COST ACTION TU1208

CIVIL ENGINEERING APPLICATIONS OF GROUND PENETRATING RADAR

2014 Working Group Progress Meeting - Proceedings

Nantes, France, February 24 – 25, 2014

Editors: Lara Pajewski & Xavier Dérobert

EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

TU1208 Basic Info
Start - End of Action: 4 April 2013 - 3 April 2017

Chair of the Action:
Dr. Lara Pajewski
Roma Tre University, IT
lara.pajewski@uniroma3.it

Vice-Chair of the Action:
Prof. Andreas Loizos
National Technical University of Athens, EL

COST TUD DC Chair:
Prof. Cristina Pronello
Politecnico di Torino, IT

COST TUD DC Rapporteur:
Dr. Goran Mladenovic
University of Belgrade, RS

COST Science Officer:
Dr. Mickael Pero
COST Office, BE

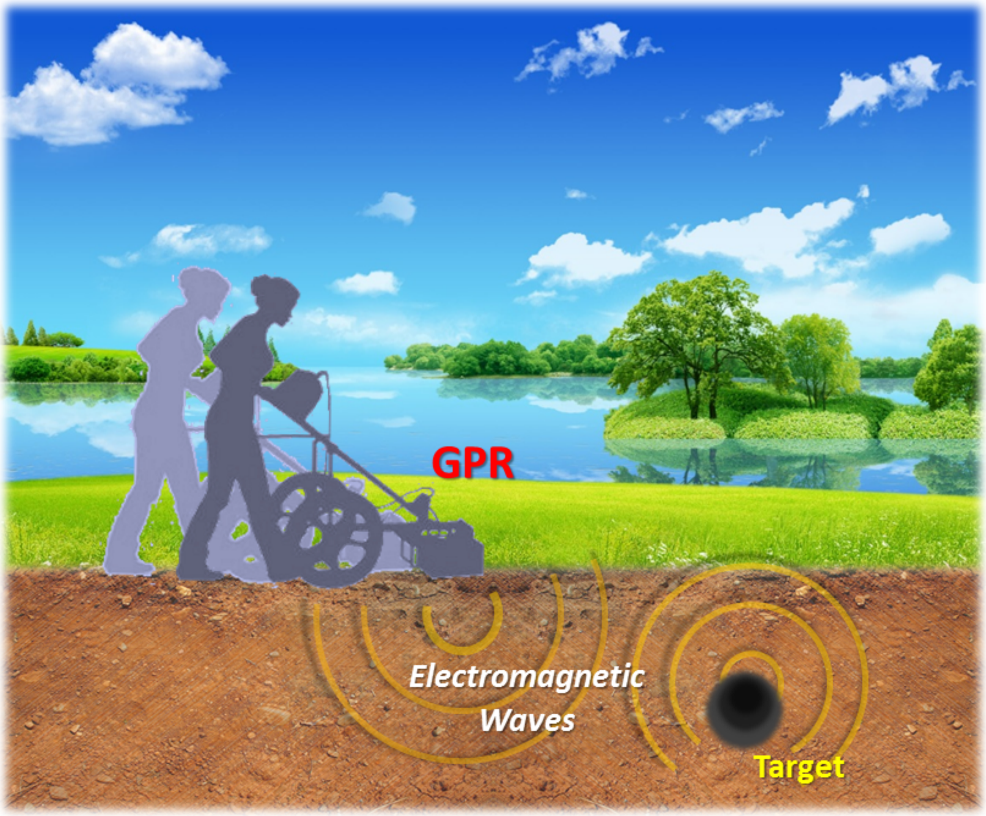
COST Administrative Officer:
Ms. Carmencita Malimban
COST Office, BE

Grant Holder:
Roma Tre University, Department of Engineering, IT

Editorial Coordinator of the Action:
Prof. Andrea Benedetto
Roma Tre University, IT

Chairs of the Working Groups (WGs):
- WG1: Dr. Guido Manacorda, IDS Ingegneria dei Sistemi, IT
- WG2: Dr. Christina Plati, National Technical University of Athens, EL
- WG3: Dr. Antonis Giannopoulos, University of Edinburgh, UK
- WG4: Dr. Immo Trinks, Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology, AT

Short-Term Scientific Missions (STSMs) Manager:
Prof. Marian Marciniak
National Institute of Telecommunications, PL



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ESF provides the COST Office through a European Commission Contract. The Council of the EU provides the COST Secretariat.

PREFACE

TO THE PROCEEDINGS OF THE 2014 WORKING GROUP PROGRESS MEETING

COST ACTION TU1208

"CIVIL ENGINEERING APPLICATIONS OF GROUND PENETRATING RADAR"

The 2014 Working Group Progress Meeting of the COST Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar" was held at the French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR) in Nantes, France, on February 24-25, 2014.

Over 30 delegates from both academia and industry actively participated to the meeting, being engaged in a series of presentations, discussions and brainstorming sessions, concerning the Ground Penetrating Radar (GPR) use in civil engineering tasks.

The main focus of the meeting was on the following topics: (i) inspection procedures for effective GPR surveying of critical transport infrastructures and buildings; (ii) inspection procedures for effective GPR sensing and mapping of underground utilities and voids in urban areas; (iii) inspection procedures for effective GPR monitoring of construction materials; (iv) determination, through the use of a GPR system, of water content in structures, foundations and soil; (v) advanced techniques for the solution of forward and inverse electromagnetic near-field scattering problems by complex scenarios; (vi) shape-reconstruction and quantitative estimation of electromagnetic and physical properties from GPR data; (vii) processing of GPR data collected during civil engineering surveys.

We were honoured to have Prof. Antonis Giannopoulos (The University of Edinburgh, United Kingdom) and Dr. Craig Warren (Early-Stage Reseaercher (ESR), Edinburgh Napier University, United Kingdom) holding a special Workshop on "Computational Electromagnetics with the Finite-Difference Time-Domain technique." The programme of this workshop was to resume the *Finite-Difference Time-Domain* (FDTD)

method and the potentialities of the well-known versatile and accurate *GprMax* software (www.gprmax.org), as well as to talk about some advanced topics like the modelling of complex structures and of inhomogeneous media with stochastically distributed parameters, for realistic electromagnetic representations of GPR antennas, construction materials and soils.

Numerical methods are needed in order to solve Maxwell's equations in complicated and realistic problems, as modeling the GPR response in civil engineering scenarios. Over the years a number of numerical methods have been developed to do so. The FDTD method is considered to be one of the most attractive choices, basically because of its simplicity, speed and accuracy. Kane Yee first introduced FDTD in 1966. Since then, it has been established and developed to be a very rigorous and well defined numerical method for solving Maxwell's equations. The order characteristics, accuracy and limitations are rigorously and mathematically defined. This makes FDTD reliable and easy to use. GprMax is a very useful and freeware tool implementing FDTD in 2D and 3D, which can be used in order to give insight into the electromagnetic scattering mechanisms and as an alternative approach to aid data interpretation. Numerical modelling with GprMax can be performed for a wide range of GPR applications in civil engineering, archeology, geophysics, landmine detection, and so on. In civil engineering, some applications of numerical modelling include the estimation of the effectiveness of GPR to detect voids in bridges, to detect metal bars in concrete, to estimate shielding effectiveness, etc. The main challenges in numerical modelling of GPR for civil engineering applications are: the implementation of the dielectric properties of the involved media in a realistic way, the implementation of the geometrical characteristics of the media (soils inhomogeneity, rough surfaces, vegetation, concrete features like fractures and rock fragments), and of course the modelling of the GPR transmitting and receiving antennas. During the workshop, basic information about FDTD was provided. The main features and commands of GprMax were presented in detail, how to prepare input files was explained, numerical results were presented. An accurate and realistic implementation of GPR antenna units, based

on general characteristics of the commercial antennas GSSI 1.5 GHz and MALA 1.2 GHz, was carefully described, too. Results of measurements were shown, made in different oil-in-water emulsions, which were used to simulate materials with different permittivity and conductivity; comparisons of the measured and modelled data show a very good correlation, which validates the use of the antenna models for further studies.

An interesting visit to the IFSTTAR test sites took place. In particular, participants could visit the geophysical test site, the Accelerated Pavement Testing (APT) facility and the geotechnical centrifuge.

The *geophysical test site* is an open-air laboratory including a large and deep area, filled with various materials arranged in horisontal compacted slices, separated by vertical interfaces and water-tighted in surface; several objects as pipes, polystyrene hollows, boulders and masonry are embedded in the field.

The full-scale *APT facility* is an outdoor circular carousel dedicated to full-scale pavement experiments, consisting of a central tower and four long arms equipped with wheels, running on a circular test track. In particular, the loading system includes two wheel assemblies: the first one runs on an inner track, 30 m in diameter, the second one runs on an outer track, 40 m in diameter. Loads from 40 kN up to 75 kN can be applied, at speeds of up to 105 km/h. It is possible to simulate tandem axles of 280 kN at lower speeds as well as to simulate single wheel-loading. The APT is highly active, with extensive ongoing research studies involving universities, researcher centers and enterprises.

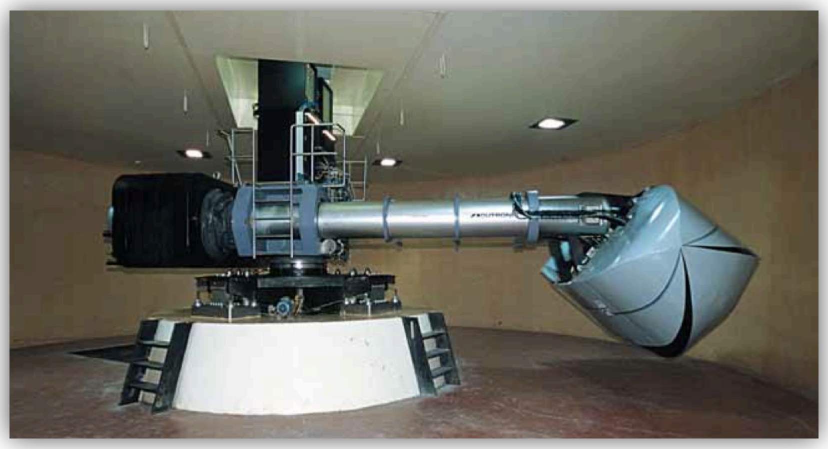
The *geotechnical centrifuge* is an indoor experimental facility, which is useful for the testing of physical-scale models of geotechnical engineering systems, such as natural and man-made slopes and earth retaining structures, or building or bridge foundations. The scale models are constructed in the laboratory and then loaded onto the end of the centrifuge. The purpose of spinning the models on the centrifuge is to increase the g-forces on the model, so that stresses in the model are equal to stresses in the prototype in Earth's gravity. The idea to use

centrifugal acceleration to simulate increased gravitational acceleration was first proposed by Phillips in 1869 and it is still extremely valid. The IFSTTAR geotechnical centrifuge has a capacity to place a 2 tonnes model at a centrifuge acceleration of 100g; its radius is 5.5 m and the platform of the swinging basket that supports the model is 1.4 m x 1.1 m. It is also possible to perform earthquake simulation tests, to this aim a shaking table set can be added in the basket of the centrifuge so that a horisontal acceleration simulating the bedrock acceleration during the earthquake is superimposed to the static vertical centrifuge acceleration modelling the gravity.

The IFSTTAR geophysical test site and APT represent the perfect location for the comparison of different GPR equipment and surveying procedures.

Keynote lectures were given by Prof. Andreas Tzanis (University of Athens, Greece) and Dr. Janne Poikajarvi (Lapland University of Applied Sciences, Finland).

Prof. Andreas Tzanis presented the well-known *matGPR* software that he developed (users.uoa.gr/~atzanis/matgpr/matgpr.html), providing a broad and functional range of tools for the analysis of zero and single-offset GPR data. He also gave an overview on *GPR data processing*, suggesting open issues and possible future developments in this area. The matGPR programme is implemented in Matlab and is available for free. It is a two-layered software system, in which the bottom layer comprises a suite of functions to handle, display and process the data, while the top layer organizes these functions by means of a GUI. At present matGPR can import GPR single-channel raw data in the formats of the manufacturers GSSI, Mala Geophysics, Sensors and Software and ZOND, as well as data stored in Seismic Unix and SEG-Y Revisions 0 and 1 formats. The software offers a collection of basic and advanced GPR processing utilities, imaging (migration) and modelling tools, routines to generate 2D and 3D GPR data pictures. This powerful tool is of great interest for Working Group 3 of our Action.

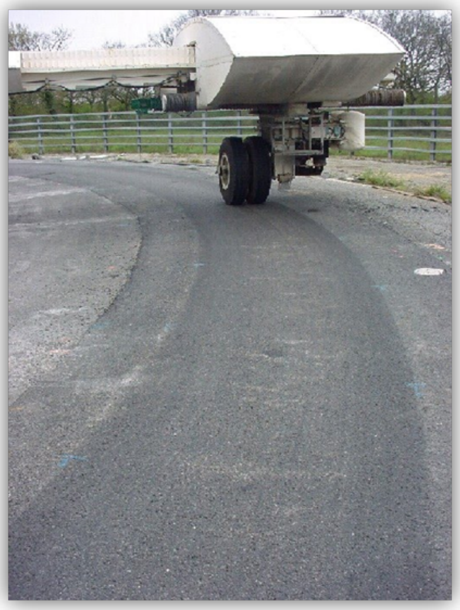


Picture of the geotechnical centrifuge at IFSTTAR.

Dr. Janne Poikajarvi presented the *Mara Nord Project*, recently carried out in Finland, Sweden and Norway. The project objectives were to demonstrate the potential of GPR in road-condition measurement and rehabilitation planning, to benchmark different available GPR systems, to create joint Nordic Scandinavian Recommendations, and to offer a GPR training programme to road administrations and to companies. Concerning recommendations, during the Mara Nord project five different joint guidelines were developed, to address the different types of surveys most commonly performed on road surveys: use of GPR in pavement design and road rehabilitation projects, use of GPR in bridge applications, use of GPR in site investigation, use of GPR in road construction quality control, use of GPR in asphalt quality control. The project is of huge interest for Working Group 2 of our Action and Dr. Poikajarvi clearly described not only the achieved results, but also how the project was carried out step by step, how road authorities played an important role to define the recommendations, how the training sessions were organised. All the project reports, guidelines and slides of the training are available at maranord.ramk.fi.

On Monday, a series of presentations and discussions on Working Group 3 topics took place.

Dr. Cristina Ponti (ESR, Roma Tre University, Italy) presented the progress report on Project 3.1 "Development of advanced methods for the solution of forward electromagnetic scattering problems by buried structures," describing the progress that has been done since July 2013 by the project's participants, on the topic of the modeling of forward electromagnetic scattering by buried objects. These research activities aim at providing tools for an advanced modeling of civil engineering scenarios, in order to improve the understanding of data collected by GPR systems.



Pictures of the Accelerated Pavement Testing Facility at IFSTTAR.

Picture of the Accelerated Pavement Testing Facility at IFSTTAR.

Dr. Nicolas Pinel (ESR, Alyotech, France) presented his work on the modelling of electromagnetic scattering by rough layers through the Method of Moments and its application to roadways. This is a contribution to Project 3.1 of our Action.

Subsequently, Dr. Christelle Eyraud (ESR, Institut Fresnel, France) presented her work on the modelling of the electromagnetic field emitted by a GPR horn antenna by means of a suitable set of current lines; the method has been applied to the near-subsurface imaging of a two-dimensional object embedded in an absorbing medium and numerical results have been compared with experimental data collected by a multistatic single-frequency scanner. This is a contribution to both Projects 3.1 and 3.2; it could be interesting to integrate the method in the CWA and also to exploit it in GprMax2D.

Dr. Albéric De Coster (ESR, Université Catholique de Louvain, Belgium) presented, on behalf of Prof. Sébastien Lambot, the progress

report on Project 3.3 "Development of intrinsic models for describing near-field antenna effects, including antenna-medium coupling, for improved radar data processing using full-wave inversion," describing how activities went on since July 2013.

Finally, Prof. Jan Van Der Kruk (Forschungszentrum Jülich, Germany), who recently joined COST Action TU1208, gave a talk on the state of the art and open issues in the field of Full-Waveform Inversion (FWI), one of the most promising but also challenging data fitting techniques that is able to use advanced modeling programs to derive quantitative relative permittivity and conductivity values from GPR data. Recent developments were discussed concerning FWI of experimental off-ground, crosshole, and on-ground GPR data. This is a contribution to Projects 3.2 and 3.4 of the Action.

On Tuesday, a series of presentations and discussions on Working Group 2 topics took place.

Dr. Josef Stryk (Centrum Dopravního Výzkumu, Czech Republic) presented the progress report on Project 2.1 "Innovative inspection procedures for effective GPR surveying of critical transport infrastructures (pavements, bridges and tunnels)." He described the studies that have been carried out since July 2013 by the project's participants on the topics covered by Project, updated participants attending the meeting on the ongoing cooperation with EuroGPR Association, presented the Czech National Project connected to COST Action TU1208 and the first results of an experimental activity on continual measurement of the thickness of asphalt layers. He also presented a questionnaire, which was developed in cooperation with the Action's Chair, WG2 Chair and WG2 Vice-Chair and proposed to the participants of Project 2.1; preliminary results of the survey are already available.

Prof. Gracia Vega-Perez (Universidad Politécnica de Cataluña, Spain) presented the state of the art and open issues concerning Project 2.2 "Innovative inspection procedures for effective GPR surveying of buildings." For this project, the state of the art report was not presented

during the First General Meeting of our COST Action, as Project 2.2 started later with respect to the other projects.

Dr. Xavier Dérobert (IFSTTAR, France) presented the progress report for Project 2.3 "Innovative inspection procedures for effective GPR sensing and mapping of underground utilities and voids, with a focus to urban areas" and he also presented the template for a catalogue of European GPR test sites, developed in cooperation with the Action's Chair and the WG2 Chair, to be proposed to all the Action's Members.

Dr. Lech Krysinski (Road and Bridge Research Institute, Poland) presented the progress report for Project 2.4 "Innovative procedures for effective GPR inspection of construction materials and structures," providing basic information about participants, list of project topics and ongoing research activities related to the project.

Dr. Zoubi Mehdi Sbartai (University of Bordeaux, France) presented a review on his research activity, concerning the evaluation of moisture content using GPR, as a contribution to Project 2.5. He mainly focused on the evaluation of moisture content in concrete, by using electromagnetic techniques as permittivity measurement using weak perturbation method and GPR.

Dr. Christiane Trela (Federal Institute for Materials Research and Testing (BAM), Germany) gave a talk about GPR activities at BAM. The BAM laboratories are excellent test sites for the comparison of different surveying procedures and equipment on concrete structures, with advanced experimental facilities and the possibility to construct accurate test specimens made of concrete, masonry, sand and gravels, etc., with different structural elements embedded in them (rebars, tendon ducts, cavities, honey combs, etc.) and under various conditions (wetness, salt content, temperatur, mechanical stress, accelerated corrosion, etc.). At BAM, a training course on non-destructive testing and evaluation for civil engineering applications is regularly organised and its content was presented by Dr. Trela, as well.

Dr. Colette Gregoire (Belgium Road Research Center (BRRC), Belgium) gave a talk on GPR activities for road applications at the BRRC (evaluation of the road structure with deflections measurements, estimation of the origin of road damages and collapse, evaluation of the

risk of instability of concrete slabs, detection of cables or pipes before works, etc). They recently bought a GPR system and are carrying out a research project aiming at the establishment of standard methodologies for acquisition, processing and interpretation of radar measurements that are specific for road investigation. In order to calibrate the radar equipment and to perform measurements in controlled conditions, they constructed a small test site with different road specimens.

Subsequently, talks were given by new Working Group 2 Members, who recently joined our COST Action. Dr. Pekka Hanninen (Geological Survey of Finland, Finland) presented his research activities on snow and frost GPR-monitoring in suburban areas. Prof. Simona Fontul (Laboratório Nacional de Engenharia Civil, Portugal) gave a talk on GPR research activities carried out in the National Laboratory for Civil Engineering, in Lisbon. Dr. Roger Wisen (Rambøll, Denmark) presented Rambøll activities, in Denmark, and a GPR system that they use for efficient 3D surveying in civil engineering tasks.

A presentation on COST Short Term Scientific Missions (STSMs) and COST Conference Grants was given by Dr. Lara Pajewski (Roma Tre University, Italy). COST strives to support European scientists in their networking activities: STSMs allow scientists to learn from an institution or laboratory in another COST Country - a concept of particular interest to young scientists. STSMs can vary from one week to three months, and up to six months for Early Stage Researchers (ESRs), having their PhD since no more than eight years; applicants must be engaged in a research programme in an Institution from a COST Country which must have accepted the Memorandum of Understanding (MoU) of the Action concerned, and the host institution has to be in a COST country participating in the COST Action as well. The average contribution for a mission is a fixed grant based on the applicant's budget request and the decision from the relevant assessment committee. COST Conference Grants are offered by the COST scientific domains three times per year; these grants are for ESRs, to participate in an international conference outside of the COST Action activities.

Afterwards, an open discussion took place, concerning the organisation of the next Action's events, possible dissemination initiatives, and preliminary ideas about the submission of joint Horizon 2020 proposals, as well as ideas about the possibility of submitting NATO Science for Peace proposals for a Training School and for a Workshop (in cooperation with the Mara Nord team). Finally, we had parallel brainstorming sessions for Working Groups 2 and 3.

We are deeply grateful to COST, for funding the COST Action TU1208, the 2014 Working Progress Meeting and the publication of this volume, and to the Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux, for hosting the event and for providing facilities.

Lara Pajewski, Chair of the COST Action TU1208
Xavier Dérobert, Co-Chair of TU1208 Working Group 2

A group of meeting participants visiting the APT Facility at IFSTTAR.

A group of meeting participants visiting the geotechnical centrifuge.

Scientific Programme of the 2014 Working Group Progress Meeting

Monday 24 February 2014 – Programme at a glance

10:00 – 10:40	Opening Session
10:40 – 11:30	Keynote Lecture 1
11:30 – 11:45	Coffee break
11:45 – 12:55	Presentations on WG3 topics
12:55 – 13:10	Introduction to the visit of IFSTTAR test sites
13:10 – 14:15	Lunch
14:15 – 15:15	Visit of IFSTTAR test sites
15:15 – 15:30	Coffee break
15:30 – 17:45	Workshop on Computational Electromagnetics with FDTD
20:00	Common Dinner in Nantes

TUESDAY 25 FEBRUARY 2014 - – PROGRAMME AT A GLANCE

09:00 – 09:45	Keynote Lecture 2	
09:45 – 11:05	Presentations on WG2 topics	
11:05 – 11:20	Coffee break	
11:20 – 12:55	Presentations on WG2 topics	
12:55 – 13:05	On COST STSMs and Conference Grants	
13:05 – 14:10	Lunch	
14:10 – 15:00	Open discussion on next Action's events, dissemination activities, and Horizon 2020	
15:00 – 16:00	WG2 Brainstorming session	WG3 Brainstorming session
16:00 – 16:30	Closing Session	

MONDAY 24 FEBRUARY 2014 – DETAILLED PROGRAMME

10:00 – 10:40	**Opening Session** – Chairs: Dr. Xavier Dérobert, FR, and Dr. Lara Pajewski, IT • *Welcome* - Dr. Xavier Dérobert, FR • *Introduction of participants* • *Progress report on COST Action TU1208* - Dr. Lara Pajewski, IT
10:40 – 11:30	**Keynote Lecture 1** – Chair: Dr. Xavier Dérobert, FR *On MATGPR and GPR data processing* – Prof. Andreas Tzanis, EL
11:30 – 11:45	Coffee break
11:45 – 12:55	**Presentations on WG3 topics** – Chair: Prof. Antonis Giannopoulos, UK 1. *Development of advanced methods for the solution of forward electromagnetic scattering problems by buried structures* – Progress Report by Dr. Cristina Ponti, IT (Project 3.1) (15 min, including discussion) 2. *Rigorous and asymptotic modelling of coherent scattering from random rough layers: application to roadways* – Dr. Nicolas Pinel, FR (Project 3.1) (15 min, including discussion) 3. *Development of intrinsic models for describing near-field antenna effects, including antenna-medium coupling, for improved radar data processing using full-wave inversion.* – Progress Report by Dr. Albéric De Coster, BE (Project 3.3) (10 min, including discussion)

	4. *Near-subsurface imaging in an absorbing embedding medium with a multistatic/single frequency scanner* – Dr. Christelle Eyraud, FR (Projects 3.1 and 3.2) (15 min, including discussion) 5. *GPR full-waveform inversion – state of the art and open issues* – Prof. Jan Van der Kruk, DE (Projects 3.2 and 3.4) (15 min, including discussion)
12:55 – 13:10	**Introduction to the visit of IFSTTAR test sites** *The IFSTTAR geophysical test site and the road carousel* – Dr. Xavier Dérobert, FR
13:10 – 14:15	Lunch
14:15 – 15:15	**Visit of IFSTTAR test sites**
15:15 – 15:30	Coffee break
15:30 – 17:45	**Workshop on Computational Electromagnetics with FDTD** Prof. Antonis Giannopoulos, UK, and Dr. Craig Warren, UK
20:00	Common Dinner in Nantes

TUESDAY 25 FEBRUARY 2014 – DETAILLED PROGRAMME

09:00 – 09:45	**Keynote Lecture 2 (WG2)** – Chair: Prof. Andreas Loizos, EL *On the Mara Nord Project* – Dr. Janne Poikajarvi, FI
09:45 – 11:05	**Presentations on WG2 topics** – Chair: Dr. Christina Plati, EL 1. *Innovative inspection procedures for effective GPR surveying of critical transport infrastructures (pavements, bridges and tunnels)* – Progress Report by Dr. Josef Stryk, CZ (Project 2.1) (15 min) 2. *Innovative inspection procedures for effective GPR surveying of buildings* – State of the Art Report by Prof. Gracia Vega-Perez, ES (Project 2.2) (15 min) 3. *Innovative inspection procedures for effective GPR sensing and mapping of underground utilities and voids, with a focus to urban areas* – Progress Report by Dr. Xavier Dérobert, FR (Project 2.3) (15 min) 4. *The main areas of interest and current efforts in Project 2.4: Innovative procedures for effective GPR inspection of construction materials and structures* – Progress Report by Dr. Lech Krysinski, PL (Project 2.4) (15 min) 5. *Evaluation of moisture content using GPR* – Dr. Zoubi Mehdi Sbartai, FR (Project 2.5) (20 min)
11:05 – 11:20	Coffee break
11:20 – 12:55	**Presentations on WG2 topics** – Chair: Dr. Christina Plati 1. *Snow and frost GPR-monitoring in suburban areas* – Dr. Pekka Hanninen, FI (20 min) 2. *GPR experience at the National Laboratory for Civil Engineering, in Portugal* – Prof. Simona Fontul, PT (20 min)

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<table>
<tr><td></td><td colspan="2">3. GPR activities at the Federal Institute for Materials Research and Testing (BAM), in Germany – Dr. Christiane Trela, DE (20 min)
4. GPR activities for road applications at the BRRC, in Belgium – Dr. Colette Gregoire, BE (20 min)
5. An efficient system for GPR surveying of pavement, bridges and tunnels – Dr. Roger Wisen, DK (15 min)</td></tr>
<tr><td>12:55 – 13:05</td><td colspan="2">COST STSMs and Conference Grants – Dr. Lara Pajewski, IT</td></tr>
<tr><td>13:05 – 14:10</td><td colspan="2">Lunch</td></tr>
<tr><td>14:10 – 15:00</td><td colspan="2">Open discussion
• Next Action’s events
• Dissemination
• Horizon 2020 proposals</td></tr>
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Chairs:
Dr. Christina Plati, EL
Prof. Andreas Loizos, EL</td><td>WG3 Brainstorming session
Chairs:
Prof. Antonis Giannopoulos, UK
Dr. Lara Pajewski, IT</td></tr>
<tr><td>16:00 – 16:30</td><td colspan="2">Closing Session – Chairs: Dr. Xavier Dérobert, FR, and Dr. Lara Pajewski, IT
• Reports from WG Chairs, resuming the meeting - Dr. Christina Plati, EL, and Prof. Antonis Giannopoulos, UK
• Closure of the 2014 Working Group Progress Meeting - Dr. Xavier Dérobert, FR, Prof. A. Loizos, EL, and Dr. L. Pajewski, IT</td></tr>
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Progress Report on COST Action TU1208
"Civil Engineering Applications of Ground Penetrating Radar"

Lara Pajewski - Roma Tre University, Rome, Italy
lara.pajewski@uniroma3.it

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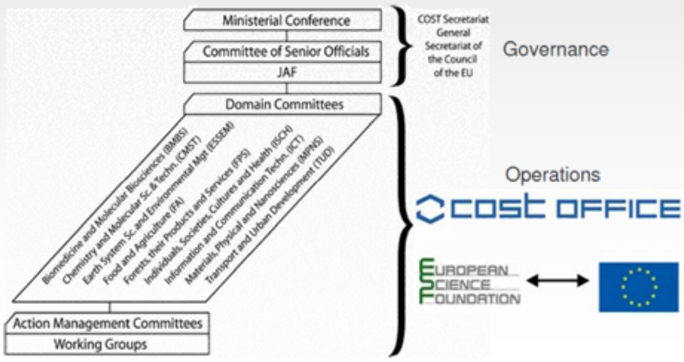
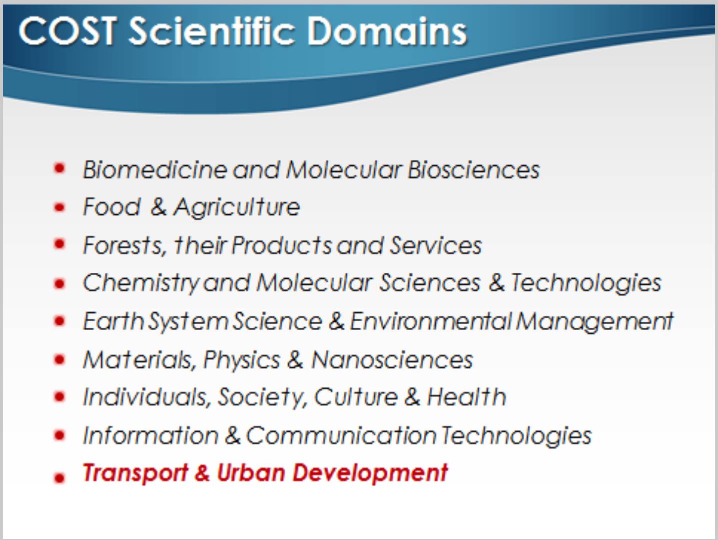
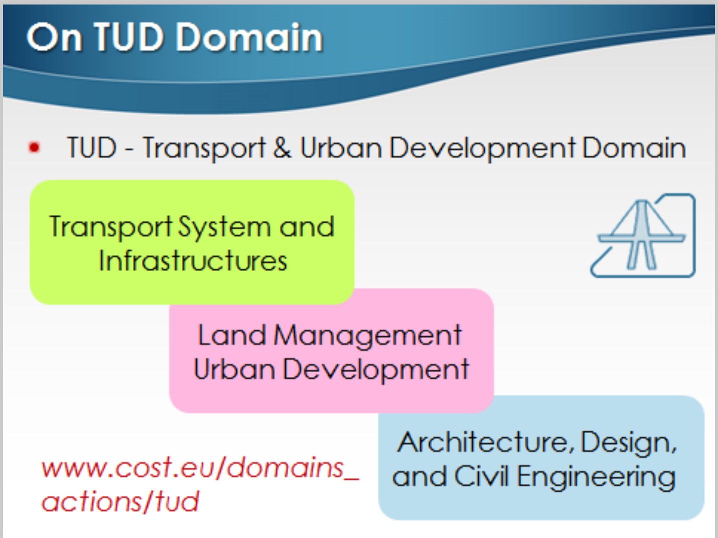
International Partner Countries (all the other Countries - Reciprocal Agreements to increase cooperation with New Zealand, South Africa and Argentina).

COST Organisation







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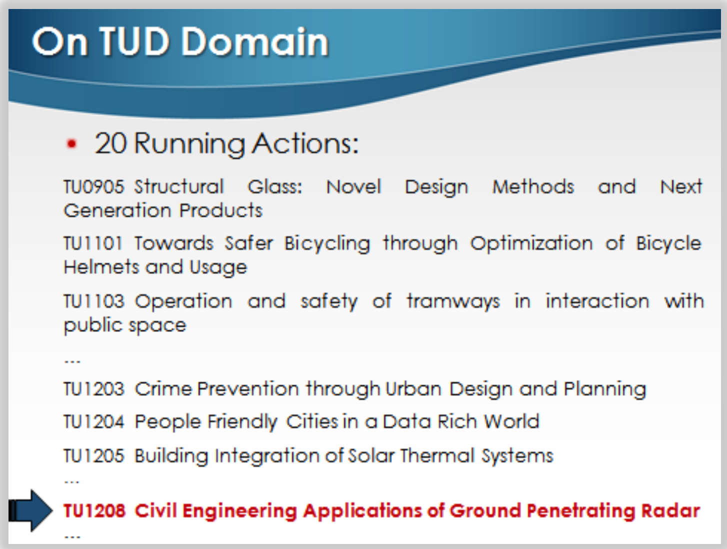
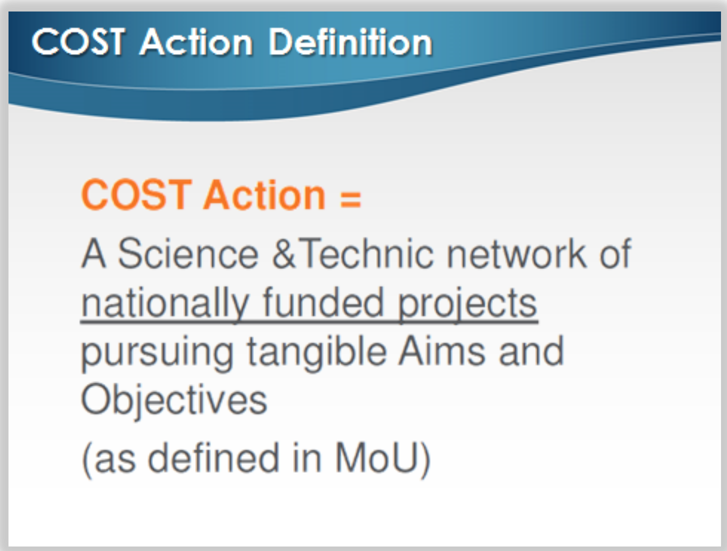
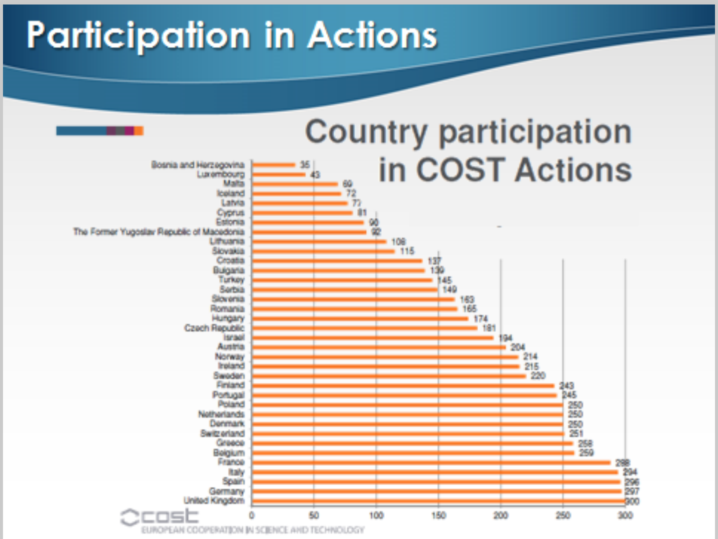

On TUD Domain
• 20 Running Actions:
TU0905 Structural Glass: Novel Design Methods and Next Generation Products
TU1101 Towards Safer Bicycling through Optimization of Bicycle Helmets and Usage
TU1103 Operation and safety of tramways in interaction with public space
...
TU1203 Crime Prevention through Urban Design and Planning
TU1204 People Friendly Cities in a Data Rich World
TU1205 Building Integration of Solar Thermal Systems
...
TU1208 Civil Engineering Applications of Ground Penetrating Radar
...


COST Action Definition
COST Action =
A Science &Technic network of nationally funded projects pursuing tangible Aims and Objectives
(as defined in MoU)


Participation in Actions
Country participation
in COST Actions
Bosnia and Herzegovina 35
Luxembourg 43
Malta 69
Iceland 72
Latvia 77
Cyprus 81
Estonia 90
The Former Yugoslav Republic of Macedonia 92
Lithuania 108
Slovakia 115
Croatia 137
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Czech Republic 181
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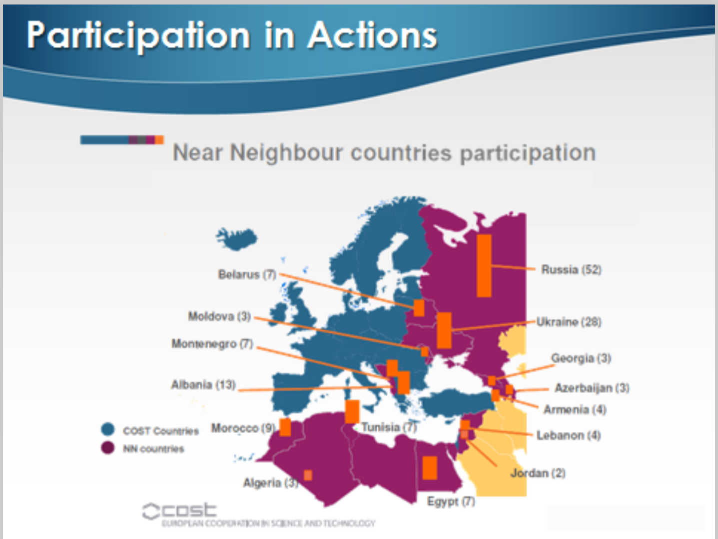
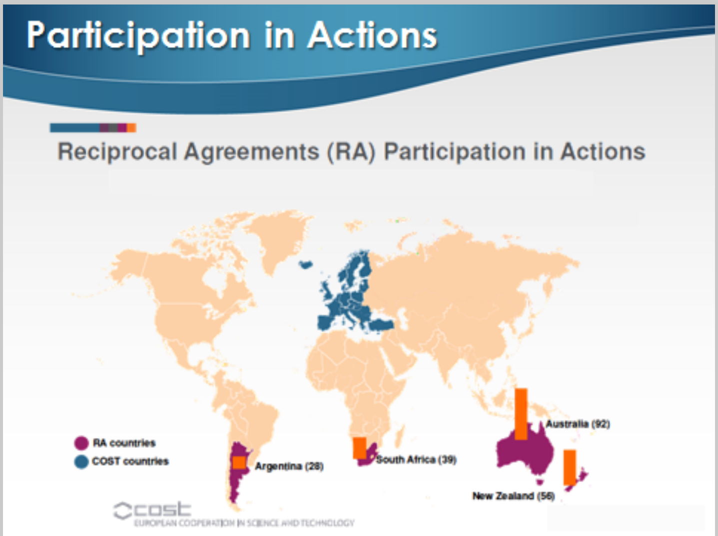
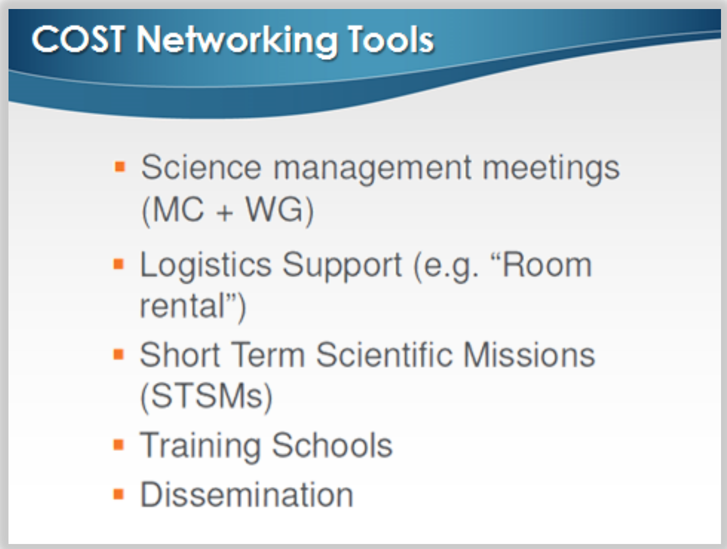
Greece 258
Belgium 259
France 288
Italy 294
Spain 296
Germany 297
United Kingdom 300
0 50 100 150 200 250 300
cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY


Participation in Actions
Non-COST Countries
Participation in COST Actions excluding Reciprocal Agreements and Near Neighbour Countries
Canada (39)
USA (99)
Mexico (6)
Colombia (2)
Peru (1)
Brazil (13)
Chile (1)
Uruguay (1)
Namibia (1)
Sudan (1)
UAE (1)
Mauritius (1)
Pakistan (3)
India (10)
China (24)
Japan (16)
Rep of Korea (3)
Taiwan (1)
Hong Kong (2)
Thailand (1)
Singapore (2)
Indonesia (1)
only one Action
COST Countries

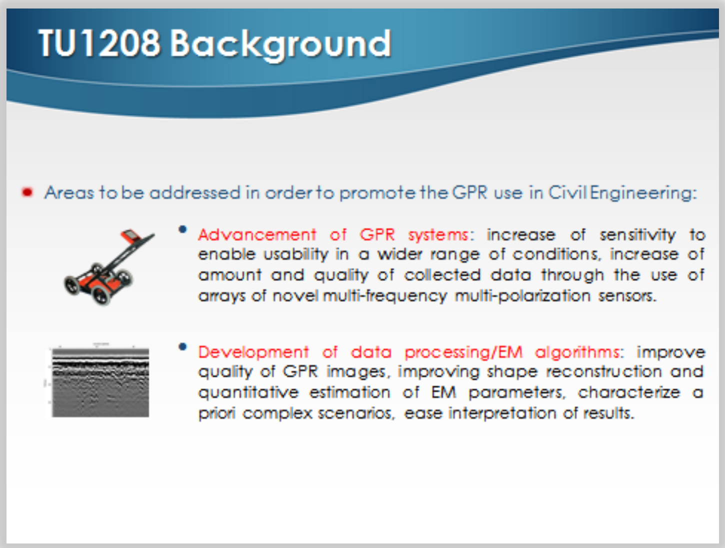

Participation in Actions
Near Neighbour countries participation
Belarus (7)
Moldova (3)
Montenegro (7)
Albania (13)
Morocco (9)
Tunisia (7)
Algeria (3)
Egypt (7)
Russia (52)
Ukraine (28)
Georgia (3)
Azerbaijan (3)
Armenia (4)
Lebanon (4)
Jordan (2)
COST Countries
NN countries
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

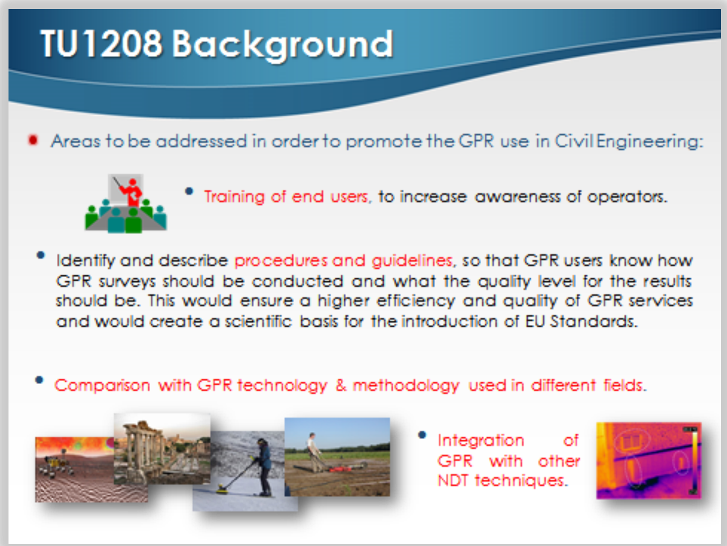

Participation in Actions
Reciprocal Agreements (RA) Participation in Actions
RA countries
COST countries
Argentina (28)
South Africa (39)
Australia (92)
New Zealand (56)
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

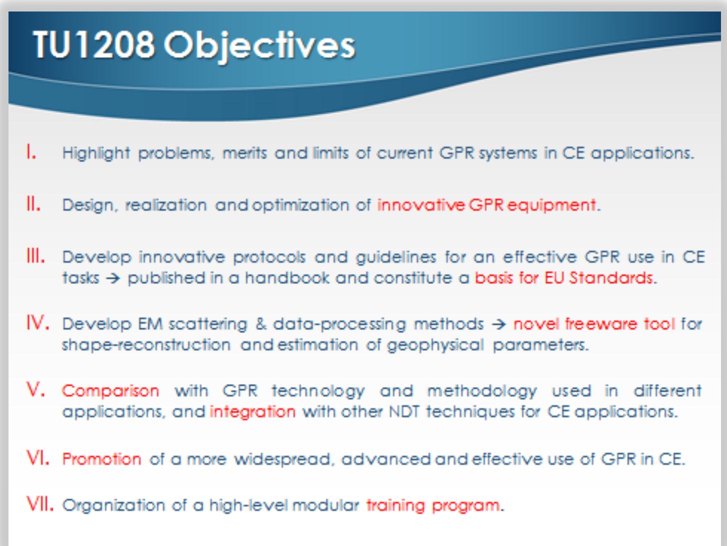

COST Networking Tools
Science management meetings (MC + WG)
Logistics Support (e.g. "Room rental")
Short Term Scientific Missions (STSMs)
Training Schools
Dissemination


COST Action TU1208
Chair of the Action
Lara Pajewski (IT)
"Roma Tre" University
lara.pajewski@uniroma3.it
Vice-Chair of the Action
Andreas Loizos (EL)
National Technical University of Athens
Science & Administrative Officers
Mickael Pero & Carmencita Malimban (BE)
COST Office
Start date – End date
4th April 2013 – 3rd April 2017
DC Rapporteur
Goran Mladenovic (RS)
University of Belgrade
Visit our website and download the MoU at www.GPRadar.eu
You can still join the Action !!


TU1208 Main Objective
Exchange and increase scientific-technical knowledge and experience of GPR techniques in Civil Engineering, simultaneously promoting throughout Europe the effective use of this safe and non-destructive technique.
The COST Action TU1208 is establishing and strengthening active links between universities, research institutes, companies and end users working in this field, fostering and accelerating its long-term development in Europe.


TU1208 Background
Areas to be addressed in order to promote the GPR use in Civil Engineering:
Advancement of GPR systems: increase of sensitivity to enable usability in a wider range of conditions, increase of amount and quality of collected data through the use of arrays of novel multi-frequency multi-polarization sensors.
Development of data processing/EM algorithms: improve quality of GPR images, improving shape reconstruction and quantitative estimation of EM parameters, characterize a priori complex scenarios, ease interpretation of results.

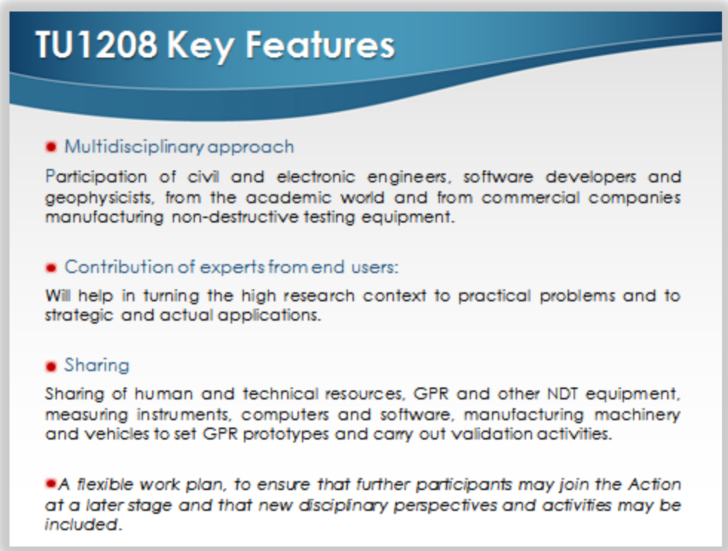


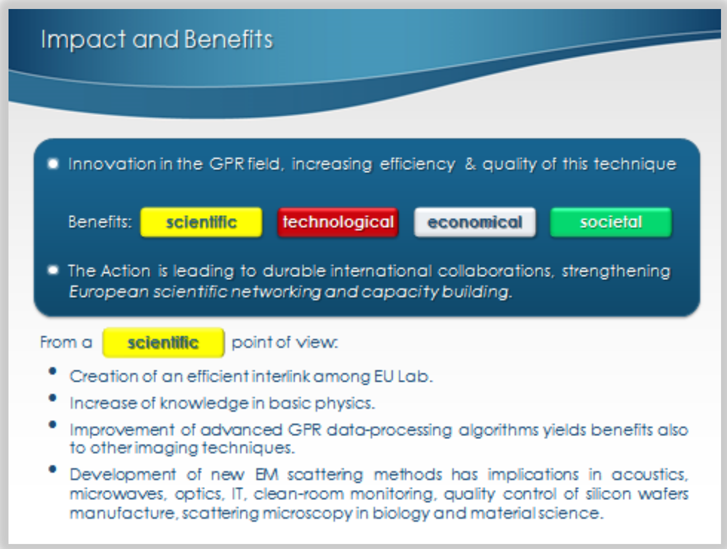


COST is supported by the EU RTD Framework Programme.

ESF provides the COST Office through a European Commission Contract. The Council of the EU provides the COST Secretariat.

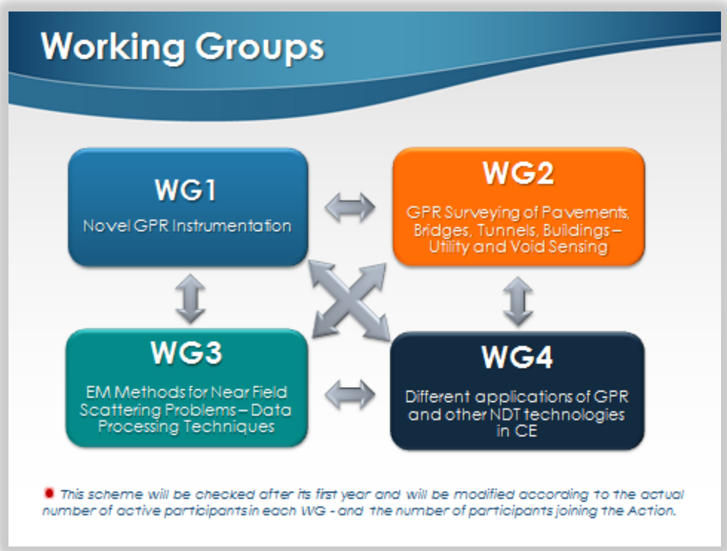

TU1208 Objectives
Interaction with other COST Actions
Interaction with other European and international research projects
Establishment of cooperation with
IEEE
EAGE
EUROPEAN GPR ASSOCIATION
FEHRL
Promotion of Early-Stage Researchers and of gender balance


TU1208 Key Features
Multidisciplinary approach
Participation of civil and electronic engineers, software developers and geophysicists, from the academic world and from commercial companies manufacturing non-destructive testing equipment.
Contribution of experts from end users:
Will help in turning the high research context to practical problems and to strategic and actual applications.
Sharing
Sharing of human and technical resources, GPR and other NDT equipment, measuring instruments, computers and software, manufacturing machinery and vehicles to set GPR prototypes and carry out validation activities.
A flexible work plan, to ensure that further participants may join the Action at a later stage and that new disciplinary perspectives and activities may be included.


Impact and Benefits
Innovation in the GPR field, increasing efficiency & quality of this technique
Benefits: scientific technological economical societal
The Action is leading to durable international collaborations, strengthening European scientific networking and capacity building.
From a scientific point of view:
Creation of an efficient interlink among EU Lab.
Increase of knowledge in basic physics.
Improvement of advanced GPR data-processing algorithms yields benefits also to other imaging techniques.
Development of new EM scattering methods has implications in acoustics, microwaves, optics, IT, clean-room monitoring, quality control of silicon wafers manufacture, scattering microscopy in biology and material science.

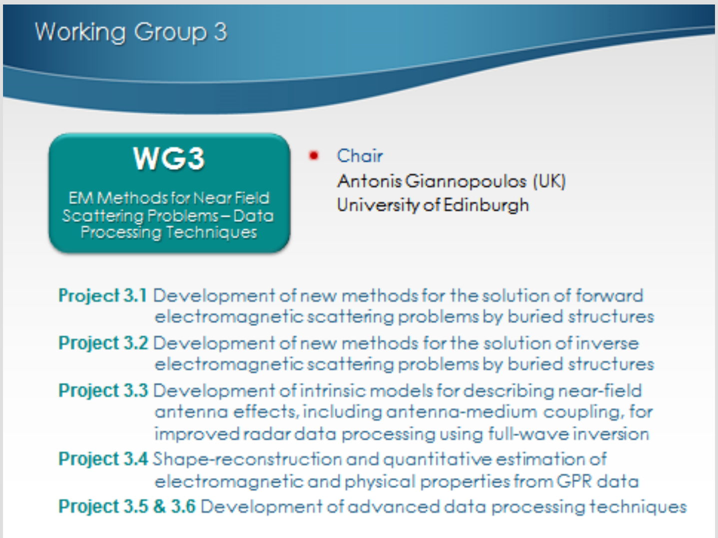

Impact and Benefits
The technological impact is clear when considering the innovative GPR equipment that will be designed, fabricated and tested through the activities of this Action.
Societal and economical benefits derive from the wider and more effective application of GPR that will take place thanks to the Action's activities.
Many structures/infrastructures are affected all over Europe and throughout the world, by diffused poor condition which influences the safety of citizens. Where structural rehabilitation is ineffective or absent, or sub-standard management planning is adopted and ineffective traditional tools are used, the cost of maintenance dramatically increases.
Other areas using GPR that will take advantage of the Action:
archaeology, detection of landmines/explosive remnants of war, planetary exploration, geology, geophysics, agriculture, environment research, forensics and security.

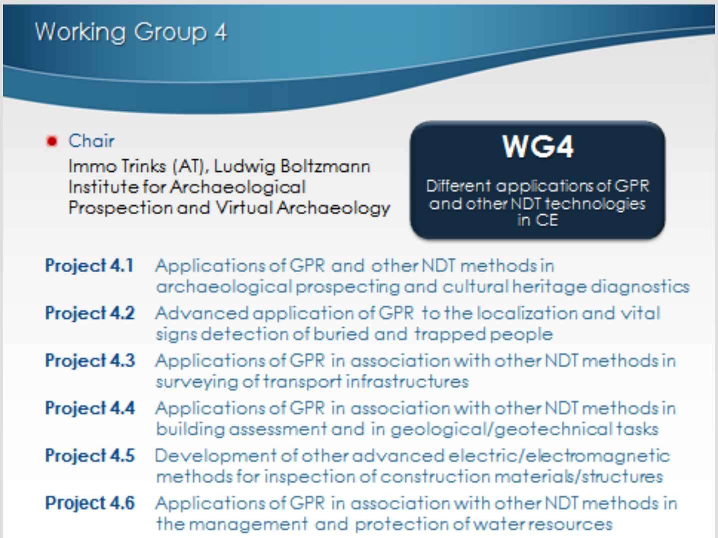

TU1208 Participants
Universities
Research Institutes
Small and Medium Enterprises
GPR manufacturers
Public Agencies responsible for infrastructure management and maintenance
Other end users
180 Members
100 Institutions
Armenia
Ukraine
USA
Rwanda
Australia
Austria
Belgium
Croatia
Czech Republic
Denmark
Estonia
Finland
France
Germany
Greece
Italy
Latvia
Macedonia
Malta
Netherlands
Norway
Poland
Portugal
(Romania)
Slovakia
Slovenia
Spain
Switzerland
Turkey
United Kingdom


Working Groups
WG1
Novel GPR Instrumentation
WG2
GPR Surveying of Pavements, Bridges, Tunnels, Buildings – Utility and Void Sensing
WG3
EM Methods for Near Field Scattering Problems – Data Processing Techniques
WG4
Different applications of GPR and other NDT technologies in CE
This scheme will be checked after its first year and will be modified according to the actual number of active participants in each WG - and the number of participants joining the Action.


Working Group 1
WG1
Novel GPR Instrumentation
Chair
Guido Manacorda (IT)
IDS Ingegneria dei Sistemi
Vice-Chair
Luca Gamma (CH)
Scuola Universitaria Professionale
della Svizzera Italiana
Project 1.1
Design, realization and optimization of innovative GPR equipment for the monitoring of critical transport infrastructures (pavements, bridges and tunnels)
Project 1.2
Development and definition of advanced testing, calibration and stability procedures and protocols, for GPR equipment


Working Group 2
Chair
Christina Plati (EL)
National Technical University Athens
Vice-Chair
Xavier Derobert (FR)
IFSTTAR
WG2
GPR Surveying of Pavements, Bridges, Tunnels, Buildings – Utility and Void Sensing
Innovative inspection procedures for effective GPR surveying of ...
Project 2.1
...critical transport infrastructures (pavements, bridges and tunnels)
Project 2.2
...buildings
Project 2.3
...underground utilities and voids, with a focus to urban areas
Project 2.4
...construction materials and structures
Project 2.5
Determination, by using GPR, of the volumetric water content in structures, sub-structures, foundations and soil


Working Group 3
WG3
EM Methods for Near Field Scattering Problems – Data Processing Techniques
Chair
Antonis Giannopoulos (UK)
University of Edinburgh
Project 3.1 Development of new methods for the solution of forward electromagnetic scattering problems by buried structures
Project 3.2 Development of new methods for the solution of inverse electromagnetic scattering problems by buried structures
Project 3.3 Development of intrinsic models for describing near-field antenna effects, including antenna-medium coupling, for improved radar data processing using full-wave inversion
Project 3.4 Shape-reconstruction and quantitative estimation of electromagnetic and physical properties from GPR data
Project 3.5 & 3.6 Development of advanced data processing techniques


Working Group 4
Chair
Immo Trinks (AT), Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology
WG4
Different applications of GPR and other NDT technologies in CE
Project 4.1 Applications of GPR and other NDT methods in archaeological prospecting and cultural heritage diagnostics
Project 4.2 Advanced application of GPR to the localization and vital signs detection of buried and trapped people
Project 4.3 Applications of GPR in association with other NDT methods in surveying of transport infrastructures
Project 4.4 Applications of GPR in association with other NDT methods in building assessment and in geological/geotechnical tasks
Project 4.5 Development of other advanced electric/electromagnetic methods for inspection of construction materials/structures
Project 4.6 Applications of GPR in association with other NDT methods in the management and protection of water resources

Time-table

Year 1

- Collection and sharing of information about state-of-the-art, ongoing studies and open problems, in the field of CE applications of GPR.
- Definition and coordination of test scenarios, representing both typical and unusual situations that may occur in CE applications, for an advanced comparison of available GPR equipment, inspection techniques, EM methods and data-processing algorithms, to be performed during the next year of activity.
- Creation of end-user database.
- Set-up of an advanced communication system, for partnership integration and dissemination of results. Set-up of the Action website.
- Short-Term Scientific Missions

Time-table

Year 2

- Multidisciplinary and multinational application and comparison of GPR equipment, inspection practice, EM and data-processing algorithms.
- Strong human exchange and sharing of resources: numerous Short-Term Scientific Missions.

Year 3

- Outline and test of innovative inspection procedures, on the basis of the activity carried out during the previous years.
- Codification and development of new EM algorithms and of new methods for an effective data-processing.
- Assessment for design of novel GPR equipment and prototype realization.
- Short-Term Scientific Missions!

