal section of the gneiss 14/20 gravel region, with pipes buried at different depths, big blocks and a beton tube. Here, GPR measurements were carried out with ground-coupled antennas having central frequencies of 200 MHz, 250 MHz, 400 MHz, 500 MHz, 800 MHz, and 900 MHz, by using different systems manufactured by different companies. All data are included in the TU1208 open database of radargrams.



Transversal section of the first part of the gneiss 0/20 gravel region, with pipes buried at different depths, big blocks and a beton tube. Here, GPR measurements were carried out with ground-coupled antennas having central frequencies of 250 MHz, 400 MHz, 500 MHz, 800 MHz, and 900 MHz, by using different systems manufactured by different companies. All data are included in the TU1208 open database of radargrams.



Transversal section of the second part of the gneiss 0/20 gravel region, with masonry having a variable height and several blocks of different size. Here, GPR measurements were carried out with ground-coupled antennas having central frequencies of 400 MHz and 900 MHz, by using different systems manufactured by different companies. All data are included in the TU1208 open database of radargrams.

Available equipment, with main specifications
GSSI SIR-3000 radar system with ground-coupled antennas (500 MHz (2) – 900 MHz (2), 1500 MHz (2), 2600 MHz (2)).
Radan6.6 and ReflexW6.0.5 software.

Structures/infrastructures/materials that can be tested
GPR systems, GPR software (modelling & processing), NDT systems.

Quantities/characteristics that can be tested
GPR performances (depth penetration, accuracy of spatial detection...).

Uncertainty/reliability of the results
GPR performances (accuracy of spatial detection...).

Qualification and quality assurance
GPR training – GPR system qualification.

Germany

BAM – Technical Safety test site

General Information

Test Site	**Technical Safety test site**
Country	Germany
Institution	BAM Federal Institute for Materials Research and Testing Division 8.2 – Non-Destructive Damage Assessment and Environmental Measurement Method
Address	Unter den Eichen 87 12205 Berlin
Website	http://www.bam.de
Contact Person	Thomas Kind
E-mail	thomas.kind@bam.de
Tel	+49 30 8104 3225

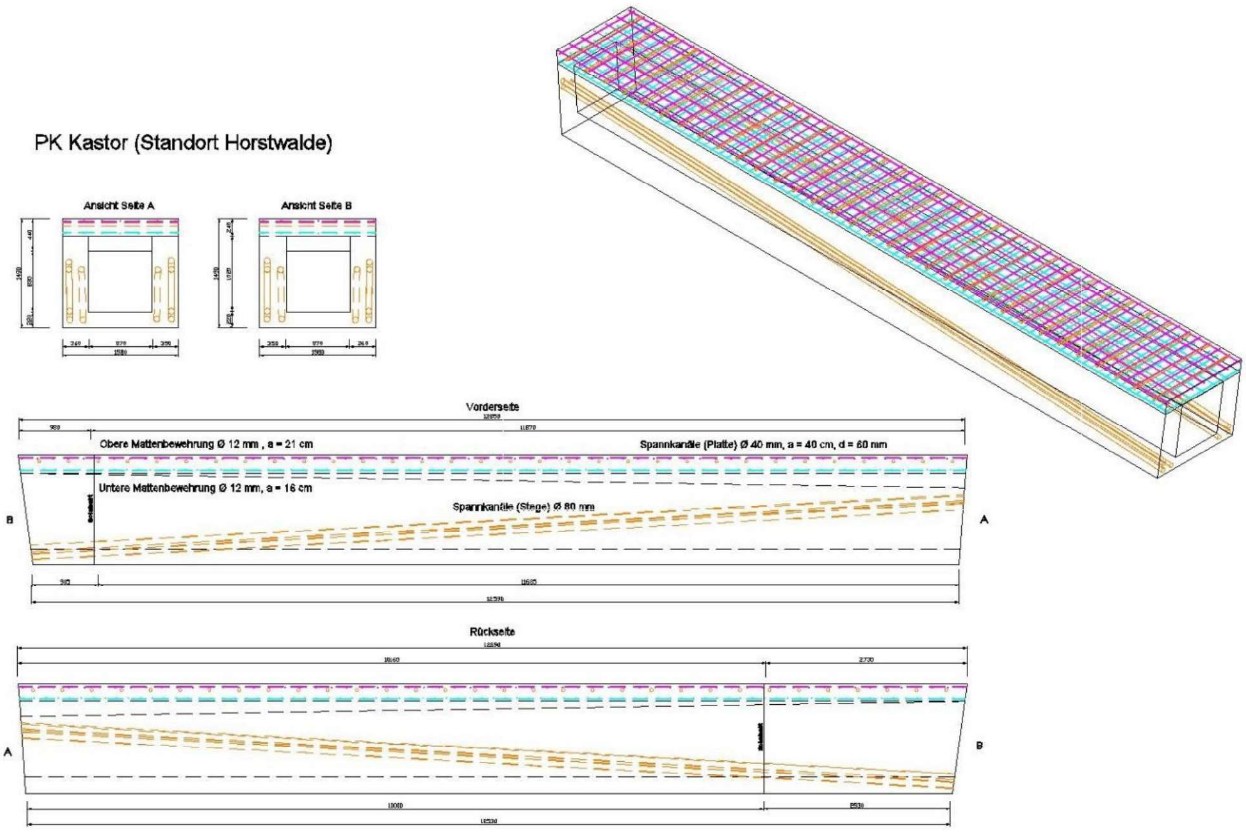
BAM Federal Institute for Materials Research and Testing

Aerial view of the test site.

Technical description

The testing facility is a section of a box-girder of a former prestressed concrete bridge in Berlin (Spandauer Dammbrücke), with reinforcement and tendon ducts. The size of the section is 12 m × 1.6 m × 1.5 m (length × width × height).

Part of a box-girder of a prestressed concrete bridge, called "Castor."



Recent and ongoing research studies

Highway Research Programme (2008-2009) "Demolition Spandau Dam Bridge": Non-destructive testing methods were applied to sections of the demolished bridge, in combination with poor analysis approaches.

GPR and ultrasonic echo measurements for the non-destructive testing of cracks (determination of crack depth and course); measurements were carried out before and after filling the cracks with epoxy resin.

GPR measurements for the detection of tendon ducts.

BAM – Testing hall

General Information

Test Site	**Testing hall**
Country	Germany
Institution	BAM Federal Institute for Materials Research and Testing Division 8.2 – Non-Destructive Damage Assessment and Environmental Measurement Method
Address	Unter den Eichen 87 12205 Berlin
Website	http://www.bam.de
Contact Person	Thomas Kind
E-mail	thomas.kind@bam.de
Tel	+49 30 8104 3225

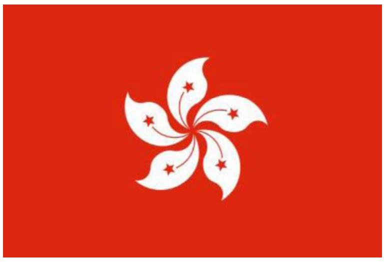
BAM
Federal Institute for Materials Research and Testing

Technical Description

Several test specimens are available. The typical specimen size is: length 1-2 m, width 0.3 - 0.5 m, height 1 - 2 m.

Most specimens are made of concrete and contain reinforcement and tendon ducts. A masonry specimen contains cavities of different size.

Hong Kong



Underground Utility Survey laboratory

General Information	
Test Site	Underground Utility Survey
Country	Hong Kong
Institution	The Hong Kong Polytechnic University
Address	181 Chatham Road South, Hung Hom, Kowloon, Hong Kong.
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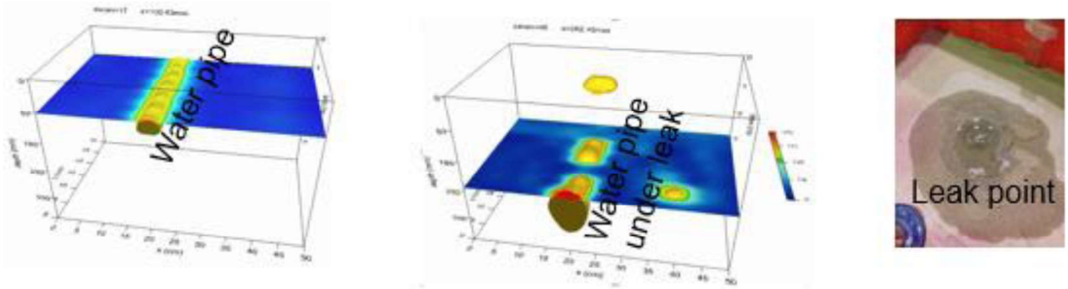
Tel	+85 2 34 00 89 60

Technical Description

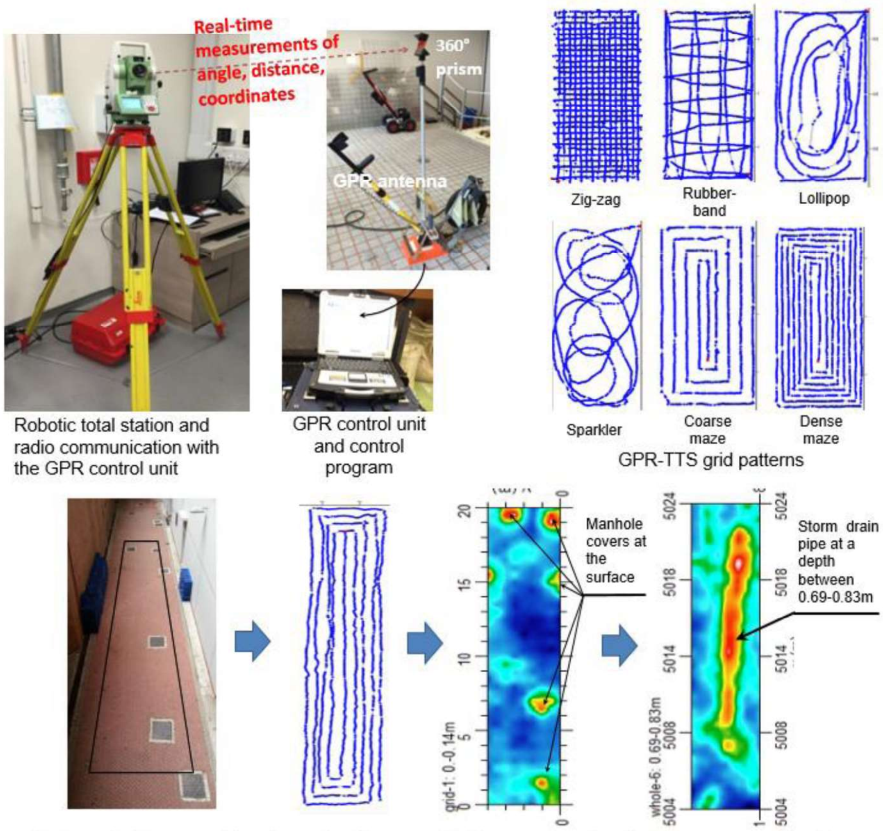
The laboratory occupies a floor area of 73.3 m². Scale-down networks and a matrix consisting of metallic & non-metallic fresh & salt water supply pipes, drainage & sewerage pipes connected with manholes, power cables and gas cables, and valve chambers of various kinds are embedded in a big tank in the lab. These networks of underground utilities and the back-filled soil serve as a scale-down model comparable to actual field conditions.