Time-table

Year 4

- Critical study and review of results obtained during preceding years.
- Coordination and elaboration of a handbook with protocols and guidelines at EU level.
- Optimization of the new EM and data-processing codes. Realization of graphical user interface and manuals. Releasing freeware software for the benefit of GPR community.
- Test and optimization of the new GPR equipment.
- Short-Term Scientific Missions!

www.GPRadar.eu

"matGPR: A BRIEF INTRODUCTION"

Andreas Tzanis - Department of Geophysics, University of Athens
atzanis@geol.uoa.gr

Abstract

The Ground Probing Radar (GPR) has become an invaluable means of exploring shallow structures for geoscientific, engineering environmental and archaeological work. At the same time, GPR analysis software is mostly proprietary and expensive. The academic freeware community has been slow to react and the limited free software is usually highly focused on specific problems and generally unorganized. This paper describes the result of a continued effort to produce a cross-platform freeware analysis and interpretation package, which can also be expandable and customizable to the requirements of a particular user with relatively little programming effort. MATLAB ™ is an ideal platform for the development of such a kind of software, as it offers a complete programming environments and solutions for the development of advanced analysis software. The result of this undertaking, matGPR Release 2, is a GUI-driven, user friendly program providing a quite broad and functional range of tools for the analysis and visualization of zero and single-offset GPR data collected with several different types of instruments. However, the effort is by no means complete: notwithstanding its present utility, one can think of a multitude of analysis tools that can and will be included in future releases of matGPR, which will be available to the interested GPR practitioner in the spirit of the GNU project.

I. GENERAL FEATURES AND ORGANIZATION

matGPR is a two-layered software system, in which the bottom layer comprises a suite of functions to handle, display, inspect and process the data, while the top layer organizes these functions, automating data management and streamlining the flow of work.

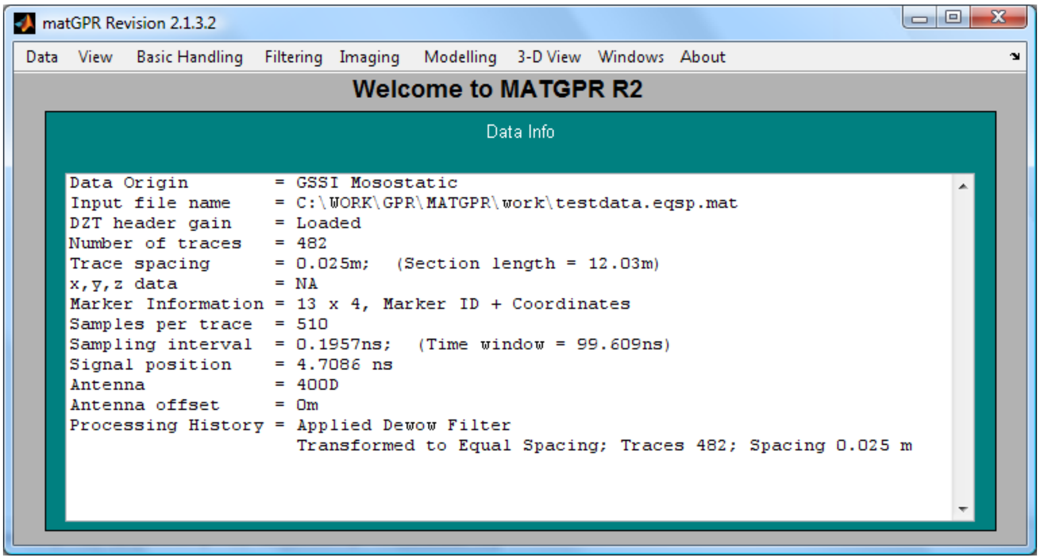


Figure 1. The matGPR GUI, complete with information about the data being handled and its processing history.

The top layer and backbone of the program is realized in the form of the matGPR GUI (Figure 1). Data management decisions are made with the appropriate choices under the Data menu. Visualization and inspection is facilitated by utilities offered in the View menu, while processing and interpretation utilities can be found in the Basic Handling, Filtering, Imaging and Modeling menus. The 3D-View menu provides a suite of functions to assemble, manipulate and visualize three-dimensional GPR data volumes and the Windows menu offers a fast navigation and window-switching service exclusive to matGPR. Finally, the About menu includes the on-line help and updater services.

The operation of the program is quite simple and succinctly outlined in Figure 2: work flows in a continuous cycle between the current Input Data, i.e. that data before some processing operation (step) and the Output Data, i.e. the data resulting from this operation. One may import, display and inspect the Input Data with the appropriate choices under the Data and View menus. Then one decides and applies a

processing step and displays/ inspects the result, i.e. the Output Data. If satisfied, one keeps (holds) the result, replacing the Input Data with the Output Data and repeats the cycle with a new processing step. If not, one may discard the result and cycle with another processing step. A multi-level undo/ restore utility is available at any time at which control is returned to the matGPR GUI. The Input Data may also be saved/ exported via the matGPR GUI. Soft and hard copies of the Input and Output Data (and any figure produced during a session), can be made at any time using the FigureTools menu of the figure windows (see below). The IPD and OPD structures are accessible through MATLAB's base workspace and can be used or manipulated independently.

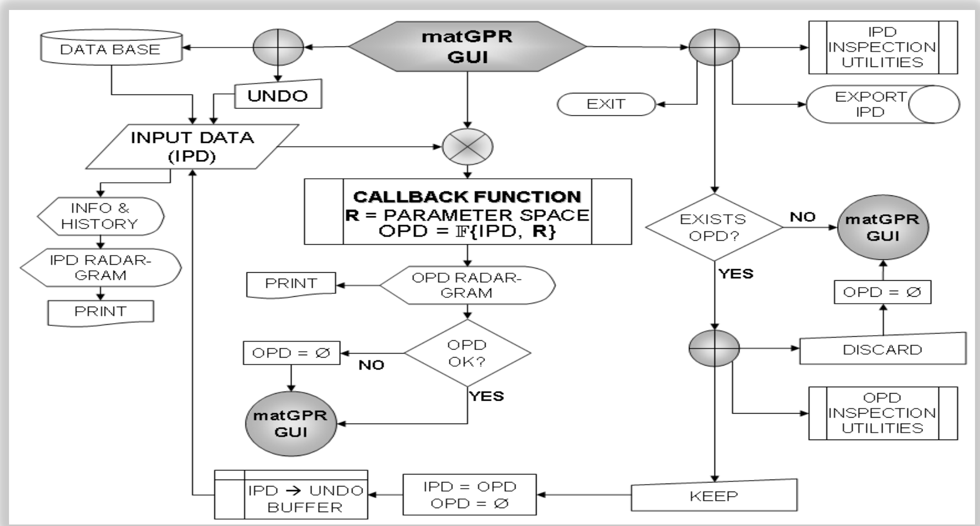


Figure 2. The flowchart of a data analysis session with matGPR.

matGPR is a modular program With the exception of the management and direct visualization utilities each module performs a self-contained operation. In Figure 2, a module is displayed as a subprogram which includes (calls) the analysis function F{IPD,**R**}, where **R** is the set of

parameters required for the execution of F. Now, consider that M-code (MATLAB's language) executes rather slowly, on account of being interpreted and not compiled. This may be a serious shortcoming when it comes to computationally intensive tasks. However, MATLAB offers three solutions.

- It makes an honest effort to use an efficient programming style: for many applications, vectorized and well-written M-code is as fast as compiled code, to the point of being competitive.
- It can integrate fast, compiled C or FORTRAN code with M-code by means of the MEX-file concept. The FORTRAN-MEX sources are included in the distribution bundle, so that the MEX-file may be (re)built if its functionality is somehow lost.
- It provides a set of alternative (computationally intensive) functions that drive external, stand-alone FORTRAN executables to do the number crunching.

Details about which processes use MEX-files or alternative functions and how to implement them can be found in the matGPR Documentation.

The modular architecture of matGPR allows one to expand the program with new analysis modules easily and without having to know many details about the program's infrastructure. At any rate, familiarity with the MATLAB language and graphical object manipulations in particular, is necessary. The matGPR Documentation provides detailed instructions of how to expand the program.

II. Input and Output Utilities

matGPR can import raw data in the formats of the GPR manufacturers GSSI (DZT), Måla Geophysics (RD3), Sensors and Software (DT1) and ZOND (SEG-Y), as well as data stored in Seismic Unix (SU) and SEG-Y Revision 0 and Revision 1 formats. Only single-channel data files are acceptable, inasmuch as matGPR is currently being offered for zero- or single-offset surveys.

With reference to RAMAC/ RD3 data, as of Release 3 it is possible to import and assimilate GPS trace positioning, if available, by decoding the associated .cor file where GPS information is stored. The positions of the GPS-located traces are projected in the UTM coordinate system and are treated as marker traces: they are stored in the IPD.markertr field whence they can be manipulated in various ways.

With reference to bistatic Pulse Ekko (DT1) radars, only data recorded in reflection mode (single-offset) are fully supported. Multiple-offset data, (e.g. CMP gathers) can be imported and displayed, but at this stage of development, matGPR does not offer any processing utilities beyond rudimentary editing and filtering.

Prior to importing any raw data and at any time during a matGPR session, the user can inspect the complete information held in the file header of any one of the supported data formats.

Consecutive or broken sections can be joined into a single data set via a specialized GUI.

matGPR can save the IPD either in the native MGP-file format (default), or in MATLAB binary format (native MAT-file), for long-term storage and fast access during subsequent analysis sessions. The current IPD can be saved at any time during a processing session.

For distribution or exchange, the data can be exported to SEG-Y Revision 1, SU and DZT file format.

It is possible to undo any number of processing steps in order to restore the data to a previous state. A GUI facilitates this operation and lets the user decide at which state he/she desires to restore the data. The number of undo's is user specified and can be changed during runtime.

III. Data Visualization and Properties

Data visualization options include image (colour-graded) displays with several colour maps, wiggle-trace displays, variable-area displays as well as their combinations. Utilities are also provided to:

- Change the colour map and colour scheme of image displays.
- Edit the colour scheme, zoom, pan, peek elements (pixels) of the data matrix, export the display in all standard graphics formats, print the display and edit the display figure, the data axes figure and their children objects.

It is also possible to display, zoom, pan, peek, export, print, edit and evaluate:

- Individual IPD and OPD traces.
- Individual IPD and OPD trace spectra.
- The time-frequency characteristics of IPD and OPD traces.
- The attenuation characteristics of the IPD and OPD.
- The instantaneous attributes of the IPD radargram.
- The centroid frequency of the IPD radargram.

IV. Basic Processing

matGPR offers a collection of rudimentary and data handling (conditioning) procedures that include:

- Graphically assisted determination and adjustment of time-zero.
- Graphically assisted Time-Window Trimming. It is common for the later parts of the traces to contain noise; matGPR allows one to reduce of the size of the radargram by discarding late-time arrivals. In combination with time-zero adjustment, this is useful for extracting a certain part of the data for some specific purpose.
- Graphically assisted Spatial-Window trimming. This allows one to discard traces at the beginning or the end of the radargram, or extract parts of the radargram to a separate data set.
- Graphically assisted elimination of errant traces appearing singular or in small groups (for instance due to the antenna coupling with local ground features or bouncing on small obstacles).
- Per-trace DC component removal.
- Dewow filtering.
- Trace Equalization.

- Gain Manipulation with the following options: 1) Standard Automatic Gain Control (AGC); 2) Gaussian-tapered AGC (Automatic Gain Control); 3) Inversion of Amplitude Decay, which applies a smooth empirical gain function that exactly compensates the mean or median amplitude attenuation observed in a radargram; 4) Inversion of Power Decay, which applies an inverse power-law compensation of the mean or median power attenuation and may also be used for the spherical divergence correction.
- Resampling (increase or decrease of the sampling-rate) in time and/or space with band limited sinc interpolation.
- Marker Interpolation and Trace Positioning utilities. These include: editing and management of marker traces, i.e., traces whose locations are a priori assigned with reference to a local coordinate frame; transformation of data collected in equal-time spacing mode, to data at equal-distance spacing for GPR instruments without survey wheels or other automatic triggering devices - this can be done by piecewise cubic Hermite polynomial interpolation between marker traces, or by stacking with reference to the location of the marker traces; assignment of x, y and z coordinates to the IPD traces by reference to the known coordinates of marker traces - this information can be used in the application of static corrections (see below), as well as for 2D and 3D data visualization.
- Planning and execution of batch jobs (sequential processing) on single or multiple data sets (IPDs). All operations available for batch-mode execution pertain to data conditioning; those manipulating structural or geometric information are deliberately not included in a batch job. Operations available for execution in batch mode include: 1) Time-zero adjustment; 2) Time window Trimming; 3) Per-trace subtraction of the DC component; 4) Dewow; 5) Standard Automatic Gain Control; 6) Gaussian-tapered AGC; 7) Amplification by the Inverse Power Decay method; 8) Amplification by the Inverse Amplitude Decay method; 9) Modification of the sampling rate; 10) Modification of trace spacing; 11) Trace equalization; 12) Global Background (mean trace) subtraction; 13) Karhunen – Loeve Filtering; 14) FIR Frequency

Filtering; 15) B-Spline Wavelet Filtering; 16) F-X Deconvolution; 17) Predictive Deconvolution.

V. ADVANCED PROCESSING

matGPR offers an extensive suite of advanced to very advanced processing utilities. These include:

- Mean and median spatial filtering in one and two dimensions.
- Foreground/ Background Trace manipulation:
- Background (mean) trace subtraction to reduce source effects.
- Removal of a sliding window's mean (background) trace to expose high-angle dipping reflections.
- Removal of a sliding-window's "foreground" traces to eliminate high-angle reflections and enhance horizontal (e.g. hydrogeologic features).
- Karhunen–Loeve filtering based on a low-dimensional subspace approximation of the radargram. This is extremely useful in eliminating small-scale data components to enhance lateral coherence, or very large-scale (low frequency/ short wavenumber) spatio-temporal components and noise (e.g. banding).
- Graphically assisted design and implementation of zero-phase FIR filtering (low-pass, high-pass, band-pass, band-stop and notch), in the frequency domain (applied 'vertically' to traces), or, in the wavenumber domain (applied 'horizontally' to equally spaced traces).
- Interactive (graphically assisted) F-K filter design and implementation, facilitating the application of zone pass/stop filters, fan filters and up-dip/ down-dip mapping in the frequency - wavenumber domain.
- Advanced S/N enhancement and orientation-and-scale-sensitive data manipulation and information retrieval with: orientation-and-scale selective 2-D Wavelet and Gabor Filters, tunable multidirectional scale-selective 2-D Wavelet and Gabor Filters, and graphically assisted multi-scale & multidirectional curvelet based optimal filtering.
- Interactive (graphically assisted) Tau-P domain modelling and filtering.

- F-X Deconvolution for the suppression of random noise.
- Predictive Deconvolution to suppress multiple reflections and other reverberation (e.g. banding) in 2-D radargrams.
- Sparse Deconvolution to estimate a maximally parsimonious reflectivity structure of the subsurface.

VI. Data Imaging

matGPR offers a collection of imaging (migration) and modeling tools to assist in the interpretation. These require velocity analysis and velocity models constructed with in-house utilities. Notably, some migration routines incorporate frequency dependence of the phase velocity due to the frequency dependence of the dielectric constant, (resistivity and magnetic permeability are assumed to be constant). matGPR also provides a utility to manually calculate phase velocities. At present, "velocity analysis" means the graphically assisted manual fitting of diffraction front hyperbolae based on the premise of non-dispersive propagation in a uniform halfspace and targets comprising point diffractors, or finite sized objects with quasi-circular cross section. Imaging utilities include:

- Static (topographic) corrections (elevation data is necessary).
- 1-D Migration. The required uniform or layered velocity model may be generated internally via the hyperbola fitting procedure, imported from a disk file or supplied via an appropriate UI dialog box (the Get 1-D Velocity Model utility under the Imaging menu). One-dimensional migration techniques include: 1) F-K Time Migration for uniform or layered velocity structures (uses Stolt stretching to account for layered velocity structures); 2) Phase-Shifting Time Migration for uniform or layered velocity structures; 3) 1-D Depth Migration. The 1-D Depth Migration algorithm implemented in matGPR follows a rather complex procedure: first, it computes a time vs. depth function t(z) from the velocity vs. depth function v(t) and inverts it to z(t) by inverse

linear interpolation. Next, it remaps z(t) to depth z and, based on this function, remaps a trace y(t) to a trace y(z).

- 2-D Depth Migration. The necessary two-dimensional velocity model may either be read from a disk file, or generated by a suitable utility form a synthetic structural model previously prepared by the Model Builder utility specified in §5. The available options are: 1) Phase-shift Plus Interpolation (PSPI) migration for zero-offset data. The PSPI migration routine uses only the non-dispersive phase velocity term because, at present, there's no accurate method to interpolate the dispersive terms in the sense required by the Gazdag and Sguazzero algorithm. 2) 2-D Split-step Migration augmented to account for frequency dependence of the phase velocity (dispersion).

VII. Modelling

matGPR offers a utility, the Model Builder, to facilitate graphically assisted construction of 2-D structural models for use with the 2-D Depth Migration methods and for forward modelling. Each structural model comprises an ensemble of objects with polygonal or circular cross-sections and may be edited, saved and modified indefinitely. The model editing utilities include:

- Graphically assisted deletion of old objects or/and insertion of new objects.
- Graphically assisted modification of an object's geometry by relocation, removal of old vertices and insertion of new vertices (modifications may be undone).
- Interactive modification of an object's properties (dielectric constant, resistivity and magnetic permeability).
- Visualization enhancement utilities (e.g. colouring).

matGPR includes two modelling methods, both of which require synthetic structural models constructed with the Model Builder:

- A fast, Adjoint Split-Step approach, (modified and expanded method of Bitri and Grandjean, Geophysical Prospecting, 46, 287-301, 1998).

This is a fast and relatively dirty approach, lacking in detail (does not model secondary effects like multiples), and possibly prone to artifacts if applied indiscriminately. Conversely, it is efficient enough to effectively supplement the interpretation.

- The slow but precise Finite Difference Time-Domain method of Irving and Knight (Computers & Geosciences, 32, 1247–1258, 2006).

VIII. 3-D VISUALIZATION

matGPR offers a suite of functions to generate three-dimensional GPR data volumes using a stacking technique: It is assumed that the 3-D GPR survey has been conducted in a local co-ordinate system in which:

- Radargrams can have any shape, length, orientation and trace spacing with respect to the coordinate axes.
- The vertical axis can be either time or depth and the data do not need to have the same time window sizes or sampling rates, or depth window sizes, or depth spacing.
- Volumes can be created for absolute trace values, squared trace values, absolute-log trace values, instantaneous trace amplitude and instantaneous trace power.

The stacking procedure is as follows: The data files (in MGP and/or MAT formats only) are read in. For each file, traces that fall within a two-dimensional horizontal search window around a volume cell are transformed and stacked together. After all the data files have been processed, the final volume cell value is calculated by averaging all values added to it.

Visualization techniques include:

- The GPR-slice utility, to generate orthographic opaque or translucent slices that are: 1) horizontal and perpendicular to the vertical grid direction (z-axis); 2) vertical and perpendicular to the x-axis; 3) vertical and perpendicular to the y-axis. Prior to displaying, each slice may be smoothed with a robust discretized smoothing spline

technique. The horizontal and vertical size of the slices is controlled by the user. Slices may be added or removed from the display, thus enabling an arbitrarily intricate and detailed visualization of the data volume. The user controls the azimuth and elevation of the viewing position, the aspect ratio, the axes limits and the colour saturation (contrast) of the display.

- Isosurface displays, i.e., orthographic representations of the data in the form of lit isometric surfaces with equal signal amplitudes, or less rigorously stated lit surfaces of equal reflectivity. The user may manipulate the display by: 1) specifying the isosurface value (signal amplitude); 2) specifying the azimuth and elevation of the viewer position; 3) specifying the aspect ratio of the display and the direction of lighting (light position); 4) specifying the colour of the iso-surface.
- The 3-D Slices utility, to visualize the entire data volume with orthographic opaque or translucent slices parallel to the x-axis. Horizontal slices perpendicular to the z-axis and vertical slices perpendicular to the y-axis can be overlaid one at a time. The user controls the azimuth and elevation of the viewing position, the aspect ratio and the colour saturation of the display.

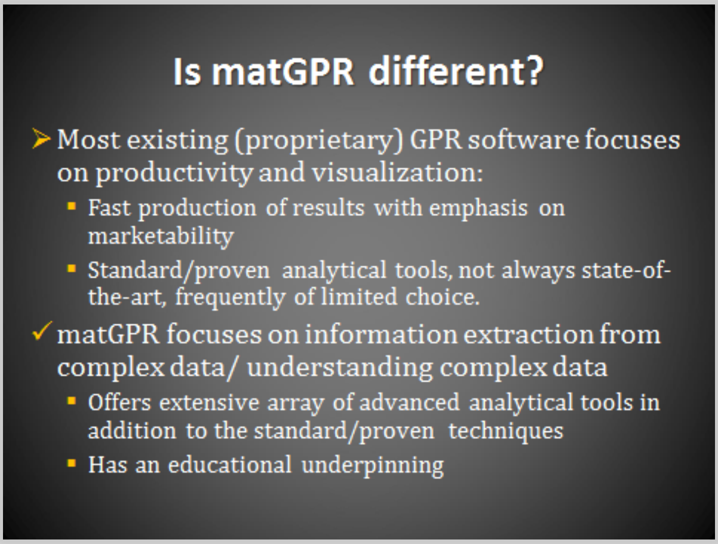
matGPR

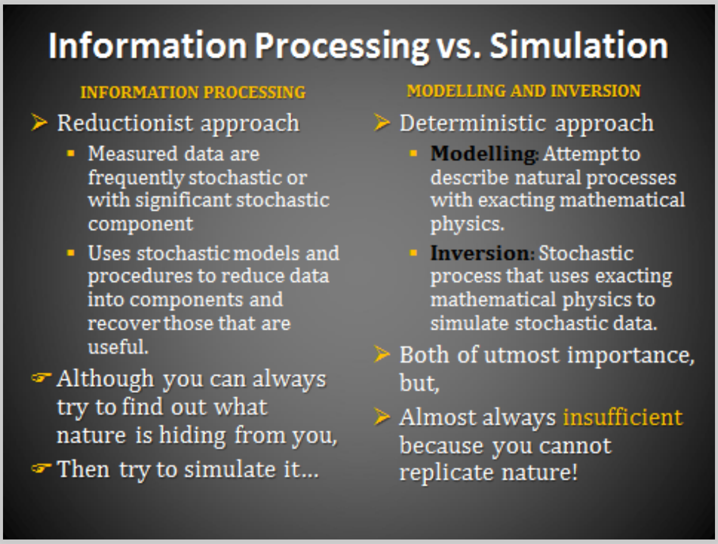
Andreas Tzanis, PhD

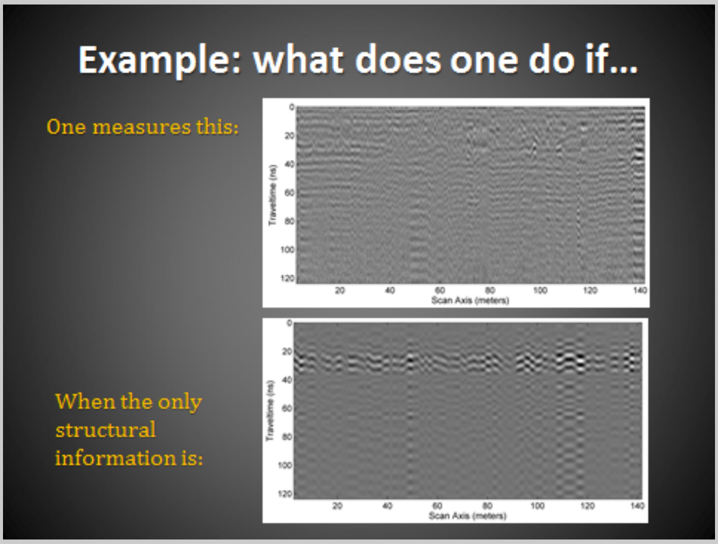
Department of Geophysics
National and Kapodistrian University of Athens

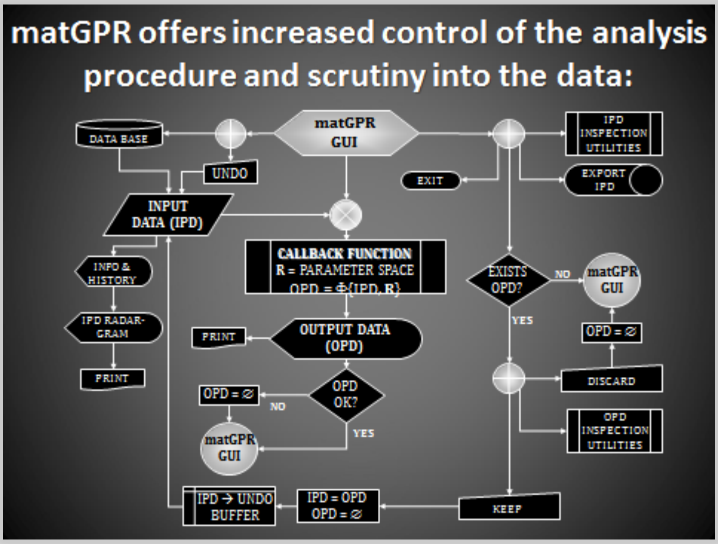
What is matGPR?

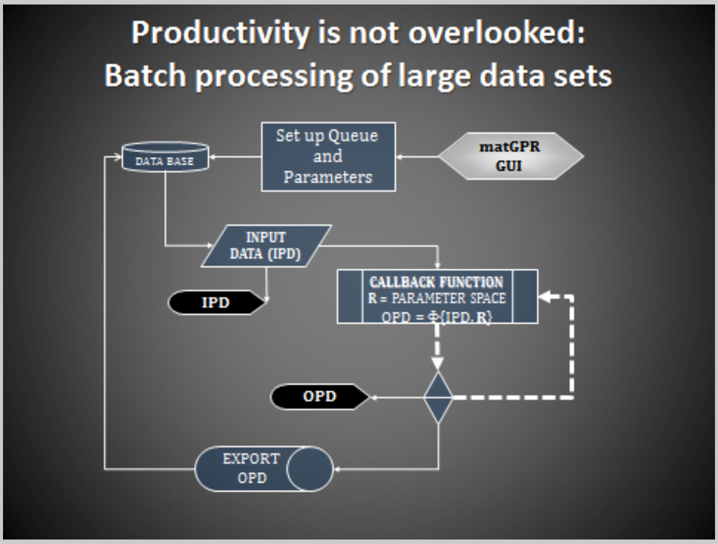
- ✓ Accessible and advanced GPR analysis and interpretation program …
  - Cross-platform
  - Expandable/ Customizable by its user
- ✓ … based on MATLAB™…
  - … which provides an all-inclusive high level programming and visualization environment.

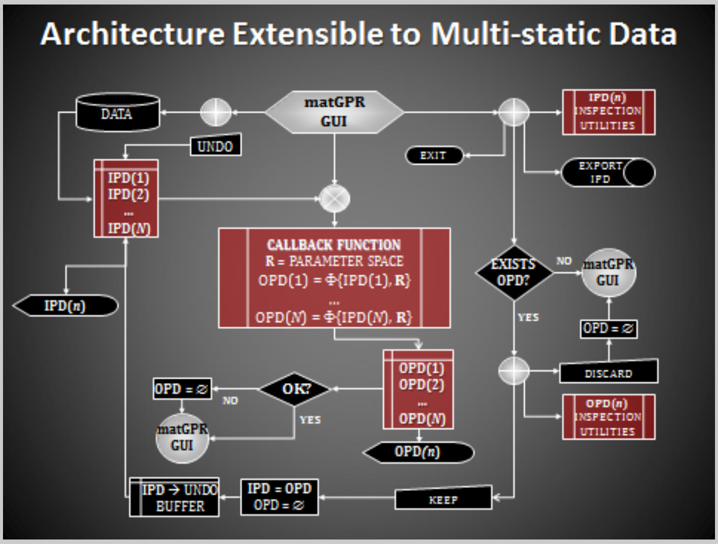

Is matGPR different?
Most existing (proprietary) GPR software focuses on productivity and visualization:
Fast production of results with emphasis on marketability
Standard/proven analytical tools, not always state-of-the-art, frequently of limited choice.
matGPR focuses on information extraction from complex data/ understanding complex data
Offers extensive array of advanced analytical tools in addition to the standard/proven techniques
Has an educational underpinning


Information Processing vs. Simulation
INFORMATION PROCESSING
Reductionist approach
Measured data are frequently stochastic or with significant stochastic component
Uses stochastic models and procedures to reduce data into components and recover those that are useful.
Although you can always try to find out what nature is hiding from you,
Then try to simulate it…
MODELLING AND INVERSION
Deterministic approach
Modelling: Attempt to describe natural processes with exacting mathematical physics.
Inversion: Stochastic process that uses exacting mathematical physics to simulate stochastic data.
Both of utmost importance, but,
Almost always insufficient because you cannot replicate nature!

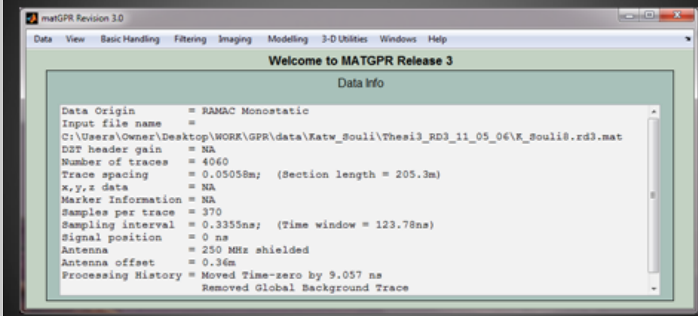

Example: what does one do if…
One measures this:
When the only structural information is:
Traveltime (ns)
Scan Axis (meters)


matGPR offers increased control of the analysis procedure and scrutiny into the data:
DATA BASE
matGPR GUI
IPD INSPECTION UTILITIES
UNDO
EXIT
EXPORT IPD
INPUT DATA (IPD)
CALLBACK FUNCTION
R = PARAMETER SPACE
OPD = Φ{IPD, R}
INFO & HISTORY
EXISTS OPD?
NO
matGPR GUI
IPD RADAR-GRAM
YES
PRINT
OUTPUT DATA (OPD)
OPD = ∅
PRINT
OPD = ∅
OPD OK?
NO
DISCARD
YES
matGPR GUI
OPD INSPECTION UTILITIES
IPD → UNDO BUFFER
IPD = OPD
OPD = ∅
KEEP


Productivity is not overlooked:
Batch processing of large data sets
DATA BASE
Set up Queue and Parameters
matGPR GUI
INPUT DATA (IPD)
IPD
CALLBACK FUNCTION
R = PARAMETER SPACE
OPD = Φ{IPD, R}
OPD
EXPORT OPD


Architecture Extensible to Multi-static Data
DATA
matGPR GUI
IPD(n) INSPECTION UTILITIES
UNDO
EXIT
EXPORT IPD
IPD(1)
IPD(2)
...
IPD(N)
CALLBACK FUNCTION
R = PARAMETER SPACE
OPD(1) = Φ{IPD(1), R}
...
OPD(N) = Φ{IPD(N), R}
EXISTS OPD?
NO
matGPR GUI
YES
IPD(n)
OPD = ∅
DISCARD
OPD = ∅
OK?
NO
YES
OPD(1)
OPD(2)
...
OPD(N)
matGPR GUI
OPD(n) INSPECTION UTILITIES
OPD(n)
IPD → UNDO BUFFER
IPD = OPD
OPD = ∅
KEEP

The matGPR GUI

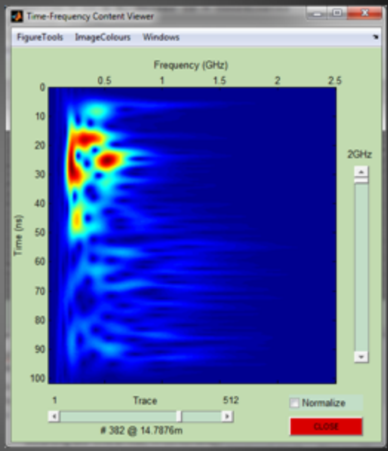


Data Properties and Visualization

- ✓ Image (colour-graded) displays, wiggle-trace displays, variable-area displays and combinatory displays
  - Colour scheme editing, zooming, panning, peeking, exporting to all standard graphics formats, printing, figure editing, axes editing, graph editing
- ✓ Individual traces and trace Fourier spectra
- ✓ **Time-frequency characteristics of traces.**
- ✓ **Attenuation characteristics** of the input and output radargrams
- ✓ The instantaneous attributes of the input radargram
- ✓ **Centroid frequency** of the input radargram
- ✓ **Curvature attributes** of the input radargram

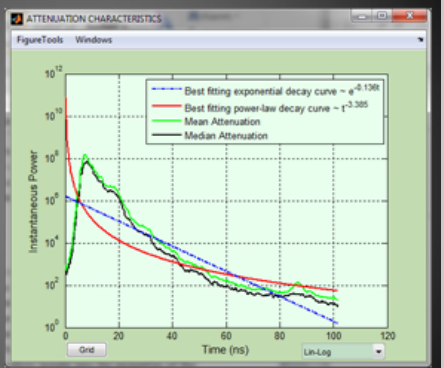
Time-Frequency analysis

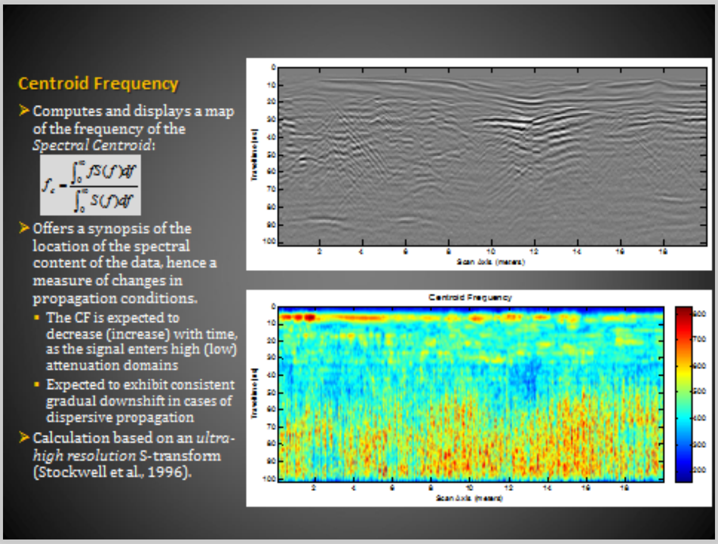
- Intended for detailed study of the input or output data.
- Computes a *time-frequency representation* of individual traces using the ultra-high resolution S-transform (Stockwell et al. 1996)
- Helpful in assessing the characteristics of propagation in complex media

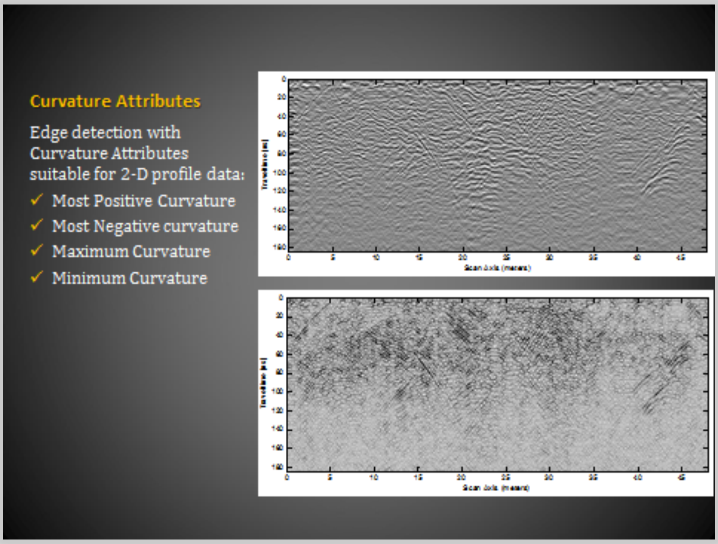


Attenuation Characteristics

- Allows insight into the properties of the propagation medium and facilitates gain manipulations
- Computes instantaneous power of all traces.
- Computes the median and mean instantaneous power of all traces in the section.
- Determines best fitting power-law and exponential attenuation models based on the median attenuation function.
- Displays attenuation functions and the best fitting power-law and exponential decay models.




Centroid Frequency
Computes and displays a map of the frequency of the *Spectral Centroid*:
$f_c = \frac{\int_0^\infty f S(f) df}{\int_0^\infty S(f) df}$
Offers a synopsis of the location of the spectral content of the data, hence a measure of changes in propagation conditions.
The CF is expected to decrease (increase) with time, as the signal enters high (low) attenuation domains
Expected to exhibit consistent gradual downshift in cases of dispersive propagation
Calculation based on an *ultra-high resolution* S-transform (Stockwell et al., 1996).
Centroid Frequency
Scan Axis (meters)


Curvature Attributes
Edge detection with Curvature Attributes suitable for 2-D profile data:
Most Positive Curvature
Most Negative curvature
Maximum Curvature
Minimum Curvature
Scan Axis (meters)

Basic Processing

- Graphically assisted determination and adjustment of time-zero
- Graphically assisted Trace and Radargram Editing utilities: Time-Window Trimming, Scan-line trimming.
- Elimination of errant traces
- DC removal, Dewow
- Equalization
- Gain Manipulation:
  - Standard and Gaussian-tapered Automatic Gain Control (AGC)
  - **Inversion of Amplitude Decay**
  - Inversion of Power Decay
- Resampling in *time* and/or *space* with band limited sinc interpolation.
- Marker Interpolation and Trace Positioning
  - Editing and management of *marker traces* whose locations are *a priori* assigned with reference to a local coordinate frame.
  - Transformation of data collected in equal-time mode, to data at equal-spacing.
  - Assignment of x, y and z coordinates to traces by reference to the known coordinates of marker traces.

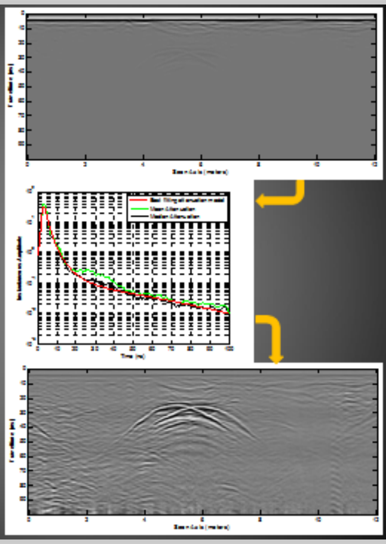
Inversion of Amplitude decay

Empirical gain function which almost exactly compensates the mean or median attenuation.

- Computes the median and a mean amplitude attenuation function from instantaneous amplitude of all traces
- Computes empirical best fitting attenuation models with a function of the form

$$A(t) = c_1 e^{-a_1 t} + c_2 e^{-a_2 t} + \cdots + c_N e^{-a_N t}$$

- Displays the mean and median attenuation and best fitting model and allows for interactive optimization
- The gain function is the normalized inverse of the amplitude decay model



Filtering – Advanced Filtering

- ✓ Mean and median spatial filtering in one and two dimensions.
- ✓ Background (mean) trace subtraction to reduce source effects
- ✓ Removal of a sliding window's mean (background) trace to expose high-angle dipping reflections.
- ✓ Removal of a sliding-window's "foreground" traces to eliminate high-angle reflections and enhance horizontal (e.g. hydrogeologic features)
- ✓ **Karhunen–Loeve filtering** based on low-dimensional subspace approximation
- ✓ Graphically assisted design and implementation of zero-phase FIR filters in the frequency and wavenumber domains.
- ✓ Interactive, graphically assisted F-K filter design and implementation
- ✓ S/N enhancement and *orientation and scale-sensitive* information retrieval with
  - **Tuneable Directional B-spline and Gabor Wavelet Filters**
  - **Tuneable Multidirectional Scale-selective B-spline and Gabor Wavelet Filters**
  - **Multi-scale/Multidirectional *Curvelet* based Optimal Filtering.**
- ✓ Graphically assisted Tau-P domain modelling and filtering
- ✓ F-X Deconvolution to suppress random noise.
- ✓ **Predictive Deconvolution** to suppress reverberation
- ✓ Sparse Deconvolution to obtain a maximally parsimonious reflectivity structure

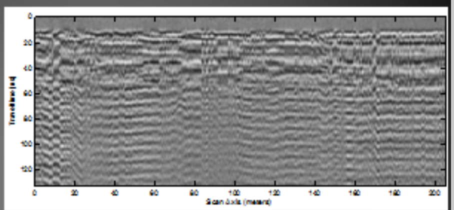
Karhunen – Loeve Filter

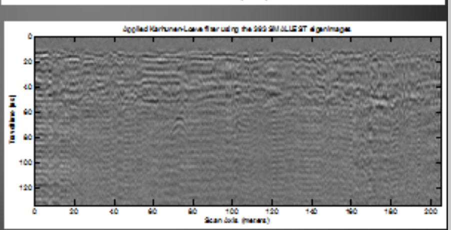
The Karhunen - Loeve transform is approximates a set of vectors or images by a with a low-dimensional subspace.

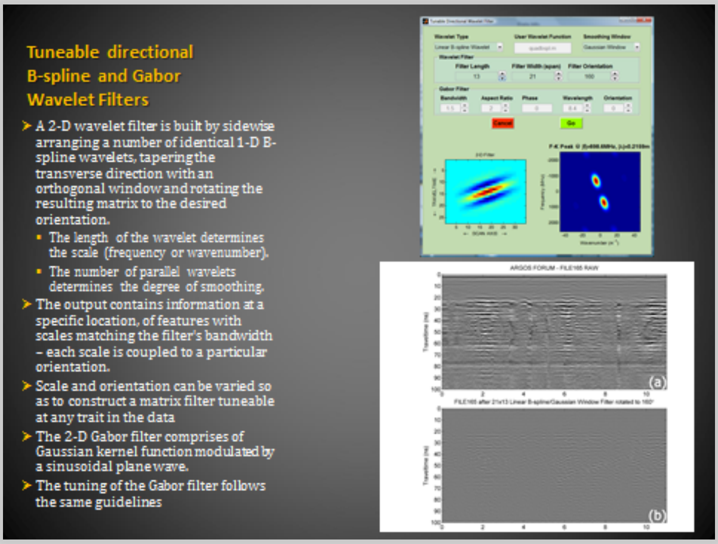
- The approximating subspace is defined in terms of the first (largest) N singular values and singular vectors (*eigenimages*) of the data.
- The appropriate value of N is unique for each data set and should be determined by experiment.

Example:

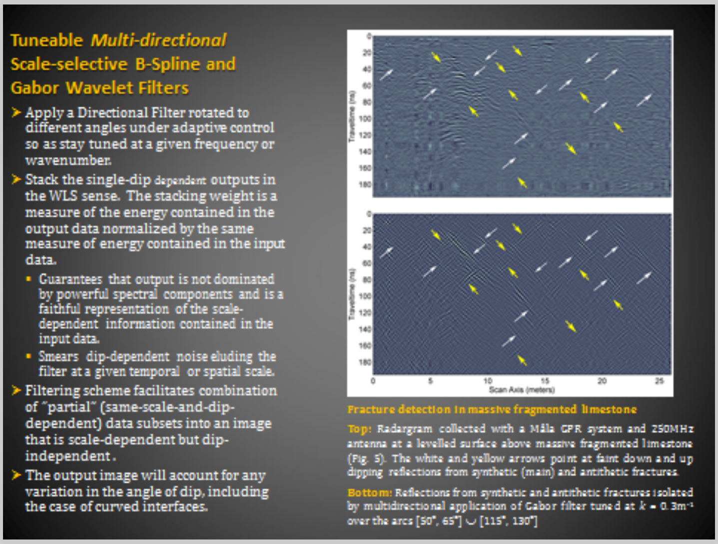
- **Top:** Full-space data comprising 397 eigenimages.
- **Bottom:** N = 4; complimentary low subspace approximation based on the 393 smallest eigenimage.
- Large scale interference is effectively removed.



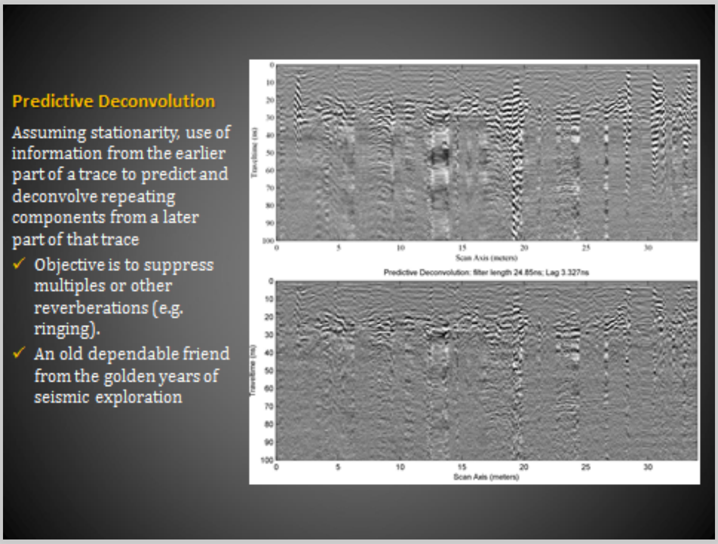


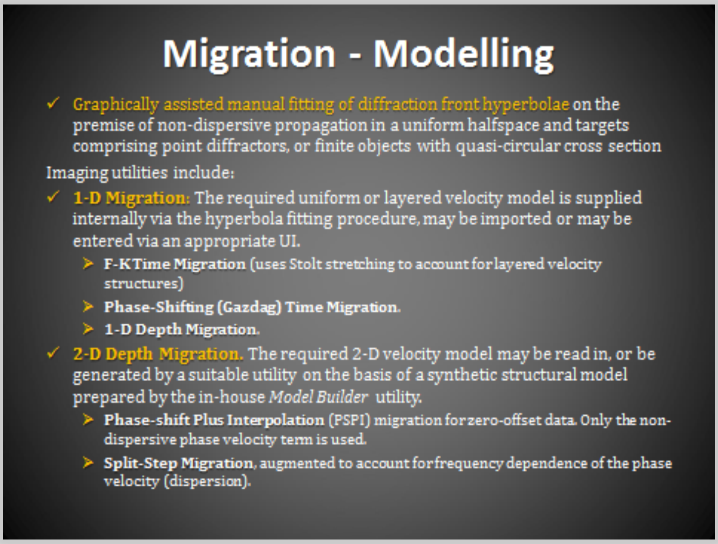


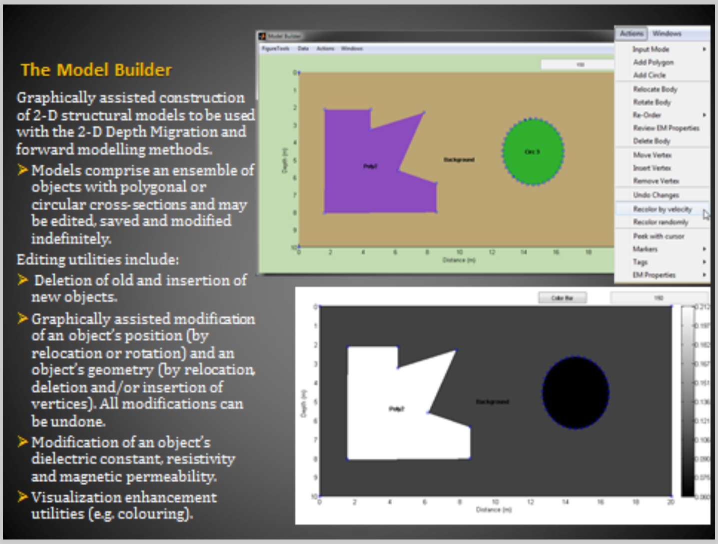
Tuneable directional
B-spline and Gabor
Wavelet Filters
A 2-D wavelet filter is built by sidewise arranging a number of identical 1-D B-spline wavelets, tapering the transverse direction with an orthogonal window and rotating the resulting matrix to the desired orientation.
The length of the wavelet determines the scale (frequency or wavenumber).
The number of parallel wavelets determines the degree of smoothing.
The output contains information at a specific location, of features with scales matching the filter's bandwidth – each scale is coupled to a particular orientation.
Scale and orientation can be varied so as to construct a matrix filter tuneable at any trait in the data
The 2-D Gabor filter comprises of Gaussian kernel function modulated by a sinusoidal plane wave.
The tuning of the Gabor filter follows the same guidelines
ARGOS FORUM - FILE165 RAW
(a)
(b)

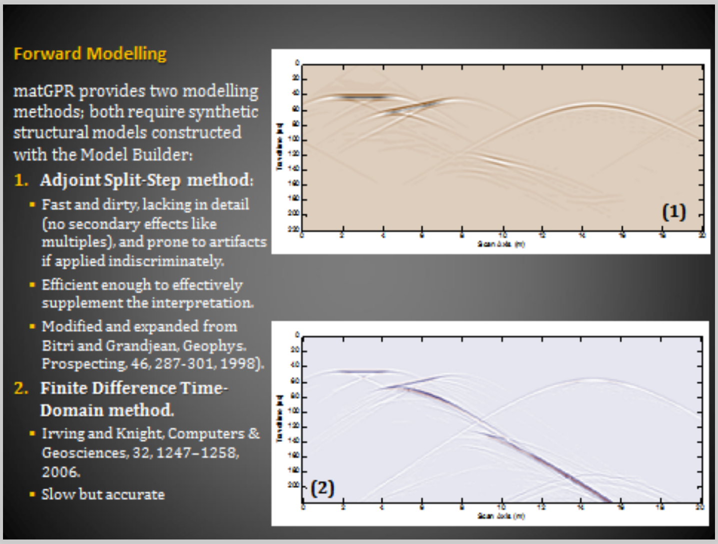


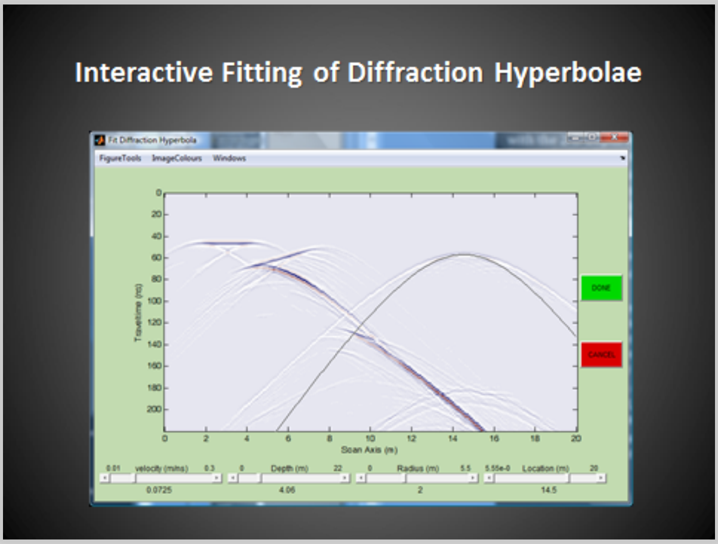
Tuneable Multi-directional
Scale-selective B-Spline and
Gabor Wavelet Filters
Apply a Directional Filter rotated to different angles under adaptive control so as stay tuned at a given frequency or wavenumber.
Stack the single-dip dependent outputs in the WLS sense. The stacking weight is a measure of the energy contained in the output data normalized by the same measure of energy contained in the input data.
Guarantees that output is not dominated by powerful spectral components and is a faithful representation of the scale-dependent information contained in the input data.
Smears dip-dependent noise eluding the filter at a given temporal or spatial scale.
Filtering scheme facilitates combination of "partial" (same-scale-and-dip-dependent) data subsets into an image that is scale-dependent but dip-independent.
The output image will account for any variation in the angle of dip, including the case of curved interfaces.
Traveltime (ns)
Scan Axis (meters)
Fracture detection in massive fragmented limestone
Top: Radargram collected with a Måla GPR system and 250MHz antenna at a levelled surface above massive fragmented limestone (Fig. 5). The white and yellow arrows point at faint down and up dipping reflections from synthetic (main) and antithetic fractures.
Bottom: Reflections from synthetic and antithetic fractures isolated by multidirectional application of Gabor filter tuned at k = 0.3m-1 over the arcs [50°, 65°] ∪ [115°, 130°]

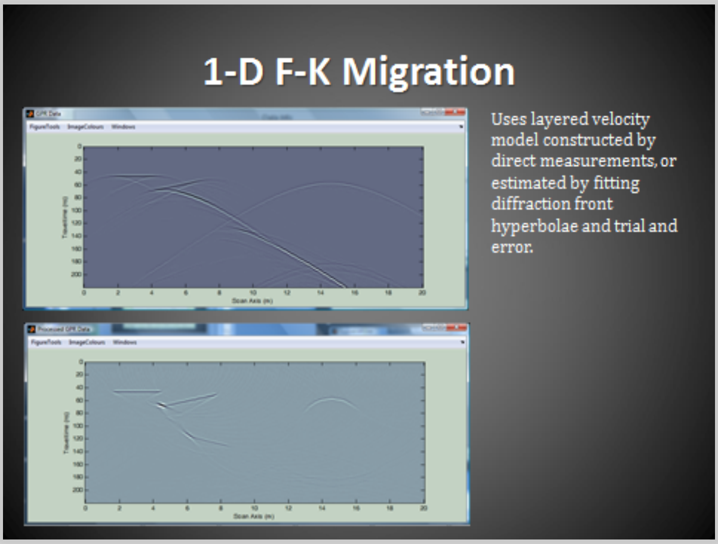

Predictive Deconvolution
Assuming stationarity, use of information from the earlier part of a trace to predict and deconvolve repeating components from a later part of that trace
✓ Objective is to suppress multiples or other reverberations (e.g. ringing).
✓ An old dependable friend from the golden years of seismic exploration
Predictive Deconvolution: filter length 24.85ns; Lag 3.327ns
Scan Axis (meters)

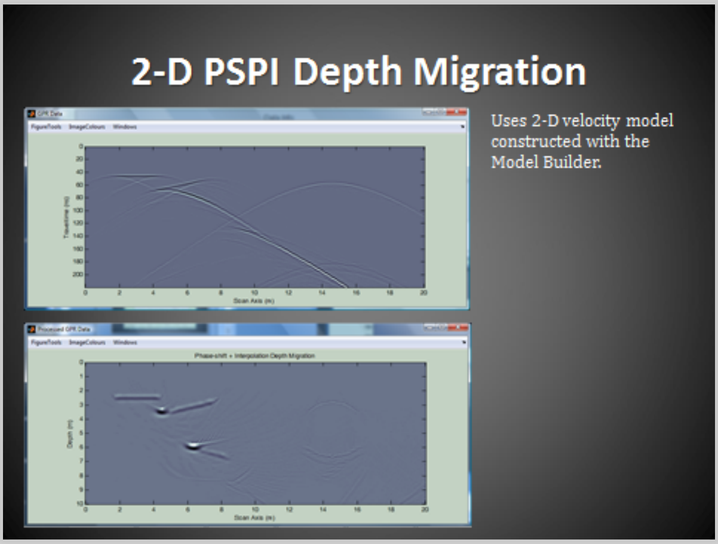

Migration - Modelling
✓ Graphically assisted manual fitting of diffraction front hyperbolae on the premise of non-dispersive propagation in a uniform halfspace and targets comprising point diffractors, or finite objects with quasi-circular cross section
Imaging utilities include:
✓ 1-D Migration: The required uniform or layered velocity model is supplied internally via the hyperbola fitting procedure, may be imported or may be entered via an appropriate UI.
➤ F-K Time Migration (uses Stolt stretching to account for layered velocity structures)
➤ Phase-Shifting (Gazdag) Time Migration.
➤ 1-D Depth Migration.
✓ 2-D Depth Migration. The required 2-D velocity model may be read in, or be generated by a suitable utility on the basis of a synthetic structural model prepared by the in-house Model Builder utility.
➤ Phase-shift Plus Interpolation (PSPI) migration for zero-offset data. Only the non-dispersive phase velocity term is used.
➤ Split-Step Migration, augmented to account for frequency dependence of the phase velocity (dispersion).

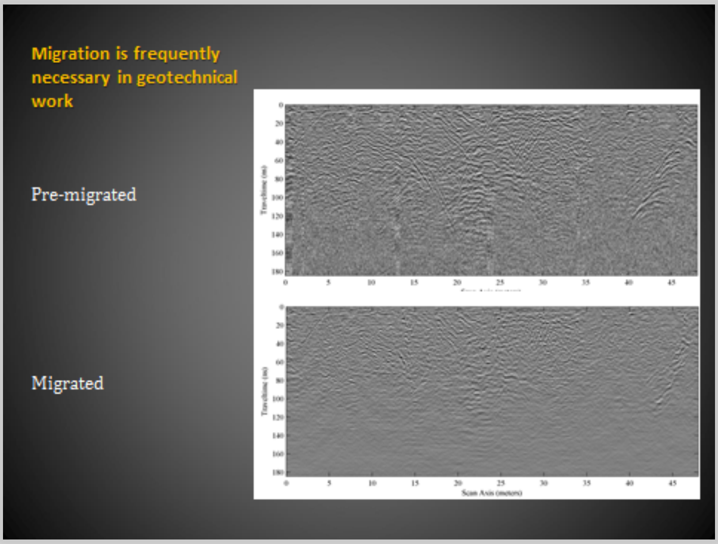

The Model Builder
Graphically assisted construction of 2-D structural models to be used with the 2-D Depth Migration and forward modelling methods.
➢ Models comprise an ensemble of objects with polygonal or circular cross-sections and may be edited, saved and modified indefinitely.
Editing utilities include:
➢ Deletion of old and insertion of new objects.
➢ Graphically assisted modification of an object's position (by relocation or rotation) and an object's geometry (by relocation, deletion and/or insertion of vertices). All modifications can be undone.
➢ Modification of an object's dielectric constant, resistivity and magnetic permeability.
➢ Visualization enhancement utilities (e.g. colouring).

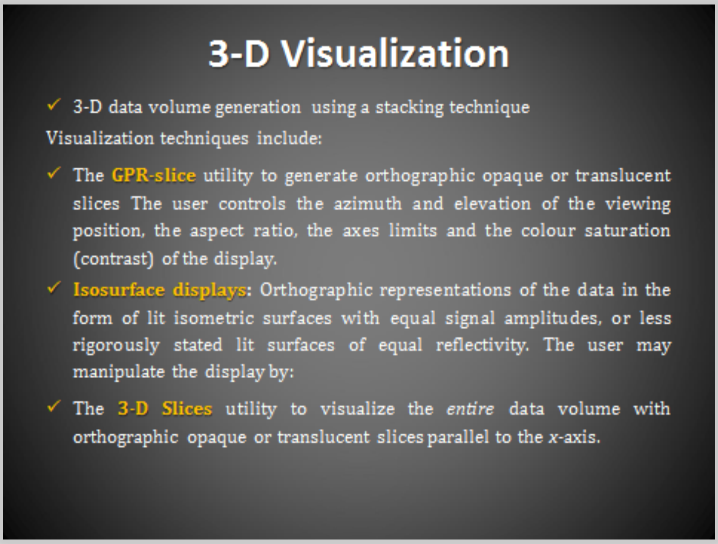

Forward Modelling
matGPR provides two modelling methods; both require synthetic structural models constructed with the Model Builder:
1. Adjoint Split-Step method:
▪ Fast and dirty, lacking in detail (no secondary effects like multiples), and prone to artifacts if applied indiscriminately.
▪ Efficient enough to effectively supplement the interpretation.
▪ Modified and expanded from Bitri and Grandjean, Geophys. Prospecting, 46, 287-301, 1998).
2. Finite Difference Time-Domain method.
▪ Irving and Knight, Computers & Geosciences, 32, 1247–1258, 2006.
▪ Slow but accurate
(1)
(2)

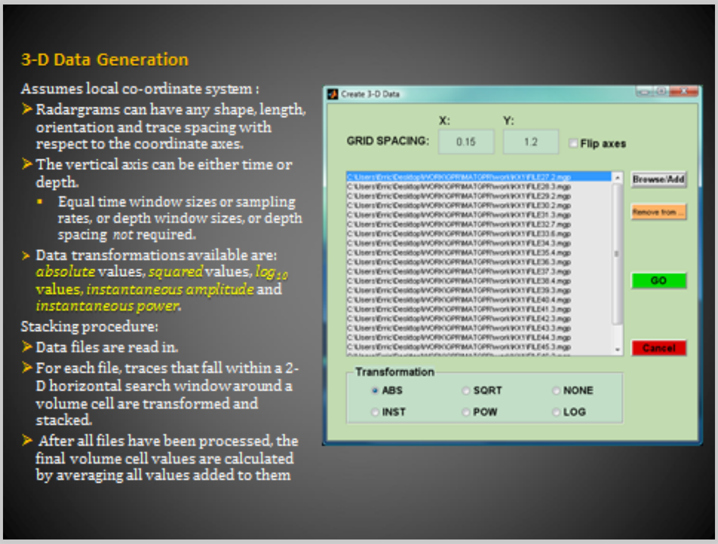

Interactive Fitting of Diffraction Hyperbolae
Fit Diffraction Hyperbola
FigureTools ImageColours Windows
Traveltime (ns)
Scan Axis (m)
DONE
CANCEL
velocity (m/ns)
Depth (m)
Radius (m)
Location (m)


1-D F-K Migration
Uses layered velocity model constructed by direct measurements, or estimated by fitting diffraction front hyperbolae and trial and error.


2-D PSPI Depth Migration
Uses 2-D velocity model constructed with the Model Builder.

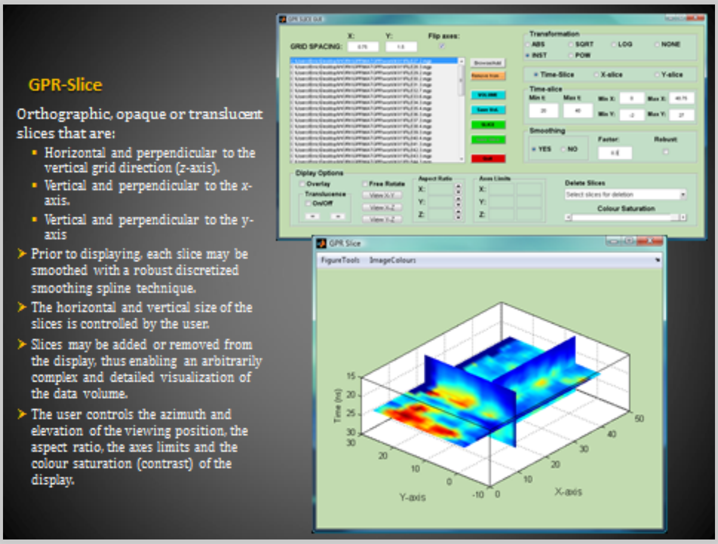

Migration is frequently necessary in geotechnical work
Pre-migrated
Migrated

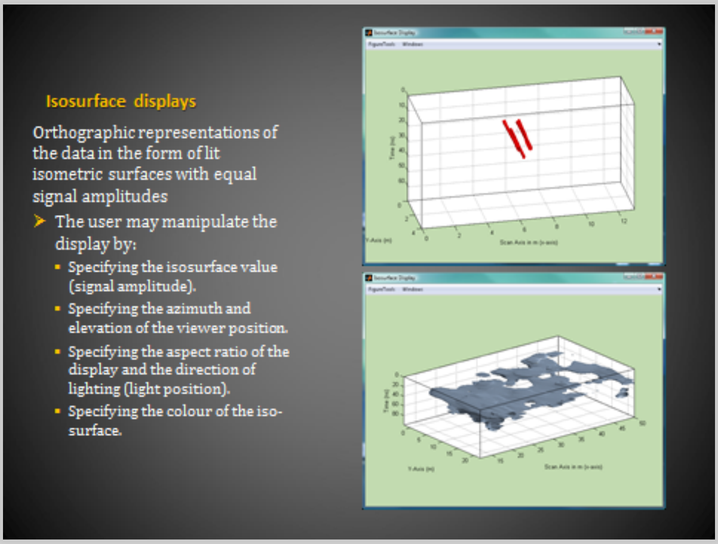




COST is supported by the EU RTD Framework Programme.

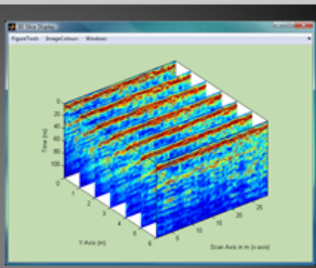
ESF provides the COST Office through a European Commission Contract. The Council of the EU provides the COST Secretariat.

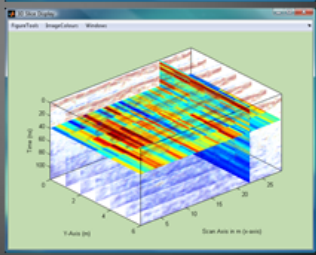

GPR-Slice
Orthographic, opaque or translucent slices that are:
Horizontal and perpendicular to the vertical grid direction (z-axis).
Vertical and perpendicular to the x-axis.
Vertical and perpendicular to the y-axis
Prior to displaying, each slice may be smoothed with a robust discretized smoothing spline technique.
The horizontal and vertical size of the slices is controlled by the user.
Slices may be added or removed from the display, thus enabling an arbitrarily complex and detailed visualization of the data volume.
The user controls the azimuth and elevation of the viewing position, the aspect ratio, the axes limits and the colour saturation (contrast) of the display.
GPR Slice
Time (ns)
Y-axis
X-axis


Isosurface displays
Orthographic representations of the data in the form of lit isometric surfaces with equal signal amplitudes
The user may manipulate the display by:
Specifying the isosurface value (signal amplitude).
Specifying the azimuth and elevation of the viewer position.
Specifying the aspect ratio of the display and the direction of lighting (light position).
Specifying the colour of the iso-surface.

3-D Slices

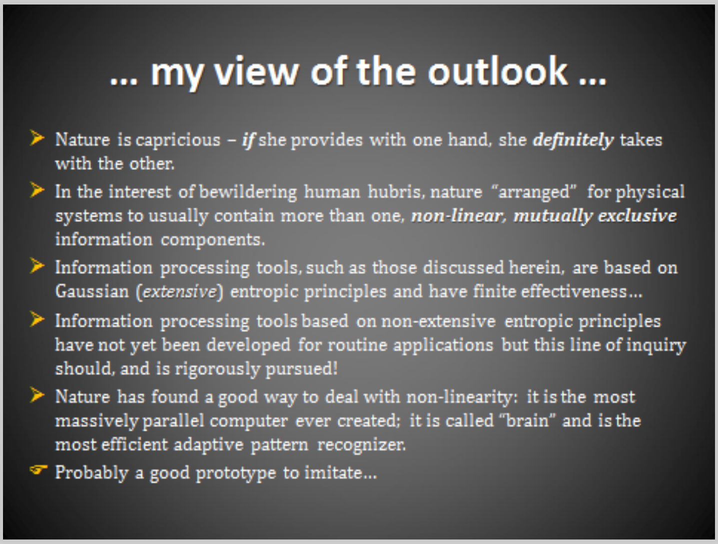
- Visualize the *entire* data volume with orthographic opaque or translucent slices parallel to the *x*-axis.
- Horizontal slices perpendicular to the z-axis and vertical slices perpendicular to the y-axis can be overlaid.
- The user controls the azimuth and elevation of the viewing position, the aspect ratio and the colour saturation of the display.





Future Feats Feasible …

- Speed-up FDTD model computations – possibly use vector FORTRAN.
- Introduce multi-offset data analysis
- Improve 3-D visualization (imperative)!
- Correct for effects of dispersive propagation
- Automatically recognize diffraction patterns and estimate diffractor size.
- Consider *curvelet-based scale-sensitive* migration
- Consider multi-static data manipulation and tomography.
- … not necessarily in this order and the list does not end here …


… my view of the outlook …
Nature is capricious – *if* she provides with one hand, she ***definitely*** takes with the other.
In the interest of bewildering human hubris, nature "arranged" for physical systems to usually contain more than one, ***non-linear, mutually exclusive*** information components.
Information processing tools, such as those discussed herein, are based on Gaussian (*extensive*) entropic principles and have finite effectiveness…
Information processing tools based on non-extensive entropic principles have not yet been developed for routine applications but this line of inquiry should, and is rigorously pursued!
Nature has found a good way to deal with non-linearity: it is the most massively parallel computer ever created; it is called "brain" and is the most efficient adaptive pattern recognizer.
Probably a good prototype to imitate…

“DEVELOPMENT OF ADVANCED METHODS FOR THE SOLUTION OF FORWARD ELECTROMAGNETIC SCATTERING BY BURIED OBJECTS”
PROGRESS REPORT ON PROJECT 3.1

Cristina Ponti
Department of Engineering, “Roma Tre” University
Via Vito Volterra 62, 00146 Rome, Italy
cristina.ponti@uniroma3.it

During the first year of the Cost Action TU1208, progress has been done on the topic of the modeling of forward electromagnetic scattering by buried structures, by the involved participants. Such research activities make an effort to provide an advanced modeling of GPR surveys in order to improve their understanding.

In [1], the integral equation solved with Method of Moments are addressed to evaluate the scattering by canonical objects, as a cylinder or a plate, by a randomly rough surface, and also by an object below or above a flat or rough surface. In the same book, the MoM is also combined with Extended- Propagation Inside Layer Method (E-PILE) to efficiently solve the scattering by two scatterers, i.e. a coated cylinder, a cylinder below a flat or rough surface, or two rough surfaces. In [2], the PILE method is used to validate an asymptotic technique, the Kirchhoff Tangent Plane approach, in order to evaluate the coherent scattering from a rough layer. In [3], it is shown how to calculate the frequency and time responses of the field scattered by three homogeneous media separated by two random rough surfaces through the PILE. In this paper, the PILE is also applied to simulate nondestructive pavement survey through ground penetrating radar (GPR) at nadir angle, by a Ricker pulse. In [4]-[5], the PILE method provides the simulation data to estimate time delay and surface parameters in GPR pavement surveys.

Further progress has been done in the time domain with integro-differential equations. In [5], an analytical solution of the time domain Pocklington integro-differential equation for the transient current flowing along the horizontal grounding electrode of finite length buried in a lossy half-space is given. The modeling of a horizontal grounding electrode has

applications to the design of Grounding and Lighting Protection Systems. Simplified reflection coefficient arising from the modified image theory is used to take into account the influence of the earth–air interface. A procedure for the calculation of the transient impedance of the horizontal grounding electrode is developed in [6], using antenna theory. The Pocklington integro-differential equation modeling the grounding electrode is solved in the frequency domain, both numerically and analytically, thus obtaining the solution for the current induced along the electrode. Antenna theory applied to the modeling of the grounding electric dipole is also presented in [7], for the evaluation of the input and transient impedance. Progress on this topic has been also reported in [9]-[11]. A novel TM reflection coefficient function for the TM polarization has been presented in [8].
On the side analytical techniques, in [12], some numerical aspects of the Cylindrical Wave Approach (CWA) are discussed, also through comparisons with finite elements method simulations. In [12], the CWA is used in its original formulations for scatterers buried in a semi-infinite medium, below a flat interface. The fundamental of the methods are the use of cylindrical waves as basis functions of the scattered fields, and spectral representations of the relevant cylindrical functions to solve reflection and transmission of such waves. In [14], the CWA has been solved in the case of targets buried in a lossy medium. The CWA has been also extended to the modeling of advanced scattering scenarios in [15]-[19]. In [15], CWA has been implemented in a multiple-reflection approach to solve the scattering by cylindrical targets placed below a dielectric wall. The proposed geometry is suitable for both geophysical modeling of a layered ground as well as simulations of targets concealed by the wall of a building. Numerical simulations for these scattering problems are reported in [16]. In [17]-[18], CWA has been combined with first order Small Perturbation Method to solve the scattering by a circular cross-section cylinder placed below a rough surface with arbitrary profile. In the numerical solution, the samples of the surfaces have been taken from a Gaussian distribution, and the surface profile has been generated on a periodic surface length. In [19] and [20], two different sources for the modeling of the GPR excitation, in the frame of

CWA solution by targets in a semi-infinite medium, are proposed: a line source excitation in [19], and a general two-dimensional beam in [20].

Acknowledgement

The author acknowledges the COST Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar", supporting this work.

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“RIGOROUS AND ASYMPTOTIC MODELLING OF COHERENT SCATTERING FROM RANDOM ROUGH LAYERS: APPLICATION TO ROADWAYS” (CONTRIBUTION TO PROJECT 3.1)

N. Pinel(1), C. Bourlier(2), C. Le Bastard(3,2)

(1) Alyotech – 2 rue Antoine Becquerel, 35700 Rennes, France
nicolas.pinel@alyotech.fr

(2) UNAN-IETR – Polytech Nantes, Nantes, France

(3) CEREMA, DTO – Les Ponts de Cé, France

This paper presents the rigorous efficient PILE (Propagation-Inside-Layer Expansion) numerical method [1] and an extension of the Ament model [2] to calculate the field scattered by three homogeneous media separated by two random rough surfaces. Here, the study is applied to ground penetrating radar (GPR) (nadir angle, wide band) for nondestructive survey by taking the roughness of the surfaces into account and by calculating the contribution of each echo coming from the multiple scattering inside the layer. The application to roadways is investigated.

The PILE method starts from the Method of Moments (MoM), and the impedance matrix is inverted by blocks from the Taylor series expansion of the inverse of the Schur complement. Its great advantage is that it is rigorous, with a simple formulation and has a straightforward physical interpretation. This last property relies on the fact that each block of the impedance matrix is linked to a particular and quasi-independent physical process occurring during the multiple scattering between the two rough surfaces. Furthermore, the PILE method allows us to use any acceleration algorithm developed for a single interface.

In addition, an asymptotic approach is extended to random rough layered media: the scalar Kirchhoff-tangent plane approximation (SKA), for calculating the coherent scattering from the rough layer. The

numerical rigorous PILE method is used as a reference to validate this asymptotic model. The study focuses on 2D problems with so-called 1D surfaces, for computational ease of the reference numerical method. Nevertheless, it must be highlighted that the SKA approach can readily be applied to 3D problems. This approach is applied to rough layers with two independent slightly rough surfaces characterized by an exponential correlation function. The height probability density function (PDF) is assumed to be Gaussian.

The SKA model is shown to correctly predict the coherent scattered field for typical configurations in pavement survey by GPR at nadir, in the whole frequency band [0.5; 10] GHz [2].

By taking into account the time delay of each echo in this new model, this direct simple electromagnetic model can be a good candidate for its use in signal processing algorithms for the estimation of physical parameters of the layer like its thickness H and also and more important, for the estimation of the RMS (root mean square) heights of the two rough interfaces simultaneously.

For the considered scenarios, she electromagnetic time responses of the first two echoes have been computed by using both the PILE and SKA methods and by considering, for the input signal, a Ricker pulse of peak frequency fc = 2 GHz over the band [0.05; 7] GHz.

ACKNOWLEDGEMENT

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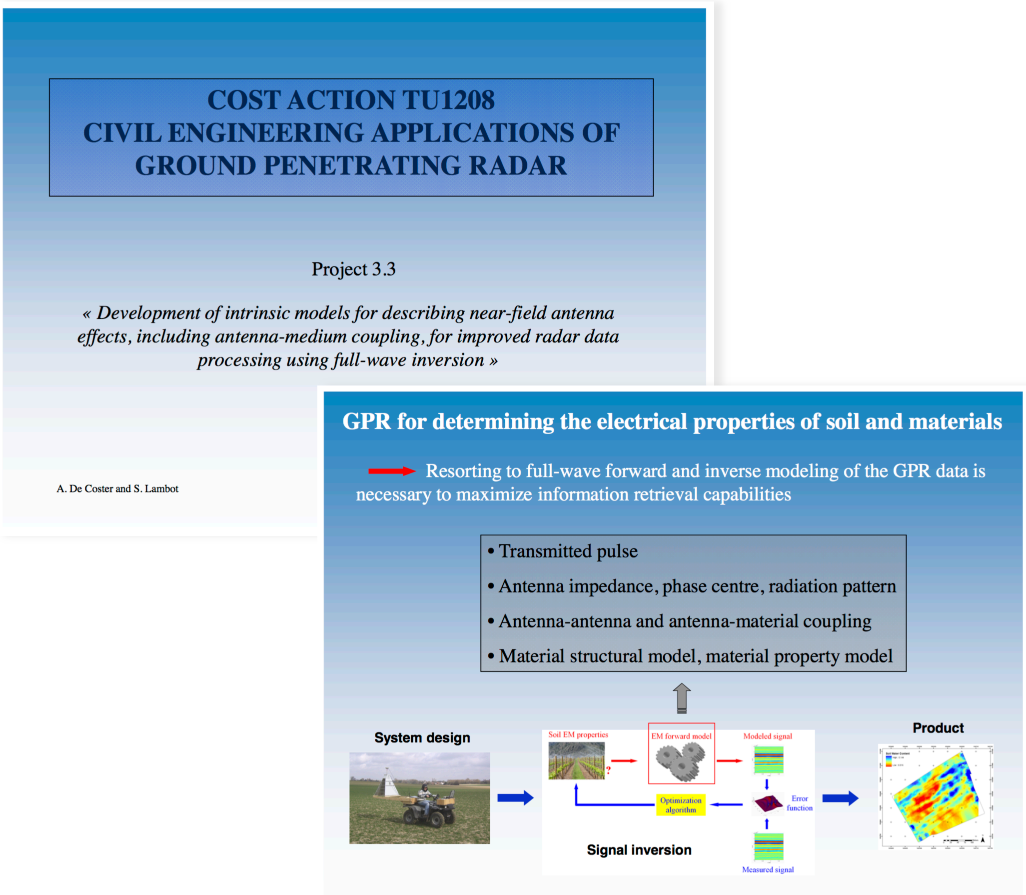
“DEVELOPMENT OF INTRINSIC MODELS FOR DESCRIBING NEAR-FIELD ANTENNA EFFECTS, INCLUDING ANTENNA-MEDIUM COUPLING, FOR IMPROVED RADAR DATA PROCESSING USING FULL-WAVE INVERSION”
PROGRESS REPORT ON PROJECT 3.3

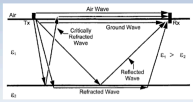
Albéric De Coster and Sébastien Lambot
Hydrogeophysics - Earth and Life Institute, Université catholique de Louvain, Croix du Sud, 2 - L7.05.02 | 1348 Louvain-la-Neuve, Belgium
alberic.decoster@uclouvain.be



COST is supported by the EU RTD Framework Programme.
ESF provides the COST Office through a European Commission Contract. The Council of the EU provides the COST Secretariat.

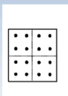
Forward modeling approaches

- Straight or curve rays
- Electric field integral equation (EFIE) formulations
- Method of moments (MoM)
- Finite-difference time-domain (FDTD)
- Finite element method (FEM)



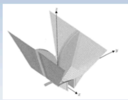
Straight rays

(Huisman *et al.*, 2003)



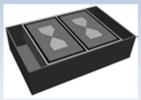
Current distribution & source wavelet

(Gentili & Spagnolini, 2000)



MoM mesh

(Bruns *et al.*, 2003)



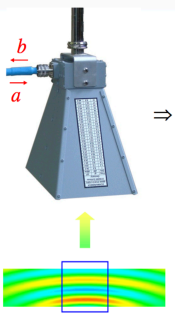
FDTD grid

(Warren & Giannopoulos, 2011)

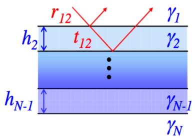
Accuracy and computation time are still limiting

Intrinsic forward model

Example: Radar equation in the frequency domain (Lambot *et al.*, IEEE TGRS, 2004, 2014)

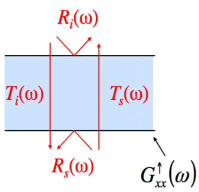


⇒



1-D multilayered medium

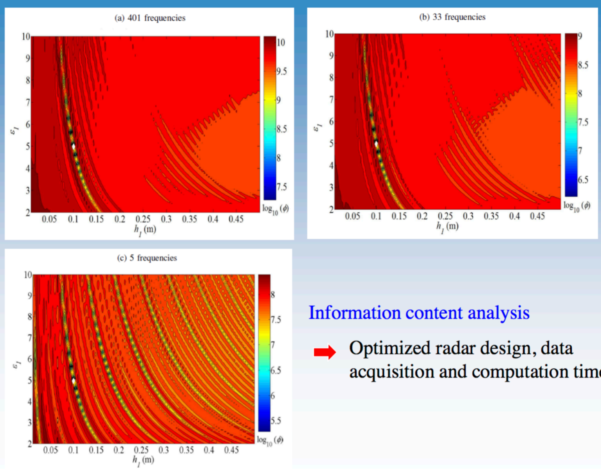
⇒



$$S(\omega) = \frac{b(\omega)}{a(\omega)} = T_0(\omega) + \mathbf{T}_s\left(\mathbf{I}_N - \mathbf{G}^0\mathbf{R}_s\right)^{-1}\mathbf{G}\mathbf{T}_i$$

Backscattered field distribution decomposed into elementary distributions

Intrinsic inversion



Information content analysis

➡ Optimized radar design, data acquisition and computation time

Perspectives for intrinsic models

- ***Design specific acquisition schemes or measurement protocols***
  - Calibration measurement protocol
  - Antenna coupling in arrays
- ***Develop intrinsic modeling solutions for specific configurations***
  - Road layer reconstruction
  - Tree trunk tomography

Worth considering tools:

- ***Information content analysis***
- ***Towards hybrid modelling methods***

"NEAR-SUBSURFACE IMAGING IN AN ABSORBING EMBEDDING MEDIUM WITH A MULTISTATIC/SINGLE FREQUENCY SCANNER"
(CONTRIBUTION TO PROJECTS 3.1 AND 3.2)

C. Eyraud, S. Nounouh, A. Litman, H. Tortel
Aix Marseille Université, CNRS, Centrale Marseille,
Institut Fresnel UMR 7249, 13397, Marseille, France
christelle.eyraud@fresnel.fr

Imaging the subsurface by means of non-destructive techniques is of great interest in several practical day-life situations as for example civil engineering [1], agricultural domain [2], archaeology [3], ... Moreover, looking to the near-subsurface in presence of absorbing media is a very challenging problem.
Within that framework, we analyse the capabilities of a mono-frequency/multistatic set-up for detecting shallowly buried targets.

In order to compensate for the associated lack of information, and as we want to take benefit from inverse scattering algorithms, we focus on a multistatic set-up.

As the antennas constitute an important part of the probing device, an accurate method for modelling the antennas behaviour is proposed. This modelling, performed thanks to a correctly balanced set of elementary sources, is then incorporated in the calculation of the scattered field, performed with a home-made Finite Element Method software [4].

Efforts have also been put into the measurement procedure. The measured fields are thus post-processed with an efficient method which takes profit of the spectral bandwidth properties of the scattered field. These fields serve as input data for the inversion algorithm, an extension of the DORT method to elongated targets [5].

This qualitative and fast imaging procedure, which exploits the spectral properties of the multistatic scattering matrix, has been adapted to the present stratified configuration.

COST is supported by the EU RTD Framework Programme.
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Imaging results of shallowly buried targets embedded in an equivalent medium with high losses will be presented to assess the well-behaviour of the proposed methodology [6].

Acknowledgement

The authors acknowledge the COST Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar", supporting this work.

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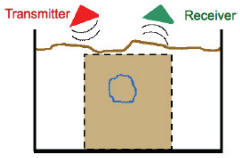
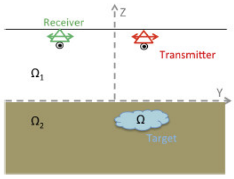
CONTEXT

Objectives: Retrieve the map of the near-subsurface (first meter) from the scattered field measurements



Difficulties:

- Temporal ambiguity between the different signals
- Wet soil: dispersive medium



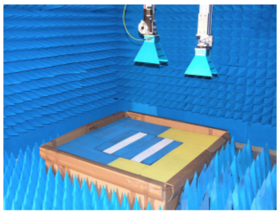
Choices:

- **Single frequency**
- **Multistatic configuration:**
  Movement of the transmitting and the receiving antennas
  Variation of the distance between the two antennas (multiple offsets)

EXPERIMENTAL STUDY

Controlled environment:

Anechoic chamber (3m x 3m x 3m)
Mechanical device : XY positioner
- Transmitting antennas: motion (X_1,Y_1,Z)
- Receiving antennas: motion (X_2,Y_2)

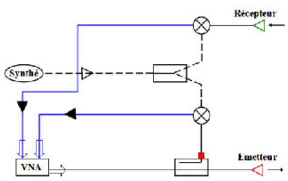


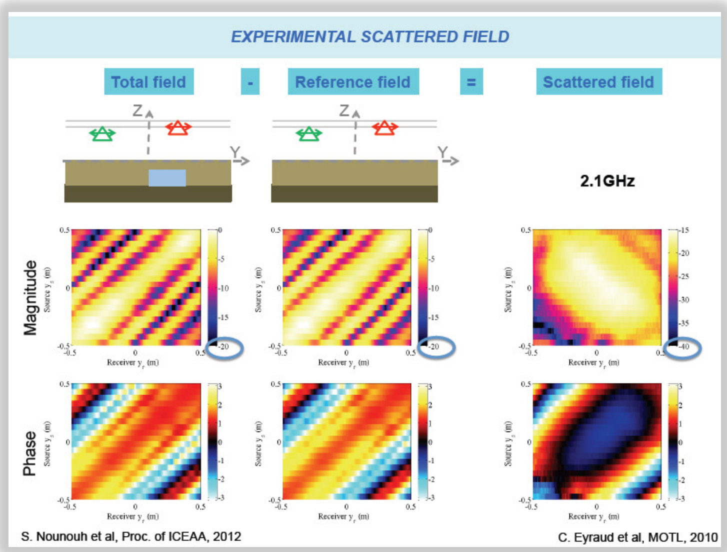
Equivalent medium:

Foams with different density of carbon particles
→ **with an imaginary part**

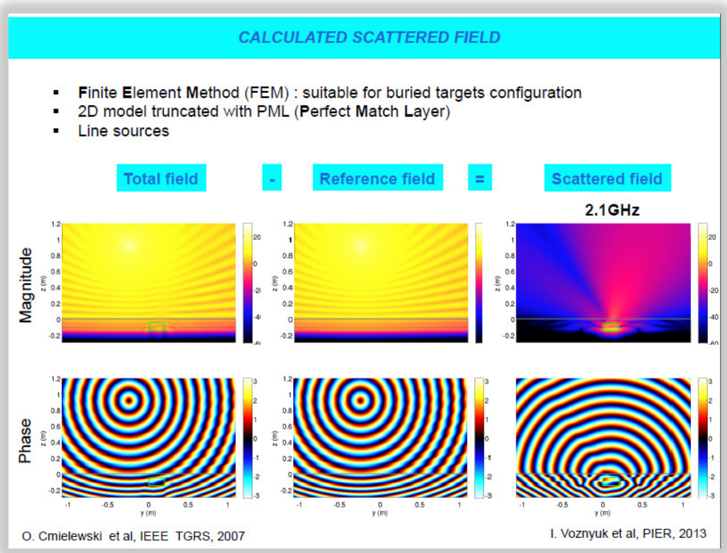
Measuring equipment:

VNA in a multi-source configuration
→ dynamic range improved

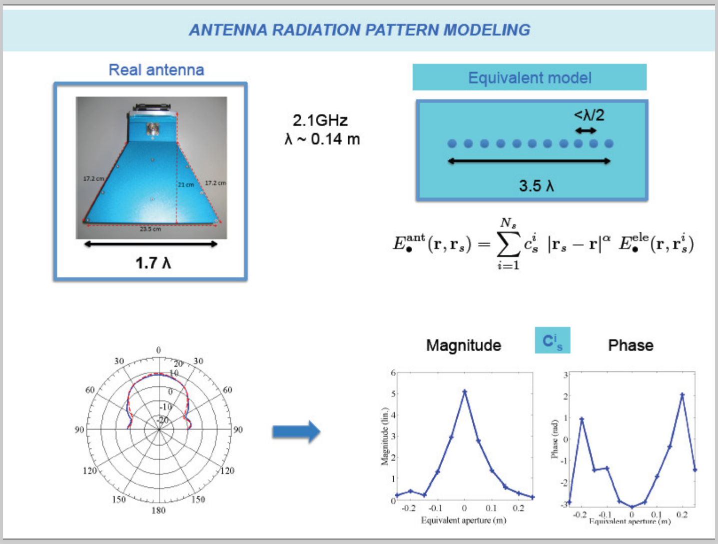


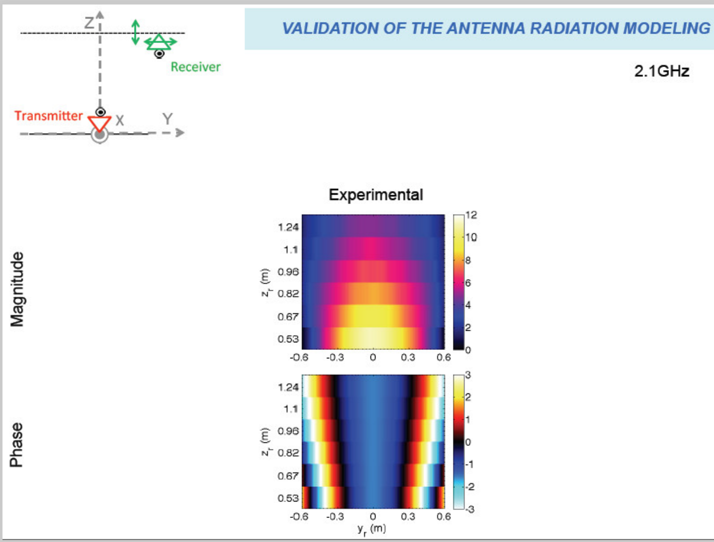


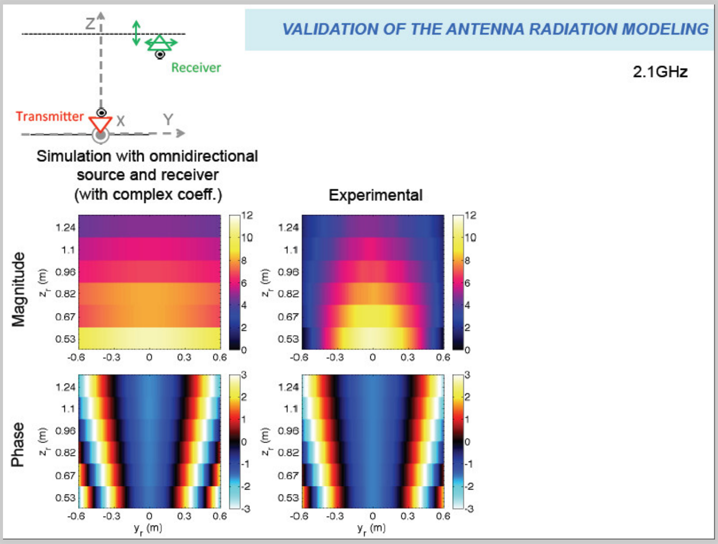
EXPERIMENTAL SCATTERED FIELD
Total field
-
Reference field
=
Scattered field
2.1GHz
Magnitude
Phase
S. Nounouh et al, Proc. of ICEAA, 2012
C. Eyraud et al, MOTL, 2010

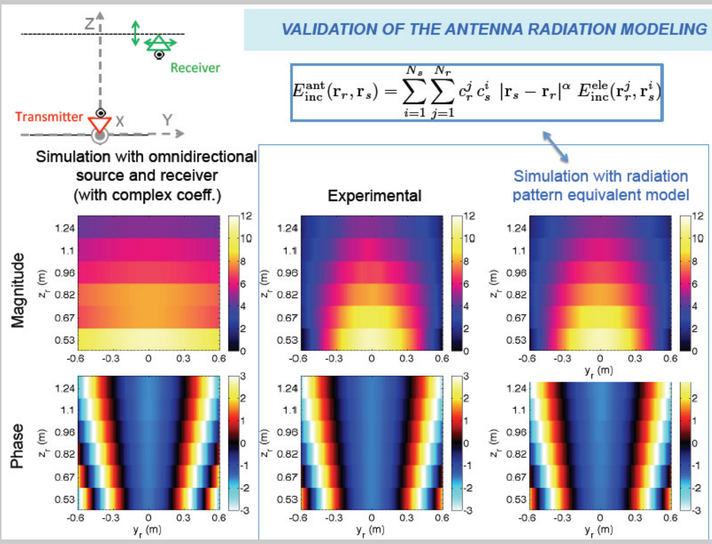


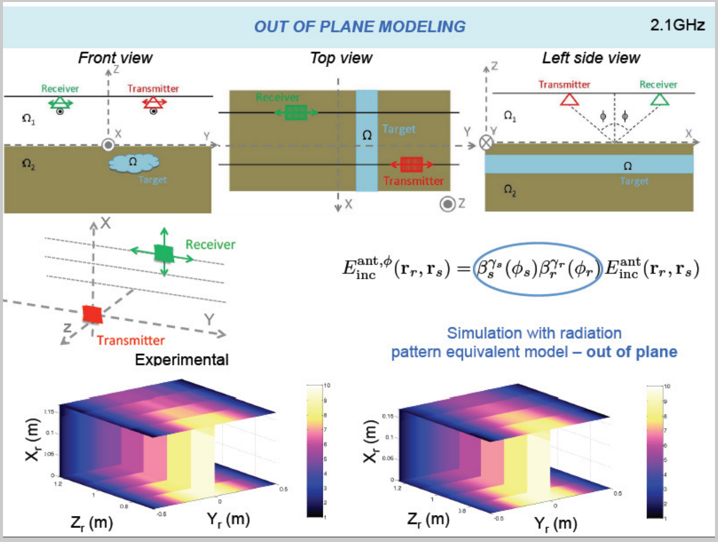
CALCULATED SCATTERED FIELD
Finite Element Method (FEM) : suitable for buried targets configuration
2D model truncated with PML (Perfect Match Layer)
Line sources
Total field
-
Reference field
=
Scattered field
2.1GHz
Magnitude
Phase
O. Cmielewski et al, IEEE TGRS, 2007
I. Voznyuk et al, PIER, 2013

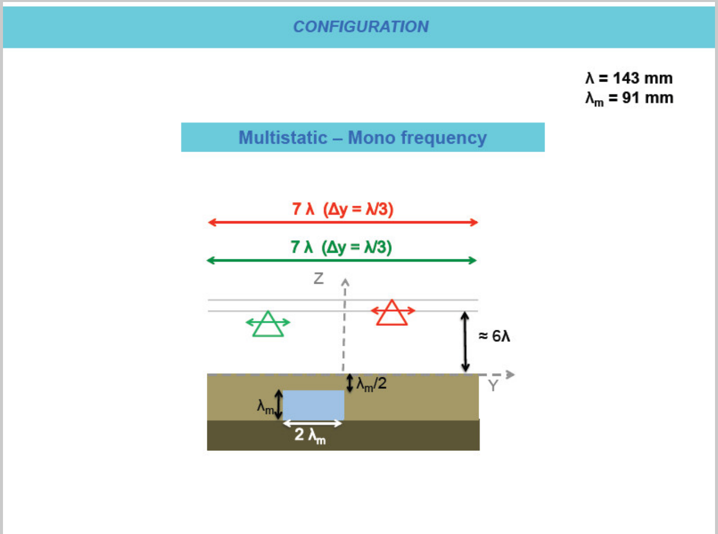

ANTENNA RADIATION PATTERN MODELING
Real antenna
1.7 λ
2.1GHz
λ ~ 0.14 m
Equivalent model
<λ/2
3.5 λ
$E_\bullet^{ant}(\mathbf{r},\mathbf{r}_s) = \sum_{i=1}^{N_s} c_s^i \; |\mathbf{r}_s - \mathbf{r}|^\alpha \; E_\bullet^{ele}(\mathbf{r},\mathbf{r}_s^i)$
Magnitude
Phase
Equivalent aperture (m)


VALIDATION OF THE ANTENNA RADIATION MODELING
2.1GHz
Receiver
Transmitter
Experimental
Magnitude
Phase


VALIDATION OF THE ANTENNA RADIATION MODELING
2.1GHz
Z
Receiver
Transmitter
X
Y
Simulation with omnidirectional source and receiver (with complex coeff.)
Experimental
Magnitude
Phase
z_r (m)
y_r (m)


VALIDATION OF THE ANTENNA RADIATION MODELING
$E_{\text{inc}}^{\text{ant}}(\mathbf{r}_r, \mathbf{r}_s) = \sum_{i=1}^{N_s} \sum_{j=1}^{N_r} c_r^j c_s^i \; |\mathbf{r}_s - \mathbf{r}_r|^{\alpha} \; E_{\text{inc}}^{\text{ele}}(\mathbf{r}_r^j, \mathbf{r}_s^i)$
Z
Receiver
Transmitter
X
Y
Simulation with omnidirectional source and receiver (with complex coeff.)
Experimental
Simulation with radiation pattern equivalent model
Magnitude
Phase
z_r (m)
y_r (m)





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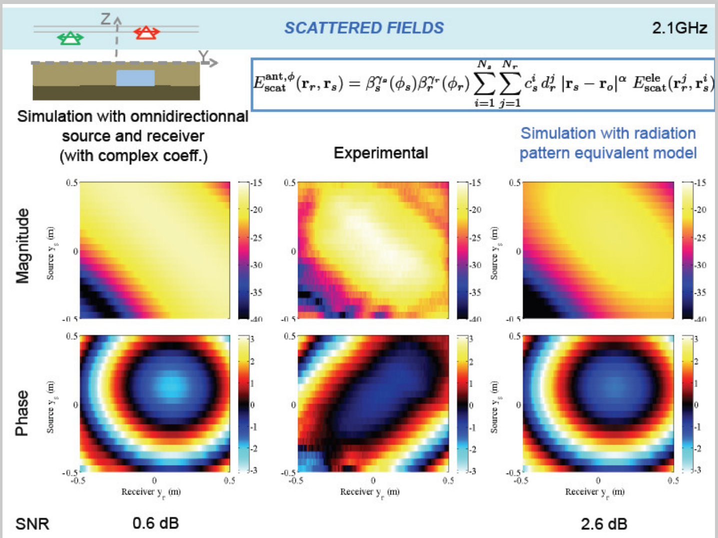
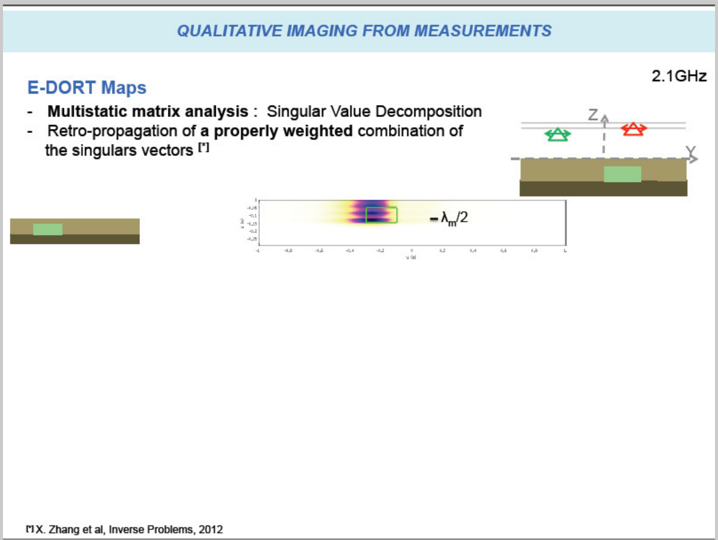
Contract. The Council of the EU provides the COST Secretariat.


SCATTERED FIELDS
2.1GHz
Z
Y
$E^{\text{ant},\phi}_{\text{scat}}(\mathbf{r}_r,\mathbf{r}_s)=\beta_s^{\gamma_s}(\phi_s)\beta_r^{\gamma_r}(\phi_r)\sum_{i=1}^{N_s}\sum_{j=1}^{N_r} c_s^i d_r^j |\mathbf{r}_s-\mathbf{r}_o|^\alpha E^{\text{ele}}_{\text{scat}}(\mathbf{r}_r^j,\mathbf{r}_s^i)$
Simulation with omnidirectionnal source and receiver (with complex coeff.)
Experimental
Simulation with radiation pattern equivalent model
Magnitude
Phase
Source y_s (m)
Receiver y_r (m)
SNR
0.6 dB
2.6 dB

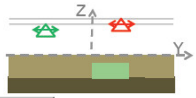

QUALITATIVE IMAGING FROM MEASUREMENTS
2.1GHz
E-DORT Maps
- Multistatic matrix analysis : Singular Value Decomposition
- Retro-propagation of a properly weighted combination of the singulars vectors [*]
Z
Y
$\lambda_m/2$
[*] X. Zhang et al, Inverse Problems, 2012

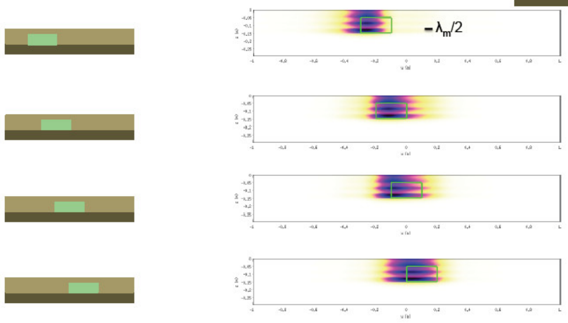
QUALITATIVE IMAGING FROM MEASUREMENTS

E-DORT Maps

2.1GHz

- **Multistatic matrix analysis** : Singular Value Decomposition
- Retro-propagation **of a properly weighted** combination of the singulars vectors [*]



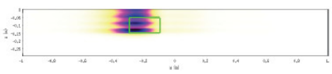


[*] X. Zhang et al, Inverse Problems, 2012

CONCLUSION / PERSPECTIVES

Near-subsurface imaging:

- Accurate modeling of the real antenna radiation pattern
- Calibration without the use of reference target
- Quantitative comparisons between measurement/calculation (FEM)
- Qualitative imaging of shallowly buried target ($\lambda_m/2$)



.... Future Work:

Quantitative imaging, Extended targets, …
Granular media (sand, soil), Transportable experimental setup

"GPR Full-waveform Inversion State of the Art and Open Issues" (contribution to projects 3.2 and 3.4)

J. Van Der Kruk
Forschungszentrum Jülich, Agrosphere (IBG-3)
Institute of Bio and Geosciences
Leo-Brandtstrasse, D-52425 Jülich, Germany
j.van.der.kruk@fz-juelich.de

Abstract

Ground penetrating Radar (GPR) is a widely used fool for high resolution subsurface characterization because of its noninvasive character and the fairly quick measurement acquisition. Compared to other non-destructive techniques GPR is able to return high resolution images due to the use of high frequency electromagnetic waves and in principle it is possible to extract relative permittivity and electrical conductivity properties from the data. Conventional inversion tools are often based on approximations that include far-field, high-frequency ray-based approximations, and often only part of the data is used. Due to the increased computation power, accurate forward modeling programs can now be used for advanced inversion algorithms where the complete measured data is used. Here, recent developments of full-waveform Ground Penetrating Radar (GPR) inversion are discussed for off-ground, crosshole, and on-ground configurations that yield higher resolution of quantitative medium properties compared to conventional approaches.

I. Introduction

GPR is often used to characterize civil engineering structures, such as critical transport infrastructures, underground utilities, and construction materials. Mostly ray-based techniques are used to locate subsurface scatterers or layer interfaces, where only part of the GPR data is exploited. Improved GPR images can be obtained by including

advanced modeling tools that are able to calculate the propagation of electromagnetic waves in complicated media configurations [1-4]. Full-waveform inversion (FWI) is one of the most promising but also challenging data-fitting techniques [5] that is able to use these advanced modeling programs to derive quantitative relative permittivity and conductivity values. Full-waveform inversion is fairly advanced in exploration seismics [e.g. 5-7]). However, seismic full-waveform inversion cannot be used for GPR inversion and dedicated inversion programs are required that honor the pertaining vectorial wave propagation and radiation patterns of GPR. In the following, recent developments will be discussed of full-waveform inversion of experimental off-ground, crosshole, and on-ground GPR data that indicate the benefits of FWI inversion to estimate quantitative permittivity and conductivity values.

II. FULL-WAVEFORM INVERSION OF OFF-GROUND GPR

Off-ground GPR uses air launched horn antennas installed at a sufficient height above the surface such that the emitted electric field can be considered independent from the subsurface. Since mainly vertical wave propagation occurs, horizontal layers are often assumed when inverting the measured reflected waves. Exact-field expressions for the electromagnetic wave propagation in a horizontally layered medium can be used that assume a point source and receiver antennas.

To effectively describe the source and receiver horn antennas, that guide the waves within the antenna until they spread spherically outside the antenna, the phase center needs to be introduced which is the virtual point from which the electromagnetic waves seem to be emitted or received assuming point source and receiver antennas. To estimate the phase center, reflections need to be measured that is reflected from a steel plate for varying heights. In addition, an effective wavelet estimation procedure needs to be implemented [8-10].

GPR data measured by a commercial GPR system for nine homogeneous concrete specimens having different moisture and chloride contents were inverted using the full-waveform inversion based on a combined global-local search algorithm [10]. The inversion results for

almost all specimens showed for increasing chloride and humidity content specimens increasing conductivity and permittivity values, respectively. In contrast to traditional ray-based techniques, it was possible to distinguish between moisture and chloride effects and to obtain quantitative values for the permittivity and conductivity. For increasing chloride content increasing frequency-dependent conductivity values were obtained [10].

This off-ground full-waveform inversion for commercial GPR systems was extended to invert for positive and negative gradients in conductivity and the conductivity gradient direction could be correctly identified [11]. Experimental specimen containing gradients were generated by exposing a concrete slab to controlled wetting-drying cycles using a saline solution. Full-waveform inversion of the measured data correctly identified the conductivity gradient direction which was confirmed by destructive analysis [11].

III. Full-waveform inversion of crosshole GPR

Using several source and receiver combinations, the area between two boreholes can be well illuminated such that the measured data can be used to determine the medium properties of a large number of unknowns using gradient-based optimizations. Within the seismic community this gradient-based full-waveform inversion has found widespread applications [5]. In contrast, FWI methods for GPR are still fairly new. One of the first implementations of crosshole GPR full-waveform inversion [12] is a conjugate gradient optimization algorithm where the gradient of the objective function is determined via an adjoint problem based on the work of [13]. A vectorial approach was implemented that honors the vectorial electromagnetic wave propagation and simultaneously updates the permittivity and conductivity [14]. Nonlinearity issues that especially in high contrast media afflict the inverse scattering problems can be avoided by starting the inversion with only the low frequency content of the data and extending the used bandwidth for later iterations [15]. To apply this method to experimental data and invert the data using 2D forward model, a 3D to 2D conversion

is required and an effective source wavelet must be estimated [16]. The starting relative permittivity and conductivity tomograms are usually obtained using standard ray-based inversion that is using the first-arrival times and first-cycle amplitudes.

Applying the full-waveform inversion on several crosshole GPR data sets acquired in gravel aquifers shows that sub-wavelength thickness low-velocity waveguiding layers can be correctly imaged [16-17], whereas ray-based inversion techniques are not able to image these thin waveguide layers because they only exploit the first-arrival times and first-cycle amplitudes. Excellent fits of amplitudes and phase between the measured and modeled data indicate the reliability of the obtained inversion results. Converting the permittivity results into porosity and comparing with Neutron–Neutron logging data show a good correspondence [17].

IV. FULL-WAVEFORM INVERSION OF ON-GROUND GPR

On-ground GPR has wider radiation patterns than off-ground GPR which enable the reconstruction of subsurface objects with higher spatial resolution. However, a reduced coverage of the subsurface is obtained compared to crosshole GPR such that the ill-posedness of the inverse problem is increased. A 2D FWI of multi-offset on-ground GPR data was recently implemented and applied on synthetic data using a quasi-Newton optimization [18] by assuming a known source wavelet. Whereas, for off-ground GPR, and in most cases also for crosshole GPR, the emitted electric field can be considered relatively constant, for on-ground GPR radiation patterns the coupling of the antennas and, therefore, the shape and amplitude of the wavelet strongly depend on the underlying medium [19]. Consequently, the estimation of the effective source wavelet and, therefore, the application of the FWI are less straightforward for experimental data. Inaccuracies in the conductivity starting model result in erroneous effective wavelet amplitudes and therefore in erroneous inversion results, because the conductivity and wavelet amplitudes are coupled.

To obtain reliable inversion results, a simultaneous permittivity and conductivity updating together with the phase and the amplitude of the source wavelet was recently implemented using a gradient-free combined global-local optimization approach [20] based on a frequency-domain solution of Maxwell's equations including far, intermediate, and near fields assuming a 3-D layered subsurface.

Applying the on-ground full-waveform inversion over a silty loam with significant variability in the soil texture returned quantitative permittivity and conductivity values that are consistent with theta probe, electromagnetic resistivity tomography, and electromagnetic induction measurements [21]. The permittivities and conductivities increase with increasing clay and silt and decreasing skeleton content. Moreover, with increasing permittivities and conductivities, the wavelet center frequency decreases, whereas the wavelet amplitude increases, which is consistent with the radiation pattern and the antenna coupling characteristics [21]. This indicates that the wavelet center frequency and amplitude return valuable information that can also be used for subsurface characterization.

V. CONCLUSION

The full-waveform inversion of GPR data uses accurate forward modeling programs, which have been recently become possible due to the increased computation power. In this way, quantitative values for the permittivity and conductivity structures can be obtained which goes beyond qualitative structural characterization.

The used forward model should describe the dominant aspects present in the electromagnetic wave propagation. Any aspect that is not correctly described in the forward model will have an influence on the obtained inversion results. It is therefore important to further develop sophisticated forward modeling algorithms that are able to accurately capture the complexity of the electromagnetic wave propagation. Also the computational efficiency using cluster computers needs to be further improved such that these detailed forward models can be used in

inversion algorithms where at each iteration the forward model needs to be calculated several times.

To apply full-waveform inversion on experimental data, a good start model should be used that already contains approximate smooth versions of the permittivity and conductivity distributions. Such a start model can be often obtained by ray-based methods and should be complemented by a priory information when available. An effective wavelet needs to be estimated that effectively describes the complicated behavior of the source and receiver antennas by using point dipole source and receiver antennas in the forward modeling program. In the presence of high contrasts, the non-linearity needs to be accommodated by using first the low-frequency information of the measured wavefield and including higher frequency information for later iterations. Independent measurements using CPT, borehole measurements or coring are necessary to validate the inversion results and optimize the inversion approach. Moreover, a multi-disciplinary approach will enable to include knowledge into the inversion process of the material properties of, and processes taking place in, civil engineering structures. In this way, the full-waveform inversion enables a high resolution subsurface characterization and can be applied to a wide range of civil engineering applications.

ACKNOWLEDGEMENT

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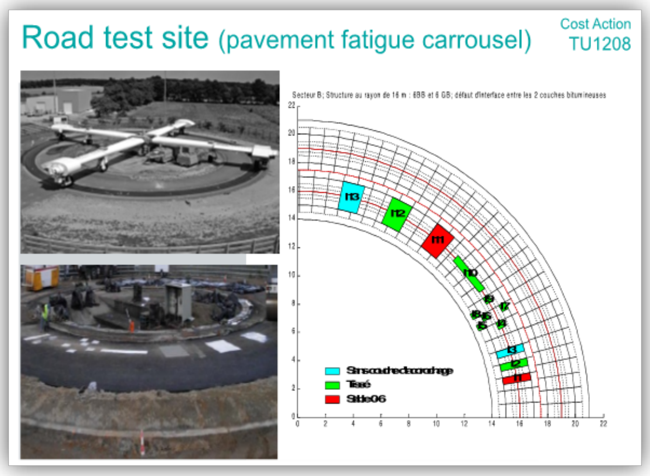
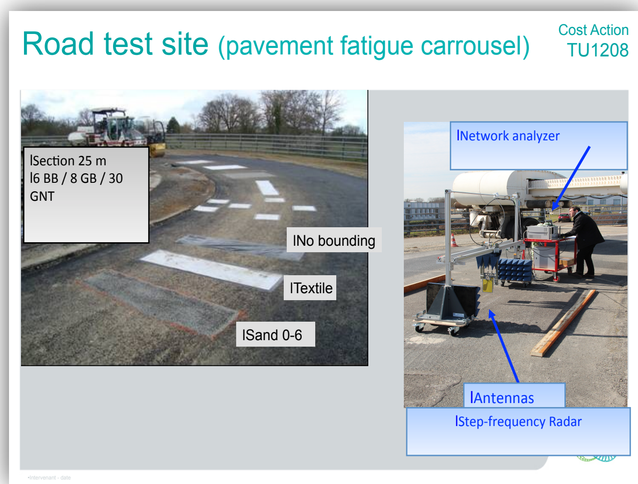
On The IFSTTAR geophysical test site and the road carousel

X. Dérobert, V. Baltazart, J. M. Simonin
IFSTTAR, Nantes, France - xavier.derobert@ifsttar.fr





COST is supported by the EU RTD Framework Programme.

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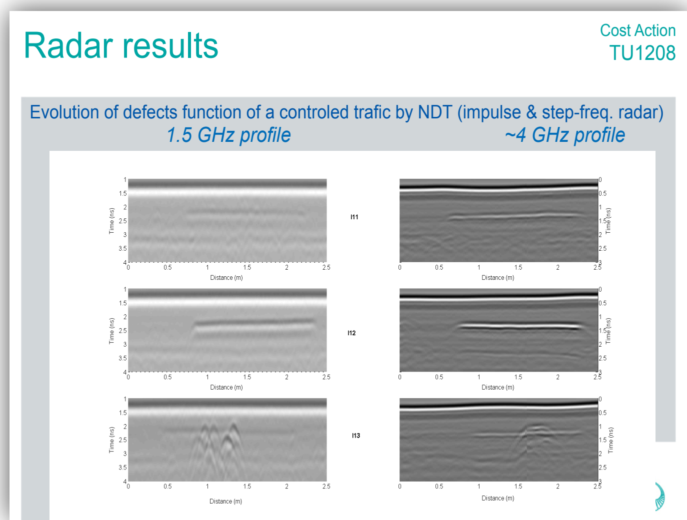
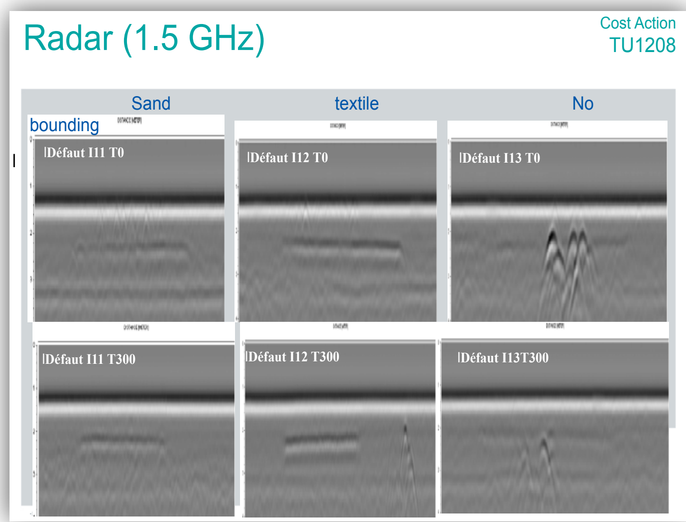
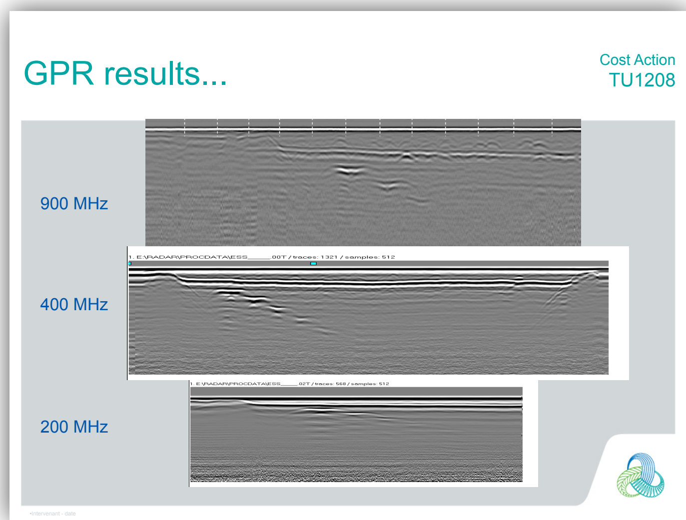

Radar results
Cost Action
TU1208
Evolution of defects function of a controled trafic by NDT (impulse & step-freq. radar)
1.5 GHz profile
~4 GHz profile
Distance (m)

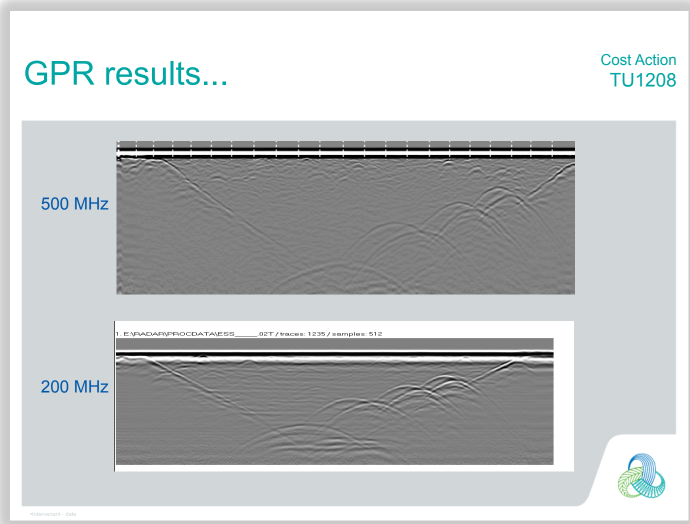

Radar (1.5 GHz)
Cost Action
TU1208
Sand
bounding
textile
No
Défaut I11 T0
Défaut I12 T0
Défaut I13 T0
Défaut I11 T300
Défaut I12 T300
Défaut I13T300

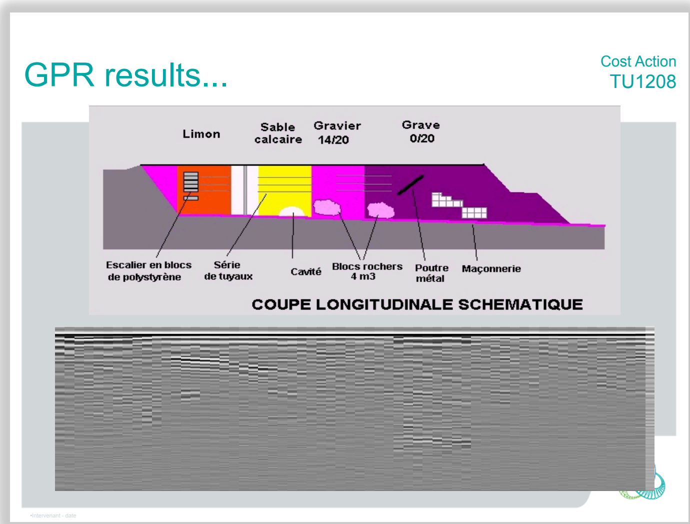

Geophysical test site
Cost Action
TU1208


Geophysical test site... not seen yet...
Cost Action
TU1208


GPR systems...
Cost Action
TU1208


GPR results...
Cost Action
TU1208
900 MHz
400 MHz
200 MHz


GPR results...
Cost Action
TU1208
500 MHz
200 MHz


GPR results...
Cost Action
TU1208
Limon
Sable calcaire
Gravier 14/20
Grave 0/20
Escalier en blocs de polystyrène
Série de tuyaux
Cavité
Blocs rochers 4 m3
Poutre métal
Maçonnerie
COUPE LONGITUDINALE SCHEMATIQUE

"MARA NORD"
(KEYNOTE LECTURE 2)

Janne Poikajärvi
Lapland University of Applied Sciences, Civil Engineering
Jokiväylä 11, 96300 Rovaniemi, Finland
janne.poikajarvi@lapinamk.fi

Abstract

Mara Nord project was implemented during 2010-2012. It was a joint development project between Norwegian, Swedish and Finnish GPR and Road experts. Road authorities had an important role to define project goals. During Mara Nord GPR training sessions were organized and GPR knowledge distributed. Education gained a lot of popularity among road specialists. Harmonization of Nordic GPR market was started by recommendations for the guidelines of GPR measurements. Also quality assurance of new asphalt pavement was researched and few development ideas were presented. This short paper is based on material produced during Mara Nord.