With focuses on nondestructive positioning, mapping, condition survey and assessment of underground utilities, the utility surveying laboratory provides an ideal control environment for students and practitioners to validate their surveying methods, procedures and capability of survey equipment, as well as training of personnel. In the lab, orientations, sizes, materials and depths of different types of buried utilities, manholes and valve chambers, as well as the properties of the cover materials (soil, asphalt and concrete), were carefully designed and accurately recorded.

Underground utility network before (left) and after backfill (middle) surveyed by nondestructive survey instrument (right).

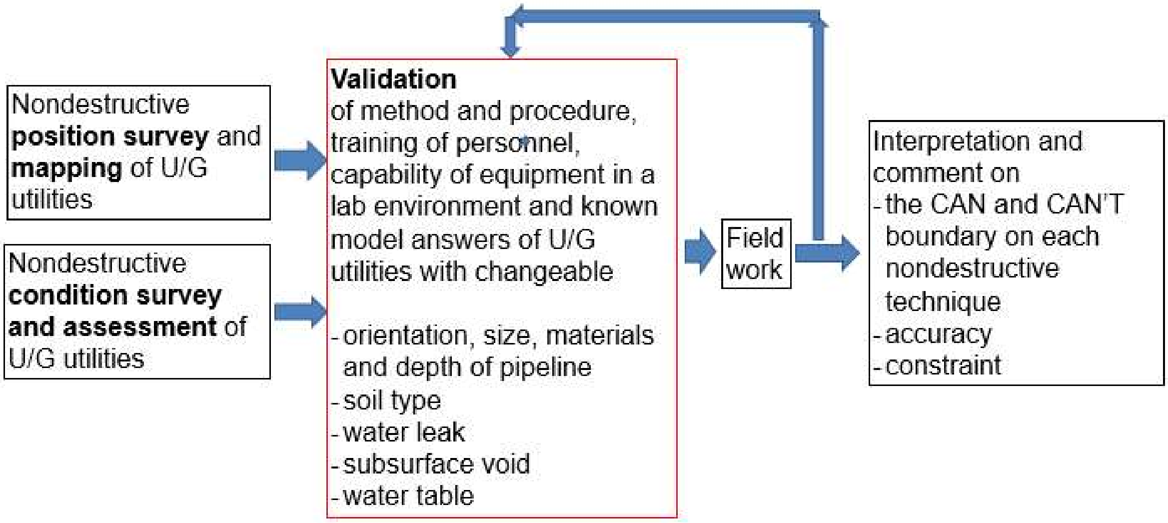


Validation of GPR signal before (left) and after (middle) water pipe leakage (right).



High-resolution carpet imaging of underground drainage network with dense maze grid pattern

Main Ongoing Research Studies

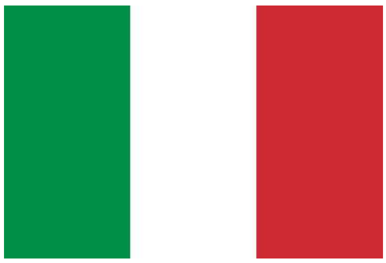


Validation works in underground utility surveying laboratory.

High-resolution carpet imaging of the underground by GPR and auto-tracking total station.

A hybrid GPR and auto-tracking robotic total stations (TTS) system is developed, for high-resolution underground carpet imaging in centimeter level's precision. With such system, coordinates of topographical upward-looking 3D (by TTS) and downward-looking 3D (by GPR) are real-time synchronized. This work studies (1) hardware synchronization between GPR and TTS by self-developed computer programs, (2) development of hardware-software interface, (3) radio communication, (4) signal reconstruction, 2D data processing and 3D imaging and (5) error analysis of positioning. Different irregular grid modes, such as zig-zag, lollipop and maze, were attempted to study the image quality. Precision of centimeter level is achieved with the advent of the developed system which is not possible in traditional GPR imaging relying on sparsely spaced orthogonal grid pattern.

Italy



Concrete Columns Test Site

General Information

Test Site	**CNR-IBAM Lecce**
Country	Italy
Institution	CNR-IBAM National Research Council Institute for Archaeological and Monumental Heritage
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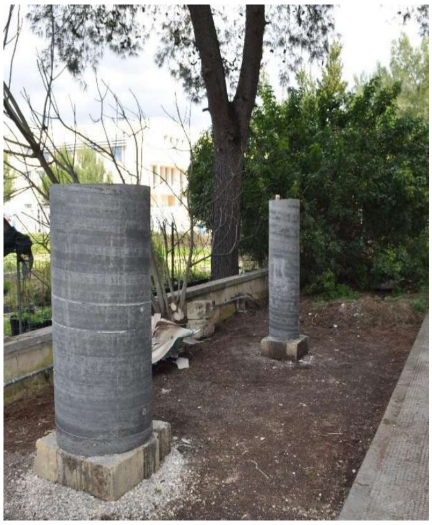
E-mail	r.persico@ibam.cnr.it g.leucci@ibam.cnr.it
Tel	+39 0 832 422 204, +39 0 832 422 223



Technical Description

This is a small test site realized for investigating the use of GPR on curved surfaces, with a curvature ray of the order of the internal wavelength (and therefore not negligible).
The test site consists of two concrete columns. Targets were embedded in the columns at the moment of construction. In particular, the targets were accurately positioned within two cylindrical empty cartons; then, liquid concrete was inserted slowly and in small progressive quantities, in order not to alter the initial target positions. Most targets were rigid, but one of them was not, and so its final position might be slightly different than projected. The targets are aimed to model fractures, elements inserted for restoration and detachments. Both columns are 150 cm high, whereas their radiuses are 35 cm and 20 cm.
The test site can be used for comparative tests of equipment and for validation of processing algorithms.

The column with radius 35 cm before the casting of liquid concrete.

The column with radius 20 cm before the casting of liquid concrete.

Main Ongoing Research Studies

Measurements were carried out, with an automatic system for the positioning of the antennas along the vertical direction, for any fixed angle, as well as along the circumference of the column, at any height from 0 to 2 m. Processing of the data was performed with an inverse scattering algorithm accounting for the curvature of the surface. This work was carried out within the research project PROMETEOS, funded by the Puglia Region.

References:

G. Gennarelli, F. Soldovieri, G. Leucci, R. Persico, Investigation of columns by means of GPR equipments, Proc. GNGTS Conference, Trieste, Italy, November 14-16 2017.

R. Persico, G. Leucci, G. Quarta, M. De Donatis, G. Gennarelli, F. Soldovieri, "Sistema GPR per la prospezione di Colonne", Italian Patent n. 0001428337 of April 24th 2017.

N. Masini, R. Persico, E. Rizzo, A. Calia, M.T. Giannotta, G. Quarta, A. Pagliuca, "Integrated Techniques for Analysis and Monitoring of Historical Monuments: the case of S.Giovanni al Sepolcro in Brindisi (Southern Italy)." Near Surface Geophysics, vol. 8 (5), pp. 423-432, 2010.

G. Leucci, R. Persico, F. Soldovieri, "Detection of Fracture From GPR data: the case history of the Cathedral of Otranto", Journal of Geophysics and Engineering, vol. 4, pp. 452-461, 2007.

Hydrogeosite Full-Scale Laboratory

General Information	
Test Site	**Hydrogeosite**
Country	Italy
Institution	CNR-IMAA National Research Council Institute of methodologies for environmental analysis
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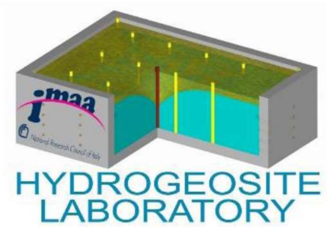
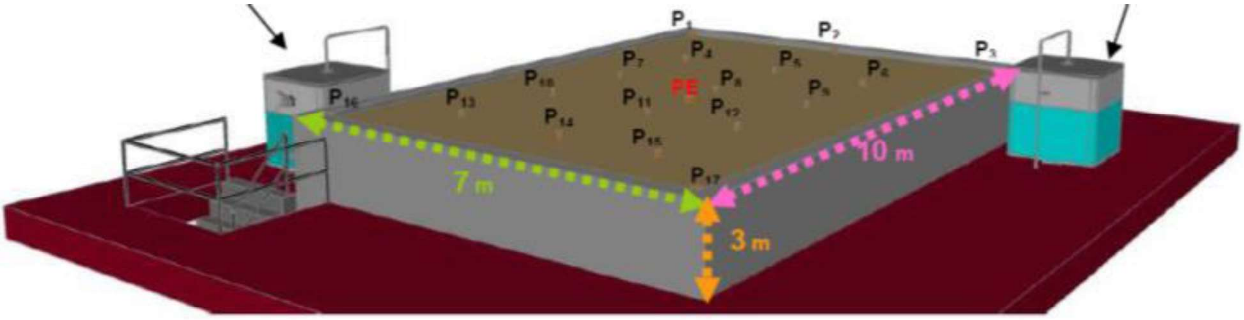
Contact Person	Enzo Rizzo
E-mail	enzo.rizzo@imaa.cnr.it
Tel	+39 0 971 42 74 02



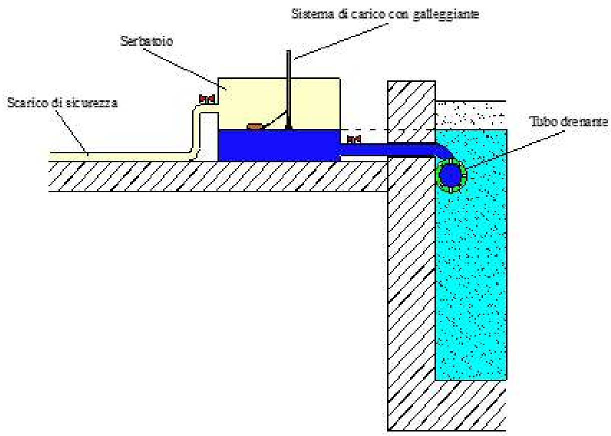
Hydrogeosite full-scale laboratory

Technical Description

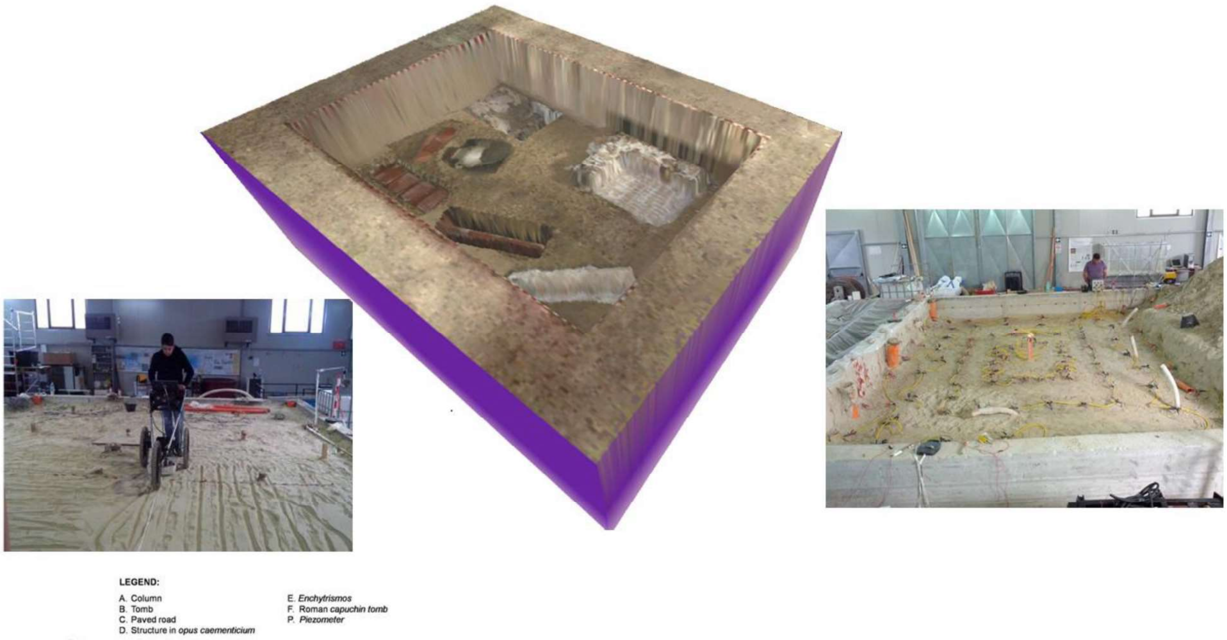
The "Hydrogeosite" is a controlled large pool-lab-scale facility for hydro-geophysical experiments and its realization was partially supported by Italian Ministry of Scientific Research (MIUR – D.M. n.1105 del 09/10/2002). It consists of a pool of 210 m^3 (10 m × 7 m × 3 m) completely covered with a steel shed. Using a regular grid of 64 close holes, it is possible to take samples and/or to install sensors without disturbing the surface of soil. The pool-laboratory is actually filled with a porous media, which has the following characteristics homogeneous siliceous sand (95% of SiO2), which has a 87% percent of granulometry between 0.063 mm to 0.125 mm and a permeability in the order of 10-5 m/s. The pool-laboratory is arranged with a reservoirs system which determines the saturation of the sand to a desired height by means of a connection to a draining pipes "ring" set along the internal perimeter of the pool connected to two inlet/outlet tanks, enables fixed head boundary conditions to be obtained (fixed or variable with time) or no flow condition depending on the configurations required during the experiment. Moreover, the pumping well is equipped with an external peristaltic-type pump, while the water level is controlled by pressure-sensing transducers. There are also sensors and equipment to collect geophysical parameters, such as electrical resistivity tomography, self potential, ground penetrating radar.



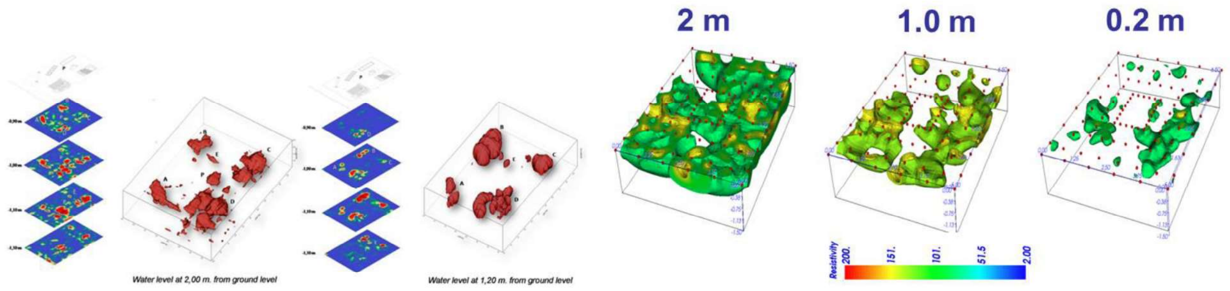
Hydraulic drainage system.



Water Tank.



Hydrogeosite experiment: archaeological site in saturated media.



Different depths of water table.

Main Recent and Ongoing Research Studies

Completed Research program (2008-2012) FP7 Model Probe - Model driven Soil Probing, Site Assessment and Evaluation.

Completed Research program (2009-2012) FP7 ISTIMES - Integrated System for Transport Infrastructures surveillance and Monitoring by Electromagnetic Sensing.

Completed Research program (2014-2015) Scoprire senza scavare, la geofisica a servizio dell’archeologia, Progetto ScSArchGeo (PO FERS – Basilicata Region).

References:

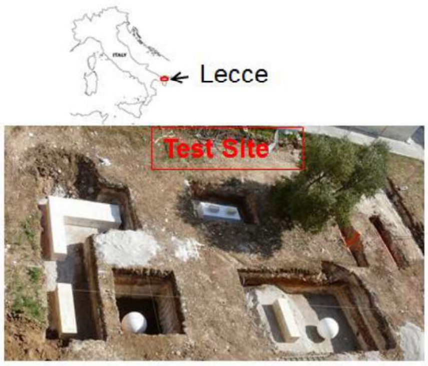
Capozzoli L., Colaiacovo R., Giampaolo V., Parisi S., Rizzo E. Near surface geophysical techniques for contaminated groundwater: laboratory experiments. 42nd IAH Congress - AQUA 2015 - Rome, 13-18 September, 2015.

Capozzoli L., Caputi A., De Martino G., Giampaolo V., Luongo R., Perciante F., Rizzo E. Geophysical-archaeological experiments in controlled conditions at the Hydrogeosite Laboratory, 43rd Computer Applications and Quantitative Methods in Archaeology CAA Siena 2015.

Straface S. and Rizzo E. The Importance of Reduced-Scale Experiments for the Characterization of Porous Media", Handbook in Environmental Chemistry. Threats to the Quality of Groundwater Resources: Prevention and Control. Springer-Verlag, Volume 40, 2016, pp. 151-174, 2016.

Laboratory of Applied Geophysics, University of Salento

General Information	
Test Site	**Laboratory of Applied Geophysics**
Country	Italy
Institution	University of Salento
Address	Via Monteroni 73100 Lecce
Website	http://www.unisalento.it
Contact Person	Sergio Negri
E-mail	sergio.negri@unisalento.it
Tel	+39 0832 29 70 89



Technical Description

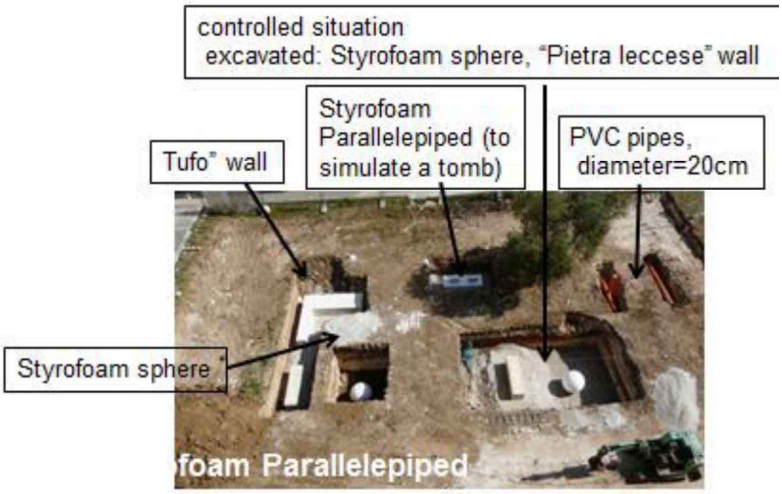
The test site area is located inside the University od Salento campus, along the Lecce-Monteroni route, and it is about 2000 m² wide. In order to simulate subsurface archaeological, environmental and engineering targets, several objects of different materials and geometries have been buried in the subsurface. Moreover, a wall with different construction techniques, both ancient and modern, has been built.

The main goal of the test site is to offer the opportunity to the scientific community to investigate the potentiality of their GPR systems. The test site is also available to test other new or existing geophysical instruments and verify their target detection capability, both in terms of data acquisition strategy and signal processing effectiveness.

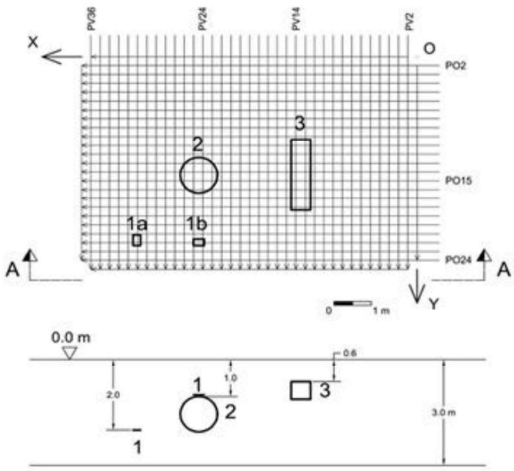
With this test site we wish to foster the interaction between private companies and academic world.

Finally, the test site has a strong educational value, giving the opportunity to students of different levels (undergraduate) to verify the accuracy of various method in detecting and estimating depth, size and nature of a target buried in the near subsurface.