I. INTRODUCTION

When talking about the GPR application on roads the Finnish Transport Agency has the largest experience in the Nordic countries. It was identified that it would be beneficial to transfer the existing practices to Swedish and Norwegian Transport Administrations and create common Nordic Recommendations that would lead towards standardizing of GPR services for road surveys. Mara Nord project was created to implement these changes. The project started in January 2010 and ended in June 2012. Mara Nord was financed by EU Interreg IVA North programme. [1]

The aim of Mara Nord project was to boost the cooperation between the Nordic Transport Administrations, research organizations and the business sector specifically by improving the market conditions

for GPR method application in civil engineering for nondestructive testing of roads. [1]

The project objective is reached through five main work packages: (1) providing GPR training to road administrations (EDU1) and to companies (EDU2), (2) creating joint Nordic Recommendations for Finland, Sweden and Norway, (3) benchmarking different GPR systems, (4) networking and dissemination of the results, (5) further testing of the GPR method applicability to new asphalt pavement quality monitoring. [1]

II. EDUCATION AND NORDIC RECOMMENDATIONS

In Mara Nord project WP1 the education in the field of GPR was provided by training sessions. Training package 1 (EDU1) was mainly aimed to the GPR service buyers and the training package 2 (EDU2) was aimed to the service providers. Both training courses where held in Norway, Sweden and Finland.

The EDU1 consisted of the GPR history, general applications, hardware, control units and different antenna types and their application to road surveys. It also included parts such as legislation and licensing and traffic safety. The practical examples where given to present the GPR data collection process and introduce the software options for data analysis and presentation. The EDU1 was very well attended in total educating more than hundred participants. [1]

The EDU2 was targeted especially towards the GPR service providers so that they can provide better service and understand the customer needs better. This training included topics such as facts to be noticed in GPR work planning and needs of the GPR service buyers. It also covered the topics of arranging GPR field data collection, safety issues and combining the survey methods, data analysis methods and interpretation techniques. It also covered important parts such as quality assurance. Many practical examples where discussed during the training and participants had the chance to explore GPR software and try interpreting the data under the supervision of experts. Trainings in

EDU1 and EDU2 were held by the project consultant Roadscanners Oy. [1]

WP2 was about writing the Nordic Recommendations. This was a step forwards towards joined management and standardized procurement practices of GPR surveys on roads. Meanwhile the national standards existed in Finland similar or the same type of coordinated procurement and service requirements did not exist either in Sweden or Norway. It is easier for the GPR companies to compete fairly across the Nordic borders if the rules and regulations are standardized and implemented as jointly as possible. During the Mara Nord project five different joint recommendations were developed to address the different types of surveys most commonly performed on road surveys. [1] Those recommendations are [2]-[6]:

- Use of GPR in pavement design and road rehabilitation projects
- Use of GPR in bridge applications
- Use of GPR in site investigation
- Use of GPR in road construction quality control
- Use of GPR in asphalt quality control

After the Mara Nord project Swedish Transport Administration has started the process to prepare two method descriptions (investigation of existing roads and quality control) based on Mara Nord guidelines. These are meant to be as a base for a tendering process.

Norwegian Public Roads Administration has used the recommendations directly in a tendering process for investigation of existing roads and quality control. Experiences have been good. It has been easier for the service providers to deliver offers and administration to compare offers with each other.

III. BENCMARKING OF DIFFERENT GPR SYSTEMS

The aim of the WP3 was to describe different types of GPR equipment available and their performance. The target was not to put the equipment in any specific order, but to describe what kind of equipment is available, how they can be used, how they perform in field work and how the results look.

In the benchmarking of different GPR equipment the target was to collect information on the equipment, perform measurements and make a brief data analysis. Only the GPR manufacturers, who were interested in this study and participated in the costs, where represented in the tests. The units and the antennas had to be approved by ECC/ETSI. [7] GPR manufacturers present in the test were:

- 3D-radar AS, Norway
- Geophysical Survey Systems, Inc., USA
- IDS, Italy
- Malå Geoscience, Sweden

GPR measurements were done at two sites, Talvitie Street and a section 505 of highway 4. Both of these sites are located outside Rovaniemi, Finland. Both sections had been rehabilitated in 2010 and therefore the layers of the road where fresh and clear. The survey sites were very good for GPR and all the systems worked at their best levels concerning depth penetration and resolution. [7]

The main conclusion from the tests where that all the tested equipment showed to be reliable and produced good quality data. All of the achieved results showed to be good or very good. [7], [10]

GPR tests showed that in the high frequency range the horn antennas still have advantages over ground coupled antennas at high speed in road surveys. Also additional data can be gathered at the same time: bouncing and dielectric value. On the other hand, when the survey

speeds are lower, the high frequency ground coupled antennas produce good quality data and the horizontal resolution is better than with the horn antennas. [7], [10]

IV. Quality assurance of new asphalt pavement

In 1997 Petri Roimela introduced a regression model between dielectric value measured by GPR and void content of new asphalt pavement. Since that time GPR have been used as a quality assurance method for new asphalt pavements in Finland. [8], [9] In this method a continuous void content profile of asphalt pavement is determined by GPR survey. The determination of void content is based on the regression model introduced by Roimela in 1997. Moreover, it requires some reference drill cores to be taken from the pavement for calibration of the model. [1], [10]

The main objective in Work Package 5 (WP 5) of Mara Nord project was to improve the reliability of the current void content method. First the research focused on the examination of current regression model. The aim was to improve the accuracy of the current regression model as well as to find out if new models need to be used with different asphalt types. Furthermore, the influence of environmental factors (temperature, moisture) on GPR results was investigated. [1], [10]

Another objective in WP 5 was to investigate the possibility to abandon asphalt core samples in calibration. The use of an asphalt calibration plate and some NDT method (e.g. Troxler) was investigated. After all, it was recognized that it might be impossible to abandon asphalt core samples with the current void content method. Therefore, another ways to access the quality of new asphalt pavement through GPR survey was also investigated. Suggestions have been made that the quality could be determined from the homogeneity of new asphalt pavement. One aim in WP 5 was to define this homogeneity and how it relates to GPR data. [1], [10]

Various laboratory measurements (GPR, Troxler, Percometer, 3D laser, air-water weighing, environmental factors, and core samples) were carried out with asphalt plates to validate the regression model used in void content method. Two common asphalt types, asphalt concrete and

stone mastic asphalt, were used and the plates were made to different compaction. Unfortunately, due to too wide variation in regression data an accurate regression model could not be validated. [1], [10]

Field test (GPR, core samples) were done on roads 18 and 725. The main aims of the field tests was to produce good quality GPR data for the Mara Nord research and to test operators and their equipment in void content measurements. The field test demonstrated that GPR has good repeatability and reproducibility in the current void content method used in Finland when the same reference drill cores are used. [1], [10]

As a summary of Mara Nord project WP5 findings, the improvements of the current void content method are the following:

- More than one reference core should be taken from each reference point location. Moreover, reference points should be placed in a location where GPR does not detect remarkable changes in dielectric values.

- Core samples should be taken from each survey line particularly when asphalt mass, working method, base treatment or environmental circumstances change.

- The possibility to place survey line between wheel paths needs to be examined when traffic has compacted new asphalt before quality assurance surveys.

- To avoid significant differences in dielectric value level of separate GPR surveys metal plate measurement should be done in the same circumstances as the survey.

- GPR operator needs to monitor GPR data to detect possible long term changes in direct pulse amplitude. If such is found, the changes need to be eliminated in dielectric value calculation.

Wavelet analysis gives another perspective to quality assurance of new asphalt pavements. Wavelet analysis together with special statistical

technique can perform qualitative as well as quantitative information of the homogeneity of asphalt pavement. The method also localizes the significant variation in GPR survey. To utilize this method for quality assurance the connection of significant dielectric value variation to detected pavement damages should be investigated in long term surveillance. [1], [10], [11]

V. Conclusion

GPR has been used widely in Nordic countries in road surveys. Recent technological development has made GPR equipment to be an effective and reliable survey method. An example is a modern full range 3D GPR system. Also it is seen that GPR is more and more integrated with other surveys and investigations. Traditionally GPR has been used for determination of layer thicknesses, but there are more applications to be discovered in the future. Evaluation of different material characteristics is one path.

Although the future of the GPR technological development is favorable, GPR market in Norway, Sweden and Finland are somewhat limited and uncertain. Unfortunately because of this many GPR service providers are reluctant to make large investments in the newest technology. Projects like Mara Nord indicates that there are still common interest among Nordic road authorities, service providers and GPR manufacturers to continue develop the use of the GPR in road surveys even further.

Mara Nord recommendations for guidelines were made to harmonize Nordic GPR market. Road administrations have used these guidelines as a part of the tendering process so some level of harmonization has been accomplished. But more work need to be done especially Europe-wide.

Also development work of new asphalt pavement quality assurance needs to be continued. For future research Mara Nord project recommends the following topics:

- The regression model between dielectric value and void content should be based rather on field tests (test site or road sections) than on laboratory test (pavement plates).

- Homogeneity is an alternative property for the void content to indicate quality assurance of new asphalt pavement. Wavelet analysis is one promising method to investigate asphalt pavement homogeneity.

Long term surveillance of road sections is needed to validate quality assurance methods. For example, in the homogeneity model correlation between statistically significant variations with pavement damage should be determined. Also the possibility to move from 2D to 3D quality assurance surveys should be investigated.

ACKNOWLEDGEMENT

The author acknowledge the COST Action TU1208 “Civil Engineering Applications of Ground Penetrating Radar”, supporting this work.

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GROUND PENETRATING RADAR APPLICATION IN PLANNING STRUCTURAL EVALUATION OF ROADS – NORDIC ACTIONS

MARA NORD PROJECT 2010-2012

Janne Poikajärvi

LAPIN AMK
Lapland University of Applied Sciences

INTERREG IV A NORD
Statens vegvesen
TRAFIKVERKET
OULUN SEUDUN AMMATTIKORKEAKOULU
Liikennevirasto
Rovaniemen ammattikorkeakoulu University of Applied Sciences
Centre for Economic Development, Transport and the Environment

1. Mara Nord – basic information
2. WP1 – Education
3. WP2 – Recommendations for guidelines
4. WP3 – Benchmarking of Different GPR Systems
5. WP4 - Networking
5. WP5 – Quality Assurance of New Asphalt Pavement
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INTERREG IV A NORD
MARA NORD P JECT
Projects purpose was to demonstrate the potential of **GPR in road surveys** to the Nordic market
Finland, Sweden and Norway have specialized in very different ways in the GPR method use and development
Mara Nord project aim was the co-operation between Nordic countries. Road authorities, universities, research institutes, companies etc.
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INTERREG IV A NORD
PA TNE SHI
Lead partner
• Rovaniemi University of Applied Sciences (1.1.2014 Lapland University of Applied Sciences)
Partners
• Oulu University of Applied Sciences
• Transport Administration of Sweden
• Road Administration of Norway
• Lapland Centre for Economic Development, Transport and the Environment, Finland
Companies
• Finland: Road Consulting Oy, Roadscanners Oy, Carement Oy
• Sweden: RAMBÖL Sverige AB, Malå GeoScience AB, VTI
• Norway: Sintef, 3D Radar AS, NCC Roads AS
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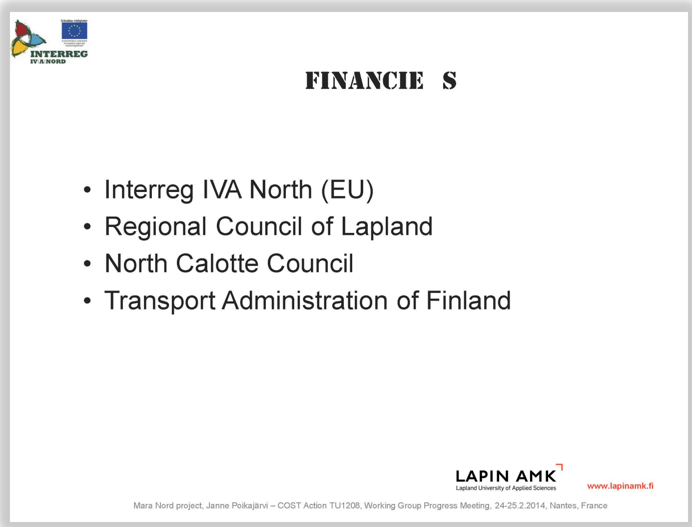
INTERREG IV A NORD
FINANCIE S
• Interreg IVA North (EU)
• Regional Council of Lapland
• North Calotte Council
• Transport Administration of Finland
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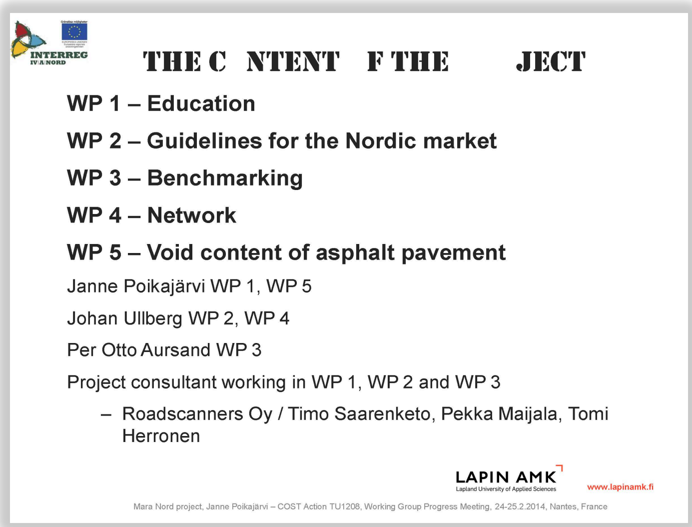
INTERREG IV A NORD
THE C NTENT F THE JECT
WP 1 – Education
WP 2 – Guidelines for the Nordic market
WP 3 – Benchmarking
WP 4 – Network
WP 5 – Void content of asphalt pavement
Janne Poikajärvi WP 1, WP 5
Johan Ullberg WP 2, WP 4
Per Otto Aursand WP 3
Project consultant working in WP 1, WP 2 and WP 3
– Roadscanners Oy / Timo Saarenketo, Pekka Maijala, Tomi Herronen
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INTERREG IV A NORD

WP1 - EDUCATI N

- One of the main parts of the project was to provide the training to GPR service buyers with the training package 1 (EDU1) and to the service providers with the training package 2 (EDU2).
- Training sessions were held in Norway, Sweden and Finland.
- EDU 1
  - Basic GPR course mainly aimed for those who needs the GPR results: road authorities, design companies, contractors
  - "Training and GPR promotion"
- EDU 2
  - Includes more detailed information about GPR
  - How to make measurements, interpretations and analyses.
  - It was mainly aimed for those who work with GPR already.

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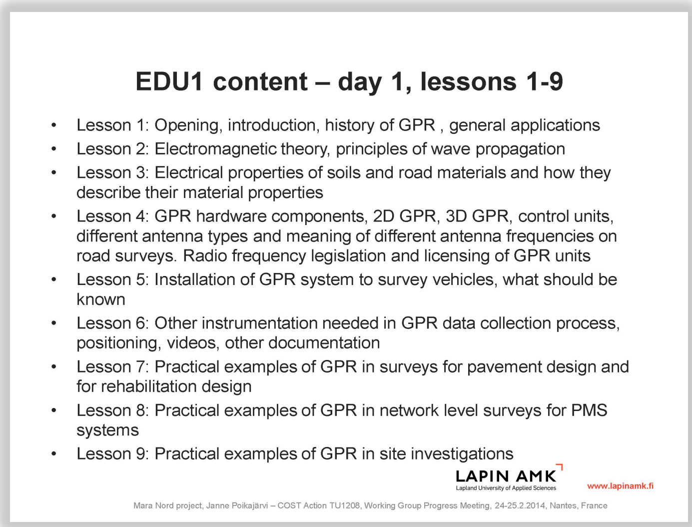
EDU1 content – day 1, lessons 1-9
• Lesson 1: Opening, introduction, history of GPR , general applications
• Lesson 2: Electromagnetic theory, principles of wave propagation
• Lesson 3: Electrical properties of soils and road materials and how they describe their material properties
• Lesson 4: GPR hardware components, 2D GPR, 3D GPR, control units, different antenna types and meaning of different antenna frequencies on road surveys. Radio frequency legislation and licensing of GPR units
• Lesson 5: Installation of GPR system to survey vehicles, what should be known
• Lesson 6: Other instrumentation needed in GPR data collection process, positioning, videos, other documentation
• Lesson 7: Practical examples of GPR in surveys for pavement design and for rehabilitation design
• Lesson 8: Practical examples of GPR in network level surveys for PMS systems
• Lesson 9: Practical examples of GPR in site investigations
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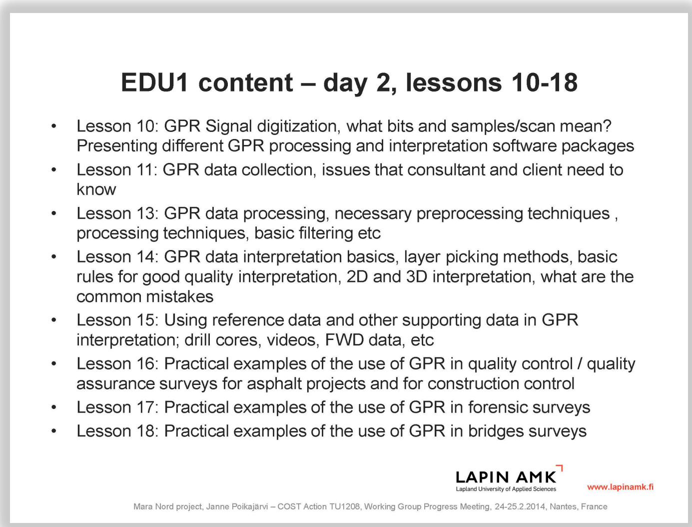
EDU1 content – day 2, lessons 10-18
• Lesson 10: GPR Signal digitization, what bits and samples/scan mean? Presenting different GPR processing and interpretation software packages
• Lesson 11: GPR data collection, issues that consultant and client need to know
• Lesson 13: GPR data processing, necessary preprocessing techniques , processing techniques, basic filtering etc
• Lesson 14: GPR data interpretation basics, layer picking methods, basic rules for good quality interpretation, 2D and 3D interpretation, what are the common mistakes
• Lesson 15: Using reference data and other supporting data in GPR interpretation; drill cores, videos, FWD data, etc
• Lesson 16: Practical examples of the use of GPR in quality control / quality assurance surveys for asphalt projects and for construction control
• Lesson 17: Practical examples of the use of GPR in forensic surveys
• Lesson 18: Practical examples of the use of GPR in bridges surveys
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EDU2 content – day 1, lessons 1-8

- Lesson 1: Introduction, Designing a GPR project, preparing procurement documents
- Lesson 2: Arranging GPR field data collection, safety issues, other surveys needed
- Lesson 3: Calibration of GPR system in the field, metal plate tests, encoder calibration, etc
- Lesson 4: Performing data collection, quality assurance of the data in the field, making back ups
- Lesson 5: GPR data analysis – preprocessing techniques needed
- Lesson 6: GPR data processing techniques, techniques to improve signal quality
- Lesson 7: 2D and 3D GPR interpretation techniques
- Lesson 8: Summary of day 1

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EDU2 content – day 2, lessons 9-18

- Lesson 9: How to identify road damages from GPR data; settlements, frost fatique, deformation, moisture, etc
- Lesson 10: Integrated analysis of GPR and FWD data, bearing capacity indexes, moduli back calculation, moduli forward calculation,
- Lesson 11: Integrated analysis of GPR and profilometer data
- Lesson 12: GPR and thermal camera data analysis
- Lesson 13: Presenting and delivering GPR surveys results
- Lesson 14: Common mistakes and how to identify cheating in the interpretations
- Lesson 15: Future of GPR technique
- Lesson 16: GPR applications
- Lesson 17: Summary of day 2
- Lesson 18: Instructions to practical demonstration cases.

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WP1 - EDUCATI N

- EDU1:
  - Rovaniemi, Finland
  - Luleå and Gothenburg Sweden
  - Bodö, Norway
- EDU2:
  - Rovaniemi, Finland
  - Luleå, Sweden
- More than hundred people participated in EDU1 trainings.
- “Extra” EDU1 training session was organized in Göteborg, Sweden
- At the end EDU2 was not organized in Norway, in stead common training session for Swedish and Norwegian participants were held in Luleå, Sweden. In total about 50 people participated in EDU2.

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WP2 - GUIDELINES

- WP2 was about writing the Nordic Recommendations. This was a step forwards towards joined management and standardized procurement practices of GPR surveys on roads.
- In Finland GPR has been used in different road measurements for last 15 years and latest guidelines were introduced in 2004.
- Meanwhile the national standards existed in Finland similar or the same type of coordinated procurement and service requirements did not exist either in Sweden or Norway.
- For the GPR companies it is easier to compete across the Nordic borders if the rules and regulations are standardized and implemented as jointly as possible.

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WP2 - GUIDELINES

Writing proces:

- Consultant wrote the draft of the guideline
- Draft was sent out for comments
- Adjusting phase
- New comments
- Finishing of the guideline

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Table 3. Different kinds of 2D and 3D surveys on roads and their characteristics.

Type	Cross-line sampling	Description	Output Data	Application examples	Position accuracy	Survey speed
2D	> 75 cm	1 – 3 channels. Multiple passes with single antenna.	Single in-line profiles	Network level surveys, Rehabilitation, QC.	< 5 m	High (Traffic speed)
2D+	20 – 75 cm	> 3 channels	Coarse 3D layer model	QC, Rehabilitation.	< 1 m	High/ medium
3D	< 20 cm	Multi-channel / antenna arrays	Full 3D layer model/ Low res. image	QC	< 20 cm	Medium / low
HD3D	< 10cm*)	Multi-channel / antenna arrays	High resolution image	Detection of cracks, reinforcement bars, individual boulders,	< 5 cm	Low

*) depends on the frequency

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INTERREG
IV A NORD
Recommendations for guidelines for the use of GPR in Site investigations
" This method description guideline should be used when doing data collection with the 2D and 3D GPR systems prior to road design projects where information from the subgrade soils and bedrock need to be collected. "
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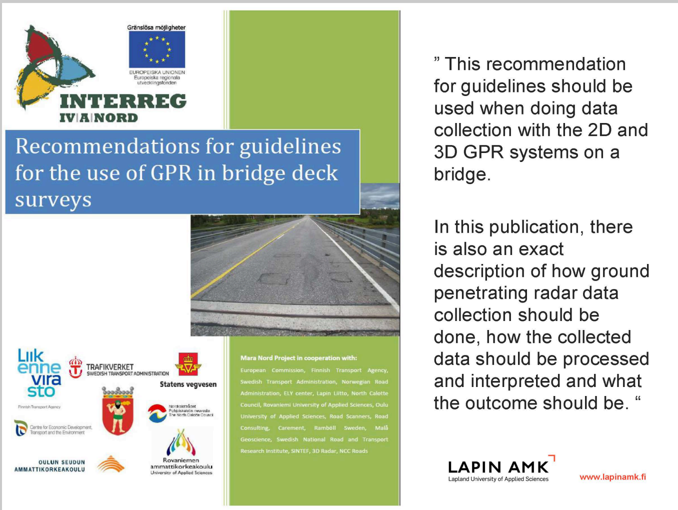
INTERREG
IV A NORD
Recommendations for guidelines for the use of GPR in bridge deck surveys
" This recommendation for guidelines should be used when doing data collection with the 2D and 3D GPR systems on a bridge.
In this publication, there is also an exact description of how ground penetrating radar data collection should be done, how the collected data should be processed and interpreted and what the outcome should be. "
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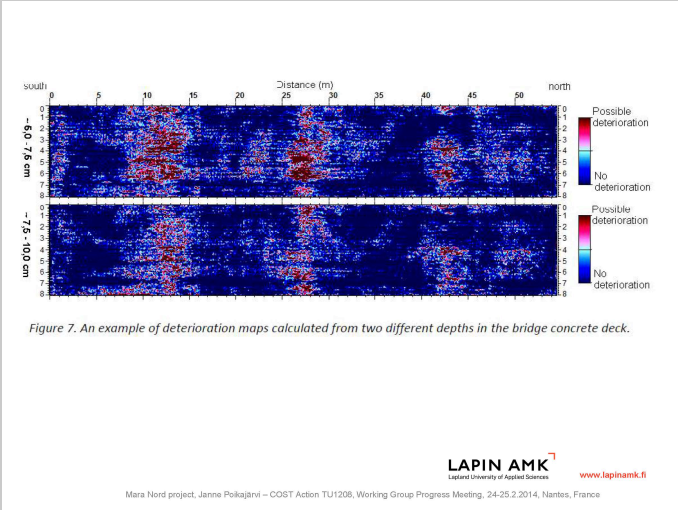
south
Distance (m)
north
0
5
10
15
20
25
30
35
40
45
50
~ 6,0 - 7,5 cm
~ 7,5 - 10,0 cm
Possible deterioration
No deterioration
Possible deterioration
No deterioration
Figure 7. An example of deterioration maps calculated from two different depths in the bridge concrete deck.
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INTERREG
IV A NORD
Recommendations for guidelines for the use of GPR in road construction quality control
Statens vegvesen
TRAFIKVERKET
Quality Control Survey
• Packages Basic package I: Bound layer thickness
• Basic package II: Top part of pavement structure
• Basic package III: Pavement structure
• Basic package IV: Road structure
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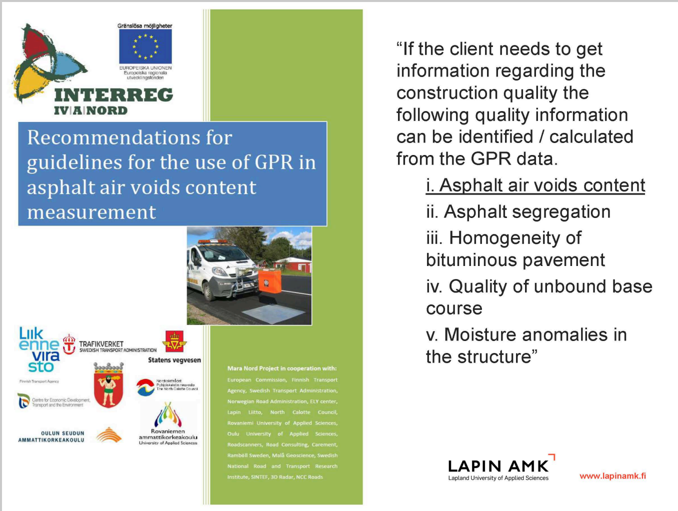
INTERREG IV A NORD
Recommendations for guidelines for the use of GPR in asphalt air voids content measurement
Statens vegvesen
"If the client needs to get information regarding the construction quality the following quality information can be identified / calculated from the GPR data.
i. Asphalt air voids content
ii. Asphalt segregation
iii. Homogeneity of bituminous pavement
iv. Quality of unbound base course
v. Moisture anomalies in the structure"
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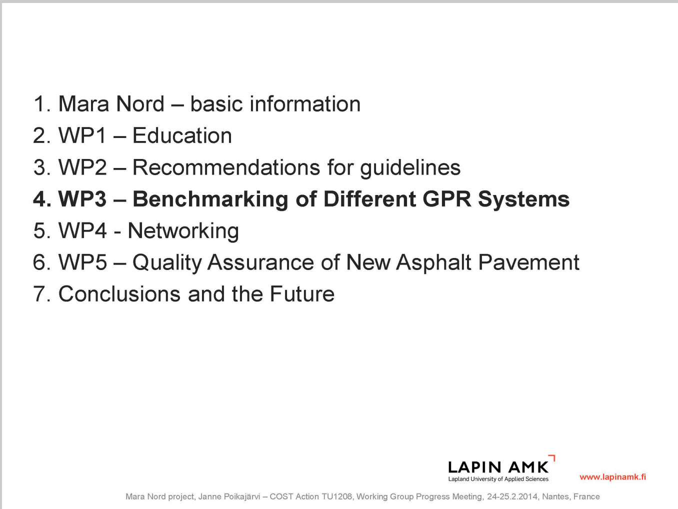
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WP3 - BENCHMA KING

- "The aim of the WP3 was to describe different types of GPR equipment available and their performance. The target was not to put the equipment in any specific order, but to describe what kind of equipment is available, how they can be used, how they perform in field work and how the results look."
- GPR manufacturers present in the test were:
  - 3D-radar AS, Norway
  - Geophysical Survey Systems, Inc., USA
  - IDS, Italy
  - Malå Geoscience, Sweden
- Surveys were done at Talvitie Street and a section 505 of highway 4, both located outside Rovaniemi, Finland.
- Sections had been rehabilitated in 2010 and therefore the layers of the road where fresh and clear.

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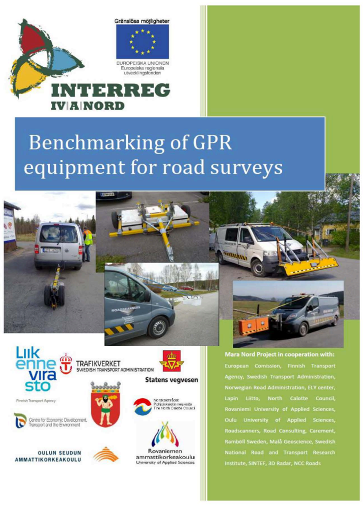

"All the tested equipment showed to be reliable and produced good quality data."

"All of the achieved results showed to be good or very good."

"High frequency horn antennas still have advantages over ground coupled antennas at high speed in road surveys."

"At low survey speeds high frequency ground coupled antennas produce good quality data and the horizontal resolution is better than with the horn antennas."

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WP4 - NET K

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Wp 5 objectives

- Improve the reliability of the current void content method used in new asphalt pavement quality assurance measurements
  - The current regression model used in Finland in GPR void content calculations was introduced by Mr. Petri Roimela in 1997.
  - Influence of environmental factors (for example temperature)
- Investigate the possibility to abandon asphalt core samples when defining the voids content by using GPR method
  - The use of the calibration plate
- Method development
  - Using more than one core sample
  - Other instructions for future measurements

$$void = 272.93\ e^{-1.3012\ k\ \epsilon_r}$$

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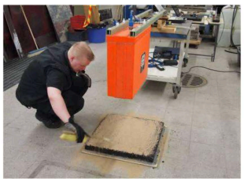
Laboratory measurements & tests

- Aspahlt plates (OAMK)
- Laser scanning (RAMK)
- Troxler (RAMK)
- Environmental factors, e.g. temperature (RAMK)
- Percometer (RAMK)
- GPR (RAMK)
- Core samples (OAMK)



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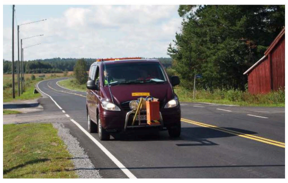
Field measurements

Comparative GPR survey tests in Seinäjoki region

- Roads 18 and 725
- Lines 6642m and 6852m, both lanes were measured (right wheel path)
- 4 GPR operators, 5 different GPR equipment



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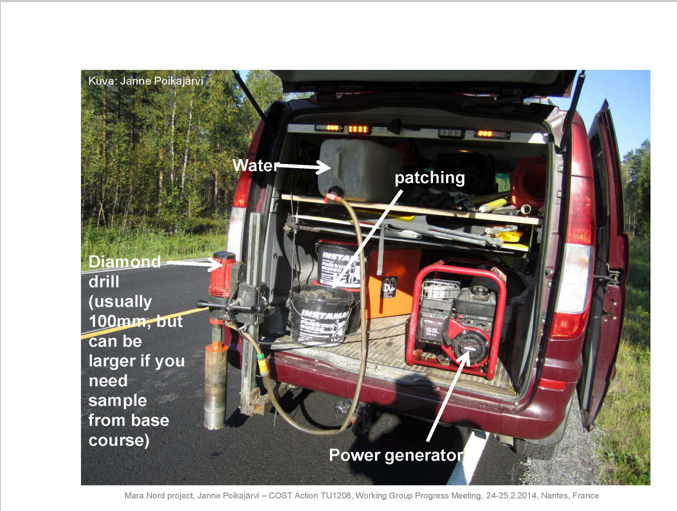
Kuva: Janne Poikajärvi
Water
patching
Diamond drill (usually 100mm, but can be larger if you need sample from base course)
Power generator
Mara Nord project, Janne Poikajärvi – COST Action TU1208, Working Group Progress Meeting, 24-25.2.2014, Nantes, France


What is the point of making holes to the new asphalt pavement?
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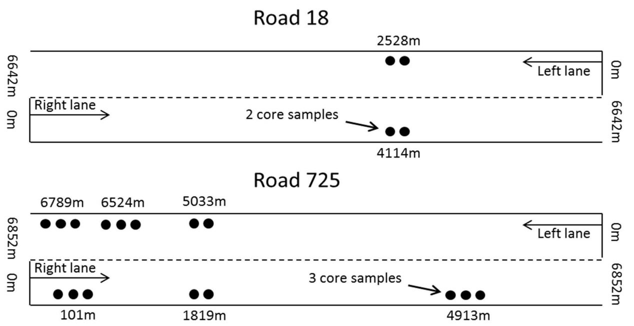
Core sampling



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Data analysis

GPR

- Processing the GPR data
- Dielectric value calculations
- Void content calculations
- Regression analysis
- Statistical and graphical analysis

Other measurements

- 3D laser scanning, air water weighing…

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Results - asphalt plate measurements

- In order to determine real void content of the calibration plate three different methods was used.
- The volume of the plate was examined by air water weighing and 3D laser scanning. The void content was calculated by using the solid density value determined from the asphalt mixture recipe.
- Results were compered to core samples taken from calibration plate.
- Void content values of one asphalt plate:
  - air water weighing 6.3 %
  - 3D scanning 6.2%
  - average of 6 drill cores 6.4%

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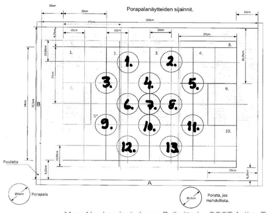
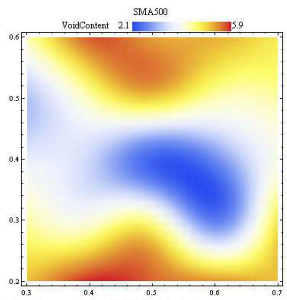
Results - asphalt plate measurements

- The regression model between dielectric value and void content should be based rather on field tests (test site or road sections) than on laboratory test (pavement plates).
  - Homogeneity
  - Size of the asphalt plate
  - Manageability in practise





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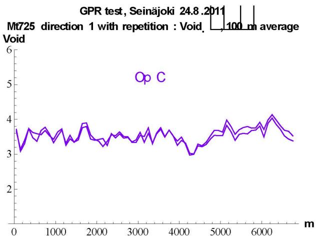
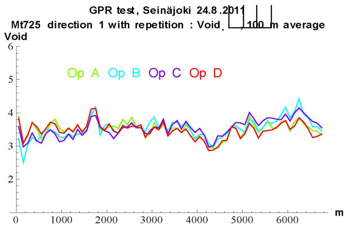
Results of field tests 1 / 4

In quality assurance of new asphalt pavement GPR has good repeatability and reproducibility when same reference data is used.





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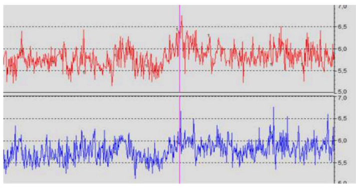
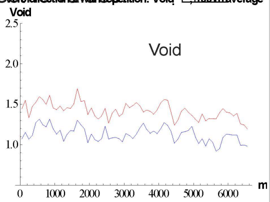
Results of field tests 2 / 4

As a summary of Mara Nord project WP 5 findings, the following methods for improvements increase the quality of void content measurement results:

- Core samples need to be taken from a location that represents the average level of dielectric value. This means that a preliminary analysis of GPR data needs to be done on site for core sample location determination.
- Core samples should be located where GPR does not detect remarkable changes in dielectric values.





Results of field tests 3 / 4

- More than one core sample should be taken from each location.
- There should be core samples taken from each survey line. At least every time when the asphalt mass, working method, base treatment or environmental circumstances change.

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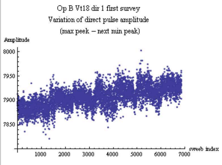
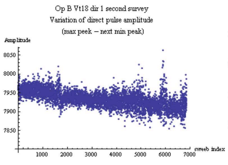
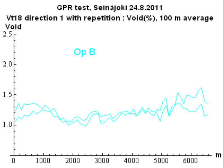
Results of field tests 4 / 4

- In case traffic compaction has been realized the possibility to place survey line between wheel paths needs to be examined.
- To avoid significant differences in dielectric value level in separate surveys metal plate measurement should be done in the same circumstances as void content survey.
- GPR operator needs to monitor GPR data whether long term changes in direct pulse amplitude appear and these changes need to be taken into account in dielectric value calculation.







Future research

- Homogeneity is an alternative property for the void content to indicate quality assurance of new asphalt pavement.
- **Wavelet analysis** is one promising method to investigate asphalt pavement homogeneity.
- Long term surveillance of road sections is needed to validate quality assurance methods. For example, in the homogeneity model correlation between statistically significant variations with pavement damage should be determined.

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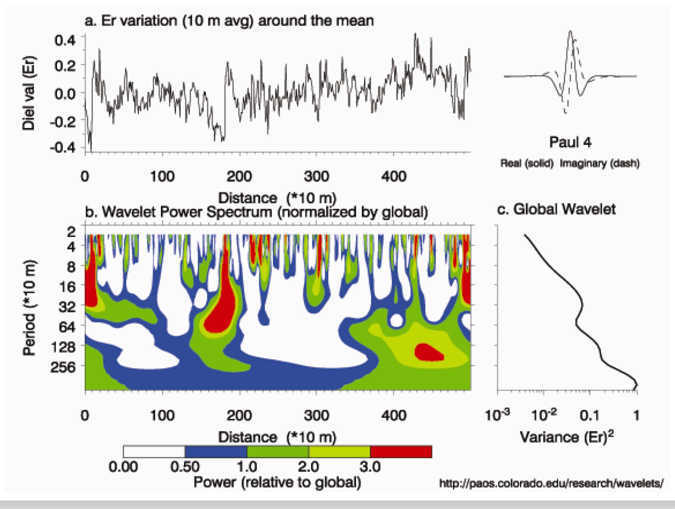

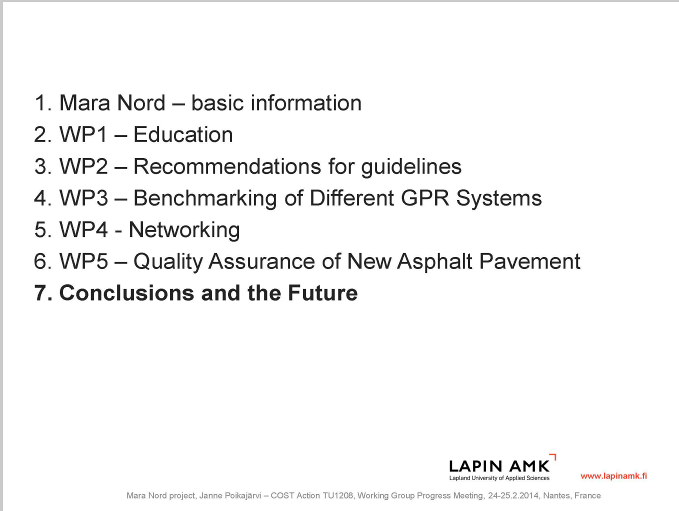
1. Mara Nord – basic information
2. WP1 – Education
3. WP2 – Recommendations for guidelines
4. WP3 – Benchmarking of Different GPR Systems
5. WP4 - Networking
6. WP5 – Quality Assurance of New Asphalt Pavement
7. Conclusions and the Future
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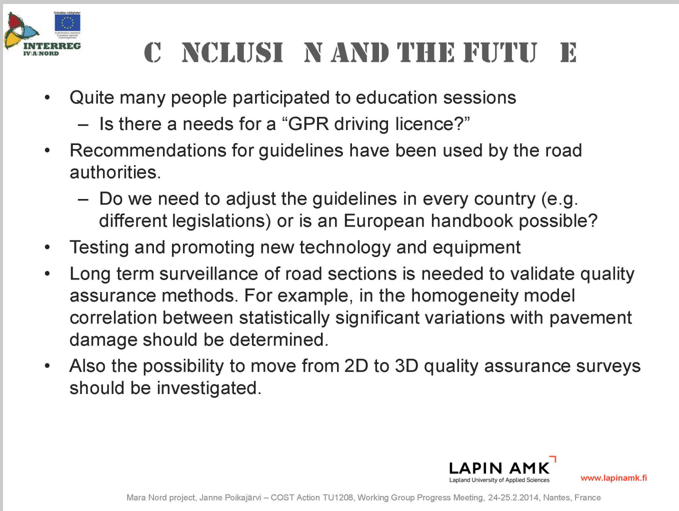
INTERREG
C NCLUSI N AND THE FUTU E
• Quite many people participated to education sessions
– Is there a needs for a "GPR driving licence?"
• Recommendations for guidelines have been used by the road authorities.
– Do we need to adjust the guidelines in every country (e.g. different legislations) or is an European handbook possible?
• Testing and promoting new technology and equipment
• Long term surveillance of road sections is needed to validate quality assurance methods. For example, in the homogeneity model correlation between statistically significant variations with pavement damage should be determined.
• Also the possibility to move from 2D to 3D quality assurance surveys should be investigated.
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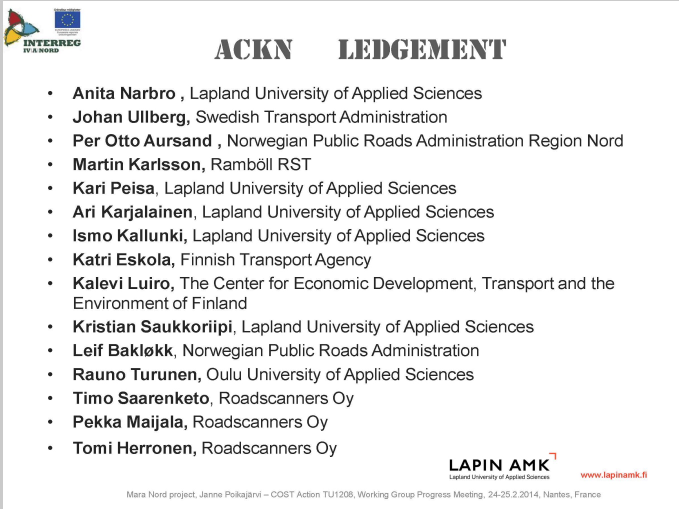
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Reports and material
maranord.ramk.fi
Project duration 01.01.2010 - 31.06.2012.
Project final reports and other material
Final project report
Recommendations for guidelines
Benchmarking of GPR equipment for road surveys
WP5 final report - Quality Assurance of New Asphalt Pavement
Wavelet Analysis
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"INNOVATIVE INSPECTION PROCEDURES FOR EFFECTIVE GPR SURVEYING OF CRITICAL TRANSPORT INFRASTRUCTURES (PAVEMENTS, BRIDGES AND TUNNELS)" PROGRESS REPORT ON PROJECT 2.1

Josef Stryk
Centrum dopravního výzkumu, v.v.i.
Lisenska 33a, 63600 Brno
Czech Republic
josef.stryk@cdv.cz

Content of the talk:

- PROJECT MEMBERS (46)
- UPDATED QUESTIONNAIRE (RESULTS OF THE SURVEY)
- OBTAINED PAPERS, REPORTS, NEWS
- EURO GPR ACTIVITIES (INFO FROM E. UTSI)
- PREPARATION OF CHAPTER FOR THE SPRINGER BOOK
- CZECH NATIONAL PROJECT TO COST ACTION
- PRESENTATION OF RESULTS OF THE FIRST CZECH COMPARATIVE TEST - CONTINUAL MEASUREMENT OF THICKNESS OF ASPHALT LAYERS BY GPR

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QUESTIONNAIRE PROJECT 2.1

COST
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

Action TU1208 – Civil Engineering Applications of Ground Penetrating Radar

Contact Information	
Country:	
Institution:	
Contact Person:	
Address:	
E-mail:	
Tel:	
Website:	

WP2 questionnaire	Check:

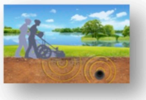
Do you have some support from state or any other source to solve COST action TU1208?	
- yes	
- no	
Comment: text	

Type of your GPR activities:	
- commercial measurements	
- research:	
- GPR hardware	
- GPR software	
- application of GPR	
Comment: text	

Which applications of GPR are you dealing with?

Pavement diagnostics:	in-situ	in lab	commercial	research
- thickness of asphalt layers				
- thickness of concrete layers				
- thickness of bound sub-base layers				
- thickness of unbound sub-base layers				
- position of reinforcement in concrete pavement				
- de-bonding and delamination of pavement layers				
- identification of caverns				
- identification of frost heaves				
- depth of surface cracks				
- localisation of bottom-surface initiated cracks				

1

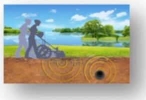


- condition of reinforcement in concrete pavement				
- moisture content				
- air voids content				
- compaction				
- segregation of aggregate				
- …				
- …				
- …				
Comment:	text			

Bridge diagnostics:	in-situ	in lab	commercial	research
- concrete cover of reinforcement in bridge deck				
- position of reinforcement in bridge deck				
- thickness of bridge deck				
- position of pre-stressed or post-tensioned tendons or tendon ducts				
- de-bonding and delamination of pavement layer				
- bridge deck deterioration (cracks, caverns, etc.)				
- bridge girder diagnostics				
- diameter of reinforcement in-build in concrete				
- condition of reinforcement in bridge deck				
- evaluation of sealing course on bridge deck				
- moisture content				
- …				
- …				
- …				
Comment:	text			

Tunnel diagnostics:	in-situ	in lab	commercial	research
- position of reinforcement in tunnel wall				
- thickness of tunnel wall				
- homogeneity of tunnel wall				
- hollow spaces between concrete and rock				
- diameter of reinforcement in-build in				

2



Action TU1208 – Civil Engineering Applications of Ground Penetrating Radar

concrete				
- condition of reinforcement in tunnel wall				
- moisture content				
- …				
- …				
- …				
Comment:	text			

Railway track diagnostics:	in-situ	in lab	commercial	research
- …				
- …				
- …				
Comment:	text			

Retaining wall diagnostics:	in-situ	in lab	commercial	research
- …				
- …				
- …				
Comment:	text			

Do you have **technical specification/guide/manual for** pavement/bridge/tunnel/… **diagnostics with GPR** in your country?

- no
- yes:

name: **text**

issued in year: **year**

	Which objects it covers?	Is the accuracy of the measurement specified there?
- pavements		**yes/no**
- bridges		
- tunnels		
- railway tracks		
- retaining walls		
- buildings		
- underground utilities and voids		
- …		
- …		
- …		
Comment:	text	

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Action TU1208 – Civil Engineering Applications of Ground Penetrating Radar

Are any **comparative tests** for GPR diagnostics organised in your country?			
- no			
- yes:			
Which objects it covers?			
- roads		- bridges	
- tunnels		- railway tracks	
- retaining walls		- buildings	
- underground utilities and voids		- …	
- …		- …	
Do you have technical specification/guide/manual for it?			
- no			
- yes:			
name:	**text**		
issued in year:			**year**
Which objects it covers?			
- roads		- bridges	
- tunnels		- railway tracks	
- retaining walls		- buildings	
- underground utilities and voids		- …	
- …		- …	
Comment:	text		

Is any **authorisation** required for GPR measurements on civil engineering structures in your country?		
- no		
- yes	on which objects:	**text**
Who is granting the authorisation?		**text**
Comment:	text	

How many channels do you use with your GPR system during the measurement?			
- roads	**number**	- bridges	
- tunnels		- railway tracks	
- retaining walls		- buildings	
- underground utilities and voids		- …	
- …		- …	
Comment:	text		

4

Which way do you **determine the speed of EM signal propagation** through the material/layers during in-situ measurements?	
- table values	
- using set of antennas (CMP or WARR method)	
- measuring of permittivity:	
- which equipment do you use for it:	**text**
- direct method (taking cores, reading thickness at construction joints, altitudinal survey before and after construction of layers, etc.)	
- other method, please specify:	**text**
- combination of methods, please specify:	**text**
Comment:	text

What **accuracy** do you state for the following GPR **applications**?	% or mm
- thickness of new or sound asphalt pavement layers	
- thickness of degraded asphalt pavement layers	
- thickness of cement concrete pavement	
- thickness of sub-base layer	
- position (depth) of dowels and tie bars in concrete pavement	
- position (depth) of reinforcement in concrete structures (thickness up to 300 mm)	
Comment:	text

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"INNOVATIVE INSPECTION PROCEDURES FOR EFFECTIVE GPR SURVEYING OF BUILDINGS" STATE OF THE ART AND OPEN ISSUES ON PROJECT 2.2

Vega Pérez-Gracia
Department of Strengthen of materials and structures, EUETIB,
Technical University of Catalonia
C/Urgell187, 08036 Barcelone, Spain
vega.perez@upc.edu

Abstract

A considerable number of studies about GPR applications in building inspection can be found in the literature. These applications are mainly focused on rebar detection and in cultural heritage evaluations. Remarkable results can be found about cracks detection and inspection of masonry walls and columns. It is also remarkable the development of data processing to enhance the images and to facilitate the data interpretation. Other special works are based on laboratory tests to determine quantitative properties of constructive materials. Therefore, damp measures, concrete degradation due to corrosion, and damages due to tree roots are tested in laboratory specimens. Although it is a promising subject, few studies have been applied in buildings.

I. INTRODUCTION

Ground Penetrating Radar (GPR) is frequently used in building inspection, mainly in rebar detection (e.g., [1];[2]) and in cultural heritage studies (e.g., [3], [4] [5]). GPR surveys use to be applied as a support or preliminary analysis to determine characteristics that are needed in more extensive evaluations. In these cases, GPR provides valuable data that helps in the simulation of the building behavior or in the selection of part of the building that require further analysis with

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other methods. Consequently, precise data are usually required and, therefore, inspection in buildings needs accurate data acquisition, processing and interpretation.

Building inspection is performed for diverse reasons: (1) in many cities, a periodic inspection is required in some old buildings, (2) to conduct careful evaluations after an earthquake or other natural hazard, (3) as a previous task in restoration of cultural heritage or special buildings, (4) to define risk maps in cities, (5) to evaluate restorations or changes in the structure of the building, (6) to inspect structures when damages are detected, etc. A careful and minimally invasive inspection use to be required in all these cases, because buildings often should be kept in service.

Tasks for building inspection require, usually, a first visual evaluation consisting of a visual scrutiny that provides information about external elements and damages. This information about the external state is used to consider the possible internal conditions and deterioration.

The preliminary information obtained in the visual inspection can be applied to select the most significant areas that must be evaluated more in depth. The next inspection is often a slightly invasive evaluation, random destructive tests are executed in selected areas. These studies provide valuable and punctual information about the building. However, in many cases, a more intensive scrutiny is required. Then, it is usual to perform complementary investigation involving non-destructive testing (NDT) techniques that supplies indirect information about the internal elements of the structure.

Ground-Penetrating Radar is one of the most usual NDT methods in buildings inspection because of the low cost and on the expeditious data acquisition, although in many cases this technique is applied combined with other inspection methods. GPR survey is an especially attractive technique in cultural heritage inspection, where noninvasive evaluations is required. Examples as [3]-[7] highlight the importance of historical buildings radar explorations. Other proposed GPR applications are in the inspection of modern buildings that are reaching a critical age [8].

The great differences in structural solutions, as well as the different requirements depending on the projects, yield to many different strategies and solutions and, in many cases, the potential of the method is still being verified, mostly in experimental laboratory tests or in simulations.

II. Types of buildings

A great number of applications related to buildings are referred to cultural heritage. These buildings are often masonry structures. Stone and brick walls are the most studied parts of these structures. However, in some cases, these buildings are combined structures as a result of later reconstructions. Then, modern constructive elements coexists with ancient masonry ones. In some cases, the evaluation of reconstructed buildings involves the detection of the contacts between old and modern parts [9], the detection of metallic connecting elements between the structures of different epochs, or the confirmation of the existence of old remains under less ancient elements [10].

Other common types of buildings which can be studied by means of GPR are modern concrete structures. In these cases, common applications are the detection of rebar, damages, or beams under enclosures.

GPR applications in wooden buildings are unusual, however in many cases the buildings include structural wood elements. Many masonry buildings have wooden beams or wood supports. The deterioration of these timber elements occurs generally by dampness, woodworms and fungi. In the few studies on this subject [11], [12], the importance of combining different non-invasive techniques is highlighted, to define clearly the cause of the anomalies and the resistant characteristics of the wooden elements.

III. Application in building diagnosis: detection of damages

Landslides, earthquakes and the age of the buildings are usual causes for diagnosis studies. Recent earthquakes have emphasized the

importance of detailed assessments of the impaired buildings, prior its rehabilitation. Several proposals of diagnosis procedures include GPR as a supporting methodology, being applied in different cases [13]-[15]. Other common causes are the restoration projects in cultural heritage buildings and the appearance of visible damage to the structure or cladding, such as damp patches, cracking and detachment of materials.

As a combined methodology usually appropriate to detect damages, in many cases, GPR is applied to detect internal cracks and unfilled joints in masonry buildings [16], [17]. It is common to evaluate walls and, in some cases, other supporting structures, as columns [18], [19]. In several cases, suggestive applications reveals the correlation between GPR depth slices and anomalies observed visually [20]. Interesting works shows the potential of GPR by means of simulation models and laboratory tests [21]. Several ongoing research projects are focused on the development of new processing methodologies and strategies to obtain satisfactory results in the study of masonry damages, with promising results. These projects lead to a methodological approach for the detection of multiple defects inside dielectric or conductive media [22], [23]. In other cases, effectiveness of processing techniques is evaluated, focusing on obtaining qualitative imaging of damages due to cracks. Advances to define crack shape and position are presented in different works; in [24] the possibility of using a microwave approach based on a genetic algorithm is presented, to detect defects inside a known host object.

In concrete reinforced buildings damages could be caused by steel corrosion. Several researches propose the application of GPR to detect this kind of damage. The content of ions in the porous water produces alteration in parts of the structure affected by corrosion. Therefore, the electromagnetic properties are modified, enabling the detection due to differences in travel times, amplitudes and peak frequencies [8], [25].

Other usual application is the detection of parts of the structure affected by humidity. Remarkable applications are developed in buildings [2], [26], [27], being one of the objectives the study the humidity in walls or in the floor. Analogous methodologies are also

successfully applied to other different kind of structures such as bridges [28], [29] and towers [30], obtaining similar results.

GPR was also applied to determine the concrete degradation in a factory floor, demonstrating that changes in concrete conditions could be clearly detected [31].

IV. Detection of internal elements

Another common application of GPR in buildings is the detection of internal elements. Rebar, reinforcements, changes in constructive materials or embedded elements use to be the most common targets detected with GPR [4], [32]-[35]. In other cases, this geophysical method is applied in order to detect older constructions or constructive elements inside the walls or under the actual building structure [26], [36], [37]. In many cases, B-scans are used to infer the existence of hidden elements, but currently are more habitual 3D images and time slices, which make available tridimensional patterns of the embedded structures.

V. Foundations and ground

The study of the ground and the building foundations is also a task in several geophysical explorations of buildings. The aim of studying the ground under and around the building is, frequently, the detection of geological structures that could cause damages or failure of the building [36], [38], [39] to detect man-made structures that could affect the safety of the structure [4], [37], or to detect wet areas, as the cause of damp damages [2], [40]. GPR was also proposed to study the ground because of root damages in buildings [41]. However, in these evaluations it is usual to apply combined methodologies, being resistivity surveys the most common techniques combined with GPR, even in some cases, seismic surveys are also shared with GPR and resistivity, showing promising results.

Few GPR applications cover the evaluation of foundations, perhaps due to the difficult in the access, an important limit in GPR surveys. Examples of these kind of applications can be found in [42] and

in [43]. Detection of foundations of archaeological remains in urban environments (e.g., [44]) is a more common application. In these cases, integrated studies and combined methodologies – usually GPR and resistivity techniques – are the most usual surveys.

VI. Methodologies

Radar data acquisition methodologies depend greatly on the building element being studied. In many evaluations, ground, walls and floor are scrutinized to detect buried elements or zones affected by water or cracks. In these cases, single radar lines use to be the most habitual data acquisition method, and many examples show valuable results (e.g., [2]-[5]).

Depending on the dimensions of the building, parallel radar profiles could be also used to obtain three dimensional radar images of floors and walls, providing good visualization of cracks [20], of changes in materials [45] and of the internal elements such as rebar [46]. In some cases, the authors discuss about the density of the grid to obtain better images [47] by using a single antenna. Even in occasions it is possible to utilize an array of antennas, it is not the most usual case inside building evaluations because of the dimensions of the arrays.

Other authors propose the tomography as a proper methodology to detect embedded objects within walls, showing impressive results and even detecting wooden beams and polystyrene bodies inside masonry [32].

Combined evaluations by using other geophysical techniques are also a good option proposed and used by different authors in the search of underneath remains under the building or in the ground evaluation to determine the cause of building damages. The methods used most often, combined with GPR are resistivity surveys [48]. In some cases, other additional geophysical techniques are used together with these two methods. It is possible to find works where GPR and resistivity are applied jointly with very low frequency electromagnetic technique (e.g., [49]), and seismic methods (e.g., [36]) or ultrasonic methods (e.g., [50]).

VII. New and experimental developments

Instead detection of structural elements is a regular task, the challenge of know detailed characteristics about structural materials force to laboratory experiments, synthetic models and new processing methodologies. Several applications highlight the difficulties in the buildings evaluations.

One of the problems is the confuse images produced by the non-homogeneous structures, due to the scattering in multiple and different targets. Reconstruction of the shapes of the scatterers is, in many cases, a complex task. Development and evaluation of numerical methodologies that facilitates pattern reconstruction [51]-[54] is an interesting working line that could get an effective improvement of the results and interpretations of GPR data from surveys in buildings. Synthetic and experimental data have been used to evaluate the new processing techniques, obtaining in many cases better or equivalent resolution and a non-negligible improvement of results [51].

Software tools used in pattern reconstruction could be applied to the detection of cracks and structural damages in different parts of the buildings and, in many cases, focused to the detection and reconstruction of internal cracks and damages [22], [23], [55] and on the detection of its position and its orientation [56].

Calibration of the GPR ability to determine thicknesses and the resolution is another interesting line of study partially applied in building studies. In some cases, GPR data is compared to laser-scanning results during the study of stone masonry walls [57]. In other cases, experimental controlled tests are in quasi homogeneous media are the tool to determine GPR resolution to detect embedded targets [58], [59].

Laboratory tests provide significant results that help in the interpretation of radar images from applied cases in buildings. Some experiences try to obtain accurate methodologies for the detection of voids, combining GPR with other techniques like thermography [60] or capacitive techniques [61].

However, some of the most interesting experimental measures under controlled conditions are focused to establish methods to measure properties of the constructive materials. The knowledge of these properties could be crucial in building assessment. Remarkable laboratory analysis are focused on the characterization of the electromagnetic concrete properties [8], [32], [62], [63], on the detection of steel corrosion [25], [64], [65], and on the detection of moisture [66]-[68].

VIII. Conclusion

The review of the GPR applications in buildings inspection shows that this method is widely used in building inspection to evaluate damages and to detect embedded targets. The greatest number of applications is done in cultural heritage buildings and, usually, combined with other geophysical techniques. In many cases, radar data is used as complimentary information to decide wider and more extensive studies. In other cases, radar data assessment is required as a preliminary evaluation in damaged buildings after natural hazards as earthquakes or landslides.

Some cases studies are done in concrete buildings, to detect rebar and to determine the zones probably affected by damp.

Therefore, the most common applications are realized on masonry and concrete structures. Few applications can be found in wood structures, although GPR is sometimes used to determine the existence of wooden beams or structural elements in masonry buildings.

However, these applications provide always qualitative results. In an effort to determine possible quantitative data, laboratory experiences under controlled conditions have been developed, obtaining interesting results. Regardless, few applications exist in buildings to determine quantitative results, perhaps due to the inherent complexity of the studied structures, being one of the open issues in the study of buildings.

The noticeable advances in data processing, in pattern reconstruction and in the acquisition data technologies have facilitated

the application of GPR in different problems associated to building inspection.