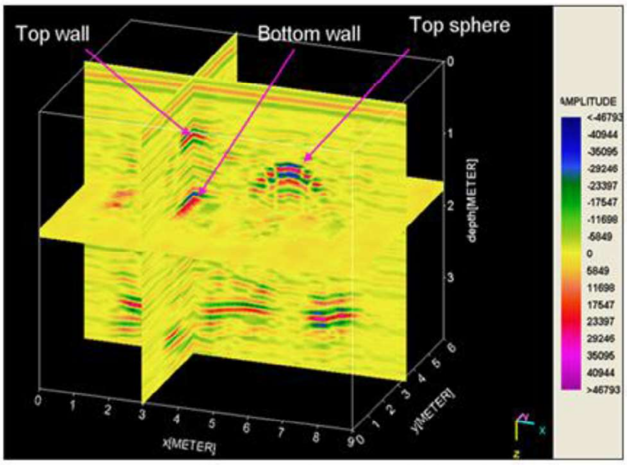
small building



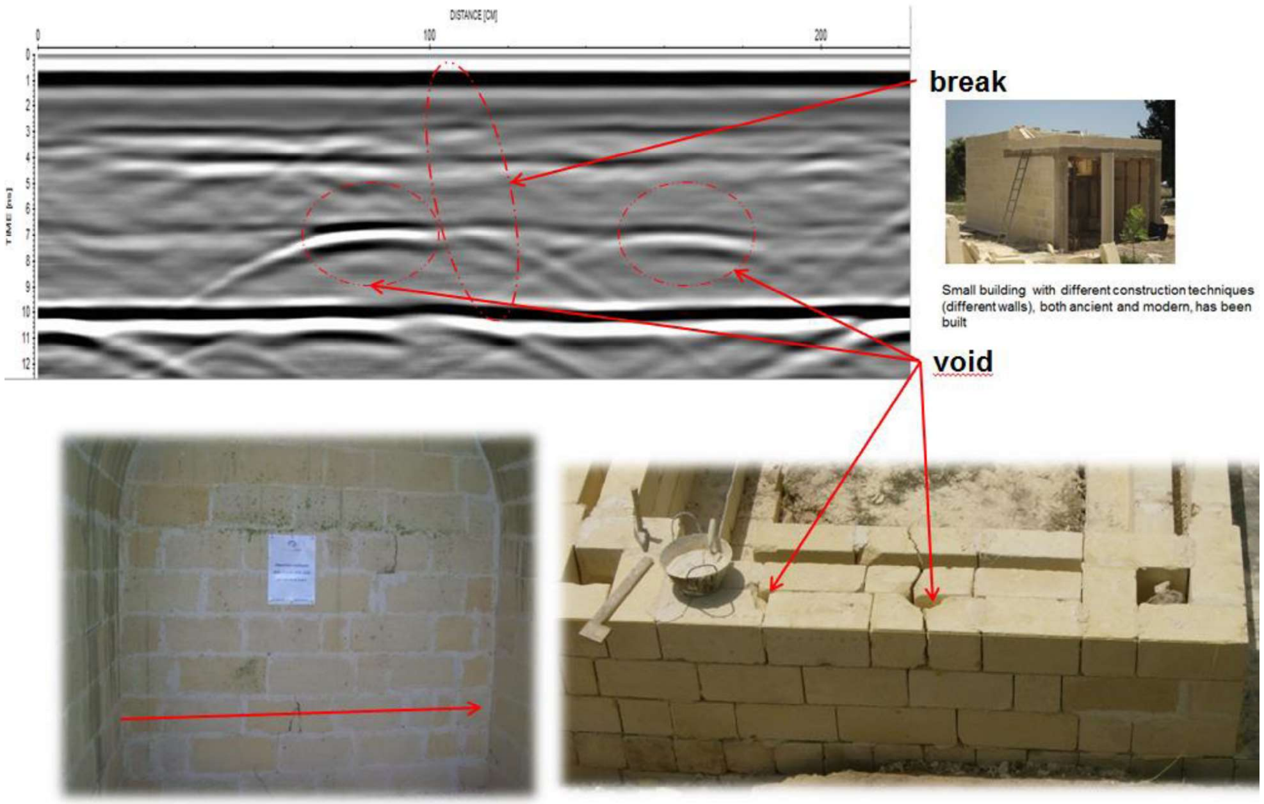
Metal barrel



Section A-A
Survey line grid; 1°, 1b: metal sheet;
2: Styrofoam sphere; 3: Pietra leccese wall



GPR data volume 3D (migrated data).
Cats: x=3m, y=3.25m, z=31.09 ns



References

S. Negri and T.A.M. Quarta; Ground penetrating radar survey for civil-engineering applications: Results from the test site. 2012 14th International Conference on Ground Penetrating Radar, GPR 2012, Pages 835-839.

S. Negri, T.A.M. Quarta, G. Moroni. GNGTS – 34° Convegno Nazionale Trieste, 17-19 Novembre 2015.

Laboratory of Humanitarian Demining

General Information

Test Site	**Laboratory of Humanitarian Demining**
Country	Italy
Institution	Sapienza University of Rome
Address	Cisterna di Latina, Lazio
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E-mail	marco.balsi@uniroma1.it
Tel	+39 0 6 44 58 53 76

LABORATORIO di SMINAMENTO UMANITARIO

SAPIENZA UNIVERSITÀ DI ROMA

Technical Description

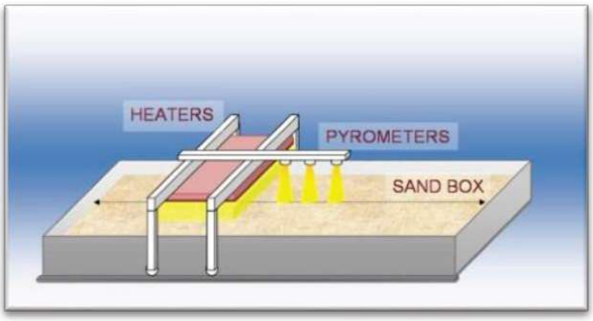
The Humanitarian Demining Laboratory (HDL) is managed by the Department of Information Engineering, Electronics and Telecommunications (DIET) of Sapienza University of Rome; it is funded by the Local Council of Cisterna di Latina and by "Tecnologie Solidali Onlus".

A computer-controlled cart can move over a 2.6 m^3 sand box, holding heaters and pyrometers see Figure. An outdoor "minefield" has also been realized.

The sandbox is 3.5 m long, 1.3 m wide, and 0.5 m deep, filled with river sand. In the sandbox six different objects were buried: two TS-50 APM low-metal-content mine surrogates produced by C-King Associates Ltd, a cylindrical block of beeswax (with similar shape and size as the APM but without any air gaps, to simulate the effect of the explosive bulk of the mine alone), an empty plastic container (to simulate the APM air gap), a rock, and finally an iron hammer head.

The computer-controlled cart runs, at constant velocity, on two rails; it is moved by two motors coupled by rack wheels and controlled by a microcontroller communicating via a radio link with a computer. The cart carries four infrared heaters and three pyrometers. Each heater has 500 W power. It has rectangular shape (123 mm (a) × 60 mm (b)), and radiates quite uniformly over an area slightly larger than its size. Each heater can be switched independently and all heaters form a compound of 60×500 mm. At full-power (500 W × 4 = 2 kW) the system delivers about 70 kW/m^2, i.e., two orders of magnitude stronger than the maximum solar radiation.

The pyrometers are contactless infrared thermometers with a temperature range (-20°C +350°C) and a resolution of 0.1°C, connected to the computer by USB cables and equipped with proprietary data acquisition GUI. While the cart scans the sandbox, at controlled speed, the data collected by the pyrometers are stored and visualized on the computer.



Main Ongoing Research Studies

The main purpose of the Sapienza research team working in this Laboratory is to develop new anti-personnel mine detection devices. Experimental activities were carried out by using a promising and novel active thermal technology, based on localized heating and sensing. Moreover, electromagnetic simulations of the sand box were performed by using an in-house finite-difference time-domain solver and compared to real data collected by a GPR. Experiments were carried out by using vibrometric/acoustic techniques. The development of a multi-sensor platform is under study.

GRS-Lab Geophysical test site – ITABC

General Information

Test Site	**ITABC CNR**
Country	Italy
Institution	CNR-ITABC National Research Council Institute for Technologies Applied to Cultural Heritage
Address	Area della Ricerca CNR Roma1, Via Salaria Km 29,300, Montelibretti, Roma
Website	http://www.itabc.cnr.it
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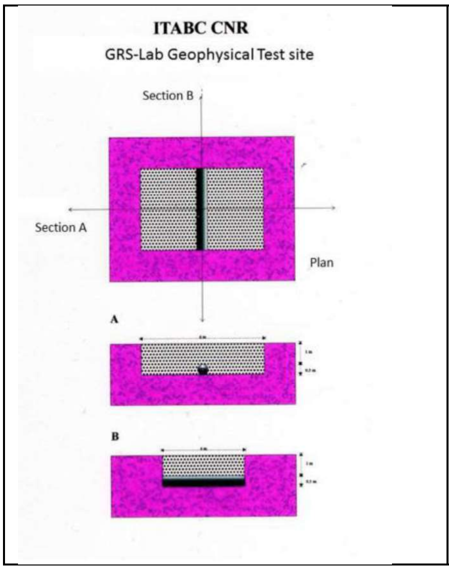
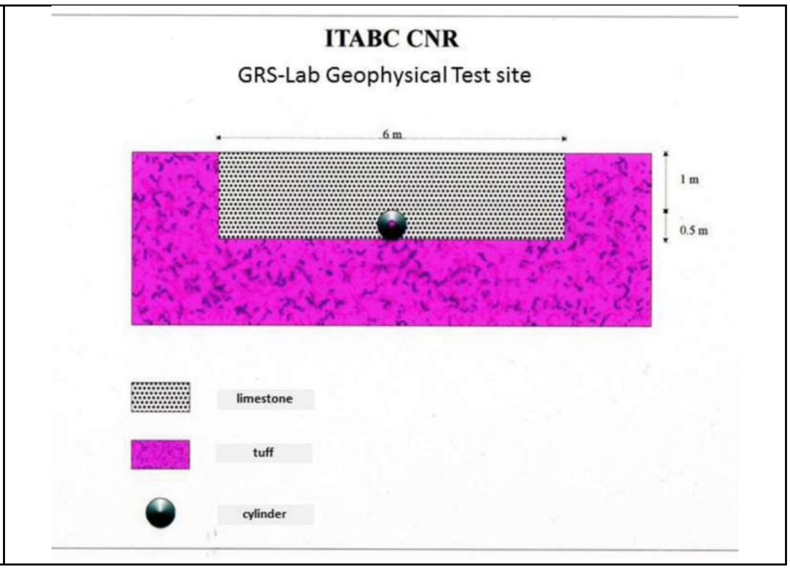
E-mail	salvatore.piro@itabc.cnr.it
Tel	+39 06 90 67 23 75

Technical Description

The GRS-Lab test site consists of two pits excavated in the tuff layer, close the building of ITABC institute. Inside the two pits there are two metallic (alluminium) targets with different geometrical shapes. The pits have the following dimenions: 6 m × 4 m × 1.5 m and 4 m × 4 m × 1.5 m. The metallic targets are a cilinder with dimension 4 m × 0.5 m and a sphere with diameter of 0.5 m. These are located in the middle of the pits at the depth of 1 m from the surface.
The test sites was realised in 1992 to study the characteristic of the reflected GPR impulse in the case of metallic targets. Two pits are full of lime limestone, to have a high contrast between the natural soil characterised by tuff layer (with low resistivity average value of about 40 Ohm / m) and the high resistivity value of the limestone (more than 300 Ohm / m).
The experimental site is frequently used to test geophysical instruments as GPR (single and multichannel systems), gradiometer and ERT.