Several open issues could be: (1) to define the casuistic in buildings and to propose suitable radar data acquisition procedures in each case or problem; (2) to enhance GPR imaging; (3) to apply in different buildings those methods evaluated under laboratory test, to determine electromagnetic parameters of the buildings materials; (4) to enhance the radar equipments adapting the antennas to the different structural elements and spaces inside buildings. Probably more open issues will be defined during the tasks development of the working group. Perhaps it could be suitable to establish a catalog of projects and significant publications related with this subject, shared with all participants in this project.

ACKNOWLEDGEMENT

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Inspection Procedures for Effective GPR Surveying of Buildings

Project 2.2
State of the art, open issues

V. Pérez-Gracia
(Politechnical University of Catalonia, Spain)

With the collaboration of:

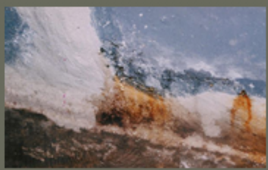
M. Solla (Defense Center University, University of Vigo, Spain)
I. Catapano (Inst. for Electromagnetic Sensig of the Environment, Italy)
A. Massa (ELEDIA Research Center, University of Trento, Italy)

Project 2.2. State of the art, open issues

- All building materials deteriorate with age and exposure to the weather.
- Natural hazards can cause damage, although sometimes they cannot be detected by visual inspection.

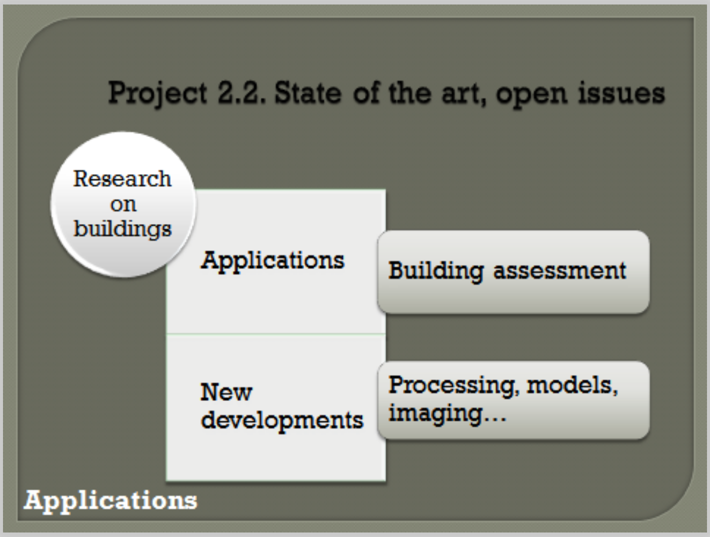
Project 2.2. State of the art, open issues

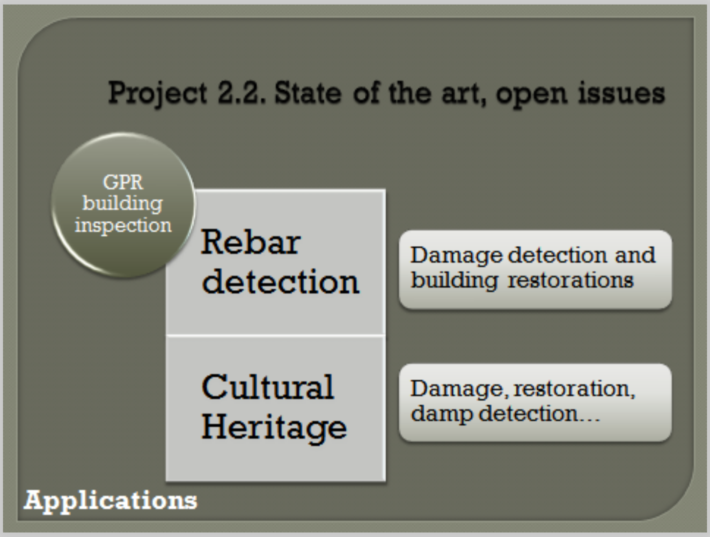
- There are buildings that look in good conditions, but they are affected by hidden problems as damp in basements, deterioration of wood structures, corrosion, etc.

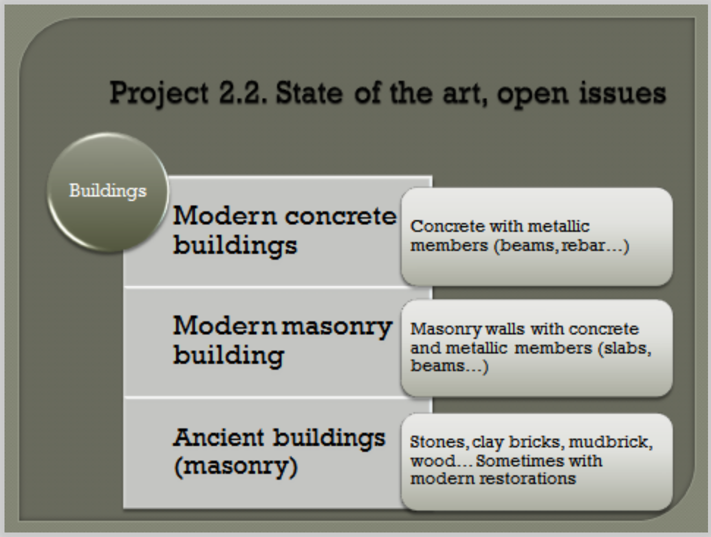


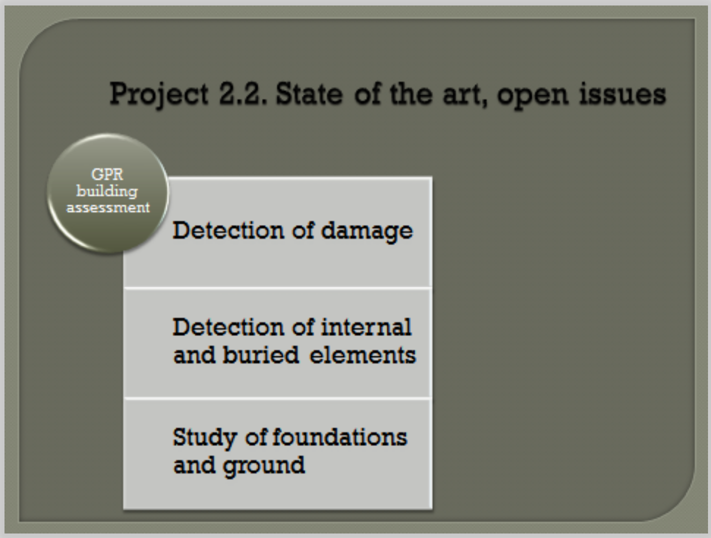

Project 2.2. State of the art, open issues

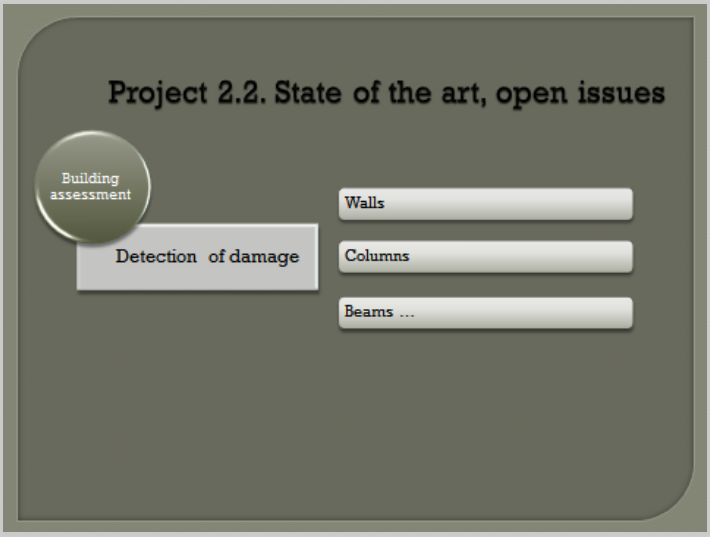
- GPR is one of the most usual NDT methods in buildings inspection because of the low cost and on the expeditious data acquisition.
- In many cases, this technique is applied combined with other inspection methods.
  - Seismic
  - Resistivity
  - Thermography
  - Endoscopy
  - …

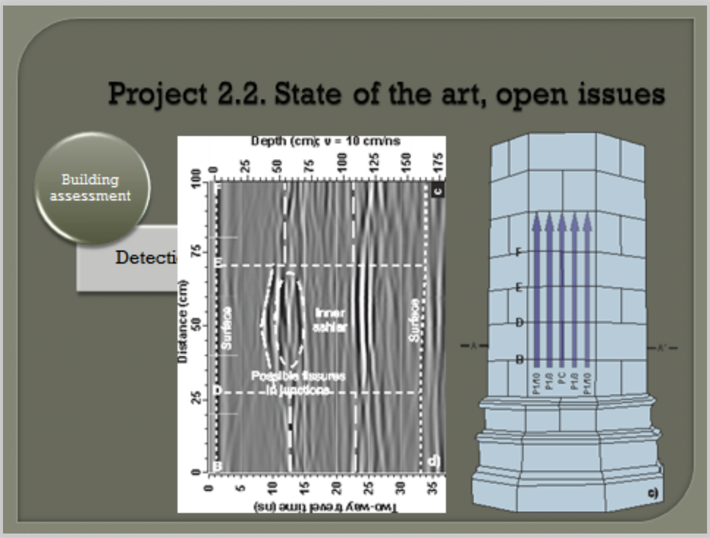

Project 2.2. State of the art, open issues
Research on buildings
Applications
Building assessment
New developments
Processing, models, imaging…
Applications


Project 2.2. State of the art, open issues
GPR building inspection
Rebar detection
Damage detection and building restorations
Cultural Heritage
Damage, restoration, damp detection…
Applications


Project 2.2. State of the art, open issues
Buildings
Modern concrete buildings
Concrete with metallic members (beams, rebar…)
Modern masonry building
Masonry walls with concrete and metallic members (slabs, beams…)
Ancient buildings (masonry)
Stones, clay bricks, mudbrick, wood… Sometimes with modern restorations


Project 2.2. State of the art, open issues
GPR building assessment
Detection of damage
Detection of internal and buried elements
Study of foundations and ground


Project 2.2. State of the art, open issues
Building assessment
Detection of damage
Walls
Columns
Beams …


Project 2.2. State of the art, open issues
Building assessment
Detecti
Depth (cm); v = 10 cm/ns
Distance (cm)
Two-way travel time (ns)
Surface
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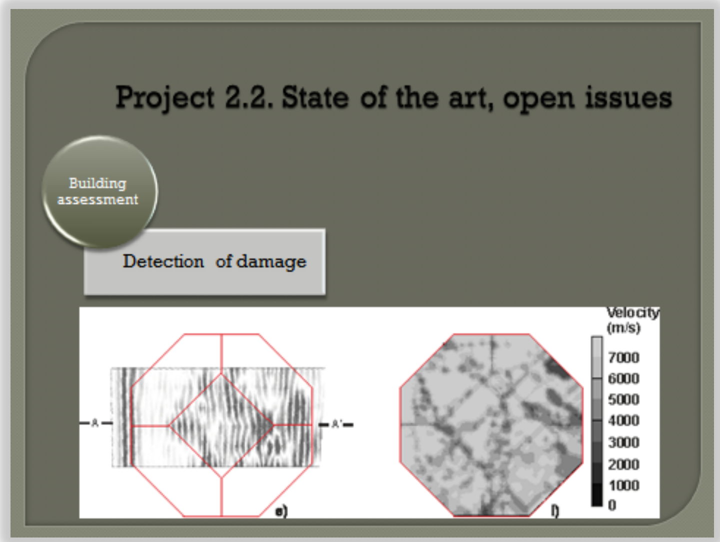
Possible fissures in junctions
Surface


Project 2.2. State of the art, open issues
Building assessment
Detection of damage
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1000
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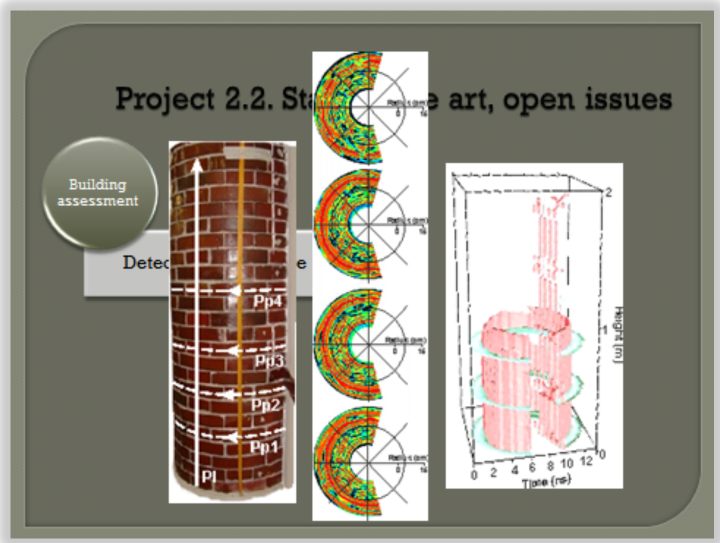
Project 2.2. St
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Building assessment
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Pp2
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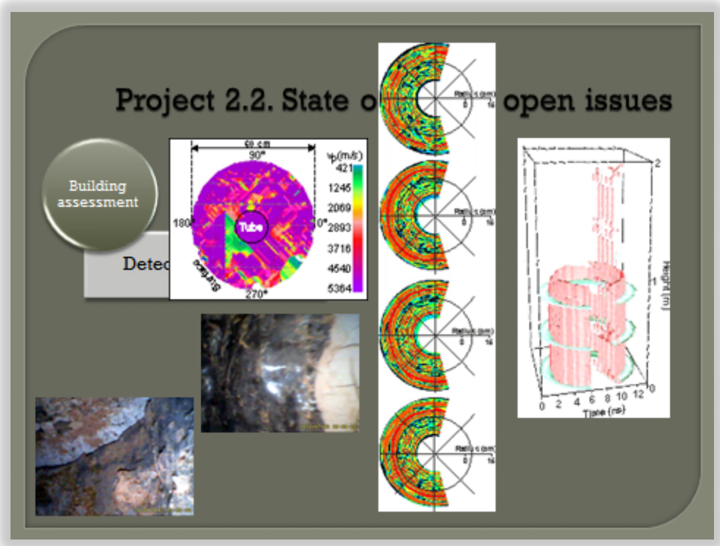
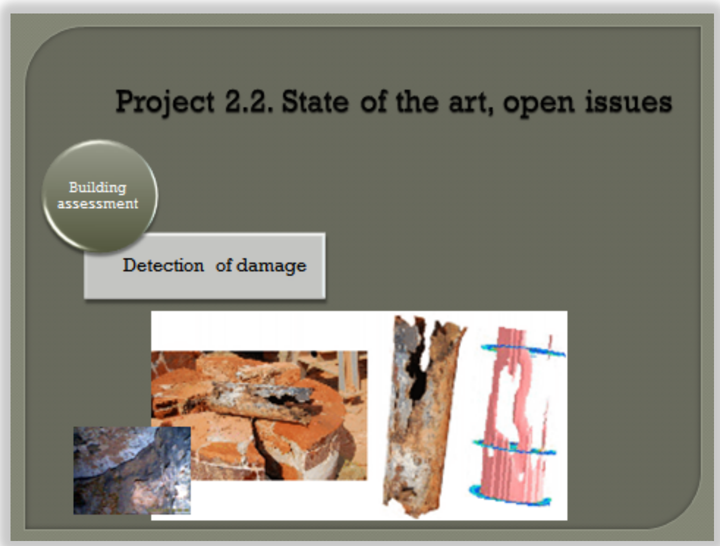
Height (m)
0 2 4 6 8 10 12
Time (ns)


Project 2.2. State o
open issues
Building assessment
Detec
Tube
Surface
90°
270°
5364
Height (m)
Time (ns)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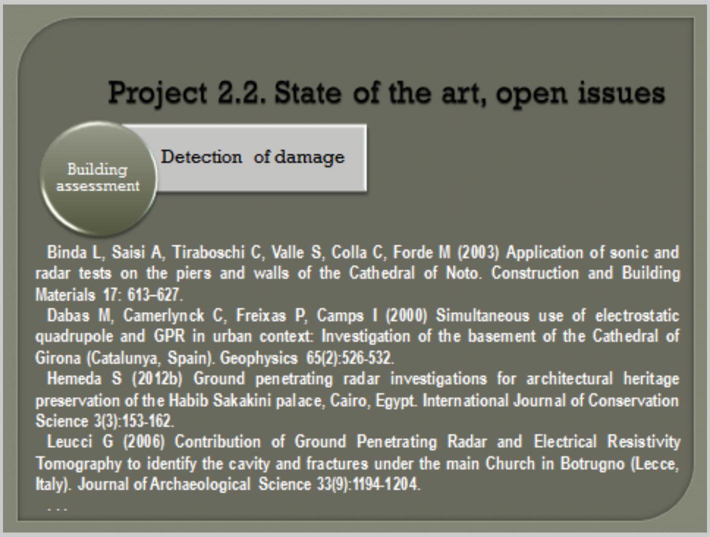
Building assessment
Detection of damage


Project 2.2. State of the art, open issues
Building assessment
Detection of damage
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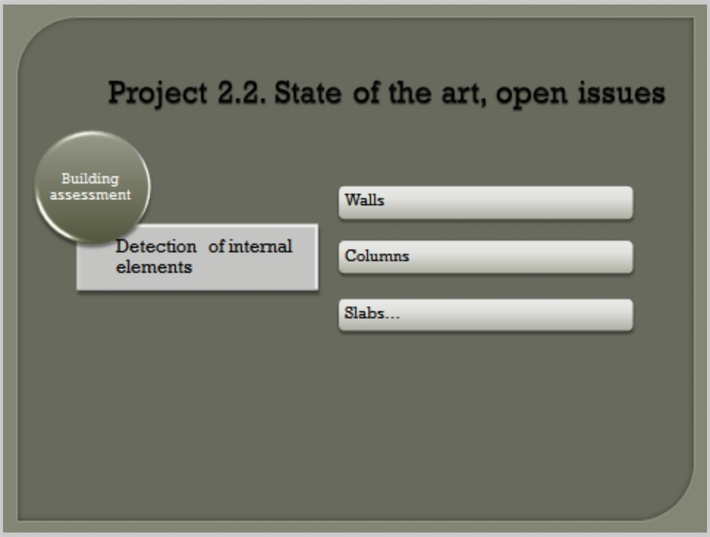
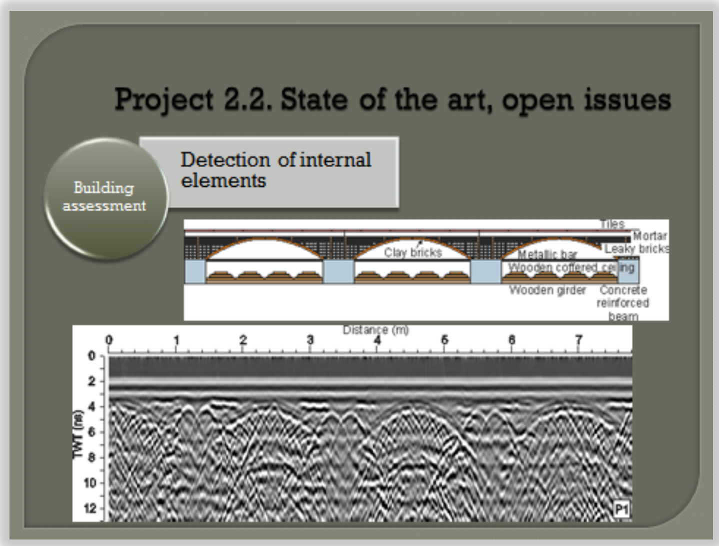
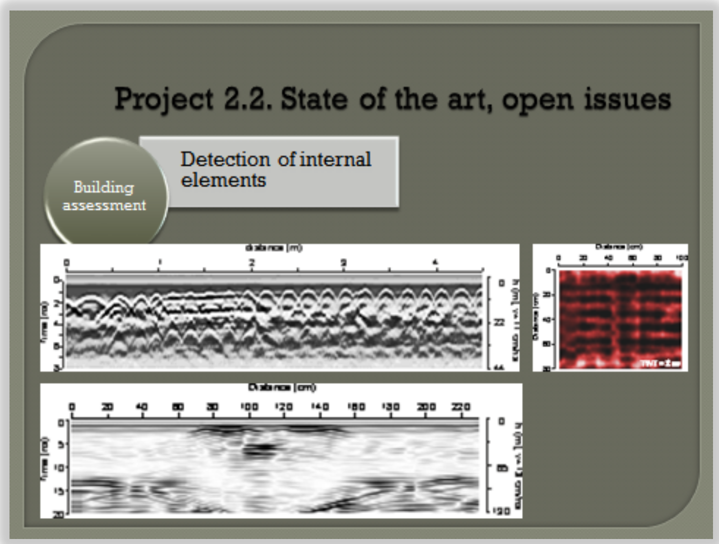
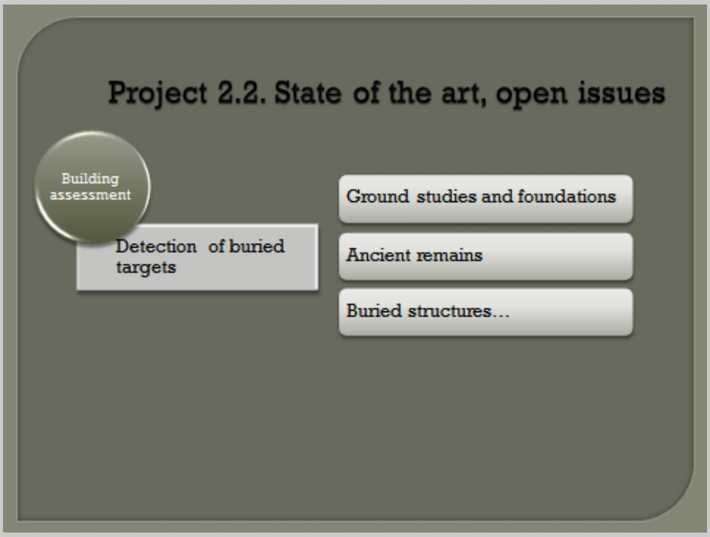
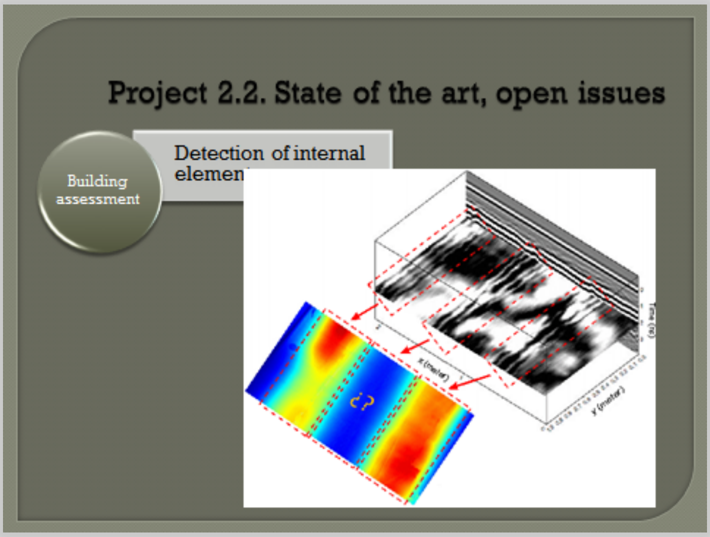

Project 2.2. State of the art, open issues
Building assessment
Detection of internal elements
Walls
Columns
Slabs…


Project 2.2. State of the art, open issues
Building assessment
Detection of internal elements
Tiles
Mortar
Leaky bricks
Clay bricks
Metallic bar
Wooden coffered ceiling
Wooden girder
Concrete reinforced beam
Distance (m)
TWT (ns)
P1


Project 2.2. State of the art, open issues
Building assessment
Detection of internal elements

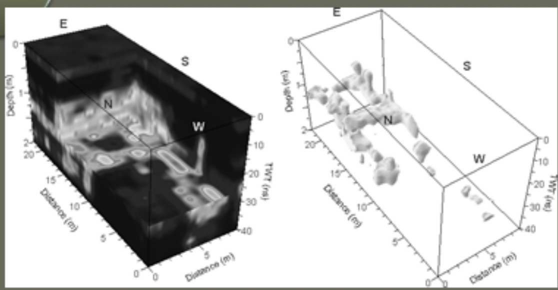

Project 2.2. State of the art, open issues
Building assessment
Detection of buried targets
Ground studies and foundations
Ancient remains
Buried structures…


Project 2.2. State of the art, open issues
Building assessment
Detection of internal elemen

Project 2.2. State of the art, open issues

Building assessment

Detection of buried targets



Project 2.2. State of the art, open issues

Building assessment

Detection of internal elements and buried targets

Abbas AM, Kamei H, Helal A, Atya MA, Shaaban FA (2005) Contribution of geophysics to outlining the foundation structure of the Islamic Museum, Cairo,Egypt. Arch. Prosp. 12,167-176.

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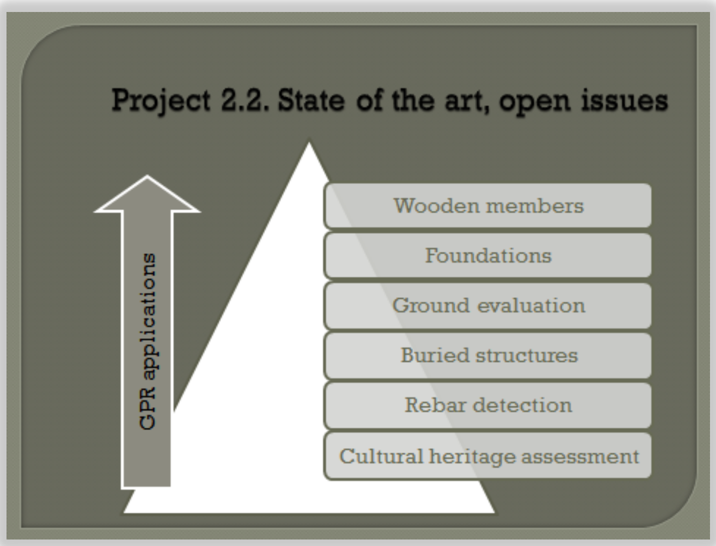
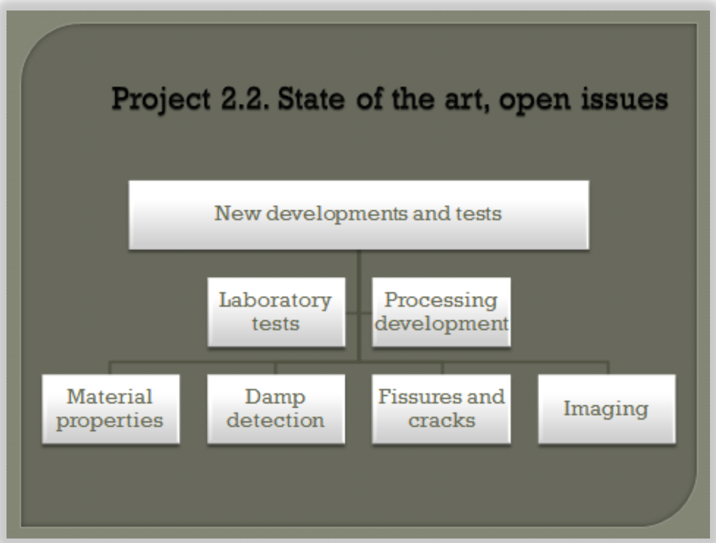
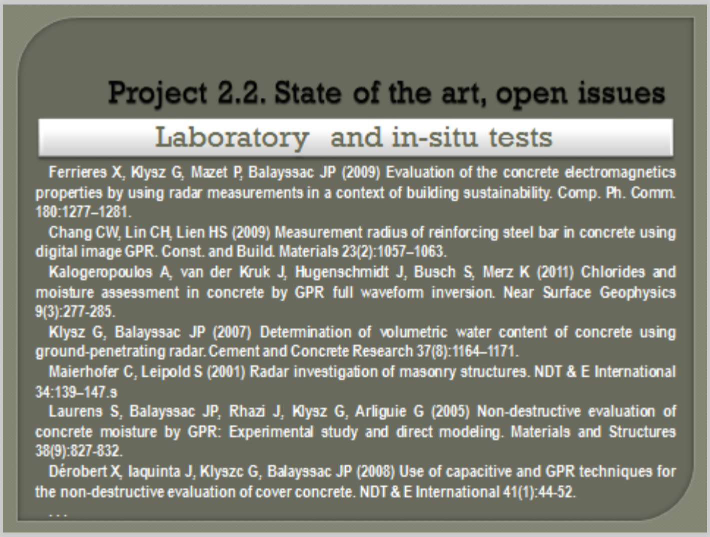


Project 2.2. State of the art, open issues
GPR applications
Wooden members
Foundations
Ground evaluation
Buried structures
Rebar detection
Cultural heritage assessment



Project 2.2. State of the art, open issues
New developments and tests
Laboratory tests
Processing development
Material properties
Damp detection
Fissures and cracks
Imaging


Project 2.2. State of the art, open issues
Laboratory and in-situ tests
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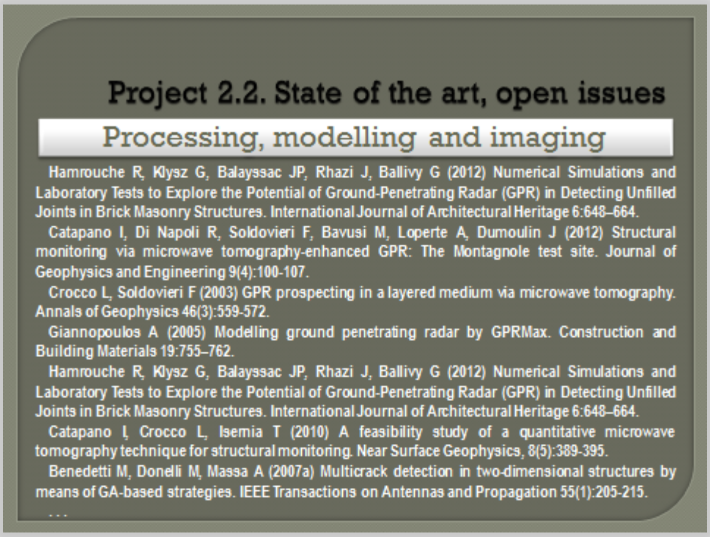
Project 2.2. State of the art, open issues
Processing, modelling and imaging
Hamrouche R, Klysz G, Balayssac JP, Rhazi J, Ballivy G (2012) Numerical Simulations and Laboratory Tests to Explore the Potential of Ground-Penetrating Radar (GPR) in Detecting Unfilled Joints in Brick Masonry Structures. International Journal of Architectural Heritage 6:648–664.
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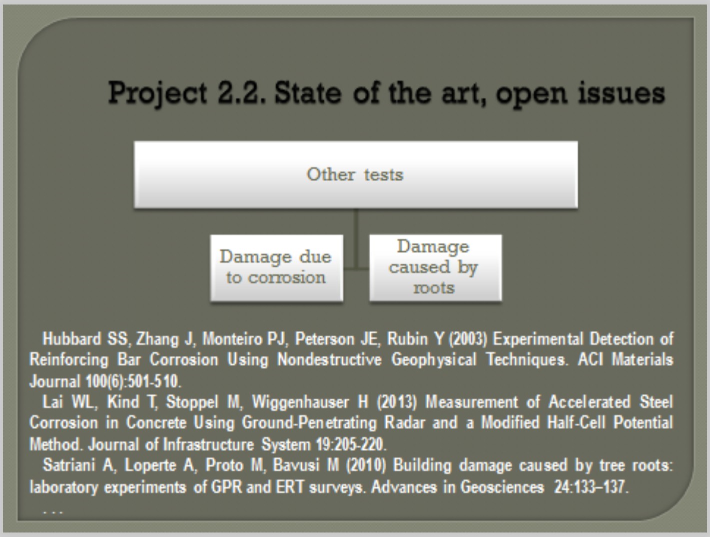
Project 2.2. State of the art, open issues
Other tests
Damage due to corrosion
Damage caused by roots
Hubbard SS, Zhang J, Monteiro PJ, Peterson JE, Rubin Y (2003) Experimental Detection of Reinforcing Bar Corrosion Using Nondestructive Geophysical Techniques. ACI Materials Journal 100(6):501-510.
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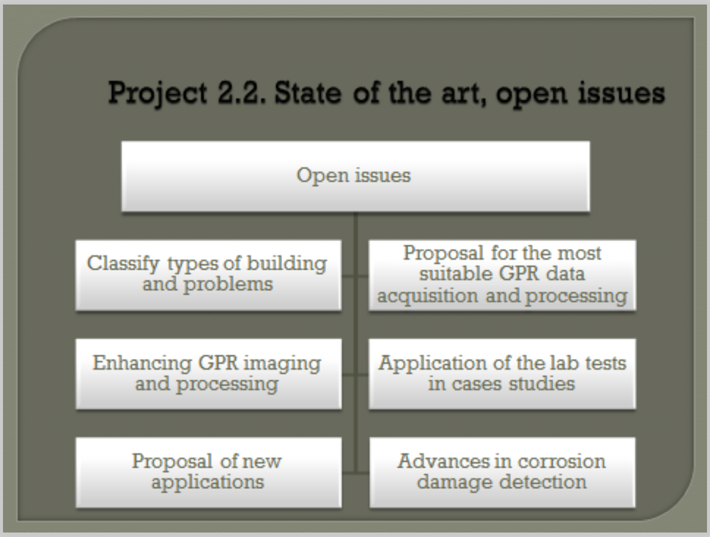
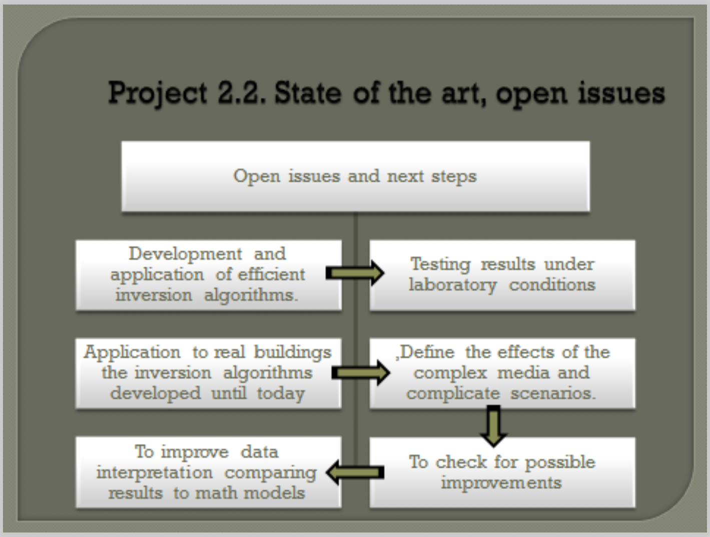
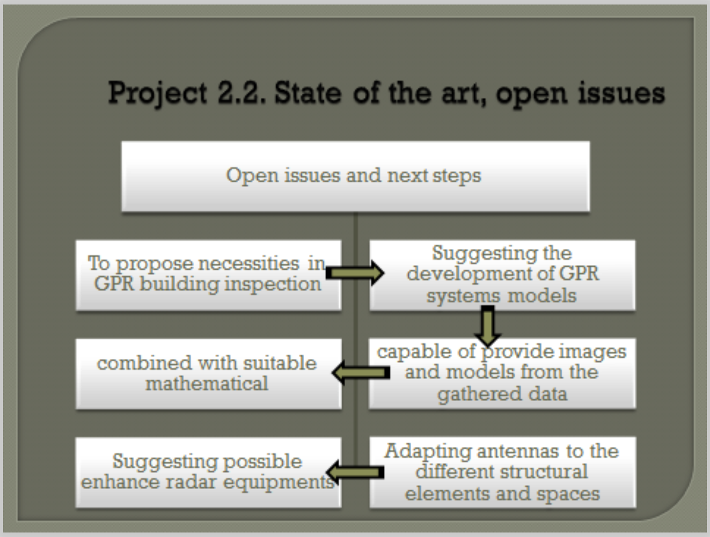
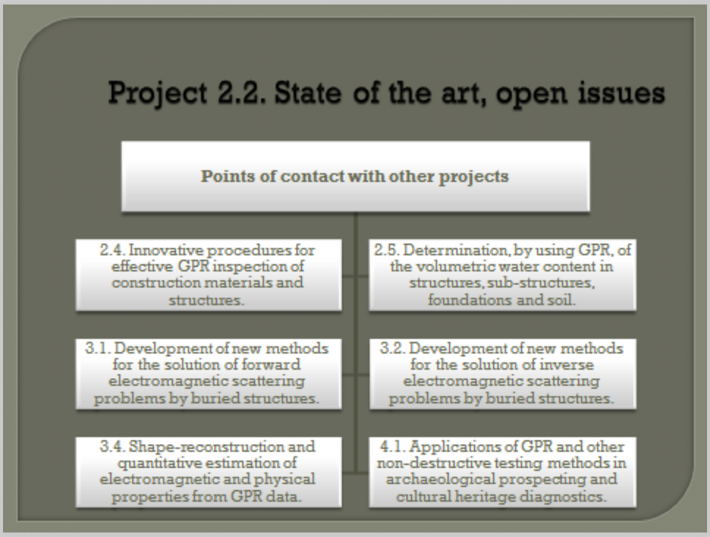
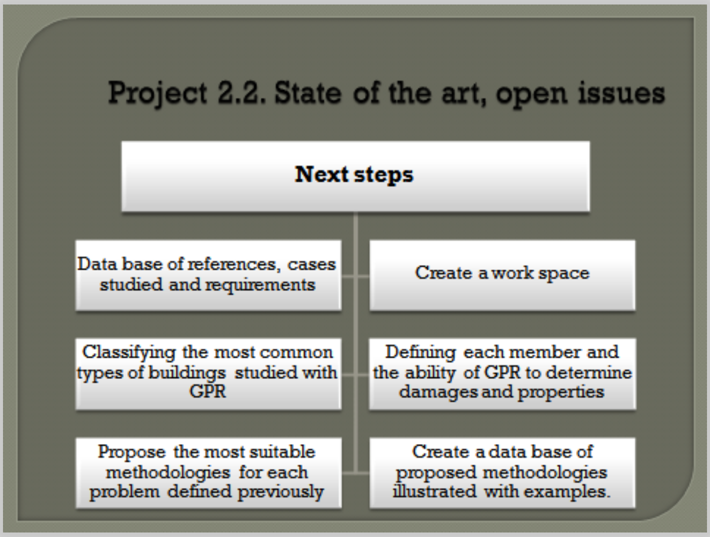
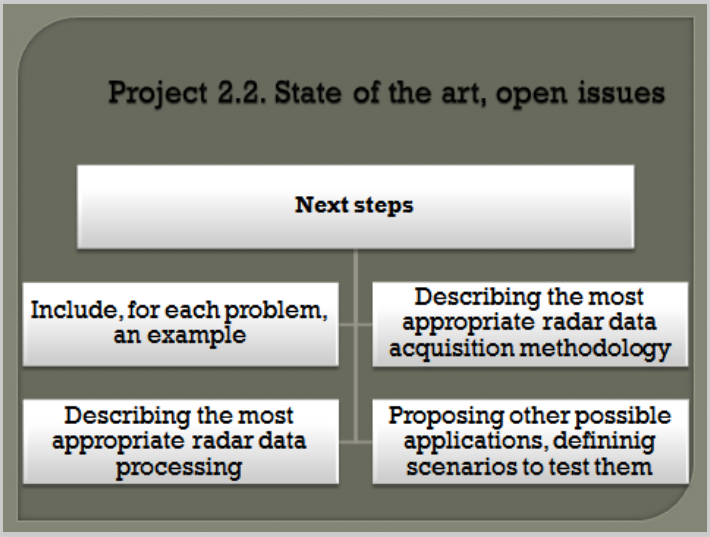

Project 2.2. State of the art, open issues
Open issues
Classify types of building and problems
Proposal for the most suitable GPR data acquisition and processing
Enhancing GPR imaging and processing
Application of the lab tests in cases studies
Proposal of new applications
Advances in corrosion damage detection


Project 2.2. State of the art, open issues
Open issues and next steps
Development and application of efficient inversion algorithms.
Testing results under laboratory conditions
Application to real buildings the inversion algorithms developed until today
,Define the effects of the complex media and complicate scenarios.
To check for possible improvements
To improve data interpretation comparing results to math models


Project 2.2. State of the art, open issues
Open issues and next steps
To propose necessities in GPR building inspection
Suggesting the development of GPR systems models
capable of provide images and models from the gathered data
combined with suitable mathematical
Adapting antennas to the different structural elements and spaces
Suggesting possible enhance radar equipments

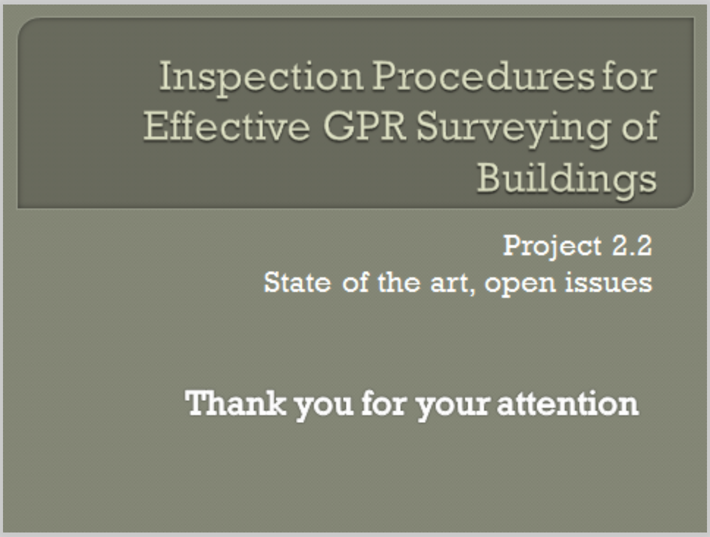

Project 2.2. State of the art, open issues
Points of contact with other projects
2.4. Innovative procedures for effective GPR inspection of construction materials and structures.
2.5. Determination, by using GPR, of the volumetric water content in structures, sub-structures, foundations and soil.
3.1. Development of new methods for the solution of forward electromagnetic scattering problems by buried structures.
3.2. Development of new methods for the solution of inverse electromagnetic scattering problems by buried structures.
3.4. Shape-reconstruction and quantitative estimation of electromagnetic and physical properties from GPR data.
4.1. Applications of GPR and other non-destructive testing methods in archaeological prospecting and cultural heritage diagnostics.


Project 2.2. State of the art, open issues
Next steps
Data base of references, cases studied and requirements
Create a work space
Classifying the most common types of buildings studied with GPR
Defining each member and the ability of GPR to determine damages and properties
Propose the most suitable methodologies for each problem defined previously
Create a data base of proposed methodologies illustrated with examples.


Project 2.2. State of the art, open issues
Next steps
Include, for each problem, an example
Describing the most appropriate radar data acquisition methodology
Describing the most appropriate radar data processing
Proposing other possible applications, defininig scenarios to test them

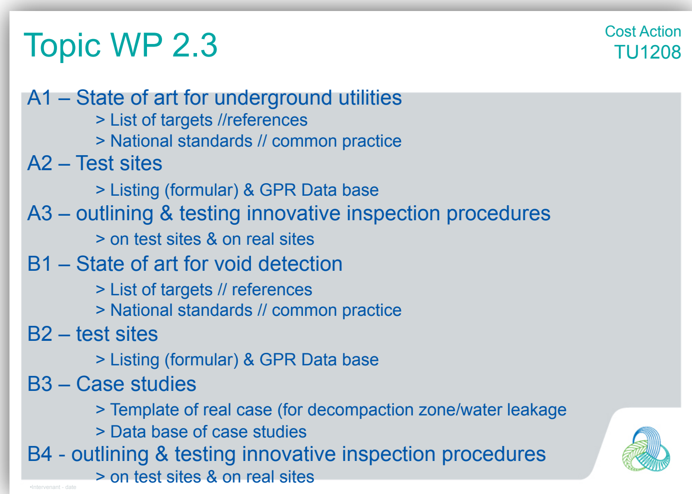

Project 2.2. State of the art, open issues
18 Participants in project 2.2 in the Roma Meeting
Mario Bacic, University of Zagreb, Zagreb, Croatia
Maksim Bano, EOST, Strasbourg University, Strasbourg, France,
Jean-Paul Balayssac, University of Toulouse, Tolouse Cedex, France
Andrea Benedetto, "Roma Tre" University, Rome, Italy
Ilaria Catapano, Centro Nazionale delle Ricerche, Naples, Italy
Francisco M. Fernandes, University of Minho, Guimarães, Portugal
Colette Grégoire, Belgian Road Research Centre, Brussels, Belgium
Amine Ihamouten, CETE Ouest, Angers, France
Thomas Kind, Federal Institute for Material Research and Testing (BAM), Berlin, Germany
Gilles Klysz, Institut National des Sciences Appliquées (INSA), Toulouse, France
Lovorka Libric, University of Zagreb, Zagreb, Croatia
Andreas Loizos, National Technical University of Athens, Athens, Greece
Danijela Marcic, University of Zagreb, Zagreb, Croatia
Andrea Massa, ELEDIA Research Center, Trento, Italy
Raúl Mínguez, Geofisica Consultores, Spain
Jorge Pais, University of Minho, Guimarães, Portugal
Christina Plati, National Technical University of Athens, Athens, Greece
Fabio Tosti, "Roma Tre" University, Rome, Italy
8 Countries: Croatia, France, Italy, Portugal, Belgium, Germany, Greece, Spain


Project 2.2. State of the art, open issues
22 participants in project 2.2 in Nantes Meeting:
Mario Bacic, University of Zagreb, Zagreb, Croatia
Maksim Bano, EOST, Strasbourg University, Strasbourg, France
Andrea Benedetto, "Roma Tre" University, Rome, Italy
Ilaria Catapano, Consiglio Nazionale delle Ricerche (CNR) - IREA, Naples, Italy
Xavier Derobert, IFSTTAR (Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux), Bouguenais cedex, France
Egil Eide, 3d-Radar AS, Trondheim, Norway
Francisco M. Fernandes, University of Minho, Guimarães, Portugal
Colette Grégoire, Belgian Road Research Centre, Brussels, Belgium
Amine Ihamouten, CETE Ouest, Angers, France
Thomas Kind, Federal Institute for Material Research and Testing (BAM), Berlin, Germany
Lovorka Libric, University of Zagreb, Zagreb, Croatia
Andreas Loizos, National Technical University of Athens, Athens, Greece
Danijela Marcic, University of Zagreb, Zagreb, Croatia
Andrea Massa, ELEDIA Research Center, Trento, Italy
Raúl Minguez, Geofisica Consultores, Spain
Jorge Pais, University of Minho, Guimarães, Portugal
Vega Pérez-Gracia, Universidad Politécnica de Catalunya, Barcelona, Spain
Christina Plati, National Technical University of Athens, Athens, Greece
Jørgen Ringgaard, Rambøll Denmark - Department of Geophysics and Geohydrology, Copenhagen, Denmark
Jacopo Sala, 3d-Radar AS, Oslo, Norway
Mercedes Solla, Universidade de Vigo
Fabio Tosti, "Roma Tre" University, Rome, Italy
10 Countries: Croatia, France, Italy, Norway, Portugal, Belgium, Germany, Greece, Spain, Denmark


Inspection Procedures for Effective GPR Surveying of Buildings
Project 2.2
State of the art, open issues
Thank you for your attention

"Innovative inspection procedures for effective GPR sensing and mapping of underground utilities and voids, with a focus to urban areas" - Progress Report on Project 2.3

Xavier Dérobert
IFSTTAR, Nantes, France
xavier.derobert@ifsttar.fr



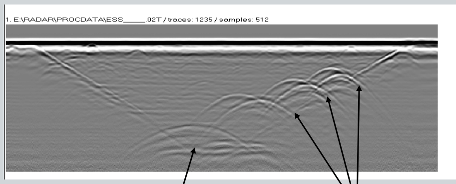
Test sites & Data base

Cost Action TU1208

Utility test sites
List & Data base

Void test sites
List & Data base

Void decompaction
Case study examples



Innovative approaches

Cost Action TU1208

Links with WG1 (arrays of antennas)

and WG3 (signal processing & tomography reconstructions)

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ESF provides the COST Office through a European Commission Contract. The Council of the EU provides the COST Secretariat.

General Information

IFSTTAR

Test Site:	**Geophysical test site**
Country:	France
Institution:	IFSTTAR – Nantes site
Address:	Route de Bouaye – CS4 44344 Bouguenais, France
Website:	www.ifsttar.fr
Contact Person:	X. Dérobert
E-mail:	Xavier.derobert@ifsttar.fr
Tel:	+33 (0)2 40 84 59 11



Technical Description

Testing facilities, with technical characteristics

Geophysical test site – Scale 1:1

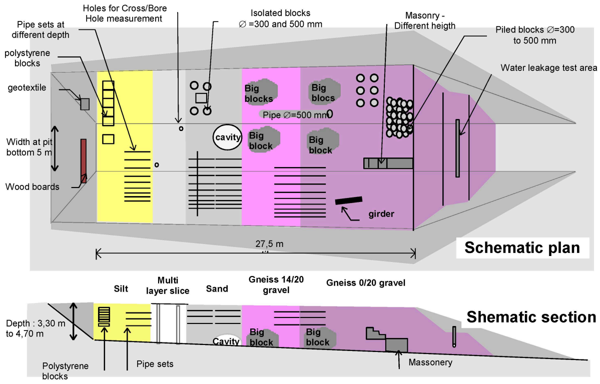
This site is constituted essentially by a pit length of 30 m and 5 m in width in bottom with sides sloping to 2/1. Useful depth varies from 3.30 to 4.70 m. This pit is filled with various materials arranged in horizontal compacted slices separated by a vertical interface and water-tighted in surface:

a silt trench (5 m width) / a multilayer trench (2.5m 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 : 1m – 1.5m – 2m / 3 natures: metal – PVC(air) – PVC(water)),
- Polystyren hollows (few depths : 0.65m to 2.3m), cavity (depth: 3.47, ~2m large)
- Boulders (various size/various depths : from 0.9m to 3.3m),
- Masonry (depth: from 1.5m to 3.5m)

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



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 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...)

Qualification and quality assurance

GPR training – GPR system qualification

"INNOVATIVE PROCEDURES FOR EFFECTIVE GPR INSPECTION OF CONSTRUCTION MATERIALS AND STRUCTURES"
PROGRESS REPORT ON PROJECT 2.4

L. Krysinski
Road and Bridge Research Institute
ul. Instytutowa 1, 03-302 Warsaw, Poland
lkrysinski@ibdim.edu.pl

Abstract

The note is focused on the characterization of scope of the research interests in project 2.4. The basic information about participants, topic list and the suggested beginning activities was provided. The examples of some current researches related to the Project were shortly outlined.

I. Basic information

The project 2.4 currently has 24 participants from 9 countries (Belgium, Croatia, Denmark, France, Germany, Greece, Italy, Poland, Spain). Two new participants declared willingness to take part in the project.

II. Scope of the project

The project will be dedicated to a wide area of problems related to material properties determination in GPR inspection practice.

The beginning suggestion was to omit problems related to structural studies of constructions, as construction structures usually belong to buildings (P2.2) and transport infrastructure (P2.3). But there are some suggestions to include structural studies related to exceptional constructions which do not belong clearly to these two categories (like retaining walls). The quality/damage characteristics (like cracks and delaminations) will be treated, as well. The review chapter [1] is being prepared.

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III. List of topics

The following list of topics was created as a result of consultations and with the help of the WG2 projects leaders; its form is enough wide and elastic to cover the extensions suggested during discussions:

1) List of the most important construction materials and pre-cast structures:
   - Characterisation of material properties being investigated
   - Major measuring and interpretation problems
2) List of laboratory methods, which have practical use in direct determination of permittivity on technical samples/mixings:
   - Standard equipment
   - Convenient laboratory settings
3) List of methods for determination of the near-surface permittivity:
   - Test scenarios, settings and configuration of the measuring systems
   - Pre-processing and signal interpretation issues
4) List of GPR techniques for the estimation of EM properties and characterisation of material structural condition:
   - Test scenarios, settings and configuration of the measuring systems
   - Pre-processing and signal interpretation issues
5) List of the field and laboratory test sites, where calibration and comparative measurements (reflection amplitude, permittivity, layer velocity, monitoring sensors installed: humidity/temperature...) can be performed on large samples or on real constructions.

IV. Suggested questionnaire

A special questionnaire dedicated to project 2.4 is suggested to allow exchange of information as to the possibilities of tests on large samples (properties determination and laboratory structural modeling, Fig. 1) and laboratory techniques for the determination of the EM properties. This area has crucial importance for practical activity.

V. Recent research efforts connected with the project topics.

Research activities observed in recent months concern the following subjects:

- Numerical modeling of the GPR response for different types of damage structures, which is an important tool in echogram interpretation practice [2],
- Attempts of finding relation between bearing capacity of asphalt pavement and its GPR characteristics in field measurements [3],
- Investigations of raw construction materials permittivity for the purposes of GPR diagnostics [4],
- Detailed studies of 3D imaging abilities in investigations of the cracking process in asphalt pavements [5],
- Effectiveness of the use of surface permittivity estimation in the asphalt package thickness determination [6].

ACKNOWLEDGEMENT

The authors acknowledge the COST Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar", supporting this work.

REFERENCES

[1] L. Krysinski, J. Hugenschmidt, "Effective GPR Inspection Procedures for Construction Materials and Structures", Springer, 2014.

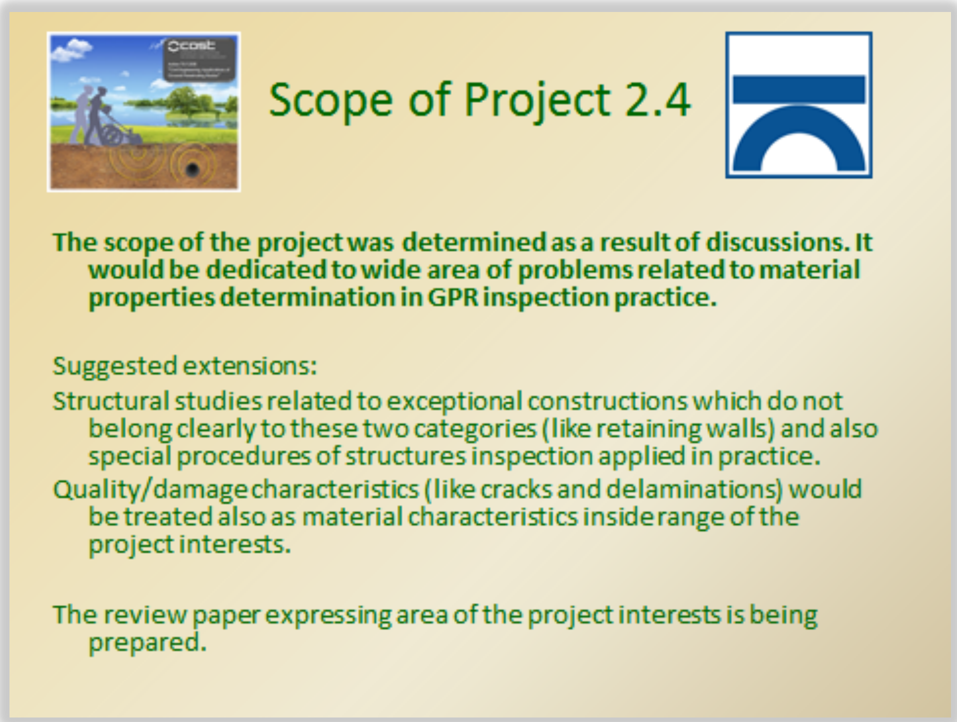
[2] A. Benedetto, F. Tosti, L. Pajewski, F. D'Amico, W. Kusayanagi, "FDTD Simulation of the GPR Signal for Effective Inspection of Pavement Damages", 2014.

[3] F. Tosti, S. Adabi, L. Pajewski, G. Schettini, A. Benedetto, "Large-scale analysis of dielectric and mechanical properties of pavement using GPR and LFWD", 2014.

FIG. 1 – Examples of the field and laboratory test sites allowing measurements on large scale samples (testing and calibration of material inspection methods and laboratory modeling of GPR response for real structures).

[4] L. Krysinski, "Permittivity Investigations of the Road Construction Raw Materials for Purposes of GPR Data Interpretations", *Geophysical Research Abstracts*, vol. 16, 2014 EGU General Assembly 2014, 27 April - 02 May 2014, Wien, Austria, 1pp.

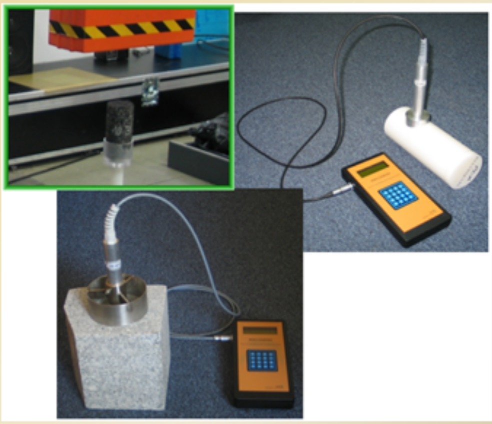
[5] L. Krysinski, J. Sudyka, “Efficiency of 3D imaging in GPR diagnostics of joints and vertical construction contacts”, submitted to *15th International Conference on Ground Penetrating Radar (GPR 2014)*, Brussels, Belgium, June/July, 2014, 4pp.
[6] M. Graczyk, L. Krysinski, J. Sudyka, “Application of ground penetrating radar in the diagnosis of the state of pavement design and operational safety assessment of airports” (in Polish), (accepted) *Logistyka* 2/2014.



List of topics P2.4

1) **List of the most important construction materials and pre-cast structures**
   (Characterization of the material properties being investigated for the given material type, Major measuring and interpretation problems)
2) **List of laboratory methods, which have practical use in direct determination of permittivity on technical samples/mixings**
   (Standard equipment, Convenient laboratory settings)
3) **List of methods for determination near-surface permittivity using GPR**
   (Test scenarios, settings and configuration of the measuring systems, Pre-processing and signal interpretation issues)
4) **List of GPR techniques involved in estimation of EM properties and characterization of material structural condition**
   (Test scenarios, settings and configuration of the measuring systems, Pre-processing and signal interpretation issues)
5) **List of the field and laboratory test sites** (available for participants), where calibration and comparative measurements (reflection amplitude, permittivity, layer velocity, monitoring sensors installed: humidity/temperature…) can be performed e.g. on large homogeneous samples or on real constructions.

Questionnaire (lab methods)



Recent research activities

Modeling of the GPR response for different types of damage structures [1], relation between bearing capacity of HMA and its GPR response [2], raw construction materials permittivity [3], 3D imaging abilities in cracking process study [4], effectiveness of the use of surface permittivity estimation in thickness determination [5].

[1] A. Benedetto, F. Tosti, L. Pajewski, F. D'Amico, W. Kusayanagi, "FDTD Simulation of the GPR Signal for Effective Inspection of Pavement Damages", 2014.

[2] F. Tosti, S. Adabi, L. Pajewski, G. Schettini, A. Benedetto, "Large-scale analysis of dielectric and mechanical properties of pavement using GPR and LFWD", 2014.

[3] L. Krysiński, "Permittivity Investigations of the Road Construction Raw Materials for Purposes of GPR Data Interpretations", Geophysical Research Abstracts, vol. 16, 2014 EGU General Assembly 2014, 27 April - 02 May 2014, Wien, Austria, 1pp.

[4] L. Krysiński, J. Sudyka, "Efficiency of 3D imaging in GPR diagnostics of joints and vertical construction contacts", submitted to 15th International Conference on Ground Penetrating Radar (GPR 2014), Brussels, Belgium, June/July, 2014, 4pp.

[5] M. Graczyk, L. Krysiński, J. Sudyka, "Application of ground penetrating radar in the diagnosis of the state of pavement design and operational safety assessment of airports" (in Polish), (accepted) Logistyka 2/2014.

Permittivity of rock construction materials

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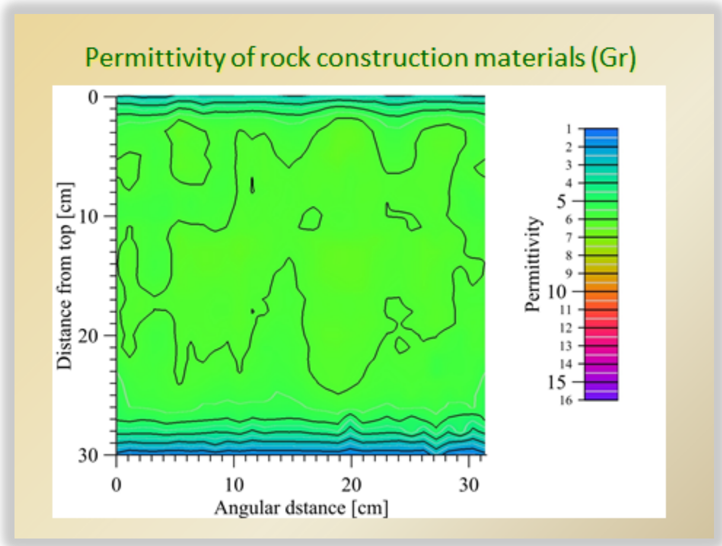
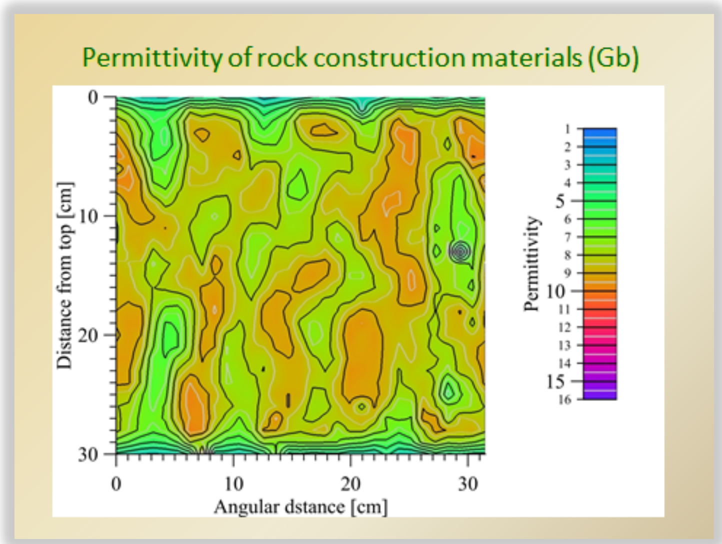
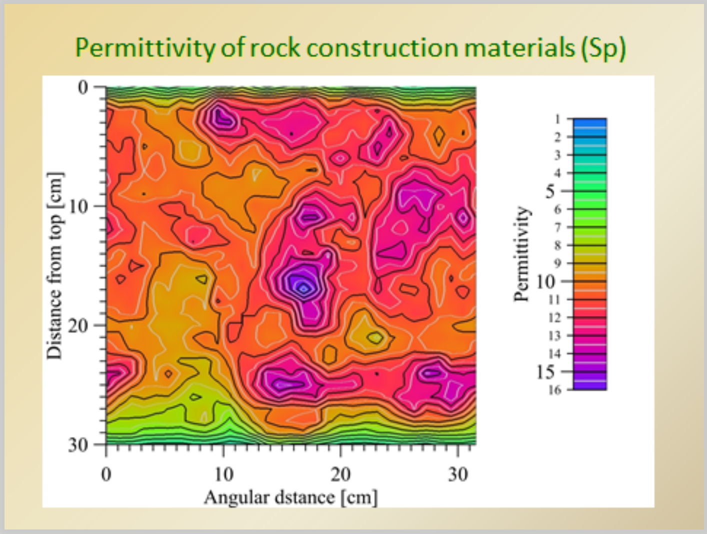

Permittivity of rock construction materials (Gr)
Distance from top [cm]
Angular dstance [cm]
Permittivity


Permittivity of rock construction materials (Gb)
Distance from top [cm]
Angular dstance [cm]
Permittivity


Permittivity of rock construction materials (Sp)
Distance from top [cm]
Angular dstance [cm]
Permittivity

"EVALUATION OF MOISTURE CONTENT USING GPR"
(CONTRIBUTION TO PROJECT 2.5)

Zoubir Mehdi Sbartaï
I2M, Civil Engineering Dept, University of Bordeaux, France
zm.sbartai@i2m.u-bordeaux1.fr

Abstract

This study deals with the evaluation of moisture content of concrete using electromagnetic techniques (permittivity measurement using weak perturbation method at 1.26 GHz and GPR technique at 1.5 GHz). The results show good correlation between concrete permittivity, GPR amplitude and moisture content.

I. INTRODUCTION

Water ingress through concrete pores is considered among the major causes of physicochemical pathologies, and the risk of damage is related to the degree of saturation or the moisture content (1). For example, a relative humidity value of approximately 65% is optimal for carbonation to proceed (2). Chlorides diffuse through water in the pores (3). The expansion of concrete associated with alkali-aggregate reaction is significant when the water content by weight of concrete exceeds approximately 4% (4). Freezing-and-thawing cycles present a risk of damage above a critical degree of saturation of approximately 0.8 for non-air-entrained concrete (5). Therefore, knowledge of the moisture variation in concrete structures is critical for predicting pathological risks at early stages of deterioration.

Traditional methods aiming to assess the condition of structures, such as electrical resistivity measurement or half-cell potential test, are slow and require lane closures for the sounding of bridge decks. In contrast, GPR measurement is a potentially powerful technique because it is a non-destructive method, relatively insensitive to ambient conditions, and it can investigate large surfaces in a relatively short time. Many researchers have emphasized the capability of GPR

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technology to evaluate the rate of degradation of reinforced concrete structures (6-8). Such work, however, generally focuses on the assessment of damage or deterioration, which has developed over time, such as delamination or cracks mainly caused by the progression of physicochemical pathologies. According to many studies, the propagation of GPR waves is affected by the presence of water in concrete (9,12). Therefore, analyses of the recorded GPR signals can provide quantitative information on the moisture of concrete. In addition, it is also important to study the effect of moisture and concrete type on the variation of concrete permittivity that governs the propagation of GPR waves.

II. Experiments

The present study was undertaken to assess the effect of the degree of saturation, water-cement ratio (w/c), and volumetric water content on the permittivity and the GPR features (amplitude variation of direct and reflected waves). Permittivity measurements were undertaken using a weak perturbation method at 1.26 GHz, which is close to the frequency of the used GPR antennas (1.5 GHz). The behaviour of the permittivity variation with respect to moisture was also modelled using analytical mixing models (CRIM, De Loor and Debye) [9].

III. Results

Test results show that an increase in the degree of saturation leads to significant increase in both real and imaginary part of the permittivity. The analytical models such as CRIM and De Loor fit well the real part (Fig 1). However, the imaginary part of the permittivity is not well evaluated using the De Loor model but the CRIM simulations are in good agreement with the experimental results.

Regarding GPR signal (Fig 3), the moisture decreases the amplitude of the direct wave. This is mainly attributed to the increase in complex permittivity related to the polarization and conduction mechanisms occurring in concrete. Generally, the GPR measurements

showed good repeatability, which was evaluated using the coefficient of variation, and the statistical dispersion of the direct wave amplitude was lower than that of the reflected wave.

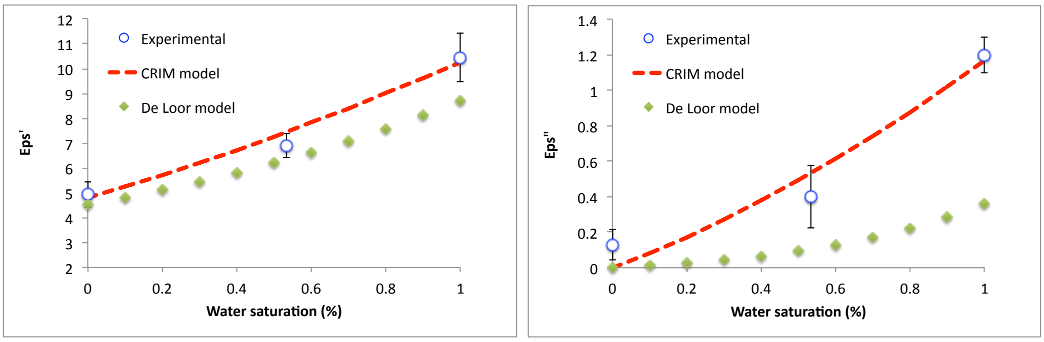

FIG. 1-2 – Experimental and modelling of the effect of moisture on concrete permittivity

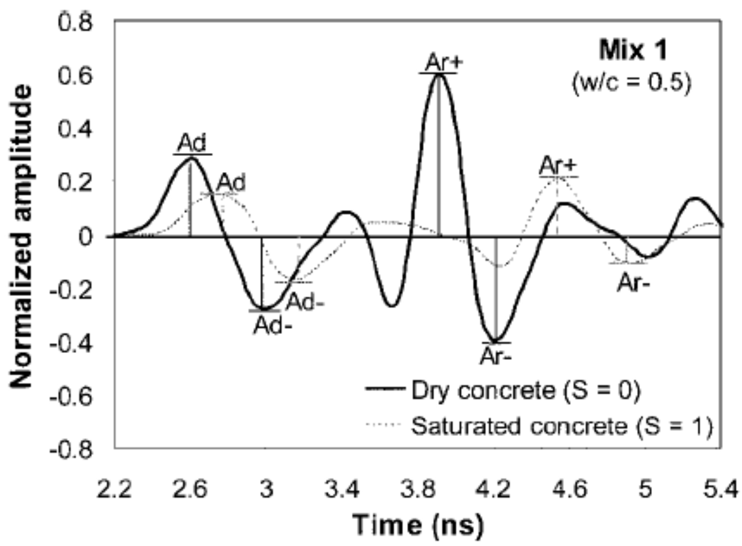

FIG. 3 – Typical GPR signal recorded on concrete slab at dry and saturated condition

For dry and wet concrete, w/c did not appear as an influent parameter regarding the experimental results. A good correlation was found between the amplitude of direct wave for each degree of saturation (Fig 4). Irrespectively of w/c and the depth of reflector, an empirical relationship between signal amplitude of direct wave and volumetric water content was established that could be used to estimate concrete moisture.

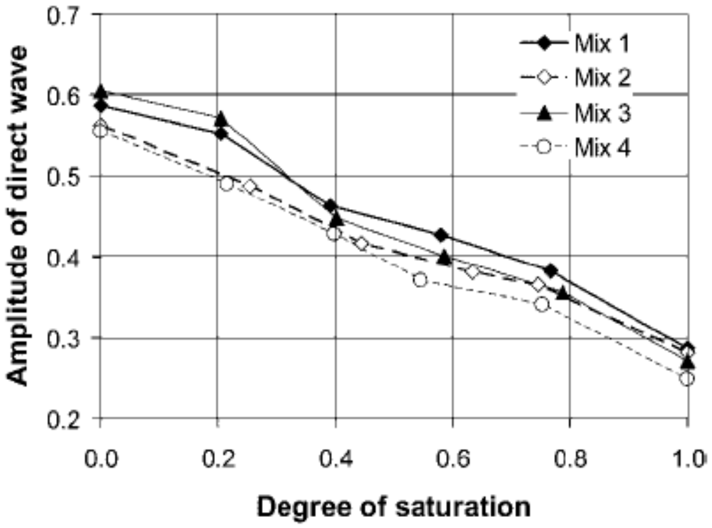

FIG. 4 – Relation between normalized amplitude of the direct wave and moisture content

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techniques for the non-destructive evaluation of cover concrete. NDT&E 2008;44:41–52.
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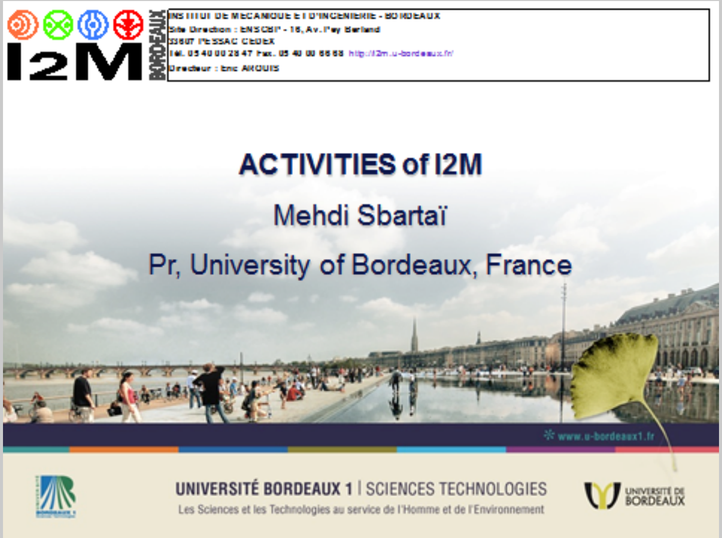
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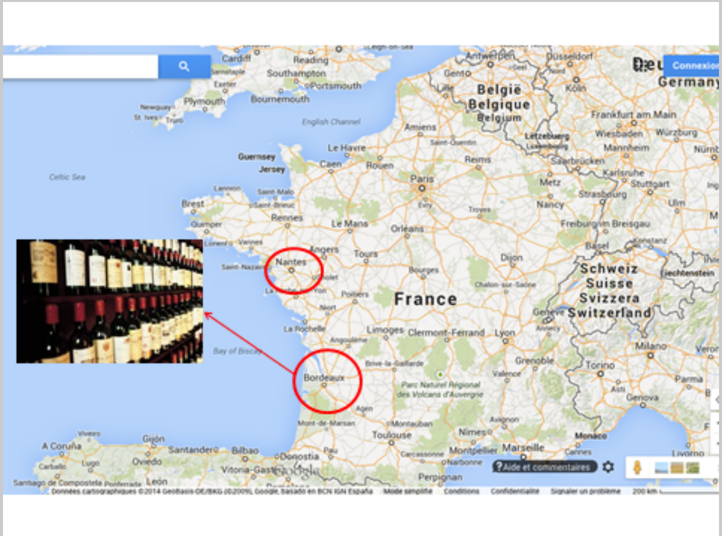
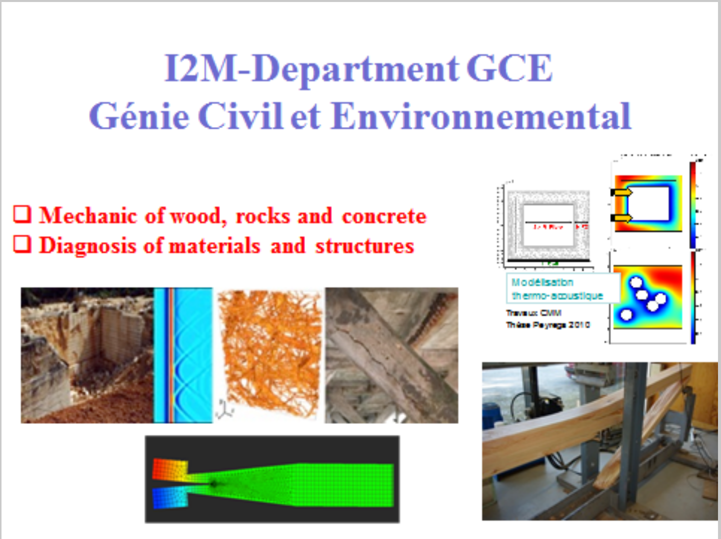
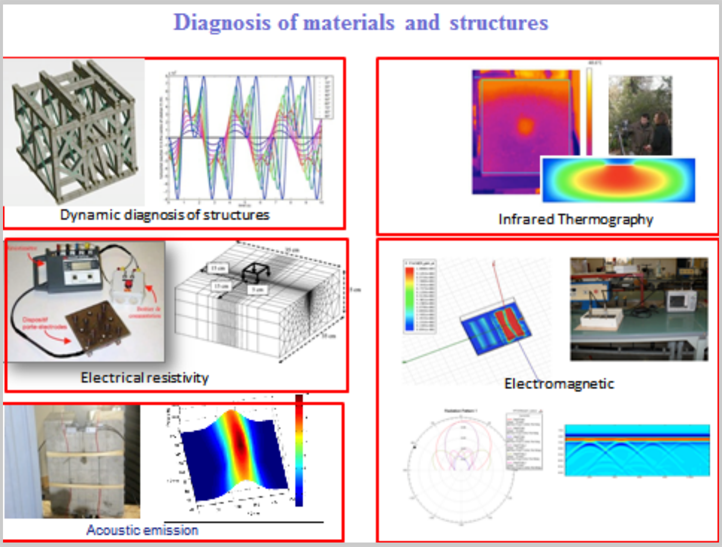
ACTIVITIES of I2M
Mehdi Sbartaï
Pr, University of Bordeaux, France
UNIVERSITÉ BORDEAUX 1 | SCIENCES TECHNOLOGIES
Les Sciences et les Technologies au service de l'Homme et de l'Environnement
UNIVERSITÉ DE BORDEAUX


France
Nantes
Bordeaux
Paris
Schweiz
Suisse
Svizzera
Switzerland


I2M-Department GCE
Génie Civil et Environnemental
❑ Mechanic of wood, rocks and concrete
❑ Diagnosis of materials and structures
Modélisation thermo-acoustique
Travaux CMM
Thèse Peyrega 2010


Diagnosis of materials and structures
Dynamic diagnosis of structures
Infrared Thermography
Electrical resistivity
Electromagnetic
Acoustic emission

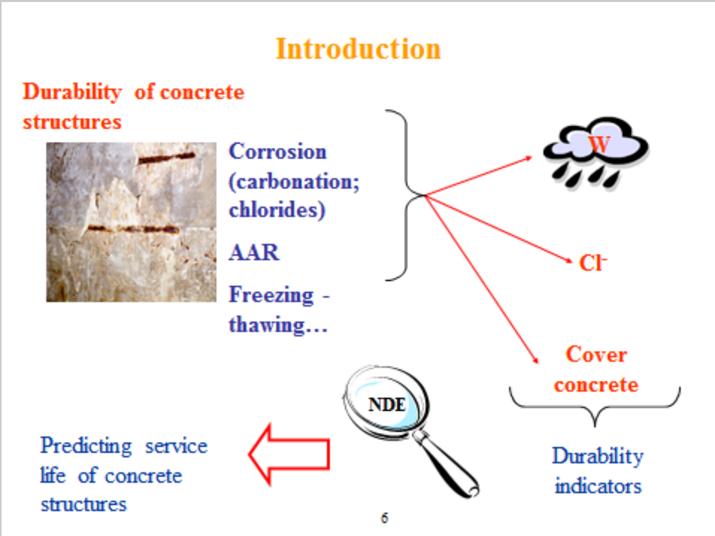
NDT evaluation of construction materials using electromagnetic techniques

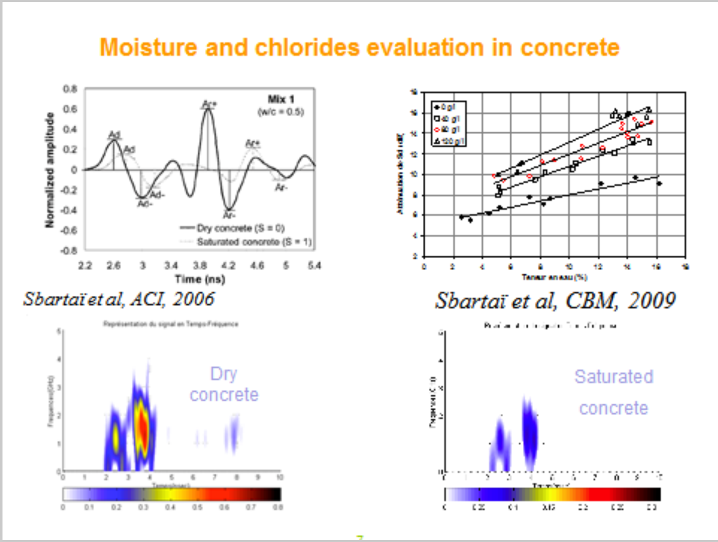
Mehdi Sbartaï

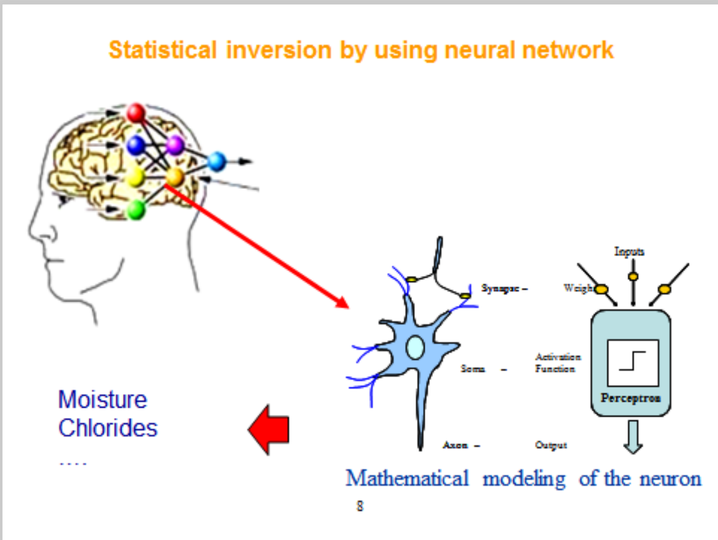
Maître de Conférences U.Bordeaux 1

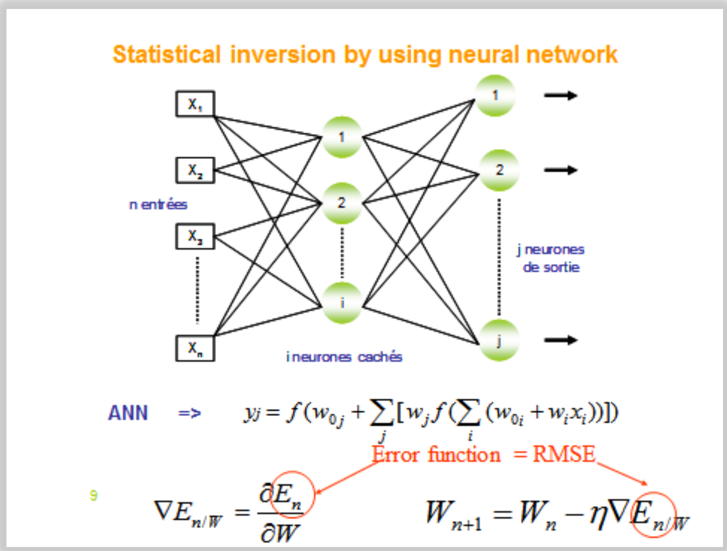
I2M, Département Génie Civil Environnemental

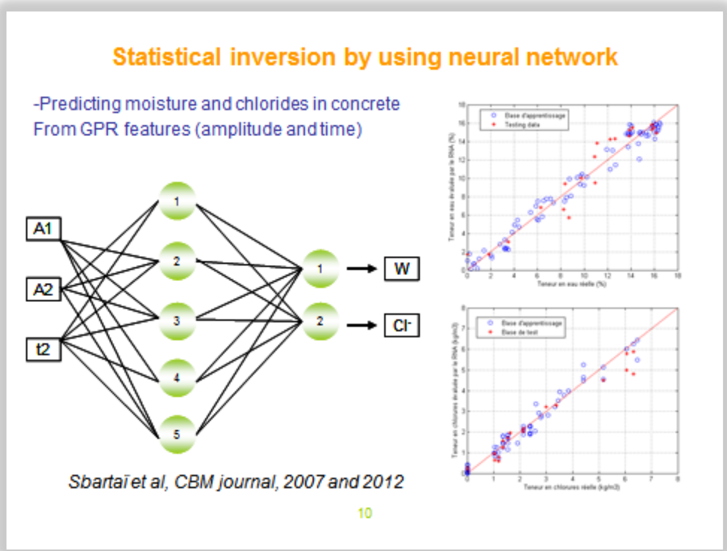
5



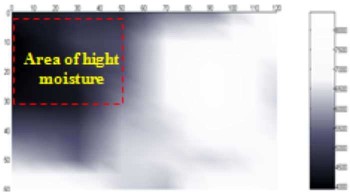

Moisture and chlorides evaluation in concrete
Sbartaï et al, ACI, 2006
Sbartaï et al, CBM, 2009
Dry
concrete
Saturated
concrete

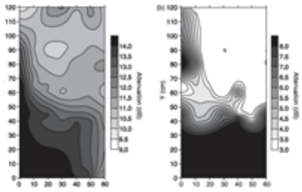

Statistical inversion by using neural network
Moisture
Chlorides
....
Mathematical modeling of the neuron
8


Statistical inversion by using neural network
X1
X2
X3
Xn
n entrées
1
2
i
i neurones cachés
1
2
j
j neurones de sortie
ANN => $y_j = f(w_{0j} + \sum_j [w_j f(\sum_i (w_{0i} + w_i x_i))])$
Error function = RMSE
9
$\nabla E_{n/W} = \frac{\partial E_n}{\partial W}$
$W_{n+1} = W_n - \eta \nabla E_{n/W}$


Statistical inversion by using neural network
-Predicting moisture and chlorides in concrete
From GPR features (amplitude and time)
A1
A2
t2
1
2
3
4
5
W
Cl-
Sbartaï et al, CBM journal, 2007 and 2012
10

On site results





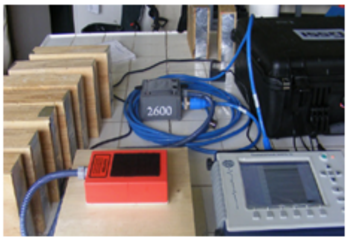
Sbartaï et al, NDT & E International, 2006

GPR tests on wood

Detection of moisture for :

Better evaluation of mechanical behaviour (depending on w)

Evaluating the risk of fungi

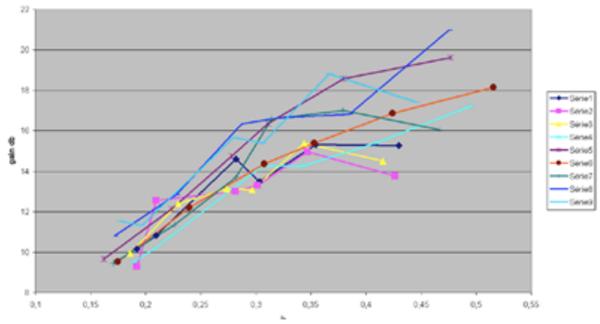


	Masse volumique kg/m³
Echantillon 1	565
Echantillon 2	592
Echantillon 3	534
Echantillon 4	476
Echantillon 5	493
Echantillon 6	478
Echantillon 7	484
Echantillon 8	499
Echantillon 9	512

Moisture variation from 15% to 50%

12

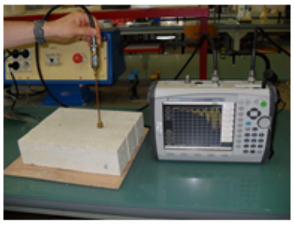
GPR tests on wood

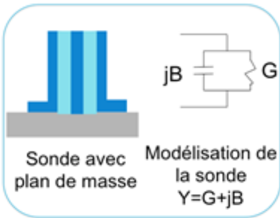


Sbartaï et al, SFR, 2010

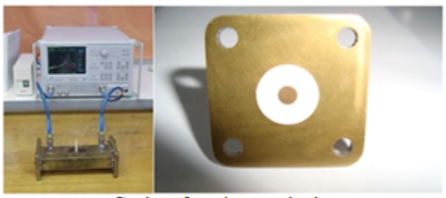
13

Permittivity measurments

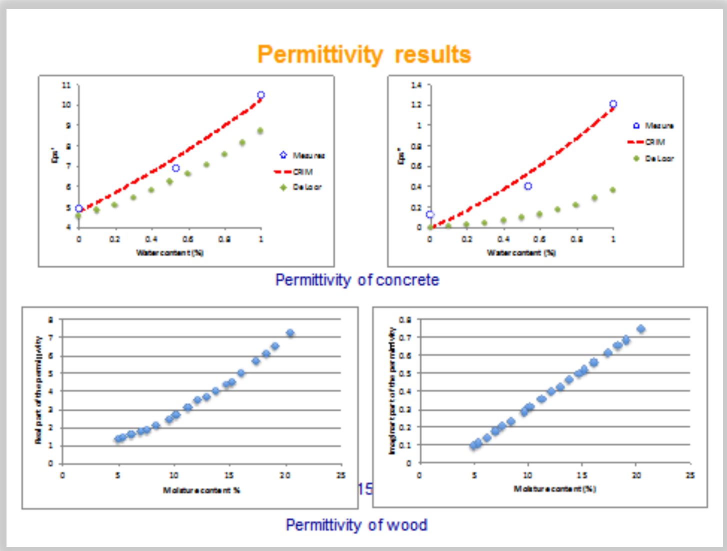


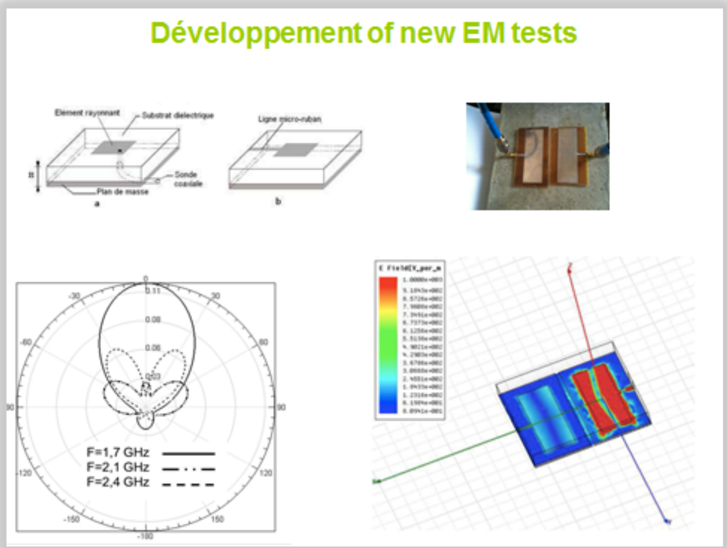


Open end probe

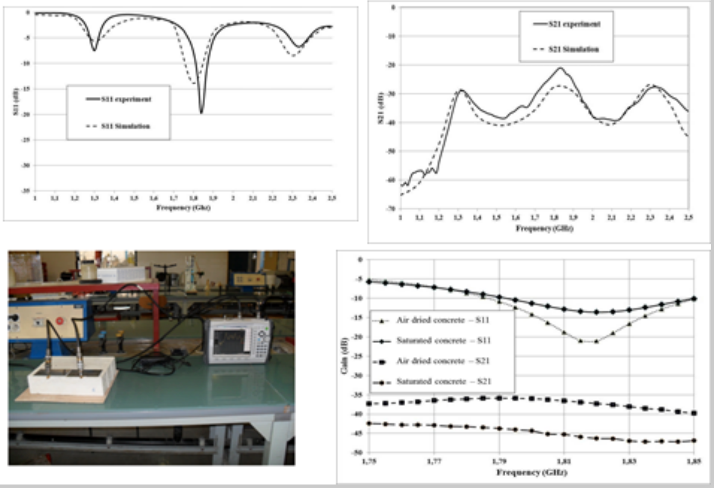


Cavity of weak perturbation

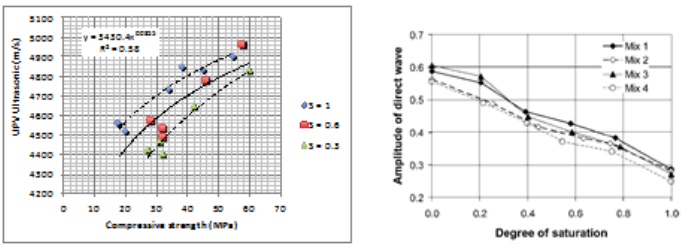

Permittivity results
Permittivity of concrete
Permittivity of wood
Water content (%)
Moisture content %
Moisture content (%)
Mesures
CRIM
De Loor


Développement of new EM tests
F=1,7 GHz
F=2,1 GHz
F=2,4 GHz

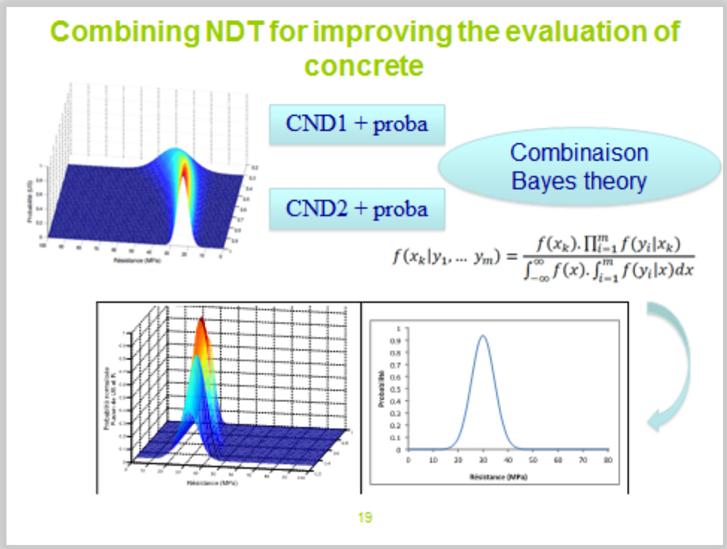
Mesures

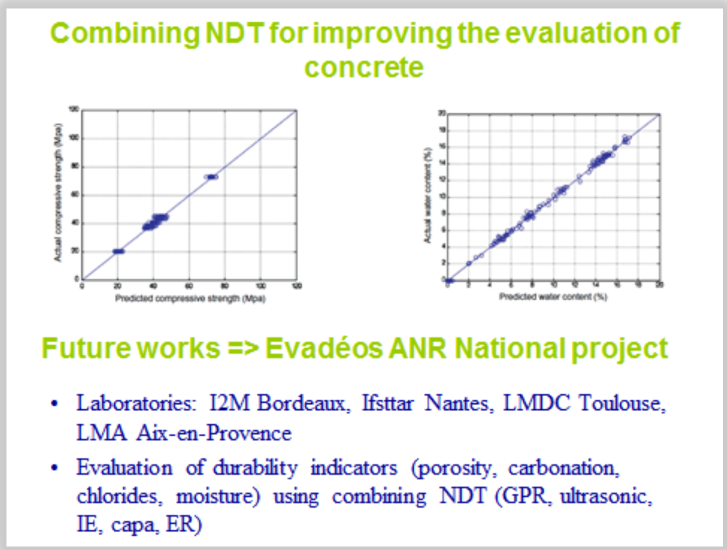


Combining NDT for improving the evaluation of concrete



ZM. SBARTAÏ and al. Cement & Concrete Composites 34 (2012).


Combining NDT for improving the evaluation of concrete
CND1 + proba
CND2 + proba
Combinaison
Bayes theory
$f(x_k|y_1,\dots y_m) = \frac{f(x_k).\prod_{i=1}^{m} f(y_i|x_k)}{\int_{-\infty}^{\infty} f(x).\int_{i=1}^{m} f(y_i|x)dx}$
Résistance (MPa)
19


Combining NDT for improving the evaluation of concrete
Actual compressive strength (Mpa)
Predicted compressive strength (Mpa)
Actual water content (%)
Predicted water content (%)
Future works => Evadéos ANR National project
• Laboratories: I2M Bordeaux, Ifsttar Nantes, LMDC Toulouse, LMA Aix-en-Provence
• Evaluation of durability indicators (porosity, carbonation, chlorides, moisture) using combining NDT (GPR, ultrasonic, IE, capa, ER)

“GPR-MONITORING OF SNOW AND FROST ON SUBURBAN AREAS”

Pekka Hänninen(1), Juha Majaniemi(1) and Raimo Sutinen(2)
(1)Geological Survey of Finland
Southern Finland office Land use and environment
Betonimehenkuja 4, 02150 Espoo, Finland
(2)Geological Survey of Finland
Northern Finland office, Land use and environment
Lähteentie 2, 96100 R0vaniemi

In Northern countries long and cold winter causes snow and frost. Snow cover protects the subsurface frost penetration but the snowmelt as well as the melting frost cause problems. Snow thawing causes flood and over saturates the subsurface while soil freezing and melting cause frost damages.

Radar antennas of several GHz has been used for automatic monitoring of snow thickness, but the prediction of snow water content and the date and duration of melting. In our study we used 1 GHz antenna and SIR3000 GPR (GSSI) to monitor snow thickness, snow water content and soil surface wetness. We standardized antenna position at 1.3 m over the ground surface, hence the time differences of ground pulse are related to the amount of snow, the mixture of air and ice. Because our aim was to automatize the interpretation of surface signals the zero point of scan, measuring time and the number of samples of a scan were standardized to keep the surface signal locations sub-constant. Filtters and gains were locked to notice changes in ground surface pulse amplitude. An automatic soil water content (Campbell Scientific CS616) and temperature (T107) monitoring station was established as a reference for the ground pulse amplitude measurements.

The repeatability of GPR pulses was excellent, but we found the pulse of snow surface difficult to interpret. Amplitude of the ground pulse was not only proportional to the changes in soil water but also the unfrozen water content in the snow cover. During the period no thawing there was a good linear relationship between the ground pulse travel

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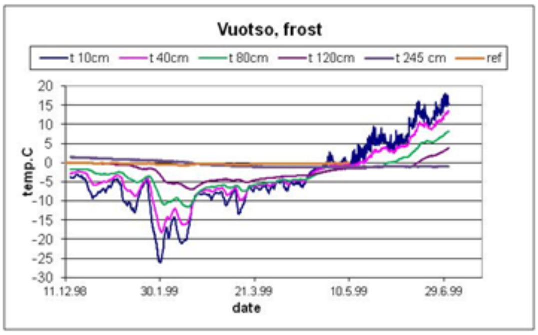
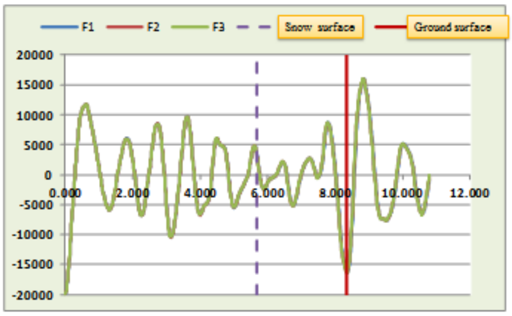
time and snow water content but the results differed in case of unfrozen water in snow.

Because of the excellent repeatability we decided to try GPR with 400 MHz antenna in frost monitoring on sub-urban road. Two 100 m long lines were marked at 5 m interval and the GPR background profiles and a soil water content and temperature monitoring station were done at the time with no frost. From January to April the profiling was repeated 8 times. It became evident that it is possible to follow the frost penetration and melting cycle by GPR, but interpretation of freezing front is unreliable without no-frost background profile.



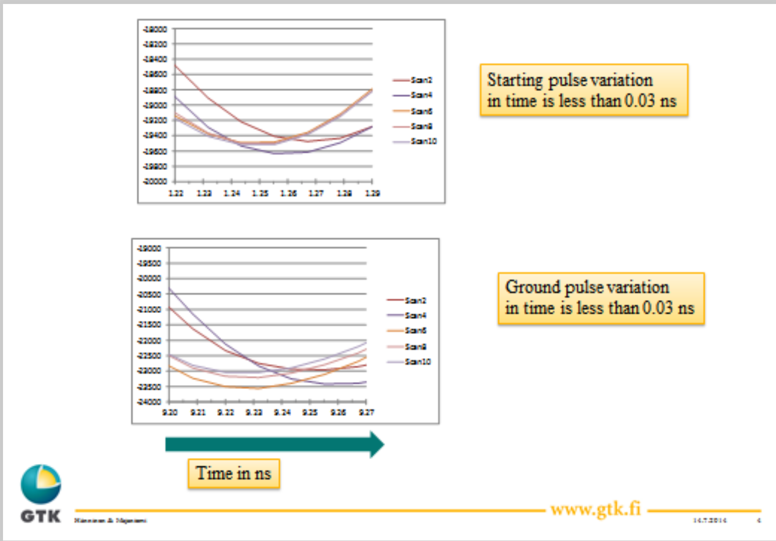
Vuotso lat/lon 68° / 27°
T 10, 40, 80, 120, 245 cm yard, no snow
ref, forest, snow covered

www.gtk.fi

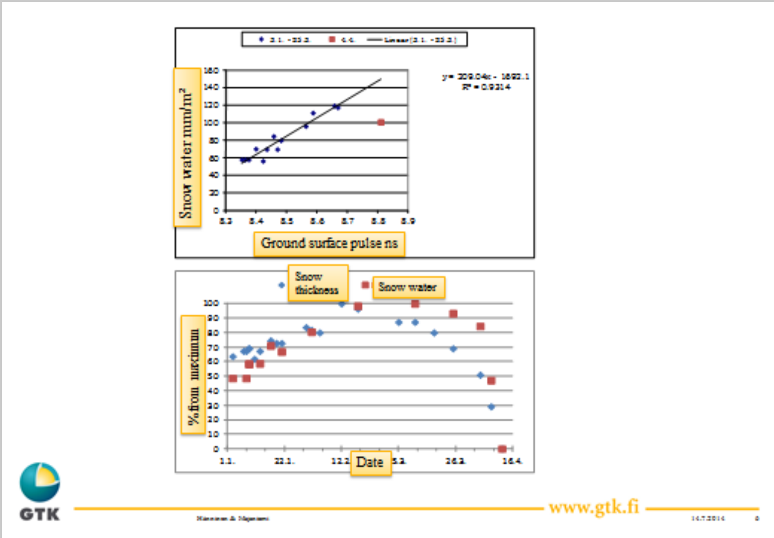


F1-2-3 are average signals from ten scans

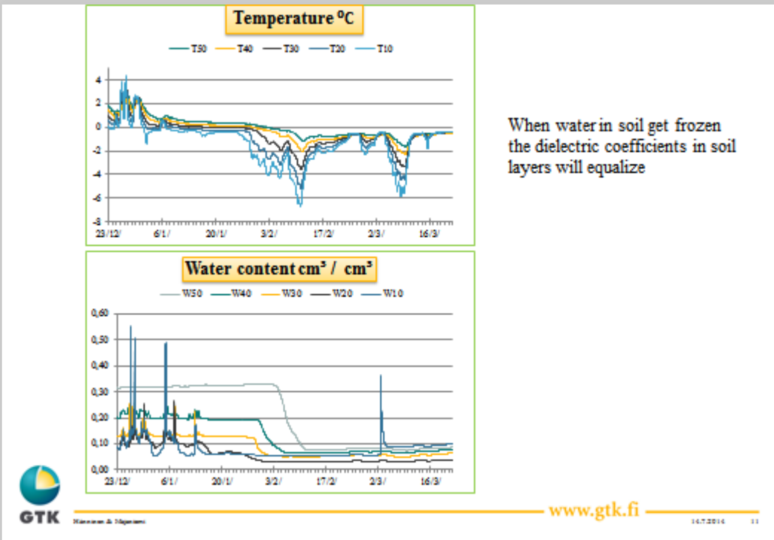
www.gtk.fi


Scan2
Scan4
Scan6
Scan8
Scan10
Starting pulse variation
in time is less than 0.03 ns
Scan2
Scan4
Scan6
Scan8
Scan10
Ground pulse variation
in time is less than 0.03 ns
Time in ns
GTK
www.gtk.fi


Snow monitoring station based on GPR and 1 GHz antenna
GTK
www.gtk.fi


Snow water mm/m2
Ground surface pulse ns
y = 209.04x - 1692.1
R² = 0.9314
Snow thickness
Snow water
% from maximum
Date
GTK
www.gtk.fi


Itäsalmi
Östersundom
Station
Test site
Picture was taken
GTK
www.gtk.fi



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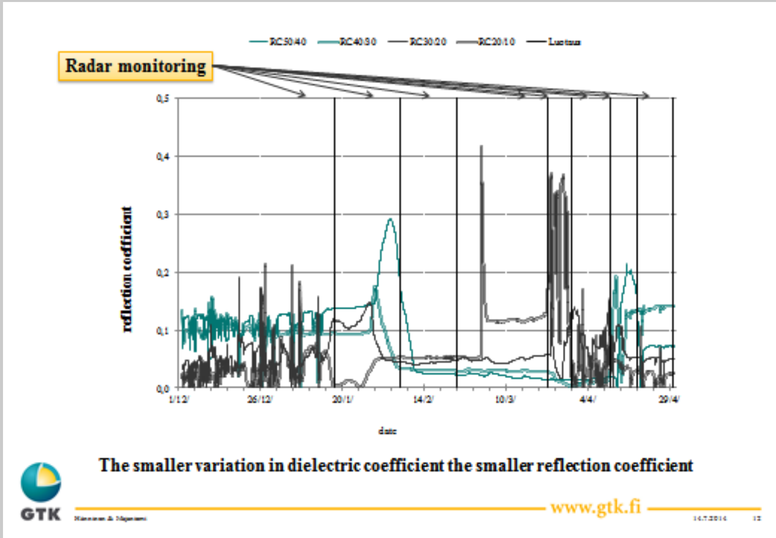
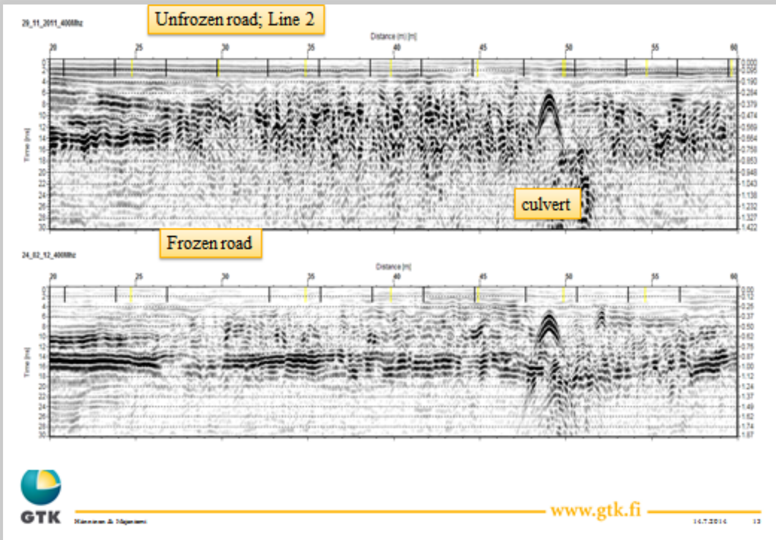
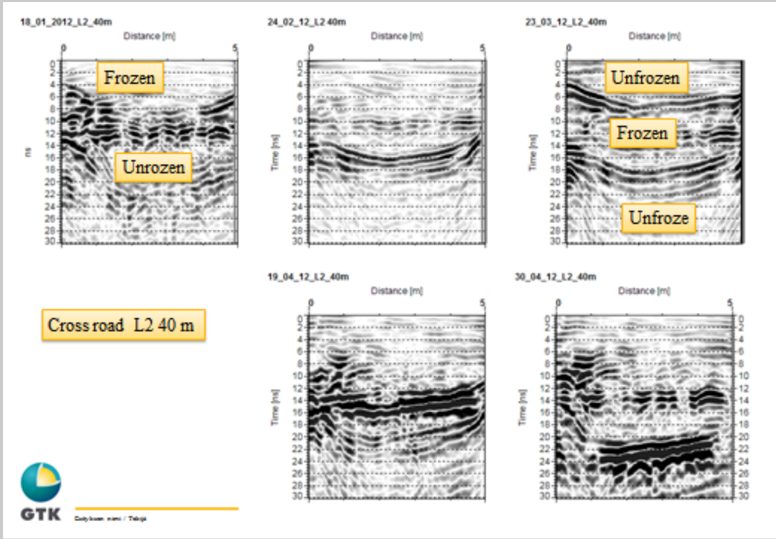

RC50/40
RC40/30
RC30/20
RC20/10
Radar monitoring
reflection coefficient
0,0
0,1
0,2
0,3
0,4
0,5
1/12/
26/12/
20/1/
14/2/
10/3/
4/4/
29/4/
date
The smaller variation in dielectric coefficient the smaller reflection coefficient
GTK
www.gtk.fi


Unfrozen road; Line 2
culvert
Frozen road
GTK
www.gtk.fi



- GPR is repeatable
- GPR echos vary with time
- Single echo is difficult to interpret but
- Changes in water content or electrical conductivity of medium can be monitored

- Roads / railroads
- Pipes
- Walls
- Geotextiles
- Basements

GTK www.gtk.fi

"GPR EXPERIENCE AT THE NATIONAL LABORATORY FOR CIVIL ENGINEERING, LISBON, PORTUGAL"

Simona Fontul
Transportation Department, National Laboratory for Civil Engineering, Av. do Brasil, 101, 1700-066 Lisbon, Portugal
simona@lnec.pt

This report presents the experience gathered at National Laboratory for Civil Engineering, Portugal. The main experience is on road and airfield pavement evaluation, since 1998, namely the layer thickness measurement. In the last two years, research has been done in the railway evaluation using GPR.

Two different research areas are addressed, the GPR testing and the joint interpretation of GPR with other non-destructive tests, such as Falling Weight Deflectometer.

A selection of case studies of GPR application is presented and some of the main lessons learnt from the experience are referred. The specific conditions for GPR measurements in each of these cases are briefly presented and the results are analysed. Both flexible and rigid pavements were studied, new and overlaid, including one case of concrete reinforced pavement of a runway.

In the last year, laboratory tests were performed on railway ballast, with different GPR antennas, in order to study the sensitivity of the dielectric constant with different water contents and ballast fouling levels. The main results obtained and the validation with some in situ tests, are also presented herein.

Research has been done in joint interpretation of GPR and FWD for bearing capacity evaluation. Artificial Neural Networks (ANN) tool was used to improve the backanalysis of flexible pavements.

Another ongoing research at LNEC is the interpretation of GPR tests performed on railway together with rail geometry parameters, in order to improve the monitoring and to support the maintenance decisions.

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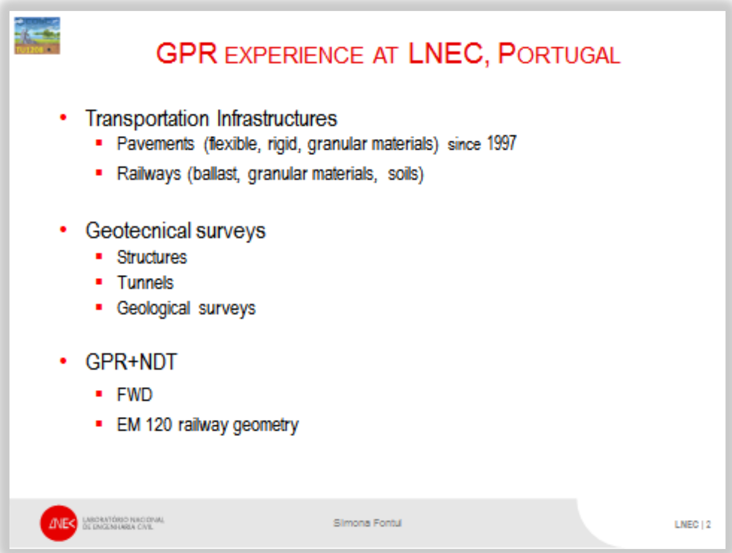
Also, LNEC is participating in the European project Tomorrow's Road Infrastructure Monitoring and Management (TRIMM). This project intents to contribute to the improvement of pavement's structural evaluation with new monitoring techniques, in order to take full advantage of the monitoring systems and integrate this information on the pavement management systems. LNEC is involved in the improvement of GPR for pavement monitoring at traffic speed, CORELESS GPR, namely an approach of using combined antennas measurements to evaluate the pavement without coring.