References:

Bernabini M., Pettinelli E., Pierdicca N., Piro S., Versino L., 1992. Field experiments for characterization of GPR antenna and pulse propagation. Journal of Applied Geophysics, special issue on GPR Vol.33 (1995), pp 63-76.

Piro S., Rosso F., Versino L., 1996. Experimental tests for characterization of the GPR pulse using different antennae configurations. Detection of shallow-depth bodies and archaeological structures. Archaeological Prospection, Vol. 3, n.2, pp.89-105.

Pierdicca N., Piro S., 1997. Experiments for the characterization of GPR pulse propagation in the ground. 1th International EMEMACH, Ostuni.

Pierdicca N., Piro S., 1998. Analysis of GPR pulse response from experimental and archaeological test sites. XXIII General Assembly of EGS, session Archaeological Prospection. Annales Geophysicae, Suppl. I, Vol. 16, pp. C227.

Japan

The test sites for borehole radar in Osaka electro-communication University

General Information	
Test Site	**Neyagawa campus** **Shijonawate campus**
Country	Japan
Institution	Osaka electro-communication University
Address	Neyagawa campus: 18-8 Hatsucho, Neyagawa-shi, Osaka 572-8530 Shijonawate campus: 12-16 Hayakocho, Neyagawa-shi, Osaka 572-0837
Contact Person	Satoshi Ebihara
E-mail	ebihara@osakac.ac.jp
Tel	+81 72 824 11 31
Fax	+81 72 824 00 14

Technical Description

Neyagawa campus

The test site in Neyagawa campus is located at lat. 34°45′37″ N. and long. 135°37′40″ E. Three boreholes were drilled there. The test site is composed of wet soil. The estimated average relative permittivity of the medium is about 24, and we may interpret the medium as a highly lossy one. Figure 1 shows the location of the boreholes. As shown in Figure 2, the entrances of three boreholes are on one line on the ground surface. Figure 3 shows two views of the boreholes. The blue-colored layer is composed of clay, while the orange-colored one is composed of sand mainly. Table 1 shows the properties of the boreholes 1-3. We used these boreholes in the experiments which results are presented in [1] and [2].

Shijonawate campus

The test site in Shijonawate campus is located at $34°44'24''$ N. and long. $135°39'30''$ E. Figure 4 shows the location of the three boreholes, which are named BR1-3. These boreholes are drilled in a parking lot in Shijonawate campus. The test site is composed of granite. Figure 5 shows the cross section of BR1 and BR2. The layer below the depth of about 5 m is composed of granite. The groundwater level is at a depth of about 9 m. Two faults cross the boreholes. The borehole properties are in Table I. We used these boreholes in the experiments which results are presented in [3] and [4].

Fig. 1 - The test site in Neyagawa campus in Osaka electro-communication University. The red arrow indicates the location of the boreholes.

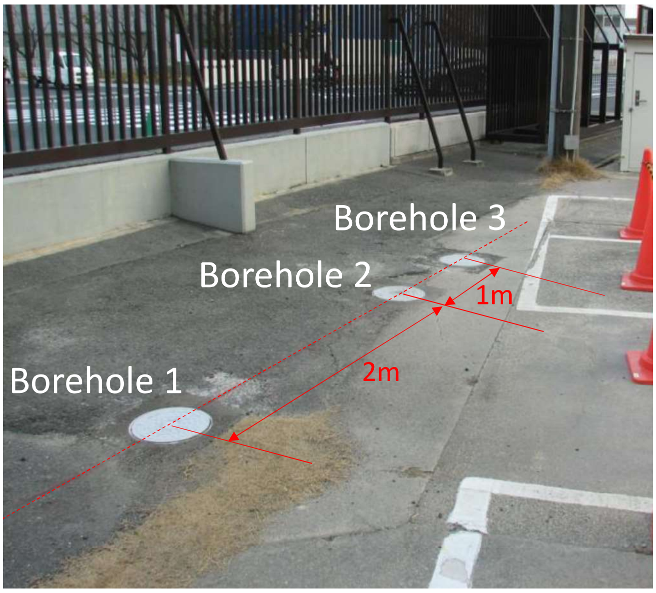


Fig. 2 - The entrances of the three boreholes in Neyagawa campus.

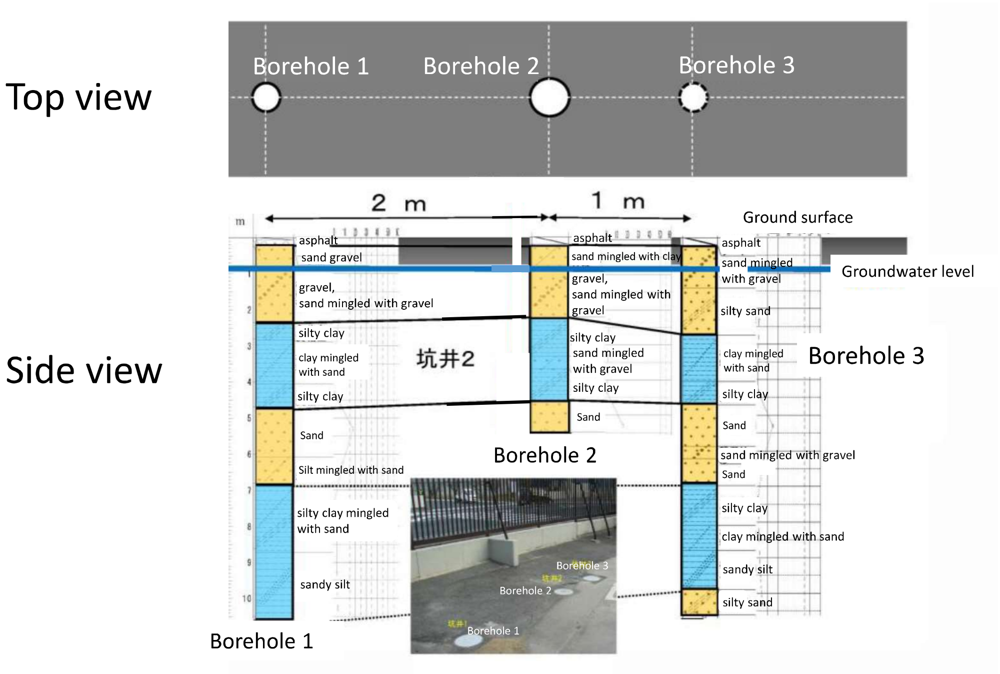


Fig. 3 - The views of the three boreholes in Neyagawa campus.

Fig. 4 - The entrances of the three boreholes in Shijonawate campus.

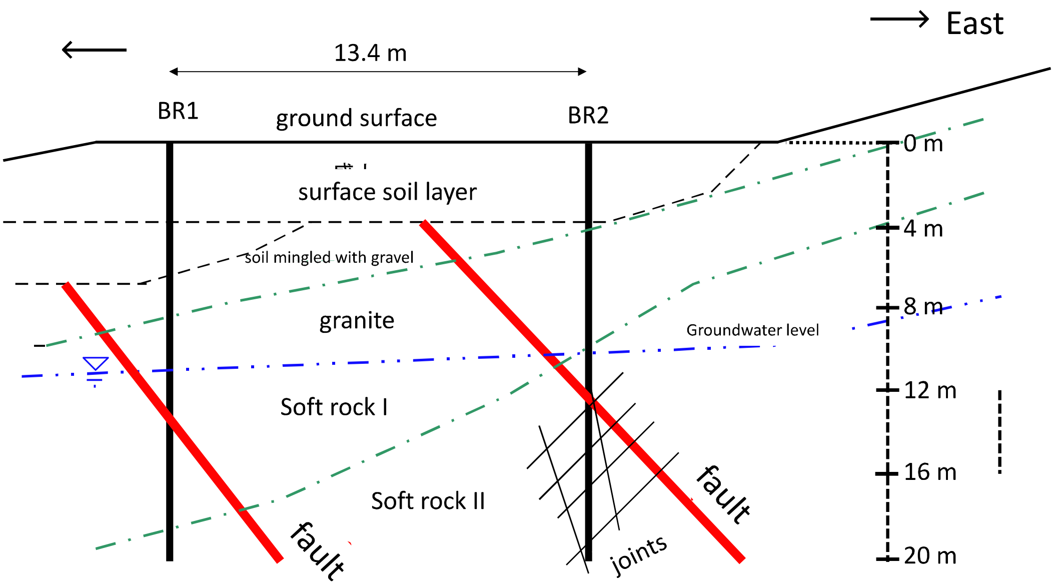


Fig. 5 - The cross section of the test site in Shijonawate campus.

Tab. I - Properties of the boreholes

No.	Borehole name	Location	Borehole diameters	Casing	The maximum depth of the boreholes
1	Borehole 1	Neyagawa	67 mm	Boreholes cased by a polyvinyl chloride pipe	10 m
2	Borehole 2		10 cm		5 m
3	Borehole 3		67 mm		10 m
4	BR1	Shijonawate	10 cm		20 m
5	BR2		10 cm		20 m
6	BR3		77 mm		20 m

References

[1] S. Ebihara, K. Wada, S. Karasawa, and K. Kawata, "Probe rotation effects on direction of arrival estimation in array-type directional borehole radar," Near Surface Geophysics, vol. 15, no. 3, pp. 286-297, 2017.

[2] S. Ebihara, T. Kuroda, Y. Koresawa, K. Inada, A. Uemura, and K. Kawata, "Improved Discrimination of Subsurface Targets Using Polarization-sensitive Directional Borehole Radar," IEEE Transaction on Geoscience and Remote Sensing, vol. 54, no. 11, pp. 6429 – 6443, 2016.

[3] S. Ebihara, Y. Kimura, T. Shimomura, R. Uchimura, and H. Choshi, "Coaxial-fed Circular Dipole Array Antenna with Ferrite Loading for Thin Directional Borehole Radar Sonde," IEEE Transaction on Geoscience and Remote Sensing, vol. 53, no. 4, pp. 1842 – 1854, 2015.

[4] S. Ebihara, H. Hanaoka, T. Okumura, and Y. Wada, "Interference Criterion for Coaxial-Fed Circular Dipole Array Antenna in a Borehole," IEEE Transaction on Geoscience and Remote Sensing, vol. 50, no. 9, pp. 3510 – 3526, Sep. 2012.