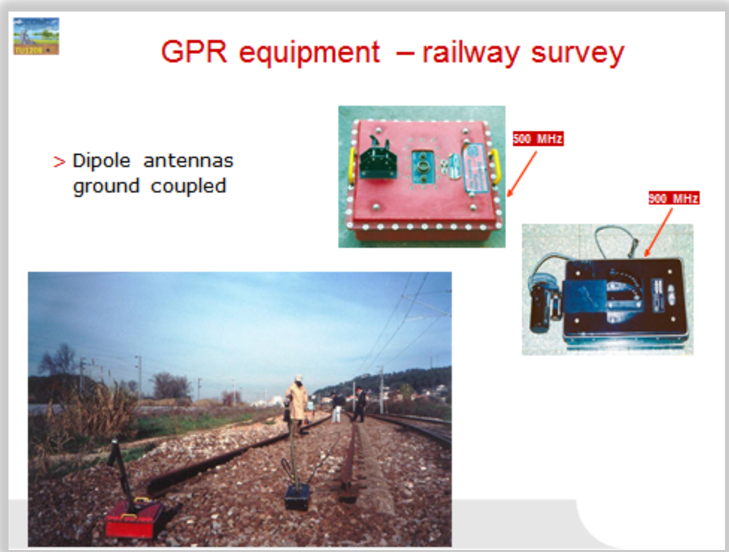

GPR EXPERIENCE AT LNEC, PORTUGAL
Transportation Infrastructures
Pavements (flexible, rigid, granular materials) since 1997
Railways (ballast, granular materials, soils)
Geotecnical surveys
Structures
Tunnels
Geological surveys
GPR+NDT
FWD
EM 120 railway geometry
Simona Fontul
LNEC | 2


GPR equipment available at LNEC
GSSI: 1GHz and 1,8GHz - Air coupled
REFER
IDS: 400 MHz - Semi-air coupled
GSSI: 500MHz and 900MHz - Ground coupled

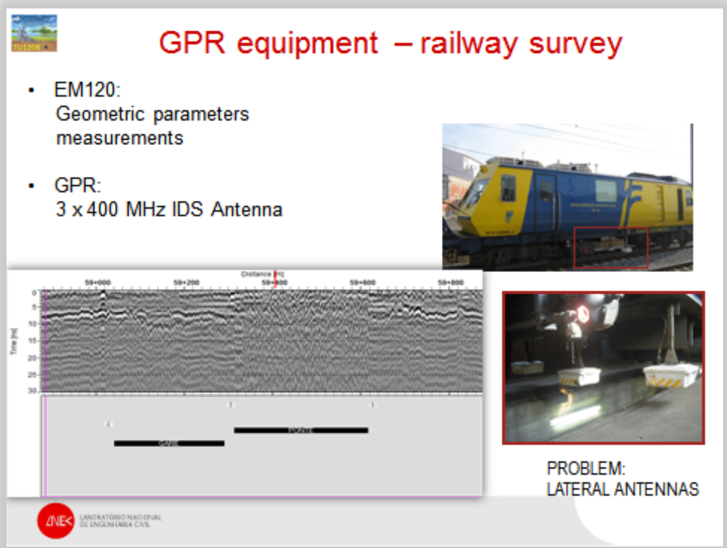

GPR equipment available at LNEC
Acquisition systems:
GSSI SIR-10H
GSSI SIR-20
System IDS
Software:
• RADAN 6.5
• IDS – Railwaydoctor


GPR equipment – pavement survey
> Horn Antennas
1.8 GHz
1.0 GHz

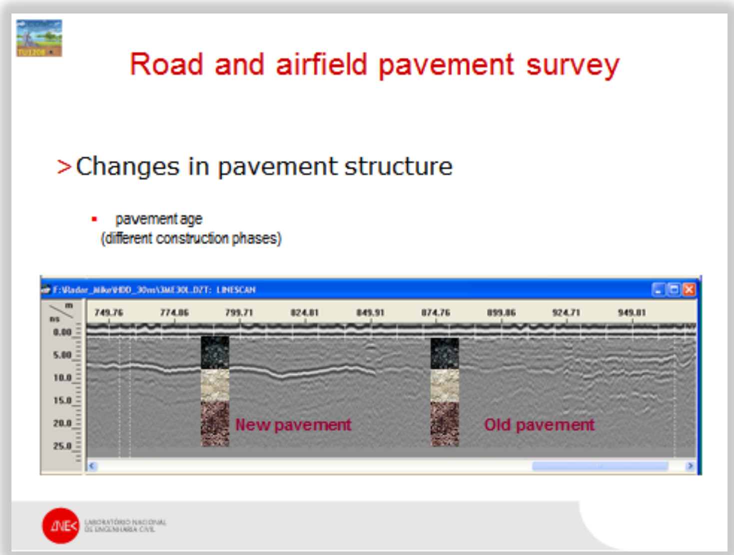

GPR equipment – railway survey
Existing Railway
During construction
LNEC | 6

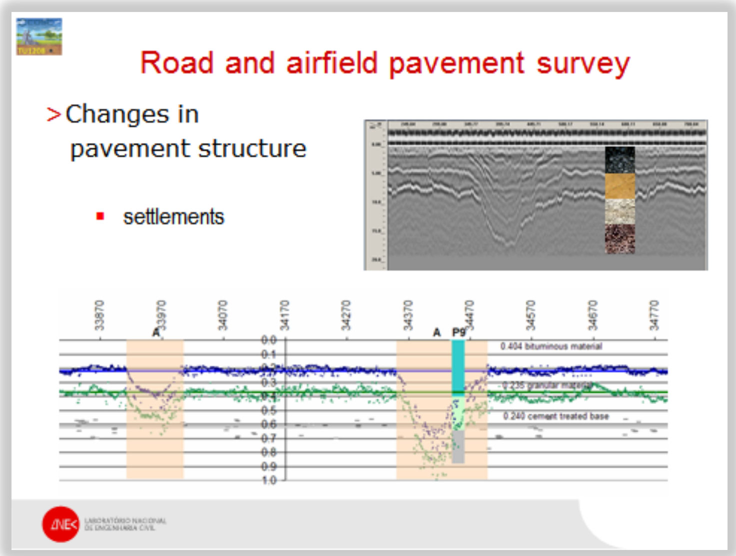

GPR equipment – railway survey
> Dipole antennas ground coupled
500 MHz
900 MHz

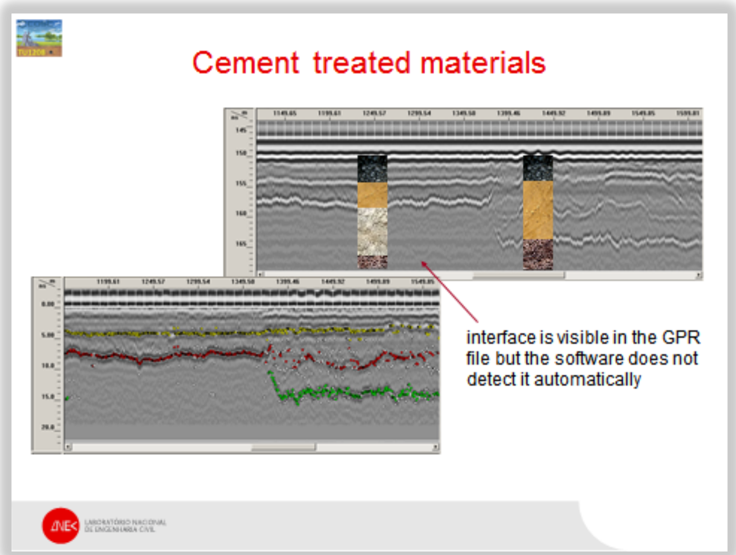

GPR equipment – railway survey
> Dipole antennas ground coupled
500 and 900 MHz
v ≈ 20 km/h
suspended at 0.2 m
5 scans/m
> Horn Antennas

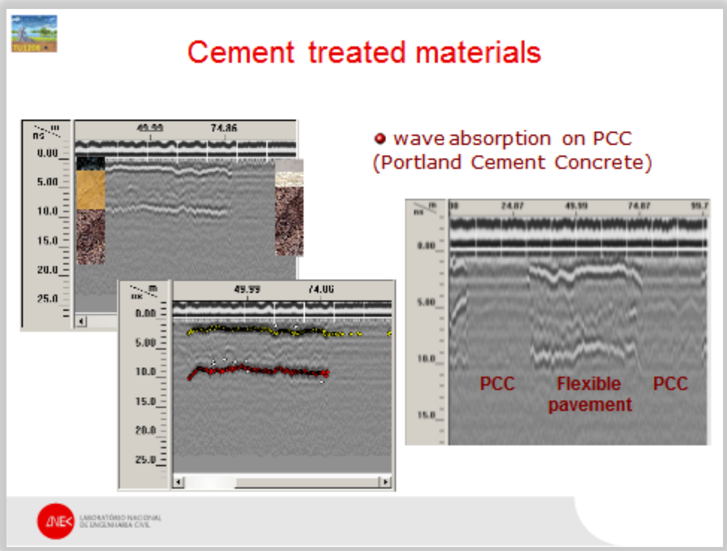

GPR equipment – railway survey
EM120:
Geometric parameters measurements
GPR:
3 x 400 MHz IDS Antenna
PROBLEM:
LATERAL ANTENNAS

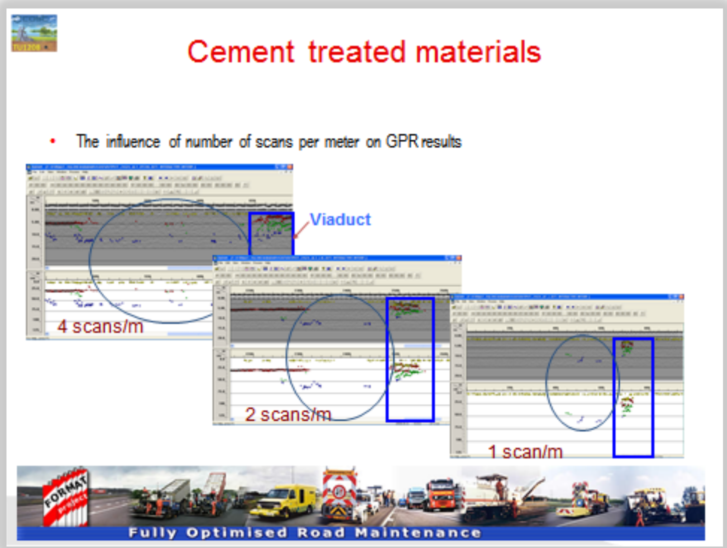

Road and airfield pavement survey
> Layer thickness measurement


Road and airfield pavement survey
> Changes in pavement structure
pavement age
(different construction phases)
New pavement
Old pavement


Road and airfield pavement survey
> Changes in pavement structure
settlements
33870
33970
34070
34170
34270
34370
34470
34570
34670
34770
A
A
P9
0.404 bituminous material
0.235 granular material
0.240 cement treated base


Cement treated materials
interface is visible in the GPR file but the software does not detect it automatically





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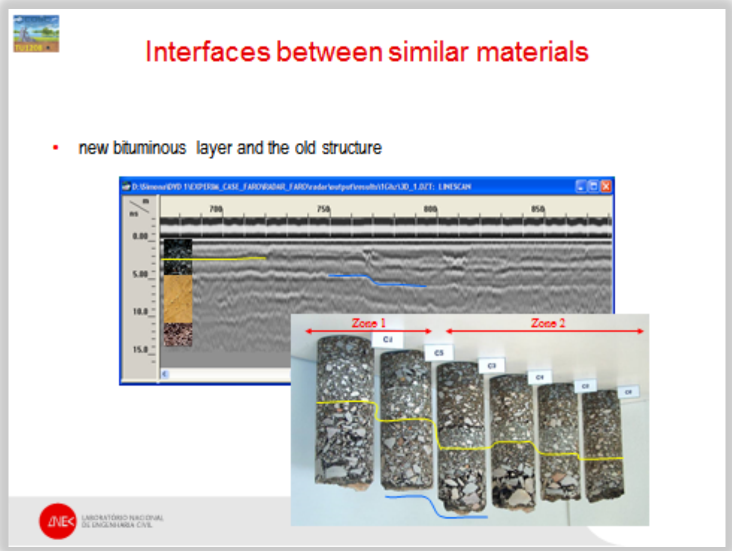
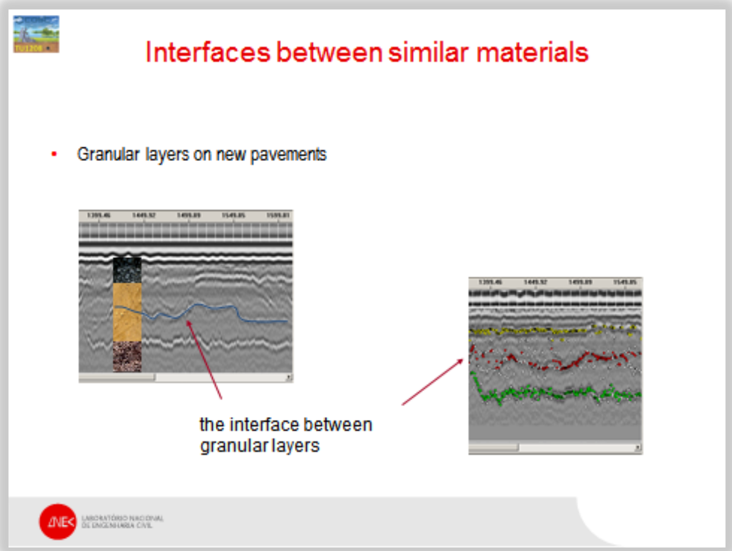
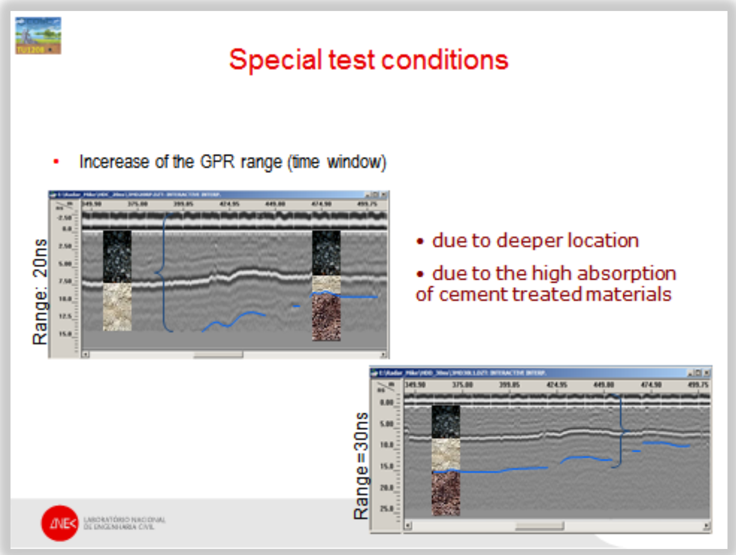
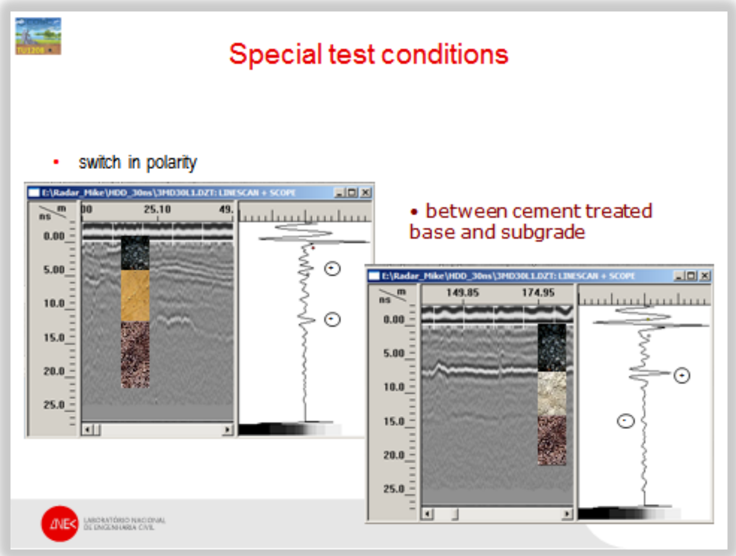
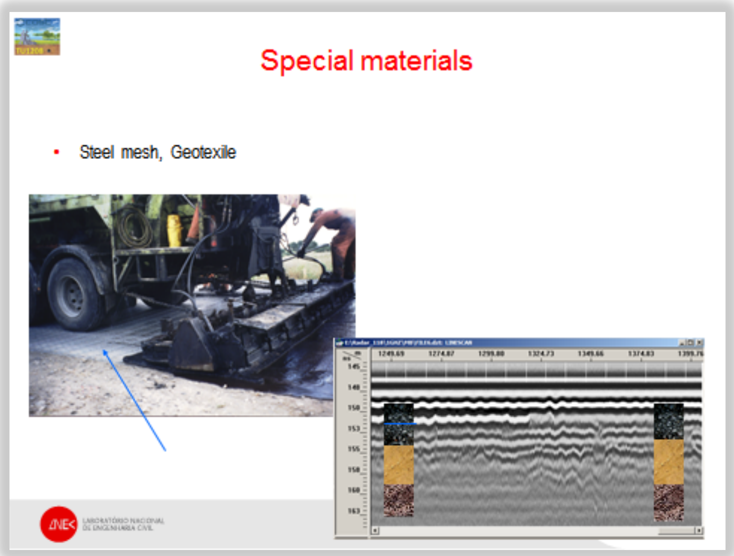
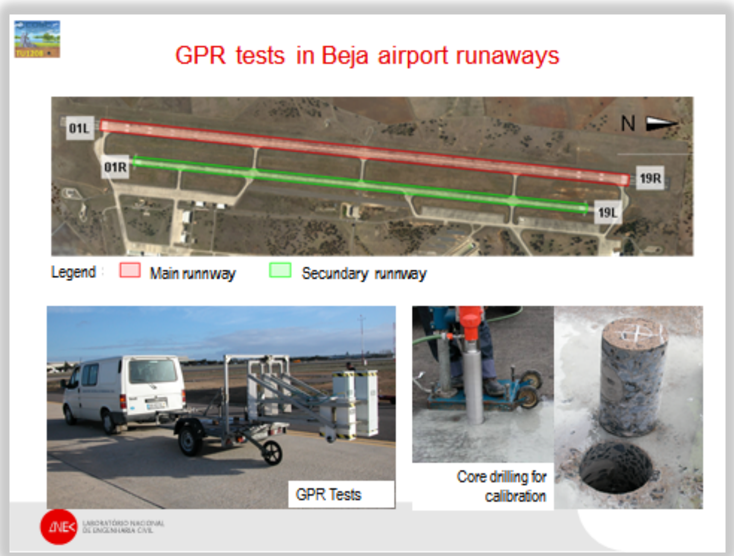

Interfaces between similar materials
new bituminous layer and the old structure
Zone 1
Zone 2

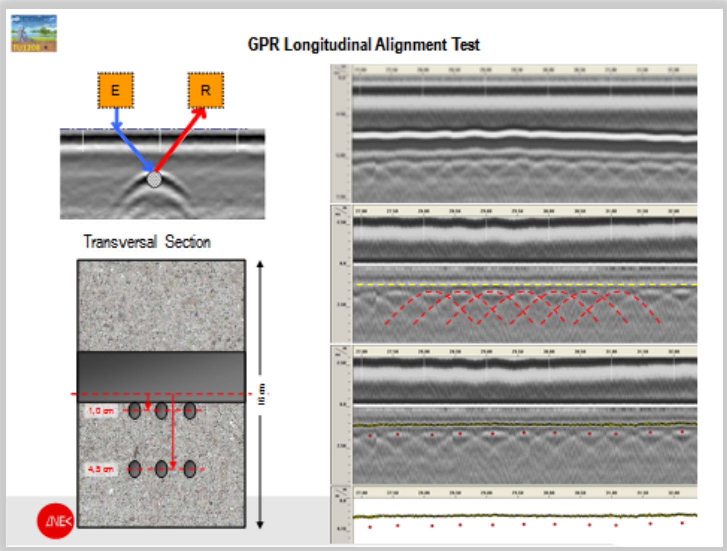

Interfaces between similar materials
Granular layers on new pavements
the interface between
granular layers

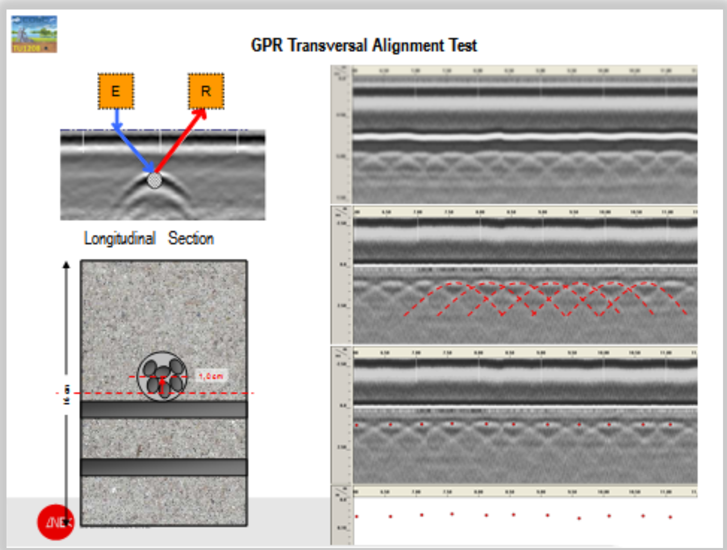

Special test conditions
Increase of the GPR range (time window)
Range: 20ns
due to deeper location
due to the high absorption of cement treated materials
Range =30ns


Special test conditions
switch in polarity
between cement treated base and subgrade


Special materials
Steel mesh, Geotexile


GPR tests in Beja airport runaways
01L
01R
19R
19L
N
Legend
Main runnway
Secundary runnway
GPR Tests
Core drilling for calibration


GPR Longitudinal Alignment Test
E
R
Transversal Section
1,0 cm
4,5 cm
16 cm


GPR Transversal Alignment Test
E
R
Longitudinal Section
1,0 cm
16 cm

Railways survey

- NDT tests performed:
  - During construction (at the top of the sub-ballast layer)
  - On the existing line
  - For reinforcement studies

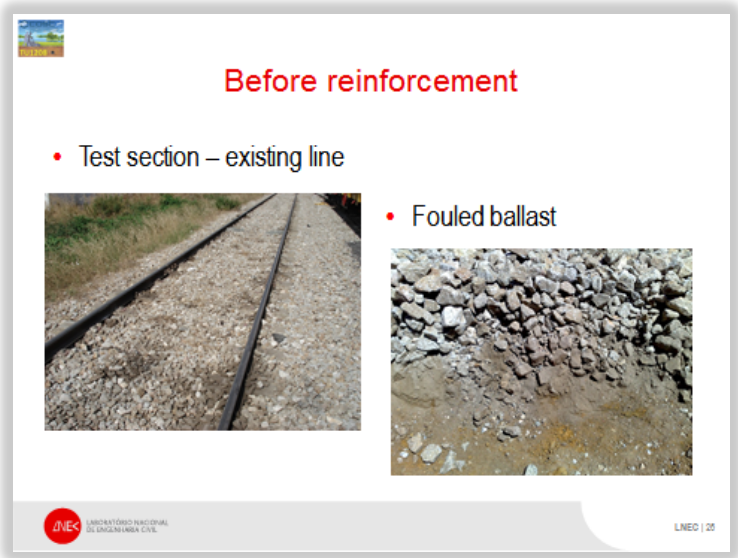
STUDIES PERFORMED ON A OLD RAILWAY LINE

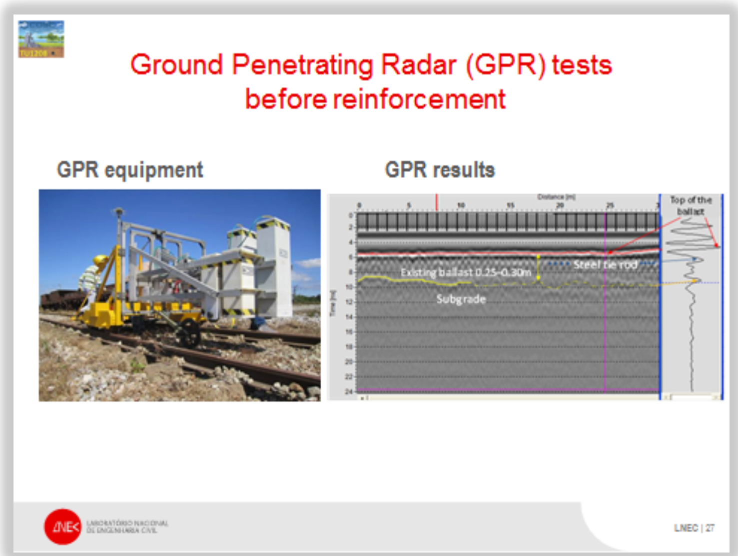
- The experimental studies presented in this work aimed to construct and evaluate various solutions for structural reinforcement of old railway tracks.

- Ballasted track section
  - 36 m long,
  - Iberian gauge (1.668 m)
  - bi-block sleepers
  - limestone ballast

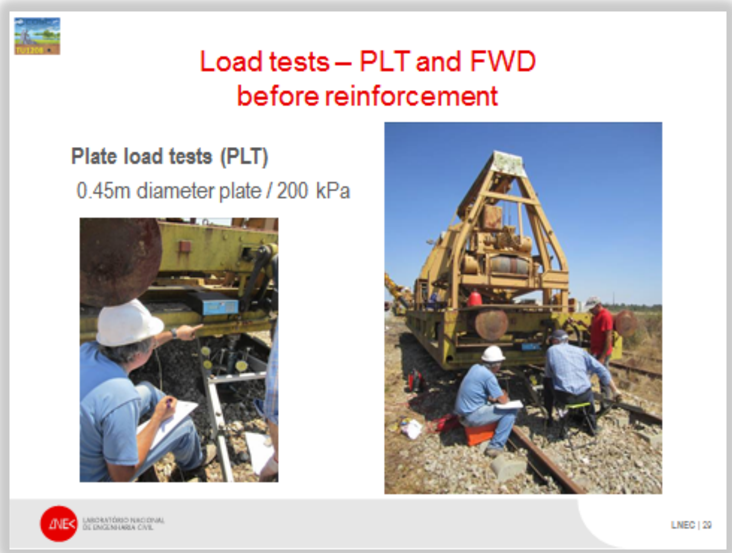
LNEC LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

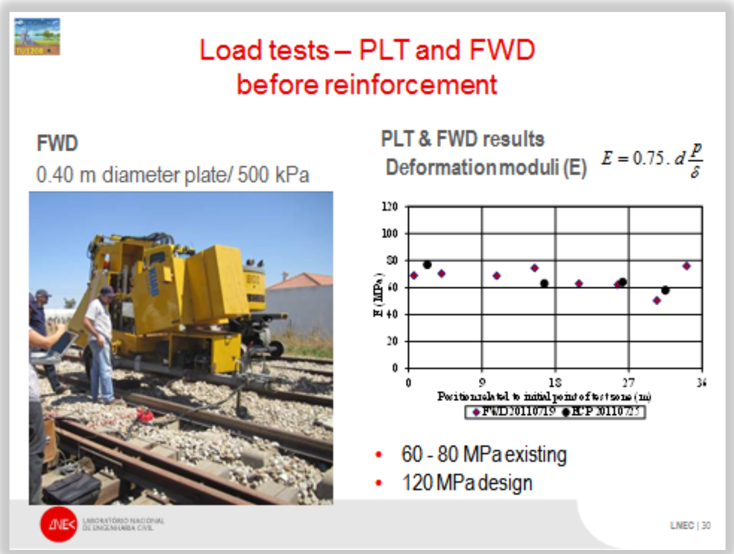
LNEC | 25

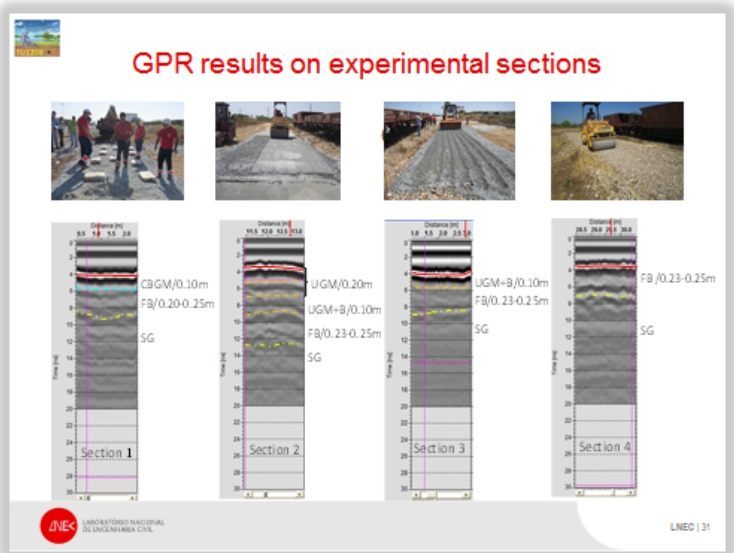

Before reinforcement
• Test section – existing line
• Fouled ballast
LNEC | 26

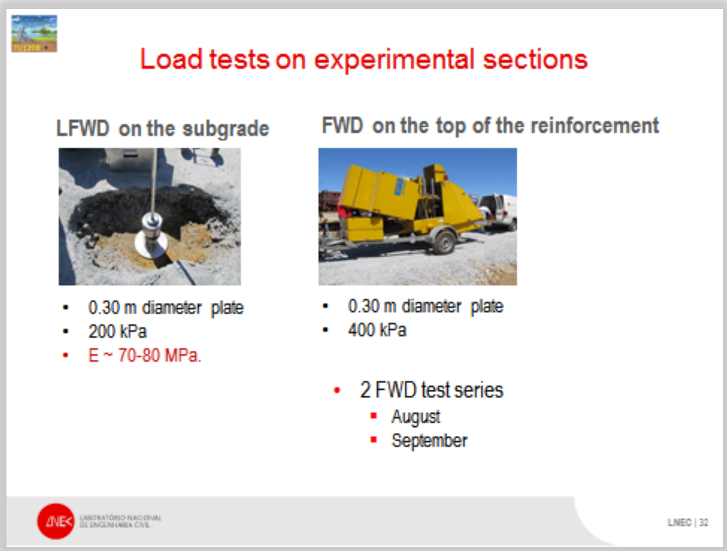

Ground Penetrating Radar (GPR) tests before reinforcement
GPR equipment
GPR results
Top of the ballast
Steel tie rod
Existing ballast 0.25-0.30m
Subgrade
LNEC | 27

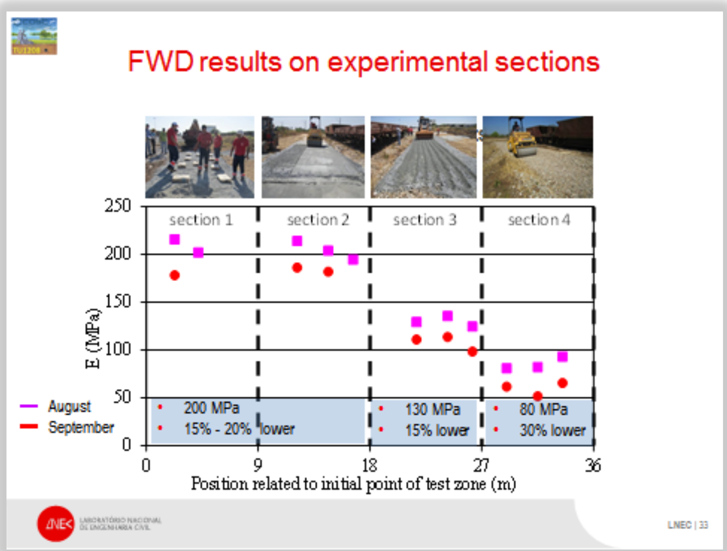

Before reinforcement
• FWD upgrading for railways tests
LNEC | 28

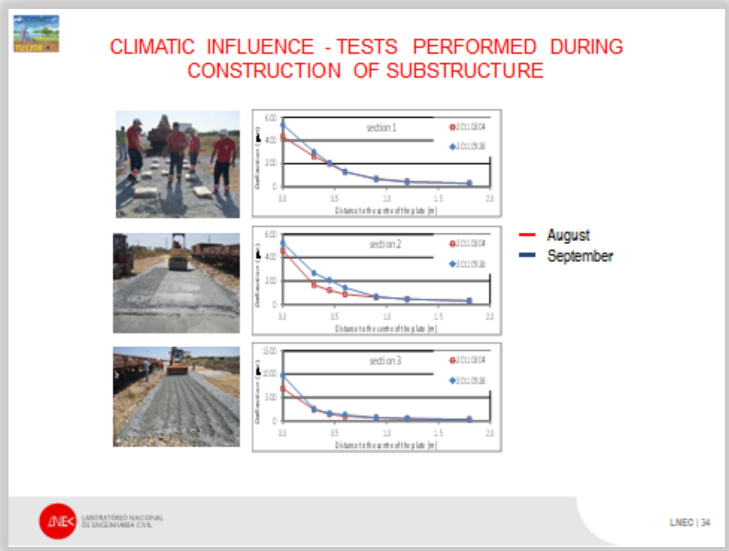

Load tests – PLT and FWD
before reinforcement
Plate load tests (PLT)
0.45m diameter plate / 200 kPa
LNEC | 29


Load tests – PLT and FWD
before reinforcement
FWD
0.40 m diameter plate/ 500 kPa
PLT & FWD results
Deformation moduli (E)
$E = 0.75 . d \frac{p}{\delta}$
E (MPa)
• 60 - 80 MPa existing
• 120 MPa design
LNEC | 30

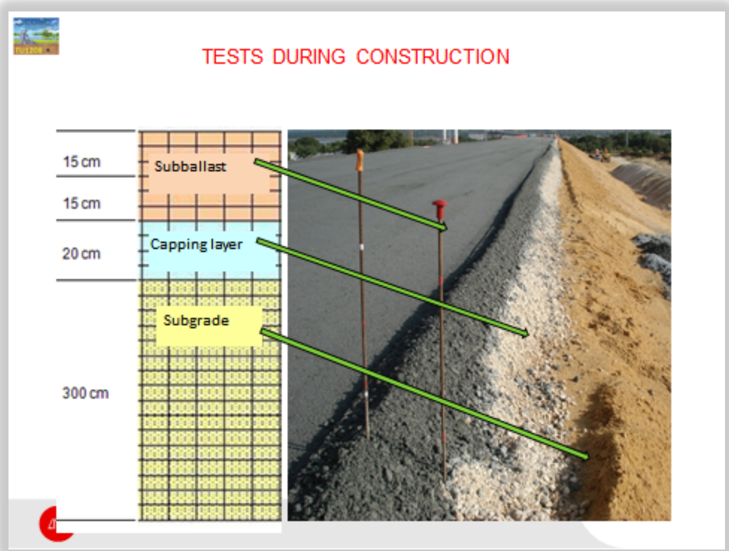

GPR results on experimental sections
CBGM/0.10m
FB/0.20-0.25m
SG
Section 1
UGM/0.20m
UGM+B/0.10m
FB/0.23-0.25m
SG
Section 2
UGM+B/0.10m
FB/0.23-0.25m
SG
Section 3
FB/0.23-0.25m
SG
Section 4
LNEC | 31


Load tests on experimental sections
LFWD on the subgrade
FWD on the top of the reinforcement
0.30 m diameter plate
200 kPa
E ~ 70-80 MPa.
0.30 m diameter plate
400 kPa
2 FWD test series
August
September
LNEC | 32

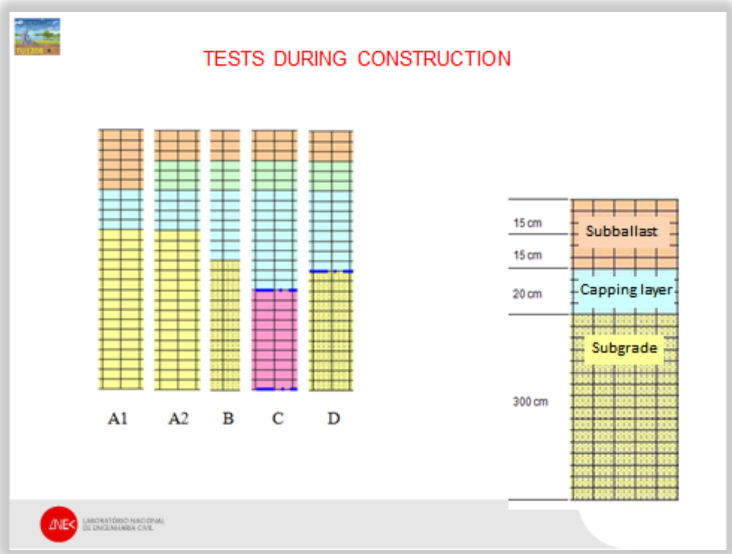

FWD results on experimental sections
section 1
section 2
section 3
section 4
E (MPa)
August
September
200 MPa
15% - 20% lower
130 MPa
15% lower
80 MPa
30% lower
Position related to initial point of test zone (m)
LNEC | 33

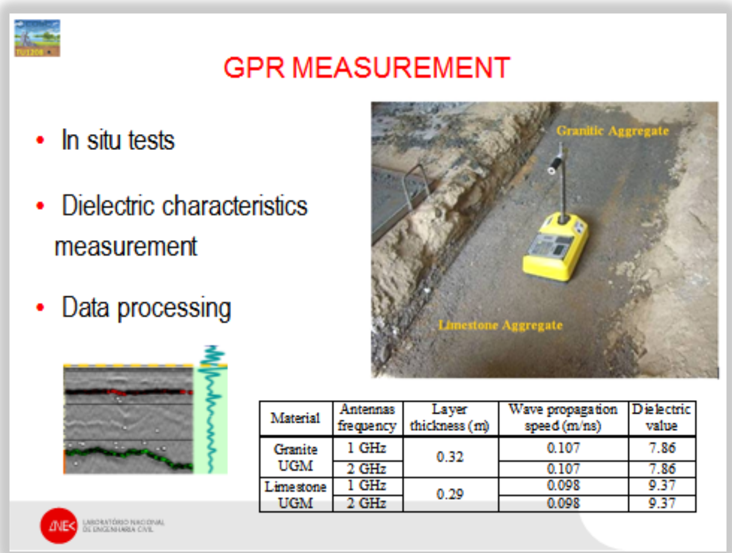


CLIMATIC INFLUENCE - TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE
section 1
section 2
section 3
August
September
LNEC | 34

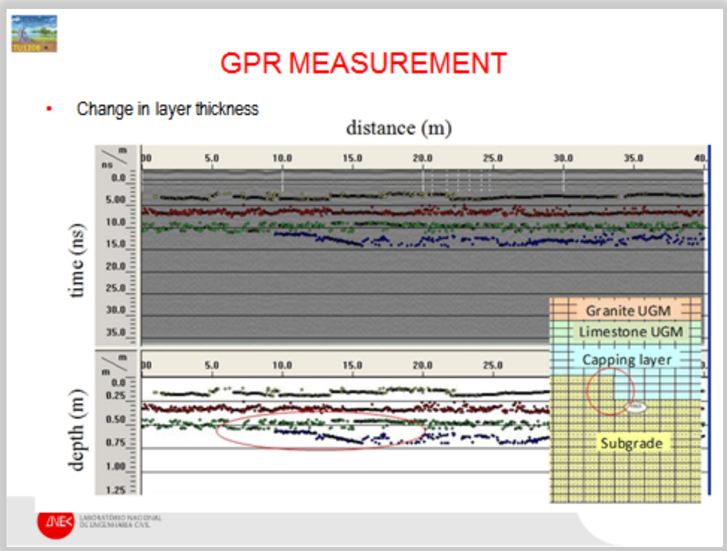


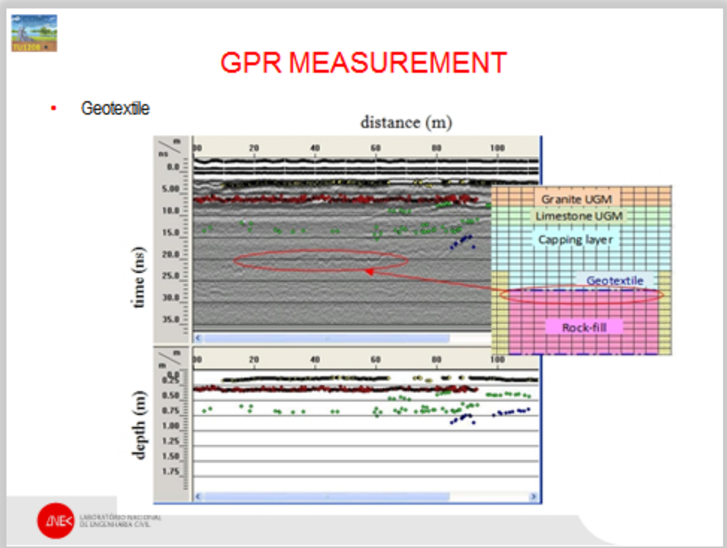
TESTS DURING CONSTRUCTION
15 cm
15 cm
20 cm
300 cm
Subballast
Capping layer
Subgrade





Material	Antennas frequency	Layer thickness (m)	Wave propagation speed (m/ns)	Dielectric value
Granite UGM	1 GHz	0.32	0.107	7.86
	2 GHz		0.107	7.86
Limestone UGM	1 GHz	0.29	0.098	9.37
	2 GHz		0.098	9.37





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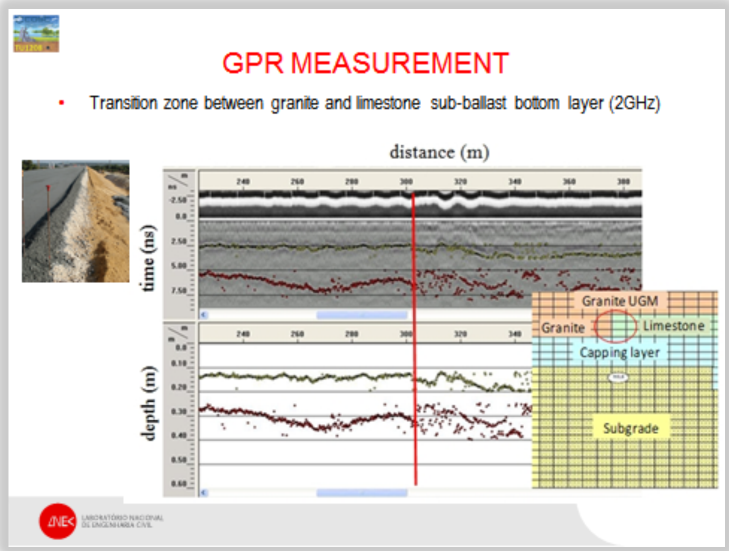
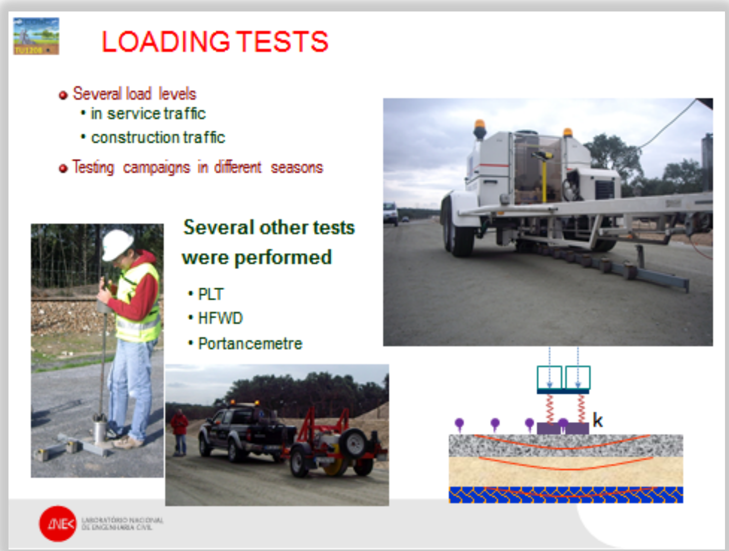
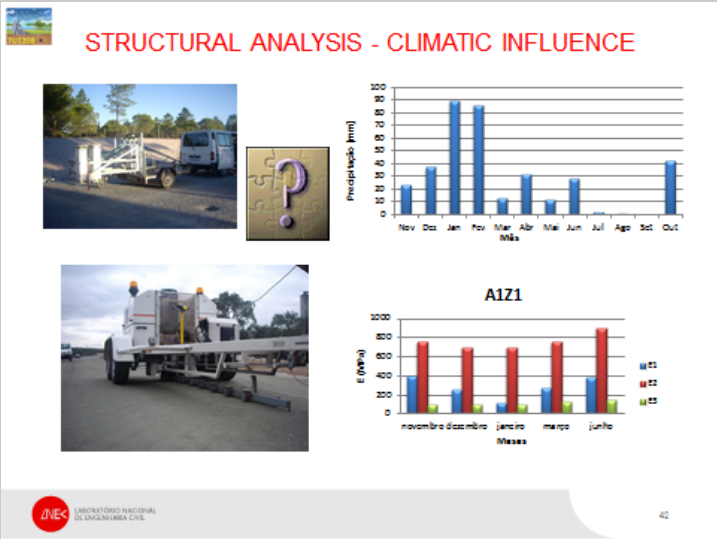
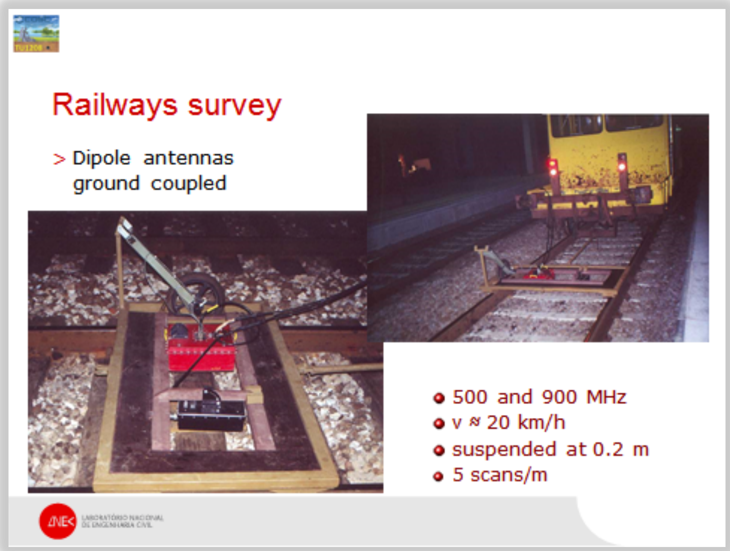

GPR MEASUREMENT
• Transition zone between granite and limestone sub-ballast bottom layer (2GHz)
distance (m)
time (ns)
depth (m)
Granite UGM
Granite
Limestone
Capping layer
Subgrade

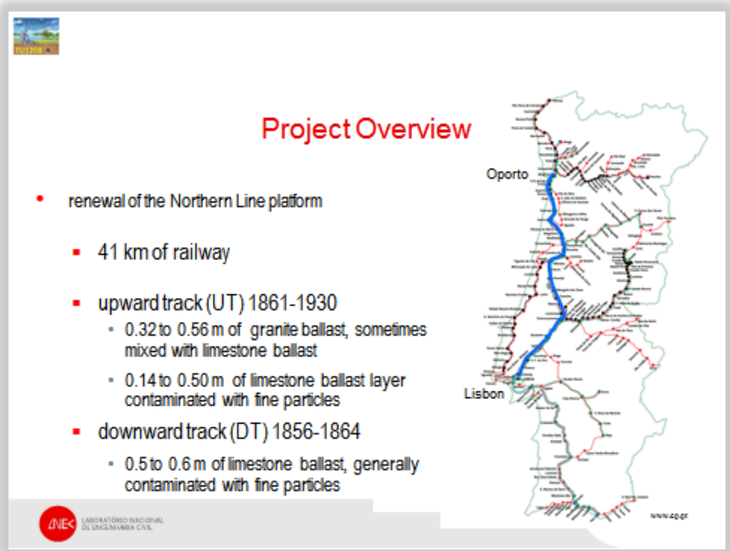

LOADING TESTS
• Several load levels
• in service traffic
• construction traffic
• Testing campaigns in different seasons
Several other tests were performed
• PLT
• HFWD
• Portancemetre
k



Railways survey

- A railway platform before and after renewal
- Test pits to confirm the results
- Several sections were studied (GPR variability)
  - *different types of ballast materials (limestone or granite)*
  - *different levels of contamination of ballast with fine particles (fouled ballast)*





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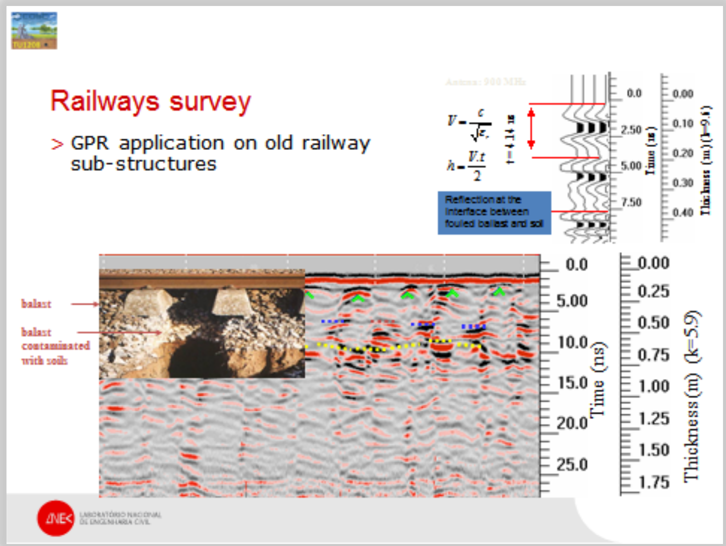
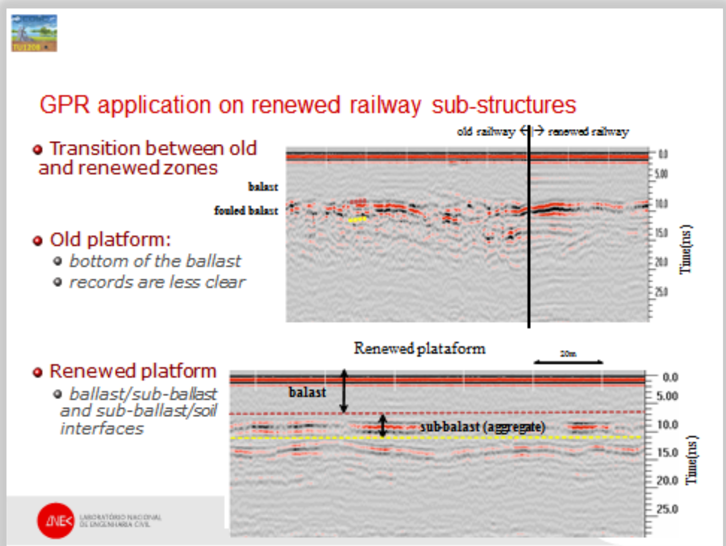
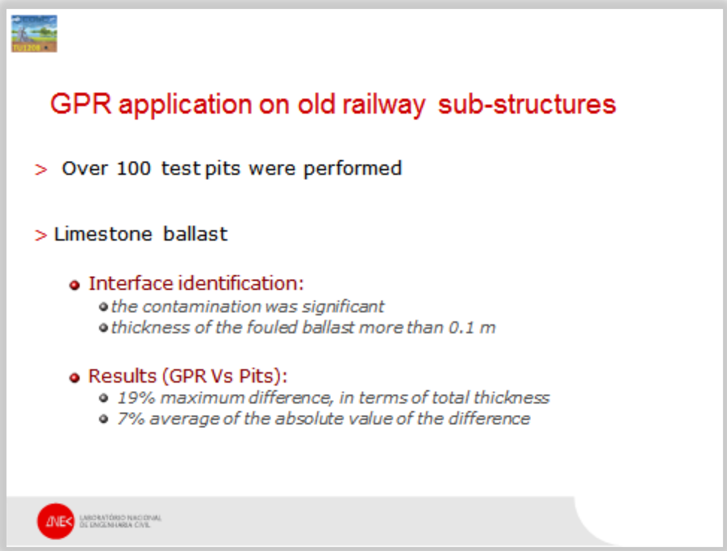
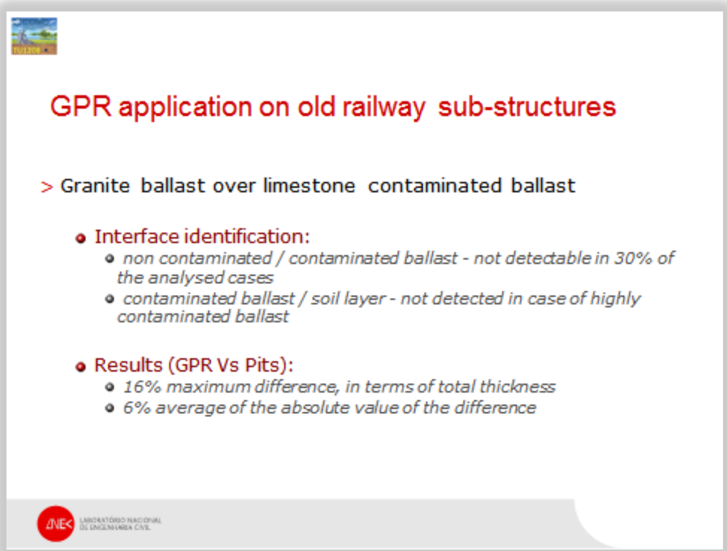
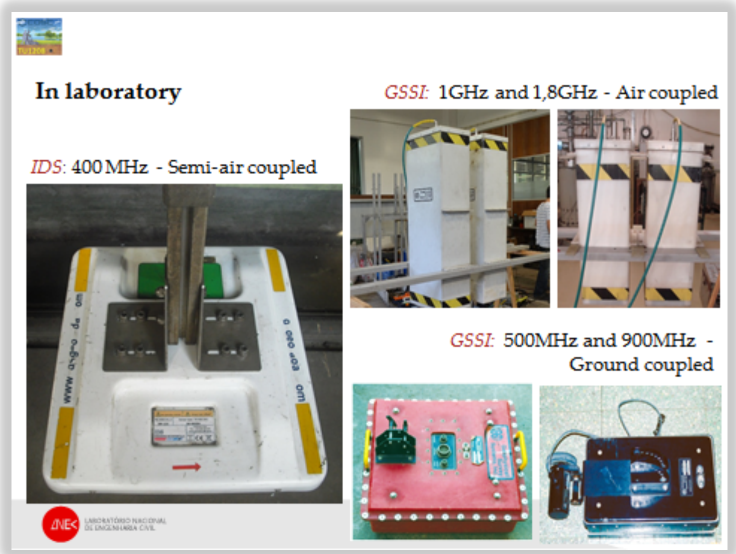
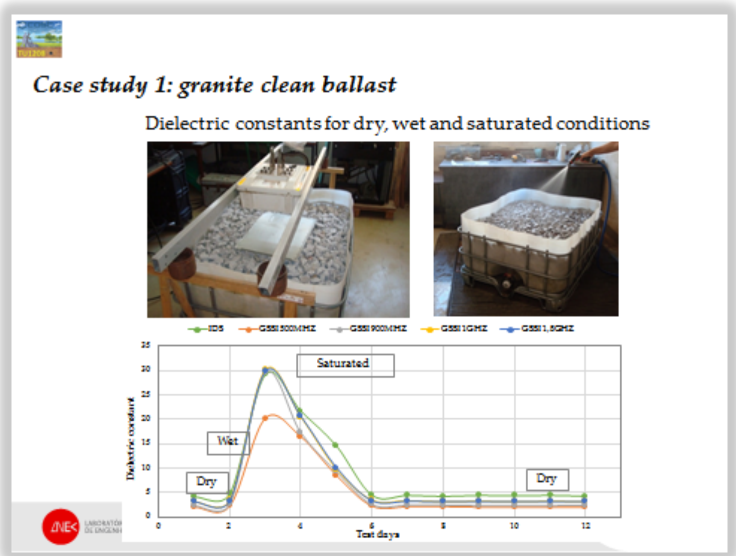

Railways survey
> GPR application on old railway sub-structures
$V = \frac{c}{\sqrt{\varepsilon_r}}$
$h = \frac{V.t}{2}$
Reflection at the interface between fouled ballast and soil
balast
balast contaminated with soils
Time (ns)
Thickness (m) (k=5.9)


GPR application on renewed railway sub-structures
Transition between old and renewed zones
old railway ← → renewed railway
balast
fouled balast
Old platform:
bottom of the ballast
records are less clear
Time(ns)
Renewed plataform
Renewed platform
ballast/sub-ballast and sub-ballast/soil interfaces
balast
sub-balast (aggregate)
Time(ns)


GPR application on old railway sub-structures
> Over 100 test pits were performed
> Limestone ballast
Interface identification:
the contamination was significant
thickness of the fouled ballast more than 0.1 m
Results (GPR Vs Pits):
19% maximum difference, in terms of total thickness
7% average of the absolute value of the difference

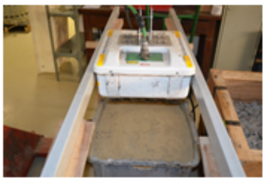

GPR application on old railway sub-structures
> Granite ballast over limestone contaminated ballast
Interface identification:
non contaminated / contaminated ballast - not detectable in 30% of the analysed cases
contaminated ballast / soil layer - not detected in case of highly contaminated ballast
Results (GPR Vs Pits):
16% maximum difference, in terms of total thickness
6% average of the absolute value of the difference

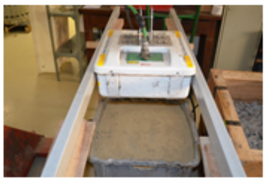

In laboratory
IDS: 400 MHz - Semi-air coupled
GSSI: 1GHz and 1,8GHz - Air coupled
GSSI: 500MHz and 900MHz - Ground coupled

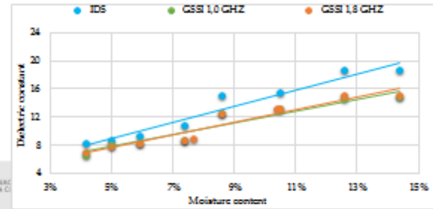

Case study 1: granite clean ballast
Dielectric constants for dry, wet and saturated conditions
IDS
GSSI 500MHZ
GSSI 900MHZ
GSSI 1GHZ
GSSI 1,8GHZ
Dielectric constant
Test days
Dry
Wet
Saturated
Dry

Case study 2: fine soil

Different moisture content



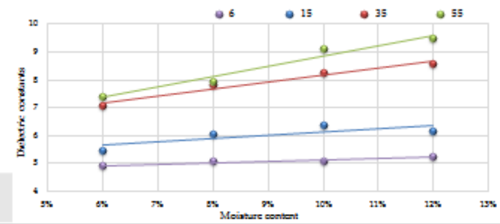




Case study 3: fouled ballast

Relative ballast fouling ratio (%)

Category	Rbf (%)	Laboratory (%)
Moderately clean	2 to 9.5	6
Moderately fouled	9.5 to 17.5	15
Fouled	17.5 to 34	35
Highly fouled	≥ 34	55

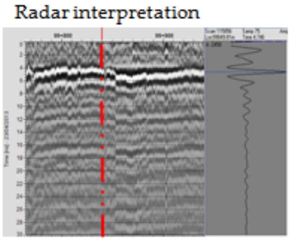


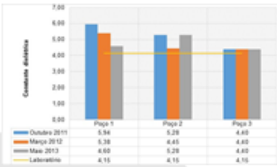
$$R_{b-f} = \frac{M_f\left(\frac{G_{s-b}}{G_{s-f}}\right)}{M_b}$$

In situ: Test Pits

Ballast thickness measurement

Radar interpretation





FWD +GPR

> Ground Penetrating Radar (GPR)

- "continuous"
- information on the structural behaviour

Type of structure → layer thickness; changes of structure

Deflection test results + Type of structure

Bearing capacity

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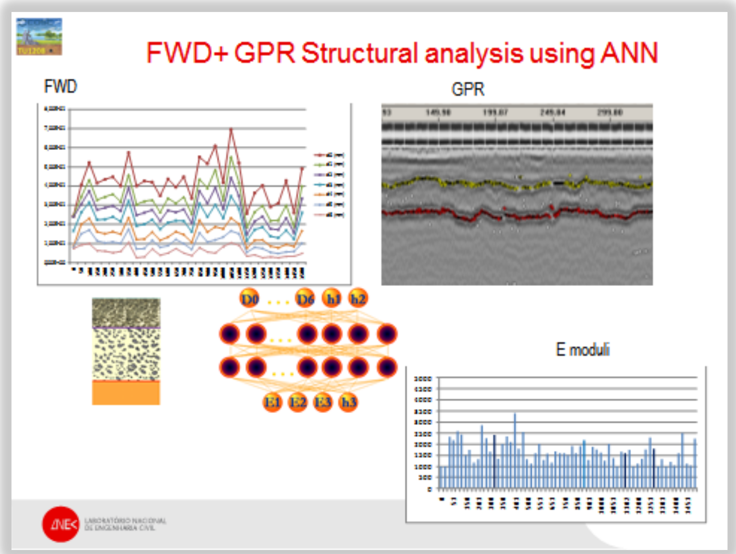
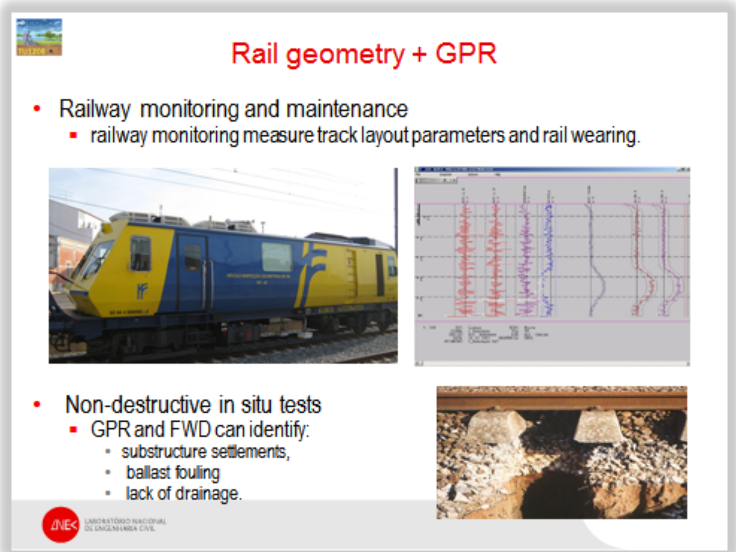
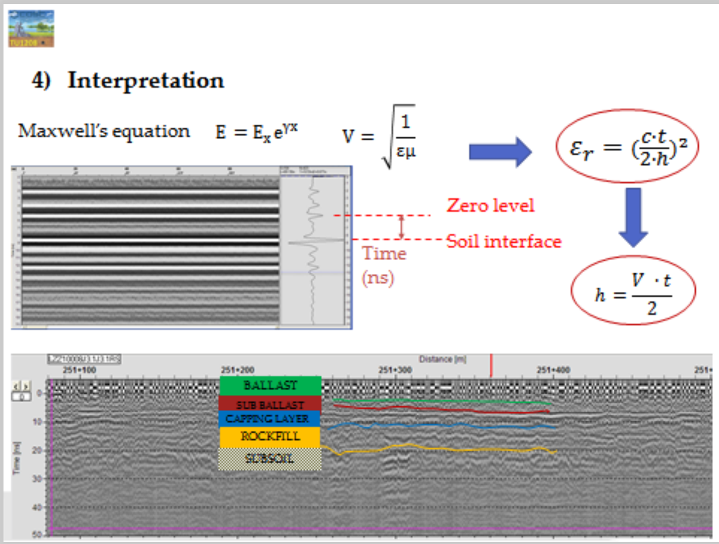


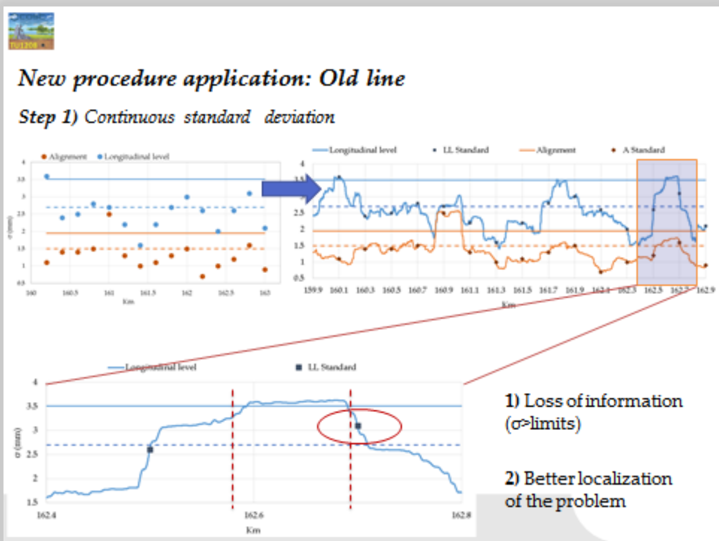
FWD+ GPR Structural analysis using ANN
FWD
GPR
E moduli



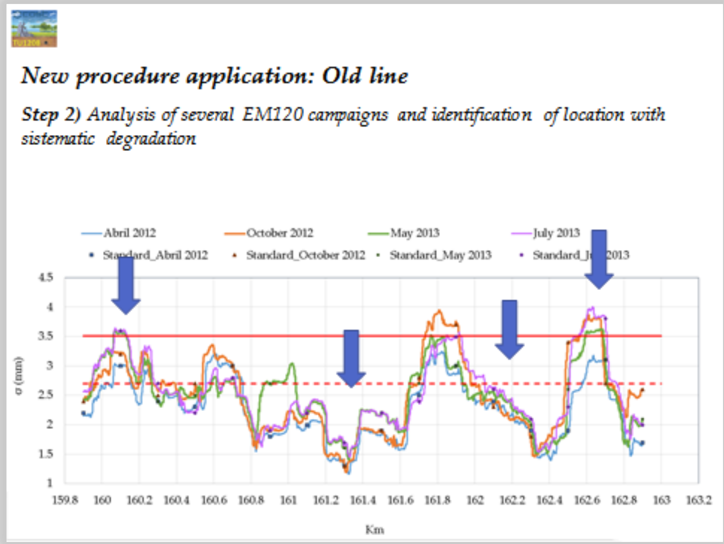
Rail geometry + GPR
• Railway monitoring and maintenance
▪ railway monitoring measure track layout parameters and rail wearing.
• Non-destructive in situ tests
▪ GPR and FWD can identify:
• substructure settlements,
• ballast fouling
• lack of drainage.

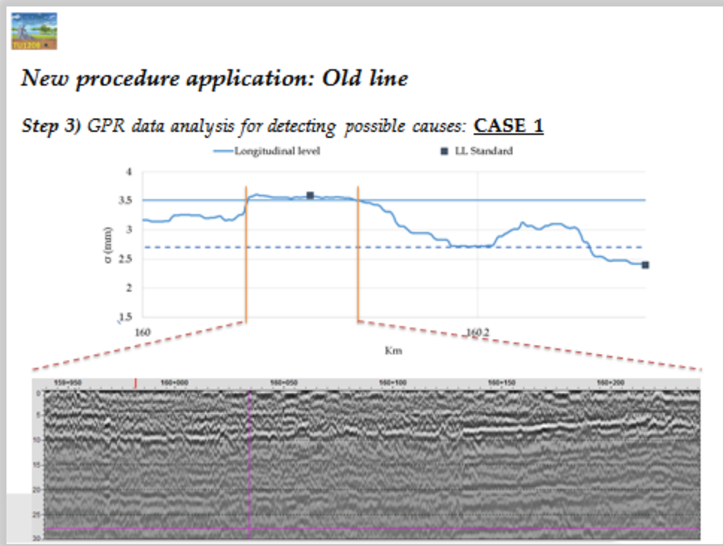


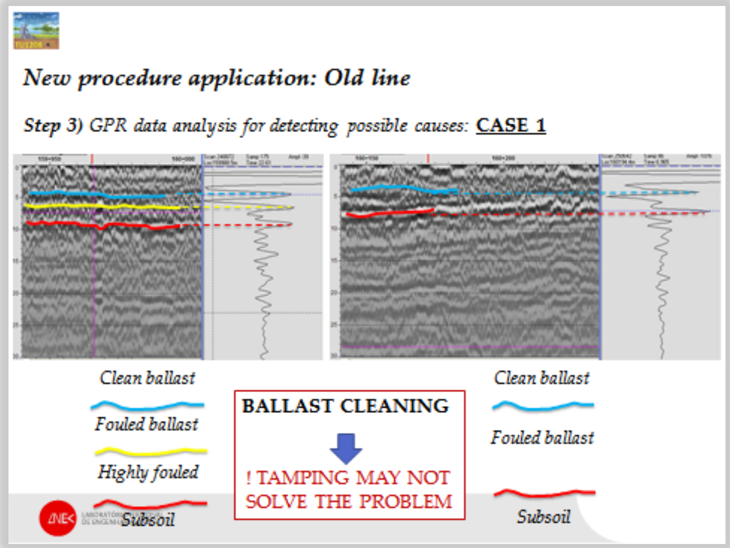
4) Interpretation
Maxwell's equation $E = E_x e^{\gamma x}$ $V = \sqrt{\frac{1}{\varepsilon\mu}}$
$\varepsilon_r = (\frac{c \cdot t}{2 \cdot h})^2$
Zero level
Soil interface
Time (ns)
$h = \frac{V \cdot t}{2}$
BALLAST
SUB BALLAST
CAPPING LAYER
ROCKFILL
SUBSOIL

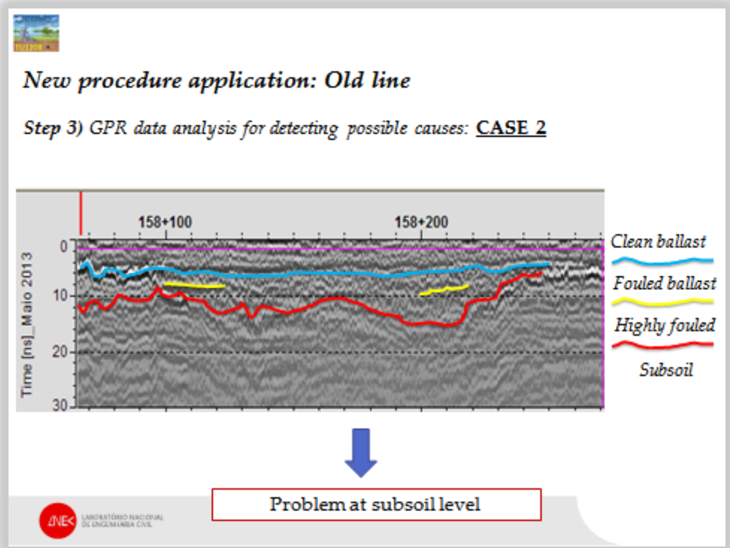


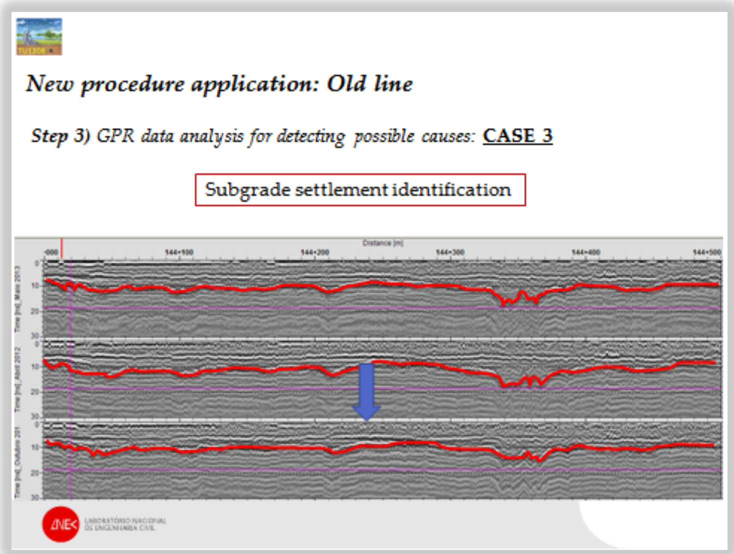
New procedure application: Old line
Step 1) Continuous standard deviation
1) Loss of information (σ>limits)
2) Better localization of the problem

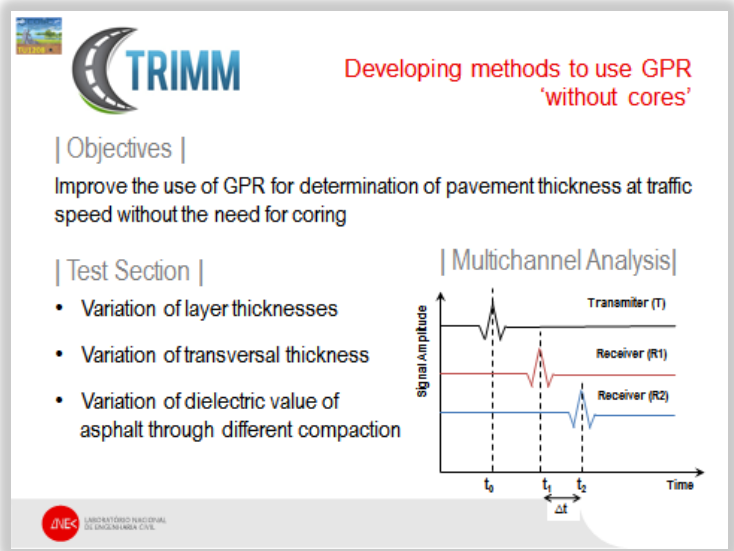

New procedure application: Old line
Step 2) Analysis of several EM120 campaigns and identification of location with sistematic degradation
Abril 2012
October 2012
May 2013
July 2013
Standard_Abril 2012
Standard_October 2012
Standard_May 2013
σ (mm)
Km


New procedure application: Old line
Step 3) GPR data analysis for detecting possible causes: CASE 1
Longitudinal level
LL Standard
σ (mm)
Km


New procedure application: Old line
Step 3) GPR data analysis for detecting possible causes: CASE 1
Clean ballast
Fouled ballast
Highly fouled
Subsoil
BALLAST CLEANING
! TAMPING MAY NOT SOLVE THE PROBLEM
Clean ballast
Fouled ballast
Subsoil


New procedure application: Old line
Step 3) GPR data analysis for detecting possible causes: CASE 2
158+100
158+200
Time [ns]_Maio 2013
0
10
20
30
Clean ballast
Fouled ballast
Highly fouled
Subsoil
Problem at subsoil level


New procedure application: Old line
Step 3) GPR data analysis for detecting possible causes: CASE 3
Subgrade settlement identification
Distance [m]


TRIMM
Developing methods to use GPR 'without cores'
| Objectives |
Improve the use of GPR for determination of pavement thickness at traffic speed without the need for coring
| Test Section |
• Variation of layer thicknesses
• Variation of transversal thickness
• Variation of dielectric value of asphalt through different compaction
| Multichannel Analysis|
Signal Amplitude
Transmiter (T)
Receiver (R1)
Receiver (R2)
Time
t_0
t_1
t_2
Δt


TRIMM
| Test Site - Construction (October 2012)|


TRIMM
| Data collection - In Situ Tests (June 2013) |


TRIMM
| Data collection - In Situ Tests (June 2013) |


TRIMM
| Data collection -Lisbon In Situ Tests (February 2014) |

"GPR ACTIVITIES AT THE FEDERAL INSTITUTE FOR MATERIALS RESEARCH AND TESTING (BAM), IN GERMANY"

Christiane Trela, BAM, Berlin, Germany
christiane.trela@bam.de

In this contribution, the GPR activities in the field of civil engineering (CE) of the division 8.2 "Non-Destructive Damage Assessment and Environmental Measurement Methods" in the Federal Institute for Materials Research and Testing (BAM) are presented.

BAM is a technical and scientific federal authority belonging to the Federal Ministry of Economics and Technology (BMWi) in Berlin / Germany. Its research focuses on safety aspects of energy supply and environmental protection as well as on materials engineering and related technologies. In this frame, new analysis and testing methods are developed and evaluated. GPR is used here as a nondestructive method (NDT) to carry out structural investigations and material tests at building components from the construction industry.

The contribution covers the following topics regarding the GPR application in CE:

- Topics of research and work activities
- GPR equipment and available testing facilities
- Testing opportunities
- GPR examples of laboratory work and case studies
- Ongoing projects.

Topics of research and work activities are summarized in the slides [3] to [17].

The members of our radar group are usually solving tasks, which were given by the construction industry, where GPR equipment is used. This includes also assessing the quality of the results.

For this purpose, typically the following work packages are agreed:

- Construction of test specimen
- Test of efficient measurement setups
- Simulation of wave propagation

- Optimization of data analysis and validation
- Presentation of results for non-specialists.

The variety of materials and structural elements, from which the test specimens were built was presented, including an overview about the situation in the laboratory and the environmental conditions under which they were used, see slide [4].

The slides [5] and [6] show the characteristic parameters which can be changed in a GPR measurement setups. An example from practice shows how the settings such as alignment and spacing of the measurement profiles etc. are selected, starting from the task to detect shear needles and tendon ducts behind reinforcement in a concrete structure.

FD modeling is often carried out for supporting the construction of test specimens and to evaluate the GPR measurements.

The slides [8] to [12] show evaluation methods and examples to optimize data analysis and validation. This includes important data processing steps such as filtering algorithms and image enhancement through migration with 3D SAFT reconstruction. Other nondestructive testing methods (NDT) like ultrasonic or X-Ray are used for validation purposes. To determine the reliability of qualitative testing tasks the POD analysis (Probability of Detection) was presented in more detail using the example of the determination of the detection depth of rebars in concrete slabs.

Finally, an important focus is set on the way of presenting the results to the clients who are usually no GPR specialists. Plots of isolines are often a good representation.

An important issue of our work is the automation of measurements. For this purpose scanner systems have been built and adapted for a variety of practical applications and we have gained a lot of experience in this field. We have been carrying out investigations at many different buildings, such as bridges, roads, foundations and can report about many successful measurements.

In order to convey this knowledge about the proper and successful use of GPR in CE, the participation in committees as well as

the essential training and development of employees is an important activity, we are seriously pursuing at BAM.

GPR equipment and available testing facilities are presented on the slides [18] and [19], reference is being made here again on slide [14], where different scanner systems are shown. Particular attention is given to the latest generation of scanners for GPR implementations, which allow significantly improved measurements.

The testing opportunities are briefly discussed on slide [20]. In addition to various laboratory tests at custom-made test specimen, field measurements at large and close-to-reality objects are possible on the large test site near Berlin.

Examples of laboratory work and case studies of our GPR activities are presented on slides [21] to [25]. Typical examples were presented at reinforced concrete. The tests can be grouped into the following three areas:

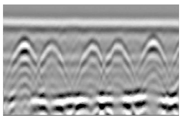
- Localization of post-tensioning reinforcement
- Quality control of precast concrete wall elements
- Proof of reinforcement mesh density in a concrete floor.

A case study for accurate localization of reinforcement has been presented in more detail on slides [22] to [25]. For the upgrading of bridges, the customer often requires the information about precise positions for damage free core drilling. This is important for the strengthening of the structure without destroying or harming the inner parts, while drilling. In preliminary studies, the GPR equipment is tested and the measurement settings are optimized for the specific testing tasks. Based on many years of experience in this field we are able to propose an optimized inspection procedure.

At the end of the presentation two ongoing projects were presented on slides [26] and [27]. One of them is a thesis that shows how corrosion of rebars in concrete in a GPR monitoring experiment can be represented via frequency mapping. The second is a research project to detect weak scatterers like honeycombs behind reinforcement with systematic studies in reflection and transmission mode.

GPR activities at the Federal Institute for Materials Research and Testing (BAM), Germany

Christiane Trela



Division 8.2: Non-Destructive Damage Assessment and Environmental Measurement Methods

2014 Working Group Progress Meeting, Nantes 1

Content:

- Topics of research and work activities
- GPR equipment and available testing facilities
- Testing opportunities
- GPR examples of laboratory work and case studies
- Ongoing projects

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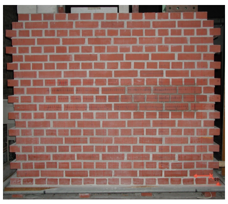
Topics of research and work activities: BAM

- Assessment of the GPR applications - determination of **accuracy** and **reliability** for specific inspection tasks
  - Construction of test specimens
  - Development of efficient measurement setups
  - Simulation of wave propagation
  - Optimization of data analysis and validation
  - Presentation of results for non-specialists

2014 Working Group Progress Meeting, Nantes 3

Assessment of the GPR applications: BAM

- Construction of test specimens
  - made of concrete, masonry, sand and gravels etc.
  - with different structural elements (rebars, tendon ducts, cavities, honey combs etc.)
  - under various conditions (wetness, salt content, temperatur, mechanical stress, accelerated corrosion etc.)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Assessment of the GPR applications:

BAM

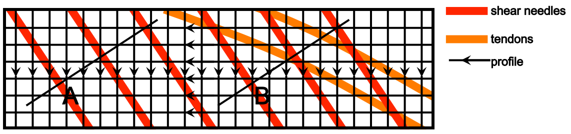
- Test of efficient measurement setups
  - Reflection and transmission mode
  - Antenna frequencies
  - Antenna orientation
  - Grid measurements with different trace distance in x or/ and y direction
  - …

2014 Working Group Progress Meeting, Nantes 5

Assessment of the GPR applications:

BAM

- Development of efficient measurement setups



[Th. Kind: Case study bridge in Bremen]

Questions:

- Is the radar penetration depth sufficient to find shear reinforcement in a depth of 25 to 45 cm?
- Is it possible to find the shear needles behind tendon ducts?
- What observational density is required for a radar survey? Single profiles, grid project with one or two polarities?

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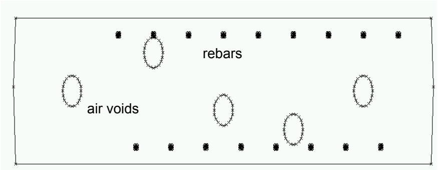
IFSTTAR ROMA TRE UNIVERSITÀ DEGLI STUDI cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

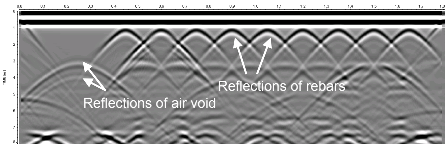
Assessment of the GPR applications:

BAM

- Simulation of wave propagation
  to understand the complex wavefield,
  based on FD solution of the EM-Wave equations



Planning of a new concrete test specimen

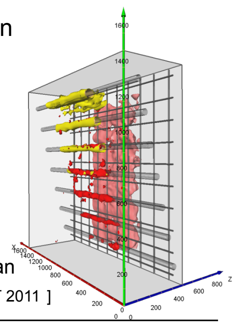


FD modeling 1500 MHz

Assessment of the GPR applications:

BAM

- Optimizing the data analysis and validation
  - Data conditioning (suppress noise,filtering etc.)
  - Imaging: Migration (3D SAFT reconstruction)
  - Image enhancement/ visualization
  - complementary investigations with ultrasonic or X-ray



3D-imaging of tendon ducts:
• Ultrasonic echo
• Radar
• Represented in construction plan

[Streicher et.al. DGZfP JT 2011]

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Assessment of the GPR applications:

BAM

- Optimizing the data analysis and validation
  - Application of POD analysis (Probability of Detection) to determine the **reliability of qualitative** testing tasks
  - Methodology is applied to GUM (Guide to the Expression of Uncertainty in Measurement) in the NDT in CE to determine **uncertainty of quantitative** testing tasks

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9

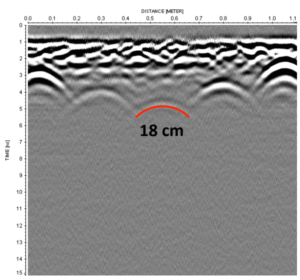
Assessment of the GPR applications:

BAM

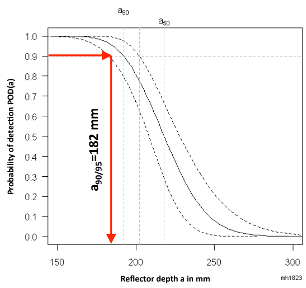
- Example: Limitation of detection [S.Feistkorn: Heft 603 DAfStB)]

Limits of Detection?

POD!



B-Scan recorded with GPR



POD-curve

$a_{90/95}$=18,2 cm

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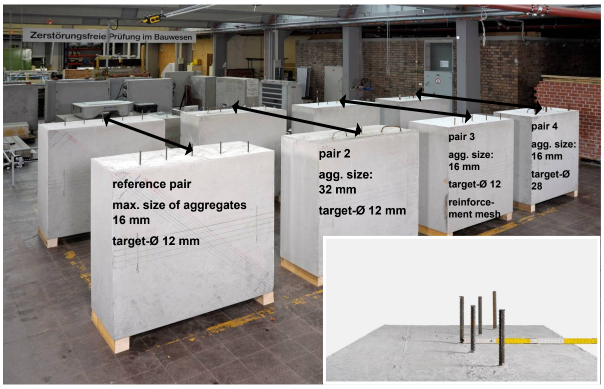
10

Assessment of the GPR applications:

BAM

Specimens for POD-experiments



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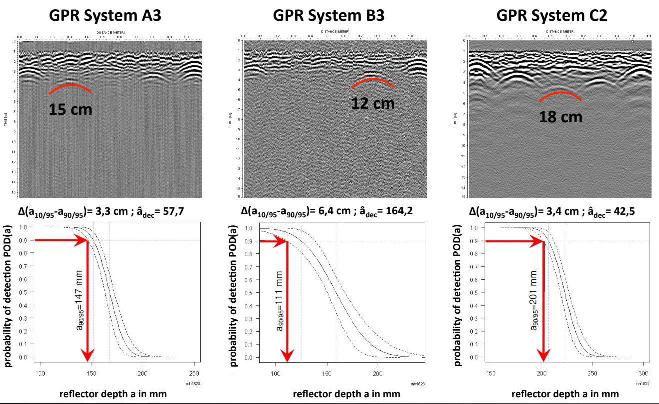
Assessment of the GPR applications:

BAM

Differences in $a_{90/95}$, GPR system noise and variance of responses â



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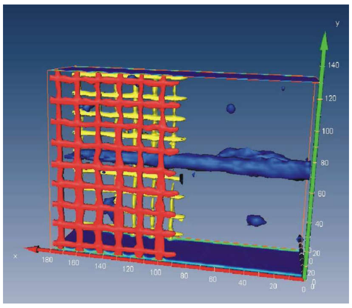
Assessment of the GPR applications:

BAM

- Presentation of results for non-specialists

Combination of different NDT methods: radar (2 polarizations) and ultrasonic



Plot of isolines [Ch.Kohl]

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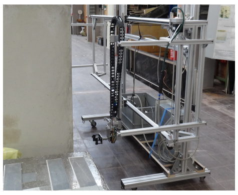
13

Topics of research and work activities:

BAM

- construction of scanners to automate the NDT measurements

Next generation of scanning systems:
large measurement area (2.3 x 1.8 m)
+ easier handling (no air pressure)
+ faster (1h for 2 mm spacing)



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14

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Topics of research and work activities:

BAM

- Application of our GPR equipment and knowhow to real investigation objects from the construction industry and road infrastructure and to geotechnical targets

Topics of research and work activities:

BAM

- Participation in committees

- Germany:
  - **no standards** for appliction of NDT methods in CE (Example: in DIN 1076 on the supervision and inspection of engineering structures with roads and paths “NDT in CE” are **mentioned** only indirectly, but **not required**).
  - users are rely on leaflets and standard literature.

- DGZfP:
  - Publication of fact sheets on various topics reflecting the state of science
  - revision of fact sheets **(Merkblatt) B10** on the **radar method** for non-destructive testing in civil engineering (2008) of the DGZfP is planned under the supervision of BAM/ 8.2

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Topics of research and work activities:

BAM

- Training for GPR services in Civil Engineering

Internal training

NDT&E Advanced Training, June 2013

coming up soon: „NDT&E Advanced Training“ at BAM, June 2014
more information http://www.bam.de/de/aktuell/veranstaltungen/veranstaltungen_medien/va_968.pdf

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GPR equipment and available testing facilities:

BAM

- commercial radar systems with antennas ranging from 200 MHz to 2600 MHz :

- diverse **universal** sytems (antennas and survey wheels **mountable**)

GSSI SIR 20

MALÅ ProEX

SIR 3000

CX system

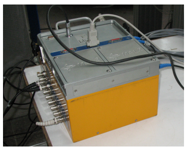
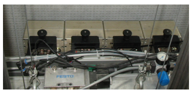
2014 Working Group Progress Meeting, Nantes 18

GPR equipment and available testing facilities:

BAM

- commercial radar systems

- an universal sytem for multi-offset antenna arrays


MALÅ MIRA multi-channel system with 1.3 GHz and 400 MHz antennas

- **compact** system
(antennas and survey wheels **fixed**)

Hilti PS 1000
X-Scan Radar Detection System
for concrete cover d < 0.5 m

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Testing opportunities:

BAM

- testing hall with a lot of test specimen of different size


- testing site near Berlin



- competent colleagues in construction

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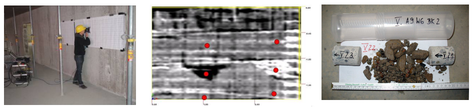
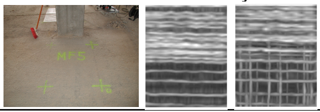
GPR Examples of laboratory work and case studies:

- Typical case studies:
  - Localization of post-tensioning reinforcement

  - Quality control of precast concrete wall elements

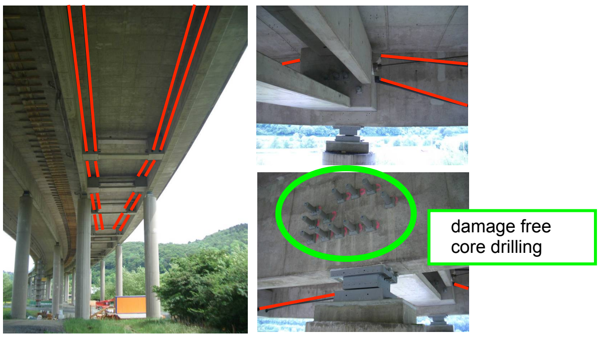


  - Proof of reinforcement mesh density in a concrete floor



GPR Examples of laboratory work and case studies:

- Presentation of a case study:
  - Customer Requirements:
    Installation of external post-stressed reinforcements



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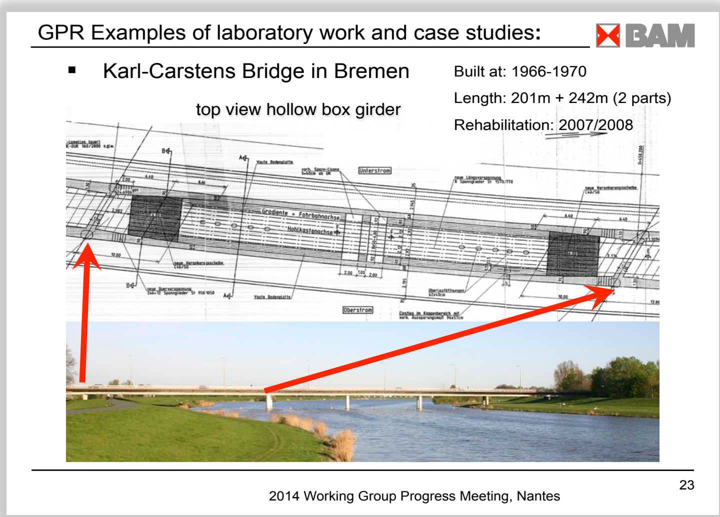

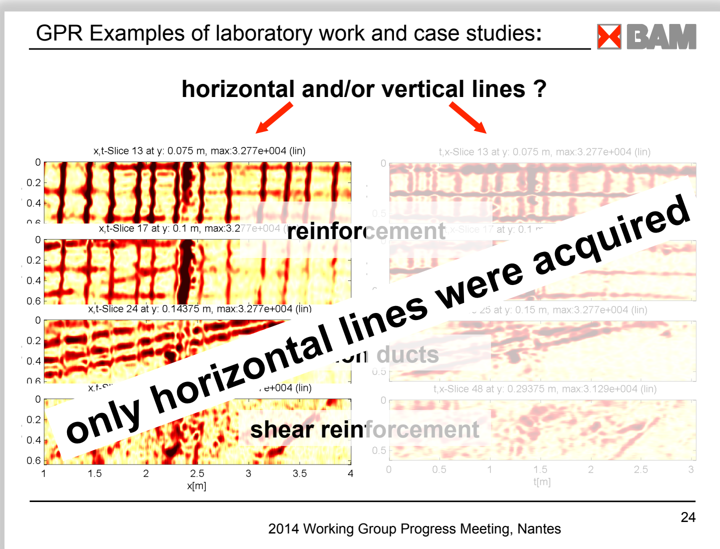

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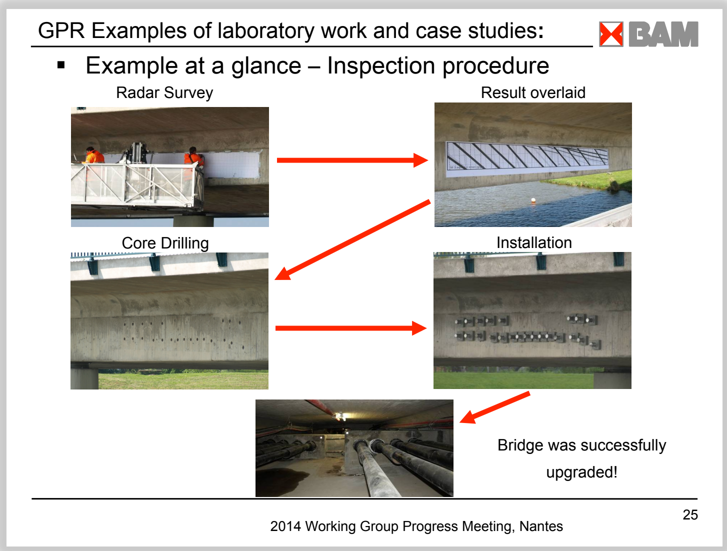
GPR Examples of laboratory work and case studies:
BAM
Example at a glance – Inspection procedure
Radar Survey
Result overlaid
Core Drilling
Installation
Bridge was successfully upgraded!
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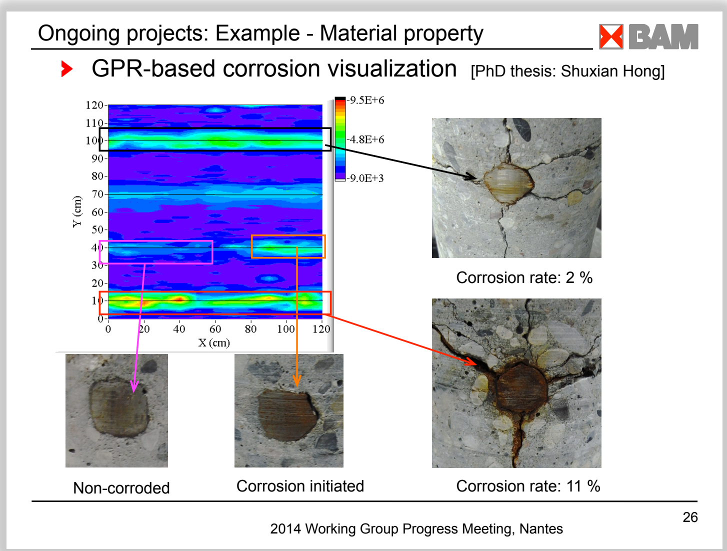
25


Ongoing projects: Example - Material property
BAM
GPR-based corrosion visualization [PhD thesis: Shuxian Hong]
9.5E+6
4.8E+6
9.0E+3
Y (cm)
X (cm)
Corrosion rate: 2 %
Non-corroded
Corrosion initiated
Corrosion rate: 11 %
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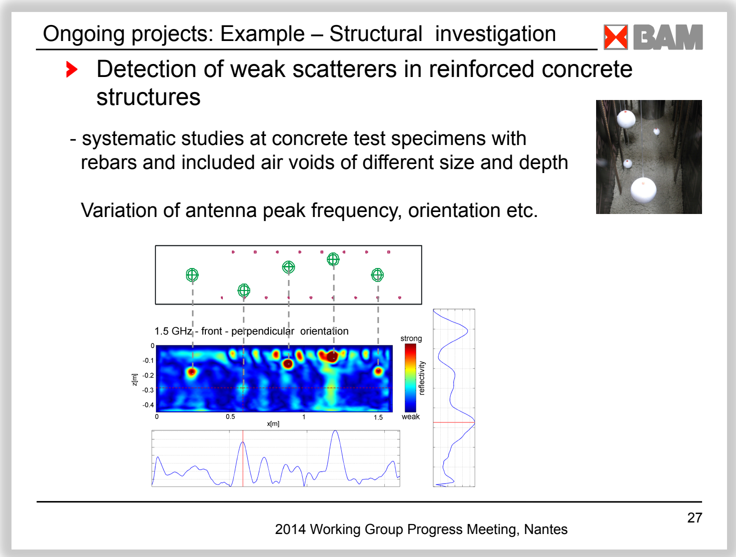
26


Ongoing projects: Example – Structural investigation
BAM
Detection of weak scatterers in reinforced concrete structures
- systematic studies at concrete test specimens with rebars and included air voids of different size and depth
Variation of antenna peak frequency, orientation etc.
1.5 GHz - front - perpendicular orientation
strong
reflectivity
weak
x[m]
z[m]
2014 Working Group Progress Meeting, Nantes
27

"GPR ACTIVITIES FOR ROAD APPLICATIONS AT THE BRRC, IN BELGIUM"

Colette Grégoire, Carl Van Geem
Belgian Road Research Centre
c.gregoire@brrc.be, c.vangeem@brrc.be

The Belgian Road Research Centre (BRRC) is often asked to evaluate the road structure with deflections measurements, the origin of road damages, the origin of collapse, the risk of instability of concrete slabs, the detection of cables or pipes before works, and so on.

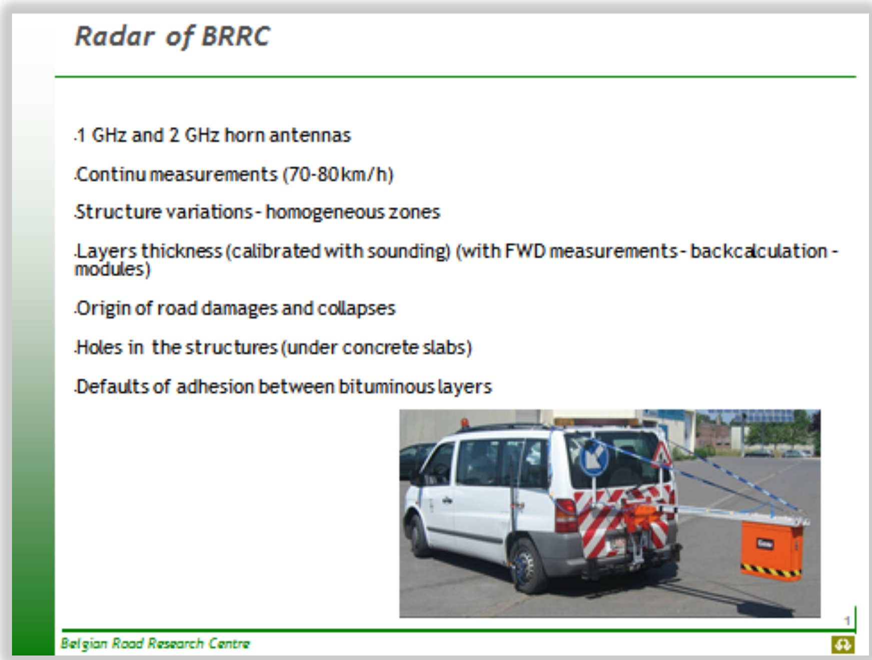
To complete and improve the inverse calculation performed on the deflections and in order to map some features in the road structures, the BRRC bought a radar, which is a well-known geophysical technique used in road investigation. The BRRC acquired a GPR acquisition system (SIR 20, GSSI) and 2 horn antennas (1 GHz and 2 GHz) in 2010.

We used the radar in different projects. In some cases, the use of radar bought some advantages. We were able to determine the thickness of asphalt layer or concrete layer useful for backcalculation, visualize the layer thickness changes and the variations in the road structures. In other cases, the use of radar was not so successful. We were not able to detect holes under the concrete slabs or loss between asphalt layers.

Due to the lack of existing methodologies and the remaining questions concerning the use of radar for road investigations, the Belgian Road Research Centre started in November 2013 a research project in partnership with 'Institut Scientifique de Service Public'. This project aims at the establishment of standard methodologies for acquisition, processing and interpretation of radar measurements that are specific for road investigation. The aspects concerned by this project are the determination of homogeneous zones in the road structure, the estimation of the thickness of the different layers and the possibility to evaluate material quantities and properties in order to recycle most of them and in order to better define the appropriated dismantling technique.

In order to calibrate the radar equipment and to perform measurements in well controlled conditions, the first action in the frame of the project is the construction of a test site in the hall of BRRC. On this test site 4 different road configurations are built (asphalt layer on concrete plates, asphalt layer on lean concrete, concrete layer on lean concrete separated by a thin layer asphalt and asphalt covering cobblestone). An unbound aggregate layer serves as a base layer. Heterogeneities (holes, voids, pipes, ...) are buried in the structure. The site will be instrumented with temperature and strain gauges. Also deflection measurements using a falling weight deflectometer will be performed on a regular basis on this test site. The building of the test site started in January.

Some results related to previous projects will be presented and we will present the above mentioned recently started research project.



BRRC experience

Road Collapse

Site 1

- Investigation with 250 and 500 MHz contact antennas
- Strong attenuation of signal in areas with collapse risk
- Bottom of the foundation visible in healthy areas (except in areas with repairs)

→ Good imaging with 500 MHz

→ Detection of areas with collapse risk (except in repairs areas due to similar signature)

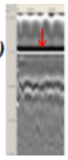
Site 2

- Collapse (depth about 3 m) due to sewer leakage and soil instability
- 1 GHz radar measurements
- No disturbance linked to the collapse could be observed

2

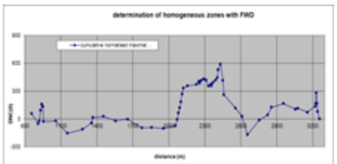
Belgian Road Research Centre

BRRC experience



Homogeneous zones in road structure (FWD and soundings)

- GPR (1 and 2 GHz) to better locate the soundings
- Proposal of 10 soundings
- Three structures - confirmed by cores and FWD measurements
- 2 GHz : 50 cm penetration
- 1 GHz : idem 2 GHz (scattering of radar waves, ...)



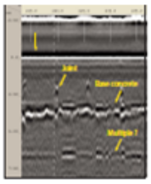
3

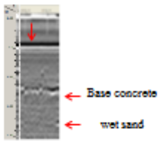
Belgian Road Research Centre

BRRC experience

Slab concrete road - detection of holes

- Joints visible + bottom of slabs
- No observed changes in slab thickness (too small)
- Base layer (bound aggregates or loamy sand) not differentiated by radar
- No voids detected

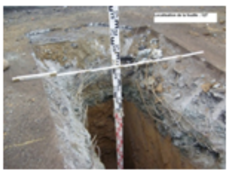
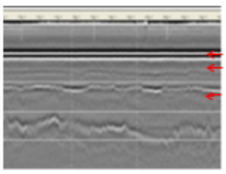


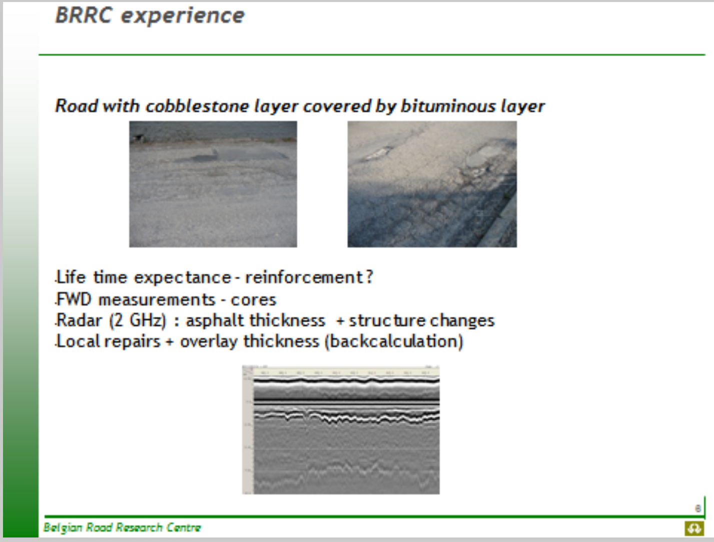


Reinforced concrete slab

- Thick reinforced concrete slab in trenches : extend ?
- Choice of dismantling technique
- 2 GHz antenna
  - Strong reflector at 2,5 ns (interface granular layer-concrete)
  - Weak reflector between surface and the strong reflector (interface asphalt-granular layer)
  - Deeper reflector quite irregular (concrete reinforcement)

- Concrete slab present along entire length of the street


BRRC experience
Road with cobblestone layer covered by bituminous layer
Life time expectance - reinforcement ?
FWD measurements - cores
Radar (2 GHz) : asphalt thickness + structure changes
Local repairs + overlay thickness (backcalculation)
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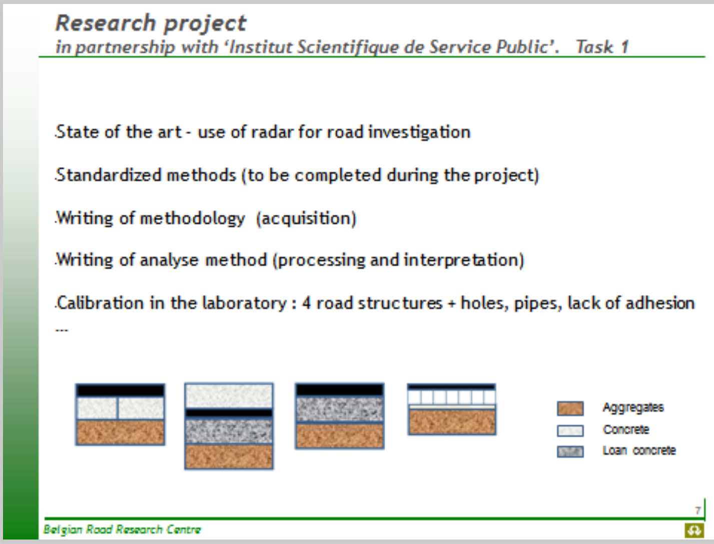
Research project
in partnership with 'Institut Scientifique de Service Public'. Task 1
State of the art - use of radar for road investigation
Standardized methods (to be completed during the project)
Writing of methodology (acquisition)
Writing of analyse method (processing and interpretation)
Calibration in the laboratory : 4 road structures + holes, pipes, lack of adhesion
...
Aggregates
Concrete
Loan concrete
7
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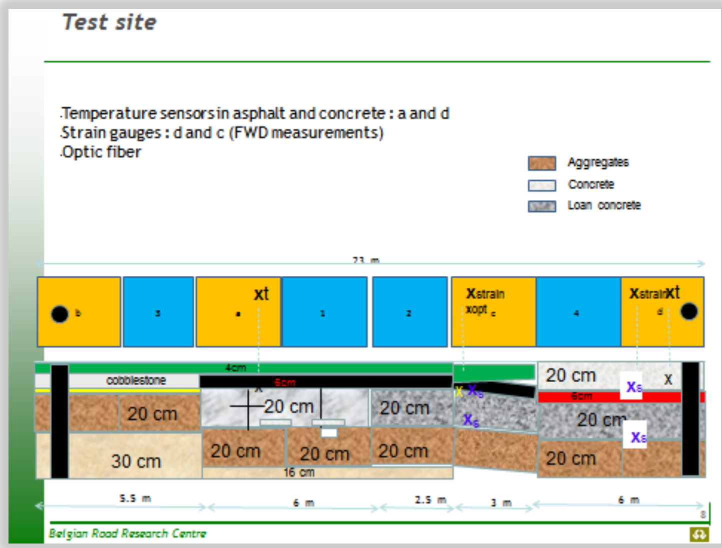
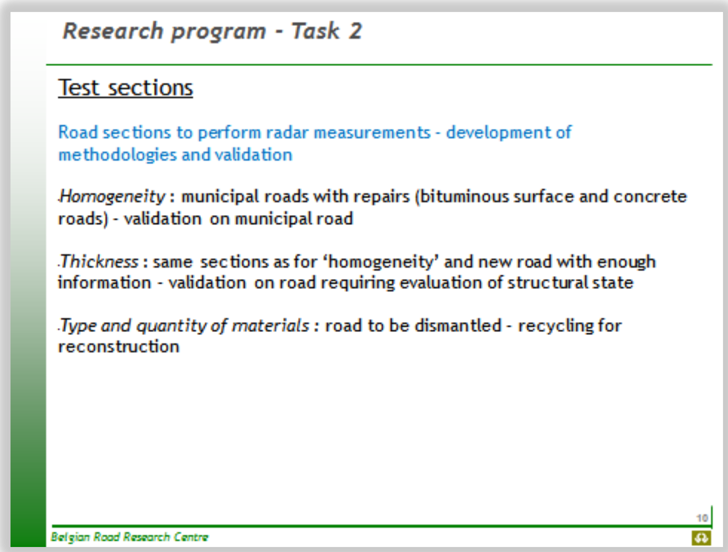

Test site
.Temperature sensors in asphalt and concrete : a and d
.Strain gauges : d and c (FWD measurements)
.Optic fiber
Aggregates
Concrete
Loan concrete
23 m
xt
Xstrain
xopt
Xstrain xt
cobblestone
4cm
6cm
20 cm
30 cm
16 cm
5.5 m
6 m
2.5 m
3 m
Belgian Road Research Centre


Test site
PT-100 (temperature)
Strain gauges : Kyowa sensors
Belgian Road Research Centre


Research program - Task 2
Test sections
Road sections to perform radar measurements - development of methodologies and validation
Homogeneity : municipal roads with repairs (bituminous surface and concrete roads) - validation on municipal road
Thickness : same sections as for ‘homogeneity’ and new road with enough information - validation on road requiring evaluation of structural state
Type and quantity of materials : road to be dismantled - recycling for reconstruction
10
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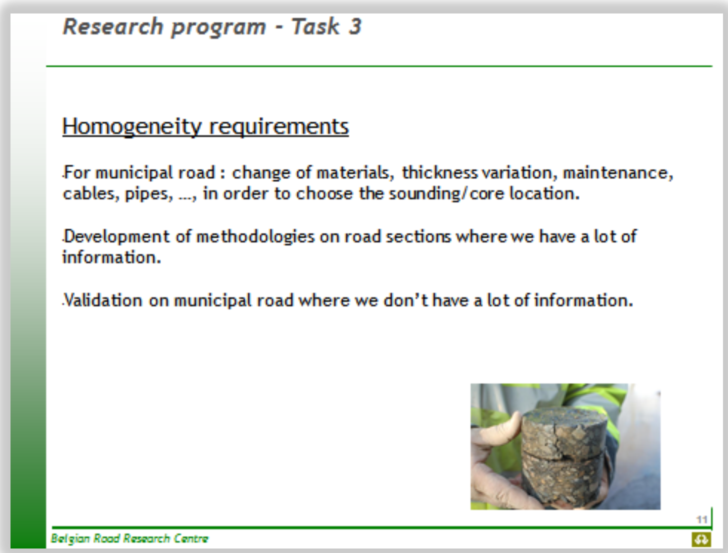
Research program - Task 3
Homogeneity requirements
For municipal road : change of materials, thickness variation, maintenance, cables, pipes, ..., in order to choose the sounding/core location.
Development of methodologies on road sections where we have a lot of information.
Validation on municipal road where we don’t have a lot of information.
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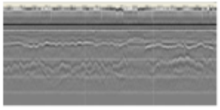
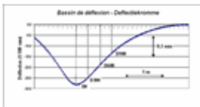
Research program - Task 4

Layer thickness



?



Development of methodology on selected road sections in order to define the layer thickness (parameter in backcalculation to estimate the structural state and residual life time of the road)

Validation on road where structural evaluation is needed - deflexions measurements and backcalculation

First calculation without radar

Second calculation with radar - cores taken in well-chosen places

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Research program - Task 5

Nature and quantity of materials to be recycled

Use of developed approach

Material characterisation, presence of water and location of cables/pipes

Material quantity

Soundings and labo characterisation

Following of recycling site

Economical advantage of radar investigation

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Belgian Road Research Centre

AN EFFICIENT SYSTEM FOR GPR SURVEYING OF PAVEMENT, BRIDGES AND TUNNELS

Roger Wisén, Jørgen Ringgaard
Department of Geophysics and Geohydrology,
Ramboll Denmark A/S,
Hannemanns allé 63, 2300 Copenhagen, Denmark
rgw@ramboll.dk

This contribution is intended to give a brief introduction to a system for efficient 3D GPR surveying conducted by Rambøll in Denmark.

The system is built up of 3 basic parts: a GPR monitoring system; a high accuracy GNSS positioning system; and a navigational software.

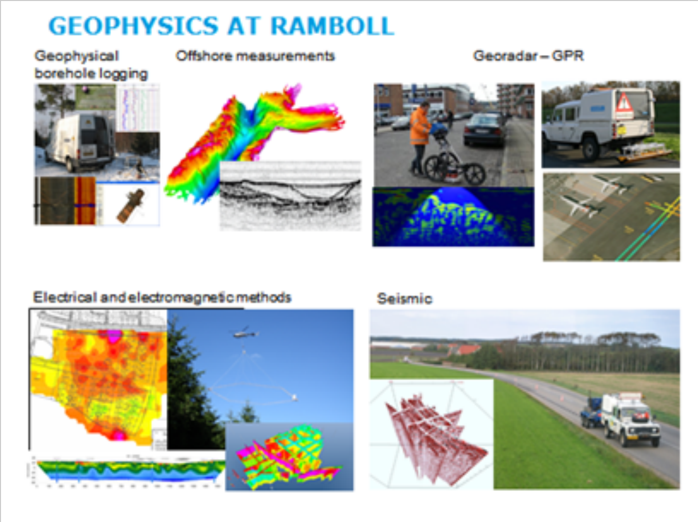
The system can be placed on any type of bearer from a man carrying a light GPR monitoring system to a heavy vehicle for work in difficult terrain or traffic.

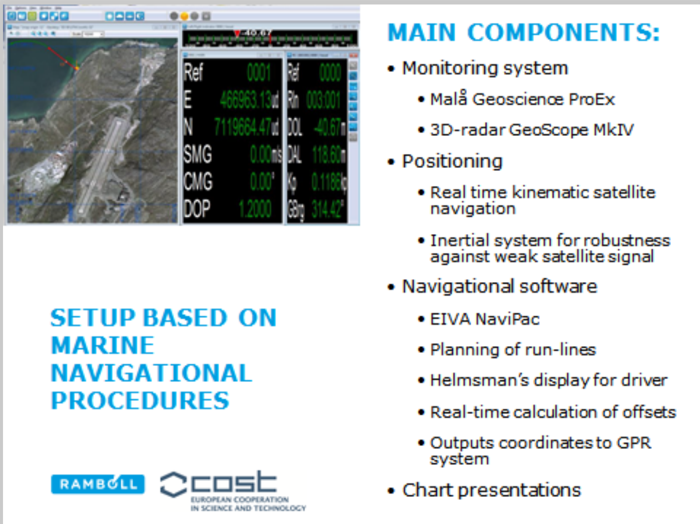
Examples of surveys performed by Rambøll are: mapping peat bogs on frozen ground in the north utilizing a dual channel 2D GPR ProEx monitoring system from Malå Geoscience; mapping of pavement and utilities on roads and airports utilizing a Geoscope Mk IV and a 1.8m DX antenna from 3D-radar; mapping of void behind cast concrete tunnel liners utilizing a Geoscope Mk IV and a 1.2m VX antenna from 3D-radar, in this example the GNSS system was replaced with a fixed height mounting and an odometer for precise inline positioning.

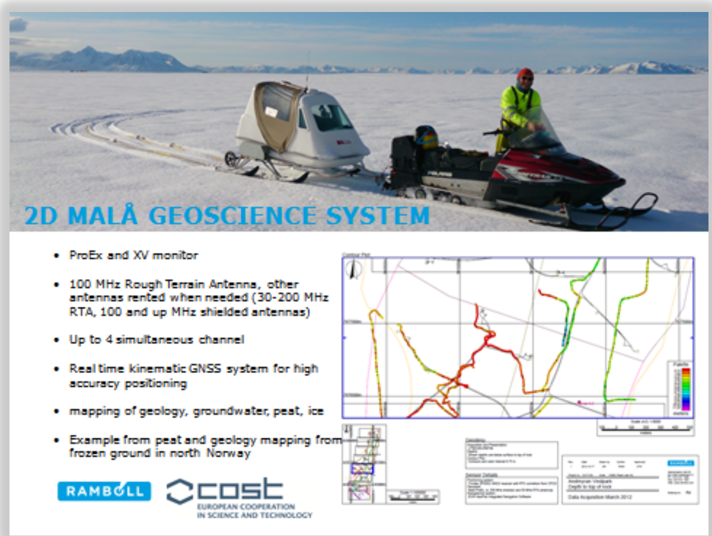
ACKNOWLEDGEMENT

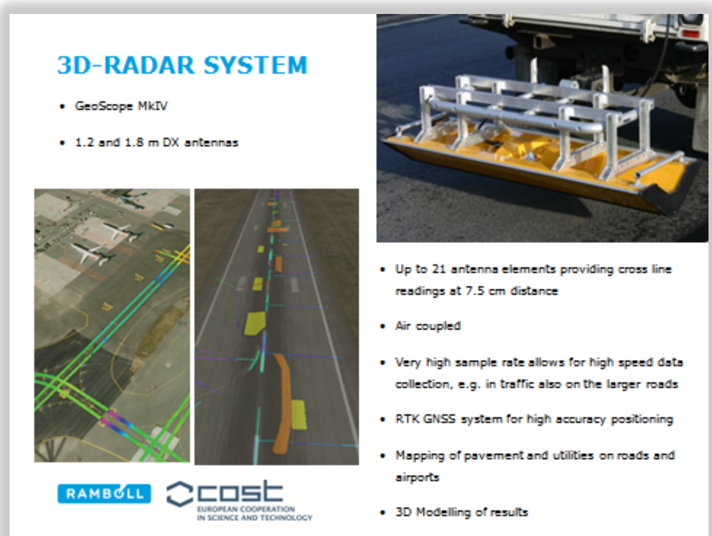
The authors acknowledge the COST Action TU1208 “Civil Engineering Applications of Ground Penetrating Radar”, supporting this work.

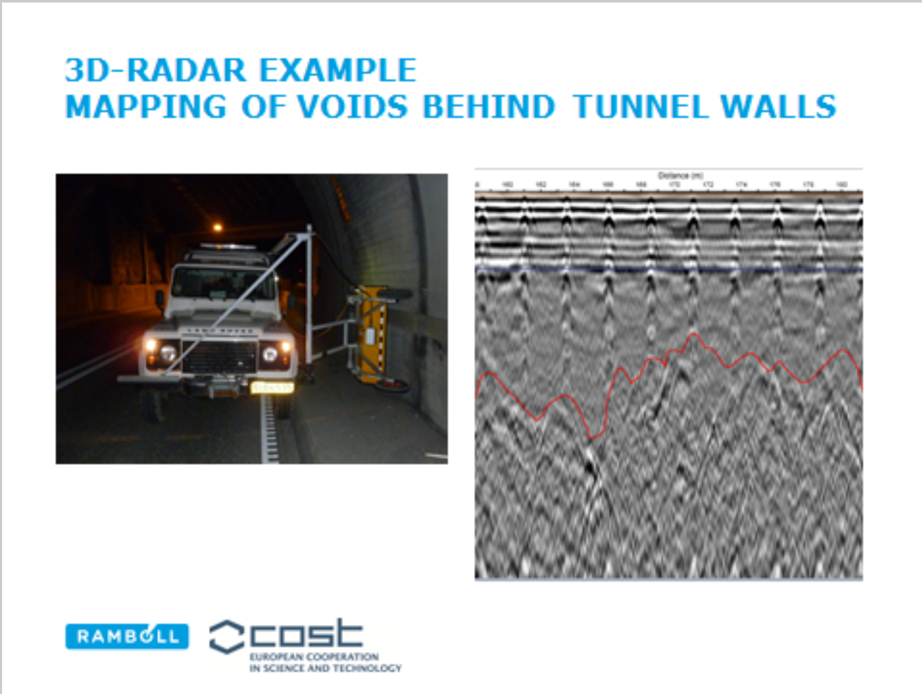
FIG. 1 – The 3D-radar 1.8m DX antenna mounted on a Landrover Defender for measurements on most surfaces.


GEOPHYSICS AT RAMBOLL
Geophysical borehole logging
Offshore measurements
Georadar – GPR
Electrical and electromagnetic methods
Seismic


MAIN COMPONENTS:
• Monitoring system
• Malå Geoscience ProEx
• 3D-radar GeoScope MkIV
• Positioning
• Real time kinematic satellite navigation
• Inertial system for robustness against weak satellite signal
• Navigational software
• EIVA NaviPac
• Planning of run-lines
• Helmsman's display for driver
• Real-time calculation of offsets
• Outputs coordinates to GPR system
• Chart presentations
SETUP BASED ON MARINE NAVIGATIONAL PROCEDURES
RAMBØLL
cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

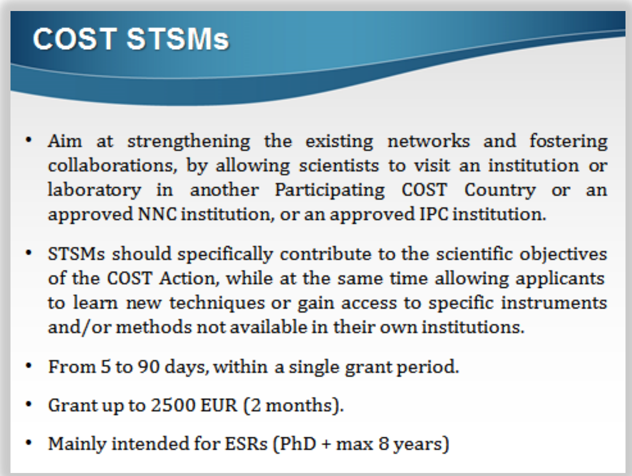

2D MALÅ GEOSCIENCE SYSTEM
• ProEx and XV monitor
• 100 MHz Rough Terrain Antenna, other antennas rented when needed (30-200 MHz RTA, 100 and up MHz shielded antennas)
• Up to 4 simultaneous channel
• Real time kinematic GNSS system for high accuracy positioning
• mapping of geology, groundwater, peat, ice
• Example from peat and geology mapping from frozen ground in north Norway
RAMBØLL
COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY


3D-RADAR SYSTEM
• GeoScope MkIV
• 1.2 and 1.8 m DX antennas
• Up to 21 antenna elements providing cross line readings at 7.5 cm distance
• Air coupled
• Very high sample rate allows for high speed data collection, e.g. in traffic also on the larger roads
• RTK GNSS system for high accuracy positioning
• Mapping of pavement and utilities on roads and airports
• 3D Modelling of results
RAMBØLL
COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY


3D-RADAR EXAMPLE
MAPPING OF VOIDS BEHIND TUNNEL WALLS
Distance (m)
RAMBØLL
cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

COST Short-Term Scientific Missions and Conference Grants

Lara Pajewski - Roma Tre University, Rome, Italy
lara.pajewski@uniroma3.it



COST STSMs

Before the STSM

- Obtain written agreement of the host institution.
- Complete the online application form (e-services.cost.eu/stsm).
- Send the completed file as e-mail attachment together with the necessary supporting documents (CV, full work plan, list of publications, motivation letter, letter of support from the home institution) to the STSM host institution, to the MC Chair and the STSM Manager.
- Assessment and Grant Letter.

COST STSMs

After the STSM

The grantee is required to submit a short scientific report to the MC Chair and STSM coordinator within 30 days after the end date of the STSM containing and a confirmation by the host institution of the successful execution of the STSM.

After receiving the report approval by the MC Chair, the Grant Holder will execute the payment of the grant.

The report will be available for free download on the Action's website.

COST STSMs

1. Lara Pajewski (Rome → Edinburgh, 2 months)
2. Sonia Santos Assuncao (Barcelona → Athens, 1 month)
3. Iraklis Giannakis (Edinburgh → Rome, 2 months)
4. Philippe van de Smedt (Ghent → Vienna, 2 months)
5. …

Further applications are welcome!!

6. …

More information on STSMs: COST Vademecum, Part I, Chapter 6

COST Conference Grants

- 3 supporting grants per year up to EUR 3000, only for ESRs, to participate in an international conference held anywhere in world and outside of COST Action activities.
- The conference under consideration should take place within 6 month from the Call deadline.
- In order to be eligible for this grant, an accepted oral contribution is required.
- Deadline: 1 March 2014 (next deadlines: 1 July, 1 November)
- After the conference: report within 1 month.

COST Action TN1301

Next Generation of Young Scientist: Toward a Contemporary Spirit of R&I (Sci-GENERATION)

A targeted network started on 13 November 2013, aiming at creating a bottom up and pan-European platform for young outstanding EU researchers (MC includes ERC Starting Grantees and other talents of less research intensive countries).

More information on www.cost.eu (the MoU contains further details such as the detailed objectives, the programme, organisation and timeplan).

COST Action TN1201

Gender, Science, Technology and Environment (genderSTE)

A targeted network started on 28 November 2012, aiming at enhancing the implementation of gender-focussed policy measures, for a structural change in science and technology institutions, to promote women's careers in science and technology.

EU-US Gendered Innovation project.

Development of discipline-specific gender roadmaps and best practice guides for important fields such as the Horizon2020 Grand Challenges and Urban Europe.

More information on www.cost.eu.

COST is supported by the EU RTD Framework Programme.

ESF provides the COST Office through a European Commission Contract. The Council of the EU provides the COST Secretariat.

Table of Contents

COST - European Cooperation in Science and Technology is an intergovernmental framework aimed at facilitating the collaboration and networking of scientists and researchers at European level. It was established in 1971 by 19 member countries and currently includes 35 member countries across Europe, and Israel as a cooperating state.

COST funds pan-European, bottom-up networks of scientists and researchers across all science and technology fields. These networks, called 'COST Actions', promote international coordination of nationally-funded research. By fostering the networking of researchers at an international level, COST enables break-through scientific developments leading to new concepts and products, thereby contributing to strengthening Europe's research and innovation capacities.

COST's mission focuses in particular on: building capacity by connecting high quality scientific communities throughout Europe and worldwide; providing networking opportunities for early career investigators; increasing the impact of research on policy makers, regulatory bodies and national decision makers as well as the private sector.

Through its inclusiveness, COST supports the integration of research communities, leverages national research investments and addresses issues of global relevance. Every year thousands of European scientists benefit from being involved in COST Actions, allowing the pooling of national research funding to achieve common goals.

As a precursor of advanced multidisciplinary research, COST anticipates and complements the activities of EU Framework Programmes, constituting a "bridge" towards the scientific communities of emerging countries. In particular, COST Actions are also open to participation by non-European scientists coming from neighbour countries (for example Albania, Algeria, Armenia, Azerbaijan, Belarus, Egypt, Georgia, Jordan, Lebanon, Libya, Moldova, Montenegro, Morocco, the Palestinian Authority, Russia, Syria, Tunisia and Ukraine) and from a number of international partner countries.

COST's budget for networking activities has traditionally been provided by successive EU RTD Framework Programmes. COST is currently executed by the European Science Foundation (ESF) through the COST Office on a mandate by the European Commission, and the framework is governed by a Committee of Senior Officials (CSO) representing all its 35 member countries.

More information about COST is available at www.cost.eu.

The scientific activities of the COST Action TU1208 are carried out within four Working Groups (WGs). The effectiveness of this scheme will be checked after the first year of activities and will eventually be modified, considering the actual number of active participants in each WG. The structure of each WG will always be kept as flexible as possible, in order to enable new participants to join. All the participants, when joining the Action, are invited to provide basic information on their experience, interests, and current research projects, as well as WGs and Projects preferences. Each participant can belong to two WGs and an arbitrary number of projects within the chosen WGs.

The four TU1208 WGs are: WG1 – Novel GPR instrumentation; WG2 – GPR surveying of pavements, bridges, tunnels and buildings; underground utility and void sensing; WG3 – EM methods for near-field scattering problems by buried structures and data processing techniques; WG4 – Different applications of GPR and other NDT technologies in civil engineering. The WG meetings constitute an opportunity to present activities, results and plans for the future. Between meetings, the WG members regularly interact.