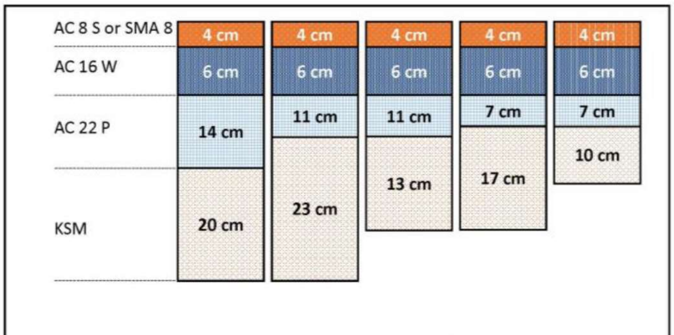
Poland

Reference Asphalt Pavement Constructions

General Information	
Test Site	**Reference asphalt pavement constructions**
Country	Poland
Institution	Road and Bridge Research Institute
Address	03-302 Warsaw 1, Instytutowa str.
Website	http://www.ibdim.edu.pl/
Contact Person	Lech Krysiński
E-mail	lkrysinski@ibdim.edu.pl
Tel	+48 22 39 00 208

Technical Description

The test site consists of 5 sections (20 m long) adhering to Polish standards for road structures. The sections have a flexible asphalt pavement, including three asphalt layers and an aggregate subbase. The test site is located in a quiet and safe area of the Institute. The test site properties are well documented and the layer thicknesses were built with centimetre precision.



Total asphalt thickness cm	24	21	21	17	17
Displacement µm	246	268	286	329	347
Traffic Category	KR4/5	KR4	KR3/4	KR3	KR3

Main Ongoing Research Studies
GPR and FWD measurements were performed on the test site.

Spain

Melide (Galicia)

General Information

Test Site	**Melide (Galicia)**
Country	Spain
Institution	University of Vigo & Extraco S.A.
Address	42°53'33.2"N 8°00'48.1"W 15809 Melide, Galicia, Spain
Contact Person	Mercedes Solla
E-mail	merchisolla@uvigo.es
Tel	+34 699 419 032

Technical Description

The experimental zone was divided into four grids 3x3 m in size, each grid containing a different type of asphalt concrete (AC 22 surf G, AC 16 surf S, AC 16 surf D and BBTM 11B), with different material compositions.

The following table describes the asphalt concrete mixes considered and the proportions of their main components.

		Asphalt concrete mixes			
		AC 22 surf G	**AC 16 surf S**	**AC 16 surf D**	**BBTM 11B**
Components	Aggregates	9%: 18-25mm 21%: 12-18mm 26%: 6-12mm 41%: 0-6mm	10%: 12-18mm 40%: 6-12mm 47%: 0-6mm	8%: 12-18mm 31%: 6-12mm 58%: 0-6mm	69%: 6-12mm 27%: 0-6mm
	Filler	3%	3%	3%	4%
	Bitumen (50/70)	3.8%	4.5%	4.8%	5.1%
	Voids	5%	6%	5.5%	13.5%
	Density	2.05 Tn/m^3	2.55 Tn/m^3	2.58 Tn/m^3	2.10 Tn/m^3

Four different cracks 3 mm width were simulated into each grid by considering different depths ranging from 1.5 to 5.5 cm.

Available equipment, with main specifications
Malå GPR CUII and ProEX systems with ground-coupled antennas (2.3 GHz, 1 GHz, 800 MHz and 500 MHz).

Structures/materials/methods that can be tested
GPR antennas, GPR software.

Quantities/characteristics that than be tested
Accuracy of crack detection and depth, dielectric constant of different asphalt concrete and asphalt concrete thicknesses.

Materials: different types of asphalt: AC 22 Surf G, AC 16 Surf S, AC 16 Surf D, BBTM 11B.

Technical characteristics: two layers with known thickness. Cracks with known depth.

Results available for malå ground-coupled GPR system. Frequencies: 2.3 GHz, 1 GHz, 800 MHz, 500 MHz.

Main Ongoing Research Studies

This test site was built from the companies Misturas S.A. and Extraco S.A. for the SITEGI project (IDI-201001770), financed by the Spanish Centre for Technological and Industrial Development.

GPR and thermographic measurements were performed in the test site, and the results obtained were published on the following scientific paper:

M. Solla, S. Lagüela, H. González-Jorge, P. Arias. Approach to identify cracking in asphalt pavement using GPR and infrared thermographic methods: Preliminary findings. NDT&E International 62 (2014) 55-65.

Allariz (Galicia)

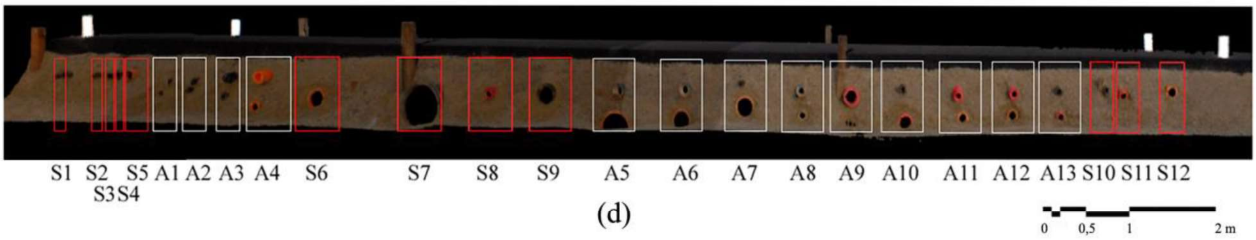
General Information	
Test Site	**Allariz (Galicia)**
Country	Spain
Institution	University of Vigo & Misturas
Address	42°12'15.8''N 7°47'30.9''W 32669 Allariz, Galicia, Spain
Contact Person	Mercedes Solla
E-mail	merchisolla@uvigo.es
Tel	+34 699 419 032

Grupo de investigación Xeotecnoloxías Aplicadas
Universida de Vigo
MISTURAS

Technical Description

An experimental zone was designed including meaningful real-life pipeline layouts. The entire scene was 14x1 m size, which was composed of three pavement layers: 75 cm of sub-base course (compacted aggregate ZA 20), 10 cm of intermediate course (AC 22 S asphalt), and 5 cm of surface course (AC 16 S asphalt).

Several types of pipes were considered, namely: diameters ranging from 25 to 315 mm and coverings (concrete, ductile iron, polyethylene pipes or PVC, polyethylene, polypropylene and Nylon). Additionally, several depths and combinations were probed to understand the influence of the vertical proximity for detection in terms of resolution. Different horizontal separations between pipes were also considered for testing.



(d)

The experimental site was built to analyze the effects of different depths, materials and proximity or overlapping in both horizontal and vertical directions on the radar-wave signal in order to characterize it and analyze its capability to detect, locate and distinguish different types of piping in subsoil.

Regarding the configuration of the GPR system, four antenna frequencies and different parameters settings (total time window, spatial sampling interval, etc.) were tested, which influence the penetration and resolution of the GPR signal and its effectiveness in detection.

The table reported in the following page describes the materials, diameters (cm) and depths (cm) employed in the pipe layout, as well as the combinations used to analyze the effect of aliasing in vertical distance.

Available equipment, with main specifications
Malå GPR CUII and ProEX systems with ground-coupled antennas (2.3 GHz, 1 GHz, 800 MHz and 500 MHz).

Structures/materials/methods that can be tested
GPR antennas, GPR software.

Quantities/characteristics that than be tested
Accuracy of detection depending on covering and setting parameters, range of penetration, spatial resolution and antenna orientation.

Pipes	Z	Ø	MAT	Aliasing	Z	Ø	MAT
S1	45	2.5	PUR	***A1***	30	2.5	PUR
					45		
S2	30	2.5	PUR	***A2***	30	4	PUR
					45		
S3	30	4	PUR	***A3***	30	7.5	PUR
					50		
S4	30	7.5	PUR	***A4***	30	11	PA
					60		
S5	30	11	PVC	***A5***	30	12.5	DI
					70	31.5	PVC
S6	50	20	PVC	***A6***	30	12.5	DI
					60	20	PVC
S7	55	50	C	***A7***	25	4	PUR
					50	20	PVC
S8	40	9	PP	***A8***	30	10	DI
					55		DI
S9	45	20	PUR	***A9***	30	16	PP
					60	6.3	PUR
S10	30	6.3	PUR	***A10***	30	6.3	PUR
					60	16	PP
S11	30	9	PP	***A11***	35	9	PP
					50	11	PA
S12	30	11	PA	***A12***	30	9	PP
					50	11	PA
				A13	30	6.3	PUR
					50	9	PP

Main Ongoing Research Studies

This test site was built from the companies Misturas S.A. and Extraco S.A. for the SITEGI project (IDI-201001770), financed by the Spanish Centre for Technological and Industrial Development.

GPR and thermographic measurements were performed in the test site, and the results obtained were published on the following scientific paper:

F.J. Prego, M. Solla, I. Puente, P. Arias. Efficient GPR data acquisition to detect underground pipes. NDT&E International 91 (2017) 22-31.

EUETIB Laboratory test site/field site

General Information	
Test Site	**Laboratory test site/field site**
Country	Spain
Institution	EUETIB and Geotechnical Engineering and Geo-Sciences department (Universitat Politècnica de Catalunya) UPC
Address	c/ Urgell 187, 08036 Barcelona
Website	www.euetib.upc.edu
Contact Person	Vega Perez Gracia
E-mail	vega.perez@upc.edu
Tel	+34 93 41 37 333 +34 93 41 37 403 +34 93 40 17 257

Technical Description

We have not a test site. However, we work with small specimens in two laboratories and also we prepare field test sites in soils and sand. The specimens are prepared in boxes. The maximum boxes size is 1.5 m × 0.75 m × 0.4 m. In some cases, we test structural members in laboratory (columns or walls).

Laboratory 1: (laboratorio de geofísica aplicada): placed in the Campus Nord of the Technical University of Catalonia.

Laboratory 2: (laboratorio de resistencia de materiales): placed in the Campus Urgell of the Technical University of Catalonia.

In both labs we can prepare specimens using gravel, sand or soil. We have PVC tubes of different diameter, rebar and metallic tubes to define different targets configuration. It is possible to evaluate interference effects in reflections ocurred in the targets. Also backscattering is defined, to simulate results from real test sites.

Available equipment, with main specifications

RAMAC radar with ground-coupled antennas (250 MHz – 800 MHz – 500 MHz – 1600 MHz centre frequencies) and one RTA antenna (25 MHz).
GSSI SIR-3000 radar system with ground-coupled antennas (100 MHz, 200 MHz, 400 MHz, 500

MHz, 900 MHz, 1600 MHz and 2000 MHz), one bistatic antenna (15 - 80 MHz) and one borehole antenna (100 MHz)

Other available geophysical equipment that could be combined with GPR in test sites of in workfields: Optim 24cannels, LAN-XI type 3053 B&K module, 20 piezoelectric B&K accelerometers, 3 PCB piezotronics accelerometres, Lennarz 3D/20 seismometer, OhmMapper Capacity coupled resistivity meter, Video endoscopy AndroV55100, Termography camera NEC 100.

Structures/infrastructures/materials that can be tested

NDT simple systems using high frequency antennas (detection of shallow tubes with different materials, inside soil or sand, changes in water content, coupling signals produced in close reflectors, ...). Backscattering

Quantities/characteristics that can be tested

Wave travel time to evaluate water content or compaction, Spatial resolution, Backscattering amplitude...

Uncertainty/reliability of the results

Accuracy depends on the tested sample. However, in the case of tests performed in small containers, boundary effects are important feature.

Recent and Ongoing Research Studies

1) Ongoing research project: 'New developments in geophysics and engineering applied to seismic risk assessment (NAGIARS)'. Part of this project is focused in GPR applications (building inspection and ground assessment). Hence, several tests are developed to determine GPR resolution and backscattering effects in the changes of materials (photographs show the different materials configurations in the test samples, and resistivity measurements during those tests)

2) Building assessment (workfield tests): wooden structures, damages… Possible interesting tests could be associated to detection of changes in wooden members.

3) Columns inspection (workfield tests and structrual members test in laboratory): the inspection of one masonry column that was also tested in a structures laboratory using destructive testing (compression test). Previously, the column was evaluated by means of GPR, seismic and endoscopy. Photographs show different parts of the inspection in workfield tests (a) and laboratory tests (b).

(a) Workfield tests (GPR inspection and seismic tomography)

(b) Laboratory tests

Ukraine

Test Site for Geophysical Researches

General Information

Test Site	**Test Site for Geophysical Researches**
Country	Ukraine
Institution	Transient Technologies LLC, Taras Shevchenko National University of Kyiv
Address	Ukraine, Kyiv, Vasilkovskaya 90
Website	www.viy.ua
Contact Person	Volodymyr Ivashchuk
E-mail	ive@viy.ua
Tel	+38 0 44 24 08 594 +38 0 50 46 28 594

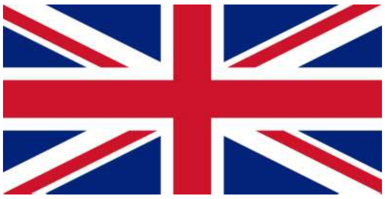
Technical Description

The test site consists of two sections.

The first section has a length of 7 m, width of 2,5 m and depth of 4 m. It is filled with sand. Various dielectric and metallic object are buried at different depths.

The second section has a length of 6 m, width of 4,5 m, depth from 0 to 4 m. The bottom of the pit was paved with metal sheets. The pit was filled with large granite rubble. At different depths in the rubble various metal pipes are buried, 40 cm to 45 cm long.

United Kingdom



Test Site of the Near Surface Geophysics Group (NSGG) of the Geological Society of London

General Information

Test Site	**NSGG**
Country	United Kingdom
Institution	Geological Society of London
Address	Southmeads Road, Oadby, Leicester, UK
Website	http://www.nsgg.org.uk/test-sites/
Contact Person	Christopher Leech
E-mail	chris@eurogpr.org
Tel	+44 0 152 538 3438

NSGG
Near-Surface Geophysics Group
The Geological Society
serving science & profession

Technical Description

The test site lies on the summit of a gentle hill-top. The surface layer of topsoil is about 0.3 metres thick, grading down into Boulder Clay. The Boulder Clay is uniform throughout the site, containing clasts up to 200 mm set in a clay matrix. This unit is 16 to 18 metres thick, and underlain by Liassic clays and limestones. Offset Wenner resistivity soundings confirm the depth to the boundary, and give a bulk resistivity of the Boulder Clay of 23 Ohm.m and 25 Ohm.m. for the Liassic Clay and limestone sequence. The water table is shallow, but the clay is of low permeability. During excavations water seeped slowly into most pits at depths of about 2 metres below the surface. The content and disposition of the test structures was discussed in detail by the EIGG committee, with the resulting plan being as shown in Figure 4. Each structure is defined in detail with plan and section drawings as necessary. Major considerations in the design were:

1) To provide targets suitable for most shallow geophysical methods such as magnetics, electromagnetics, radar, resistivity and possibly gravity and seismics.
2) To provide some simple targets for training purposes
3) To provide a series of more challenging targets which would test the limits of present equipment resolution and field techniques.
4) To provide a variety of targets which are of practical importance, but are currently undetectable by geophysical methods, e.g. plastic pipes.

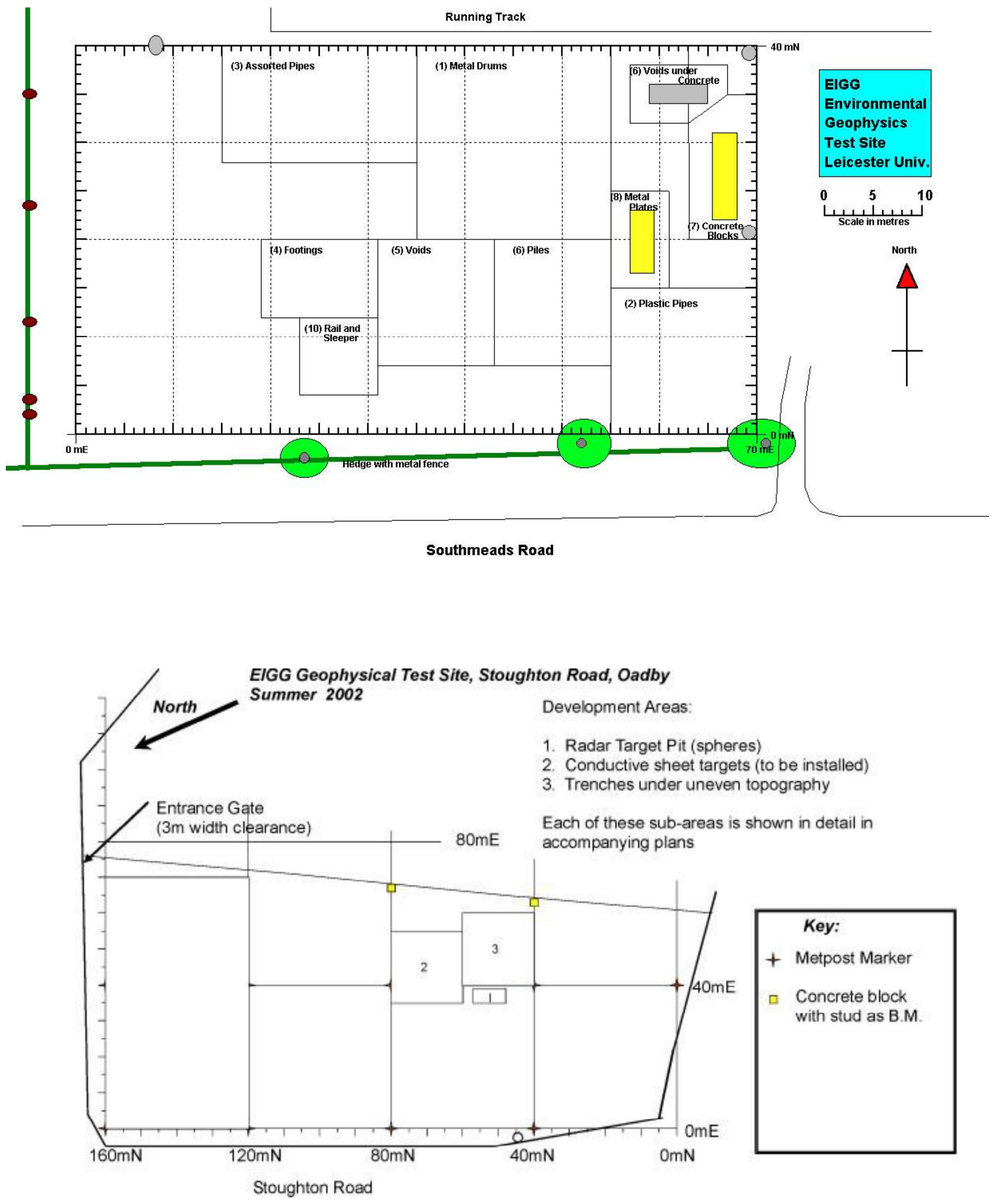
The targets comprise a variety of different shapes and sizes of objects made from different materials. Tubes or beams, sheets, spheres and cubes, made of metal, concrete, brickwork and plastic are the major targets. Sizes range from 0.3 metres to 2 metres.
The disturbance to the area caused by constructing the site was minimised. Burial holes were as small as possible,and back-filled with the extracted materials and compacted with a "Wacker". It is important that we can be sure that our measurement responses come from the buried objects, and not from the ground disturbance caused around them. To this end some trenches are back-filled with different materials (e.g. gravel, mixed ((homogenised) extracted subsoil) to act as controls. For practical reasons as well as to contain disturbance no excavation was deeper than 3 metres. Some soil compaction has occurred due to movement of plant. Continued maintenance may be necessary to level any further subsidence and ensure a uniform level surface with even grass cover.
Here a synthetic description is provided, but test site n. 1 contains 10 areas whereas test site n. 2 contains 3 areas where "thematic targets" have been displaced. The test site can be booked, and the booking conditions plus many more details are available at the provided web site of the test site.

Large boulder buried close to the waste drums (test site n. 1).

Further targets from test site n. 1: Simulated brownfield or achaeological target and sandpit with cast concrete blocks.

A buried floor from test site n. 2.

A buried wall from test site n. 2.



Map of the NSGG test site. It is composed of two tests sites whose maps are the top (test site n.1) and bottom images (test site n. 2) here represented.

RECOMMENDATIONS FOR THE DESIGN OF A NEW GPR TEST SITE

Realizing a GPR test site is a possibly costly activity and it is not trivial. In this chapter, we provide some ideas and suggestions to be kept in mind when designing a new test site.

A test site will provide significant simplifications for GPR data analysis and interpretation if: 1) the materials hosting the targets are homogeneous and their electromagnetic properties are known; 2) the positions of the targets, as well as their geometrical and electromagnetic properties, are known; 3) there is a clear contrast at the interfaces between host materials and targets; 4) there is absence of moisture (or a controlled level of water); 5) there is absence of objects causing unwanted reflections and clutter. Of course, these suggestions are not absolute and depend on the purposes of the test site! A clean scenario is desirable in several cases. For example, it allows achieving a deeper insight into the electromagnetic phenomena occurring when a GPR signal interacts with the environment; but, this is not always the aim of a study and, for various reasons, scientists may be interested in investigating GPR performances in controlled nonideal conditions. Furthermore, in a clean scenario GPR manufacturers can easily test equipment, experienced end-users can verify whether their equipment is working properly, and novices can learn how to correctly perform measurements; however, in a plethora of situations, professionals may need to carry out experiments in the presence of specific nonidealities.

Let us now look more in detail into the five recommendations given above.

As far as recommendation 1) is concerned, the homogeneity of the host material is an ideal condition that guarantees the absence of unwanted echoes generated by randomly distributed scatterers. Nevertheless, if the objective of the test site is to investigate how the GPR imaging capability degrades when the host material becomes more and more hetereogeneous, then of course its homogeneity is no longer desirable. In the latter case, a test site might include different sections where the degree of hetereogenity is gradually increased.

From a practical point of view, the homogeneity of the host material is always difficult to achieve. Geophysical test sites are usually composed by pits filled with various kinds of soils. Homogeneity of the soil can be expected if compaction is suitably performed during the test site realization, while setting up elementary soil layers (i.e., 20-cm thick layers). Moreover, the upper surface of each elementary layer has to be slightly scraped before laying the next layer: in this way, the surface aggregates - which were flattened by the compactor - are randomly reorganized, and the electromagnetic contrast between adjacent soil layers is minimized. Test sites made of concrete can be water tightened after a few months of curing and drying, else it is possible to water tight the lateral sides of a concrete structure in order to obtain depth-dependent water gradients.

Still concerning recommendation 1), and in particular the usefulness of knowing the electromagnetic properties of the test site media, it is advised to measure their permittivity and conductivity at different frequencies (within the range of interest), given that all materials have a frequency-dependent electromagnetic behaviour. We would like to point out that, of course, it is easier to accurately know the electromagnetic properties of an indoor test site; for an outdoor test site, the degree of uncertainty is inevitably higher due to the greater variability of the atmospheric conditions (temperature, humidity. In the particular case of a testing facility involving compacted soil, it would be very difficult to measure the electromagnetic properties of the host material versus frequency in the laboratory, before constructing the test site: instead, it is advised to perform the soil characterization on-site, by means of indirect GPR measurements (better if done in common mid-point configuration) or other methods (such as, very localized ground truthing or time-domain reflectometry mesurements).

Regarding recommendation 2), it may be interesting to include in the site identical targets placed at different distances from each other and/or with different orientations (to experience different interaction phenomena between the electromagnetic fields scattered by the targets and, consequently, obtain different signatures in the radargrams), and/or buried at different depths (to test the penetration properties of the radar). It may be worth including in the site targets having identical shape, burial depth and orientation, but made of different materials and/or having different size. Composite targets (i.e., different combinations of basic targets) can also be of great interest.

In practice, a key point is to make reliable measurements of the target location (on a reference system *x*, *y*, *z*), with the accuracy level required by the application. For test sites with objects embedded in concrete, it is important to carefully control the filling of concrete, to avoid any unwanted displacement of the targets. To this aim, the liquid concrete should be slowly casted while targets should be locked in their chosen position and orientation. Concerning geophysical test sites, achieving an accurate positioning of the targets is more challenging. For radiofrequency GPR applications, the desirable accuracy is of the order of a few centimeters, at most. It is advised to control the following points, by using a theodolite, a Differential Global Navigation Satellite System (DGNSS), a local total station, or rectified photographs shot from a drone:

(i) the bottom of the pit, which must remain stable and not vary in altitude under the weight of the test site; indeed, it is better to construct a geophysical test site above a suitable substratum;

(ii) the positions of all embedded objects, which are usually placed over compacted layers – please note that it is important to avoid overcompaction of the deep layers, when setting up the upper layers, in order not to increase too much the global weight they have to bear;

(iii) a series of referential points on the surface – this measurement should be performed again one or two years after the construction of the test site, in order to detect any delayed settlement.

Obviously, it is possible to have a more accurate knowledge about the target position and size when the test site is indoor. For an outdoor test site, instead, the degree of uncertainty is inevitably higher, because of the greater exposure to the elements (for example, the size of a target may change when the ground is wet, due to rain or snow; moreover, metallic targets can get rusty with time and plastic targets can crystallize, etc., and these processes progress faster in outdoor scenarios).

Recommendations 3) and 4) are true in general, unless the test site is specifically conceived for studying the effects of irregular/rough interfaces and/or moisture, in which cases it can be equipped with suitable technologies for achieving different levels of roughness and/or for controlling the water content. In order to guarantee absence of moisture and contamination of the host medium, the testing area of the site has to be properly isolated from the surrounding environment and protected from the elements.

In general, a strong electromagnetic contrast between the host material and targets is desirable, as well as the use of a lossless host material, so that the targets can be easily detected. However, the required levels of electromagnetic contrast and host-material losses are application dependent. For example, it may be useful to realize a test site where the electromagnetic contrast between the host material and targets is weak, in order to investigate the detection performance of a GPR system/procedure/algorithm in such a challenging condition and/or its capability to discriminate small differences of electromagnetic properties. It may also be interesting to realize a test site including some areas that can be easily imaged, with lossless host materials and metallic targets, as well as some other areas with lossy materials and/or a low electromagnetic contrast between the host material and targets.

As previously mentioned, it is not always true that the presence of water in a test site has to be avoided. A test site may be designed and realized to study the moisture effects on the propagation of the GPR signal, to investigate the effectiveness of GPR-based methods for the evaluation of water content in a structure or in the subsoil, and more in general to carry out hydrogeophysics experiments. In such cases, the (controlled) presence of water is intrinsically necessary.

Regarding recommendation 5), both the size and location of the testing area have to be properly chosen. The size is important to avoid edge effects. It has to be determined by taking into account the lowest frequency of interest, the electromagnetic properties of the involved materials, and the largest possible angle of the GPR antenna beam along with the maxium antenna height (if air-coupled antennas are to be used). For the antenna beam, it is advised to use 90 degrees when designing the test size area, if more detailled information is not available.

While it is commonly true that clutter has to be limited, a test site might be specifically designed and realized to investigate the effects of a controlled level of clutter on the GPR performance. For example, this can be of interest for demining applications, where the GPR false-alarm rate is usually high due to clutter.

Further to our previous comments, a test site can be indoor or outdoor. Depending on the frequency range of interest and involved materials, the testing area needs to be at a suitable distance from walls, buildings, metallic objects and constructions, electric poles, trees, car parks, and lakes or ponds (or other water bodies). For an outdoor site, of course no buried utilities should exist in the proposed area and the watertable should be distant enough from the bottom level of the site. To facilitate the access with equipment, the doors of an indoor test site have to be large enough. A paved road arriving to the test site is also well advised, if the test site is outdoor.

Finally, let us mention that electromagnetic simulation is a powerful tool for a successful design of a new test site. It is advised to use a forward modelling software, such as gprMax, or ask an experienced person to use it, in order to build an electromagnetic model of the planned site. This will allow to investigate different alternatives, predict the behaviour of the whole scenario, avoid some unpleasant surprises, and overall conceive a test site that meets all (or, at least, most of) the desired requirements.

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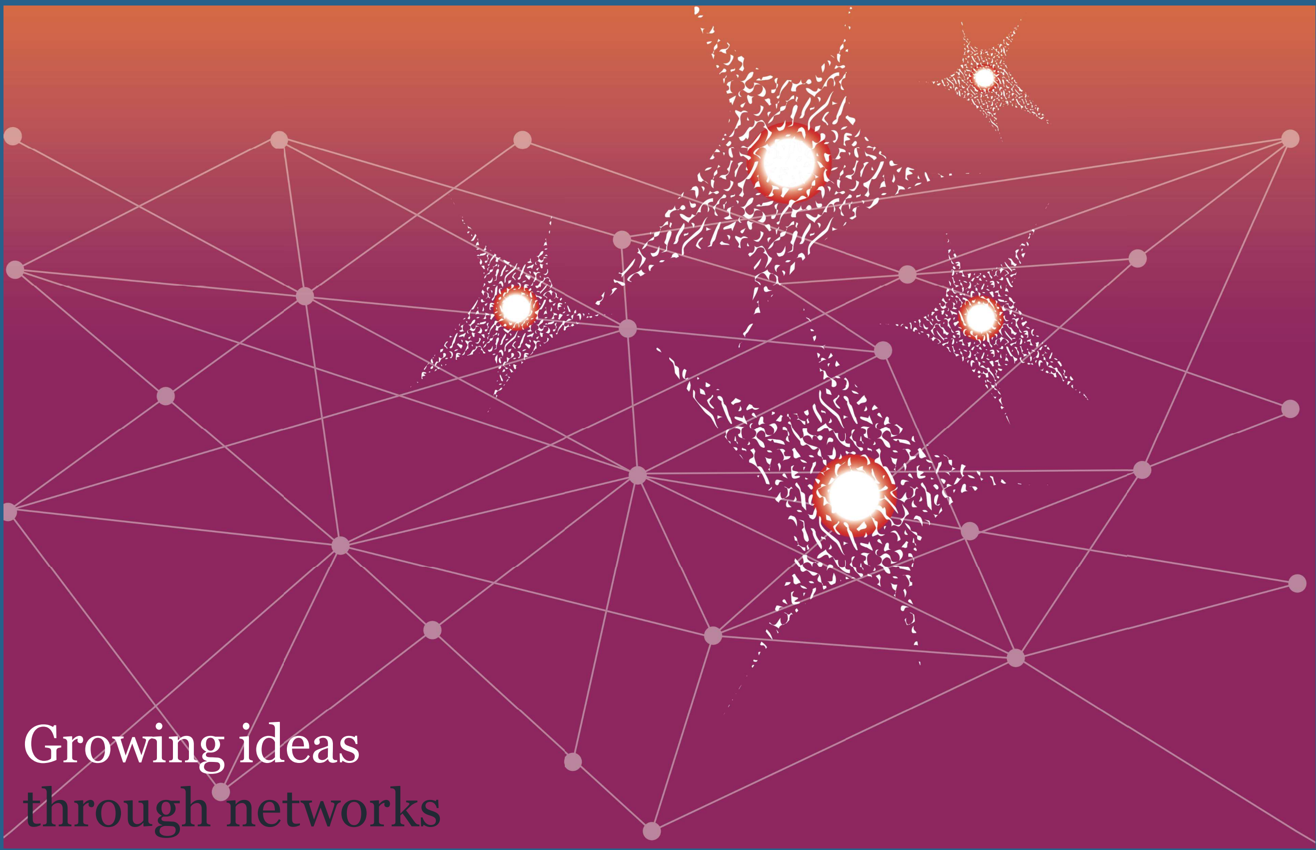

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